SHA-SHIB GROUP OF INSTITUTIONS
Training Notes

Module 06- Materials & Hardware

SHA-SHIB GROUP
EMPOWERING KNOWLEDGE THROUGH VISION

FOREWORD

- The information in this book is for study/ training purposes only and no revision service will be provided to the holder.

- While carrying out a procedure/ work on aircraft/ aircraft equipment you must always refer to the relevant Aircraft Maintenance Manual or Equipment Manufacturer's Handbook.

- For health and safety in the workplace you should follow the regulations/ Guidelines as specified by the Equipment Manufacturer, your company, National Safety Authorities and National Governments.

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Knowledge Levels – Category A, B1, B2, B3 and C Aircraft Maintenance Licence

Basic knowledge for categories A, B1, B2 and B3 are indicated by the allocation of knowledge levels indicators (1, 2 or 3) against each application subject. Category C applicants must meet either the category B1 or the category B2 basic knowledge levels.

The knowledge level indicators are defined as follows:

LEVEL 1

- A familiarization with the principal elements of the subject.

Objectives: The applicant should be familiar with the basic elements of the subject.

- The applicant should be able to give a simple description of the whole subject, using common words and examples.
- The applicant should be able to use typical terms.

LEVEL 2

- A general knowledge of the theoretical and practical aspects of the subject.
- An ability to apply that knowledge.

Objectives: The applicant should be able to understand the theoretical fundamentals of the subject.

- The applicant should be able to give a general description of the subject using, as appropriate, typical examples.
- The applicant should be able to use mathematical formulae in conjunction with physical laws describing the subject.
- The applicant should be able to read and understand sketches, drawings and schematics describing the subject.
- The applicant should be able to apply his knowledge in a practical manner using detailed procedures.

LEVEL 3

- A detailed knowledge of the theoretical and practical aspects of the subject.
- A capacity to combine and apply the separate elements of knowledge in a logical and comprehensive manner.

Objectives: The applicant should know the theory of the subject and interrelationships with other subjects.

- The applicant should be able to give a detailed description of the subject using theoretical fundamentals and specific examples.
- The applicant should understand and be able to use mathematical formulae related to the subject.
- The applicant should be able to read, understand and prepare sketches, simple drawings and schematics describing the subject.
- The applicant should be able to apply his knowledge in a practical manner using manufacturer’s instructions.
- The applicant should be able to interpret results from various sources and measurements and apply corrective action where appropriate.

-: DGCA MODULARISATION :-

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CAR – 66 ISSUE II R 2

(LICENSING OF AIRCRAFT MAINTENANCE ENGINEERS)

DIRECTORATE GENERAL OF CIVIL AVIATION

TECHNICAL CENTRE, OPP SAFDURJUNG AIRPORT, NEW DELHI

Modules	Subject	A or B1 Aero plane with		A or B1 Helicopter with		B2
		Turbine Engine (s)	Piston Engine (s)	Turbine Engine (s)	Piston Engine (s)	Avionics
1	Not Applicable					
2	Not Applicable					
3	ELECTRICAL FUNDAMENTALS	X	X	X	X	X
4	ELECTRONIC FUNDAMENTALS	X	X	X	X	X
5	DIGITAL TECHNIQUES ELECTRONIC INSTRUMENT SYSTEMS	X	X	X	X	X
6	MATERIALS AND HARDWARE	X	X	X	X	X
7A	MAINTENANCE PRACTICES	X	X	X	X	X
7B	MAINTENANCE PRACTICES					
8	BASIC AERODYNAMICS	X	X	X	X	X
9A	HUMAN FACTORS	X	X	X	X	X
9B	HUMAN FACTORS					
10	AVIATION LEGISLATION	X	X	X	X	X
11A	TURBINE AEROPLANE AERODYNAMICS, STRUCTURES AND SYSTEMS	X				
11B	PISTON AEROPLANE AERODYNAMICS, STRUCTURES AND SYSTEMS		X			
11C	PISTON AEROPLANE AERODYNAMICS, STRUCTURES AND SYSTEMS					
12	HELICOPTER AERODYNAMICS, STRUCTURES AND SYSTEMS			X	X	
13	AIRCRAFT AERODYNAMICS, STRUCTURES AND SYSTEMS					X
14	PROPULSION					X
15	GAS TURBINE ENGINE	X		X		
16	PISTON ENGINE		X		X	
17A	PROPELLER	X	X			
17B	PROPELLER					

	MODULE 6. Materials & Hardware	LEVEL	
		B1.1	B2
6.1	**6.1 Aircraft Materials — Ferrous** (a) Characteristics, properties and identification of common alloy steels used in aircraft; Heat treatment and application of alloy steels; (b) Testing of ferrous materials for hardness, tensile strength, fatigue strength and impact resistance.	2	1
6.2	**6.2 Aircraft Materials — Non-Ferrous** (a) Characteristics, properties and identification of common non-ferrous materials used in aircraft; Heat treatment and application of non-ferrous materials; (b) Testing of non-ferrous material for hardness, tensile strength, fatigue strength and impact resistance.	2	1
6.3	**6.3 Aircraft Materials - Composite and Non- Metallic** **6.3.1 Composite and non-metallic other than wood and fabric** (a)Characteristics, properties and identification of common composite and non-metallic materials, other than wood, used in aircraft; Sealant and bonding agents. (b) The detection of defects/deterioration in composite and non-metallic material. Repair of composite and non-metallic material. **6.3.2 Wooden structures** Construction methods of wooden airframe structures; Characteristics, properties and types of wood and glue used in aeroplanes; Preservation and maintenance of wooden structure; Types of defects in wood material and wooden structures; The detection of defects in wooden structure; Repair of wooden structure. **6.3.3 Fabric covering** Characteristics, properties and types of fabrics used in aeroplanes; Inspections methods for fabric; Types of defects in fabric; Repair of fabric covering.	2	2
6.4	**6.4 Corrosion** (a) Chemical fundamentals; Formation by, galvanic action process, microbiological, stress; (b) Types of corrosion and their identification; Causes of corrosion; Material types, susceptibility to corrosion.	1	1
6.5	**6.5 Fasteners** **6.5.1 Screw threads** Screw nomenclature; Thread forms, dimensions and tolerances for standard threads used in aircraft; Measuring screw threads; **6.5.2 Bolts, studs and screws** Bolt types: specification, identification and marking of aircraft bolts, international standards; Nuts: self locking, anchor, standard types; Machine screws: aircraft specifications;	2	2

	Studs: types and uses, insertion and removal; Self tapping screws, dowels. **6.5.3 Locking devices** Tab and spring washers, locking plates, split pins, palnuts, wire locking, quick release fasteners, keys, circlips, cotter pins. **6.5.4 Aircraft rivets** Types of solid and blind rivets: specifications and identification, heat treatment.		
6.6	**6.6 Pipes and Unions** (a) Identification of, and types of rigid and flexible pipes and their connectors used in aircraft; (b) Standard unions for aircraft hydraulic, fuel, oil, pneumatic and air system pipes.	2	2
6.7	**6.7 Springs** Types of springs, materials, characteristics and applications.	2	1
6.8	**6.8 Bearings** Purpose of bearings, loads, material, construction; Types of bearings and their application.	2	2
6.9	**6.9 Transmissions** Gear types and their application; Gear ratios, reduction and multiplication gear systems, driven and driving gears, idler gears, mesh patterns; Belts and pulleys, chains and sprockets.	2	2
6.10	**6.10 Control Cables** Types of cables; End fittings, turnbuckles and compensation devices; Pulleys and cable system components; Bowden cables; Aircraft flexible control systems.	2	1
6.11	**6.11 Electrical Cables and Connectors** Cable types, construction and characteristics; High tension and co-axial cables; Crimping; Connector types, pins, plugs, sockets, insulators, current and voltage rating, coupling, identification codes.	2	2

Module 6: Enabling Objectives and Certification Statement

Certification Statement

These Study Notes comply with the syllabus of DGCA, CAR – 66 (Appendix I) and the associated Knowledge Levels as specified.

REVISION LOG

TABLE OF CONTENTS

CHAPTER PAGE

6.1: AIRCRAFT MATERIALS — FERROUS

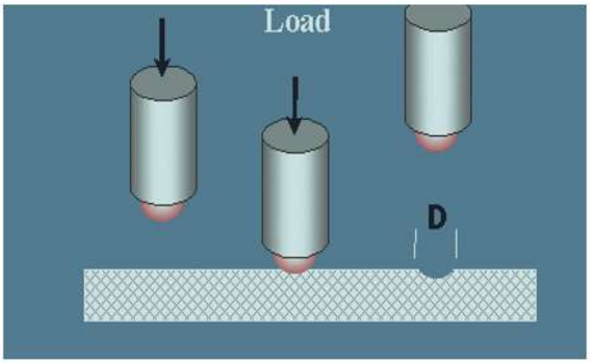
a) Characteristics, properties and identification of common alloy steels used in aircraft; Knowledge and understanding of the uses, strengths limitations, and other characteristics of structural metals is vital to properly construct and maintain any equipment, especially airframes. In aircraft maintenance and repair, even a slight deviation from design specification, or the substitution of inferior materials, may result in the loss of both lives and equipment. The use of unsuitable materials can readily erase the finest craftsmanship. The selection of the correct material for a specific repair job demands familiarity with the most common physical properties of various metals.

Properties of Metals

primary concern in aircraft maintenance are such general properties of metals and their alloys as hardness, malleability, ductility, elasticity, toughness, density, brittleness, fusibility, conductivity contraction and expansion, and so forth. These terms are explained to establish a basis for further discussion of structural metals.

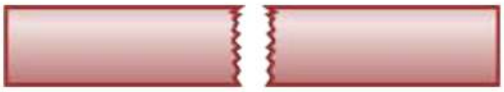
HARDNESS

Hardness refers to the ability of a material to resist abrasion, penetration, cutting action, or permanent distortion. Hardness may be increased by cold working the metal and, in the case of steel and certain aluminium alloys, by heat treatment. Structural parts are often formed from metals in their soft state and are then heat treated to harden them so that the finished shape will be retained. Hardness and strength are closely associated properties of metals.



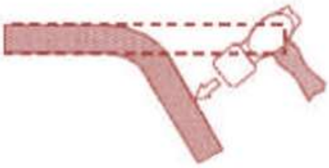
BRITTLENESS

It is the property of metals to resist a change in the relative position of its molecules under load. Or is the tendency of metal to fracture without change of shape under shock load. Brittleness and hardness are very closely associated. Hard materials are more brittle than the soft materials. A brittle metal is apt to break or crack without change of shape. Because structural metals are often subjected to shock loads, brittleness is not a very desirable property. Cast iron, cast aluminium, and very hard steel are examples of brittle metals.



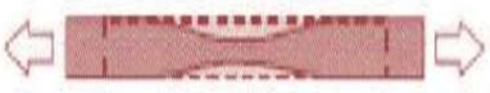
MALLEABILITY

It is the property of material which allows it to be hammered rolled or pressed into various shapes without cracking or leaving some other detrimental effect. A metal which can be hammered, rolled, or pressed into various shapes without cracking, breaking, is said to be malleable. This property is necessary in sheet metal that is worked into curved shapes, such as cowlings, fairings, or wingtips. Copper is an example of a malleable metal.



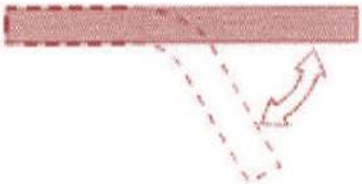
DUCTILITY

It is the property of metal which permits it to be plastically deformed (permanently drawn bent or twisted) into various shapes without breaking (Without loss of strength). This property is essential for metals used in making wire and tubing. Ductile metals are greatly preferred for aircraft use because of their ease of forming and resistance to failure under shock loads. For this reason, aluminium alloys are used for cowl rings, fuselage and wing skin, and formed or extruded parts, such as ribs, spars, and bulkheads. Chrome molybdenum steel is also easily formed into desired shapes. Ductility is similar to malleability.



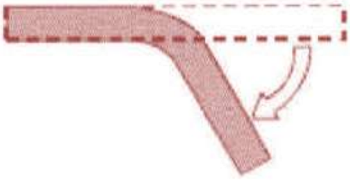
ELASTICITY

Elasticity is that property that enables a metal to return to its original size and shape when the force which causes the change of shape is removed. This property is extremely valuable because it would be highly undesirable to have a part permanently distorted after an applied load was removed. Each metal has a point known as the elastic limit, beyond which it cannot be loaded without causing permanent distortion. In aircraft construction, members and parts are so designed that the maximum loads to which they are subjected will not stress them beyond their elastic limits. This desirable property is present in spring steel.



PLASTICITY

It is the property of material to remain deformed after the force is removed.



DENSITY

Density is the mass of a unit volume of a material. In aircraft work, the specified weight of a material per cubic inch is preferred since this figure can be used in determining the weight of a part before actual manufacture. Density is an important consideration when choosing a material to be used in the design of a part in order to maintain the proper weight and balance of the aircraft

FUSIBILITY

Fusibility is the ability of a metal to become liquid by the application of heat. Metals are fused in welding. Steels fuse around 2,600 °F and aluminium alloys at approximately 1,100 °F.

CONDUCTIVITY

Conductivity is the property which enables a metal to carry heat or electricity. If a metal is able to transmit heat it is said to be thermally conductive. If a metal is able to transmit electricity it is said to be electrically conductive.

The heat conductivity of a metal is especially important in welding because it governs the amount of heat that will be required for proper fusion. Conductivity of the metal, to a certain extent, determines the type of jig to be used to control expansion and contraction. In aircraft, electrical conductivity must also be considered in conjunction with bonding, to eliminate radio interference.

THERMAL EXPANSION

Thermal expansion refers to contraction and expansion that are reactions produced in metals as the result of heating or cooling. Heat applied to a metal will cause it to expand or become larger. Cooling and heating affect the design of welding jigs, castings, and tolerances necessary for hot rolled material.

STRENGTH

One of the most important properties of a material is strength. Strength is the ability of a material to resist deformation. Strength is also the ability of a material to resist stress without breaking. The type of load or stress on the material affects the strength it exhibits.

TENSILE STRENGTH

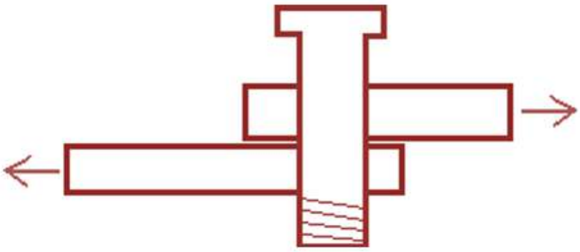
It is the ability of material to withstand tensile load (pulling force) is called tensile strength.

COMPRESSIVE STRENGTH

It is the ability of material to withstand compressive load is called compressive strength.

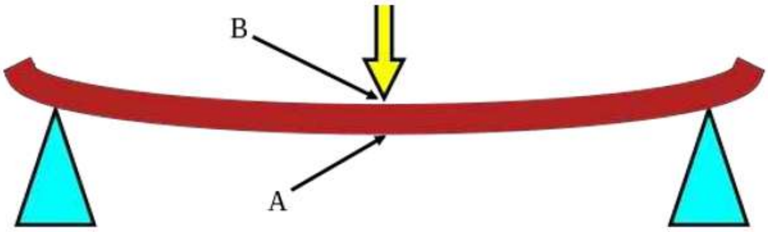
SHEAR STRENGTH

It is the ability of metal to resist opposing forces that can cause the internal structure of the metal to slide against itself.



BENDING STRENGTH

It is the ability of material to resist bending stress (combination of tension and compression)



TOUGHNESS

It is the ability of material to resist tearing or breaking when it is bent or stretched. It is a measure of how much energy a material can absorb before rupturing under impact load. It is the opposite of brittleness.

A material which possesses toughness will withstand tearing or shearing and may be stretched or otherwise deformed without breaking. Toughness is a desirable property in aircraft metals.

Ferrous Metals

Many different metals are required in the repair of aircraft. This is a result of the varying needs with respect to strength, weight, durability, and resistance to deterioration of specific structures or parts. In addition, the particular shape or form of the material plays an important role. In selecting materials for aircraft repair, these factors plus many others are considered in relation to the mechanical and physical properties.

Among the common materials used are the ferrous metals. The term "ferrous" applies to the group of metals having iron as their principal constituent. Iron is a chemical element which is soft malleable and ductile in its pure form. Iron when alloyed with other elements it is one of the most important metal to the engineer.

PLAIN CARBON STEELS

If carbon is added to iron, in varying percentages, the product is vastly superior than iron alone and is classified as Plain carbon steel. Plain Carbon steel forms the base of those alloy steels produced by combining carbon steel with other elements known to improve the properties of steel. A base metal (such as iron) to which small quantities of other metals have been added is called an alloy. The addition of other metals changes or improves the chemical or physical properties of the base metal for a particular use.

In fact the classification of iron and steel is based on the percentage of carbon present. The generally accepted classification is as follows,

Wrought Iron Trace to 0.08%
Low Carbon Steel -- 0.10% to0.30%
Medium Carbon Steel -- 0.30% to 0.70%
High Carbon Steel -- 0.70% to 2.2%
Cast Iron -- 2.2% to 4.5%

WROUGHT IRON

Wrought iron is an iron alloy with very low carbon (0.04 to 0.08%) content in contrast to cast iron (2.1% to 4%). An advantage of its low carbon content is its excellent weld ability. Wrought iron is tough, malleable, ductile and easily welded.

It is used to make pipes, rivets, bolts, chains, and anchors, and is also used for ornamental ironwork but due to its high production cost and comparatively low strength; wrought iron is now only used for specialist applications

LOW CARBON STEEL

Steel containing carbon in percentages ranging from 0.10 to 0.30 percent is classed as low carbon steel. It is also known as mild carbon steel. Steels of this grade are used for making such items as safety wire, certain nuts, cable bushings, or threaded rod ends. This steel in sheet form is used for secondary structural parts and clamps, and in tubular form for moderately stressed structural parts.

MEDIUM CARBON STEEL

Steel containing carbon in percentages ranging from 0.30 to 0.70 percent is classed as medium carbon steel. This steel is especially adaptable for machining or forging, and where surface hardness is desirable.

HIGH CARBON STEEL

Steel containing carbon in percentages ranging from 0.70 to 2.2 percent is classed as high carbon steel. In the fully heat-treated condition it is very hard, will withstand high shear and wear, and will have little deformation. It has limited use in aircraft.

An interesting fact in connection with the above percentage is that all Carbon above 2.2% is not combined with the iron and is present in the form of graphite which accounts for the easy breakage of cast iron.

Besides iron and carbon the plain carbon steel also normally contains small amounts of silicon, sulphur, phosphorus, and manganese. Silicon and manganese are beneficial elements whereas sulphur and phosphorus are harmful impurities which cannot be completely eliminated but are kept as low as possible.

CAST IRON

Cast iron, an alloy of iron that contains 2.2 to 4.5 percent carbon, along with varying amounts of silicon and manganese and traces of impurities such as sulfur and phosphorus.

ALLOY STEEL:

The addition of metallic alloying elements to plain carbon steel results in the formation of new alloy steel with completely different properties. The carbon content of the steel is of primary importance but the varying properties can be obtained by adding the different metals. The metals commonly used in steel as alloying elements are nickel, chromium, molybdenum, vanadium, and tungsten. Small amount of titanium is also used particularly in the corrosion resisting steel. In some alloy steel two alloying elements are used to obtain the desire properties, such as chromium-nickel, and chromium-molybdenum. One alloy steel which is commonly used for propeller hubs contains chromium- nickel-molybdenum. Silicon and manganese are also used as alloying elements but much larger amounts than are usually present in the plain carbon steel.

SPARK TEST

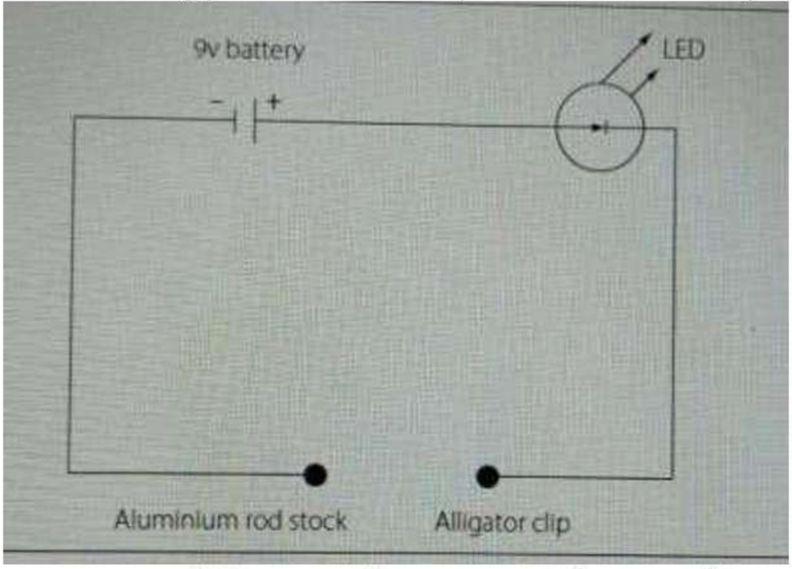
Spark testing is a common means of identifying various ferrous metals. In this test the piece of iron or steel is held against a revolving grinding stone and the metal is identified by the sparks thrown off. Each ferrous metal has its own peculiar spark characteristics. The spark streams vary from a few tiny shafts to a shower of sparks several feet in length.

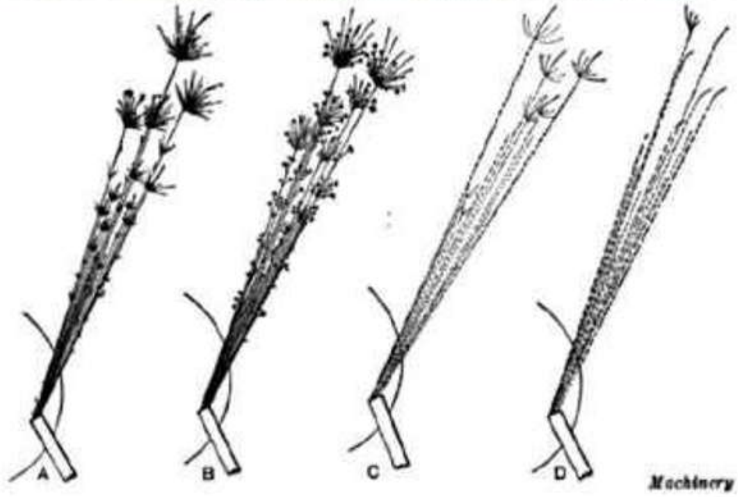
Wrought iron produces long shafts that are straw color as they leave the stone and white at the end. Cast iron sparks are red as they leave the stone and turn to a straw color. Low carbon steels give off long, straight shafts having a few white sprigs. As the carbon content of the steel increases, the number of sprigs along each shaft increases and the stream becomes whiter in color. Nickel steel causes the spark stream to contain small white blocks of light within the main burst.

(A) High-carbon steel (B) Manganese steel (C) Tungsten steel (D) Molybdenum steel

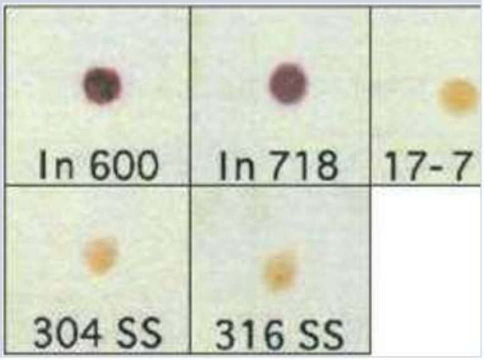
ELECTROCHEMICAL TEST

Prepare a wiring assembly as shown in Figure, and prepare the two reagents (ammonium fluoride and dimethyl glyoxime solutions) placing them in separate dedicated dropper solution bottles. Before testing, you must thoroughly clean the metal in order for the electrolytic deposit to take place. You may use non-metallic hand scrubbing pads to remove deposits and corrosion products (thermal oxide).





Connect the alligator clip of the wiring assembly to the bare metal being tested. Place one drop of a 0.05 percent reagent grade ammonium fluoride solution in de ionized water on the center of a 1 inch × 1 inch sheet of filter paper. Lay the moistened filter paper over the bare metal alloy being tested. Firmly press the end of the aluminum rod over the center of the moist paper. Maintain connection for 10 seconds while rocking the aluminum rod on the filter paper. Ensure that the light emitting diode (LED) remains lit (indicating good electrical contact and current flow) during this period. Disconnect the wiring assembly and set it aside. Remove the filter paper and examine it to determine that a light spot appears where the connection was made. Deposit one drop of 1.0 percent solution of reagent grade di methyl glyoxime in ethyl alcohol on the filter paper (same side that was in contact with the test metal). A bright, distinctly pink spot will appear within seconds on the filter paper if the metal being tested is Inconel (nickel-chromium-iron alloy). A brown spot will appear if the test metal is stainless steel. Some stainless steel alloys may leave a very light pink color. However, the shade and depth of color will be far less than would appear for Inconel. For flat surfaces, the test spot will be circular while for curved surfaces, such as the outside of a tube or pipe, the test spot may appear as a streak.

Colour	Metal
Brown spot	Stainless steel
Light pink	Stainless steel
Bright pink 	Inconel

IDENTIFICATION OF STEEL

To facilitate the discussion of steels, some familiarity with their nomenclature is desirable. A numerical index, sponsored by the Society of Automotive Engineers (SAE) and the American Iron and Steel Institute (AISI), is used to identify the chemical compositions of the structural steels. In this system, a four-numeral series is used to designate the plain carbon and alloy steels; five numerals are used to designate certain types of alloy steels.

In the SAE numbering system,

- The first digit indicates the type to which the steel belongs.
  “1”-indicates a carbon steel
  “2”-indicates a nickel steel
  “3”-indicates nickel-chromium steels
- The second digit indicates the percentage of the main alloy in the steel (but not always).
- The last 2 or 3 digits show the average carbon content in points or hundredths of1%.

Thus the “2340” indicates a nickel steel of approximately 3% nickel (3.25 to 3.75) and 0.40% carbon (0.38 to 0.43). Small quantities of certain elements are present in alloy steels that are not specified as required. These elements are considered as incidental and may be present to the maximum amounts as follows: copper, 0.35 percent; nickel, 0.25 percent; chromium, 0.20 percent; molybdenum, 0.06 percent.

Major classifications of steel[2]

SAE designation	Type
1xxx	Carbon steels
2xxx	Nickel steels
3xxx	Nickel-chromium steels
4xxx	Molybdenum steels
5xxx	Chromium steels
6xxx	Chromium-vanadium steels
7xxx	Tungsten steels
8xxx	Nickel-chromium-molybdenum steels
9xxx	Silicon-manganese steels

Heat Treatment and Application of Alloy Steels; Heat Treatment of Ferrous Metals

HEAT TREATMENT OF STEEL

Heat treatment of the steel is based on the fact that the metal has a crystalline structure which assumes different forms at various temperatures. The change in the structure as the temperature decreases is normally slow and it has been found that by rapid cooling, such as dropping the metal in a cold liquid, the normal structure at high temperature can be retained at atmospheric temperatures. This new structure has totally different physical properties from the normal atmospheric temperature structure. Numerous variations in the properties of the metal are possible depending upon the temperature from which the metal is quenched (cooled) and the speed of quenching. The practical terms which describes the heat treatment are, Annealing, Normalizing, Hardening and Tempering or Drawing. In addition to this there are some special treatment given to the metals are Carburizing, Cyaniding and Nitriding. To develop the desired properties all aircraft steel are subjected to one or more of these above operations.

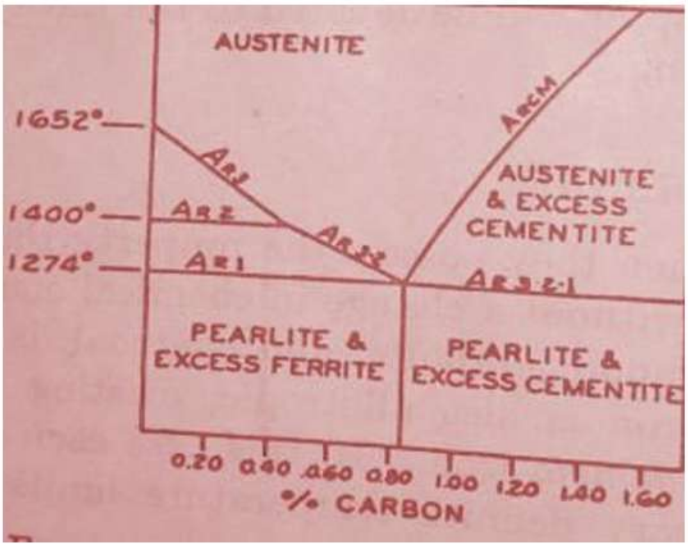
CRITICAL RANGE

Materials are said to be allotropic when they possess the property that permits them to exist in various form without a change in chemical composition. Carbon, which exists as diamond, graphite, and charcoal, is a common allotropic substance. Pure iron is also allotropic, existing in three states: namely, alpha beta, and gamma iron. In this case each of these states is stable only between very define temperature limits, alpha iron up to 14000F, beta iron from 14000F. To 16520 F., and gamma iron above the latter temperature.

When molten iron solidifies and is permitted to cool at a uniform rate, it is found that at 16520F. The cooling stops momentarily. At this point a changes in the structure of the iron has taken place, in which gamma iron has been transformed into beta iron. This rearrangement of the structure has resulted in the evolution of heat, which accounts for the retardation of the cooling. This point is designated by the symbol Ar3 and is called the upper critical point. As the cooling continues, it is found that a second retardation occurs at 14000F. Obviously this is caused by the transformation of beta into alpha iron with the resultant evolution of heat. This point is indicated by Ar2, the second critical point.

In the heating of pure iron similar points occur in which heat is absorbed without a rise in the metal temperature. These points are designated Ac2, and Ac3.These heat-absorption points are some 200F higher than the respective Ar2 and Ar3 points. The critical range is the range of temperature between the lower and upper critical points.

Carbon steel have definite critical points and a critical range. The exact temperature at which these points occur and the number of points depends upon the carbon content of the steel. Low carbon steel have three critical points. In addition to the preceding two points described for the iron, when a small amount of carbon is added to the iron another point designated as Ar1 occurs at 12740F. There is a similar point on the rising heat designated as Ac1. The point Ar1 is called lowest critical point.



Referring above figure it can be seen that the number of critical points and the scope of the critical range depends upon the carbon content. There are three critical points up to a little over 0.4% carbon. In this region the two upper critical points merge forming a single point. At

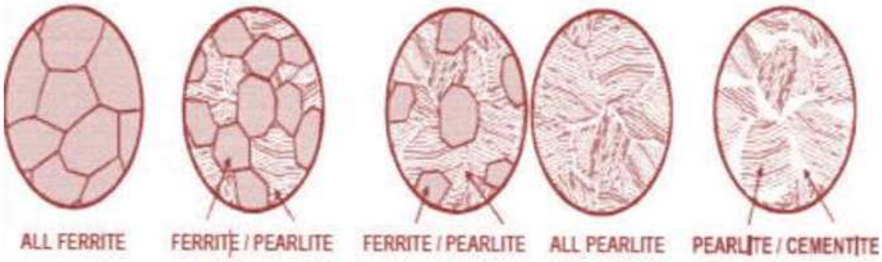
0.85% carbon all the critical points unite and we have one point. Above 0.85% carbon, a new critical point is designated. Alloy steel possess similar critical points but they occur at different temperatures for each steel. Nickel and manganese have the property of lowering the critical range.

INTERNAL STRUCTURE OF STEEL

The internal structure of steel is almost wholly dependent upon the exact relationship of the iron and carbon. The carbon is in chemical combination with the iron as iron carbide (Fe3C), called cementite. In steels containing 0.85% carbon the cementite forms a perfect mixture with the pure iron (called ferrite) present. This mixture is called pearlite. Pearlite is a mechanical mixture of six parts of ferrite to one part of cementite. Steels with less than0.85% carbon are composed of pearlite and excess ferrite. Practically all aircraft steels are of this type. On the other hand, tool steels which contain more than 0.85% carbon are composed of pearlite and excess cementite.

In metallurgy the name eutectic alloy is given to that alloy of two substances which has the lowest fusing point. In every alloy there is one percentage combination of the two elements that will fuse at the lowest temperature. Variation of the percentage composition of either element, up or down, will increase the temperature of fusion. A similar condition exists in steel in the critical range . You will note in Figure that the lowest temperature for the upper critical point occurs at 0.85% carbon contest. This alloy has been named the eutectoid. Steel with less than 0.85% carbons is called hypo- eutectoid and with more 0.85% hyper- eutectoid. Steels with excess ferrite are hypo-eutectoid, and steels with excess cementite are hyper-eutectoid

Pearlite is normally a laminated structure consisting of alternate layers of ferrite and cementite In some cases pearlite has a granulated appearance and is called granular pearlite. If steel is cooled very slowly through the critical range, laminated pearlite, which is the most stable form, will result. Pearlite is relatively strong, hard and ductile, it has a tensile strength of over 100,000 p.s.i, an elongation of approximately 10% and maximum hardening power. This latter point is extremely significant. It means that the greatest hardness from heat treatment is obtainable by steelcontaining 0.85% carbon. It is also



true that starting with low- carbon steel greater hardness is obtainable as the carbon content increases and approaches 0.85%. This point is important when selecting a steel to give greater strength and hardness after heat treatment.
Ferrite is the pure alpha iron in carbon steel. In alloy steel containing nickel, molybdenum or vanadium, these alloying elements are in the solid solutions in the ferrite (A solid solution is a solid-state solution of one or more solutes in a solvent. Such a mixture is considered a solution rather than a compound when the crystal structure of the solvent remains unchanged by addition of the solutes, and when the mixture remains in a single homogeneous phase.). Ferrite is very ductile and has the tensile strength of about 40000 psi. It should be noted that it imparts these properties to low carbon steels of which it is the major constituent. Ferrite does not have any hardening properties. Cementite is iron carbide. It is very hard and brittle and produces a hardening quality to steel of which it is a part.

Austenite, the name given to the steel when it is heated above the critical range consist of a solid solution of cementite in gamma iron. It is stable only when maintained at a temperature above a critical range. It will attain perfect homogeneity if sufficient time is allowed. The grain size of the steel has been found smallest just above the critical range, and it is known fact that the smallest grain size will give the strongest and best metal. For this reason when steel is heated for hardening its temperature is kept just above the upper critical point for the time necessary to insure the thorough heating of the material.

THEORY OF HEAT TREATMENT:

When molten steel solidifies austenite is formed. As further cooling takes place the critical range is reached and the austenite goes through the transition until at the lower critical point, the pearlite either with the excess ferrite or cementite, depending upon the carbon content of the steel is formed. The transition from austenite to pearlite through the critical range is normally a slow operation. This transition can be arrested if this operation is speeded up by such a means as dropping austenitic steel just above the critical range in cold water or oil. This operation is so severe that an extremely hard and brittle material is obtained. By reheating the metal below the critical range, brittleness can be reduced thus creating a useful condition of moderate hardness and strength.

Martensite is an intermediate form of cementite in alpha iron obtained when the transition from austenite to pearlite is arrested. Martensite is the hardest structure obtained in the steel.
Troostite is another intermediate form similar to Martensite, which is often present in the harden steel. Troostite is also present in drawn or tempered steel whereas Martensite is not.
Sorbiteis the third intermediate form between austenite and pearlite. It is the main constituent of tempered steel and gives the maximum strength and ductility to steel.
Harden steel consists almost entirely of Martensite with some Troostite. When the steel is reheated as in tempering, the martensitic structure breaks down and Sorbite with small amount of Troostite remains. By varying the tempering or drawing temperatures different amount of Troostite and Sorbite can be retained and consequently a variation in the physical properties is obtainable.

The effects of heating to various temperatures and cooling at different rates may be summarized as follows.

1. When a piece of steel is heated to the upper critical point, Ac3, it becomes as fine grained as possible no matter how coarse or distorted the grain was previously.
2. After it has been heated to Ac3, if the steel allowed to cool slowly it retains the fine grained structure and is also soft and ductile.
3. After it has been heated to Ac3, if the steel is cooled rapidly as by quenching in cold water or oil, it retains the fine grained structure and fully hardened.
4. If the steel is heated above Ac3, permitted to cool to Ac3, and then quenched it will be fully hardened but more coarse grained than if it had only been heated to Ac3, originally.
5. The higher temperature above Ac3, form which the steel is cooled, either slowly or rapidly coarser the grain.
6. When the piece of harden steel , which has been previously heated to Ac3, or just above, soaked and quenched, is again heated to somewhere below Ac1, it is soften but without change in grain size. The softening is greater as the temperature increases up toAc1.

ANNEALING

It is the process of heating steel above the critical range, holding it at that temperature until it is uniformly heated and the grain is refined and then cooling it very slowly. Annealed steel is fine grained, soft, ductile and without internal stress or strain. It is readily machinable and workable. In the annealed state the steel has its lowest strength. For this reason it is often given a subsequent heat treatment so as to increase the strength after all machining and mechanical work is complete.

Purpose Of Annealing:

1. To reduce the internal stresses.
2. To reduce the hardness
3. To improve machinability,
4. To increase the ductility
5. To refine the crystalline structure
6. To prepare steel for subsequent heat treatment.

There are several modifications of the full annealing treatment used when all of the effects are not essential, and speed and economy are important.

Process annealing is the method of heating steel below Ac1 in the region between 10200F and 12000F. This treatment is commonly used in sheet and wire industries to restore the ductility.

Spheroidizing is the form of annealing applied particularly to high carbon steel to improve their machinability. As indicated by the name a globular cementite structure is obtained. In this form the cementite can be push aside by the cutting tool instead of offering great resistance as when present in the laminar form. The operation of Spheroidizing consists of prolonged heating just slightly below the critical range followed by slow cooling.

Shop Annealing is the term used to describe the practice of heating the steel with a welding torch to 9000F to 10000F and dropping it into pail of ashes or lime to restrict the cooling rate. This treatment Will relive the internal strains. It is never used in aircraft work unless it is to be followed by regular heat treatment.

In all annealing process due to prolonged heating at high temperatures and slow cooling from this temperature the surface of the metal is subjected to scale. The scale on the steel is iron oxide.

Whenever possible annealing should be done in closed receptacles to exclude air form the metal.

NORMALIZING

Normalizing is the form of annealing which consists of heating the steel above Ac3 and then cooling in still air. Due to the more rapid quenching obtained by air cooling as compared to furnace cooling, the steel is stronger and harder but less ductile than the annealed steel. If annealed steel is used in fabrication for ease of working, it is subsequently normalized or heat treated to higher strength.
Medium and high carbon steels should be normalized and then annealed before fabrication or machining. This sequence of operations is sometimes called double annealing.

Purpose of Normalizing:

1. To refine grain structure,
2. To remove internal stresses,
3. To improve the mechanical properties of the steel
4. To reduce brittleness caused by cold working,
5. To restore toughness of metal.

Compassion between annealed component and normalized components is as follows,

Annealed components	Normalized components
Annealed steels have lower yield Point, tensile strength and impact Strength.	normalized steels have slightly higher yield point and tensile strength
Ductility and obtained by somewhat higher.	machinability annealing is Ductility and machinability obtained By normalizing is somewhat lower.

HARDENING

Hardening can be defined as the process of heating the steel above the critical temperature, holding it at this temperature for considerable time and cooling suddenly.
This sudden cooling is called quenching. And the quenching media used is water, oil or brine solution

Purposes:

1. The main purpose of hardening of steel is to increase strength and wear resistance.
2. To obtain a suitable microstructure which will have desired mechanical properties.

After hardening the parts become brittle, poor in ductility and toughness, good in tensile strength and poor in impact strength, relative elongation and reduction in area.

The heat absorption of oil is slower than that of water or brine solution and hence the cooling operation is more gentle. Less cracking occurs and sufficient hardness is obtained.

Quench cracking is the result of non-uniform or too rapid cooling of the steel.

TEMPERING OR DRAWING

Tempering may be defined as the process of reheating the hardened steel to a temperature below Ac1, holding it at this temperature and slow cooling. Exact temperature at which tempering should be carried out depends upon the purpose for which the work piece is to be used.

1. To increase impact toughness of an already hardened steel.
2. To improve yield point of structural steel which is already hardened.
3. To stabilize the structure of the metal.
4. To reduce internal stresses produced during previous heating.

Necessity of tempering:

The structure of steel obtained after hardening is not suitable directly for engineering applications because of the following reasons:

- The structure of steel obtained after hardening is extremely hard and brittle and may result in failure by cracking.
- Due to sudden cooling high internal stresses set up which may result in distortion or cracking of the part during service.

PRACTICAL HEAT TREATMENT:

The first important consideration in the heat treatment of a piece of steel is to know its chemical composition which in turn determines its critical range. When the critical range is known the next consideration is the rate of heating, soaking and cooling to be employed to ensure completion of transition or retardation of transition as the case may be. This involve the use of furnace for uniform heating, pyrometers for controlling the temperatures, handling of hot metals and quenching them in suitable mediums.

HEATING:

The object in heating is to transform pearlite (a mixture of alternate strips of ferrite and iron carbide in a single grain) to austenite as the steel is heated through the critical range. Since this transition takes time, a relatively slow rate of heating must be used. Ordinarily, the cold steel is inserted when the temperature in the furnace is from 300 °F to 500 °F below the hardening temperature. In this way, too rapid heating through the critical range is prevented.

Several types of furnace are used in the heating. The common type is a Dry Heat furnace and is fired by either oil, gas or electricity. A uniform temperature must be maintained throughout the furnace and the work must be properly placed to ensure uniform heating. The work must not be placed too close to the wall of the furnace, otherwise radiated heat from the wall of the furnace will heat one face of the work over others, with the resultant of uneven heating.

If temperature measuring equipment is not available, it becomes necessary to estimate temperatures by some other means. An inexpensive, yet fairly accurate method involves the use of commercial crayons or paints that melt at various temperatures within the range of 125 °F to 1,600 °F. The least accurate method of temperature estimation is by observation of the colour of the furnace or of the work.

In the dry furnace it is often necessary or desirable to protect steel from surface oxidation (scaling) and loss of carbon from the surface layers (decarburization). Commercial furnaces, therefore, are generally equipped with some means of atmosphere control. When no atmosphere control is used special paint coating such as Galvo Anti-Scale are sometimes used to minimise the scaling during the heating operation.

A Liquid Heat type of furnace is frequently used for parts which have been finished-machined before heat treatment. In this type of furnace parts are heated in a molten salt bath. There are several advantages of this type, the most important being the complete elimination of scaling. In addition better temperature regulation and more uniform heating is achieved.

SOAKING

The temperature of the furnace must be held constant during the soaking period, since it is during this period that rearrangement of the internal structure of the steel completed. The length of the soaking period depends upon the type of steel and the size of the part. Naturally, heavier parts require longer soaking to ensure equal heating throughout. As a general rule, a soaking period of 30 minutes to 1 hour is sufficient for the average heat-treating operation.

QUENCHING:

The rate of cooling through the critical range determines the form that the steel will retain. Various rates of cooling are used to produce the desired results. Still air is a slow cooling medium, but is much faster than furnace cooling. Liquids are the fastest cooling media and are therefore used in hardening steels. There are three commonly used quenching liquids brine, water, and oil. Brine is the strongest quenching medium, water is next, and oil is the least. Generally, an oil quench is used for high carbon steel and alloy steels. Medium carbon steel water quench and low carbon steel is quenched either in water or brine. A severe quench is required for steels with relatively low carbon content in order to develop the required hardness.

Oil quench is preferred over water or brine because of the reduced strength and less cracking of the steel when cooled more slowly. When the structure changes from austenite to Martensite, the volume is increased, and if the change is too sudden, cracking will occur. Cracking occurs particularly in the lower temperature range when the steel is no longer plastic enough to readjust itself to expansion and contraction.

The quenching tank should be of the proper size to handle the material being quenched. Use circulating pumps and coolers to maintain approximately constant temperatures when doing a large amount of quenching. Tank location in reference to the heat- treating furnace is very important. Situate the tank to permit rapid transfer of the part from the furnace to the quenching medium. A delay of more than a few seconds will, in many instances, prove detrimental to the effectiveness of the heat treatment.

SURFACE HARDENING:

Surface hardening is a heat treatment process, which produces a hard wear resistant layer over a tough core portion of steel. Casehardening is ideal for parts which require a wear-resistant surface and, at the same time, must be tough enough internally to withstand the applied loads.

In few engineering applications such as gears, crankshafts etc. hard and wear resistant surface is required with tough inside portion to withstand high impact loads. The steels best suited to casehardening are the low carbon and low alloy steels. If high carbon steel is casehardened, the hardness penetrates the core and causes brittleness. In casehardening, the surface of the metal is changed chemically by introducing a high carbide or nitride content. The core is unaffected chemically.

The methods commonly used for surface hardening are, Carburizing, Cyaniding and Nitriding. The combination of carburizing and the subsequent heat treatment is called casehardening. Casehardening is used more than any other method in aircraft work.

CARBURIZING:

Carburizing is a casehardening process in which carbon is added to the surface of low carbon steel. Thus a carburized steel has a high carbon surface and a low carbon interior. When the carburized steel is heat treated, the case is hardened while the core remains soft and tough. This process consists of heating the steel in contact with carbonaceous material. This material may be either solid, liquid or gaseous. The low carbon steels are week solutions and will absorb free carbon. The carbon rich materials when heated give off a gas containing carbon which diffuses into the steel surface. The depth of the penetration depends upon the carbonaceous material, the temperature and the time allowed.

The absorption of carbon at the surface will greatly increase the carbon content in this region. This carbon content will range from 0.80 to 1.25% at the surface and will taper off towards the center with the core remaining at the original content. Subsequent heat treatment will harden the case and toughen the core.

Solid Carburizing:

This is the most commonly used method of carburizing. It uses the solid carbonaceous materials. When carburizing is to be done by this method, the steel parts are packed in a container with charcoal or some other material rich in carbon. The container is then sealed with fire clay, placed in a furnace, heated to approximately1,700° F, and soaked at that temperature for several hours. The temperature should be kept as close to the critical range as possible to avoid grain growth. As the temperature increases, carbon monoxide gas forms inside the container and, being unable to escape, combines with the gamma iron in the surface of the steel. The depth to which the carbon penetrates depends on the length of the soaking period. For example, when carbon steel is soaked for 8 hours, the carbon penetrates to a depth of about 0.062 inch.

After the carburizing the container is removed from the furnace and allowed to cool in air or the parts removed and quenched in oil form the carburizing temperature. This cooling completes the carburizing process and the parts are then ready for hardening and tempering.

Liquid Carburizing:

Carburizing in a liquid salt bath is called liquid carburizing. This method is applicable to small parts when depth of case not more than 0.040 inch is sufficient. This method has an advantage of forming a case uniform in depth and carbon content. Also this method is faster than the solid carburizing as the laborious packing is eliminated. A salt that melts several hundred degrees below the carburizing temperature is used as a liquid heat. An amorphous carbon is added to furnish the required carbon. As with the solid material the depth of the case obtained is dependent on the time and the temperature. After carburizing the parts may be quenched in water or oil and are ready for hardening and temperature.

Gas Carburizing:

In this method of carburizing a material rich in carbon is introduced into the furnace atmosphere. The carburizing atmosphere is produced by the use of various gases or by the burning of oil, wood, or other materials. When the steel parts are heated in this atmosphere, carbon monoxide combines with thegamma iron to produce practically the same results as those described under the solid carburizing process.

Refining the Core:

Due to the fact that sometimes carburizing temperature is well above the critical range and is held for a long period of time, an excessive grain growth may take place in the steel. In order to obtained a fine ductile grain in the core it is necessary to reheat the steel to just above the upper critical point, soak until the metal is uniformly heated and then quench in oil.

Hardening of the case:

Since the case of a carburized steel part has a high carbon content, the temperature required to refine the low carbon core is considerably above the critical range of the case. This high temperature results in the grain growth and embrittlement of the case. It is therefore necessary to reheat the steel to just above the critical range of the high carbon case and then quench in oil. This treatment refines the grain and hardens the case. The hardening temperature for the high carbon case is well below the upper critical point of low carbon core, hence the only effect this reheating has on the core is a tempering action.

Tempering:

In order to relive hardening strain carburized steel parts are tempered by heating in the region of 300 to 4000F. This tempering should be done immediately after the hardening quench. The furnace or oil bath should be kept at tempering temperature when the parts are inserted. The parts should be soaked until uniformly heated and then removed and cooled slowly in still air.

Selective Casehardening:

In many design it is required to harden only that portion of the part which is subjected to severe wear. Methods have been developed to protect the other portions of the part from getting harden. The best method is to copper plate the sections to be left soft. Before copper plating the sections to be harden are painted with special paints to protect them from being copper plated. The paint is removed after copper plating but before the hardening operation.

It is customary to finish hardened carburized part by grinding. In some cases where soft section is desired, sufficient material is left during the original machining to allow for grinding. By this method the case is completely removed by grinding where a soft section is desired.

Warpage and Cracking

Warpage of carburized parts is very common and is caused by improper packing or sever quenching. It is customary to finished grind caseharden parts to reduce the distortion. Cracking of parts occurs in the hardening quench. It is necessary to avoid all sharp corners, notches or sudden changes of the section in the parts to be harden. In some cases it is preferable to design the part in two or more pieces to avoid hardening cracks. Some carburizing steel requires a less severe quench than others and are not as subjected to warping and cracking. SAE 4615 (nickel-molybdenum steel) is generally recommended for case harden parts.

Carburizing Steels

Carburizing steels are either plain carbon or alloy steels but are in low carbon range. A low carbon content is necessary to retain the tough core after the heat treatment. In special cases a steel with the carbon content as high as 0.55% has been successfully carburized. Normally the carbon content is restricted to a maximum of 0.25%. For light parts requiring extremely tough core 0.18% carbon is the maximum that should be permitted. For heavy parts requiring strong core, the carbon content of the steel should be 0.15% to 0.25%.

Since the carbon content of the carburizing steels is limited, in order to obtain the greater strength without decrease in toughness after the heat treatment it is necessary to use alloy steel. The alloy steels commonly used are nickel, nickel-chromium and molybdenum. The greatest core strength is obtained by using a nickel steel SAE2515.

When a hard case is important the plain carbon steel SAE 1020 is used. Alloys decreases the hardness of the case somewhat. SAE2515 steel has the softest case of the carburizing steel.

CYANIDING

Cyaniding is a surface hardening of steel obtained by heating it in contact with cyanide salt followed by quenching. Only superficial case hardening is obtained by this method and hence very rarely used in aircraft work. It has the advantage of speed and economy and may be used on less important parts.

The cyanide bath which is usually sodium or potassium cyanide is maintained at 15500F16000F. The work to be harden is preheated to 7500F and then immersed in the bath for 10 to 20 min. It is then withdrawn and quenched in water until cold. A superficial case of 1/64 inch maximum depth is obtained. The case is hard but not homogeneous. In cyaniding it is important to use closed pot since fumes are extremely poisonous.

The hard case obtained by cyaniding is not wholly due to a high carbon content, as a matter of fact the carbon content is relatively low. Chemical analysis shows the presence of nitrogen in the form of iron nitride in the case. It is this constituent which imparts the hardness as well as brittleness to the case.

NITRIDING

Nitriding is unlike other casehardening processes in that, before nitriding, the part is heat treated to produce definite physical properties. Thus, parts are hardened and tempered before being nitrided. Most steels can be nitrided, but special alloys are required for best results. These special alloys contain aluminium as one of the alloying elements and are called “nitralloys.” In nitriding, the part is placed in a special Nitriding furnace and heated to a temperature of approximately 1,000 ° F. With the part at this temperature, ammonia gas is circulated within the specially constructed furnace chamber. The high temperature cracks the ammonia gas into nitrogen and hydrogen. The ammonia which does not break down is caught in a water trap below the regions of the other two gases. The nitrogen reacts with the iron to form nitride. The iron nitride is dispersed in minute particles at the surface and works inward. The depth of penetration depends on the length of the treatment. In nitriding, soaking periods as long as 72 hours are frequently required to produce the desired thickness of case. Nitriding can be accomplished with a minimum of distortion, because of the low temperature at which parts are case hardened and because no quenching is required after exposure to the ammonia gas.

Advantages:

1. No other heat treatment is required after nitriding.
2. Nitrided steel parts possess very high hardness and very good wear resistance.
3. It also possess higher fatigue life and good corrosion resistance

INDUCTION HARDENING

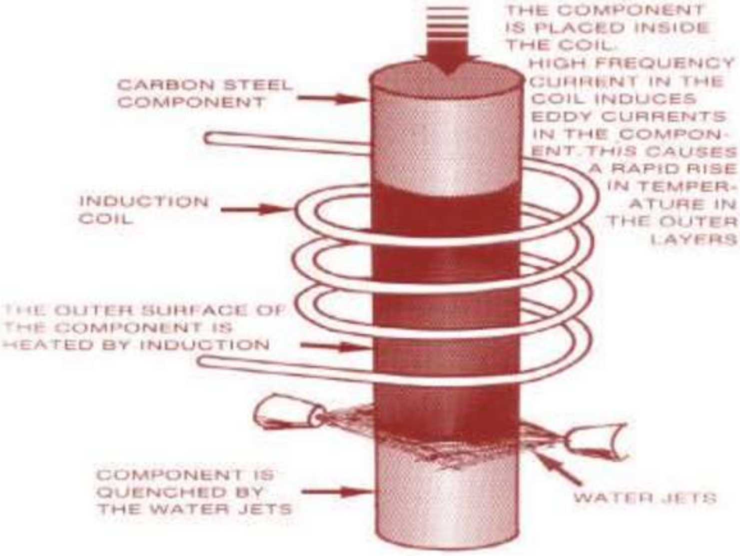
The heat treatment process, which utilizes electric induction heating followed quenching for producing a hard wear resistant layer on a tough core of a steel part, is known as induction hardening.

Process:

The surface of the steel to be hardened is surrounded by a perforated block through which high frequency current is passed. The frequency varies from10000 to 500000 cycles per second. This perforated block act as a primary coil of a transformer. This block is placed around the work piece but does not touch to it.

This produces eddy current and hysteresis loss in the surface of the work piece which causes extremely rapid heating above the upper critical temperature just within 3 to 5 sec.

The heated areas are then quenched immediately by sprays of water delivered through numerous small holes in the block.



Advantages:

1. Very fast and clean operation.
2. No scale generation takes place
3. Very small distortion of the parts.

Limitations:

1. Not suitable for irregular shaped parts
2. Poor surface properties

SHOT PEENING

Shot Peening is sometimes refer as shot blasting. It should not however be confused with sand blasting or other surface blasting processes. Shot peening improves the fatigue and abrasion resistance of the metal parts. It is applicable to ferrous and nonferrous metals, but it is mostly used on steel surfaces.

The shot peening process consists of throwing hardened steel ball at the surface of the work to be peened. The steel balls are thrown against the surface either by compress air or by centrifugal force as the steel ball is fired from the rotating wheel. The intensity of the process can be varied by regulating the size of the steel ball, the hardness of the steel ball, the speed at which it is fired and the length of time the work is exposed to this process. Saturation of the surface with the little indentation made by the steel ball is a quick visual method of inspecting the intensity of shot peening operation. It is desirable to run the sample piece to set up the conditions to be used in the production process. Shot peening pre stresses the surface of the work and adds to the fatigue and abrasion resistance.

Effect of Individual Elements in Steel and Its Alloys

The development of alloy steels in the past has been largely the result of trial and error. It was practically impossible to predict with any degree of accuracy the exact properties that can be obtained by a given combination of elements. Hence it is of great importance to know the effect of adding a specific alloying element. This information is useful to the aircraft designer in identifying which material possesses just right properties for the proposed design.

CARBON:

Carbon is the most important constituent of the steel. It combines readily with iron to form iron carbide (Fe_3C) which is a compound known as cementite. It is largely due to the quantity and behavior of this compound that the steel can be heat treated to various degrees of strength and toughness. Within certain limitations, the higher the carbon content of steel is, the greater will be Ultimate Tensile Strength, the hardness and the range through which it can be heat treated. At the same time the ductility, malleability, toughness, impact resistance and the weldability will be reduced as the Carbon increases.

In selecting the steel for a given design, the carbon content must be considered. A low carbon steel is necessary in deep drawing or excessive mechanical work is required without excessive strength. High carbon steel is necessary where great hardness is required and ductility is not important. In general low carbon steel are used for formed fittings and welded parts, and high carbon steel are used for springs. The medium carbon steels are used for forged fittings and tie rods where good strength combined with ductility is required.

MANGANESE:

Next to carbon manganese is the most important ingredient of the steel. Its primary purpose is to deoxidize and desulphurize the steel to produce a clean and tough metal. It deoxidizes by eliminating ferrous oxide which is a harmful impurity. It combines with the sulphur to form manganese sulphide which is harmless in small amounts. Sufficient manganese is added to the steel to leave an excess of not more than 1% in the metal. This excess manganese exists as manganese carbide (Mn_3C) which has the characteristics in hardening and toughening the steel similar to those of cementite (Fe_3C).
Manganese also possess the property known as penetration hardness which means that in a heat treatment of large sections the harness is imposed not only on the surface but penetrates to the core as well.

The presence of Manganese in the steel will greatly improve the forging qualities of steel by reducing the brittleness at forging and rolling temperature. An excess of more than 1% of manganese will increase the brittleness of the metal. There is however a manganese steel containing approximately 13% manganese which is exceptionally hard and ductile. But it is too hard to cut and must be forged, rolled or cast to finished shape.

Manganese increases hardenability and tensile strength of steel, but to a lesser extent than carbon. It is also able to decrease the critical cooling rate during hardening, thus increasing the steels hardenability much more efficient than any other alloying elements. This material was used for tail skid shoes which were cast to size. It has a property of being non-magnetic.

SILICON:

Silicon increases strength and hardness but to a lesser extent than manganese. It is one of the principal deoxidizers used in the making of steels to improve soundness, i.e. to be free from defects, decays or damages. Only a very small amount not exceeding 0.3% of silicon is present in steel. A small amount of silicon improves the ductility of the steel.

For galvanizing purposes, steels containing more than 0.04% silicon can greatly affect the thickness and appearance of the galvanized coating. This will result in thick coatings consisting mainly zinc iron alloys and the surface has a dark and dull finish. But it provides as much corrosion protection as a shiny galvanized coating where the outer layer is pure zinc.

Silicon and manganese in large amount are used as alloying elements in formation of silico-manganese steel. This steel have a good impact resistance.

SULPHUR:

Sulphur is a very undesirable impurity which must be kept limited in amount not more than 0.06% in steel. The presence of Sulphur renders the steel brittle at rolling or forging temperatures. In this condition the steel is said to be Hot Short. As stated earlier manganese combines with the Sulphur to form manganese sulphide, which is harmless in small amounts. When too much Sulphur is present an iron sulphide is formed which because of its lower melting point, is in liquid form at forging temperatures of the steel. This liquid ingredient breaks up the cohesion of the crystals of the metal and hence cracking and breaking results. With a minimum of 0.30% manganese present and a not more than 0.06% Sulphur, all the Sulphur will be in form of manganese sulphide, which is harmless in small quantities. For welding, weldability decreases with increasing sulphur content.

PHOSPHORUS:

Phosphorus like Sulphur is an undesirable impurity and must be kept limited in amount not more than 0.05% in steel. Phosphorus is responsible for cold shortness or brittleness of the steel when the metal is cold. Below the 0.05% amount of phosphorus there is a little, if any, brittleness in the steel. There is some evident that very small amount of phosphorus increase the strength slightly but on the cost of ductility of steel.In terms of welding, phosphorus content of over 0.04% makes weld brittle and increases the tendency to crack. The surface tension of the molten weld metal is lowered, making it difficult to control.

NICKEL:

Nickel is a white metal as bright as silver. In the pure state it is malleable, ductile, and weldable. It does not corrode easily. Nickel combines with molten steel in all proportions. The commonly used nickel steel contains from 3% to 5% of nickel. The addition of nickel in steel increases the strength, yield point and hardness without affecting the ductility. In the heat treatment the presence of nickel in the steel slows down the critical rate of hardening which in turn increases the depth of hardening and produces a finer grain structure. There is also less warpage and scaling of heat treated nickel steel parts. Nickel increases the corrosion resistance of the steel. It is one of the constituent of the stainless or corrosion resisting steels. A high percentage of nickel gives higher magnetic permeability than obtained with soft iron.

CHROMIUM:

Chromium is a hard gray metal with high melting point. It imparts hardness, strength, wear resistance and corrosion resistance to steel. It also improves the magnetic qualities to such an extent that chromium steel is used for magnets. Chromium possesses the excellent penetration hardness characteristics and its can be heat treated well. The main use of chromium in alloy is in conjunction with nickel, molybdenum, and vanadium. About 1% of chromium is present in these alloys which are strong, hard and have fair ductility. These alloys are also resistant to shock load. It is possible to heat treat the nickel-chromium alloy to an ultimate tensile strength as high as 250000 psi and still retain ductility.

Corrosion resistance steel contains large amount of chromium. The most common of these steel is 18-8 steel which contains approx. 18% chromium and 8% nickel. This metal is extremely corrosion resistance. At the same time it is practically nonmagnetic although some chromium steel are used for magnets and nickel in its pure form is magnetic. This material is a good example of the fact that the alloy does not necessarily retain the properties of the constituents.

Some chromium alloys are used where great wear resistance is required. Thus a chrome-vanadium alloy is used for ball bearing and a tungsten-chromium alloy for high speed cutting tools.

MOLYBDENUM:

Molybdenum is very effective alloying element. A small percentage has much effect as much larger amounts of other alloying elements. It improves the homogeneity of the metal and reduces the grain size. It also increases the elastic limit, the impact value, wear resistance and fatigue strength.

Molybdenum in small percentages is used in combination with chromium to form chrome-molybdenum steel, which has various uses in aircraft. Molybdenum is a strong alloying element. It raises the ultimate strength of steel without affecting ductility or workability. Molybdenum steels are tough and wear resistant, and they harden throughout when heat treated. They are especially adaptable for welding and, for this reason, are used principally for welded structural parts and assemblies. This type steel has practically replaced carbon steel in the fabrication of fuselage tubing, engine mounts, landing gears, and other structural parts.

For example, a heat-treated SAE X4130 tube is approximately four times as strong as an SAE 1025 tube of the same weight and size.

A series of chrome-molybdenum steel most used in aircraft construction is that series containing 0.25 to 0.55 percent carbon,
0.15 to 0.25 percent molybdenum, and 0.50 to 1.10 percent chromium. These steels, when suitably heat treated, are deep hardening, easily machined, readily welded by either gas or electric methods, and are especially adapted to high temperature service.

VANADIUM:

Vanadium is the most expensive of the alloying elements. It is seldom used in amounts over 0.20%. It is an extensive deoxidizing agent and improves the grain structure and fatigue strength. Vanadium also increases the ultimate strength, yield point, toughness, and resistance to impact, vibration and stress reversal. The vanadium alloys as used generally contains about 1% chromium and are called chrome-vanadium steel. These steel have good ductility along with high strength. Vanadium alloys are used for propeller hubs and engine bolts.

TUNGSTEN:

Tungsten steel have no direct application in aircraft construction but it possesses an interesting property known as Red hardness. High speed steel is a tungsten-chromium steel used for cutting tools which will retain their cutting edge even when heated to dull redness by working. This tool steel contains from 14% to 18% tungsten and 2% to 4%chromium.

TITANIUM:

Titanium is often added in small quantities to 18-8 corrosion resisting steel to reduce the embrittlement at operating temperatures of exhaust attacks and collectors.

Aircraft Steel – Properties and Uses

In selecting type of steel for aircraft use, the designer must first assure himself that it possesses the required mechanical properties to withstand the loads and service conditions it will be subjected to. The steel chosen must also be capable of ready fabrication into desire shape. Other important consideration are the availability and cost of the material. It is common practice in aircraft construction to heat treat to heat treat or case harden the steel to obtain the desire properties. Whenever there is choice of two materials, it is advisable to select the one which requires the less sever treatment in order to avoid as much distortion as possible.

Following are the commonly used steel in aircraft construction and their properties,

Carbon Steel:

If carbon is added to iron, in varying percentages, the product is vastly superior than iron alone and is classified as Plain carbon steel. Following are the types of carbon steel commonly used for the aircraft material.

SAE 1015: A galvanised (zinc coated) steel wire is made from this material. It is used as a locking wire on nuts and turn buckles. This wire has a tensile strength of approx. 75000 psi and a minimum elongation of 8% to 10%.

SAE 1020: This steel is used for caseharden parts. In this form it is often used for bushing that must resist abrasion. It is also used for the fabrication of stamping dies that requires hard wear resisting surface. When caseharden this steel has a core strength of 60000 psi, and a good ductility. In normal state it has a UTS of 55000 psi, a yield strength of 36000 psi and an elongation of 22%. This steel machines well. It can be brazed or welded.

SAE 1025: This steel is commonly referred to as Mild carbon steel. For most purpose this steel has been superseded by chrome- molybdenum steel SAE 4130. It is still used for aircraft nuts and similar standard parts and also for non-structural clamps which required lots of bending. When used for aircraft nuts, it is heat treated and develops an ultimate tensile strength of 70000 psi. In sheet form this material can be bend through 1800 without cracking. This material machines fairly well. It can be brazed or welded.

SAE 1045: This steel is used for the fabrication of aircraft tie rods, chain, sprockets, hubs and crankshafts. The cold drawn wires of this steel has the ultimate tensile strength of 140000psi.

SAE 1095: This is a high-carbon steel also called as spring steel. It can be obtain in the following forms,

Spring Steel (sheet or strips) - It is used for the fabrication of flat spring in aircraft work.

MIL-W-6101 spring steel (wire) – It is used for the fabrication of standard grade music wire and small springs. It is obtainable from 0.005 to 0.180 inch diameter with variation in UTS of 350000 psi to 225000 psi respectively for these two sizes.

Bar stocks is used for parts subjected to high shear and wear if case hardening is not desirable. It is sometimes referred to as drill rod since it is used for the fabrication of drills, taps and dies.

Nickel Steel:

The various nickel steels used in aircraft are produced by combining nickel with carbon steel. Steels containing from 3 to 3.75 percent nickel are commonly used. Nickel increases the hardness, tensile strength, and elastic limit of steel without appreciably decreasing the ductility. It also intensifies the hardening effect of heat treatment. The different types of nickel steel are,

SAE 2317: This is a carburizing steel with moderately strong core. Its case has excellent wear and fatigue resisting characteristics. It is used to produce bushings and other parts requiring wear resisting surface combined with a shock resisting core of moderate strength. The normal core strength is 80000 psi.

SAE 2330: This is the standard nickel steel and possesses good strength and toughness. This steel contains 3% nickel and 0.30% carbon, and it is used in producing aircraft hardware such as bolts, turnbuckles, tie rod terminals. This steel can be heat treated to get the UTS of 125000 psi to 150000 psi. This steel can be bent over a diameter equal to its thickness. It also has good machining properties.

SAE 2515: This is a carburizing steel with extremely high strength core. In this steel carbon content is limited to 0.17% max. It is used for engine gears, knuckle pins and other applications requiring high strength core. By proper heat treatment core strength of 120000 psi to 160000 psi can be obtained. This steel machines fairly well but not as good as SAE 2320.

Chromium steel:

Chromium is alloyed with steel to increase strength and hardness as well as improve its wear and corrosion resistance. Because of its characteristics chromium steel is used in balls and rollers of antifriction bearings.

Chrome-nickel steel:

Also known as 'Stainless Steel' or Corrosion Resistant Steel'. The anticorrosive degree of this steel is determined by the surface condition of the metal as well as by the composition, temperature, and concentration of the corrosive agent. The principal alloy of stainless steel is chromium. The corrosion resistant steel most often used in aircraft construction is known as 18-8 steel because of its content of 18 percent chromium and 8 percent nickel. One of the distinctive features of 18-8 steel is that its strength may be increased by cold working.

Stainless steel may be rolled, drawn, bent, or formed to any shape. Because these steels expand about 50 percent more than mild steel and conduct heat only about 40 percent as rapidly, they are more difficult to weld. Stainless steel can be used for almost any part of an aircraft. Some of its common applications are in the fabrication of exhaust collectors, stacks and manifolds, structural and machined parts, springs, castings, tie rods, and control cables.

The other types of nickel-chromium steels are SAE 3115, SAE 3140,SAE 3250 and SAE 3312.

Molybdenum Steel:

Molybdenum steels are tough and wear resistant, and they harden throughout when heat treated. They are especially adaptable for welding and, for this reason, are used principally for welded structural parts and assemblies.

SAE 4037: This molybdenum steel that has been used as a substitute for SAE 2330 nickel steel for the fabrication of bolts , terminals and other similar parts. It is normally heat treated to the UTS of 125000 psi, yield strength of 100000 psi and elongation of 17%.

A series of chrome-molybdenum steel most used in aircraft construction is that series containing 0.25 to 0.55 percent carbon, 0.15 to 0.25 percent molybdenum, and 0.50 to 1.10 percent chromium. These steels, when suitably heat treated, are deep hardening, easily machined, readily welded by either gas or electric methods, and are especially adapted to high temperature service.

SAE 4130: This is the chrome-molybdenum steel. It is the most commonly used alloy in aircraft. It machines readily, is easily welded by gas or electric arc, and respond well to heat treatment. Heat-treated SAE 4130 steel has an ultimate tensile strength about 4 times that of SAE 1025 steel. It is used in fabrication of landing gears, fuselage tubings, engine mounts and other structural parts. The other types of chrome-molybdenum steel are SAE 4135 and SAE4140.

SAE 4340: This is nickel-chromium-molybdenum steel with excellent properties. It has good depth hardening qualities and also has good impact and fatigue resistance at high strength. Propeller hubs, crankshafts and other large forgings are made from this material. It is an ideal material for highly stressed aircraft parts requiring good hardenability. This material has the UTS of 180000 psi, a yield strength of 160000 psi and an elongation of 16%. It is sometimes heat treated as high as 280000 psi UTS.

SAE 4615: This is nickel-molybdenum steel having 1.75% of nickel. This is one of the best of the carburizing steel. It has very fine grain. It has a file hard case for resisting wear and is excellent for use in bushing, rollers and locations requiring wear resisting and accurate dimensions. A core strength of 80000 psi to 100000 psi is obtainable with this steel. It has high fatigue resistance in addition to the other good properties.

Chrome-Vanadium Steel:

The chrome-vanadium steels are made of approximately 18 percent vanadium and about 1 percent of chromium. When this alloy is heat treated, they have strength, toughness, and resistance to wear and fatigue. A special grade of this steel in sheet form can be cold formed into intricate shapes. It can be folded and flattened without signs of breaking or failure. SAE 6150 is used for making springs; chrome vanadium with high carbon content, SAE 6195, is used for ball and roller bearings.

Special Steels:

Silicon-Chromium Steel: Important springs are manufactured form this high strength steel which may be obtained in rod form. For this purpose it can be interchangeable with SAE 6150 steel. It can be heat treated to an UTS of 200000 psi and yield strength of 180000 psi and an elongation of6%.

Nitriding Steel: This is a special steel used only for nitrided parts. It is used for bushing and gears requiring great surface hardness and wear resistance.

Austenitic Manganese Steel: This material is also known as Had field"s manganese steel. It has exceptional resistance to wear and abrasion and is extremely tough. It is almost impossible to machine and should be cast to size and finished by grinding when necessary. This material has been used for tail skids and for arresting hook toes.

Hy-Tuf: Hy-tuf is a trade name for a steel used in high tensile strength range of 220,000 psi to 240,000 psi. This steel has found wide use in aircraft landing gear components arresting hooks and structural fittings. After being hardened and tempered this steel has UTS of 230,000 psi, yield strength of 194,000 psi and elongation of14%.

Corrosion resistant steel:

Corrosion resistant steels are often called as stainless steels. They are normally classified into three groups.

Group 1. Chrome-nickel steel: This group consists of those steels containing 0.2% carbon or less, 17% to 25% chromium and 7-13% nickel. The well-known "18-8" corrosion resisting steels is on of this group, in fact this steel with minor modification is most often used in aircraft construction. A distinctive property of this group is that the strength cannot be increased by heat treatment but only by cold working.

Group 2: Hardenable chromium steel: This steel contains 12- 18% chromium and varying amounts of carbon up to as high as 1%. As indicated by the name they are Hardenable by heat treatment. This type of steel is commonly used in manufacture of aircraft bolts and fittings requiring good corrosionresistance.

Group 3. Non-Hardenable chromium steel: These steels are not hardenable by heat treatment. They may be used for special applications but as yet have not been used in aircraft construction.

For aircraft purpose no attention is paid to the above grouping. It is important to think of the corrosion resistant steel in relation to their uses in the aircraft construction. The two main uses are

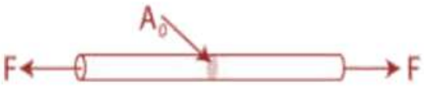
1. Non-structural, such as manufacture of exhaust collectors, which are dependent upon the excellent corrosion resistant and heat resistant qualities of the steel.
2. Structural, which depends on high strength, ease of fabrication as well as corrosion resistance.

Corrosion resistant steels are not fully resistant to all the corrosive agents. Their corrosion resistance depends upon their own physical state as well as the temperature and the concentration of the particular corrosive agent.

b) Testing of ferrous materials for hardness, tensile strength, fatigue strength and impact resistance.

Physical Test Terms

Stress



Stress is a measure of the internal force an object is experiencing per unit cross sectional area.

$$\text{Stress, } \sigma = \frac{\text{Force}}{\text{Cross-Sectional Area}} = \frac{F}{A_0}$$

Strain

Strain is the deformation of material caused by an applied load.

Tensile strength

This is often referred to as the ultimate tensile strength (U.T.S.). It is the maximum tensile load per square inch which a material can withstand. It is computed by dividing the maximum load obtained in a tensile test by the original cross sectional area of the test specimen. In this country it is usually recorded as pounds per square inch.
Tensile means the material is under tension. Tensile Strength is the ability of a material to resist fracture (breaking) under a tension (stretching) force. The tensile test measures the stress that required to cause fracture of a test specimen in tensile load.

In the tensile test, a test piece of known cross sectional area is gripped in the jaws of a tensile testing machine. A tensile force is then applied which is increased by suitable increments. For each increment of force applied the amount by which the „gage length‟ of the test piece increases, is measured using an extensometer. When the test piece begins to stretch rapidly the extensometer is removed, otherwise it may be damaged. The maximum force applied to the test piece before it fractures is measured. Using the results obtained during the test a stress/strain diagram can be plotted.

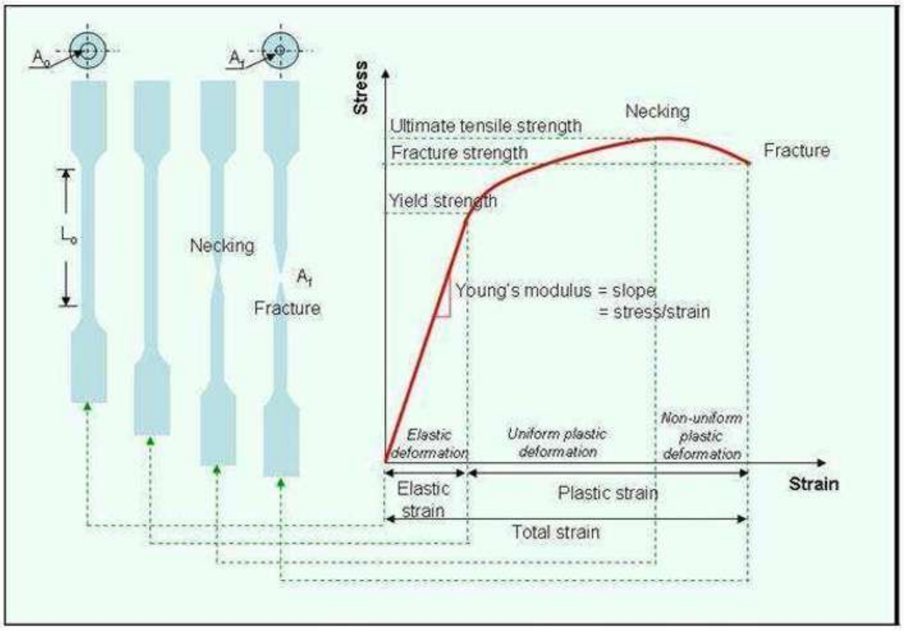
Tensile testing is an engineering testing procedure used to determine properties of various engineering materials. These properties include Young‟s modulus, elastic limit, ultimate tensile strength, proof stress and yield stress. When a specimen is subjected to an external tensile loading, the metal will undergo elastic and plastic deformation. Initially, the metal will elastically deform giving a linear relationship of load and extension. These two parameters are then used for the calculation of the engineering stress and engineering strain to give a relationship

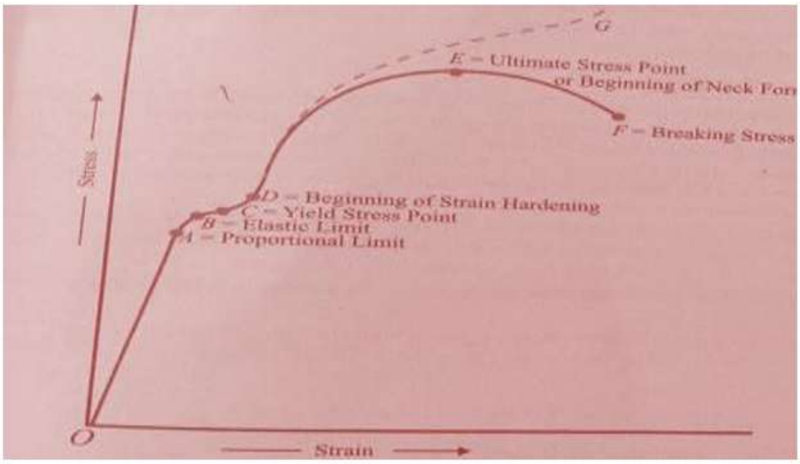
Elastic limit

The elastic limit is the greatest load per square inch of original cross sectional area which a material can withstand without permanent deformation remaining upon complete release of the load. As stated under "elasticity," the aim in aircraft design is to keep the stress below this point.

Proportional limit

The proportional limit is the load per square inch beyond which the increases in strain ceases to be directly proportional to the increases in stress. The law of proportionality between stress and strain is known as Hooke's law. The determination of the proportion limit can be more readily accomplished than that of the elastic limit, and since they are very nearly equivalent the proportional limit is usually accepted in place of the elastic limit test work Stress /Strain curve of mild steel bar.





Stress /Strain curve of mild steel bar.

Proof Stress

The proof stress is the load per square inch a material can withstand without resulting in a permanent elongation of more than 0.0001 inch, per inch of gage length after complete release of load. With the standard 2 inch gage length the total permissible elongation would be 0.0002 inch.

Yield Point

The yield point is the load per square inch at which there occurs a marked increase in deformation of a material without an increase in load. Only few materials have a definite yield point. Steel is one of these materials.

Yield Strength

The yield strength is the load per square inch at which a material exhibits a specified limiting permanent set or a specified elongation under load. This load is fairly easily determined and is commonly used.

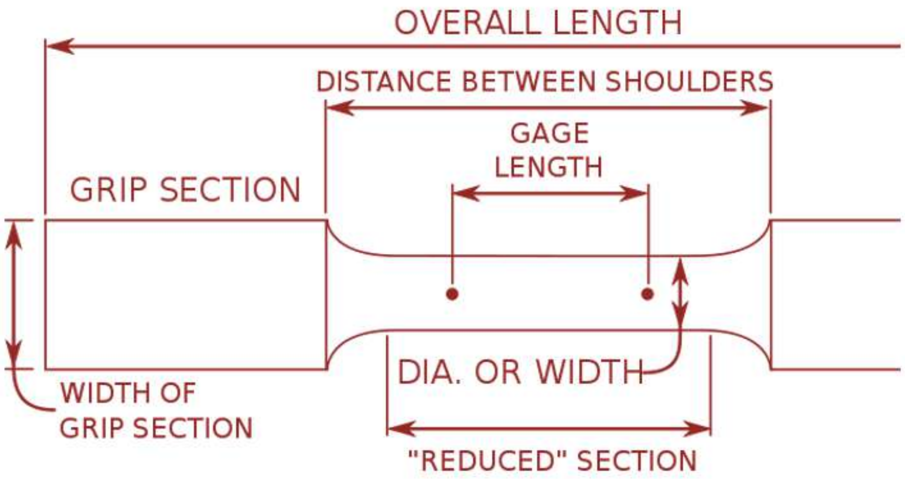
Elongation (Percentage)

The percentage elongation is the difference in gage length before being subjected to any stress and after rupture expressed in percentage of the original gage length. The length after rupture is obtained by removing the two pieces from the machine and piecing them together on a flat surface. The distance between the gage marks is then accurately measured.

Reduction of area (Percentage)

The percentage reduction of area is the difference between the original cross sectional area and the least cross sectional area after rupture expressed as a percentage of the original cross sectional area. This information is seldom used other than as an indication of ductility.

Tensile Test Specimen



Modulus of Elasticity

Stress is directly proportional to strain;

stress = a constant x strain

$$\frac{\text{stress}}{\text{strain}} = \text{constant E, a constant for the material}$$

This constant 'E' is known as Young's Modulus of elasticity for the material and is:

$$E = \frac{\text{stress}}{\text{strain}} \quad \text{where stress} = \frac{\text{load}}{\text{area}}$$

Strain is the ratio or fraction:

$$\text{strain} = \frac{\text{Final Length - Original Length}}{\text{Original Length}} = \frac{\text{Change in length}}{\text{Original Length}}$$

The modulus of elasticity of a material is the ratio of stress to strain within the elastic limit.
During elastic deformation, the engineering stress-strain relationship follows the Hooke's Law and the

slope of the curve indicates the modulus of elasticity (E).

TESTING AIRCRAFT MATERIALS TENSION TESTING

Tension test of a material is probably the most valuable test that can be made to obtain the basic properties of a material. A test almost universally employed to express physical properties and to provide the most useful fundamental information regarding the behavior of metal is the tensile test. The testing machine commonly used is called the universal testing machine.

Beside the ultimate tensile strength it is also possible to determine the yield strength, elongation and reduction of area. The yield strength of a material is a definite indication of the maximum applied load that the material can withstand. The elongation and the reduction of area are the measure of material's ductility and ease of working.

PRECAUTIONS TO BE OBSERVED WHILE TESTING

1. During the test the specimen must be held in true axial alignment by the grips.
2. The speed of the testing machine crosshead should not exceed 1/16th inch per inch of gage length per minute up to the yield point.
3. The speed of the testing machine crosshead should not exceed 1/2 inch per inch of gage length per minute beyond yield point up to rupture.
4. The extensometer must be calibrated to read 0.0002 inch or less and it must be attached to the specimen only at the gage marks and not to the shoulder of the specimen or any part of the testing machine.
5. The test specimen should be subjected to the same treatment and processes as the material they represent.
6. The test specimen must not be bent, hammered or straightened by any method involving cold working of the part.
7. The test specimen for a bar or forging stock of uniform cross-section and less than 1.5 inch thick should be machined concentrically from the stock. When the stock is over 1.5 inch thick the specimen should be taken from a point midway between the outer surface and the centre.
8. Tubing is tested by putting solid plugs in each end, which permits griping without crushing. It is a standard practice to keep at least 6 inches of hollow tubing between the near ends of the plug.

Elastic Limit Determination:

The elastic limit of a material is the greatest stress that can be held without permanent deformation remaining upon the complete release of load. In practical testing the elastic limit is consider to have been reached when a permanent set of 0.00003inch per inch of gage length has been obtained. An accurate reading extensometer must be used to read the permanent set. The method of testing is as follows,

A load is applied until the stress is 20% of the expected elastic limit and the extensometer reading is recorded. The load is then increased to 75% of the elastic limit after which it is dropped to below 20% and then brought up to 20% and extensometer reading is recorded. If no permanent set is obtained the extensometer should read the same value as when the first 20% of the load was imposed. Again the load is increased to 75 % of the elastic limit. After the 75% load the additional increments of the load should be added and released as before to 20% and the extensometer reading is recorded for each increment of load. These increments should not exceed 3% of the elastic limit as this point is approached. The elastic limit of the material under test is calculated from the last load prior to the one that caused a permanent set of over 0.00003 inch per inch of gage length of test specimen.

Proof Stress Determination:

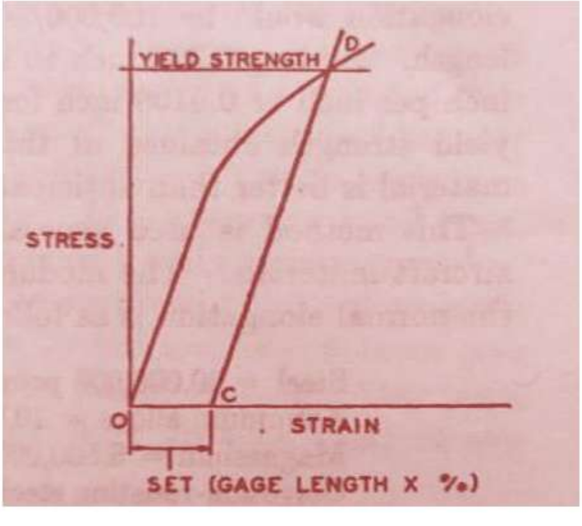
The Proof stress of a material is the greatest stress it can withstand without resulting in a permanent set of over 0.0001 inch per inch of gage length after complete release of load. For the standard 2 inch gage length this amounts to a permanent set of 0.0002 inch. The proof stress can be determined in same manner as the elastic limit, or the load can be released to zero after each increment.

Yield Strength Determination:

The yield strength is the stress at which a material exhibits a specified limiting permanent set or a specified elongation under load. The commonly used method for determining this stress is known as set method.

Set Method:

In this method the loads are applied and the extensometer readings are taken for a number of loads. The loads usually selected are 20%, 75%, 90% and several other loads just under and over the expected yield strength. The curve is then plotted as shown in figure in which the applied loads or stress are on
„y‟axis and the extensometer reading or strain on„x‟axis. This curve will be similar to the curve OD of the figure. It will be noted that the lower part of this curve is a straight line. The line CD is constructed parallel to the straight portion of the line OD and at a distance to the right equal to the specified set. The point of intersection D read on „y‟ axis gives the applied load for the yield strength. The applied load / the original cross section area is the yield strength.



This method of determination is used when the yield strength is specified in psi for a given percent of set. For metals 0.2% is usually specified. For a standard 2 inch gage length this set would be 0.004 inch. In this case the point C in figure would beat a distance of 0.004 inch on „x‟ axis. The principle of this method is based on the fact that if the load was released at D the curve for the decreasing load would follow the line DC. OC would then represent the permanent set. The yield strength value obtained by the set method is arbitrary but it is a measurable value of plastic yielding of the material below which the damaging effects of the material are considered to be negligible.

The set method is frequently specified for determining the yield strength of aircraft material. Steel, aluminum alloys, magnesium and structural corrosion resisting steel are metals whose yield strength is often determined as a point where a permanent set of 0.002 inch per inch of gage length is obtained.

Yield Point Determination:

The yield point of a material is the point at which there is a marked increase in elongation without increase in load. This phenomenon is found only in some materials such as wrought iron, and mild carbon steel. For these materials the stress-strain curve has a sharp break at the yield point. When the stress- strain curve of a material is smooth in this region, the material does not have a yield point. The yield point of a material can be determined by either of two methods,

1. Divider Method: In this method a pair of divider is set at the exact distance between two gage marks. The load is then applied to the specimen with one arm of the dividers centered in one gage mark and the other arm held free above the other gage mark. At the instant visible stretch is noted between this later gage mark and the divider, the load should be noted. The yield point stress is computed from this load.

2. Drop of Beam Method: In this method the load is applied uniformly and the recording beam kept balanced by the operator. At the yield point load the beam will drop suddenly as the elongation increases rapidly at this point without increase in load. If the testing machine is equipped with a self-indicating load measuring device the pointer will halt momentarily at the yield point load. The yield point stress is computed from this load.

Hardness and Hardness Testing:

Hardness

It is the property of material to resist penetration or permanent distortion. The harness of a metal can usually be increased by hammering, rolling or otherwise working on it and by heat treatment also.
Hardness testing is a method of determining the results of heat treatment as well as the state of a metal prior to heat treatment.
There is no positive assurance that a manufactured article has the same strength as developed by tested specimen. The test specimen has different dimensions and may have responded to the heat treatment better, or it might have been taken from a different location or it may not have been subjected to the same fabricating stress as the manufactured article. It is apparent that some means are needed to check the comparative strength of manufactured article without destroying or harming them in anyway. The development of hardness test has solved this problem.

It has been found that hardness and tensile strength will correspond very closely for any particular material. By coordinating a large number of tensile and hardness tests results made on the same specimen it has been possible to construct a table from which the tensile strength can be obtained if the hardness is known. Manufactured articles need to be subjected only to a simple hardness test to determine their approximate tensile strength. This correlation does not apply to relatively soft materials such as aluminium alloys. Any process which affects the surface such as buffing and plating or the presence of decarburized or porous areas and hard spot will affect the hardness and the corresponding relation between hardness and tensile strength. The tensile strength and hardness relationship is quite uniform for parts which are sufficiently large and rigid to permit obtaining a full depression on a flat surface without deflection of the piece.

There are four methods in general used for determining the hardness of the material. They are;
1. BRINELL 2.ROCKWELL 3.VICKERS 4. SHORE SCLEROSCOPE

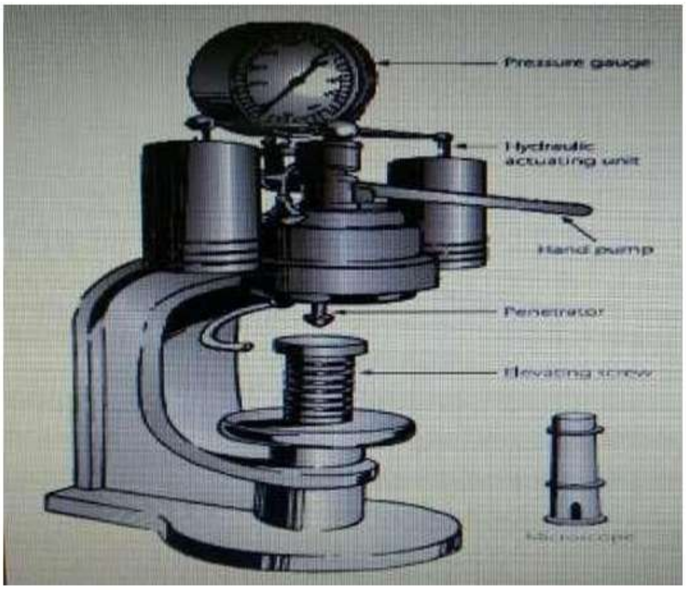
These methods depend upon the impression made in the metal by a diamond cone or hardened steel ball or the rebound of a small diamond pointed hammer dropped from a fixed side. Each of these methods have their limitations and special uses. It is important in all the cases that the tested surface should be smooth and free from scratches and ridges, scales or other unevenness. The specimen must also be sufficiently thick so that the impression made by the testing apparatus does not bulge the opposite side and thereby give a false reading. Care must also be taken to see that there is sufficient edge distance to avoid any deflection due to the depression.

Brinell Hardness Tester

The Brinell Hardness tester uses a hardened spherical ball, which is forced into the surface of the metal. This ball is 10 millimetres (D=0.3937 inch) india meter.

A load of 3,000 kilograms (6600 lbs) is used for ferrous metals and 500 kilograms (1102 lbs) for nonferrous metals. The load must be maintained at least 10 seconds for ferrous metals and at least 30 seconds for nonferrous metals. The load is applied by hydraulic pressure. The hydraulic pressure is built up by a hand pump or an electric motor, depending on the model of tester. A pressure gauge indicates the amount of pressure. There is a release mechanism for relieving the pressure after the test has been made, and a calibrated microscope is provided for measuring the diameter of the impression in millimeters. The machine has various shaped anvils for supporting the specimen and an elevating screw for bringing the specimen in contact with the ball penetrator.

To determine the Brinell hardness number for a metal measure the diameter of the impression, using the calibrated microscope furnished with the tester. Then convert the measurement into the Brinell hardness number on the conversion table furnished with the tester.



Brinell Hardness Tester

The Brinell number is the load in kilograms divided by the area of the spherical surface of the impression in square millimetres. It is obvious that hard materials will have small impressions and consequently large Brinell number.

For Brinell testing the surface of the material should be free from scratches and smooth. It is advisable to polish lightly with fine emery paper to remove any surface defects.

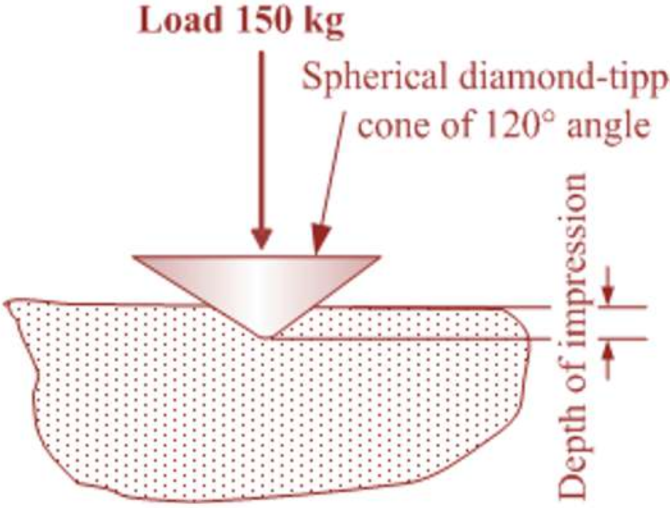
Rockwell Hardness Tester

The Rockwell hardness test is the most common method for determining hardness of ferrous and many nonferrous metals. The Rockwell hardness is determined by measuring the penetration of the diamond cone or harden steel ball under definite loads.

Two types of penetrators are used with the Rockwell tester:

1) A diamond cones with included angle of 120° and 2) A hardened steel ball.

Instead of measuring the diameter of the impression, the Rockwell tester measures the depth of impression and the hardness is indicated directly on a dial attached to the machine. Rockwell hardness numbers are based on the difference between the depth of penetration at major and minor loads. The greater this difference, the lower the hardness number and the softer thematerial.



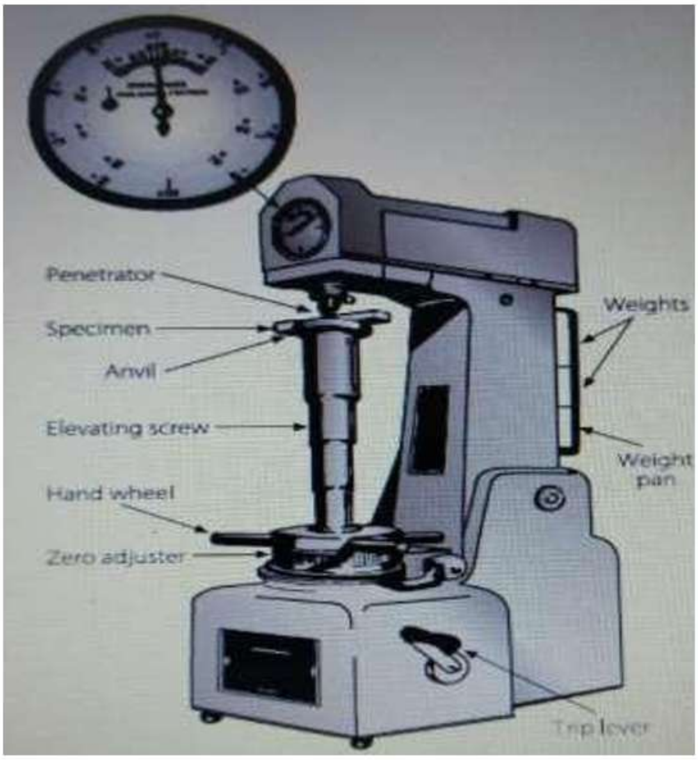
Before the major load is applied, securely lock the test specimen in place to prevent slipping and to seat the anvil and penetrator properly. To do this, apply a load of 10 kilograms. This preliminary load is called the minor load. The minor load is 10 kilograms regardless of the scale setup. The direct reading dial is set to zero and the major load is applied. This forces the penetrator into the metal and after removal of the load the Rockwell hardness can be read from the dial.

The dial of the tester has two sets of figures, one red and one black. The red figures are used with the ball penetrators and the black figures with diamond cone penetrators. To cover the wide range of hardness in various materials more than dozen combinations of load and penetrators are available with Rockwell tester. Ball penetrators up to ½ inch dia. And major loads of 60, 100 and 150 kgs are used. Each of these combinations is designated by letter such as A, B, C, D, E,……. Only B and C combinations or scales are commonly used for testing aircraft steel.

Scale Symbol	Penetrator	Major load kgs	Dial color / number
A	Diamond cone	60	Black
B	1⁄16-inch ball	100	Red
C	Diamond cone	150	Blac

			k
D	Diamond cone	100	Blac k
E	1⁄8-inch ball	100	Red
F	1⁄16-inch ball	60	Red
G	1⁄16-inch ball	150	Red
H	1⁄8-inch ball	60	Red

Rockwell Hardness Tester



For hardened steels, the diamond penetrator is used; the major load is 150 kilograms; and the hardness is read on the “C” scale. When this reading is recorded, the letter “C” must precede the number indicated by the pointer. The C-scale setup is used for testing metals ranging in hardness from C-20 to the hardest steel (usually about C-70). If the metal is softer than C-20, the B-scale setup is used. With this setup, the 1⁄16-inch ball is used as a penetrator; the major load is 100 kilograms; and the hardness is read on the B- scale. The working range of B scale is from B-0 to B-100. There is a danger that the ball penetrator will be flattened if used on materials harder than B-100. For softer materials it is necessary to reduce the applied major loads and increase the penetrator diameter to obtained proper reading.

The metal to be tested in the Rockwell tester must be ground smooth on two opposite sides and be free of scratches and foreign matter. The surface should be perpendicular to the axis of penetration, and the two opposite ground surfaces should be parallel. If the specimen is tapered, the amount of error will depend on the taper. A curved surface will also cause a slight error in the hardness test. The amount of error depends on the curvature; i.e., the smaller the radius of curvature, the greater the error. To eliminate such error, a small flat should be ground on the curved surface if possible Clad aluminium alloy sheets cannot be tested directly with any accuracy with a Rockwell hardness tester. If the hardness value of the base metal is desired, the pure aluminum coating must be removed from the area to be checked prior to testing.

Barcol Tester

The Barcol tester is a portable unit designed for testing aluminium alloys, copper, brass, or other relatively soft materials. It should not be used on aircraft steels. Approximate range of the tester is 25 to 100 Brinell. The unit can be used in any position and in any space that will allow for the operators hand. It is of great value in the hardness testing of assembled or installed parts, especially to check for proper heat treatment. The hardness is indicated on a dial conveniently divided into 100 graduations. The design of the Barcol tester is such that operating experience is not necessary. It is only necessary to exert a light pressure against the instrument to drive the spring loaded indenter into the material to be tested. The hardness reading is instantly indicated on the dial.

Note that the harder the material is, the higher the Barcol number will be. To prevent damage to the point, avoid sliding or scraping when it is in contact with the material being tested. If the point should become damaged, it must be replaced with a new one. Do not attempt to grind the point.

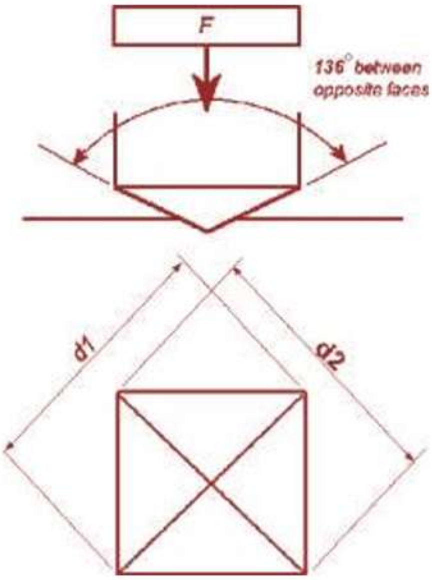
Each tester is supplied with a test disk for checking the condition of the point. To check the point, press the instrument down on the test disk. When the downward pressure brings the end of the lower plunger guide against the surface of the disk, the indicator reading should be within the range shown on the test disk.

Barcol Tester

Vickers Hardness method

It is also known as Diamond Pyramid hardness method.

Type of penetrator: diamond penetrator in the form of a square-base pyramid having an included angle of 136°.



It is similar to the Brinell test in that an impression is made by applying a load to an indenter. The hardness number is then obtained by measuring the impression.
The Vickers hardness is the quotient obtained by dividing the load by the area of indentation.
An advantage of the Vickers hardness test is that hardness values for very hard materials are more accurate than the corresponding Brinell numbers. This is because a diamond does not deform under high pressure, as a steel ball does, and so the result will be more accurate. The higher the number, the harder is the material.

Shore Scleroscope hardness

Shore Scleroscope hardness testing consists of dropping a small diamond pointed hammer from a fixed height and measuring and comparing the height of the rebound with that from a standard test piece. It is an excellent means of obtaining comparative hardness of large number of production parts. If absolute hardness is desire it is essential that the instrument be set level and rigidly fixed in a position to prevent movement in any direction. If the slightest movement occurs, the rebound will be inaccurate. The rebound is measured directly on a vertical scale in one instrument and in another it is registered on a recording dial.
The Shore method is widely used for measuring hardness of large machine components like rolls, gears, dies, etc. These components could not be placed on the table of one of the other hardness testing machines.
The height of rebound is less with soft materials as they absorb more of the kinetic energy of the hammer. Hard materials produce a greater height of rebound.
The harder the material, the higher will be the rebound.

The test specimen should be smooth and free from scratches. The average of five separate determinations is usually taken as the hardness of the part. By this means errors due to rebound or due to hard spot in the material are eliminated.

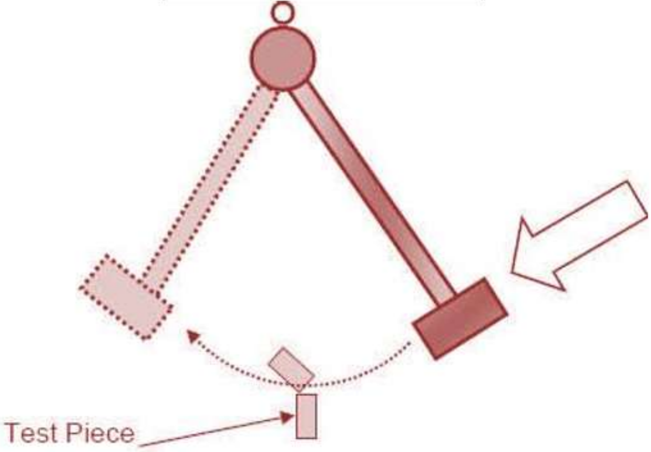
IMPACT TESTING

The impact test (refer to Fig.) is designed to determine the toughness of a material and the two most commonly used methods are those using the Charpy and Izod impact-testing machines.

Both tests use notched-bar test pieces of standard dimensions, which are struck by a fast-moving, weighted pendulum. The energy, which is absorbed by the test piece on impact, will give a measure of toughness. A brittle material will break easily and will absorb little energy, so the swing of the pendulum (which is recorded against a calibrated scale) will not be reduced significantly. A tough material will, however, absorb considerably more energy and thus greatly reduce the recorded pendulum swing.

Most materials show a drop in toughness with a reduction in temperature, though some materials (certain steels in particular) show a rapid drop in toughness as the temperature is progressively reduced. This temperature range is called the Transition Zone, and components, which are designed for use at low temperature, should be operated above the material's Transition Temperature. Nickel is one of the most effective alloying elements for lowering the Transition Temperature of steels.

FATIGUE TESTING



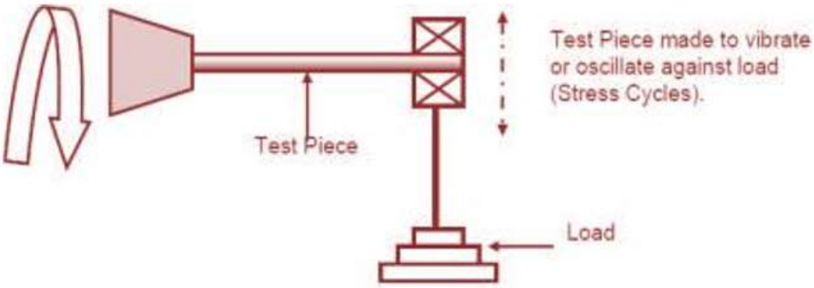
Impact Test

An in-depth survey, in recent years, revealed that over 80 percent of failures of engineering components were caused by fatigue. Consequences of modern engineering have led to increases in operating stresses, temperatures and speeds. This is particularly so in aerospace and, in many instances, has made the fatigue characteristics of materials more significant than their ordinary, static strength properties.

Engineers became aware that alternating stresses, of quite small amplitude, could cause failure in components, which were capable of safely carrying much greater, steady loads. This phenomenon of small, alternating loads causing Failure was likened to a progressive weakening of the material, over a period of time and hence the attribution of the term „fatigue". Very few constructional members are immune from it, and especially those operating in a dynamic environment.

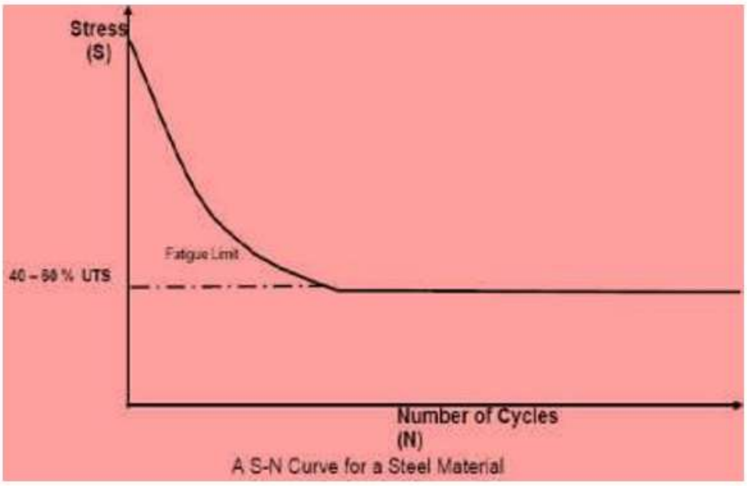
Experience in the aircraft industry has shown that the stress cycles, to which aircraft are subjected, may be very complex, with occasional high peaks, due to gust loading of aircraft wings. For satisfactory correlation with in-service behavior, full-size or large- scale mock-ups must be tested in conditions as close as possible to those existing in service.

German engineer (Wohler) did work in this direction and eventually developed a useful fatigue-testing machine which bears his name and continues to be used in industry. The machine uses a test piece, which is rotated in a chuck and a force is applied at the free end, at right angles to the axis of rotation (refer to Fig.).The rotation thus produces a reversal of stress for every revolution of the test piece.



Simple Fatigue Testing

One of the most useful end-products, from fatigue testing, is an S- N curve, which shows, graphically, the relationship between the amount of stress (S), applied to a material, and the number of stress cycles (N), which can be tolerated before failure of the material. Using a typical S-N curve, for a steel material (refer to Fig. 11), it can be seen that, if the stress is reduced, the steel will endure a greater number of stress cycles. The graph also shows that a point is eventually reached where the curve becomes virtually horizontal, thus indicating that the material will endure an infinite number of cycles at a particular stress level. This limiting stress is called the "Fatigue Limit" and, for steels, the fatigue limit is generally in the region of 40% to 60% of the value of the static, ultimate tensile strength (U.T.S.)



A S-N Curve for a Steel Material

6.2 Aircraft Materials — Non-Ferrous

a) Characteristics, properties and identification of common non-ferrous materials used in aircraft:

Ferrous alloys are consumed in exceedingly large quantities because they have a wide range of mechanical properties and can be fabricated with relative ease and are economical to produce. But they have some drawbacks to forge.

1. A relatively high density; therefore heavier in weight,
2. A comparatively low electrical conductivity, and
3. An inherent susceptibility to corrosion in some common environments.

Thus for many applications it is advantageous or even necessary to utilize other alloy. Non- ferrous alloys, having more suitable property combination.

The term ―nonferrous refers to all metals which have elements other than iron as their base or principal constituent. This group includes such metals as Copper, Aluminum, Magnesium, Lead, Nickel, Tin, Zinc and Cobalt etc.

ALUMINUM AND ALUMINUM ALLOYS

Aluminum is mainly produced from bauxite. Over 90% of the world's bauxite resources are concentrated on the tropical and sub- tropical belt in Australia, Guinea, Jamaica, Surinam, Brazil, and India. Bauxite consists of 40-60% alumina, as well as earth silicon, ferrous oxide, and titanium dioxide. To separate pure alumina, the Bayer process is applied. First, the ore is heated in an autoclave with caustic soda. It is then cooled and a solid residue—«red mud» — is separated from the liquid. Aluminium hydroxide is then extracted from this solution and calcined (reduced or oxidized) to produce pure alumina.

Commercially pure aluminum is a white lustrous metal which stands second in the scale of malleability, sixth in ductility, and ranks high in its resistance to corrosion. Aluminum combined with various percentages of other metals forms alloys which are used in aircraft construction. Aluminum alloys in which the principal alloying ingredients are manganese, chromium, or magnesium and silicon show little attack in corrosive environments. Alloys in which substantial percentages of copper are used are more susceptible to corrosive action. The total percentage of alloying elements is seldom more than 6 or 7 percent in the wrought alloys. Aluminum is one of the most widely used metals in modern aircraft construction. It is vital to the aviation industry because of its high strength to weight ratio and its comparative ease of fabrication. The outstanding characteristic of aluminum is its light weight. Aluminum melts at the comparatively low temperature of 1,250 °F. It is nonmagnetic and is an excellent conductor.

Commercially pure aluminum has a tensile strength of about 13,000 psi, but its strength may be approximately doubled by rolling or other cold working processes. By alloying with other metals, or by using heat-treating processes, the tensile strength may be raised to as high as 65,000 psi or to within the strength range of structural steel. Aluminum alloys, although strong, are easily worked because they are malleable and ductile. They may be rolled into sheets as thin as 0.0017 inch or drawn into wire 0.004 inch in diameter. Most aluminum alloy sheet stock used in aircraft construction range from 0.016 to 0.096 inch in thickness; however, some of the larger aircraft use sheet stock which may be as thick as0.356 inch.

The various types of aluminum may be divided into two general classes: (1) casting alloys (those suitable for casting in sand, permanent mold, or die castings) and (2) wrought alloys (those which may be shaped by rolling, drawing, or forging). Of these two, the wrought alloys are the most widely used in aircraft construction, being used for stringers, bulkheads, skin, rivets, and extruded sections. Aluminum casting alloys are divided into two basic groups. In one, the physical properties of the alloys are determined by the alloying elements and cannot be changed after the metal is cast. In the other, the alloying elements make it possible to heat treat the casting to produce the desired physical properties.

Aluminum alloy castings are produced by one of three basic methods: (1) sand mold, (2) permanent mold, or (3) die cast. In casting aluminum, it must be remembered that in most cases different types of alloys must be used for different types of castings. Sand castings and die castings require different types of alloys than those used in permanent molds. Sand and permanent mold castings are parts produced by pouring molten metal into a previously prepared mold, allowing the metal to solidify or freeze, and then removing the part. If the mold is made of sand, the part is a sand casting; if it is a metallic mold (usually cast iron) the part is a permanent mold casting. Sand and permanent castings are produced by pouring liquid metal into the mold, the metal flowing under the force of gravity alone. The two principal types of sand casting alloys are 112 and 212. Little difference exists between the two metals from a mechanical properties standpoint, since both are adaptable to a wide range of products. The permanent mold process is a later development of the sand casting process, the major difference being in the material from which the molds are made. The advantage of this process is that there are fewer openings (called porosity) than in sand castings. The sand and the binder, which is mixed with the sand to hold it together, give off a certain amount of gas which causes porosity in a sand casting. Permanent mold castings are used to obtain higher mechanical properties, better surfaces, or more accurate dimensions. There are two specific types of permanent mold castings: (1) permanent metal mold with metal cores, and (2) semi-permanent types containing sand cores.

Because finer grain structure is produced in alloys subjected to the rapid cooling of metal molds, they are far superior to the sand type castings. Alloys 122, A132, and 142 are commonly used in permanent mold castings, the principal uses of which are in internal combustion engines.

Die castings used in aircraft are usually aluminum or magnesium alloy. If weight is of primary importance, magnesium alloy is used because it is lighter than aluminum alloy. However, aluminum alloy is frequently used because it is stronger than most magnesium alloys. A die casting is produced by forcing molten metal under pressure into a metallic die and allowing it to solidify; then the die is opened and the part removed. The basic difference between permanent mold casting and die casting is that in the permanent mold process the metal flows into the die under gravity. In the die casting operation, the metal is forced under great pressure.

Die castings are used where relatively large production of a given part is involved. Remember, any shape which can be forged can be cast.

Properties of aluminium

After iron, aluminium is now the second most widely used metal in the world. The properties of aluminium include: low density and therefore low weight, high strength, superior malleability, easy machining, excellent corrosion resistance and good thermal and electrical conductivity are amongst aluminium's most important properties. Aluminium is also very easy to recycle.

Properties of aluminum Weight

One of the best known properties of aluminium is that it is light, with a density one third that of steel, 2.700 kg/m3. The low density of aluminium accounts for it being lightweight but this does not affect its strength.

Strength

Aluminium alloys commonly have tensile strengths of between 70 and 700 MPa. The range for alloys used in extrusion is 150 – 300MPa. Unlike most steel grades, aluminium does not become brittle at low temperatures. Instead, its strength increases. At high temperatures, aluminium's strength decreases. At temperatures continuously above 100°C, strength is affected to the extent that the weakening must be taken into account.

Linear expansion

Compared with other metals, aluminium has a relatively large coefficient of linear expansion. This has to be taken into account in some designs.

Machining

Aluminium is easily worked using most machining methods – milling, drilling, cutting, punching, bending, etc. Furthermore, the energy input during machining is low.

Formability

Aluminium's superior malleability is essential for extrusion. With the metal either hot or cold, this property is also exploited in the rolling of strips and foils, as well as in bending and other forming operations.

Conductivity

Aluminium is an excellent conductor of heat and electricity. An aluminium conductor weighs approximately half as much as a copper conductor having the same conductivity.

Joining

Features facilitating easy jointing are often incorporated into profile design. Fusion welding, Friction Stir Welding, bonding and taping are also used for joining.

Reflectivity

Another of the properties of aluminium is that it is a good reflector of both visible light and radiated heat.

Corrosion resistance

Aluminium reacts with the oxygen in the air to form an extremely thin layer of oxide. Though it is only some hundredths of a (my) mm thick (1 (my) is one thousandth of a millimeter), this layer is dense and provides excellent corrosion protection. The layer is self-repairing if damaged.

Anodizing increases the thickness of the oxide layer and thus improves the strength of the natural corrosion protection. Where aluminium is used outdoors, thicknesses of between 15 and 25 ¥ìm (depending on wear and risk of corrosion) are common.

Aluminium is extremely durable in neutral and slightly acid environments.

Wrought aluminum and wrought aluminum alloys are divided into two general classes: non-heat-treatable alloys and heat-treatable alloys. Non-heat-treatable alloys are those in which the mechanical properties are determined by the amount of cold work introduced after the final annealing operation. The mechanical properties obtained by cold working are destroyed by any subsequent heating and cannot be restored except by additional cold working, which is not always possible. The “full hard” temper is produced by the maximum amount of cold work that is commercially practicable. Metal in the “as fabricated” condition is produced from the ingot without any subsequent controlled amount of cold working or thermal treatment. There is, consequently, a variable amount of strain hardening, depending upon the thickness of the section.

For heat-treatable aluminum alloys, the mechanical properties are obtained by heat treating to a suitable temperature, holding at that temperature long enough to allow the alloying constituent to enter into solid solution, and then quenching to hold the constituent in solution. The metal is left in a supersaturated, unstable state and is then age hardened either by natural aging at room temperature or by artificial aging at some elevated temperature.

Wrought Aluminum

Wrought aluminum and wrought aluminum alloys are designated by a four digit index system. The system is broken into three distinct groups: 1xxx group, 2xxx through 8xxx group, and 9xxx group (which is currently unused).

The first digit of a designation identifies the alloy type. The second digit indicates specific alloy modifications. Should the second number be zero, it would indicate no special control over individual impurities. Digits 1 through 9, however, when assigned consecutively as needed for the second number in this group, indicate the number of controls over individual impurities in the metal.

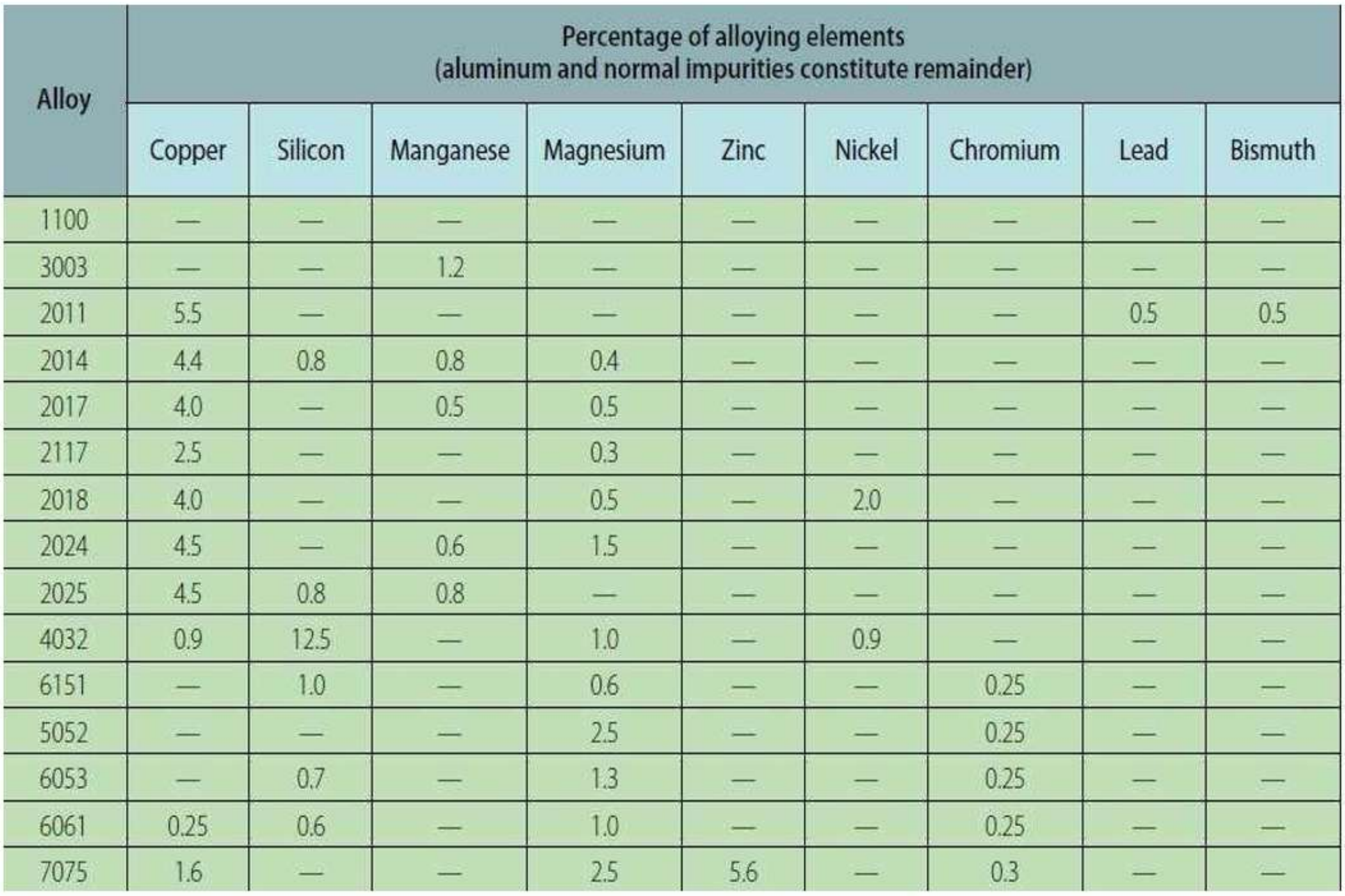
The last two digits of the 1xxx group are used to indicate the hundredths of 1 percent above the original 99 percent designated by the first digit. Thus, if the last two digits were 30, the alloy would contain 99 percent plus 0.30 percent of pure aluminum, or a total of 99.30 percent pure aluminum. Examples of alloys in this group are:

- 1100—99.00 percent pure aluminum with one control over individual impurities.
- 1130—99.30 percent pure aluminum with one control over individual impurities.
- 1275—99.75 percent pure aluminum with two controls over individual impurities.

In the 2xxx through 8xxx groups, the first digit indicates the major alloying element used in the formation of the alloy as follows:

- 2xxx—copper
- 3xxx—manganese
- 4xxx—silicon
- 5xxx—magnesium
- 6xxx—magnesium and silicon
- 7xxx—zinc
- 8xxx—otherelements

In the 2xxx through 8xxx alloy groups, the second digit in the alloy designation indicates alloy modifications. If the second digit is zero, it indicates the original alloy, while digits 1 through 9 indicate alloy modifications. The last two of the four digits in the designation identify the different alloys in the group. [Ref table below]



Alloy	Percentage of alloying elements (aluminum and normal impurities constitute remainder)								
	Copper	Silicon	Manganese	Magnesium	Zinc	Nickel	Chromium	Lead	Bismuth
1100	—	—	—	—	—	—	—	—	—
3003	—	—	1.2	—	—	—	—	—	—
2011	5.5	—	—	—	—	—	—	0.5	0.5
2014	4.4	0.8	0.8	0.4	—	—	—	—	—
2017	4.0	—	0.5	0.5	—	—	—	—	—
2117	2.5	—	—	0.3	—	—	—	—	—
2018	4.0	—	—	0.5	—	2.0	—	—	—
2024	4.5	—	0.6	1.5	—	—	—	—	—
2025	4.5	0.8	0.8	—	—	—	—	—	—
4032	0.9	12.5	—	1.0	—	0.9	—	—	—
6151	—	1.0	—	0.6	—	—	0.25	—	—
5052	—	—	—	2.5	—	—	0.25	—	—
6053	—	0.7	—	1.3	—	—	0.25	—	—
6061	0.25	0.6	—	1.0	—	—	0.25	—	—
7075	1.6	—	—	2.5	5.6	—	0.3	—	—

Effect of Alloying Element

1xxx series: 99 percent aluminum or higher, excellent corrosion resistance, high thermal and electrical conductivity, low mechanical properties, excellent workability. Iron and silicon are major impurities. In this group minimum aluminum content is 99% and there is no major alloying element. The second digit indicates modifications in impurity limits. If the second digit is zero, there is no special control on individual impurities. Digits 1 through 9, which are assigned consecutively as needed, indicate special control of one or more individual impurities. The last two digits indicate specific minimum aluminum content. Although the absolute minimum aluminum content in this group is 99%, the minimum for certain grades is higher than 99%, and the last two digits represent the hundredths of a per cent over 99. Thus, 1030 would indicate 99.30% minimum aluminum. Without special control on individual impurities. The designations 1130, 1230, 1330, etc. Indicate the same purity with special control on one or more impurities. Likewise 1100 indicate minimum aluminum content of 99.00% with individual impurity control. Steel brushes should not be used on aluminum because it will cause galvanic corrosion.

2xxx series: Copper is the principal alloying element. Solution heat treatment, optimum properties equal to mild steel, poor corrosion resistance unclad. It is usually clad with 6000 or high purity alloy.

Its best known alloy is 2024. The addition of copper as main alloying element (mostly range 3–6 %, but can be much higher), with or without magnesium as alloying constituent (range 0–2 %), allows material strengthening by precipitation hardening, resulting in very strong alloys. Also the fatigue properties are very good for this series. The presence of copper is however very bad for the corrosion resistance. Copper tends to precipitate at grain boundaries, making the metal very susceptible to pitting, inter granular corrosion and stress corrosion. These copper rich zones are more noble/cathodic than the surrounding aluminum matrix and act as preferred sites for corrosion through galvanic coupling. Copper is also very bad for anodizing. Copper precipitates dissolve in the anodizing electrolytes (acid electrolytes for porous film formation) leaving holes in the oxide, and solute copper migrates under the high electric field towards the aluminum/oxide interface compromising the anodic film properties.

Up to 12 % copper the strength of the alloy can increase through precipitation hardening, with or without the presence of Mg; Above 12 % Cu the alloy becomes brittle. Copper also improves the fatigue properties, the high-temperature properties and the machinability of the alloy. Lower copper content levels then in the conventional 2024 and 2014 type alloys are required for the automotive industry. These alloys have sufficient formability, spot weld ability and good corrosion resistance (as opposed to the higher copper containing alloys). The 2xxx series alloys are used for high strength structural applications such as aircraft fittings and wheels, military vehicles and bridges, forgings for trucks, etc. The low melting phase elements, lead and/or bismuth, facilitate machining of the 2xxx series alloys, making them also suitable for applications where hard extruded and machined parts are required (screws, bolts, fittings, machinery components,etc).

3xxx series: Manganese is the principal alloying element of this group which is generally non-heat treatable. The percentage of manganese which will be alloy effective is 1.5 percent. The most popular is 3003, which is of moderate strength and has good working characteristics. Manganese as main alloying element in the 3xxx series (range 1–2 %) makes the alloys ductile, resulting in good formability while still allowing a wide range of mechanical properties through various strain hardened tempers. The 3xxx series are medium strength alloys.

Mn fine precipitates also stabilize grain size during high temperature annealing which improves strength and formability. Manganese makes the alloy ductile; in combination with iron it improves the cast ability of the alloy and reduces shrinkage during metal solidification. Up to 2 %, manganese also increases strength and hardness but less effective than copper or magnesium.

4xxx series: Silicon is the principal alloying element of this group, and lowers melting temperature. Its primary use is in welding and brazing. When used in welding heat-treatable alloys, this group will respond to a limited amount of heat treatment. The 4xxx series this alloy series is seldom used in the aerospace industry.

5xxx series: Magnesium is the principal alloying element. It has good welding and corrosion resistant characteristics. High temperatures (over 150 °F) or excessive cold working will increase susceptibility to corrosion. The 5xxx series magnesium is one of the most effective and widely used alloying elements for aluminum. When it is used as the major alloying element , or with manganese, the result is a moderate to high strength non-heat treatable alloy. Alloys in this series posse's good welding characteristics and good resistance to corrosion in various atmospheres. It is widely used for the fabrication of tanks.

6xxx series: Silicon and magnesium form magnesium silicide which makes alloys heat treatable. It is of medium strength, good forming qualities, and has corrosion resistant characteristics. 6xxx series are high strength alloys that can be strengthened by heat treatment (precipitation hardening), through the

presence of their main alloying elements silicon and magnesium (mostly in the range 0.3–1.5 % Si and Mg). These alloys are generally less strong than the 2xxx and 7xxx series, but have good formability and are wieldable
Extruded 6xxx series alloys are also often used for machined products; by adding low melting phase elements such as lead, bismuth and/or tin 6xxx series alloys show very good machinability. These alloys can be easily anodized (often hard anodizing for extruded parts of brake systems, electronic valves, pistons, etc) where hard surfaces, good corrosion resistance and high strength are required.

7xxxx series: Zinc is the principal alloying element. When coupled with magnesium, it results in heat-treatable alloys of very high strength. It usually has copper and chromium added. The principal alloy of this group is 7075. The 7xxx series Zinc is the major alloying element in this group, and when couple with a smaller percentage of magnesium results in heat treatment alloys of very high strength . Usually other elements such as copper and chromium are also added in small quantities. The outstanding member of this group is 7075 which is among the highest strength alloys available and is used in airframe structures for highly stressed parts.

8xxx series: These are the relatively recently developed Al–Li alloys 8090, 8091 and 8093. Lithium has a significantly lower density than aluminum and since its solubility is also relatively high, it can be alloyed with aluminum in sufficient quantities to give a significant reduction in density (typically about 10% less than other aluminum alloys). Not only do the resulting alloys also have increased stiffness, they also respond to age-hardening. Further, the resistance against fatigue crack growth is increased at intermediate stress levels. This attractive combination of properties has led to much interest, particularly for aerospace applications. Alloys such as 8011 are based on Al–Fe–Si, but with more than 1% total alloying element present to give correspondingly higher strengths. Such alloys find application as foil and closures as well as heat exchanger finstock.

DURALUMIN

Duralumin, strong, hard, lightweight alloy of aluminum, widely used in aircraft construction, discovered in 1906 and patented in 1909 by Alfred Wilma, a German metallurgist; it was originally made only at the company Darner Metalworker at Duren, Germany. (The name is a contraction of Darner and aluminum.) The original composition has been varied for particular applications; it may contain about 4 percent copper, 0.5–1 percent manganese, 0.5–1.5 percent magnesium, and, in some formulations, some silicon. After heat treatment and aging, these alloys are comparable to soft steel in strength. Duralumin alloys are relatively soft, ductile, and work able in the normal state; they may be rolled, forged, extruded, or drawn into a variety of shapes and products. Their light weight and consequent high strength per unit weight compared with steel suit them for aircraft construction. Because aluminum loses corrosion resistance when alloyed, a special laminated sheet form called alclad is used for aircraft construction; it has thin surface layers of pure aluminum covering the strong duralumin core. A piece of duralumin has been annealed and bent into shape prior to fitting to an aircraft it should be fitted within 24 hours.

HIDUMINIUM ALLOYS

The Hiduminium alloys or R.R. Alloys are a series of high- strength, high-temperature aluminum alloys, developed for aircraft use by Royce before World War II. They were manufactured and later developed by High Duty Alloys Ltd.. The name Hi-Du- Minimum is derived from that of High Duty Aluminum Alloys.
The first of these Hiduminium alloys was termed 'R.R.50' This alloy was first developed for motor racing pistons, and was only later adopted for aircraft engine use. It was a development of the earlier Y alloys, the first of the nickel-containing light aluminum alloys. These alloys are one of the three main

groups of high- strength aluminum alloys, the nickel-aluminum alloys having the advantage of retaining strength at high temperatures, making them particularly useful for pistons.

ALCLAD

Alclad is a duplex metal product made by cladding an aluminum alloy core with surface layers of pure aluminum or aluminum alloy, resulting in increased resistance to corrosion. It is a sandwich of high-strength aluminum alloy between two sheets of commercially pure metal for a combination of strength and corrosion resistance produced by rolling. The use of Alclad results in greatly increased life for a structural part, Alclad is a composite- wrought product comprised of an aluminum alloy core having on one or both surfaces a metallurgic ally bonded aluminum or aluminum alloy coating that is anodic to the core and thus electrochemically protects the core against corrosion. It is an Alcoa trademark name for high-strength sheet aluminum clad with a layer (approximately 5.5% thickness per side) of high-purity aluminum, popularly used in airplane manufacture.

Alclad is heat-treated aluminum, copper, manganese, magnesium alloy that has the corrosion resistance of pure metal at the surface and the strength of a strong alloy underneath. Of particular importance is the strong bond between the alloy and the pure aluminum. Alcladding is an important way to protect an aircraft against corrosion. Sheets of 2024-T3 Alclad are a good example of this. The first aircraft to be constructed from Alclad was the all- metal Navy airship ZMC-2, constructed in 1927 at Naval Air Station Grosse Ile. In applications involving aircraft construction, Alclad has proven to have increased resistance to corrosion at the expense of increased weight when compared to sheet aluminum. Heavy corrosion deposit on clad aluminum allows should be removed by chemically by use of non-abrasive pads.

Hardness Identification

Where used, the temper designation follows the alloy designation and is separated from it by a dash: i.e., 7075-T6, 2024-T4, and so forth. The temper designation consists of a letter indicating the basic temper which may be more specifically defined by the addition of one or more digits. These designations are as follows:

- F — as fabricated
- O — annealed, re crystallized (wrought products only)
- H — strain hardened
- H1 (plus one or more digits) — strain hardened only
- H2 (plus one or more digits) — strain hardened and partially annealed
- H3 (plus one or more digits) — strain hardened and stabilized

The digit following the designations H1, H2, and H3 indicates the degree of strain hardening, number 8 representing the ultimate tensile strength equal to that achieved by a cold reduction of approximately 75 percent following a full anneal, 0 representing annealed state Basic Temper Designations F—As fabricated. Denotes metal that has been fabricated to order Dimensions without any attempt on the part of the producer to control the results of either strain- hardening Operations or thermal treatments. There are no mechanical property limits, and the strength levels may Vary form lot to lot and from shipment to shipment.

Temper Designation O —Annealed‖. Applies to wrought products that have undergone a thermal treatment to reduce their mechanical property levels to their minimums. Often described as "dead soft" metal.

Temper Designation H —Strain-hardened‖. Applies to those wrought products which have had an increase in strength by reduction through strain-hardening or cold working operations The "H" is always followed by two or more digits.

MAGNESIUM AND MAGNESIUM ALLOYS

Magnesium, the world's lightest structural metal, is a silvery white material weighing only two-thirds as much as aluminum. Magnesium does not possess sufficient strength in its pure state for structural uses, but when alloyed with zinc, aluminum, and manganese it produces an alloy having the highest strength to weight ratio of any of the commonly used metals. Magnesium is probably more widely distributed in nature than any other metal. It can be obtained from such ores as dolomite and magnesite, and from sea water, underground brines, and waste solutions of potash. With about 10 million pounds of magnesium in 1 cubic mile of sea water, there is no danger of a dwindling supply.

It is the lightest engineering metal in general use, having a relative density of 1.7 and a weight only 66% that of aluminum. Silvery-white pure magnesium is a fairly weak metal but alloying with small amounts of aluminum, zinc, manganese and zirconium will increase its strength. Although weaker than aluminum alloys, their lower densities often result in magnesium alloys having a better strength to weight ratio.

Some of today's aircraft require in excess of one-half ton of this metal for use in hundreds of vital spots. Some wing panels are fabricated entirely from magnesium alloys, weigh 18 percent less than standard aluminum panels, and have flown hundreds of satisfactory hours. Among the aircraft parts that have been made from magnesium with a substantial savings in weight are nose wheel doors, flap cover skin, aileron cover skin, oil tanks, floorings, fuselage parts, wingtips, engine nacelles, instrument panels, radio masts, hydraulic fluid tanks, oxygen bottle cases, ducts, and seats. Magnesium alloys possess good casting characteristics. Their properties compare favorably with those of cast aluminum. In forging, hydraulic presses are ordinarily used, although, under certain conditions, forging can be accomplished in mechanical presses or with drop hammers.

Without protection magnesium alloy corrodes easily, but chemical surface treatments and coating processes give it good protection from corrosion by excluding oxygen. Use of compatible bolts, nuts, rivets etc. is also important in combating dissimilar metal corrosion. Magnesium alloy must not heat in salt bath. Most of the alloys can be annealed, solution treated precipitation hardened in a similar way to that used for aluminum alloys. Magnesium alloys used in aircraft can be recognized by yellowish surface due to protective treatment (chromatizing).

Magnesium alloys are subject to such treatments as annealing, quenching, solution heat treatment, aging, and stabilizing. Sheet and plate magnesium are annealed at the rolling mill. The solution heat treatment is used to put as much of the alloying ingredients as possible into solid solution, which results in high tensile strength and maximum ductility. Aging is applied to castings following heat treatment where maximum hardness and yield strength are desired.

Magnesium embodies fire hazards of an unpredictable nature. When in large sections, its high thermal conductivity makes it difficult to ignite and prevents it from burning. It will not burn until the melting point of 1,204 °F is reached. However, magnesium dust and fine chips are ignited easily. Precautions must be taken to avoid this if possible. Should a fire occur, it can be extinguished with an extinguishing powder, such as soapstone or graphite. Water or any standard liquid or foam fire extinguisher cause magnesium to burn more rapidly and can cause explosions. Magnesium alloys produced in the United States consist of magnesium alloyed with varying proportions of aluminum, manganese, and zinc. These alloys are designated by a letter of the alphabet, with the number 1 indicating high purity and maximum corrosion resistance. Many of the magnesium alloys manufactured in the United States are produced by the Dow Chemical Company and have been given the trade name of Dow metal ™ alloys. To distinguish between these alloys, each is assigned a letter. Thus, we have Dowmetal J, Dowmetal M, and so forth.

Another manufacturer of magnesium alloys is the American Magnesium Corporation, a subsidiary of the Aluminum Company of America. This company uses an identification system similar to that used for aluminum alloys, with the exception that magnesium alloy numbers are preceded with the letters AM. Thus, AM240C is a cast alloy, and AM240C4 is the same alloy in the heat-treated state. AM3S0 is an annealed wrought alloy, and AM3SRT is the same alloy rolled after heat treatment.

Magnesium alloys have been used to make aircraft wheels, piston engine crankcases, turbine engine compressor casings, gearboxes, valve bodies etc. Magnesium alloy sheet is used in the structure of some aircraft and helicopters where weight saving is particularly important.

TITANIUM AND TITANIUM ALLOYS

Titanium is a greyish white metal having a high strength to weight ratio. It has a relative density of 4.5, making it 60% heavier than aluminum, but twice as strong, and 45% lighter than steel but equal in strength. Titanium also falls between Aluminum and Stainless Steel in terms of elasticity, and elevated temperature strength.

Titanium has excellent corrosion resistance properties due to the oxide film which forms. It is not normally susceptible to stress, fatigue, intergranular or galvanic corrosion, pitting or localized attack. Under certain circumstances it will burn in air, so to prevent its reaction with oxygen or nitrogen it may be treated with chlorine gas to form a coating of titanium dioxide.

Titanium was discovered by an English priest named Gregot. A crude separation of titanium ore was accomplished in 1825. In 1906 a sufficient amount of pure titanium was isolated in metallic form to permit a study. Following this study, in 1932, an extraction process was developed which became the first commercial method for producing titanium. The United States Bureau of Mines began making titanium sponge in 1946, and 4 years later the melting process began. The use of titanium is widespread. It is used in many commercial enterprises and is in constant demand for such items as pumps, screens, and other tools and fixtures where corrosion attack is prevalent. In aircraft construction and repair, titanium is used for fuselage skins, engine shrouds, firewalls, longerons, frames, fittings, air ducts, and fasteners.

Titanium is used for making compressor disks, spacer rings, compressor blades and vanes, through bolts, turbine housings and liners, and miscellaneous hardware for turbine engines. Titanium, in appearance, is similar to stainless steel. One quick method used to identify titanium is the spark test. Titanium gives off a brilliant white trace ending in a brilliant white burst. Also, identification can be accomplished by moistening the titanium and using it to draw a line on a piece of glass. This will leave a dark line similar in appearance to a pencil mark. Titanium falls between aluminum and stainless steel in terms of elasticity, density, and elevated temperature strength. It has a melting point of from 2,730 °F to 3,155 °F, low thermal conductivity, and a low coefficient of expansion. It is light, strong, and resistant to stress corrosion cracking. Titanium is approximately 60 percent heavier than aluminum and about 50 percent lighter than stainless steel. Because of the high melting point of titanium, high temperature properties are disappointing. The ultimate yield strength of titanium drops rapidly above 800 °F. The absorption of oxygen and nitrogen from the air at temperatures above 1,000 °F makes the metal so brittle on long exposure that it soon becomes worthless. However, titanium does have some merit for short time exposure up to 3,000 °F where strength is not important. Aircraft firewalls demand this requirement. Titanium is nonmagnetic and has an electrical resistance comparable to that of stainless steel. Some of the base alloys of titanium are quite hard. Heat treating and alloying do not develop the hardness of titanium to the high levels of some of the heat-treated alloys of steel. It was only recently that a heat-treatable titanium alloy was developed. Prior to the development of this alloy, heating and rolling was the only method of forming that could be accomplished. However, it is possible to form the new alloy in the soft condition and heat treat it for hardness. Iron, molybdenum, and chromium are used to stabilize titanium and produce alloys that will quench harden and age harden. The addition of these metals also adds ductility. The fatigue resistance of titanium is greater than that of aluminum or steel. Titanium becomes softer as the degree of purity is increased. It is not practical to distinguish between the various grades of commercially pure or unalloyed titanium by chemical analysis; therefore, the grades are determined by mechanical properties.

Titanium Designations

The A-B-C classification of titanium alloys was established to provide a convenient and simple means of describing all titanium alloys. Titanium and titanium alloys possess three basic types of crystals: A (alpha), B (beta), and C (combined alpha and beta). Their characteristics are:

- A (alpha) — all-around performance; good weld ability; tough and strong both cold and hot, and resistant to oxidation.

- B (beta)—bend ability; excellent bend ductility; strong both cold and hot, but vulnerable to contamination.

- C (combined alpha and beta for compromise performances) — strong when cold and warm, but weak when hot; good bend ability; moderate contamination resistance; excellent forge ability.

Titanium is manufactured for commercial use in two basic compositions: commercially pure titanium and alloyed titanium. A-55 is an example of commercially pure titanium. It has yield strength of 55,000 to 80,000 psi and is a general purpose grade for moderate to severe forming. It is sometimes used for nonstructural aircraft parts and for all types of corrosion resistant applications, such as tubing. Type A-70 titanium is closely related to type A-55 but has yield strength of 70,000 to 95,000 psi. It is used where higher strength is required, and it is specified for many moderately stressed aircraft parts. For many corrosion applications, it is used interchangeably with type A-55. Both type A-55 and type A-70 are weldable.

One of the widely used titanium base alloys is designated as C- 110M. It is used for primary structural members and aircraft skin, has 110,000 psi minimum yield strength, and contains 8 percent manganese. Type A-110AT is a titanium alloy which contains 5 percent aluminum and 2.5 percent tin. It also has high minimum yield strength at elevated temperatures with the excellent welding characteristics inherent in alpha-type titanium alloys.

The melting point of titanium is 1668°C, and it has low thermal conductivity and a low coefficient of expansion. Its high temperature properties are, however, disappointing. Ultimate yield strength falls rapidly above 425°C, and atmospheric oxygen and nitrogen absorption above 540°C makes the metal brittle and worthless after long exposure. It is useful for short duration, high temperature applications where strength is not important such as aircraft fire walls where it can withstand brief exposure at 1650°C.

Special care is required when machining titanium due to its extreme work hardening properties. For example, center drilling should be used prior to drilling, as center punching would harden the metal, causing difficulty in starting the drill.

Cadmium coated fasteners must not be used with titanium as, when stressed, cadmium atoms will migrate into the titanium causing localized embrittlement and cracking. Chlorinated hydro- carbons such as trichloroethylene cleaning fluids will cause hydrogen embrittlement as will phosphate ester hydraulic fluids (e.g. Skyros) at elevated temperatures.

Corrosion Characteristics

The corrosion resistance of titanium deserves special mention. The resistance of the metal to corrosion is caused by the formation of a protective surface film of stable oxide or chemi- absorbed oxygen. Film is often produced by the presence of oxygen and oxidizing agents. Corrosion of titanium is uniform. There is little evidence of pitting or other serious forms of localized attack. Normally, it is not subject to stress corrosion, corrosion fatigue, intergranular corrosion, or galvanic corrosion. Its corrosion resistance is equal or superior to 18-8 stainless steel. Laboratory tests with acid and saline solutions show titanium polarizes readily. The net effect, in general, is to decrease current flow in galvanic and corrosion cells. Corrosion currents on the surface of titanium and metallic couples are naturally restricted. This partly accounts for good resistance to many chemicals; also the material may be used with some dissimilar metals with no harmful galvanic effect on either.

COPPER AND COPPER ALLOYS

Copper is one of the most widely distributed metals. It is the only reddish colored metal and is second only to silver in electrical conductivity. Its use as a structural material is limited because of its great weight. However, some of its outstanding characteristics, such as its high electrical and heat conductivity, in many cases overbalance the weight factor. Because it is very malleable and ductile, copper is ideal for making wire. It is corroded by salt water but is not affected by fresh water. The ultimate tensile strength of copper varies greatly. For cast copper, the tensile strength is about 25,000 psi, and when cold rolled or cold drawn its tensile strength increases to a range of 40,000 to 67,000 psi. In aircraft, copper is used primarily in the electrical system for bus bars, bonding, and as lock wire.

Beryllium copper is one of the most successful of all the copper base alloys. It is a recently developed alloy containing about 97 percent copper, 2 percent beryllium, and sufficient nickel to increase the percentage of elongation. The most valuable feature of this metal is that the physical properties can be greatly stepped up by heat treatment, the tensile strength rising from 70,000 psi in the annealed state to 200,000 psi in the heat-treated state. The resistance of beryllium copper to fatigue and wear makes it suitable for diaphragms, precision bearings and bushings, ball cages, and spring washers. Brass is a copper alloy containing zinc and small amounts of aluminum, iron, lead, manganese, magnesium, nickel, phosphorous, and tin. Brass with a zinc content of 30 to 35 percent is very ductile, but that containing 45 percent has relatively high strength.

Muntz metal is a brass composed of 60 percent copper and 40 percent zinc. It has excellent corrosion resistant qualities in salt water. Its strength can be increased by heat treatment. As cast, this metal has an ultimate tensile strength of 50,000 psi, and it can be elongated 18 percent. It is used in making bolts and nuts, as well as parts that come in contact with salt water. Red brass, some times termed—bronze because of its tin content, isused in fuel and oil line fittings. This metal has good casting and finishing properties and machines freely. Bronzes are copper alloys containing tin. The true bronzes have up to 25 percent tin, but those with less than 11 percent are most useful, especially for such items as tube fittings in aircraft. Among the copper alloys are the copper aluminum alloys, of which the aluminum bronzes rank very high in aircraft usage. They would find greater usefulness in structures if it were not for their strength to weight ratio as compared with alloy steels. Wrought aluminum bronzes are almost as strong and ductile as medium carbon steel, and they possess a high degree of resistance to corrosion by air, salt water, and chemicals. They are readily forged, hot or cold rolled, and many react to heat treatment. These copper base alloys contain up to 16 percent of aluminum (usually 5 to 11 percent), to which other metals, such as iron, nickel, or manganese, may beaded.

Aluminum bronzes have good tearing qualities, great strength, hardness, and resistance to both shock and fatigue. Because of these properties, they are used for diaphragms, gears, and pumps.

Aluminum bronzes are available in rods, bars, plates, sheets, strips, and forgings. Cast aluminum bronzes, using about 89 percent copper, 9 percent aluminum, and 2 percent of other elements, have high strength combined with ductility, and are resistant to corrosion, shock, and fatigue. Because of these properties, cast aluminum bronze is used in bearings and pump parts. These alloys are useful in areas exposed to salt water and corrosive gases. Manganese bronze is an exceptionally high strength, tough, corrosion resistant copper zinc alloy containing aluminum, manganese, iron and, occasionally, nickel or tin. This metal can be formed, extruded, drawn, or rolled to any desired shape. In rod form, it is generally used for machined parts, for aircraft landing gears and brackets.

Silicon bronze is a more recent development composed of about 95 percent copper, 3 percent silicon, and 2 percent manganese, zinc, iron, tin, and aluminum. Although not a bronze in the true sense because of its small tin content, silicon bronze has high strength and great corrosion resistance.

NICKEL AND NICKEL ALLOYS

There are basically two nickel alloys used in aircraft. They are Monel and Inconel. Monel contains about 68 percent nickel and 29 percent copper, plus small amounts of iron and manganese. Nickel alloys can be welded or easily machined. Some of the nickel Monel, especially the nickel Monels containing small amounts of aluminum, are heat-treatable to similar tensile strengths of steel. Nickel Monel is used in gears and parts that require high strength and toughness, such as exhaust systems that require high strength and corrosion resistance at elevated temperatures.

MONEL

Monel, the leading high nickel alloy, combines the properties of high strength and excellent corrosion resistance. This metal consists of 68 percent nickel, 29 percent copper, 0.2 percent iron, 1 percent manganese, and 1.8 percent of other elements. It cannot be hardened by heat treatment. Monel, adaptable to casting and hot or cold working, can be successfully welded. It has working properties similar to those of steel. When forged and annealed, it has a tensile strength of 80,000 psi. This can be increased by cold working to 125,000 psi, sufficient for classification among the tough alloys. Monel has been successfully used for gears and chains to operate retractable landing gears, and for structural parts subject to corrosion. In aircraft, Monel is used for parts demanding both strength and high resistance to corrosion, such as exhaust manifolds and carburetor needle valves and sleeves.

K-Monel

K-Monel is a nonferrous alloy containing mainly nickel, copper, and aluminum. It is produced by adding a small amount of aluminum to the Monel formula. It is corrosion resistant and capable of being hardened by heat treatment. K-Monel has been successfully used for gears, and structural members in aircraft which are subjected to corrosive attacks. This alloy is nonmagnetic at all temperatures. K-Monel sheet has been successfully welded by both oxyacetylene and electric arc welding.

Inconel alloys of nickel produce a high strength, high temperature alloy containing approximately 80 percent nickel, 14 percent chromium, and small amounts of iron and other elements. The nickel Inconel alloys are frequently used in turbine engines because of their ability to maintain their strength and corrosion resistance under extremely high temperature conditions. Inconel and stainless steel are similar in appearance and are frequently found in the same areas of the engine. Sometimes it is important to identify the difference between the metal samples. A common test is to apply one drop of cupric chloride and hydrochloric acid solution to the unknown metal and allow it to remain for 2 minutes. At the end of the soak period, a shiny spot indicates the material is nickel Inconel, and a copper colored spot indicates stainless steel.

Invar: Also called Alloy 36 or Invar 36, Invar is a low expansion alloy whose name is derived from —invariable because it won’t react to thermal expansion. Invar is used predominantly in precision instruments like stencils, fine line etching and laser cutting, as well as scientific instruments, physics laboratory devices, motor valves and solar panel manufacturing tools.

42 Alloy: Very similar to Invar, 42 Alloy has a slightly different coefficient of thermal expansion. 42 Alloy is well-suited for the lid, lead frames, and stencil/etching and aircraft industries. Easily machined and formed hot or cold, 42 Alloy is also used extensively in the medical, electronics and automotive industries.

Tungsten: Tungsten has a hardness and high density that make it ideal for military applications, rocket nozzles, turbine blades and wear-resistant parts and coatings. Tungsten has the lowest coefficient of thermal expansion, highest melting point, lowest vapor pressure and highest tensile strength of all metals in pure form.

LEAD AND ITS ALLOYS

Lead is bright and lustrous when freshly cut, but soon oxidizes to a dull grey. It is very heavy and has a relative density 11.3. It is soft and malleable, resistant to corrosion and has a low melting point, 327°C. It also has self-lubricating properties and is used in some bushing alloys.

Lead is a major constituent of soft solder. It has been used to make flying control surface mass balance weights. It gives protection from X-rays and is used to make containers for radio- active isotopes, used during certain non-destructive tests on aircraft engines and air frames.

White bearing metals used in piston engines are either tin base or lead base. Tin base bearing metals are known as Babbitt metals and contain between 3.5%and 15%Antimory. E.g. 7% antimony, 90%tin and 3% copper. They are generally heavy duty bearing metals.

The lead based white metals are intended for lower duty since they can withstand only limited pressured they also contain tin and antimony e.g. 13% antimony , 12% tin 0.75% copper and lead the remainder.

BABBITT

Babbitt, also called Babbitt metal or bearing metal, is any of several alloys used for the bearing surface in a plain bearing.

The original Babbitt metal was invented in 1839 by Isaac Babbitt in Taunton, Massachusetts, USA. Babbitt metal is most commonly used as a thin surface layer in a complex, multi-metal structure, but its original use was as a cast-in-place bulk bearing material. Babbitt metal is characterized by its resistance to galling. Babbitt metal is soft and easily damaged, which suggests that it might be unsuitable for a bearing surface. However, its structure is made up of small hard crystals dispersed in a softer metal, which makes it a metal matrix composite. As the bearing wears, the softer metal erodes somewhat, which creates paths for lubricant between the hard high spots that provide the actual bearing surface. When tin is used as the softer metal, friction causes the tin to melt and function as a lubricant, which protects the bearing from wear when other lubricants are absent.

Internal combustion engines use Babbitt metal which is primarily tin-based because it can withstand cyclic loading. Lead-based Babbitt tends to work-harden and develop cracks but it is suitable for constant-turning tools such as saw blades.

CADMIUM

Cadmium is a minor metallic element, one of the naturally occurring components in the earth’s crust and waters, and present everywhere in our environment. It was first discovered in Germany in 1817 as a by-product of the zinc refining process. Its name is derived from the Latin word cadmic and the Greek word kalmia that are ancient names for calamine or zinc oxide.

Naturally-occurring cadmium-sulfide based pigments were used as early as 1850 because of their brilliant red, orange and yellow colors ,and appeared prominently in the paintings of Vincent Van

Gogh in the late 1800s. Germany was the first and only commercial producer of cadmium metal for industrial applications up until World War I. Thomas A. Edison in the United States and Wald mar Judger in Sweden developed the first nickel-cadmium batteries early in the 20th Century. However, the most significant early use of cadmium was as a sacrificial corrosion protection coating on iron and steel.

Exposure to certain forms and concentrations of cadmium is known to produce toxic effects on humans. Long-term occupational exposure to cadmium at excess concentrations can cause adverse health effects on the kidneys and lungs. Adverse human health effects have generally not been encountered under normal exposure conditions for the general population except in areas of historically high cadmium contamination. The potential risks from cadmium exposure have been extensively studied, and are now tightly controlled by occupational exposure standards, regulations for cadmium in ambient air, water and soil, and legislation covering cadmium emissions, labeling and disposal of cadmium-containing products, and impurity levels in other products such as fossil fuels, fertilizers and cement.

Heat Treatment of Nonferrous Metals

ALUMINUM ALLOY

In the wrought form, commercially pure aluminum is known as 1100. It has a high degree of resistance to corrosion and is easily formed into intricate shapes. It is relatively low in strength and does not have the properties required for structural aircraft parts. High strengths are generally obtained by the process of alloying. The resulting alloys are less easily formed and, with some exceptions, have lower resistance to corrosion than 1100 aluminum. Alloying is not the only method of increasing the strength of aluminum. Like other materials, aluminum becomes stronger and harder as it is rolled, formed, or otherwise cold worked. Since the hardness depends on the amount of cold working done, 1100 and some wrought aluminum alloys are available in several strain hardened tempers. The soft or annealed condition is designated O. If the material is strain hardened, it is said to be in the H condition. The most widely used alloys in aircraft construction are hardened by heat treatment rather than by cold work. These alloys are designated by a somewhat different set of symbols: T4 and W indicate solution heat treated and quenched but not aged, and T6 indicates an alloy in the heat treated hardened condition.

- W — Solution heat treated, unstable temper
- T — Treated to produce stable tempers other than F, O, or H
- T2 — Annealed (cast products only)
- T3 — Solution heat treated and then cold worked
- T4 — Solution heat treated
- T5 — Artificially aged only
- T6 — Solution heat treated and then artificially aged
- T7 — Solution heat treated and then stabilized
- T8 — Solution heat treated, cold worked, and then artificially aged
- T9 — Solution heat treated, artificially aged, and then cold worked
- T10 —Artificially aged and then cold worked

Additional digits may be added to T1 through T10 to indicate a variation in treatment which significantly alters the characteristics of the product.

Aluminum alloy sheets are marked with the specification number on approximately every square foot of material. If for any reason this identification is not on the material, it is possible to separate the heat treatable alloys from the non-heat-treatable alloys by Immersing a sample of the material in a 10 percent solution of caustic soda (sodium hydroxide). The heat-treatable alloys will turn black due to the copper content, whereas the others will remain bright. In the case of clad material, the surface will remain bright, but there will be a dark area in the middle when viewed from the edge.

There are two types of heat treatments applicable to aluminum alloys. One is called solution heat treatment, and the other is known as precipitation heat treatment. Some alloys, such as 2017 and 2024, develop their full properties as a result of solution heat treatment followed by about 4 days of aging at room temperature. Other alloys, such as 2014 and 7075, require both heat treatments. The alloys that require precipitation heat treatment (artificial aging) to develop their full strength also age to a limited extent at room temperature; the rate and amount of strengthening depends upon the alloy. Some reach their maximum natural or room temperature aging strength in a few days, and are designated as - T4 or -T3 temper. Others continue to age appreciably over a long period of time. Because of this natural aging, the -W designation is specified only when the period of aging is indicated, for example, 7075-W (1⁄2 hour). Thus, there is considerable difference in the mechanical and physical properties of freshly quenched (W) material and material that is in the -T3 or -T4 temper.

The hardening of an aluminum alloy by heat treatment consists of four distinct steps:

1. Heating to a predetermined temperature.
2. Soaking at temperature for a specified length of time.
3. Rapidly quenching to a relatively low temperature.
4. Aging or precipitation hardening either spontaneously at room temperature, or as a result of a low temperature thermal treatment.

The first three steps above are known as solution heat treatment, although it has become common practice to use the shorter term, ―heat treatment. Room temperature hardening is known as natural aging, while hardening done at moderate temperatures is called artificial aging, or precipitation heat treatment.

Solution Heat Treatment Temperature

The temperatures used for solution heat treating vary with different alloys and range from 825°F to 980°F.As a rule, they must be controlled within a very narrow range (±10 °F) to obtain specified properties. If the temperature is too low, maximum strength will not be obtained. When excessive temperatures are used, there is danger of melting the low melting constituents of some alloys with consequent lowering of the physical properties of the alloy. Even if melting does not occur, the use of higher than recommended temperatures promotes discoloration and increases quenching strains.

Time at Temperature (soaking)

The time at temperature, referred to as soaking time, is measured from the time the coldest metal reaches the minimum limit of the desired temperature range. The soaking time varies, depending upon the alloy and thickness, from 10 minutes for thin sheets to approximately 12 hours for heavy forgings. For the heavy sections, the nominal soaking time is approximately 1 hour for each inch of cross-sectional thickness. Choose the minimum soaking time necessary to develop the required physical properties. The effect of an abbreviated soaking time is obvious. An excessive soaking period aggravates high temperature oxidation. With clad material, prolonged heating results in excessive diffusion of copper and other soluble constituents into the protective cladding and may defeat the purpose of cladding.

Quenching

After the soluble constituents are in solid solution, the material is quenched to prevent or retard immediate re precipitation. Three distinct quenching methods are employed. The one to be used in any particular instance depends upon the part, the alloy, and the properties desired.

Cold Water Quenching

Parts produced from sheet, extrusions, tubing, small forgings, and similar type material are generally quenched in a cold water bath. The temperature of the water before quenching should not exceed 85 °F. Using a sufficient quantity of water keeps the temperature rise under 20 °F. Such a drastic quench ensures maximum resistance to corrosion. This is particularly important when working with such alloys as 2017, 2024, and 7075. This is the reason a drastic quench is preferred, even though a slower quench may produce the required mechanical properties.

Hot Water Quenching

Large forgings and heavy sections can be quenched in hot or boiling water. This type of quench minimizes distortion and alleviates cracking which may be produced by the unequal temperatures obtained during the quench. The use of a hot water quench is permitted with these parts because the temperature of the quench water does not critically affect the resistance to corrosion of the forging alloys. In addition, the resistance to corrosion of heavy sections is not as critical a factor as for thin sections.

Spray Quenching

High velocity water sprays are useful for parts formed from clad sheet and for large sections of almost all alloys. This type of quench also minimizes distortion and alleviates quench cracking. However, many specifications forbid the use of spray quenching for bare 2017 and 2024 sheet materials because of the effect on their resistance to corrosion.

Lag Between Soaking and Quenching

The time interval between the removal of the material from the furnace and quenching is critical for some alloys and should be held to a minimum. When solution heat treating 2017 or 2024sheet material, the elapsed time must not exceed 10 seconds. The allowable time for heavy sections may be slightly greater. Allowing the metal to cool slightly before quenching promotes re precipitation from the solid solution. The precipitation occurs along grain boundaries and in certain slip planes causing poorer formability. In the case of 2017, 2024, and 7075 alloys, their resistance to inter granular corrosion is adversely affected.

Reheat Treatment

The treatment of material which has been previously heat treated is considered a reheat treatment. The unclad heat-treatable alloys can be solution heat treated repeatedly without harmful effects. The number of solution heat treatments allowed for clad sheet is limited due to increased diffusion of core and cladding with each reheating. Existing specifications allow one to three reheat treatments of clad sheet depending upon cladding thickness.

straightening after solution heat treatment Some warping occurs during solution heat treatment, producing kinks, buckles, waves, and twists. These imperfections are generally removed by straightening and flattening operations. Where the straightening operations produce an appreciable increase in the tensile and yield strengths and a slight decrease in the percent of elongation, the material is designated -T3 temper. When the above values are not materially affected, the material is designated-T4temper.

Precipitation Heat Treating

As previously stated, the aluminum alloys are in a comparatively soft state immediately after quenching from a solution heat- treating temperature. To obtain their maximum strengths, they must be either naturally aged or precipitation hardened. During this hardening and strengthening operation, precipitation of the soluble constituents from the supersaturated solid solution takes place. As precipitation progresses, the strength of the material increases, often by a series of peaks, until a maximum is reached. Further aging (over aging) causes the strength to steadily decline until a somewhat stable condition is obtained. The submicroscopic particles that are precipitated provide the keys or locks within the grain structure and between the grains to resist internal slippage and distortion when a load of any type is applied. In this manner, the strength and hardness of the alloy are increased.

Precipitation hardening produces a great increase in the strength and hardness of the material with corresponding decreases in the ductile properties. The process used to obtain the desired increase in strength is therefore known as aging, or precipitation hardening. The strengthening of the heat-treatable alloys by aging is not due merely to the presence of aprecipitate. The strength is due to both the uniform distribution of a finely dispersed submicroscopic precipitate and its effects upon the crystal structure of the alloy. The aging practices used depend upon many properties other than strength. As a rule, the artificially aged alloys are slightly over aged to increase their resistance to corrosion. This is especially true with the artificially aged high copper content alloys that are susceptible to inter granular corrosion when inadequately aged. The heat-treatable aluminum alloys are subdivided into two classes: those that obtain their full strength at room temperature and those that require artificial aging. The alloys that obtain their full strength after 4 or 5 days at room temperature are known as natural aging alloys. Precipitation from the supersaturated solid solution starts soon after quenching, with 90 percent of the maximum strength generally being obtained in 24 hours. Alloys 2017 and 2024 are natural aging alloys. The alloys that require precipitation thermal treatment to develop their full strength are artificially aged alloys. However, these alloys also age a limited amount at room temperature, the rate and extent of the strengthening depending upon the alloys.

Many of the artificially aged alloys reach their maximum natural or room temperature aging strengths after a few days. These can be stocked for fabrication in the -T4 or -T3 temper. High zinc content alloys such as 7075 continue to age appreciably over a long period of time, their mechanical property changes being sufficient to reduce their formability. The advantage of -W temper formability can be utilized, however, in the same manner as with natural aging alloys; that is, by fabricating shortly after solution heat treatment, or retaining formability by the use of refrigeration.

Refrigeration retards the rate of natural aging at 32°F, the beginning of the aging process is delayed for several hours, while dry ice (−50 °F to −100 °F) retards aging for an extended period of time.

Precipitation Practices

The temperatures used for precipitation hardening depend upon the alloy and the properties desired, ranging from 250 °F to375 °F. They should be controlled within a very narrow range (±5 °F) to obtain best results. The time at temperature is dependent upon the temperature used, the properties desired, and the alloy. It ranges from 8 to 96 hours. Increasing the aging temperature decreases the soaking period necessary for proper aging. However, a closer control of both time and temperature is necessary when using the higher temperatures. After receiving the thermal precipitation treatment, the material should be air cooled to room temperature. Water quenching, while not necessary, produces no ill effects. Furnace cooling has a tendency to produce over aging.

Annealing Of Aluminum Alloys

The annealing procedure for aluminum alloys consists of heating the alloys to an elevated temperature, holding or soaking them at this temperature for a length of time depending upon the mass of the metal, and then cooling in still air. Annealing leaves the metal in the best condition for cold working. However, when prolonged forming operations are involved, the metal will take on a condition known as—mechanical hardness and will resist further working. It may be necessary to anneal a part several times during the forming process to avoid cracking. Aluminum alloys should not be used in the annealed state for parts or fittings. Clad parts should be heated as quickly and carefully as possible, since long exposure to heat tends to cause some of the constituents of the core to diffuse into the cladding. This reduces the corrosion resistance of the cladding.

Heat Treatment of Aluminum Alloy Rivets

Aluminum alloy rivets are furnished in the following compositions: Alloys 1100, 5056, 2117, 2017, and2024.
Alloy 1100 rivets are used in the —as fabricated "condition for riveting aluminum alloy sheets where a low strength rivet is suitable. Alloy 5056 rivets are used in the —as fabricated‖ condition for riveting magnesium alloy sheets. Alloy 2117 rivets have moderately high strength and are suitable for riveting aluminum alloy sheets. These rivets receive only one heat treatment, which is performed by the manufacturer, and are anodized after being heat treated. They require no further heat treatment before they are used. Alloy 2117 rivets retain their characteristics indefinitely after heat treatment and can be driven anytime. Rivets made of this alloy are the most widely used in aircraft construction. Alloy 2017 and 2024 rivets are high strength rivets suitable for use with aluminum alloy structures. They are purchased from the manufacturer in the heat-treated condition. Since the aging characteristics of these alloys at room temperatures are such that the rivets are unfit for driving, they must be reheat treated just before they are to be used. Alloy 2017 rivets become too hard for driving in approximately 1 hour after quenching. Alloy 2024 rivets become hardened in 10 minutes after quenching. Both of these alloys may be reheat treated as often as required; however, they must be anodized before the first reheat treatment to prevent inter granular oxidation of the material. If these rivets are stored in a refrigerator at a temperature lower than 32 °F immediately after quenching, they will remain soft enough to be usable for several days.

Rivets requiring heat treatment are heated either in tubular containers in a salt bath, or in small screen wire baskets in an air furnace. The heat treatment of alloy 2017 rivets consists of subjecting the rivets to a temperature between 930 °F to 950°F for approximately 30 minutes, and immediately quenching in cold water. These rivets reach maximum strength in about 9 days after being driven. Alloy 2024 rivets should be heated to a temperature of 910 °F to 930 °F and immediately quenched in cold water.

These rivets develop a greater shear strength than 2017 rivets and are used in locations where extra strength is required. Alloy 2024 rivets develop their maximum shear strength in 1 day after being driven. The 2017 rivet should be driven within approximately 1 hour and the 2024 rivet within 10 to 20 minutes after heat treating or removal from refrigeration. If not used within these times, the rivets should be re-heat treated before being refrigerated.

HEAT TREATMENT OF MAGNESIUM ALLOYS

Magnesium alloy castings respond readily to heat treatment, and about 95 percent of the magnesium used in aircraft construction is in the cast form. The heat treatment of magnesium alloy castings is similar to the heat treatment of aluminum alloys in that there are two types of heat treatment:

(1) Solution heat treatment and
(2) Precipitation (aging) heat treatment.

Magnesium, however develops a negligible change in its properties when allowed to age naturally at room temperatures.

Solution Heat Treatment

Magnesium alloy castings are solution heat treated to improve tensile strength, ductility, and shock resistance. This heat- treatment condition is indicated by using the symbol -T4 following the alloy designation. Solution heat treatment plus artificial aging is designated -T6. Artificial aging is necessary to develop the full properties of the metal.

Solution heat-treatment temperatures for magnesium alloy castings range from 730 °F to 780 °F, the exact range depending upon the type of alloy. The temperature range for each type of alloy is listed in Specification MIL-H-6857. The upper limit of each range listed in the specification is the maximum temperature to which the alloy may be heated without danger of melting the metal. The soaking time ranges from 10 to 18 hours, the exact time depending upon the type of alloy as well as the thickness of the part. Soaking periods longer than 18 hours may be necessary for castings over 2 inches in thickness. NEVER heat magnesium alloys in a salt bath as this may result in an explosion.
A serious potential fire hazard exists in the heat treatment of magnesium alloys. If through oversight or malfunctioning of equipment, the maximum temperatures are exceeded, the casting may ignite and burn freely. For this reason, the furnace used should be equipped with a safety cutoff that will turn off the power to the heating elements and blowers if the regular control equipment malfunctions or fails. Some magnesium alloys require a protective atmosphere of sulfur dioxide gas during solution heat treatment. This aids in preventing the start of a fire even if the temperature limits are slightly exceeded. Air quenching is used after solution heat treatment of magnesium alloys since there appears to be no advantage in liquid cooling.

Precipitation Heat Treatment

After solution treatment, magnesium alloys may be given an aging treatment to increase hardness and yield strength. Generally, the aging treatments are used merely to relieve stress and stabilize the alloys in order to prevent dimensional changes later, especially during or after machining. Both yield strength and hardness are improved somewhat by this treatment at the expense of a slight amount of ductility. The corrosion resistance is also improved, making it closer to the —as cast alloy. Precipitation heat treatment temperatures are considerably lower than solution heat-treatment temperatures and range from 325 °F to 500 °F. Soaking time ranges from 4 to 18hours.

HEAT TREATMENT OF TITANIUM

Titanium is heat treated for the following purposes:

- Relief of stresses set up during cold forming or machining.
- Annealing after hot working or cold working, or to provide maximum ductility for subsequent cold working.
- Thermal hardening to improve strength.

Stress Relieving

Stress relieving is generally used to remove stress concentrations resulting from forming of titanium sheet. It is performed at temperatures ranging from 650 °F to 1,000 °F. The time at temperature varies from a few minutes for a very thin sheet to an hour or more for heavier sections. A typical stress relieving treatment is 900 °F for 30 minutes, followed by an air cool. The discoloration or scale which forms on the surface of the metal during stress relieving is easily removed by pickling in acid solutions. The recommended solution contains 10 to 20 percent nitric acid and 1 to 3 percent hydrofluoric acid. The solution should be at room temperature or slightly above.

Full Annealing

The annealing of titanium and titanium alloys provides toughness, ductility at room temperature, dimensional and structural stability at elevated temperatures, and improved machinability. The full anneal is usually called for as preparation for further working. It is performed at 1,200–1,650 °F. The time at temperature varies from 16 minutes to several hours, depending on the thickness of the material and the amount of cold work to be performed. The usual treatment for the commonly used alloys is 1,300 °F for 1 hour, followed by an air cool. A full anneal generally results in sufficient scale formation to require the use of caustic de scaling, such as sodium hydride salt bath.

Thermal Hardening

Unalloyed titanium cannot be heat treated, but the alloys commonly used in aircraft construction can be strengthened by thermal treatment, usually at some sacrifice inductility. For best results, a water quench from 1,450 °F, followed by reheating to 900 °F for 8 hours is recommended.

TESTING OF NON-FERROUS MATERIALS

Non-ferrous metals are tested for strength, toughness, fatigue and hardness using exactly the same techniques as described in Subsection 6.1 (b) for Ferrous Metals. Please refer to that section for descriptions of those

6.3 Aircraft Materials-Composite and Non- Metallic

INRTODUCTRION TO COMPOSITES

The use of composite materials for aircraft manufacturing has elicited a variety of reactions among members of the aviation industry.

- Aircraft manufactures hail composites as a very durable, highly manufacture able material.
- Aircraft owners regard the new composite aircraft as light- weight and more cost effective than their metal counterparts.
- Aircraft technicians all too often regard composites as either another name for traditional fiberglass or as a mystery material only engineers can understand Composite materials are quickly becoming recognized as the most advanced substance for fabrication of aircraft parts. Composite structures are made from a combination of fabric, fibers m foams, and honeycomb materials bonded by a matrix or resin system.

WHAT IS A COMPOSITE STRUCTURE?

The term composite is used to describe two or more materials that are combined to form a structure that is much stronger than the individual components. The simplest composite is composed of two elements: a matrix that serves as a bonding substance, and a reinforcing material. Prior to combination , the matrix is generally in liquid from and the reinforcing material is a sold . Many times a core material is also added. All of these materials are combined and cure to make a structure that is stronger than each was originally.

The concept of composite material is not new. The oldest manmade building material, adobe, is a composite formula. Adobe is produced by combining two dissimilar components mud and straw, the resulting building block is substantially stronger and more durable than the original component were alone. The centuries old ruins of the Anasazi Indians in southwestern Colorado bear eloquent testimony to the durability of the simple composite material.

A more contemporary example of composite material is the traditional dope and fabric airplane. In this instance, nitrate or butyrate dope is combined in proper proportions with grade A cotton fabric producing a strong. Light-weight skin covering. The strength and simplicity of the dope and fabric airplane has endured through the years and is still a favorite airframe material for hand crafted classic and high performance aerobatic airframe material for hand crafted classic and high performance aerobatic airplanes, The smooth lines and meticulous workmanship of the dope and fabric airplanes can be seen in the high performance airplanes as the Stinson. Beech staggering and them christen eagle, all of which perform at summer air shows throughout the world.

ADVATAGES

The greatest advantage of using composites is the high strength to weight ratio. Since weight is one of the key considerations for the use of any material in aircraft construction, if it can be saved more cargo, fuel or passengers can be carried.

A composite part can be designed as strong as a metal part, but with considerable weight savings typically 20 percent or more weight reductions are achieved when aluminum parts are replaced with composite structures.

When designing with composite materials the weight savings are the primary pursuit. However the composites also lend themselves well to the formation of complex, aerodynamically contoured shapes. The parts do not have to be flat but can have smooth sweeping contours that would be difficult and expensive to fabricate from sheet metal. The reduced drag produced by these contoured shapes, in combination with the weight savings, enables an aircraft‘s range to be extended significantly.

The number of parts and fasteners may be reduced by the use of composites as well simplifying construction and reducing cost. In some cases, very large structures can be manufacture in one piece, eliminating the riveting and seams.

Composites are becoming increasingly cost effective as materials and manufacturing technologies mature, composites may be designed to be very flexible, resisting vibrations thus eliminating the problem of stress fatigue found in metal structures.

Composites don‘t corrode like metal does; either however, they do have their own problems which will be discussed in later chapters. Many people talk as if composites are indestructible. If this were the case a book on the repair to composites would not have to be written as they would never fail or break. Reduced wear is another advantage of using composites.

Composites will flex in flight without producing stress cracks like metal. For example helicopter rotor blades in flight have many stresses imposed on them. When made of composites, the wear is less because the fibers can take the bending and twisting forces without developing metal fatigue.

Many articles written on composite materials state that a composite part can be built many times stronger than a metal part. This is true but can be built many times stronger than a metal part. This is true , but when working with aircraft components weight is also a very big factor . If the part has as sufficient strength as a metal component, the composite part can be made worth the same strength while saving considerable weight.

If you are using composite materials to build something other than an aircraft such as a bridge , weight would not be an issue and the component could be made many times stronger than metal . The strength of the composite depends on the type of fibers used, the bonding materials used, and how the part is engineered to take specific stresses. In short composites are years ahead of traditional aluminum alloy and are the closest thing yet to an ideal aircraft material.

USES

Composites today are being used throughout the world. On helicopters, military aircraft, commercial aircraft and homebuilt composites are being used in the power plants as well as the airframe design. This book concentrates on the airframe uses of composites. European and other foreign aircraft manufacturers may be utilizing more composites materials in their designs than be due in part to the more conservative policies of the American Federal Aviation Administration (FAA).

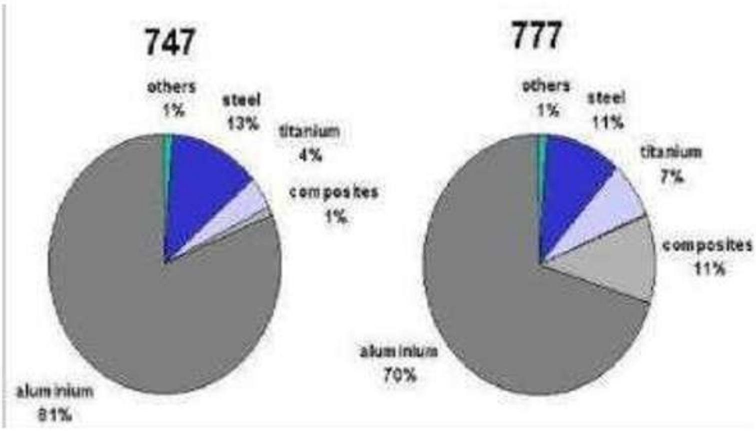


Fig. 3.1 Relative compression of use of composite in Boeing - 747 & Boeing -777

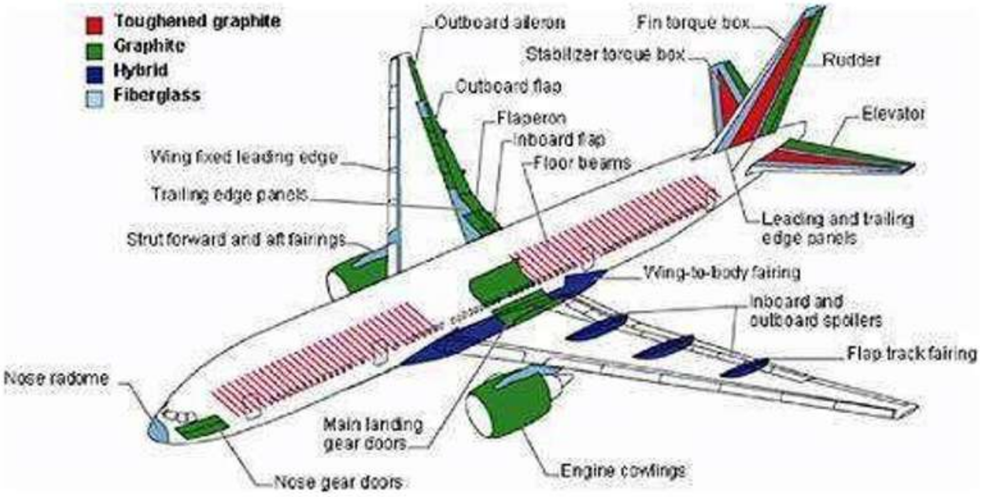


Fig. 6.2 Use of composite in airbus-777

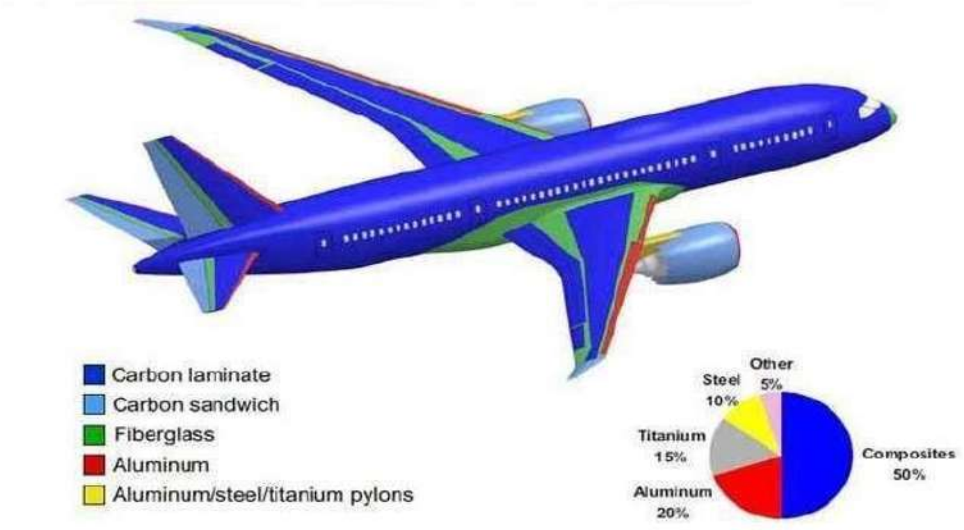


Fig. 6.3 Use of composite in Boeing -787

REINFORCING FIBERS

When combined with a matrix, the reinforcing fibers give the primary strength to the composite structure. There are three common types of reinforcing fibers: Fiberglass, aramid, and carbon/graphite. Other fibers that aren't quite as common include ceramic and button. All of these fibers cab be used in combination with one another ,woman in specific pattern in combination with other materials such as rigid foams or simply in combination with various provides specific advantages . The following information details each of the five common types of reinforcing fibers and their characteristics

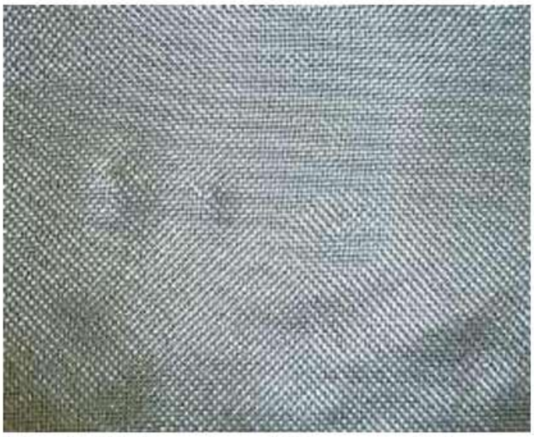


Fig. 3.4 Fiberglass (Glass cloth)

Fig. 3.5 Fiberglass

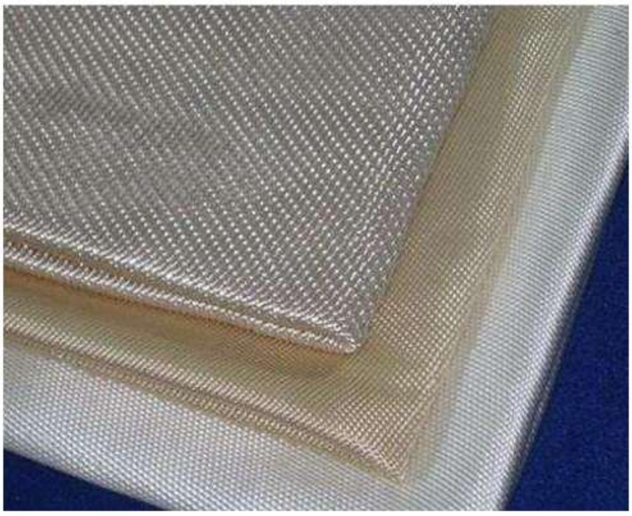


Fig. 3.6 Fiberglass

Fiberglass is made from small strands of molten silica glass (about 2,3000F) that are spun together and woven into cloth. Glass fibers are somewhat fragile. So a sizing is used as a protective shield during the weaving process. After it is woven the sizing may be removed and a finish applied. Which makes the fibers more compatible with the matrix or resin system to be used? There are many different weaves of fiberglass available, depending on the particular application its widespread availability and its low cost make fiberglass one of the most popular reinforcing fibers.

Fiberglass weights more than most other composite fibers but has less strength. In the past fiberglass was used for nonstructural applications; the weave was heavy and polyester resins were used making the part brittle. Recently however, newly developed matrix formulas have increased the benefits of using fiberglass. The three common types of fiberglass are E-glass, S- glass (S2glass). And C-glass. In structural applications E-glass and glass are most common .E-glass also known as _‘ electric glass‘‘ for its high electrical resistance , is a borosilicate glass commonly used for reinforcement because of its low cost and good strength characteristics.

S-glass is a magnesia –alumina-silicate glass that is up to 40 percent stronger than E-glass and retains its strength characteristics at higher temperatures. S –glass is used where a very high tensile strength fiberglass is needed.

ARAMID

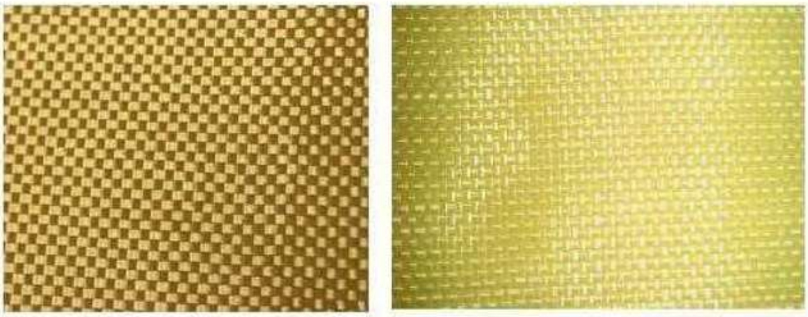


Fig. 3.7 ARAMID

An aramid , or aromatic polyamide fiber, is usually characterized by its yellow color light weight tensile strength and remarkable flexibility . Kevlar is a registered trademark of the EI Dupont Company and is the best known and most widely used aramid. Kevlar will ordinarily stretch a great deal before it breaks. The tensile strength of alloyed aluminum is about 65,000 psi , or about one-fourth that of Kevlar composite however , the objective in aviation is not necessarily to have a stronger part, but rather to have a part that weighs much less . By using a Kevlar reinforcing fiber, a component can be fabricated with the strength of a metal counterpart, at a fraction of the weight.

The aircraft structural grade of Kevlar fiber is known as Kevlar 49. Kevlar 29 is used for boats and Kevlar 129 is bulletproof material. A common misconception about Kevlar is that if Kevlar fabric is bulletproof, and an aircraft is made with Kevlar are typically made of a different weave weight and process than aircraft-type Kevlar. A bulletproof vest also omits the matrix, which makes a part more brittle. A bulletproof vest is made with multiple layers of Kevlar fabric , Which will stretch as the bullet impacts the fabric preventing penetration. Kevlar and nomex is the part of advanced composite.

Aramid is an ideal material for use in aircraft parts that are subject to high stress and vibration for example some advanced helicopter designs have made use of aramid to fabricate main rotor blades and hub assemblies . the flexibility of the aramid fabric allows the blade to bend made of metal develops fatigue and stress cracks more frequently under the same conditions.

Aramid materials also have their drawbacks. Because aramid stretches, it can cause problems when it is cut. Drilling aramid, for example can be a problems when it is cut. Drilling aramid. For example can be a problem when the drill bit grabs a fiber and stretches it to the breaking point instead of cutting it. This material will look fuzzy , if the fuzzy , if the fuzzing material around fastener holes or seams is not sealed . It may act as a wick and absorb moisture fluid probably won‘t damage the aramid fibers but it may cause problems with the resin system by causing them to deteriorate causing layers of laminates to separate . The fuzzing around the drilled hole may also prevent a fastener from seating properly, which may cause the fastened joint to fail, Some manufactures recommend using fiberglass to repair aramid material because even a slight amount of moisture will prevent aramid from bonding properly. To combat any extra moisture in the fabric , the raw fabric may be vacuum bagged to dry out any excess moisture . Although aramid exhibits great tensile strength, it does not have as much compressive strength as carbon / graphite Composites.

CARBON /GRAPHITE

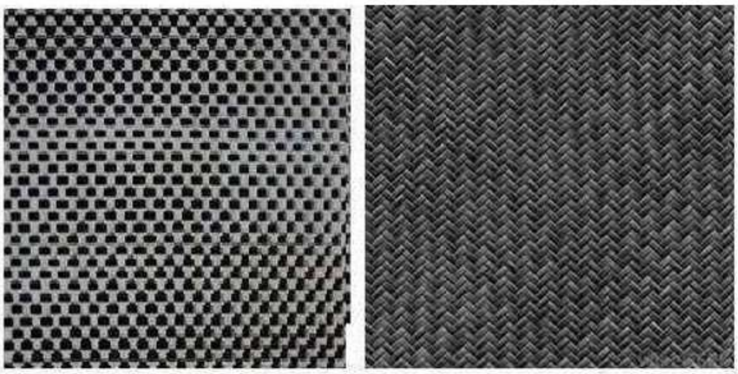


Fig. 3. 8 Carbons /Graphite

Carbon fiber, also known as graphite fiber, is a very strong, stiff reinforcement. For many years. American manufactures used the term graphite, while European manufactures used the term carbon. Carbon correctly describes the fiber since it contains no graphite structure. Regardless of what you call it, you order it by number. If you order Carbon #584 you will get the same weight and weave as if you order Graphite #584 . It is the same material. Some structural repair manuals may call for carbon #584 in one area and graphite #584 in another. Recently, Carbon has become the favored term by both American and European manufacturers.

There are still many structural repair manuals however, that use the term Graphite, so understanding that this material can be referred to in either way is still important to the maintenance technician.

This black fiber is very strong stiff, and used for its rigid strength characteristics. Carbon/graphite fiber composites are used to fabricate primary structural components, such as ribs and wings kins. Even very large aircraft cab be designed with a reduced number of reinforcing bulkheads, ribs and stringers, thanks to the high strength and high rigidity of carbon fiber composites. Carbon/graphite is stronger in compressive strength than Kevlar, but it is more brittle.

Carbon fibers are electrically conductive have low thermal expansion coefficients and have high fatigue resistance. The impact resistance of carbon fibers is less than some other composite materials and may splinter or crack with high impact.

At one time, because of its conductivity, manufactures didn‘t require lightning or static protection on incorporate some kind of lightning protection.

Carbon graphite has the problem of being corrosive when bonded to aluminum special corrosion control techniques are employed when carbon/ graphite, materials are in contact with aluminum components. Usually a layer of fiberglass is used as a barrier, and the aluminum is anodized, primed, and painted prior to assembly.

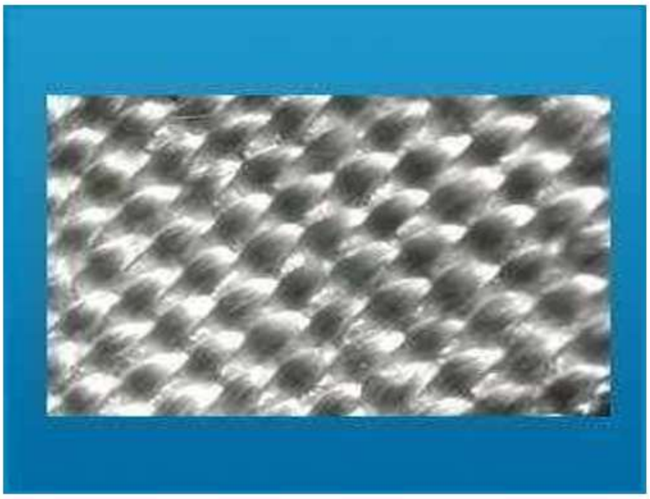


Fig. 3.9 Boron

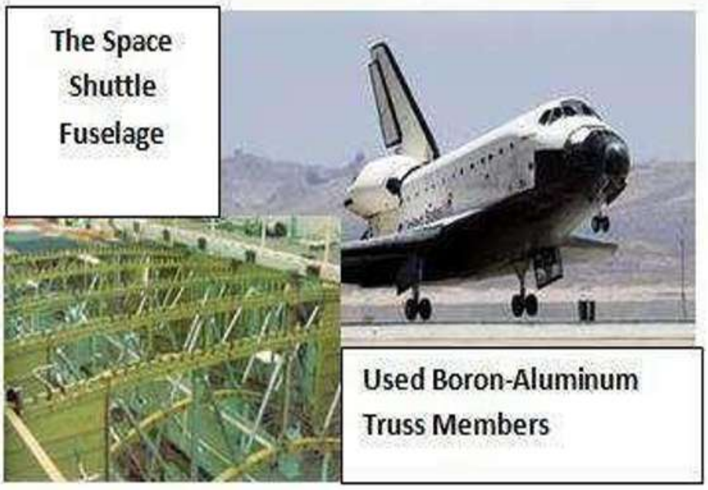


Fig. 3.10 Boron

Boron fibers are made by depositing the element born onto a thin filament of tungsten. The resulting fiber is about .004-inch in diameter, has excellent compressive strength and stiffness, and is extremely hard. Because boron can be hazardous to work with along with its high expense, it is not commonly used in civil aviation. Boron fibers were first used in the early 1960‘s for military application of the.

Boron fiber usually comes in a unidirectional pre preg material. Boron composites have very high strength and stiffness i9n tension, compression, and bending stresses. The extent of these strengths, however, depends on the type of fiber science designed into the part.
At one time, boron fibers were used to see if they could help extend the life of the ageing aircraft fleet. When aluminum wing skins developed tiny stress cracks, boron patches were bonded to the aluminum to prevent further cracking.

In designing a composite component that needs both strength and stiffness associated with boron, many civil aviation manufacturers are utilizing hybrid composite materials of aramid and carbon/ graphite, instead of boron.

Fig. 3.11 Ceramic

Ceramic fibers are used when a high temperature application is needed. This form of composites retains most of its strength and flexibility at temperatures up to 2,2000F. The tiles on the space shuttle, for example, are made of a special ceramic composite that is heat resistant and dissipates heat quickly.

Firewalls are often made of ceramic fiber composites to dissipate the heat; Ceramic fibers are often also used with a metal matrix.

OTHER FIBERS

There are a variety of other fibers which can be used in advanced composite structures but their use is not widespread. These include Polyester.

Fig. 3.12 Polyester

A low density, high tenacity fiber with good impact resistance but low modulus. Its lack of stiffness usually precludes it from inclusion in a composite component, but it is useful where low weight, high impact or abrasion resistance, and low cost are required. It is mainly used as a surfacing material, as it can be very smooth, keeps weight down and works well with most resin types.

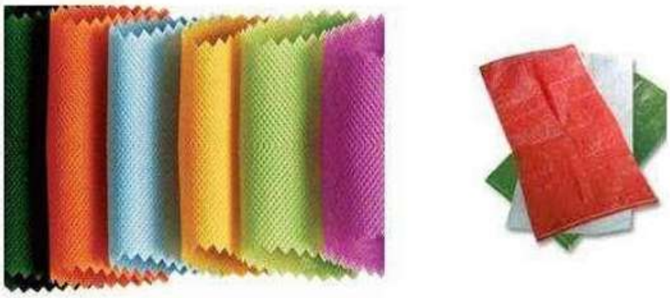


Fig. 3.13 Polyethylene

In random orientation, ultra-high molecular weight polyethylene molecules give very low mechanical properties. However, if dissolved and drawn from solution into a filament by a process called gel-spinning, the molecules become disentangled and aligned in the direction of the filament. The molecular alignment promotes very high tensile strength to the filament and the resulting fiber. Coupled with their low S.G. (<1.0), these fibers have the highest specific strength of the fibers described here. However, the fiber‘s tensile modulus and ultimate strength are only slightly better than E-glass and less than that of aramid or carbon. The fiber also demonstrates very low compressive strength in laminate form. These factors, coupled with high price, and more importantly, the difficulty in creating a good fiber/matrix bond means that polyethylene fibers are not often used in isolation for composite components.

Fig. 3.14 Quartz

A very high silica version of glass with much higher mechanical properties and excellent resistance to high temperatures (>1,000°C). However, the manufacturing process and low volume production lead to a very high price's.

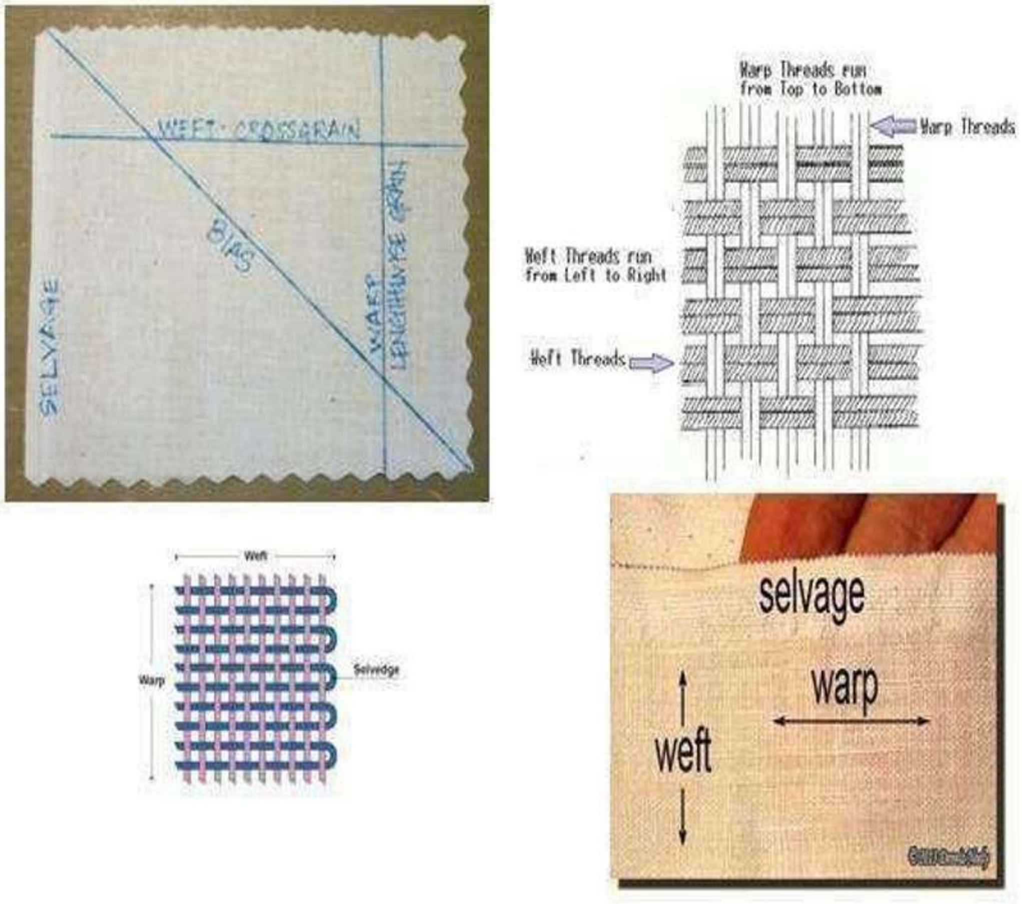


Fig. 3.15 Fiber Science

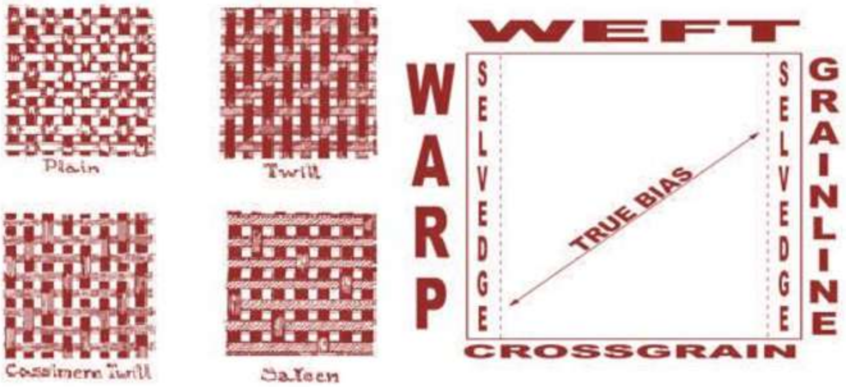


Fig. 3.16 Fiber Science

The selective placement of fibers needed to obtain the greatest amount of strength in various applications is known as fiber science. The strength and stiffness of a composite depend on the orientation of the plies to the load direction. A sheet metal component will have the same strength no matter which direction it is loaded.

For example, a helicopter rotor blade has high stress along its length because of centripetal forces. If the blade is made of metal, the strength is the same in all directions, giving strength in directions that are not needed. If fabricated of composites, however the blade may have the majority of fibers running through its length to give more strength in the direction in which the most stress is concentrated. These vectors of strength might be referred to as zero degree plies (To react to axial loads like those to which a rotor blade is subjected).450plies (to react to shear vectors). Or 900plies (to react to side loads).

For example .if a wing in flight bends up as well as twists. The part can be manufactured so one layers of fibers runs the length of the wing. Reducing the bending tendency. And another layer with the fibers running at 450and at 900to limit the twist. Each layer may have the major fibers running in a different direction. The strength of the fibers are parallel to the direction. The strength of the fibers are parallel to the direction the threads run. This is how designers can customize fiber direction for the type of stress the part might encounter.

FIBER ORIENTATION

Some of the terms used to describe fiber orientation are:

WARP

The threads that run the length of the fabric as it comes off the bolt are referred to as the warp. The warp direction is designated at 00. In to the warp than the fill direction. Ultimately, a material is stronger in the warp direction than in the fill direction. Since the warp direction is often critical in fabricating or repairing composites, it may be identified by inserting another type of thread at periodic intervals. The plastic backing on the underside of materials that have been pre- impregnated with resins may also be marked to identify the warp threads.

WEFT (FILL)

Weft threads are those that run perpendicular to the warp fibers they are designated as 900. The weft, or fill threads are the threads that interweave with warp threads.

SELVAGE EDGE

A tightly woven edge produced by the weaver to prevent the edge from raveling is referred to as the selvage edge. It is parallel to the warp threads. The selvage edge is removed for all fabrication and repair work because the weave is different than the body of the fabric and would not give the same strength as the rest of the fabric.

BIAS

The bias is at a 450 angle to the warp threads. Fabric can be formed into contoured shapes by using the bias. Fabrics can often be stretched along the bias but seldom stretched along the warp or weft. This is important to keep in mind when it is necessary to wrap a fabric around a contoured shape.

UNIDIRECTIONAL

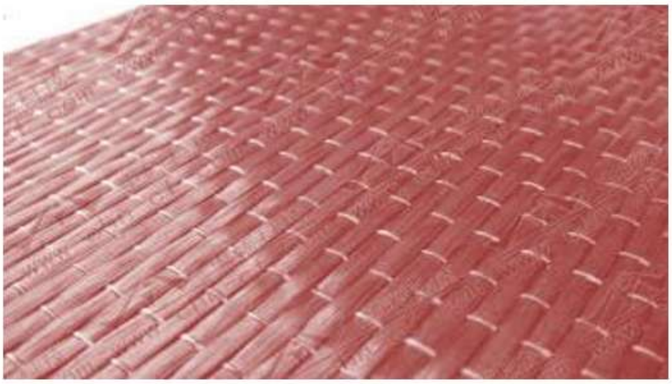


Fig. 3.17 Unidirectional

Fiber orientation in which all of the major fibers run in one direction. Giving strength in that direction, are known as unidirectional. This type of fabric is not woven together. In other words, there is no weft. Sometimes, small cross threads are used to hold the major fiber bundles in place, but they are not considered woven together. Most of the time , they come in pre preg form , and the resin/ curing agent holds the fibers in place .Occasionally . You may see a strand of a different type of fiber along with the major fiber. This fiber is used to maintain the correct fiber alignment. Unidirectional fabric may be laminated together with the fibers of each layer running in a different direction than the first layer. Tapes are unidirectional and are usually only made of carbon/graphite material. It is less expensive than fabric and creates a smoother surface. Tapes are sometimes replaced with fabric for repair work. Unidirectional tapes are usually pre impregnated with resin, because unidirectional materials are difficult to saturate with resin manually.

BIDIRECTIONAL OR MULTIDIRECTIONAL

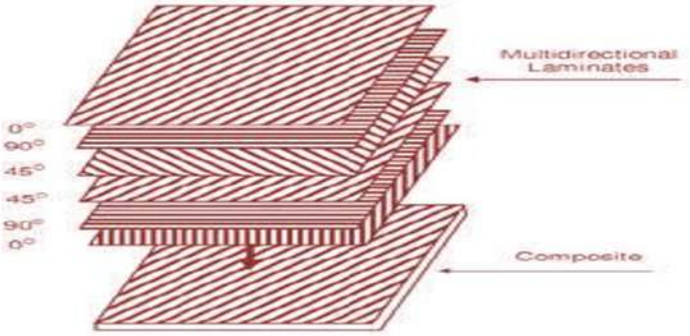


Fig. 3. 18 Bidirectional Or Multidirectional

This type of fiber orientation calls for fibers to run in two or more directions. Usually, these are woven together and may be seen in many different weaves. Again the warp threads have more fibers woven together than the weft, so it is important to line up the warp threads when doing a repair. In this arrangement, there usually is more strength in the warp direction then in the fill direction.

MATS

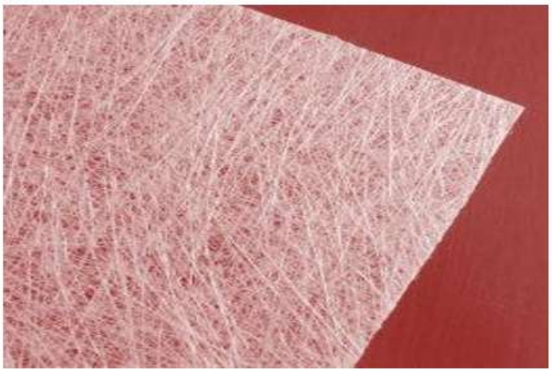


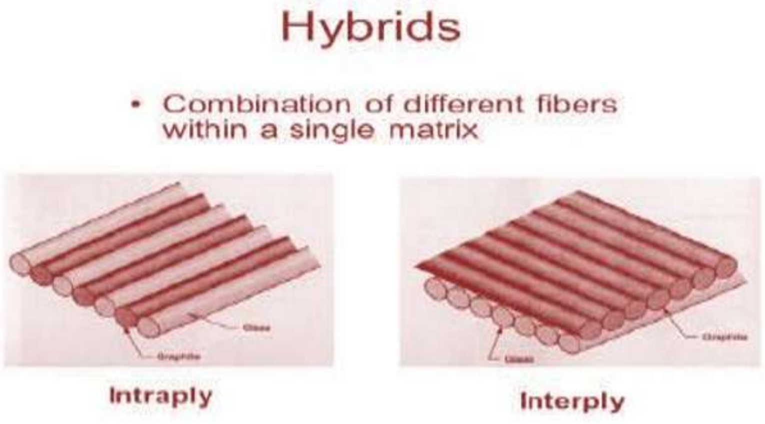
Fig. 3.19 MATS

Chopped fibers that are compressed together are often called mats. These mats typically are used in combination with other Woven or unidirectional layers of fabric. A mat is not as strong as a unidirectional or woven fabric and therefore is not commonly used in repair work.

HYBRIDS

Fig. 3.20 Hybrids

A manufacturer can design a part by using different types of fiber combination to tailor a part for strength, or to reduce cost. This can be done in a number of ways. The different materials are combined to give the characteristics of each different fiber. For example, Kevlar may be combined with carbon/graphite to produce a structure that combines the flexibility of Kevlar with the stiffness of carbon/graphite. Another example (I section) would be a combination of Kevlar and fiberglass to produce a less expensive high- strength material. There are three common types of hybrid structures used in aviation today.



Hybrids

- Combination of different fibers within a single matrix

Fig. 3.21 Interplay & interplay

Interplay hybrids utilize reinforcing material that is woven from two or more different fibers. The strength of the final structure can be designed based on the proportions of each fiber used.

INTERPLY HYBRID

An interplay hybrid two or more layers of different reinforcing material that are laminated together. Each layer, in addition to being a different material may be used in the form of unidirectional or bidirectional fabric

SELECTIVE PLACEMENT

Fibers may be selectively placed to give greater strength flexibility or reduced cost. The I-beam shown in figure2-15 may use carbon/graphite if stiffness is desired, and blends in fiberglass to reduce the cost of the structure.

SUMMARY

When a part is manufactured, designers can decide on the fiber science, or the placing of the fibers, to produce the greatest strength for a specific stress. They can also use different types of fibers together as a hybrid to develop the characteristics of different fiber materials, or they may elect to use a core structure . As a result, designers use different types of fiber combinations to customize a part of their specific aircraft. Each aircraft part is made differently as opposed to sheet metal components, which are all typically the same type of material throughout the structure or throughout the entire aircraft skin.

PHENOL RESINS

Phenolic resins were the first resin types used for aerospace adhesive and composite applications and are still used extensively for metal-to-metal bonding and as matrix resins for aircraft passenger cabin furnishing panels where the low smoke and toxic gas emissions characteristics of Phenolic resins is advantageous. The key problems with Phenolic resins however is that they produce water as a product of cure and need cure temperatures of 125°c to 150°c to achieve acure

EPOXY RESINS

Epoxy resins are the most widely used resin types for aerospace adhesive and composite applications. They range in type from two-part, room temperature curing pastes (e.g. Araldite) to liquid resins and hot-cure film adhesives capable of operating up to 150°C for long periods of time in aero engine applications Epoxy based matrix resins for aerospace composites tend to fall into three categories:

350°f (177°C) Cure Epoxy Systems

These systems are mainly used for components that will meet elevated temperature conditions in service and are most resistant to moisture absorption. Most major structural items such as airframe class 1 items are based on these resins. They need a high temperature cure to be able to develop attractive elevated temperature mechanical properties in service structure. However, the degradation of properties after long term exposure to humidity means that these systems are generally limited to service temperatures of around135°C/275°f.

These matrix systems are good for fabrication of solid composite laminates, but is generally not possible to cure these prepregs directly onto honeycomb core and achieve satisfactory core-to- skin strength from the matrix resin attachment to the honeycomb cell ends. If these resin systems are to be used for composite sandwich panel skins, it is customary to use an epoxy film adhesive to bond the pre-cured skins to the honeycomb core in a secondary bonding operation

250°f (121°C) Cure Epoxy Systems

These systems are used on less highly loaded structures such as fairings and access panels and are less resistant to elevated temperatures and moisture absorption.
They are designed to operate in aerospace applications such as exterior secondary structures for civil and military sub-sonic aircraft and helicopters. Generally, the long term continuous operating temperatures for structures using these resins does not exceed the 93° C/200°f level and their use tends to be limited to secondary structural items These modified epoxy systems can be formulated to have the characteristic of one-shot laminating and bonding to substrate (e.g. honeycomb core) without the need for a separate structural adhesive. The matrix system flows and fillets around the cell end of the honeycomb core to form a high strength adhesive bond. This honeycomb bonding behavior considerably simplifies the fabrication of sandwich panels using 250°f cure matrix resins.

Room Temperature Cure Epoxy Systems

These systems are used for repair of composite parts and recent developments in paste adhesive technology provide systems with performance close to that of 250°f (121°C) cure resin .The convenience of mixing, applying and curing a two-part epoxy liquid or paste adhesive at room temperature is very attractive in terms of repairs to composite structures. However, until recently, these resin systems had relatively poor elevated temperature strength and poor toughness characteristics. Recent improvements in room temperature cure epoxy resins allow us to use these materials to a greater extent in composite structure repair.

Epoxy Wet Resins

These are usually two part systems

- Part A is a poly epoxide resin (base resin)
- Part B is a curing agent (hardener) - this can be an acidic, amine or amide cross link linking agent to achieve the polymerization process.

The ratio of Part A to Part B will vary according to the particular epoxy material but the manufacturer's instructions should always be followed. Keep kits of the two parts together and do not mix the lids as these will tend to bond. The tolerance on ratio quantities is + 1% pbw(parts by weight). Mixing by weight is preferred to mixing by volume. Use digital scales (0.1% accuracy). Mixing should be for 3 minutes minimum to ensure good dispersion of hardener into the base resin. Dyes are sometimes included to provide a color change which gives a visual check on mixing Mix in non-metallic receptacles (e.g. wax less paper cups) using flat non-metallic stirrers (e.g. wooden or plastic spatulas). If air is introduced into the mix, it may be desirable to vacuum, de- gas or allow to stand for a while to allow air to reach the surface. The higher the viscosity, the fewer gas/air bubbles will ever reach the surface and escape. Care should therefore be taken to avoid trapping air during mixing.

Gel Point

On addition of the hardener a resin will begin to become more viscous until it reaches a state when it is no longer a liquid and has lost its ability to flow. This is the gel point‘. The resin will continue to harden after it has gelled, until, at some time later, it has obtained its full hardness and properties.

Cure

Wet resins will usually cure at ambient temperatures (21- 24°C) in 16-72 hours though they will harden in less time than this. Cure can be accelerated (and properties improved) by the addition of heat. For Boeing aircraft, the cure temperature should be less than 66°C for 'room temperature' repairs. These do not replicate the strength of the original 350° or 250°f cures used during fabrication. Manufacturer‘s recommendations, which are based on extensive research, should always be followed for optimum performance It is very important to refer to the manufacturer‘s instructions when using resins of all kinds.

Resin/Fiber Ratio

An important feature of a composite structure is the proportion of fiber to resin used, or the resin/fiber ratio. If too much resin is used, the fibers will have little effect and the composite will be weak. If too little is used the fibers may not be fully encapsulated and the structure will lack rigidity.

There is an optimum resin/fiber ratio to produce the best composite. The value will vary depending on the fiber and resin used. With polyesters the ratio is usually about two parts of resin to one part of fiber by weight. This is because of the inferior adhesion of the polyester resin to the fiber, and it is usual to use a slight excess of resin to make sure that the fibers are thoroughly wetted with resin.

Epoxy resins, with their superior adhesion, bond very well to the fibers so the fiber resin ratio can be higher to produce a lighter but strong composite. For example, when using glass fiber and carbon fiber with epoxy resin, equal parts by weight of resin and fiber are used. Precise resin/fiber ratios are given by the fiber and resin manufacturers.

Epoxies have other useful properties which make them superior to polyesters.

- Very good resistance to chemicals
- Low shrinkage as they cure
- Variable curing time - different combinations of resin and hardeners can be used to give Curing times varying from a few minutes to days. Pot life can also be varied by choice or hardener.
- Variable curing temperature - some epoxides cure at room temperature, but by choosing
- The right hardeners, materials can be produced which will only cure when heated. This gives more. Time in which to work with the mixed resin.

Epoxy resins do have some disadvantages

- They are more expensive
- They are more difficult to use than polyester
- They are possibly hazardous to health

Workshop Conditions for Good Bonding

The environmental conditions required for good bonding include

- Air temperature 18°C to 30°C Repair surface temperature 18°C to 30°CRelative humidity 65% maximum (humidity should be kept as low as possible. Dependent on the temperature)Dust free atmosphere (positive pressure work area to keep out the dust)

- No smoking
- No exhaust or other oily fumes
- No aerosols
- No silicone release agents are permitted in any bonding shop. This includes WD40 and any other silicone de- watering fluids.
- Clean white cotton gloves must be worn at all times during and after surface preparation prior to bonding
- Handle parts by their edges (do not touch the faces to be bonded at anytime).

Resins should not be used if excessive humidity exists (>85%) because water will condense on the resin and affect the cure and subsequent properties. Containers should also be closed. Immediately after removal of the required quantity of resin or hardener. This is especially important for the curing agent which picks up atmospheric moisture more quickly than the resin.
Health and Safety Major points are

- Handling of resins, curing agents and solvents –clean gloves of correct type
- Skin protection - barrier creams and protective equipment
- Fume and dust extraction and ventilation
- Clean up of self and tools – Clean overalls
- Disposal of uncured resin and contaminated materials – special waste
- Flammability risk

Storage
Epoxy resins should be stored in their original containers in metal cabinets in a dry environment. If they are used as kits, these kits should not be mixed up. The performance of each resin can be found on the manufacturers‘ data sheets. Data sheets also give details of storage and the associated temperatures If applicable allow kits of resin to reach ambient temperature before opening. Resin storage categories.

- Category A -18°c and below
- Category B 1°c to5°c
- Category C Ambient

Fig. 3.22 Bonding Room

MATRIX MATERIALS

The matrix is a bonding material that completely surrounds the fiber giving it extra strength. The strength of a composite lies in the ability of the matrix to transfer stress to the reinforcing fibers. An advanced composite uses various manufacturing techniques and newer matrix formulas with newer reinforcing fabrics.

Polyester resin is an example of an early matrix formula used with fiberglass for many nonstructural applications such as fairings, spinners, and trim. The old polyester /fiberglass formulas did not offer sufficient strength to be used to fabricate primary structural members; It can be somewhat brittle. The newer matrix materials display remarkably improved stress distributing characteristics, heat resistance chemical resistance, and durability. Most of the newer matrix formulas for aircraft are epoxy resins.

Resin matrix is two-part systems consisting of a resin and a catalyst, or hardener, which acts as a curing agent. The term resin often times means both parts together, not just the resin. For simplicity, this book uses the term resin to mean both parts together. ,Many times a maintenance manual may use the term catalyzed resin, meaning that the resin and the curing agent or hardener have been mixed , but not necessarily cured.

MATRIX STSTEMS

Resin matrix systems are type of plastic. Some companies refer to composites as fiber reinforced plastics. There are two general categories of plastics; thermoplastic and thermoses. By themselves, these resins do not have sufficient strength for use in structural applications, however, when used as a matrix and reinforced with other materials. They form the high strength lightweight structural composites used today.

THERMOPLASTIC

Thermoplastic resins use heat to form the part into the desired shape; one that is not necessarily permanent. If a thermoplastic is heated a second time, it will flow to form another shape. Plexiglas, which is used to form aircraft windshields, is an example of thermoplastic. The shape of the windshield is retained after it is cooled at the factory. But if the windshield is heated again, the plastic will flow to form another shape.

Thermoplastic resins may be found in overhead storage bins and nonstructural applications. However, with the advancements being made in composite science, thermoplastic resins are finding their way into the structural airframe applications too. With the development of high temperature thermoplastic resins, these plastics can be used in more places, as long as the temperature does not exceed 7500.F

POLYESTER RESIN SYSTEMS

Polyester resins were developed in the 1930s by a chemist named Carleton Ellis. He patented the first process for making polyester resins in 1936. A year later Ellis improved the basic design of polyester resin when he discovered what is still used today combining unsaturated polyester alkyd with vinyl acetate or styrene and curing it with a peroxide catalyst. The new formula was less viscous than the original, and it cured faster and more completely. The process for the new polyester resin system was patented in 1941. Polyester resin was one of the core product advances that launched the modern plastics industry. Annual production of polyester resin in the United States is now at about one billion pounds per year.

CHEMISTRY OF POLYESTER RESINS

The reasons for the widespread use of polyester resins are simple. Polyester resins are very stable at room temperature and can be kept in storage for years without affecting the quality of the materials. The resins cure at room temperature in just a few minutes when an inexpensive peroxide catalyst is added. Plus , no by products are released ,and the curing process actually produces are released , and the curing process actually products additional heat, thus enhancing the curing process. Polyester resins are low in cost and are very versatile. They are not very resistant to alkali, however, nor are they strong enough to use as matrix material for structural components .Different curing agents can be mixed with the basic polyester resins to provide different pot-life and cure times. Furthermore, accelerator the rate of the cure process can be varied. Use of too much hardener will reduce pot life. Here accelerator and catalyst are dangerous to mix together.

THERMOSETS

Thermoses use head to form and set the shape of the part permanently. The plastic, once cured, cannot be reformed even if it is reheated. Most structural airframe applications are presently constructed of thermo set resins.

EPOXY RESIN SYSTEMS

Epoxies are a type of thermosetting plastic resin well known for their outstanding adhesion, strength, and their resistance to moisture and chemicals. They are very useful for bonding nonporous and dissimilar materials, such as a metal part to a composite component.

In 1946, an innovative company named Ciba (now know as Ciba - Geeing Corporation) introduced a new product called —Araldite— at the Swiss Industries Fair . This was the first formal introduction of epoxy resin to the manufacturing industry. Since that introduction, Epoxy resins have become one of the most widely used resin formulas in the world Araldite is still widely used in the manufacturing industry.

Epoxy resins are among the most common matrix systems used in composite fabrication and repair because;

(1) They are extremely flexible in terms of their application. More specifically, epoxy resins can be formulated to provide rigid or flexible strength, to perform at high or low temperatures or to provide a combination of these characteristics.

(2) They exhibit good adhesive characteristics when used with a broad range of reinforcing materials, fillers, and substrates. They exhibit an extraordinary ability to completely wet a wide variety of materials and to adhesively cure together a variety of dissimilar materials.

(3) After being cured, epoxy resins are resistant to deterioration by water, acids, and bases, many chemical solvents, and UV light. They are so durable that they present a problem from a disposal perspective. There have been suggestions that discarded epoxy based composite material be ground up and mixed with asphalt to enhance the durability of roadways and at the same time dispose of an almost indestructible material.

(4) Epoxy resins are easily cured at room temperature or at slightly elevated temperatures, and they do not require exotic equipment to process. The cure process emits no volatiles or water with in terms of toxicity. These characteristics make epoxy material suitable for wet lay –up pre- preging fabric or tapes, or wet filament winding.

(5) Epoxy resins are very dimensionally stable –they shrink very little during the curing process

and are very acceptable for use as structural parts mold fabrication material, or tooling fabrication material. Epoxy resins are used in many instances to mold parts in mass production to very close tolerances.

(6) The resins exhibit the strongest adhesive characteristics of any known polymeric material. For this reason alone, epoxy resins are ideal for the fabrication of lightweight structural materials for aircraft and space vehicles.

(7) Although epoxy resins are initially more expensive than some other matrix material in the long run their superior strength ,long shelf life, and ease of use make them more economical to use for fabrication and repair than other matrix materials.

The quality of obtainable bonds is depended upon the manner in which joints are designed and the surface prepared. They may be designed for different uses; high temperature, low temperature, rigidity , flexibility, fast cure, or other characteristics, Each system is designed for a specific purpose . For example a cowling may use an epoxy resin system that withstands high temperatures, while an aileron may use an epoxy resin system made to withstand bending stresses. Both parts are made of advanced composites, but they are used for different in their chemical makeup, producing structures with different characteristics.

Just because it is an epoxy doesn‘t mean it will always work. Make sure you are using the type of epoxy resin the application calls for, For example there are two -part epoxy resins available at hardware stores. This type of epoxy resin is not used on aircraft because it may not exhibit the strength, flexibility, or moisture resistance that is needed.

The use of a high molecular weight structure attendant to the basic epoxy group makes the final cured system more flexible. These epoxy resins, known as flexibilizers, are added to aromatic epoxy resins to reduce the brittleness of the cured resin. However, the use of flexibilizers increase the flexibility of the cured epoxy resin at the expense of the tensile strength. In addition, most flexibilizers increase the viscosity of the uncured resin. There are a few curing agents that produce both flexibility and retain good tensile strength. These can be mixed in a wider range of mixing ratios than other curing agents. Thus it is possible to fine tune the curing agent for the particular application. These are less irritating to skin than some amine curing agents, but they are less resistant to chemical solvents than some other cured epoxy resins.

WORKING WITH RESINS &CATALYSTS

When working with resins and catalysts or curing agents, always follow the procedures specified in the structural repair manual it is important to mix the resin system properly. Improperly mixed resins do not provide adequate strength. Each part of the resin system is weighed before mixing –weigh resins out, don‘t mix by volume. Always mix resin and hardener before adding any filler. If the resin system requires refrigerated storage, allow each part to warm up to room temperature before weighing and mixing. A cold resin weight heavier than the same amount of a room temperature resin. Use a calibrated scale or balance to weigh the two parts of the resin to produce the proper mix. The scale surfaces or balance should always be clean.

WHEN MIXING RESIN IT IS DANGEROUS TO ADD ACCLERATOR AND CATALYST BEFORE RESIN.

Mix resins in the proper ratios. The matrix formula for most advanced composites is very exacting. A matrix improper mix ratio can make a tremendous amount of difference in the strength of the final composite. This mixing requirement will be found in the aircraft‘s structural repair manual.

Resin manufacturers will often provides convenient pre-measured packages that are combined by the user. A thorough mixing action will help to achieve maximum strength. Mix resin systems together in a wax free container. If a waxed container is used, the solvents in the resin and curing agents will dissolve any wax on the inside of the container, causing it to be mixed in with the resin. This may cause the repair to cure incorrectly or possibly not cure at all.

Mix resins for the proper amount of time. Three to five minutes is usually required to completely mix the components. Resins that are not mixed properly will not cure to the maximum strength obtainable. Do not mix the resins too fast. If they are mixed quickly, small bubbles may rise into the air and could get on your skin or in your hair. Do not be concerned if you have bubbles in the cup because they will be worked out later during the lay-up with a squeegee. Vacuum bagging further ensures that there are no trapped bubbles in the final composite.

Do not mix large amounts together. A large volume of resin and curing agent will cause an acceleration of the chemical reaction. When this happens, it starts to cure in the mixing cup, possibly becoming too thick to work completely into the fabric, the pot life, or amount of time you have to work with the resins, is also reduced. A few smaller quantity mixes will be easier to work with.

All resins cure by chemical reaction, but some generate their own heat, thus accelerating the cure. It is important to consider how long it will take to use the amount of resin that has been prepared. If the work is extensive and takes a long time, the pot life of the resin mixture may be exceeded if too much is initially prepared.

Be sure to know the resin‘s pot life before starting. This is the amount of time that the mixed resins will be workable. Some resin systems have very short pot life (15 minutes). Other have long pot life (4 hours).Pot life is not necessarily the time it is usable in the cup. The resin and fabric should be in place before the actual curing takes place. If a resin with a short pot life is used to impregnate fabric, the patches must be in place on the surface before the resin starts to cure. If the patches are allowed to sit too long them, will start their chemical reaction and become stiffer. Subsequently, when the patches are in place and vacuum bagged to cure, the chemical cross linking of the resin and the fibers may not take place as it is designed to do. The patches will have cured separately, and may not stick properly to each other or the part. Be sure to follow the mixing procedure correctly and use the mixture before the pot life has expired.

The shelf life is the time the product is good in an unopened container. The shelf life varies from product to product. If the shelf life is exceeded, the resin or catalyst must be discarded because the two components will not produce the desired chemical reaction and the cure of the part may not achieve sufficient strength. The shelf life to pre-preg materials is very important.

If too must resin is used, the part is called resin rich. Unlike transitional fiberglass work, advanced composite work is for structural applications. In this case, excessive resin is not desirable. This affects the strength of the composite by making the part brittle. It also adds extra weight, which is opposite of the reason for using composites in the first place.

A resin starved or resin lean part is one in which too little resin was used, causing the part to be weak because the matrix cannot transfer the stresses to the fibers. Sometimes you can see areas where there is more resin, which may appear as glossy, and resin. Learn areas that appear to have a whitish effect to the surface.

The correct amount of fiber to resin ratio is important to get the desired strength. In advanced composite work, a 50:50 ratio is good, however a 60:40 fiber to resin ratio is better. Remember, the fibers provide the strength, not therein.

When working the resin into the fiber care should be taken not to distort the weave of the fabric. If too much pressure is applied when using a brush or squeegee, the fibers could pull apart, changing the strength characteristic of the fabric.

Curing of the resins must also be accomplished correctly to achieve the maximum strength. Be sure to follow all manufacturers curing requirements.

Resins and curing agents can be purchased in cans that need to be weighed and thoroughly mixed together. They may also come in convenient prepackaged forms. For technicians, these are very convenient packages that eliminate the weighing process and may eliminate the mess of mixing the two components – a nice safety feature.

The resin and catalyst may be divided into separate plastic packages that are attached on one end. When ready for use, the partition that separates the resin from the catalyst is broken. Still within the package the resin /catalyst mixture can be mixed together thoroughly. When completely mixed, the corner can be cut with scissors and the resin dispensed. This saves on weighing and handling the resins, and could prevent accidents ,A disposable cartridge that stores, mixes, and applies two component materials is also available and convenient to use. They come in many sizes and can be tailored to a specific use. To use the cartridge, the seal that separates the two components must be broken with a plunger. Then the materials are mixed together by using twisting, up and down motions. The label states how many strokes are required to give a thorough mix. A needle or syringe may be installed onto the end and the resin dispensed through hit.

PRE-IMPREGNATED MATERIALS

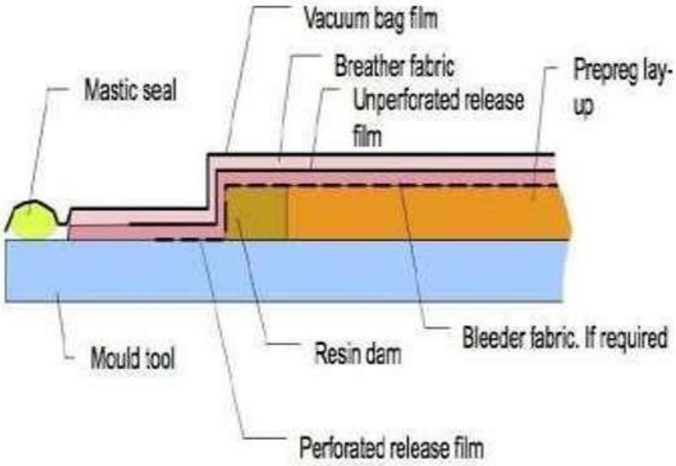


Fig. 3.23 Pre-Impregnated Materials

Pre – impregnated fabrics, or pre-pregs, are fabric that has the resin system already impregnated into the fabric. Because many epoxy resins have a high viscosity, it is often difficult to mix and work the resin system into the fabric and encapsulate the fibers. Pre-preg fabrics eliminate the need for mixing, so technicians do not have to worry about whether the proper mix ratio was used or if the proper amount of resin was applied . Pre-preg fabrics are manufactured by dipping the woven fabric into a resin solution. The resin solution has the proper amount of resin and curing agent weighed and mixed together. This fabric then goes onto a drying tower that removes any excess resin. Then a parting film may be added to one or both sides to prevent the fabric from sticking when rolled. Pre- preg fabrics come on a roll that is usually refrigerated and ready to use.

Pre-prigs can also be made in unidirectional material instead of the woven fabric. In this case, the fibers come directly from the spool of thread and are placed in the correct orientation. They are than heated on one surface while a paper with resin on it is applied to the other surface. The heat melts the resin from the paper and impregnates the threads. The paper and the threads are then squeezed together to impregnate the threads more thoroughly. The pre-prig is rolled and is ready to be used. This material should be stored properly as the two parts of the resin and hardener have already need mixed together. The plastic backing on the pre-prig material typically has a diamond pattern on the back-side. This diamond is longer in one direction than the other. The long direction of the diamond indicates the warp of the fabric. When a piece is cut away from the roll and the selvage edge is not Showing. The warp direction can easily be found by looking for the long diamonds on the pre-prig materials offer a convenience over raw fabrics in many ways.

1. The pre-prig contains the proper amount of matrix. It does not produce a resin or resin lean component if cured properly. The pre-prig contains about 50% resin before curing. During the curing process, some do this resin bleeds out of the reinforcing fibers, thus producing a structure that contains about 40% resin and 60% fibers by weight.
2. The reinforcing fibers are completely encapsulated with the matrix. During hand lay-up. If a resin system has a high viscosity, or is very thick, it is sometimes difficult to get the resin into and around each individual fiber to produce the strongest cure. This is not a problem with the pre-preg fabrics. The technician does not have to worry about distorting the fabric weave while working the resin into the fabric.
3. Pre-prig fabrics eliminate the need to manually weight and mix components. In hand lay-up the resin and curing agent must be properly weighted. If they are not weighted properly too much resin or curing agent could result in a part that will not cure properly , causing an un airworthy condition
4. In many cases, pre-prig materials produce a stronger component or repair. This is because just the right amount of matrix – to – fabric ratio has been applied and it has been mixed properly.

However, the strength of a composite repair also varies greatly upon the manner in which it is cured. Pre-prigs were invented for the use of aircraft manufactures to reduce the problems associated with completely wetting out the fabric with resin. It also saves time and reduces the problems associated with weighing and mixing the resins. Pre- prig fabrics also have disadvantages when working in a maintenance facility. Some of the disadvantages of working with pre-pregs are:

1. Many pre- prigs must be stored in a freezer. This requirement must be met. If some pre-prigs are allowed to remain at room temperature for even a few hours, the resins /catalysts start their chemical reaction and begin to cure. The term―out–of freezer life‖ is the time that the material is actually out of the freezer and is being cut or transported. During this time, the resins are warming up to room temperature and will start to cure. While in the freezer, this chemical reaction is slowed down to allow a longer shelf life. Pre-prig fabrics usually have a limited shelf life even if kept in the freezer. Some pre-prigs must also be shipped in cold storage overnight. Which adds to the expense. The amount of time out of the freezer should be carefully recorded and kept to a minimum: the allowable out of freezer time may be only a few hours. For example if a roll of pre-prig fabric is taken out of the freezer in order to cut one yard of fabric the time that the entire bolt of fabric is exposed to room temperature must be recorded, even if it _s only ten minutes . Each time the bolt is out of the freezer, the time must be recorded and added to the rest of the out-of freezer time. If the manufacturer has designated a five hour out-of-freezer life, once the accumulated time that the materials have been out of the freezer totals five hours. The fabric will no longer cure sufficiently in a repair to give the proper strength.

1.-Pre-preg material is much more expensive then raw fabric that can be impregnated with the same type of resin system. This is especially true if the material exceeds its shelf life and must be discarded. Composite components and materials have not yet been standardized. When working with metal aircraft, any manufacturer can call for 2024-T3, and you would know what type of metal to use. In composites, different manufactures use different weaves, different types of fibers, different resins, different core, materials, different adhesives, and they use them in different areas of an aircraft. If you are in changes of the composite repairs to two different aircraft with composite components you may find that the type of materials called for the aileron are completely different from a cowling. To order a whole roll of pre-prig material in one weave with one type of matrix on it would be foolish unless many, repairs are to be accomplished on the one part that used that type of fabric and matrix.

Fig. 3.24 Adhesives

Resins come in different forms. Some resins are made for laminating so they are generally thinner and can be worked into the fibers. Others are used for bonding and are generally known as adhesives because they stick parts together.

Adhesives come in many forms and can be purchased in individual cans that are weighed and mixed together. They may come in the form of a cartridge, or in convenient plastic bags. One of the most unique forms of adhesive is film form. this type has both the resin and catalyst pre- blended and cast onto a thin film of plastic. Refrigeration of the film is required because if left out at room temperature the two part would slowly start to cure. In the freezer, the curing process is slowed down , giving the film a longer shelf life. Adhesive film are used many times to help bond a pre-prig patch to a repair area. It is sometimes used when the patch covers an exposed core area and fibers. Adhesive film gives another layer of resin so the resin within the pre-prig patches does not get wicked into the dry surrounding fibers which could create a resin lean repair . The desired amount of adhesive is cut and positioned in place. Applying heat causes the resin and catalyst mixture to start curing , and the plastic backing may be hard to remove . Simply place them back in the freezer for a short time (15 second). Them the plastic backing will come off easier. The pre-prig patches are then laid over the adhesive film in the proper places and cured with head and pressure. The second part to be bonded is placed over the adhesive and cured with heat and pressure.

Forming adhesives are another type of bonding agent used with prepares materials. When heat is applied to these adhesives, they foam up and expand. These are often used to splice replacement honeycomb core segments to existing honeycomb cores. The foaming adhesive fills up the edges of the honeycomb cores. The foaming adhesives fills up the edges of the honeycomb, creating a larger surface area to bond to . In a similar manner, when installing fasteners, foaming adhesives maybe used around the area of the fastener t create more area for bonding. The adhesives come either in a roll or a sheet and are stored in a freezer. These are primarily used in conjunction with pre preg repairs because they require higher temperature to cure. In pre prig the warp direction can be found out the longer side of diamond.

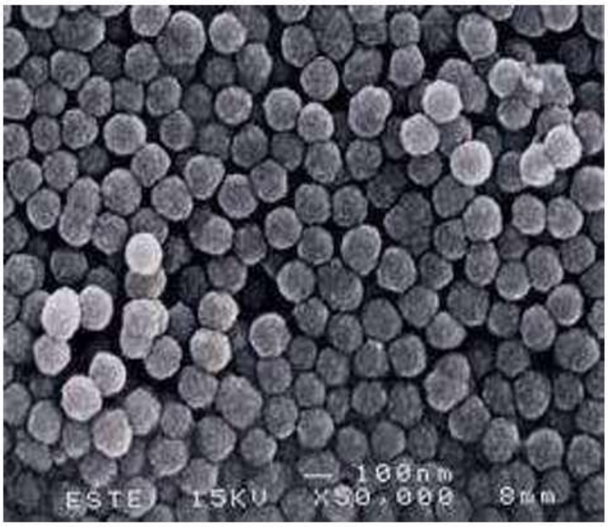


Fig. 3.25 Fillers

Fig. 3.26 Chopped Fiber

Fillers, a thixotropic agent, are materials that are added to resins to control viscosity and weight to increase pot life and strength, and to make the application of the resin easier. When filler is used as a thixotropic agent, it increases the volume of the resin making it less dense and less susceptible to cracking and lowers the weight of the material.

Fillers are inert and will not chemically react with the resin. Fillers are added to resin systems that have already been properly weighed and mixed together. The fullers are added as a percent of the total weight of the mixed epoxy resin and catalyst. The method by which the resin and fillers should be mixed is outlined in each aircraft‘s structural Repair Manual.

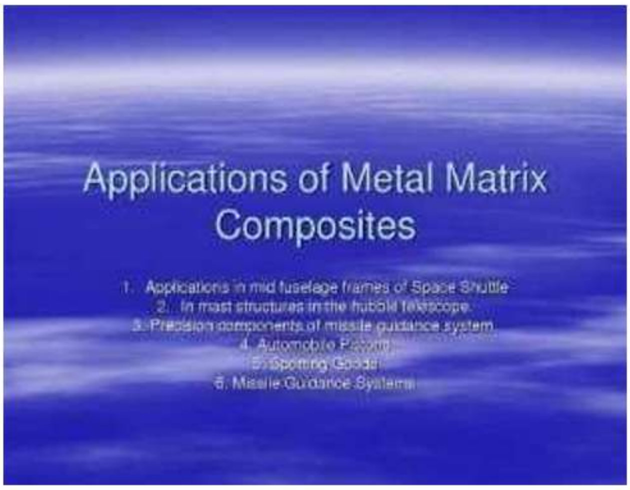
Filler material can be in the form of micro balloons. Chopped fibers, or flox. Micro balloons are small spheres of plastic or glass if plastic spheres are used they must be mixed with a compatible resin system that will not dissolve the plastic from which they are made. Glass micro balloons are more common because the solvent action of the matrix does not affect them. Micro balloons are used primarily as a thixtropic agent. Micro balloons are used primarily as a thyrotrophic agent. Micro balloons don‘t add strength the way chopped fibers or flox do.

Chopped fibers and flox can also be used as a filler material. Chopped fibers can be any type of fiber cut to a certain length (1/4-to ½-inch are common).Flox is the fuzzy fibers taken from the fabric strands. These are added to the mixed resin system when added strength is desired. For example , if a hole is accidentally drilled in the wrong place in a composite structure , the hole may be repaired by filling it with a mixture of resin and fibers . The mixture gives more strength than pure resin in the final repair . If the hole were to be filled with pure resin in the final repair. If the hole were to be filled with pure epoxy resin, it might be too brittle and add excess weight . Before filling any holes, The structural Repair Manual should be consulted to determine the appropriate repair for the type of part being worked on.

GLASS FLOX EPOXIDE MIX

This data sheet gives details of the mixing amounts for glass flox epoxide mixture

MIXTURE



Applications of Metal Matrix Composites

1. Applications in mid fuselage frames of Space Shuttle
2. In mast structures in the hubble telescope.
3. Precision components of missile guidance system
4. Automobile Pistons
5. Sporting Goods
6. Missile Guidance Systems

Fig. 3.27 Metal matrix composites

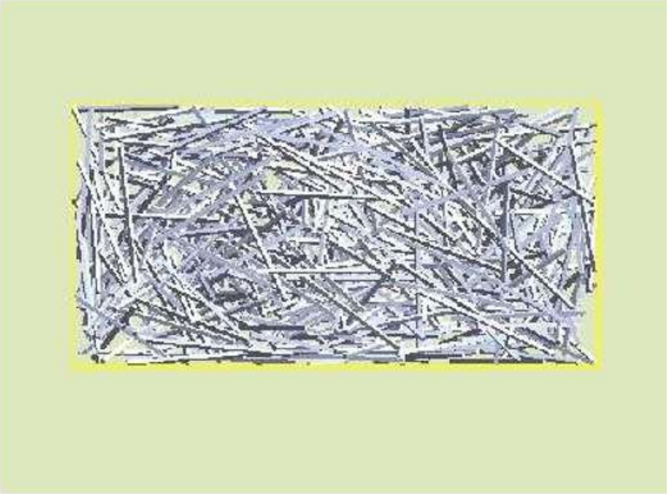


Fig. 3.28 Metal Matrix Composites

The matrix material does not always have to be in a plastic or resin form – it can be metal. The metal might be aluminum. Titanium or steel. The composite is formed when chopped fibers or fiber strands are mixed into the molten metal. The mixture is then formed molded, rolled, or extruded in the usual way. The fibers give extra reinforcement to the metal, lending more strength without adding weight. The fibers may dissipate heat more quickly, thus causing less wear in the part or it may more flexibility to the part.

Metal matrix composites are still in the experimental stage and are not found on structural airframe parts at this time. Several companies are doing research on metal matrix composites, and these structures will probably be seen in the near future. Some power plants, however, are being manufactured with ceramic fibers mixed with ceramic fibers and metal to allow heat to dissipate quicker, causing less elongating and distortion to the blade shape. On reciprocating engines, ceramics are being mixed with metals used for cylinder walls, which improves heat dissipation and reduces wear.

CORE MATERIALS

Core material is the central member of an assembly. When bonded between two thin face sheets, it provides a rigid, lightweight component. Composite structures manufactured in this manner are sometime referred to as a sandwich construction. Two popular core structures are foam and honeycomb.

The core material gives a great deal of compressive strength to a structure . For example , the sheet metal skin on a rotor blade has a tendency to flex in flight as stress is applied. This constant foam core, or honeycomb, will eliminate most flexing of the skin because the core is uniformly stiff throughout the blade

If made of sheet metal with metal ribs, the skins will twist and flex in the areas where there is no support. The solid core resists the bending and flexing of the skin , greatly increasing its life span . The core could be honeycomb or foam , and the result would be about the same.

Core materials may also come in wood. Honeycomb has the greatest strength- to - weight ratio, But foam is usually more forgiving . If a foam core is damaged , its inherent resiliency causes it to have what is commonly referred to as a memory , which returns it to about 80% of its original strength . Most honeycomb cores have little resiliency.

This type of core structure has the shape of natural honeycomb and has a very high strength –to – weight ratio. Characteristics of honeycomb cores, when used in sandwich core construction, have
high strength –to- weight ratio, a high compression strength a uniform distribution of stress , rigidity thermal and acoustical insulation and are fire resistant. Honeycomb cores may be constructed of aluminum, Kevlar, carbon, fiberglass, paper, Nomex or steel. The most common types of honeycomb used in aviation manufacturing are aluminum and Nomex. Nomex, manufactured by DuPont, is widely used as an advanced composite core material. Aluminum honeycomb, which may or may not be considered a composite by the manufacturer, is usually found with aluminum skins.

It is common to find honeycomb cores laminated with either metal or composite skins.

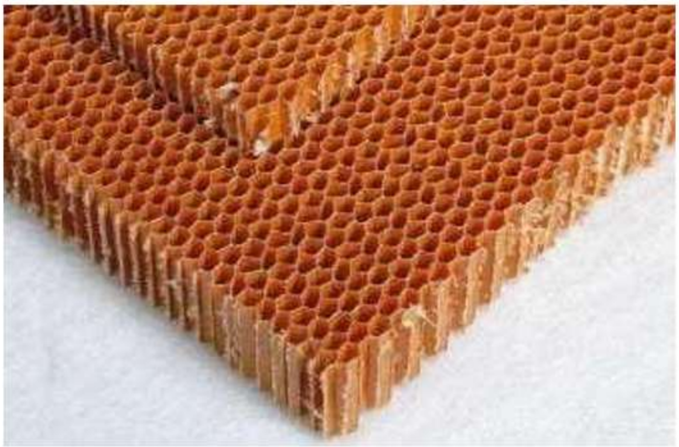


Fig. 3.29 Honey comb

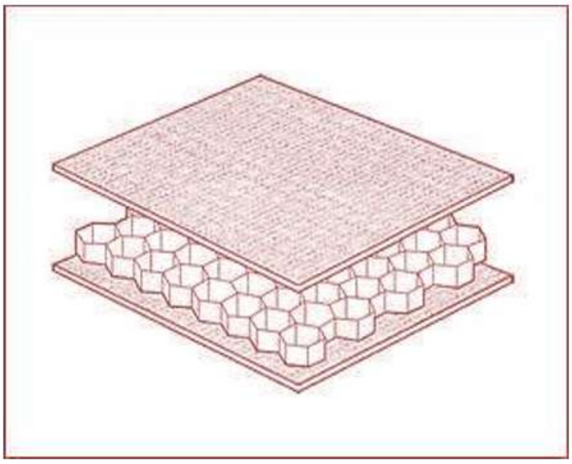


Fig. 3.30 Sandwich construction

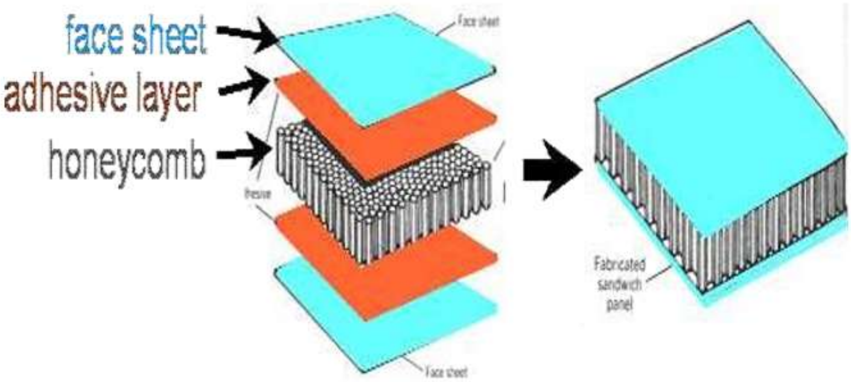


Fig. 3.31 Different part of Sandwich construction

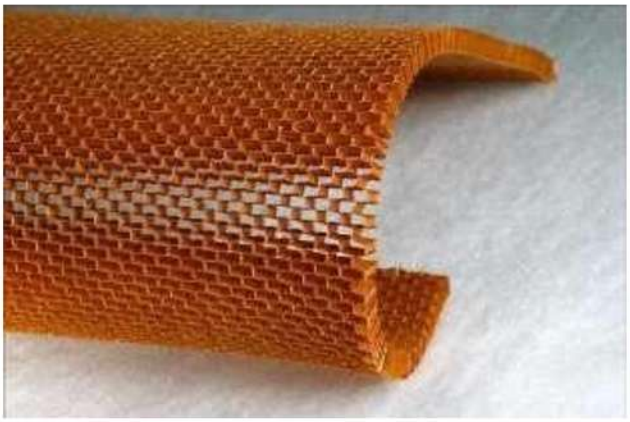


Fig. 3.32 Over expanded core

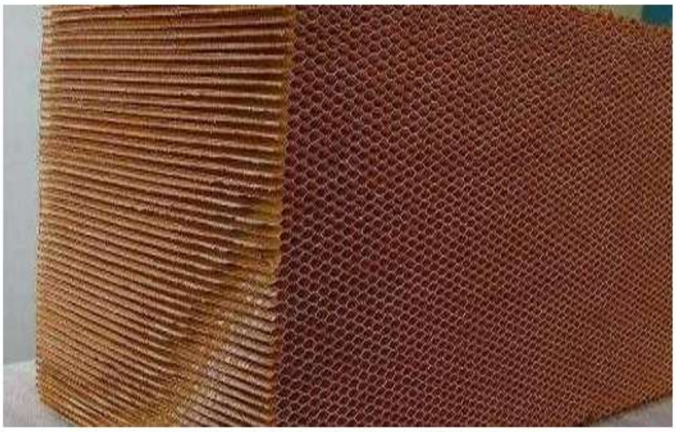


Fig. 3.32 Flexi core

Honeycomb cores are made by crimping the core material into place. The pattern has what is known as a ribbon direction. The ribbon direction can be found by attempting to tear along one side of the honeycomb. If you are tearing in the ribbon direction of the tear is parallel to the direction of the ribbon. The honeycomb will not tear except in the ribbon direction of the replacement honeycomb core with the ribbon direction of the original part.

When using honeycomb for a repair, the same type of honeycomb that was used in the original structure should be used for the replacement material. Identify the honeycomb by the specific type (aluminum, Nomex) in a certain grade (aerospace), cell size in inches (1/16,1/8), the density in pounds per cubic foot (2.0,3.0), the thickness in inches (1/2,1),and the cell shape (hexagon, over expanded). These should be listed in the Structural Repair Manual under the types of materials to be used for a specific repair.

These are different cell shapes in honeycomb, although the hexagon shape is the most common for flat or slightly curved areas. An over expanded cell shape is longer on one side of the cell and is used to bend around single curves. A cell that has a hat shape is used when the material is to be formed around compound curves. To maintain the strength of the component, always use the correct type of honeycomb cell shape in there pair.

Honeycomb can be joined together with a foam adhesive, usually in the form of a tape. The foam adhesive is laid between the parts to be joined and heated to cure. During the curing process, the foam expands into the crevices of the honeycomb core.

FOAMS

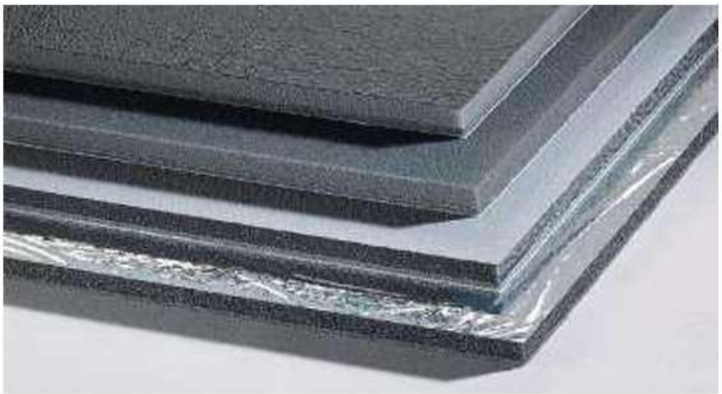


Fig. 3.33 Foams

There are many different types of foams available depending on the specific application. There are different densities and types of foams for high heat applications fire resistance, repair foams, structural foams, etc. When using foams in the repair operation it is important to use the proper type and density.

In figure 4-7 , the advantages of a sandwich structure can be shown by comparing four layers of solid fiberglass laminate to a foam core sandwich structure that is four times as thick. This part has two layers of fiberglass on top and two layers of fiberglass on the bottom of the foam. The part becomes 37 times stiffer than the laminate and ten times stronger with only a 6 percent increase in weight . This is not an excessive amount of additional weight inex change for the amount of strength and stiffness gained by using the foam core.

Styrofoam

Fig. 3.34 Styrofoam

Styrofoam is used commonly on home-built aircraft and should be used only with epoxy resin. Polyester resin will dissolve the Styrofoam. Do not confuse aircraft quality Styrofoam with the type used to make Styrofoam cups. The Styrofoam used in cups has a large cell configuration and cannot be used for structural applications. The type of Styrofoam used to make aircraft components is much stronger. To form the desired shape, Styrofoam can be cut with a hot wire cutter, a tool that uses a heated wire to cut material. The tool is typically homemade and used in constructing home built aircraft. To make cuts a template is attached to each end of the foam stock. The wire is then heated and runaround the template. Because the wire is held against precut templates, hot wire cutting is deal for making smooth, curved surfaces.

Fig .3.35 Urethane

This foam can be used with either epoxy or polyester resin Urethane cannot be cut with a hot wire cutter in the way Styrofoam is cut because a hazardous gas is created when urethane is subject to high temperatures. Instead of using a hot wire cutter, urethane can be cut with a number of common tools. Knives cab is used to get the rough shape, which can then be sanded with another piece of foam to the desired size and shape.

Poly Vinyl Chloride foam is used with either polyester or epoxy resins. It is safe to cut this material with a hot wire cutter.

STRUX (ALSO KNOWN AS CELLULAR, CELLULOSE ACETATE)

Strux foam material is used to build up ribs or other structural supports.

WOOD CORES

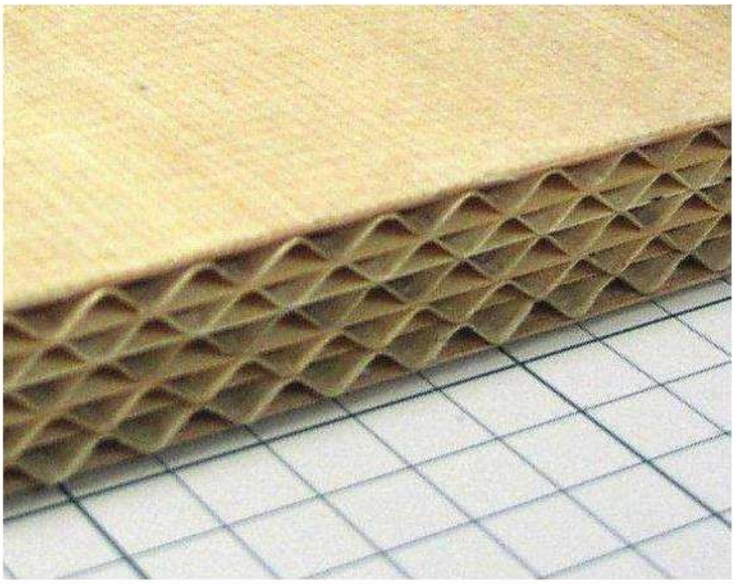


Fig. 3.36 Wood Cores

Balsa wood or laminations of hard wood bonded to laminates of high strength materials are being used for some composite construction .Monolithic carbon composites are being used increasingly to produce airframe structural components. These include floor beams, stabilizer spars, ribs and skins, flight control surfaces, cowlings and even wing box components and the rear pressure bulkhead of the Airbus A380. Monolithic components are usually formed in a mold. As well as integral stiffeners, much of the strength is obtained by the ply orientation of the cloth. Woven cloth has greater rigidity in one direction, so by laying-up the cloth plies in set Directions, the bend and twist properties of a component can be controlled. This is determined Directions, the bend and twist properties of a component can be controlled. This is determined during the design of the component and must be observed when any repairs are carried out

The advantages of monolithic structures include weight reduction compared to conventional construction, due to the reduction in the number of parts and the absence of fasteners, r resistance to corrosion and high fatigue strength To ensure proper adhesion and optimum strength and weight, all composite fabrication and repair must be completed in a controlled environment. The work area must be free from dust, oil and grease with adequate air extraction and filtration for the removal of fumes during cleaning and cure, and dust during sanding processes. Humidity and temperature must be controlled and kept within acceptable levels.

The cure cycle must be carried out with adequate heat and pressure on the structure. It is usually necessary to ensure the temperature is raised, or "ramped-up" at a set rate (degrees per minute), in a set number of steps (to ensure even temperature soak throughout the structure) and held for the correct "dwell" time and temperature. Ramp-down is also important. These parameters may be controlled manually, or by a computer based Hot Bonder. The Bonder will also produce printed and digital records of the cycle which would otherwise need to be plotted by hand. Heat may be provided by lamps or electrical mats. It is monitored by thermocouples which are situated as close to the bond as possible at several locations around the structure to check for average temperature and localized hot or cold spots. The thermocouples may be connected to a bonder or a hand held thermometer. Heat lamps may be adjusted manually, moved toward away, to regulate the temperature. A bonder will automatically control the temperature by regulating the current supplied to heater mats or lamps.

MANUFACTURING

This discussion of composite manufacturing techniques is not intended to be a comprehensive treatment of the subject. There are many books available on the subjects of composite manufacturing and engineering. The subject of composite manufacturing is addressed herein with the purpose of familiarizing the reader with those methods by which composite structures are manufactured so that when a repair is required, some of the same techniques can be used to restore a good measure of the original structural integrity. From the manufactures‘perspective, composites represent cost effectiveness. Many case histories show an average 20% cost reduction when composite assemblies are used to replace the metal counterpart. The key word in these comparison disassemblies.

There are three primary factors which are considered I an analysis of manufacturing costs:

1. Materials costs
2. Fabrication time
3. Assembly time.

Advanced composite materials cost five to ten times more than aluminum. Fabrication time, i.e. the

time required to form the final shape, is about the same for aluminum or composites. In some instances, composites require more fabrication time. The big difference between composites and aluminum lies in the assembly time.
Composite structures can be made in very complicated shapes. Consequently, stiffeners, ribs, lugs, beam, etc. Can be molded together as part of the fabrication time, it almost eliminates the assembly time. Since assembly time typically is four to five times greater than fabrication time in aluminum work, the net result is a major saving in time. In addition, an integrated fabrication requires substantially fewer numbers of fasteners, such as rivets, nuts and bolts than the assembled aluminum counterpart.

The same characteristics that make composites advantageous to use in manufacturing also require a more precise repair procedure once they are damaged. A part that is composed of many metal subassemblies, such as a wing, can be repaired by removing and replacing discrete subassemblies, e.g. skin panels and ribs. Since the composite counterpart may be molded as a single unit, with few or no subassemblies, damage must be corrected with a true repair rather than a replacement of sub assemblies.

Composite are becoming increasingly cost effective as the material and manufacturing technologies mature. When designing with composite materials the weight savings are the primary pursuit, however, the composites also lend themselves well to the formation of complex, aerodynamically contoured shapes. The parts do not have to be flat but can be smooth, sweeping contours, which would be difficult and expensive to fabricate from composite materials.

HEAT & PRESSURE

Most manufacturers of composite structures augment the strength of the finished product by applying head and pressure to the matrix/fiber mix as it cures. This accomplishes several things:

1. The heat and pressure facilitate the complete saturation of the fiber material.
2. The pressure has a tendency to squeeze out excess resin from the reinforcing fibers so that a more even blend of fiber and matrix are also eliminated when pressure is applied.
3. The heat serves to accelerate the curing process of the matrix, in some instances, high temperature is required to affect a cure the matrix formula.

MANUFACTURING PROCESS COMPRESSION MOLDING

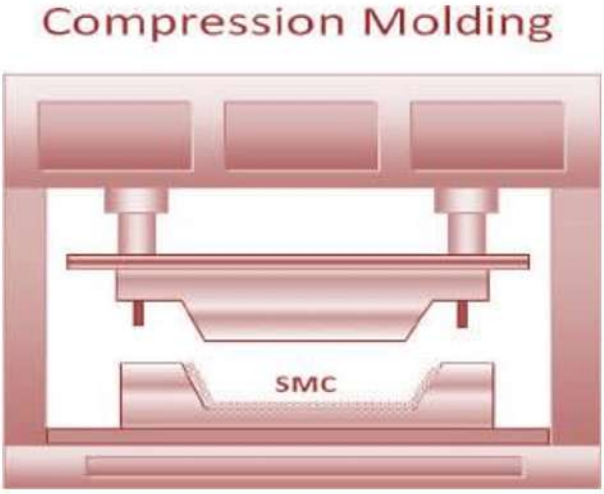


Fig. 3. 37 Compression molding

Compression molding is a manufacturing process that uses a male and female mold. The reinforcement fabric is wetted with a matrix or a pre-peg material. it is laid into a female mold and a male mold is used to form the shape of the part. If a core material is used, the fabric is wrapped around the core of the desired shape. Again, the two sides of the molds are used to apply pressure and give the part its final shape. The component cures by heating the molds to a specific temperature for a specified amount of time.

Two commonly used heating methods with compression molding are accomplished by circulating heated oil through the mold or the use of electric filaments which are imbedded into the mold. Another option is to place the entire mold assembly into an oven. The objective is to ensure an even, carefully controlled distribution of heat. Because composites start out as reinforcing fibers (cloth) and a liquid (uncured matrix material), the only limitations on the shape of a molded component are those limitations associated with the mold itself. Once a mold has been produced, it can be reused to economically turn out a very large number of precision formed parts.

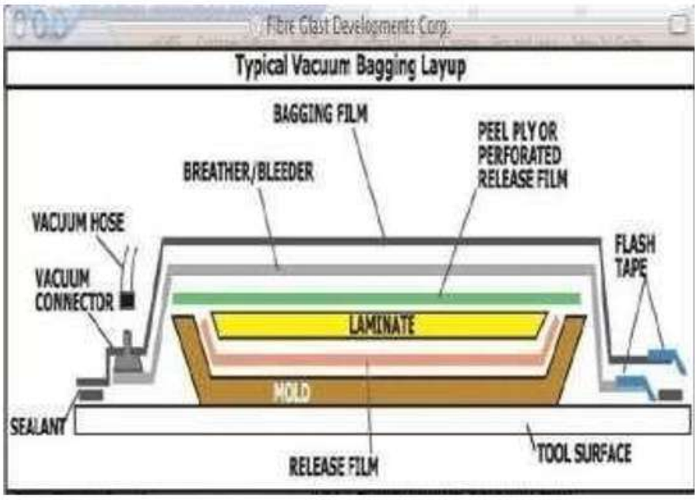


Fig. 3.38 Vacuum Bagging

With this technique the object which is to be cured is placed into a plastic bag and the air is then withdrawn by the use of a vacuum source. When the air is evacuated, pressure is applied to the component by the surrounding atmosphere. A good vacuum source for composites will pull about 28 in. Hg at sea level, which results in nearly 14 pounds per square inch pressure being applied to the surface. The vacuum bag technique can be used in combination with molds, wet layup and autoclave curing. This method applies a very uniform pressure to somewhat complicated shapes and can accommodate moderately large objects. Vacuum bagging is the most commonly used method to apply pressure for composite repairs.

Both compression molding and vacuum molding have the advantage of distributing the matrix evenly throughout the reinforcement. This helps to eliminate air bubbles and results in a seamless structure. It is easier to fabricate and usually stronger than a metallic counterpart.

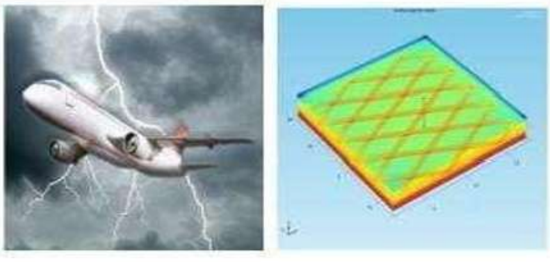


Fig. 3.39 Lightening Protection

Frequently, in the manufacturing process, some form of lightning protection must be used. It is important for a technician to be able to identify the type of protection used and able to repair the component with the lightning protection intact. Aircraft require electrical contact between all metallic and composite parts In order to prevent arcing or fiber damage. Aluminum is used to provide a conductive path for the dissipation of the electrical energy. The aluminum may be provided in a number of ways depending on the manufacture of composite, when lightning hits an aircraft it needs is aluminum or composite, when lighting hits an aircraft it needs a path for the electricity to flow through. On an aluminum skin the electricity will flow through the skin and discharge out the static wicks. Since composites do not conduct electricity, lightning protection has to be built into the component. If there is no lighting protection in the composite and the lightning exits through the composite component, the resins in the composite will evaporate, leaving bare cloth.

Carbon/graphite composite was at first believed to conduct enough electricity to dissipate the electrical charge, but this was later found not to be true. Aluminum lightning protection may be found in carbon/graphite parts. A barrier, such as a layer of fiberglass, should be used to prevent a galvanic potential between the carbon/graphite and aluminum.

ELECTICAL BONDING

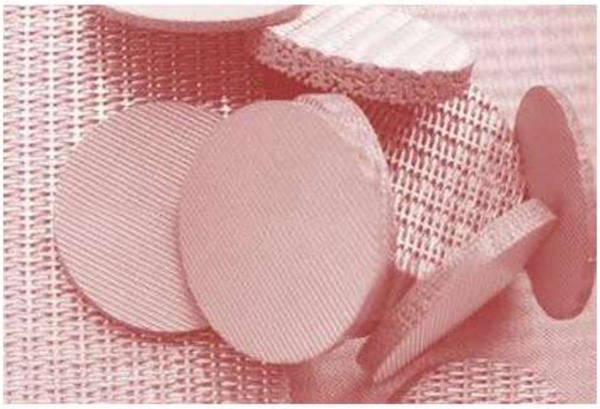


Fig. 3.40 Electrical Bonding

Different manufacturers use different methods to dissipate the electrical charge on composite structures. These are a few methods.

1. Aluminum wires may be woven into the top later of composite fabric. This is usually done with fiberglass or Kevlar and nor with carbon/graphite.

2. A fine aluminum screen may ne laminated under the top layer of fabric. If this method is used on a carbon/graphite component, it is usually sandwiched between two layers of fiberglass to prevent a galvanic potential.

3. A thin aluminum foil sheet may be bonded to the outer layer of composite during the manufacturing process.

4. Aluminum may be flame sprayed onto the component. This is molten aluminum that is sprayed on like paint. Some composite to allow the dissipation of the electrical charge out to another metal component or static wick.

TYPES OF DAMAGE

Cosmetic defects

A cosmetic defect is a defect on the outer surface that does not involve damage to the structural reinforcing fibers. Cosmetic damage is often caused by chipping or scratching during handling. Since it does not affect the strength of the part, and usually is repaired for esthetic reasons. IF there is damage to the top fiberglass layer of structural components made of either aramid or carbon/graphite, it may be considered negligible or cosmetic damage.

IMPACT DAMAGE

Fig. 3.41 Impact Damage

Impact damage occurs when a foreign object strikes the part. The degree of damage may range from slight to severe. The most common cause of impact damage is careless handling during transportation or storage, r standing parts on their edge without adequate protection.

The thin face sheets on a sandwich panel are very susceptible to impact damage. An area that has been subjected to impact damage should also be inspected for delimitation around the impacted area.

Nicking, chipping, cracking or breaking away pieces of the edge or corner can also be caused from improper handling.

DELAMINATION

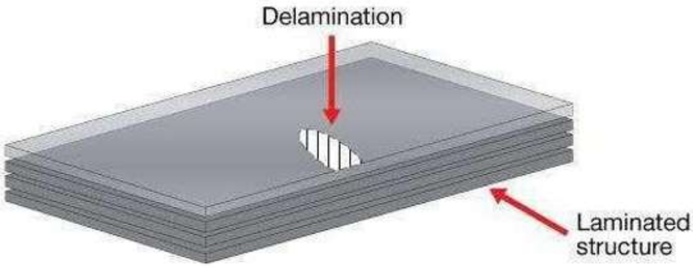


Fig. 3.42 Delamination

Delamination is the separation of fabric layers of material in a laminate. Delaminating can occur with no visible indications often accompanies other types of damage, particularly impact damage. This damage occurs as the result of several causes, including impact, moisture in the fabric, or lightning strikes. Another type of Delamination is an un bond, or as it is sometimes called a disband. A disband occurs when the skin of a sandwich structure becomes separated from the core.

In those instances in which damage is visible, it is best to assume the damage has radiated into areas that exhibit no visual damage.

An air pocket between layers of fabric may also be the result of improper bonding of the composite. This may occur during manufacturing or during a repair operation. If this is the case, it may have been caused by any of the following;

1. Improper resin/catalyst
2. Improper mixing or weighing of the two matrix components
3. Inadequate amount of pressure or heat during the cure cycle
4. Improper cleaning of dirt, grease, or foreign materials on the surface to be bonded times they may require more advanced methods of nondestructive inspection. A crack may be just in the top paint or matrix layer, and not the fiber material and into the core yet appear to be just in the top surface. A thorough inspection should be made to determine the extent of each crack.

CRACKS

Fig. 3.43 Cracks

Cracks can occur in advanced composite structures just as in metallic ones. Sometimes they can be detected visually, other

HOLE DAMAGE

Fig. 3.44 Hole Damage

Hole may occur from impact damage, over torque fasteners or as a result of fastener pull through.

Holes drilled in the wrong location, wrong size, or wrong number of holes drilled can also be classified as hole damage. Hole caused by a lightning strike may burn off resins, leaving bare cloth.

Tiny holes, known as pin holes, in the skin surface are not easily detected, however, they could lead to more extensive damage. If moisture is allowed to get into the core structure, along with the airflow over the part, it could cause a small delamination, which could grow into a very large delamination.

INSPECTION METHODOLOGY

Areas on the aircraft that are susceptible to damage, such as leading edge made of thin face sheets over a honeycomb panel, should be inspected more often than areas that are more protected, such as the vertical stabilizer. Visual inspection to these areas should be accomplished periodically, while more in depth inspection should be done at regular overhaul intervals.

Many times the inspection method requires that the component be removed from the aircraft in order to be inspected correctly. This type of inspection is usually accomplished at the time of the aircraft's overhaul. Between overhaul inspections visual inspection usually is adequate. Each manufacturer calls out a specific test method depending on the location and type of structure.

VISUAL INSPECTION

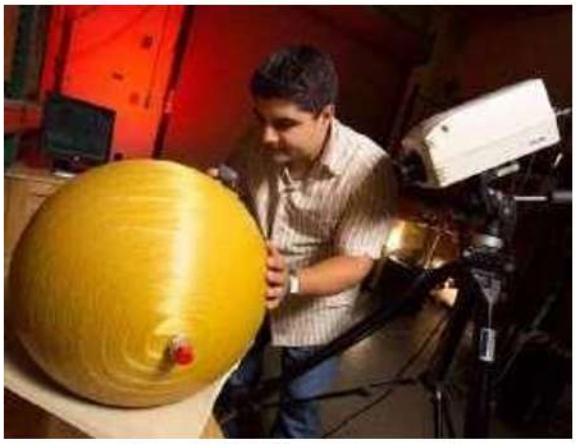


Fig. 3.45 Visual Inspection

Visual inspection is used to detect cracks, surface irregularities (from an internal flaw), and surface defects such as Delamination and blistering. A good visual inspection usually detects surface flaws. A light and a magnifying glass are useful in detecting cracked or broken fibers. A small microscope also is helpful in determining whether the fibers in a cracked surface are broken or if the crack affects only the resin .Delamination may sometimes be found by visual inspection if the area we examined at an angle with a bright light shown on the surface. The delaminated area may appear to be a bubble, or an indentation in the surface. Use a coin tap test if you suspect areas of delamination.

COIN TAP TEST

Fig. 3.46 Coin Tap Test

One of the most important tools used to detect internal flaws or delamination's is a coin tap test. Use a coin or rounded edge steel washer, as shown in Figure 11-3 to tap lightly along a bond line or area suspected of having the flaws. Listen for variations in the tapping sound. A sharp solid sound indicates a good bond, but a dull thud indicates bond separation.

However, changes in the thickness of the part, reinforcements, fasteners, and previous repairs may give false readings. Whenever damage such as a delamination that cannot be seen visually. Much of the time if there is a hole, crack, or other damage, there is also delamination around the area. This type of test only works on one side of the component at a time. The opposite side of the component must also be coin tapped to find delamination.

ULTRASONICINSPECTION

Fig. 3.47 Ultrasonic Inspection

Fig. 3.48 Ultrasonic Machine

For internal damage inspection an ultrasonic tester may be used. Ultrasonic testing uses a high frequency sound wave as a means of detecting flaws in a part by bearing a high frequency wave through the part and viewing the echo pattern (pip) on an oscilloscope. By examining the variations of a given response, delamination, flaws, or other conditions are detected. Some ultrasonic equipment cannot differentiate between a honeycomb cell and a void, resulting in an unreliable reading. A new type of ultrasonic machine has been recently developed to detect flaws in skins over honeycomb cores. This equipment only works on one kind of material, carbon/graphite, and does not work on others such as Aramid. Ultrasonic equipment may be ineffective for detecting some types of damage on some composite structures so make sure the equipment you are using can be used on the type of component you are testing.

There are three types of com manly used ultrasonic testers:

A-SCAN, B-SCAN, AND C-SCAN.AN A-SCAN is a time versus Amplitude display read from left to right. A known reference must be scanned first. Then the height of the specimen pip is compared to the height of the pip on the reference. A B-SCAN takes a cross- sectional view of the material being tested a uses an oscilloscope screen to compare the sample. A C-SCAN imaging shows the shape, size, and location of the damage, but does not show the depth.
Ultrasonic inspection methods require specialized training to provide reliable results.

THERMOGRAPH

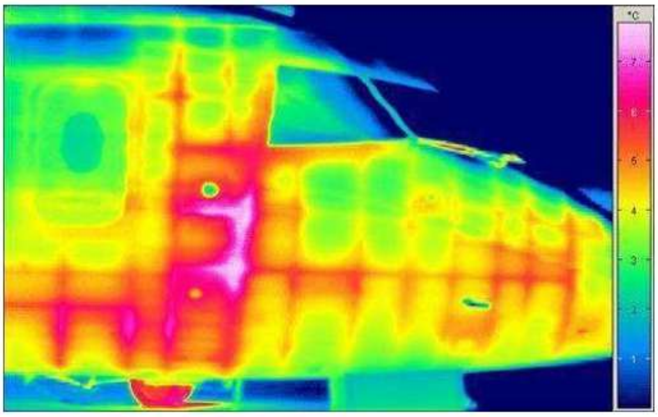


Fig. 3.49 Thermograph

Thermography locates flaws by temperature variations at the surface of a damaged part. Heat is applied to the part then the temperature gradients are measured using an infrared camera or film. On the film, a material's thickness varies and shows up as different colors because of the heat buildup in different areas of the material. Thermography requires knowledge of the thermal conductivity of the test specimen and a reference standard for comparison purposes.

LASER HOLOGRAPHY

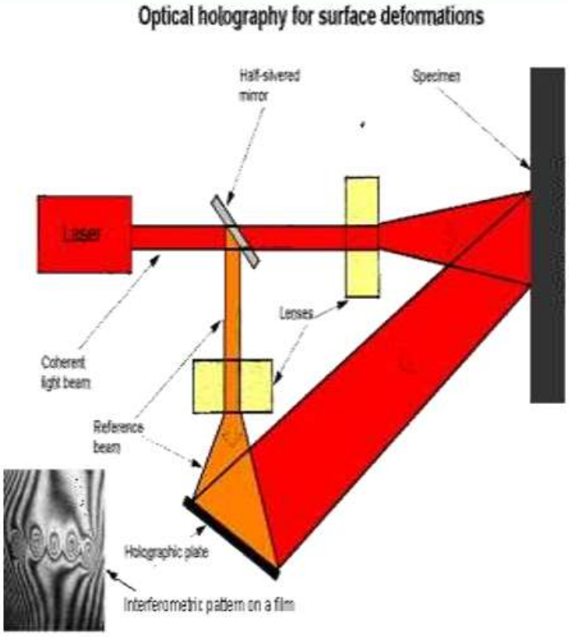

Optical holography for surface deformations

Fig. 3.50

Laser holography calls for the suspect part to be heated and then photographed using a laser light source and a special infrared camera film system. It is used to detect disbands or water in honeycomb and impact damage. Laser holography is quite expensive to use so at these only manufacturers and very large airline maintenance facilities use the process.

RADIOGRAPHY

Fig . 3.51 Radiography

Radiography can be used to detect cracks that cannot be visually detected, both internally and externally. Radiography also detects water inside the honeycomb core cells. It is useful in detecting the extent of the damage that cannot be visually detected. Again, this type of testing is used only by manufactured and large airlines. These facilities test the manufactured components to see if the ply orientation is correct , and that matrix cracks , delamination subsurface damage , resin content (resin rich or starved). And porosity can all be seen. This is helpful to the manufacturers so they can adjust their method of manufacturing to get the perfect part.

HARDNESS TESTING

After a repair has cured a hardness tester, such as a Barcol tester, can be used to determine whether the resins have reached their proper strength. A special chart is used to interpret the results for different type of resins and pre-prigs. Hardness testing does not test the strength of the composite, only the matrix strength.

DYE PENETRANT

Dye penetrant is used successfully for detecting cracks in metallic surfaces; however, it should not be used with advanced composites because if it is allowed to sit on the surface, the wicking action of the fibers may take in the dye reentrant and would no longer bond to new material. The entire effected area would have to be removed before new patches could be applied. This, in effect, could extend the damage to the size that would make the partnon-repairable.

TYPES OF REPAIRS

There are many composite repairs for various parts of an aircraft that are detailed in the appropriate Structural Repair Manual. That repairs discussed in this chapter are only a sampling of the most common repair, and many repairs are simplified for training purposes. A repair procedure described in this book may resemble a repair in a SRM, but depending on the aircraft ,and the manufacturer, different materials and resin systems may be used. If you understand the basics, and resin system may be used. If you understand the basics and can apply the different materials called for in the Structural Repair Manual, you can master composite repairs. In any repair situation, the SRM for the aircraft should be consulted before performing any repair procedures.

Repair may fall into one of four types:
1. Bolted on metal or cured composite patches
2. Bonded on metal or cured composite patches
3. Resin injection
4. Laminating on new repair plies

The bolted and bonded on surface patches are not preferred because the repair may not restore the part‘s original strength. A patch that is bolted or bonded above the surface of an external part will also cause aerodynamic changes. If the part is a rotor blade, a surface repair could cause an undesirable flutter and concentrated load stresses. These induced stress loads may prematurely pull out the blind fasteners that attach the repair.

Bolted and bonded on surface repairs may be useful for emergency field repairs where the proper equipment, tools, and materials are not available. Such repairs are many times considered to be only temporary.

Resin injection is used to fill holes or voids. This type of repair is accomplished simply by using a needle and syringe to inject resin into the void of a damaged area. Most manufacturers use this type of repair only on nonstructural parts or parts that are not subject to a great deal of stress. The injected resin repair does not restore very much strength and in some cases may actually cause the Delamination or damage to expand.

The most reliable type of repair is laminating on new repair plies. This involves removing the damaged plies and laminating on new plies of the correct material.

REPAIR FAILURES

All repairs should be performed correctly based on the type of damage and the function of the part on the aircraft. Some of the most common reasons for a repair to fail are:
1. Poor surface preparation.
2. Contamination of fabric or other materials.
3. Incorrect measuring and mixing of the resin system
4. Incorrect cure time incorrect temperature or inappropriate temperature rise and drop.
5. Inadequate pressure

TYPICAL REPAIR PROCEDURES

The following repair procedures are outlined to illustrate some of the various techniques and procedures commonly used for repairing composite structures.

Note: - All repair procedures in this book are for training purpose only. Before any repair is made to an aircraft, consult the structural repair manual for the type of aircraft involved. The following repairs are only example repairs and are provided for training purpose only.

MECHANICALLY-FASTENED REPAIRS WITH PRE- CURED PATCHES

When the proper facilities, or curing and bagging equipment are not available for on-line work, a pre-cured patch inserted with blind fasteners may be used. This type of repair usually does not give the maximum strength. Because it is not a flush repair, it may cause vibration when performed on critical parts. This type of repair may be considered a temporary repair until the damage can be scar fed down and the patches correctly laminated on with heat and pressure.

Many times these repair are performed with common repair materials such as sheet metal plates and rivets. If composite patches are required, kits with pre-cured patches may be available.
Pre-cured patches come in several sizes: two –inch, three-inch, and four –inch. These patches were produced to have the fibers of each layer in the correct orientation. Such a patch may have a peel ply layer that indicates the orientation in which it should be laid into the routed out repair.

Some manufactures offer various sizes of core material that is bonded to pre-cured laminates. These pre-made patches are available so the technician can simply route out the damaged area and insert the core and laminate patch. This type of repair may have a type of adhesive pre-applied to help it bond.
Usually the patch uses some type of mechanical blind faster that is drilled through the patch into the surface of the original part to hold the patch in place while it is further stabilized with blind fasteners. The problem with using blind fasteners in a core structure is that they have a tendency to crush the core structure. This may cause the core to delaminate from the plies. Again, this type of repair may be considered a good temporary repair.

COMPOSITE SKIN REPAIR AT RIB LOCATIONS

Fig. 3.52 Composite Skin Repair At Rib Locations

This repair uses an aluminum doublers fastened with blind rivets to a composite skin for reinforcement over a damaged rib area.

1. Remove surface finish.
2. Remove as much of the damaged skin as possible, without causing further damage to the skin or

rib.

3. Clean area with solvent.
4. Fill in removed skin areas with a potting compound.
5. Use aluminum doublers extending two inches past the edges of the damage. From the aluminum doublers to conform to the shape of the part.
6. Drill rivet holes in aluminum sheet and countersink on one side. Rivet holes should be spaced evenly at approximately one-inch spacing and close to the rib.
7. Abrade the surface of aluminum with a Scotch rite pad fir bonding to the composite.
8. Prepare adhesive and apply to composite skin and aluminum doublers.
9. Position doublers over damaged area and insert fastener.
10. Clean up excess adhesive that squeezes out around doublers.
11. Finish per manufacturer's instructions

DAMAGE TO ONE FACE AND CORE (POTTED REPAIR)

Fig. 3.53 Damage to One Face and Core (Potted Repair)

The following type of repair is similar to an older type of fiberglass repair is similar to an older type of fiberglass repair that calls for the damaged core to be routed at a vertical angle. This is a problem because the plug can pop out if the repaired part flexes during flight.

This is no problem if the repair is done to nonstructural parts. News advanced composites however, are commonly used for structural applications. For example, if a plug repair should pop out of a control surface, it could aerodynamic flutter and a subsequent loss of control. Consequently, to prevent a catastrophic failure, it is critical that any structurally repaired part be performed correctly.
One of the primary differences between the composite repair tend the fiberglass repair is in the way the repair plug is retained in the routed hole in the core. The composite repair calls for the damaged core material to be undercut with respect to the retain the repair plug during the flexing of the surface. In addition, the composite repair utilizes an overlap patch to further increase the strength of the repair.

1. Open up the puncture with a drill or router to remove the ragged edges and broken fibers.
2. Clean out crushed core and undercut core approximately 125inch. March the outline of the overlap plies on the part.
3. Prepare the surface.
4. Clean out sanding dust and vacuum the hole.
5. Apply foam filler by pouring or by using a spatulato fill up the hole. Agitate the foam to displace air pockets and fill the cavity. Allow the foam to cure.

6. Cut the repair patches to size allowing an overlap in all directions beyond the edge of the hole.
7. Prepare the bonding patches.
8. Apply pressure and cure.
9. Refinish.

DELAMINATIONS

Delamination occurs when the laminate layers become separated or when the plies separate from the core material .Delamination is sometimes a delamination can be detected by shining a light over the part and looking at the damaged area at an angle. The damage can be recognized as a bubble or an indentation.

Internal delamination is the separation of plies that do not extent to the edge or a drilled hole area. It is important to properly assess the extent of an internal delamination Using the appropriate NDI method .if the delamination is over a core area, the might fill up the core and not help sealing of the skin .in excessive cases, they might be delaminated even further because of resin injection. if you perform a resin injection ,use a low viscosity resin. And apply a pressure to the area so the skin attaches to core.

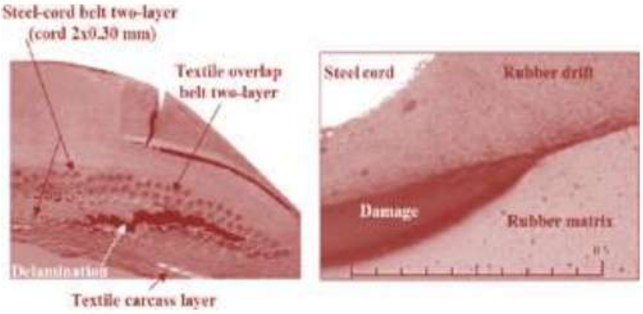


Fig. 3.54 Delamination Injection Repair

If the internal delamination is sufficiently minor .It can sometimes be repair by simply injecting resin into the cavity formed by ply separation. Injecting resin fills the area and reattaches the skin.

1. Clean both surface of the part.
2. Drill a .060-inch diameter hole from one surface down to the delamination at each end of delamination be careful not to drill through the part,
3. Clean the part with acetone or MEK.
4. Select and mix resin and curing agent as required.
5. Load the mixed resin into clean syringe with a needle attached. Inject the resin into one drilled hole until resin comes out the other drilled hole
6. Apply pressure and cure.
7. After the cure, remove clamps and vacuum bagging materials, then sand and refinish.

This repair may not be approved by the manufacturer because the delamination cavity is filled with resin, which adds extra weight. This would be of major significance if the damaged part were a primary control surface. Furthermore, the resin alone could be ineffective in restoring the strength and could cause brittleness. In flight, the extra resin in this area would not be as flexible and may cause further delamination in the damaged area.

DELAMINATION AT HONEYCOMB CORE EDGE BAND

Fig. 3.55 Delamination at Honeycomb Core Edge band

This simple repair does not need vacuum bagging, and rarely is cured with heat.

1. Clean surface with solvent.
2. Outline void area and mark injection whole locations.
3. Using a.0.60-inch diameter drill, slowly drill into disbanded area. Do not drill through the part.
4. Use a syringe to inject mixed resin into one hole, allowing air to escape through the other.
5. Clean excess resin from the surface of the part.
6. Cure according to manufacturer's instructions.

MISLOCATED POTTING COMPOUND WITHIN A HONEYCOMB STRUCTURE

In some cases, the manufacturer supplies a component with potting compound installed to accommodate a fastener. If this is not correctly positioned, it may need to be repositioned.

1. Locate the correct location of the fastener that requires the additional potting compound.
2. Drill a 1/8-inch hole at the correction through one skin only.
3. Insert a small Allen wrench through the hole and rotate 3600 to break the honeycomb cell walls to a one-inch radius around the drilled holes.
4. Vacuum out debits.
5. Using a sealant gun, or syringe, force the potting compound through the drilled hole.
6. Cure in accordance with the manufacturer's instructions.
7. Re-drill the hole and install the fitting in accordance with the manufacturer‘s requirements.

If the part failed because the fastener pulled out , filling the damaged hole and re-drilling it may not be a good repair ; it may pull out because the resin/filler mix may not provide adequate strength. An insert or grommet may be installed permanently with an adhesive. The fastener to the composite structure.

DAMAGE TO LAMINATE STRUCTURES

Solid laminates are those structures that do not have a core. They require different repairs depending on how badly they are damaged, where the damage is, and how thick the laminate is. Here are a few types of repairs for solid laminate structures.

COSMETIC DEFECT

A cosmetic defect is a surface resin scratch that does not penetrate the first structural ply (negligible damage).

1. Clean area with MEK or acetone.
2. Sand pained area around damage and feather the edges.

3. Scuff send damage, and then clean with solvent.
4. Mix resin with filler or approved surfacing putty.
5. Fill damaged area with resin-filler mixture. It may be applied with a squeegee, brush, or fairing tool.
6. Cure repair.
7. Send and refinish.

VACUUM BAGGINGMATERIALS

The materials commonly used for vacuum bagging come in a number of types, depending on the manufacturer, and how the repair is to be performed. Vacuum bagging materials are not a permanent part of the repair. They are removed and disposed of after the cure. They are tools used to facilitate the repair. There are many types of vacuum bagging materials, and your decision which ones to use may be based on:

1. The materials ability to withstand the cure temperature. Bagging materials come with different temperature ratings. If a repair is to be made at 3500F then the vacuum bagging film, bleeders, breathers, peel plies, and sealant tapes should all be able to withstand this temperature.
2. The cleanliness of the materials. Foreign materials are not desirable in are pair.
3. The ability to pull the proper amount of vacuum. Pinholes in the plastic or a moisture content that is too low may cause problems.
4. Will they produce the proper repair? If fiberglass is used in place of the bleeder will it soak out too much resin causing a resin dry part?

Although these materials may come with a conformity report, they are not required for the repair. These materials are tools. Only materials that remain in the aircraft need conformity reports. Examples of such materials includes repair fabrics and resin systems. Some of the more commonly used materials for composite repair are listed below.

VACUUM BAGGING FILMS

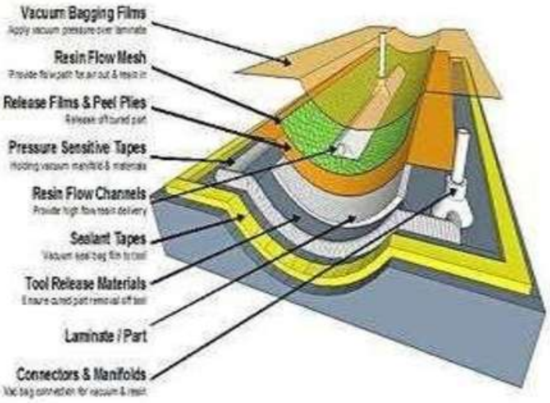


Fig. 3.56 Vacuum Bagging Films

Vacuum bagging films are used to cover the component and seal out air. They must be made with absolutely no voids or pin holes. If there are small holes in the film, air leaks through and less pressure is applied to the part while curing. Bagging films come In a variety of temperature range from room temperature up to 7500F. It is important to use the correct temperature rating for the required cure temperature. The vacuum bagging film should remain flexible at high temperature cures, especially around highly contoured shapes. If the bagging film becomes brittle, it may develop air leaks, which decreases the amount of atmospheric pressure applied to the part.

The selection of the appropriate bagging film depends on the method by which the part is cured and the required temperature of the cure. Bagging film is hydrophilic, or water sensitive material. Moisture acts as a plasticizer. The higher the moisture content of the film, the more flexible and robbery it becomes. During the vacuum bagging process, It is important that the film is a flexible a possible so the film can be formed around any contoured shape. During vacuum bagging lay up the vacuum bag is placed opposite side of vacuum port.

It is extremely important to maintain the moisture content when storing this film. When the material is shipped, it should be enclosed in a plastic wrap. Cut only the amount to be used from the roll. The rest of the roll should be stored in the original plastic wrapper. This is especially important in dry climates and during the winter months when the moisture content dry out and cause the film to become brittle.

SEALANT TAPES

Fig. 3.57 Sealant Tapes

Sealant tapes are used to maintain a possible seal between the surface of the original part and the bagging films. This seal must be leak proof to ensure maximum atmospheric pressure is held against the part. Some sealant tapes have a limited shelf life. So storage and labeling may be required. If the shelf life is exceeded, the seal will not be the standard quality, and the sealant tape might not be easily removed from surface.

The tape should hold tight even if the bagging film shrinks during the curing process, and it should be able to withstand the temperatures of the cure.

Pleats are made with sealant tape to provide extra bagging film over a part with contours. To make the pleats, a three-to four –inch piece of sealant tape is cut. The middle of the sealant tape is pinched together and the ends are attached to the sealant tape, which has been placed around the part.

When used, a pleat should be placed even with any edge or sharp contour to allow for the extra plastic where it is needed to provide a good seal. No more than half of the backing paper in the sealant tape should be removed prior to attaching the bagging film Pleats allow extra room in the bagging film to conform to the shape of the part and achieve a good seal. If extra vacuum bagging material is not available some places, or if extra material does not conform to the shape of the part a bridging effect may take place, allowing the excess resin to flow into these areas during the curing process. If enough pleats are added around the vacuum bagging area, the excess material should easily conform to the shape of the part when the vacuum is applied.

RELEASE FABRICS AND FILMS

Release fabric and films are used when a barrier is needed between the wet patches and the other vacuum bagging materials perforated films and release fabrics are also used when the resins are expected to flow up through the material and into a bleeder.

PEEL PLY

Fig. 3.58 Peel Ply

A nylon or polyester release fabric may be used next to the wet resin during the curing operation to transfer excess resin to the bleeder material without sticking to the part. After curing, the peel ply is peeled off the part, which caused a slightly rough surface. This is important if the part is to be repainted. Peel ply materials are extremely helpful over seams or where layers of fabric overlap. They will feather-in layers and eliminate the need for sanding.

Teflon release fabric is an excellent material because it releases from the repair area very cleanly. However, there are two types of Teflon release fabric; porous and non-porous . the porous material allows resin to flow through the fabric up into a bleeder material , while the non-porous release does not. The non-porous is used primarily in manufacturing against the side of amold.

Peel plies come in different finishes; some are very smooth , and others are coarse. Some peel plies may be treated with mold release, corona or Teflon to release better.

Peel plies are more desirable than release films for repair applications because they allow the resins to flow through more evenly. Peel ply used over a repair eliminates the need for sanding off the gloss or extra resin before painting. If the peel ply is left on over a repair it keeps the part clean until it is ready to be painted.

RELEASE FILMS

Fig. 3.59 Release Films

Release films come in two forms. Perforated release film is a plastic with holes that allow excess resin to flow into bleeder just as a peel ply material would so. This type of film comes with holes in different sixes and spacing depending on how much excess resin needs to be bed away from the repair area. They come in various temperature ratings.

Non-perforated film does north allow the excess resin to flow out allowing the resin to build up creating brittle, heavy repair. The non perforated release films are used when a barrier is needed between other parts of the vacuum bagging process; they are often used under a heat blanket over the bleeder material. This prevents the bleeder material and resins from coming in contact and damaging the heat blanket.

Before painting a surface that was cured with a release film the glaze created from the plastic should be removed by hand sanding otherwise the pint may not adhere to the structure. Carefully sand off the glaze and do not sand into the fiber material.

BLEEDERS

Fig. 5.60 Bleeders

Bleeders are cotton like absorbent material used to soak up excess resins. Some companies will use felt or other absorbent material. Do not use the bleeder in contact with the repair. If not used in conjunction with are lease fabric, peel ply or release film. The bleeder material will become a permanent part of the aircraft.

Different bleeder thicknesses and weight are available. Depending on the type of lay-up used for the repair, If the patches were impregnated by hand, a heavier bleeders probably needed to soak up the excess resin. Some technicians however use a very dry layup and need to use a thinner bleeder, if using a pre- prig a thinner bleeder material is the best option typical weights are 4 oz and 10 oz. bleeders.

BREATHERS

Breathers are cottony materials that allow air to flow through a valve or over the surface of part throughout the vacuum bagged area. This is typically the same materials as a bleeder and can be used as combination material called bleeder breather. When the vacuum hose is applied, air must be able to flow to the vacuum port without restrictions. A breather is used over the repair area under the vacuum bagging film.

Fig- 5.61 Breathers

CALKING PLATE

In some instances a calking plate or pressure plate is used to add extra pressure that smoother the contour of the part being cured. This is usually an optional piece made of wood aluminum , or copper. If there is a slight cur in the part or component, the calking plate must also conform to the shape of the part. If it doesn't a space between the part and the calking plate may collect resin and not cure properly

INSULATION LAYERS

Insulation may be added either outside the vacuum film or under the vacuum bagging film and over the heat blanket. If is used to minimize the amount of heat loss during the cure process, The insulation may be few layer of fiberglass or sewn blanket with many layer . if the repair work is done in very cold environments the heart blanket may lose heat around the edges an cause incomplete curing income areas . An insulation blanker may prevent thus from happening. Insulation blanket may prevent this from happening Insulation is considered optional because if the thermocouple is directly under the heat blanket the controller will keep adding heat to keep the blanket at the desired temperature.

The vacuum bagging operation can be done around a corner or over an edge as illustrated in Figure 7-8 Trailing edges can also be vacuum bagged in this manner. If the repair is dine to both sides of the edge a calking plate should be used in the vacuum bag to prevent the repair plies from bending up or down as the air evacuates the repair.

Fiber /Metal Laminate (FML)

A new type of composite used in aircraft construction is the fiber/metal laminate (FML). In the past, sheets of aluminum alloy and aramid fiber pre preg have been laminated together and used as non-structural cargo hold lining where the impact resistant qualities of the material are of great advantage. Currently a glass fiber/aluminum composite known as 'Glare' is being used to form the upper skin panels of various new aircraft designs. This material is both lighter than conventional sheet Metal, and has greater fatigue resistance and lower crack propagation. It offers better fire resistance and is less prone to corrosion as the glass fiber layers will prevent corrosion from spreading through the sheet.

The components of the Glare sheet are pre-formed and laid-up in a mold where they are heated and cured under pressure. Door and window cut-outs are milled out and the sheets are bonded onto the structure. The edges of the sheets are joined by seamless splices with no break in the fibre reinforcements.
The strength of the panel can be controlled by the number of laminates laid-up, normally 2-4 of glass cloth and 3-5 of aluminum, and the orientation of the fiber layers Plastics

Fig. 3.62 Fiber/Metal Laminate (FML) Other Non-metallic Materials

As we have seen, there are two groups of plastics

Thermoplastic materials - become soft when heated and can be molded again and again. Thermosetting materials - become permanently hard during the molding process and cannot be softened again.

A third group, referred to as Cold setting materials, are really thermosetting plastics which cure at room temperature. Some plastic resin materials used with glass fibers to repair certain types of aircraft structure are in this group. A passenger window is made from Perspex panel.
Plastics are made from materials obtained from animal or vegetable products and coal or petroleum by-products

Properties of Plastics
- They are resistant to corrosion.
- They have a fairly low relative density and lightweight.
- Their strength decreases rapidly as the temperature rises.
- They can be colored if required. Some are transparent.
- Many can be bonded together or fused by heat reducing the need for fasteners.
- Some plastics are flexible and can absorb impact by distortions but are not themselves damaged.
- Some plastics are recyclable making them more environmentally friendly.

The strength of plastics is less than that of metals. Generally the only plastic material that can be used for the load carrying parts of an aircraft are the fiber reinforced plastics. Other plastics are used to make fairings and cabin furnishings.

TYPES OF PLASTICS

POLYVINYL CHLORIDE (PVC)

PVC is a thermoplastic material often used to replace rubber for making protective gloves and aprons. It is also used to make seat covers in light aircraft. A plasticizer can be added to PVC to soften it. PVC can be shaped by injection molding and extrusion. It can also be compression molded without a plasticizer to give a tough rigid material.

Fig. 3.63 Polyvinyl Chloride

Other Thermoplastics

Two modern thermoplastics approved for aerospace structural use are poly phenylene supplied(PPS), and polyetherimide (PEI) both of which are available under several trade names. PPS is produced as granules and is molded and formed with heat and pressure, PEI is produced in both granular and resin form. Both can be modified with reinforcing materials such as glass, aramid and carbon fibers. With inherent flame retardancy and high hardness and rigidity, these engineering plastic are specially suitable for the manufacture of semi-finished products moldings and films. Continuous service temperatures up to 240°C are possible. Reinforcement with glass fibers lowers the thermal expansion coefficient to values that are typical of metal. Both are also characterized by very good chemical and oxidation resistance, minimal water absorption and low creep, even at elevated temperatures Formed products can be welded together to form light weight, fatigue resistant structures free from fasteners and the necessary processing to install them Proposed uses include wing fixed leading edges 'D' sections, leading edge ribs and stabilizer components where their impact resistance is of great value.

Elastomers

Fig. 3.64 Elastomers

From the Greek word 'elastos' meaning elastic, elastomers are rubber like materials which may be natural or synthetic (polymers) and have considerable elastic properties. Because they may also be molded into shapes, which they retain, they qualify to be included in the category of plastics. Elastomers will tolerate repeated elongation and return to their original size and shape, in a similar way to natural rubber. Some of the more common elastomers, to be found in the aerospace industry include Nitrite - also known as Buna 'N'. A synthetic rubber, made (initially in Germany) by the polymerization of butadiene and sodium (hence BuNa), it has excellent resistance to fuels and some oils, and is used for oil and fuel hoses, gaskets, and seals. This material also haslow'stiction1properties,when in contact with metal, and is ,therefore, particularly suited to 'moving-sear applications. Nitrile is not recommended for:

- Phosphate ester hydraulic fluids (Skydrol etc.).
- Ketones (MEK,acetone)
- Automotive brake fluid.

Buna 'S' relatively cheap material, also with a performance similar to natural rubber. It is often used for tiers and tubes, but its poor resistance to fuels/oils/cleaning fluids makes it unsuitable for seals .Flouro-Elastomers - these have exceptional high-temperature properties and can be used at 250°C. They are also solvent-resistant and are mainly used for high-temperature seals. A common name for these materials is Viton. Viton is recommended for:

- Petroleum oils.
- Di-ester base lubricants (MIL-L-7808,MIL-L-6085).
- Silicate ester base lubricants (MLO 8200, MLO 8515, OS-45.)
- Silicone fluids and greases.
- Selected phosphate ester fluids.

Flouro -Elastomers are not recommended for:

- Ketones (MEK,acetone).
- Skydrolfluids.

Neoprene - has very good tensile properties and excellent elastic recovery qualities. It is also solvent-resistant and, therefore, has a wide range of applications as fuel and oil seals and gaskets. Because of its special elastic recovery properties, it is also ideally suited to diaphragms. It is not recommended for ketones, esters and oxidizing acids. Silicone Rubber - has very good high- and low-temperature properties (- 80°C to + 200°C). It often used for seals and is also used for the potting of electrical circuits, because of its ability retain its rubbery state, even at low temperatures. Some types will cure or 'vulcanize' at room temperature and are supplied as sealant/adhesives in a tube. Silicones are not recommended for:

- Most petroleum fluids.
- Ketones (MEK,acetone).
- Water and steam.

Ethylene-propylene rubbers

- (EPM and EPDM) are valuable for their excellent resistance to heat, oxidation, ozone and weather aging due to their stable, saturated polymer backbone structure. One of the few compounds resistant to phosphate ester hydraulic fluids such as Skydrol.

Poly-Sulpide Rubber - although it possesses relatively poor physical properties, it has exceptionally high resistance to fuels and oils and is widely used for lining or sealing fuel tanks. It is also used for lightly stressed seals and hoses, which come into contact with fuels or oils. This compound can be mixed and cured in the work place and is commonly used as a sealant known under the trade names such as PRC and Thiokol.

CERAMICS

Ceramics are inorganic materials whose main industrial use is as an electrical insulating material, or in high temperature applications. They include Porcelain and Steatite for applications where dust and moisture readily collect. These materials can be molded into special shapes before being fired and glazed rather as crockery is. The porcelain-type insulators on high-voltage transformer and switch gear bushings, and on high voltage transmission and distribution overhead lines, are probably their most familiar use Special ceramics have been used for some times for such applications as motor vehicle spark- plug insulators and special electrical components. Advanced ceramics are under development for use in gas turbine engines for high temperature stators and turbine blades. Special ceramics have been used for some times for such applications as motor vehicle spark- plug insulators and special electrical components. Advanced ceramics are under development for use in gas turbine engines for high temperature stators and turbine blades. Mica-glass compositions are for high temperature insulation applications Ceramic Fires are used in heat resistant blankets and to weave fireproof cloth for engine and pylon protection.

ADHESIVES

The adhesive bonding of aircraft metal structure began during the second world war and has been used on an increasing scale in the aerospace industry ever since. Adhesives are used for constructional tasks varying from aircraft fuselages components and flight control surfaces, to propellers and helicopter rotor blades. The earliest process was developed by Aero Research Ltd.and was based on a phenol- formaldehyde resole resin coated with a polyvinyl formal powder. By February 1942, aluminium alloy lap joints were prepared with breaking stresses of over 2000 PSI. This synthetic structural adhesive for metals and was named Redux‘ standing for Research at Duxford. It was first on the deHavilland Sea Hornet fighter/bomber and subsequent on both military and civil aircraft. Redux is still in use today and has been joined by a wide range of epoxy and other synthetic resin adhesives.

TYPES OF BOND

The adhesive bond may be achieved mechanically or chemically, but in practice, most adhesives use both methods of bonding to form a joint.

Mechanical: Here the adhesive penetrates into the surface and forms a mechanical checked, by keying into surface irregularities. It also forms re-entrants, here the adhesive penetrate behind parts of the structure, and becomes an integral part of the component to be joined.

Chemical: In this method of bonding, the adhesive is spread over the surfaces to be and forms a chemical bond with the surface, it's molecules diffusing into the substrate.

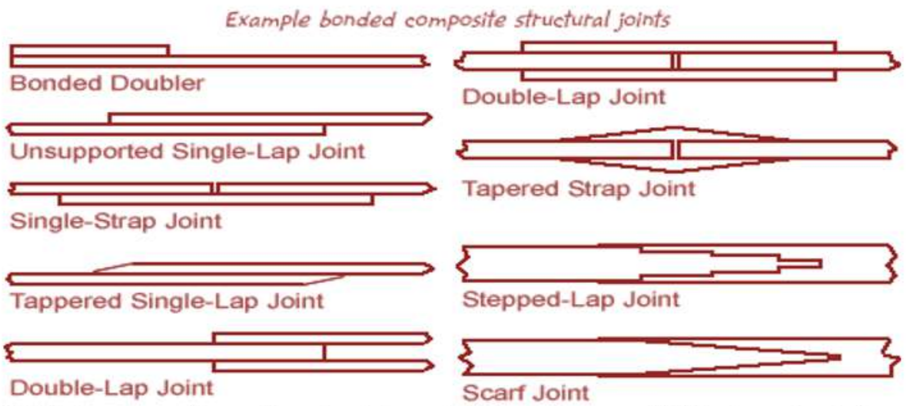


Fig. 3.65 Image of mechanical bond Advantages of Mechanical Bonding

- These mechanical bonds are easily to repair and easily to inspect while quality control.
- The mechanical joints are simple in constructions so production is faster.
- These are not affected by the environment and temperature except they undergo corrosion.
- These parts do not require a neat room and environment like adhesive joints.
- We can get a good joint by adding extra composite material metallic reinforcements at the composite join but it will increase the overall weight of the composite structure.
- Also these joints have some disadvantages.

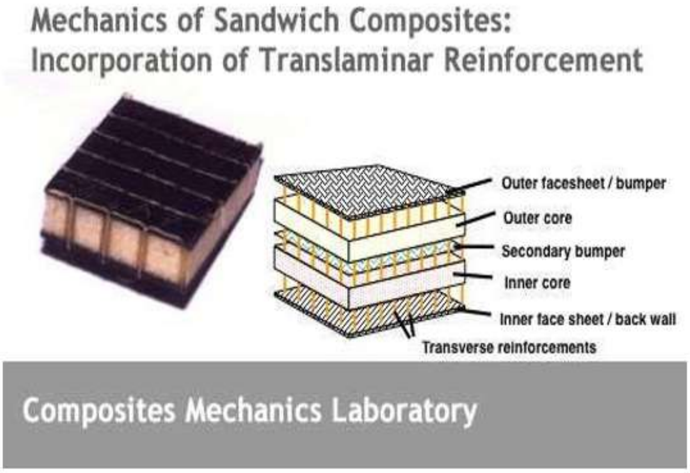


Fig. 3.66 Composite Mechanics Laboratory. Stresses on a bonded joint

Adhesive joints are liable to experience four main types of stress; Tensile, Shear, Cleavage and Peel. Tensile forces pull the bonded joint directly apart, whilst shear forces pull the upper and lower bonded plates in opposite directions, but in the same plane. Cleavage happens when separation of the plates is attempted at one end of the joint only. Peel is very similar to cleavage but the force is applied to one bonded plate only Joint strength is at a maximum when the adhesive is in shear. Adhesives should not be used if significant stresses are to be carried in tension or peel. The lap joint is generally favored, as the strength of the adhesive bond is proportional to the area bonded.

Advantages and Disadvantages

The major reasons for the widespread use of adhesives are as follows:

- No weakening of the component due to the presence of holes. Also providing a smooth finish due to lack of fastener heads.
- No local stress raisers, which are present with widely- pitched conventional fasteners such as bolts and rivets.
- Can be used to join dissimilar materials and materials of awkward shapes and of different thickness.
- Although the strength per unit area, may be inferior to a mechanical or welded joint, adhesive bonding takes place over a greater continuous area giving comparable or increased strength, coupled with improved stiffness.
- Adhesives provide electrical insulation and prevent dissimilar-metal corrosion between different materials.

- Leak-proof joints can be achieved.
- The elastic properties of some adhesives, gives flexibility to the joint and may help to damp out vibrations.
- Heat-sensitive materials can be joined.

The major disadvantages associated with adhesive bonding are:

- Limited heat resistance, normally below200°C
- Poor electrical and thermal conductivity
- High thermal expansion
- Limited resistance to certain chemicals such as paint strippers
- Integrity difficult to check with non-destructive testing procedures with regard to the strength of an adhesive bond, the three most important considerations are:
- Fail Stress: fail load within the glued area.
- Creep behavior.
- Durability: its long-life capability without serious deterioration.

TYPES OF ADHESIVE

There are many types and grades of adhesives, and the correct type for a particular application will be specified in the relevant repair procedure. Great care must be taken to ensure the correct adhesive type is used because the consequences could be fatal.

The two major groups of adhesives are Flexible and Structural.

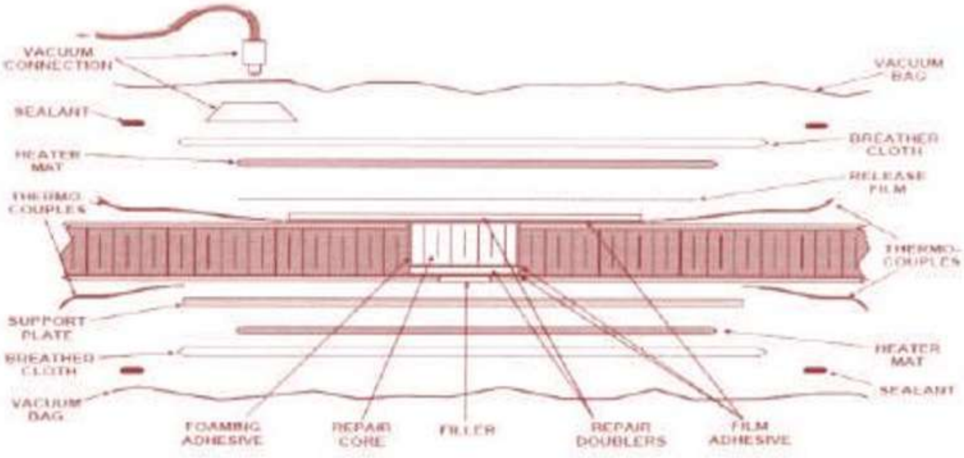
Flexible adhesives are used when some flexing, or slight relative movement of the joint, is essential and where high load-carrying properties are not paramount. In general, flexible adhesives are used when some flexing, or slight relative movement of the joint, is essential and where high load-carrying properties are not paramount. In general, flexible Structural adhesives are primarily aimed at applications where high loads must be carried without excessive creep. They are relatively rigid without being excessively hard or brittle. Structural adhesives are based on resins, (the most common ones being epoxy or polyester). Examples include Scotch-Weld and Hysol products. Another group of adhesives is the two-polymer type, which has a reasonably even balance of resin and elastomeric, which results in a flexible and fairly strong adhesive.

Adhesive Forms.

Adhesives can be obtained in a variety of forms, the most common being liquid, paste and film. Others available are those such as the special foaming types, which are used to splice. Honeycomb sections together. Some require heat for curing, whilst others can be cured at room temperature. Some require the addition of a catalyst or hardener.

Adhesive Use

To achieve optimum bonding, performance and life in service from adhesives it is absolutely crucial to follow the manufacturer‘s instructions and to pay the utmost attention to quality at every stage. As with resins, and most other chemical compounds, controlled ventilation, protective clothing, and anti-fire/explosion practices, are absolutely essential when working with adhesives. Although some of the adhesives in current use are supplied in film form, many are liquids or pastes, from which toxic/flammable vapors are emitted, prior to curing. Many of the necessary surface preparation solvents also give off toxic/flammable vapors .Surface preparation of the component is also crucial. Many high performance structural applications require a complex process such as the following:



DAMAGE REMOVAL

Very similar to composite repair. All damaged core material must be removed from sandwich construction panels. All moisture must be removed from the work area. All paint must be removed from around the repair. Taper sanding is not required.

Cleaning/degreasing

Requirements are the same as for a composite repair.

Repair part fabrication

Prepare repair core and doubler parts from approved specified materials. Prepare film adhesives and ancillary materials as required

Surface preparation

Before etching, the skin and repair doublers/s must be abraded with aluminum oxide pads to produce a water-break- free surface (i.e. when saturated with water and held vertical, a continuous film persists for 30 seconds minimum without breaking or forming droplets).

Acid etching/anodizing of existing surface

Various acids can be used for the etch process including hydrofluoric acid and sulphuric acid. Apertures and crevices must be sealed prior to application.

The Phosphoric Acid Non-Tank Anodizing (PANTA) process

The prepared area is coated with phosphoric acid gel and layers of gauze and acid gel laid on top. A stainless steel mesh is placed above this and coated with the gel. The work piece and mesh are connected to a DC power source so that the skin forms the anode (+) and the mesh is the cathode (-). A charge of 6 volts at 1-7 amps/ft2is applied for 10-12 minutes. The area must be cleaned with running water for 5 minutes with a maximum delay of 21/2minutes. The area must then be dried for at least 30 minutes.

Polarized light test;

The adequacy of the anodizing must be checked. This is done by observing the surface through a polarizing filter with fluorescent or daylight at a low angle of incidence. Rotating the filter will cause the original color to change to a complimentary color. If the color change is not observed or is patchy, the cleaning and anodizing processes must be repeated.

Epoxy priming;

Within 2 hours of anodizing, the area must be re protected with primer. Normally an epoxy based Adhesive Bonding Primer is specified producing a coating 0.00015 - 0.0004 thick. This should be air dried or infrared heated to 93°C(200°F). Some primers require curing at 93°C (200°F) and this should be done within the specified time period.

Repair Lay-up

Repair assembly is similar to prepreg composite lay-up. If the primed are has become contaminated it must be cleaned with an approved solvent. Film adhesive must be raised to room temperature and backing papers removed as pieces are used.

Cure

The repair must be cured under pressure at an elevated temperature. This may be applied using a Hot Bonder, heater mats and air bag, or in an Auto clave.

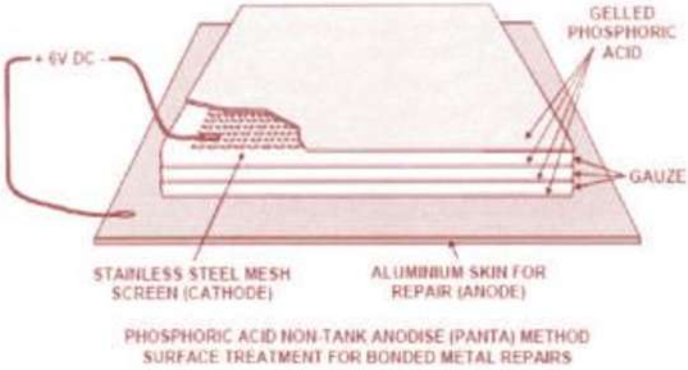


Fig. 3.68 Cure Jointing Compounds

Riveted and bolted joints in aircraft structures are interfaced with a jointing or sealing compound. The purpose of the compound is to exclude moisture or any other undesirable matter from between the materials by filling any voids and forming a thin film to prevent seepage. This reduces the risk of galvanic corrosion and prevents fretting.

Chromate Based Jointing Compounds

These materials are sometimes known as 'yellow chromate' or 'zinc chromate' or by trade names such as Duralac, JC5A and more recently Mastinox. They are used for the wet assembly of metallic mating surfaces in non-pressurized areas. Available in tubes, cans and drums, aircraft grade compounds do not dry and remain flexible throughout their working life. Mating surfaces should be well covered with the compound, including the interior of all bolt and rivet holes. The compound should be applied immediately prior to assembly in order to ensure that the filmiswet on assembly. Surplus compound is squeezed out as a fillet and should be removed with a clean cloth. Bolt shanks, underside of heads and washers should also be coated. JC5A is primarily composed of chromium compounds and barium chromate which are irritant and carcinogenic (cancer causing) and the volatile carrier xylene, which is toxic. It is hazardous by contact, ingestion and inhalation in confined spaces, and is also highly inflammable. Gloves and goggles should be worn when applying, handling and removing excess compound.

Note: JC5A has been found to be detrimental to some ferrous materials and has been withdrawn from use by many organizations. Currently Mastinox 6856K is approved for use in place of JC5A. It is used in the same way and has better performance, particularly in dissimilar metal applications. It is still chromate based and therefore the presents a similar hazard to the older materials. Non-Chromate Jointing Compounds Due to the health and safety issues associated with chromate based jointing compounds, the trend is towards the use of non-chromate compounds or-Ban 27L is one of a family of anti-corrosion treatments and is replacing Mastinox6856K in many applications. It is a low-solvent waxy paste that has superior properties to the chromate products while being safer to use. It is applied in the same manner as the older compounds and the use of gloves is still recommended.

Molybdenum Di sulphide Paste

In some instances of bolted joints molybdenum disulphide paste is specified as a jointing compound. Its purpose is to prevent fretting

Corrosion: its absence may seriously affect the fatigue life of the joint.

Hylomar

Fig. 3.69

Hylomar is one of several sealants used on bolted flange joints for engine and component assembly. It seals metal to metal joints and is resistant to water, fuel, oil, most chemicals and combustion products. It seals surfaces with imperfections and withstands vibration, heat and expansion.

Sealants

It is of the utmost importance that the pressure cabin of an aircraft be capable of sustaining the required differential pressure at high altitude, both for the safety of the passengers and crew and for the operational efficiency of the aircraft. To this end it is essential that all sources potential sources of air leakage from the cabin be carefully sealed in accordance with the process specification laid down by the manufacturers. Similarly, integral fuel tanks must be satisfactorily sealed against leakage. Like Jointing Compounds, sealants also prevent the accumulation of moisture between the elements of a structure and the risk of corrosion caused by this. In critical areas fasteners are installed with wet

sealant on their shanks and the internal side of each fastener is encapsulated with sealant. There are a number of proprietary sealants available in different grades and types and from different manufacturers. It is important that only the particular sealant specified for a job is used.
Before any sealant is applied it is important to ensure that the surfaces to which it is to be applied are clean and free from swarf and burrs. The sealant can be used in some cases on faying surfaces, and in other cases to form beads and fillets over joints. Some are ready for use in one container, others need mixing immediately before use and may be in two or three parts, because of these differences, it is important that, after having ascertained the correct sealant laid down for the task from the relevant; drawing or maintenance/overhaul manual, the process specification be checked to ensure the correct method of mixing and application.

The sealants are identified by their trade name, manufacturer‘s part number and specification number. The specification number is most important, since the product may be supplied by a number of manufacturers. Typical of the multi part sealants used is PR 1440. This two part poly sulphide compound is comprised of a base and an accelerator and is used for sealing integral fuel tanks, pressurized cabins, and for faying surfaces. It is resistant to aircraft fuels, lubricating oils, and Skydrol.

Hydraulic Fluid.

PR 1440 is the Pro Seal part number but the material satisfies all or part of the following specifications; Z-16.134, MIL-S-8802 Class A (USA), BMS 5-26 Type III (Boeing), 09-001C Airbus), ASNA 4157 (France) DTD 900 (UK) and others which will be quoted by the airframe or equipment manufacturer.

PR 1440 is available as Type A - 'Brush' type sealant which is fairly fluid for brush application to faying surfaces, and as a thicker Type B -'Non-brush' type for fillet seals and encapsulation. It may also be available with different application times, typically 'half hour' and 'two hour' to allow Flexibility of use.

It may be supplied in a pot with a separate container of accelerator attached, or as a 'Semkit' cartridge with integral accelerator and mixing facility. If in pot form, it is important to ensure the correct accelerator is used (usually identified as part number plus Part A and Part B) and that all of it is added to the base and mixed thoroughly using a spatula. In the Semkit a dash rod is supplied andisusedtoinjecttheacceleratorintothebaseastheplungercontaining it is withdrawn. The plunger is then pushed in and out and twisted to mix the two parts. In both cases it is important that the sealant is thoroughly mixed and of uniform color. Failure to add the correct amount of accelerator or to mix completely will a prevent proper cure and reduce the effectiveness of the sealant Sealant supplied in a can may be applied by brush or spatula, depending on type. Semkit cartridges can be inserted into a sealant gun for controlled application.

Fabrication and Repair of wood Structures Introduction:

Wood aircraft structures combine many of the attributes associated with metal and composite structures, such as light weight, low cost, and high strength, while requiring only the minimum of special equipment for proper maintenance and repair. For this reason, many of the lighter aircraft that have been produced have made use of wood primary and secondary components, such as wing spars, ribs, and control surfaces. A great many of these aircraft are still in operation, and a few designs are still in production using wooden structural components. Figure 3-1 shows aircraft which incorporate wood in their structures.

Fig. 3.70 Airplanes having wood structures aircraft woods

There are two principal types of wood, hardwoods and softwoods, and all woods may be classed as one or the other. The distinction between hardwoods and softwoods is not based on the ―hardness‖ of the wood but rather on the cellular structure of the wood.

SOFTWOOD

Fig. 3. 71 Softwoods

Softwoods come from trees that have needlelike or scale-like leaves and are classified as evergreens or conifers. The wood of these trees is composed primarily of fibrous cells and has a smooth, even appearance when cut in cross section. Softwood has a high strength-to-weight ratio, which makes it a very desirable structural material for use in aircraft construction. Softwood is usually Used as a solid wood for spars, cap strips, and compression members and as a veneer for plywood cores. Woods included in the softwoods used in aircraft are Sitka spruce, Douglas fir, Port Oxford white cedar, and western hemlock. Sitka spruce is the wood used as a reference material to establish the suitability of other softwoods for use in aircraft construction and repair.

Hardwoods come from trees that have broad leaves and are classified as deciduous because they lose their leaves each fall. The wood of these trees is composed of a mixture of large cells, causing pores in the wood, distributed among the smaller fibrous cells. These pores are often visible when the wood is cut smoothly. Hardwoods are generally heavier than softwoods and are used where their strength advantages make the extra weight acceptable over the softwoods. Hardwoods are commonly used as solid wood for support blocks and tip bows and as veneers for the facing and core material of plywood.

Terminology for Woods

Even though the aircraft technician may not have occasion to use standard terminology for woods very often, it is considered desirable to understand the terms illustrated.

Nomenclature for woods

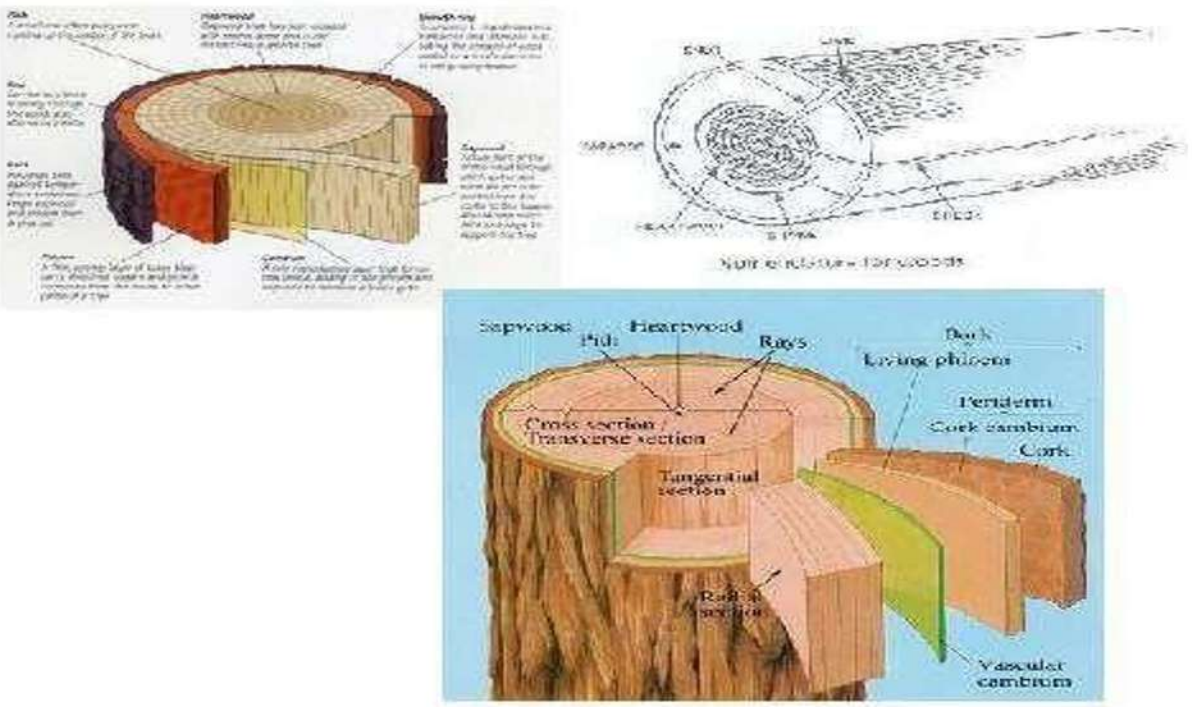


Fig. 3.72 Nomenclature for woods

Annual rings concentric layers of wood that can be seen at the end of a tree trunk that has been cut perpendicular to its length. The rings are caused by the different rates of growth during each year as the seasons change.
Bark the external covering of a tree trunk or branch.
Check a radical crack that cuts across the grain lines.
Compression failures Wrinkles or streaks across the grain line caused by mechanical stress on the wood after the annual rings had grown. For detection, compression failures may require close examination with a light source aimed almost parallel to the grain structure.
Compression wood deformed grain structure in the wood caused by mechanical stress on the tree, such as supporting the weight of a heavy limb, during growth. It is characterized by wide annual rings when compared to the normal size of the tree's growth rings.
Decay a biological growth living off of the wood and causing a breakdown in the strength of the wood. Discoloration may also be present.
Grain the lines in wood caused by the annual rings. Grain also refers to the direction of the wood fibers.
Hard Knot a knot that is firmly embedded in the wood and shows no sign of coming loose.
Hard wood the center part of tree trunk, which is dead and carries no sap. This part of the tree serves only to support the tree.

Knot the base of a limb inside the tree. A knot will cause a deviation of the grain lines as they form around the knot.
Mineral streaks Coloring in the wood caused by minerals in the soil or other naturally occurring agents during the tree‘s growth.

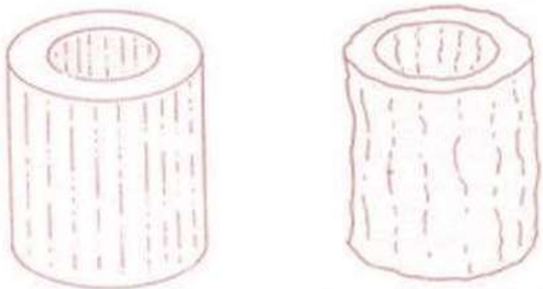
Moisture Content The weight of water contained in a wood sample compared to the eight of the wood sample if the water was removed from it.
Pin knot a knot resulting from the growth of a twig.

Pitch pocket Voids between the annual rings that contain free resin. These pockets are usually relatively small in cross section and are not to be confused with shakes, which can be extensive.
Sapwood The part of a tree that is alive or partially alive and carries sap. Sapwoods begin immediately under the bark and extend to the heartwood. The sapwood is often lighter in color than the heartwood.
Shake a separation between the annual ring layers.

Spike knot A knot that was cut through parallel to the limb during the sawing operation such that the knot runs across the board.
Split a crack in the wood resulting from rough handling.

Spring wood The soft, light-colored part of the annual ring. This wood ring is normally wider than the summerwood ring because of the rapid tree growth during the spring season.
Summer wood The harder and usually darker part of each annual ring. This wood is formed during the slow simmer season growth.

Evaluating Wood for Aircraft use



A wood cell before (left) and after (right) drying. When the cell water is removed, the wood shrinks and becomes stronger.

Fig. 3.73 Evaluating Wood for Aircraft use

The primary requirement for wood that is to be used in aircraft structures is that it be sufficiently sound and of such quality that it will provide the strength required for the structure. It has been determined through research that Sitka spruce is generally the best wood for use in aircraft structures because of its combination of lightness, strength, stiffness per unit weight, and toughness when compared to other species. Because of specific requirements, other species may be used due to unique qualities within the general evaluation criteria. The following paragraphs discuss the wood characteristics that the technician must consider when selecting wood of the desired species

There are two classifications of water in wood, free water and cell water. Free water is the water that flows up and down the tree carrying nutrients. Cell water is water trapped within the walls of the woods cells‘ structure and is part of the structure of the tree. Aircraft woods are klin- dried to remove

all the free water and a portion of the cell water, so the resulting moisture content is between 10 and 12 percent. Moisture content above or below this range is not considered acceptable.
Klin-dried wood is dried by placing the boards if fresh-cut wood in a precisely controlled oven and raising the temperature to a specified level for a specified period of time. Not only does this process reduce the moisture content to the desired level, but it also kills the insects and decay-producing organisms that may have infected the wood.

A wood cell before (left) and after (right) drying. When the cell water is removed, the wood shrinks and becomes stronger.

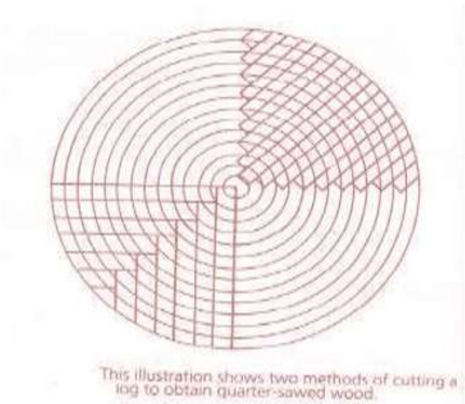
The specific gravity of aircraft woods should be from 0.34 to 0.40, depending upon the type of wood. Aircraft spruce should have a specific gravity of approximately 0.36.The grain structure of the wood must be examined to determine if the woods gas been properly cut, if the grain lined are sufficiently straight, and if there is a minimum number of annual rings per inch.

The grain structure of the wood must be examined to determine if the woods gas been properly cut, if the grain lined are sufficiently straight, and if there is a minimum number of annual rings per inch.

This illustration shows two methods of cutting a log

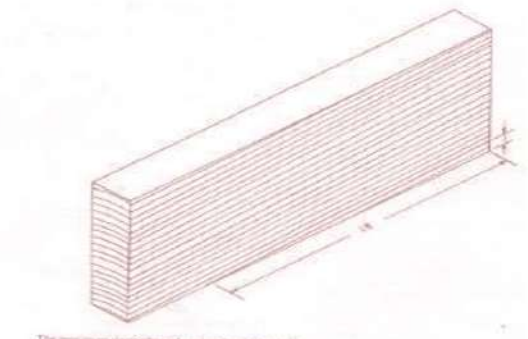
Fig. 3.74 shows two methods of cutting a log

Fig. 3.75



This illustration shows two methods of cutting a log to obtain quarter-sawed wood.

Fig.3.76



The maximum slope allowed in aircraft wood is 1:15

Fabrication and Repair of Wood Structures

Fig.3.77

The slope of a grain line is determined by looking at the side of a board and noting the angle that the grain line makes with the edge of the board. Ideally, the grain lines will be parallel to the edge of the board, but a deviation or slope of1:15 is allowed. This means that a grain line starting at the edge of the board may not move more than 1 in [2.54 cm] from the edge of the board when it is 15 in [38.1 cm] from the starting point.

The number of annual rings per inch, or grain count, is another criterion that must be checked for aircraft-quality wood. The grain count is taken by counting the number of grain lines (annual rings) per inch on the sample. This is best done by looking at the end of a board and measuring a 1-in [2.54-cm] line perpendicular to the annual rings. The minimum grain count for most softwood is six per inch [2.54 cm], with the exception of Port Oxford white cedar and Douglas fir, which must have a minimum of eight rings per inch [2.54cm].

When evaluating wood, the following defects are not acceptable: checks, shakes, splits, decay, compression wood, compression failure, and spike knots. Defects that might be acceptable, depending on their size, location, and condition are hard knots, pin knot clusters, mineral streaks, and irregularities In grain direction.

Specifications for aircrafts woods as given in Federal Aviation Advisory Circular (AC), 43.13-1A provide that certain minor defects. Such as small solid knots, and wavy grain, may be permitted if such defects do not cause any appreciable weakening of the part in which they appear. As a practical rule, aircraft technicians should not use any wood about which they have doubts. The safe policy is to use wood that is straight-grained, free from cracks, knots, or any other possible defect, and guaranteed as aircraft-quality.

Wood defects.

Defect	Acceptability
Check	Not acceptable.
Compression failure	Not acceptable
Compression wood	Not acceptable.
Cross grain	Spiral grain, diagonal grain, or a combination of the two is acceptable providing the grain does not diverge from the longitudinal axis of the material more than 1:15. A check of all four faces of the board is necessary to determine the amount of divergence. The direction of free-flowing ink will frequently assist in determining grain direction. If the deviation is greater than specified, the wood is not acceptable.
Curly grain	Acceptable if local irregularities do not exceed limitations specified for cross grain.
Decay	Not acceptable

Hard knots	Sound hard knots up to 3/8 in [9.5-mm] in maximum diameter are acceptable providing: (1) They are not in projecting portions of I-beams along the edges of rectangular or beveled un routed beams, or along the edges of flanges of box-beams (except in lowly stressed portions); (2) They do not cause grain divergence at the edges of the board or in the flanges of a beam more than 1:15; and (3) they are in the center third of the beam and are no closer than 20 in [50.8-cm] to another knot or other defect (pertains to 3/8-in [9.5-mm] knots—smaller knots may be proportionally closer).
Interlocking grain	Acceptable if local irregularities do not exceed limitations specified for cross grain

Minerals streaks	Acceptable, providing careful inspection fails to reveal any decay. Not acceptable if accompanied by decay.
Pin knot clusters	Small clusters are acceptable, providing they produce only a small effect on grain direction. Not acceptable if they produce a large effect on grain direction.
Pitch pockets	Acceptable in center portion of beam, providing they are at least 14 in[35.56-cm] apart when they lie in the same growth ring and do not exceed 1 ½ in [3.81-cm] in length by 1/8 in [3.18-mm] width by 1/8 in [3.18-mm] in depth and providing they are not along the projecting portions of I-beams, along the edges of rectangular or beveled un routed beams, along the edges of the flanges of box-beams. Otherwise, not acceptable.
Shakes	Not acceptable.
Spike knots	Not acceptable.
Splits	Not acceptable.
Wavy grain	Acceptable, if local irregularities do not exceed limitations specified for cross grain.

Specifications for aircrafts woods as given in Federal Aviation Advisory Circular (AC), 43.13-1A provides that certain minor defects. Such as small solid knots, and wavy grain, may be Permitted if such defects do not cause any appreciable weakening of the part in which they appear. As a practical rule, aircraft technicians should not use any wood about which they have doubts. The safe policy is to use wood that is straight-grained, free from cracks, knots, or any other possible defect, and guaranteed as aircraft-quality.

Wood Substitutions

Species of wood	Strength properties as compared to spruce	Maximum permissible grain deviation (slope of grain)	Remarks
Spruce (picea); Sitka (P. Sitchensis), Red (P. Rubra), White (P. Glauca)	100%	1.15	Excellent for all uses, considered as standard for this table.
Douglas Fir (Pseudotsuga Taxifolia)	Exceed spruce	1.15	May be used as substitute for spruce in same sizes or in slightly reduced sizes providing reductions are substantiated. Difficult to work with hand tools. Some tendency to split and splinter during fabrication, and considerably more care in pieces should be avoided due to inspection difficulties, gluing satisfactory.
Noble Fir (AbiesNobiles)	Slightly exceeds spruce except 80% deficient in shear	1.15	Satisfactory characteristics with respect to workability, warping, and splitting. May be used as direct substitute for spruce in same sizes providing shear does not become critical. Hardness somewhat less than spruce. Gluing satisfactory.
Western Hemlock (Tsuga Heterophylia)	Slightly exceeds spruce	1.15	Less uniform in texture than spruce. May be used as direct substitute for spruce. Upland growth superior to lowland growth. Gluing Satisfactory.

Pine, Northern White (Pinus Strobus)	Properties between 85 and 96% those of spruce	1.15	Excellent working qualities and uniform in properties but somewhat low in hardness and shock- resisting capacity. Cannot be used as substitute for spruce without increase in sizes to compensate for lesser strength. Gluing satisfactory.
White Cedar, Port Oeford (CharaecyparisLawsoniana)	Exceeds spruce	1.15	May be used as substitute for spruce in same sizes or in slightly reduced sizes providing reductions are substantiated. Easy to work with hand tools. Gluing difficult, but satisfactory joints can be obtained if suitable precautions are taken.
Poplar, Yellow (LiriodendrowTulipifera)	Slightly less than spruce except in compression (crushing) and shear	1.15	Excellent working qualities. Should not be used as a direct substitute for spruce without carefully accounting for slightly reduced strength properties. Somewhat low in shock-resisting capacity. Gluing Satisfactory.

When repairing or rebuilding wood components, species substitution may be allowed if the structural strength of the components is not reduced. Table 3-2 shows types of wood that may be considered for substitution, with spruce being the reference wood. Note that the choice of a substitution may have to take into account changes in size, different gluing qualities, and different working qualities.

Table 3-2 Aircraft woods Species of wood Strength properties as compared to spruce Maximum permissible grain deviation (slope of grain) Remarks

Spruce (picea); Sitka (P. Sitchensis), Red (P. Rubra), White (P. Glauca) 100%

1.15 Excellent for all uses, considered as standard for this table.

Douglas Fir (Pseudotsuga Taxifolia) Exceed spruce 1.15 May be used as substitute for spruce in same sizes or in slightly reduced sizes providing reductions are substantiated.

Difficult to work with hand tools. Some tendency to split

Plywood

Fig. 3.78 Plywood

Plywood is composed of an uneven number of layers (piles) of wood veneer assembled with the grain of each layer at an angle of 45 to 90 to the adjacent layers. The outside layers are called the faces, or the face and back, and thinner layers are called the core and cross bands.

The layers of plywood are bonded with special glues of the synthetic resin type. Flat aircraft plywood is usually assembled with a thermosetting (hardened by heat) glue in a large, heated hydraulic press. It must be emphasized that aircraft plywood is of much higher quality than commercial grades. Every layer of wood in a sheet of aircraft plywood must be of excellent quality to provide for uniform strength through out.

Plywood has a number of advantages over solid wood in that it is not likely to warp, it is highly resistant to cracking, and its strength is almost equal in any direction when stresses are applied along the length or width of a panel. Its change in dimension is negligible with changes in moisture content.

The most commonly used types of plywood for aircraft manufacture are mahogany and birch. The core and cross bands may be made of basswood or a similar wood that provides adequate strength.

Mahogany has a reddish-brown appearance, whereas birch is of a light yellow or cream color.

Mahogany offers a better gluing surface than birch because of it porosity.

When selecting or ordering plywood for aircraft use, the technician should make sure that the wood is of aircraft quality. Some commercial plywood appears to be as good as aircraft plywood; however, it will be found that the quality is only on the surface and the strength does not compare with aircraft-quality product.

Laminated wood

Fig 3.79 laminated wood

Laminated wood is several layers of solid wood bonded together with an adhesive. Laminated wood differs from plywood in that each layer of wood has the grain running in the same direction, whereas plywood has the grain direction of each layer at a large angle to the previous layer. Laminated wood tends to be more rigid than a piece of solid wood of the same size and is much more resistant to war page. Laminated wood is used for components that require a curved shape, such as wing-tip bows and fuselage formers, and is used in place of solid wood, such as for solid-type wing spars.

GLUES AND GLUING PROCEDURES

Glues are used almost exclusively for joining wood in aircraft and repair. A part is regarded as satisfactorily glued if the strength of the joint is equal to the strength of the wood. In a strong joint, there is complete contact of glue and wood surfaces over the entire area of the joint and a thin, continuous film of glue between the wood layers unbroken by foreign particles or air bubbles.

To accomplish satisfactory glue work in aircraft wood structures, it is necessary that a number of exacting rules be observed and that all materials be of the high quality specified for aircraft woodwork. If either the glue or the wood is not of satisfactory quality or if the techniques employed are not correct, the gluing will be inferior and may result in failure.

Fig. 3.90 Type of glues

Type of glues

There are two broad categories of glue used in aircraft wood structure, casein, and synthetic resin. The synthetic resin glues are commonly used in modern construction operations.

Casein glues are manufactured from milk products, are highly water-resistant, and require the addition of sodium salts, and lime to prevent attack by microorganisms.

Synthetic glues are of the urea formaldehyde, resorcinol formaldehyde, phenol formaldehyde, and epoxy types. Depending on the formulation of glue, it may be water-resistant or waterproof and may be purchased in a liquid or powdered form. Synthetic glues are not attacked by microorganisms.

Mixing Glues

The mixing of glues must be done in accordance with the flue manufacturer‘s instructions to assure that the full strength of the glue will be available. The following discussion is meant to present guidelines for mixing glues so that the technician will have an idea of missing requirements.

The container used for mixing glues must be of a material that will not react with the chemicals that make up the glue. The container and mixing tools must be clean and free of any contaminants or old glue.

In preparation for mixing, the ingredients are measured out in the proper proportions. These proportions may be either by weight or by volume. The ingredients may include powder and liquids, purchased as part of the glue, and water. The sequence of mixing may call for the powder to be added to water, water to be added to the powder, or two liquid components to be mixed in some specific sequence, such as adding a liquid catalyst to liquid glue.

For mixing glues properly, the room temperature generally must be at or above 70 F, [21 C]. The process of mixing the glue requires that the speed of mixing be slow enough so that air is not whipped into the mixture. Air would result in a weak glue joint. Once the glue is mixed, it may have to stand for some period of time to allow the components of the glue to interact before a proper glue joint can be formed.

Once the glue is ready to be used, it has a specific working life, during which it can be applied with assurance that a proper glue bond will form. This time is influenced by the room temperature, with high temperatures resulting in a shorter working life. If the ambient temperature is high, the working life of the glue can be extended by placing the glue container in a water bath of cool water (no lower than 70 F) [21 C]. The average working life of glues is 4 to 5 h at 70 F [21C].

Surface Preparation for Gluing

To assure a sound glue bond, the wood must be properly prepared to allow full surface contact between the components being joined. The condition of the wood must be such that the glue bonds properly with the surface of the wood. This includes being free of any surface contaminants and having the proper moisture content.

Wood surfaces to be glued should be smooth and true. Chapped or loosened grain, machine marks, and other surface irregularities are objectionable. Joints of maximum strength are made between two planed or smoothly sawed surfaces that are equally true.

Although the wood surface must be true prior to gluing, the method of obtaining this trueness may affect the strength of the bond. For example, softwoods should not be sanded when preparing the surface for gluing. Sanding fills the wood pores with wood dust and prevents the glue from properly penetrating the surface. However, hardwoods can be sanded prior to gluing without any detrimental effects on the glue bond. With either type of wood, filling and planning are considered proper methods to prepare the surface for gluing. There should be no more than 8 h between the time that the surface is prepared for gluing and the gluing operations takes place.

The surface to be glued should be free of any paints, oils, waxes, marks, or particles that would interfere in any way with the proper bonding of the glue to the wood surface. The presence of wax on a surface can be detected by placing water drops on the surface. If they bead up, then waxis present and must be removed prior to gluing. This may be particularly useful in determining the surface condition of plywood‘s that may have been protected with a waxed paper.

The moisture content of wood when it is glued has a great effect on the warping of glued members, the development of checks in the wood, and the final strength of the joints. Moisture content at the time of gluing that is between 8 and 12 percent is generally regarded as satisfactory, but the higher the moisture content within this range, the better will be the joint. If the moisture content is too low, the glue cannot wet the surface properly, and it sometimes produces what are called starved joints—that is, joints not adequately bonded. Gluing increases the moisture content of the woods; therefore, the moisture added in this manner must dry out or distribute itself in the wood before the part can be machined or finished. Other factors in establishing moisture content are the density and thickness of the wood, the number of plies, the glue mixture, and the quantity of glue used.

Proper Gluing Procedures

A strong joint in the wood is obtained from complete contact of glue and wood surfaces over the entire joint area and continuous film of good glue between the wood layers that is unbroken by air bubbles or by foreign particles. Under these conditions, the glue penetrates the pores of the wood and forms a bond that is stronger that the bond between the original wood fibers. When broken, such a joint will not separate at the glue bond but will facture in the wood outside the bond.

Glue should be spread evenly over both surfaces forming the glue joint. Either a brush or a soft-edged spreader may be used to apply the glue. If a brush is used, careful inspection must be made after spreading the glue for any bristles that may have broken off.

Two different assembly methods may be employed in joining wood parts with glue. The open assembly method is often recommended because it reduces the time required for the glue to set up in open assembly, the glue is applied to both surfaces to be joined, and the parts are not put together for a specified length of time. If pieces of wood are coated with glue and exposed to a free circulation of air, the glue thickens faster than when the pieces are laid together as soon as the glue is spread. This latter process is called closed assembly.

In gluing operations, the assembly time may be as little as 1 min. or as long as 20 min., but the glue must remain at a satisfactory consistency throughout the period. Unless specifically stated to the contrary by the manufacturer of the glue, open assembly should not permit the glue to be exposed to the open air for more than 20 mins.

Gluing Pressure

The functions of pressure on a glue joint are as follows: (1) to squeeze the glue into a thin, continuous film between the wood layers, (2) to force air from the joint, (3) to bring the wood surfaces into intimate contact with the glue, and (4) to hold the surfaces in intimate contact during the setting of the glue. A light pressure is used with thin glue and a heavy pressure is used with thick glue.

Corresponding variations in pressure are made with glues of intermediate consistencies. The pressure applied should be within the range approved for the types of wood being glued. For example, the gluing pressure should be between 125 and 150 psi [861.75 and 10.4.25 Kpa] for softwoods and between 150 and 200 psi [10.4.25 and 1378.8 k Pa] for hardwoods.

The method of applying pressure depends on the size, shape, and contour of the surface. Pressure can be applied by the use of clamps, nails, weights, nail strips, or screws.

CONSTRUCTION AND REPAIR OF WOOD STRUCTURES

Before attempting to repair a damaged wooden aircraft structure, the technician must understand the nature of the required repair and have the correct materials and technical information required at hand making the repair.

Nomenclature for Wooden Aircraft

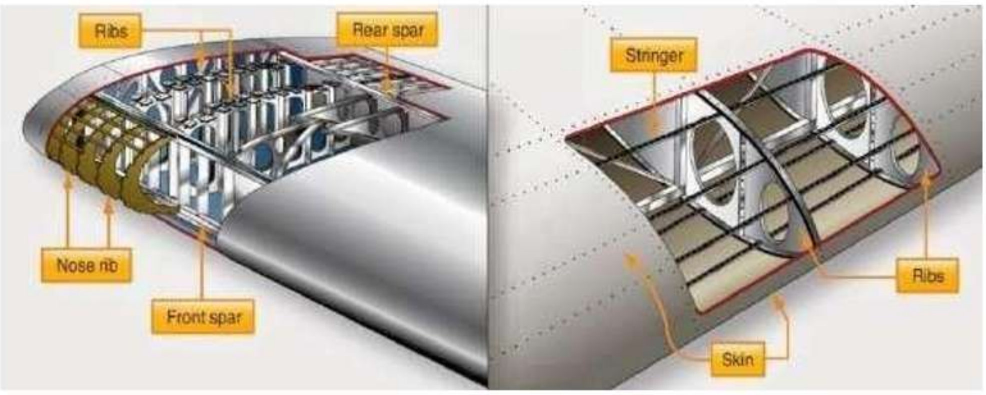
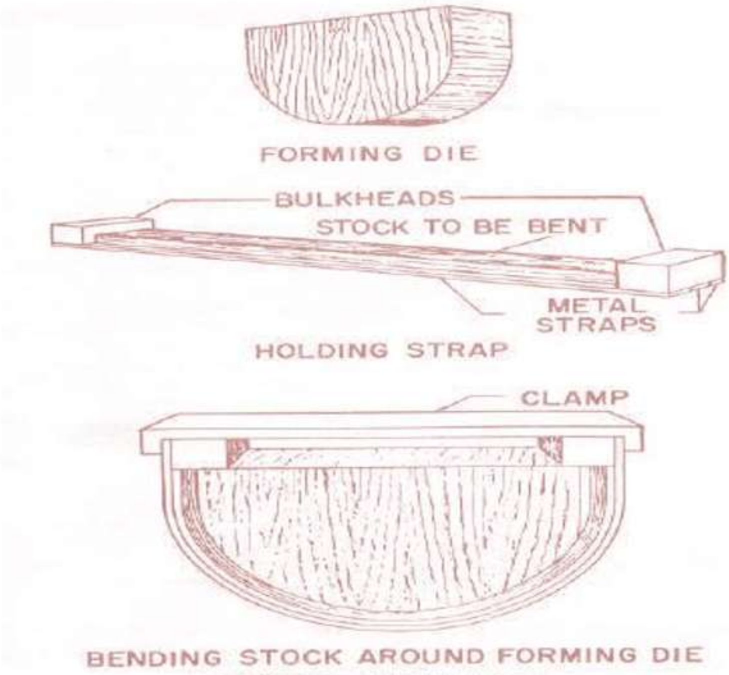


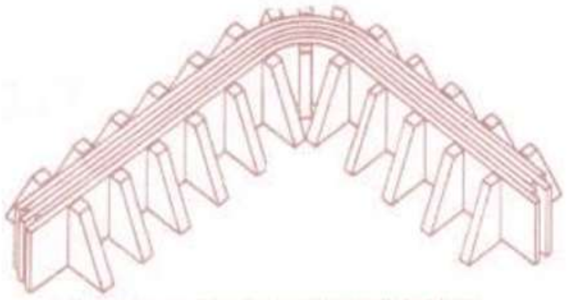
Fig.3.91 Nomenclature for Wooden Aircraft

The nomenclature for a wooden wing is shown in the illustration of Fig. 3-6. Note that the parts are named according to standard practice for both metal and wooden wings. In the illustration, the leading-edge strip, the plywood skin, and the corner block are unique to wooden wing construction. Some of the nomenclature for a wooden fuselage is given in Fog. 3-7. here again the nomenclature is similar to that given for a metal fuselage of the semi-monocoque type.

Bending and Forming Wood



a forming die and holding strap.



A laminated wood structure is normally held in a jig until the glue dries.

Fig. 3.92 Bending and Forming Wood

Bending of wood is necessary to achieve the desired shape of components while maintaining the structural strength of a straight piece of wood. Any type of wood may be bent, with the degree of shaping depending upon the size of the piece, the type of wood, and the technique used in preparing the wood for bending.

Solid wood is normally bent over a very large radius and then only when the wood is of a small cross-sectional area. Only the best, clearest, straight-grained material should be considered for bending. Woods commonly used for bent components include spruce, ash, oak. Typical airframe components made of bent solid wood include wing-tip bows rib cap strips, and fuselage stringers.

Laminated wood structures are commonly used to form any severely bent structure because of the ease with which the thin laminations can be formed and because of the high strength of the finished laminated structure. Laminated member, since they have a parallel grain construction, have about the same properties as solid wood, except that laminated members are usually more uniform in their strength properties and less prone to change shape with variations in moisture content. Curved laminated structures are used for items such as tip bows, formers, and bulkheads.

Nomenclature for a fuselage

Fig.3-93 Nomenclature for a fuselage

Plywood is formed to make leadings-edge coverings and surface panels. Most curved plywood components start out as flat sheets and, through various bending operations, are formed to the desired shape. While solid and laminated structures are normally bent in only one direction, plywood is often bent in two planes by stretching it over formers, resulting in a double curvature. This double curvature is often found in areas such as fairings and wing tips.

Wood may be bent in a dry condition or after being soaked in water for some period of time. Dry bending allows the least amount of bending, whereas soaking the wood in cold water makes the wood more flexible. To increase the flexibility of the wood, it can be soaked in hot water or, for maximum flexibility it can be heated in a steam chamber. The wood should be exposed to the steam for 1 h per inch [2.54 cm] of thickness, with a maximum of 4 h exposure. Excessive heating causes the wood to break down structurally.

Immediately after steaming, the wooden part must be bent. If the curvature is slight, the part may be bent by hand over a form of the desired shape. If the curvature is pronounced, most of the deformation (change of shape) is accomplished by compression or shortening. This is done by using a forming die and holding strap, such as the one illustrated. The wood to be bent is fitted snugly between the bulkheads shown in picture and then bent over the forming die. In some cases, the type of clamp shown in the lower drawing of Fig. 3-8 does not hold. It is then necessary to use a vise-type clamp with outer and inner forming dies.

Using a forming die and holding strap The wood, having been bent, should remain in the forms until it has cooled and dried enough to keep its shape. The forms are usually made with a slightly greater curvature than that required for the finished part to provide for the tendency of the wood to straighten out somewhat after it is taken out of the forms. In addition, the forms should be designed so that they expose as much as possible of the bent piece to the drying effect of the air.

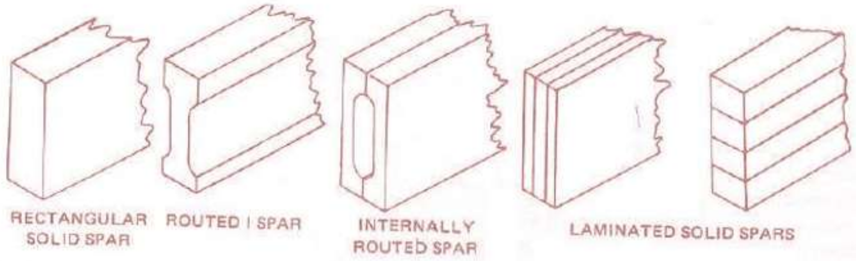
Laminated wood members that do not require severe bending, such as wing-tip bows, may be formed without steaming or any other softening preparation. If the laminations are thin enough to take the necessary bend without splitting, they are cut to size and planed on both sides. Laminations sufficient in number to make up the required thickness are coated with glue and clamped in a form of the necessary shape. Time is allowed for the glue to set and for the wood to dry thoroughly, after which the wooden part will retain the shape of the form. If there is any spring back, it will be very slight. In certain cases, where it is not desirable to use very thin laminations or where the bending curvature is severe, the laminations may be steamed and bent to shape before being glued together. A laminated component in a jig. When curved plywood members are needed, several layers of veneer may be bent and glued in one operation, or the prepared plywood may simply be bent.

When built-up plywood members are desired, veneer strips or sheets are bent over a form after glue has been applied to their surfaces. The sheets or strips are held together, often with staples, while the glue sets; the member then retains its shape after it has been removed from the form. The grain of each successive layer of veneer should be perpendicular to that of adjoining layer, but in some jobs the veneer is applied on the form with the grain running at an oblique angle of about 45 from the axis of the member. If the work is done carefully, a built-up plywood member should have about the same properties as a bent laminated member.

The degree to which plywood may be bent is illustrated in Table 3-3. Note that if plywood is selected with the grain lines 45 to the face grain line, then a sharper bend is possible. Also note that the greater the number of veneers in a plywood of a given thickness, the sharper the bend that is possible.

A laminated wood structure is normally held a jig until the glue dries

Wing Spar Construction



Solid and laminated spars.

Fabrication and Repair of Wood Structures

Fig.3-94 Wing Spar Construction

Wooden wing spars are constructed using several different techniques, depending on the size of the spar required and the structural strength requirements. Some aircraft may include several different construction techniques along the length of one spar as the required structural strength changes.

Based on the materials used in the structure, spars can be divided into two broad categories: solid spars, and built-up spars.

Solid spars use solid wood as the primary components. These spars may be made of one piece of wood that is rectangular in cross sections, several pieces of solid wood laminated together, as externally routed solid piece, or an internally routed spar formed by routing out proportions of two boards and then joining therouted sides of the boards together to form a spar. Examples of these different types of solid spars. Solid spars may change in their external dimensions along their length, may have areas that are not routed, such as fittings, and may include plywood plates attached to areas requiring reinforcements, such as at fitting attachments.

Solid and laminated spars

Built-up spars include a combination of solid wood and plywood components. Built-up spars can be divided into three basic types—C-beam, I-beam, as illustrated in Fig. 3-11.

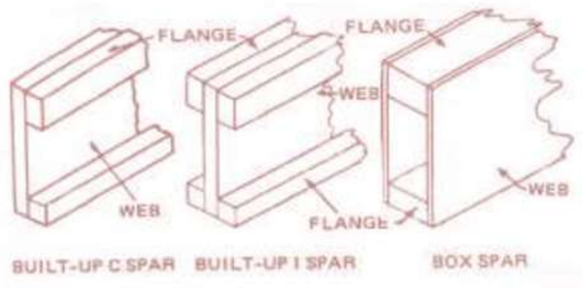
Built-up spars

C-beam and I-beam spars consist of a plywood web as the principal vertical member running the length of the spar. At the top and bottom of this web are located solid wood cap strips. For C-beam, the cap strips are on only one side of the spar, whereas an I-beam has cap strips on both sides of the web. Intercostals are located vertically between the cap strips at intervals to increase the strength and rigidity of the spar. Blocks are used between the cap strips to allow for the attachment of fittings.
A box-beam spar consists of a top and bottom solid-wood cap strip, plywood webs on the outside of the cap strips, and intercostals and blocks used for strength, stiffness, and attachment of fittings.

Spar Repairs

When a spar is damaged, the damage must be evaluated to determine if the spar can be repaired or if it must be replaced and what the economic factors are concerning the cost of repair versus the cost of replacement. The economic factors must be decided between those doing the repair and the aircraft owner. Factors that determine the repair-ability of a spar include the existence of any previous repairs, the location of the damage, and the type of damage. If a spar has been repaired twice, it is generally considered to be un-repairable. If the damage is in such a location that a splice is not possible without interfering with wing fittings, as discussed later, then the spar is un-repairable. If the damage is such that the integrity of the repair will be in doubt, such as the presence of extensive decay, then the spar is un-repairable. Keep in mind that each spar must be evaluated, and no one set of rules can apply to all spars. If a spar is determined to be repairable, the repair procedures outlined in the aircraft's maintenance manual or in AC43.13-1A should be followed.

Rib Construction



Built-up spars

Fig. 3. 94 Rib Constructions

Module 6.4: Corrosion

Chemical fundamentals; Formation by, galvanic action process, microbiological, stress;
Many aircraft structures are made of metal, and the most harmful form of damage to those structures is corrosion. From the moment the metal is manufactured, it must be protected from the bad effects of the environment that surrounds it. This protection can be the introduction of certain elements into the base metal, creating a corrosion resistant alloy, or the addition of a surface coating of a metal or paint. While in use, additional moisture barriers, such as viscous lubricants and protectants may be added to the surface.
The introduction of airframes built primarily of composite components has not eliminated the need for careful monitoring of aircraft with regard to corrosion. While the airframe itself may not be subject to corrosion, the use of metal components and accessories within the airframe means the aircraft maintenance technician must be on the alert for the evidence of corrosion when inspecting any aircraft.
In nature, most metals are found in a chemically combined state known as an ore. All the metals except gold, platinum and silver exist in nature in the form of their oxides, carbonates, Sulphides, sulphates, etc. These combined forms of the metals represent their thermodynamically stable state (low energy state). The metals are extracted from these ores after supplying a large amount of energy. Metals in the uncombined condition have a higher energy and are in an unstable state. It is their natural tendency to go back to the low energy state, i.e., combined state by recombining with the elements present in the environment. This is the main reason for corrosion.

Metal corrosion is the deterioration of the metal by chemical or electrochemical attack. This type of damage can take place internally as well as on the surface. As in the rotting of wood, this deterioration may change the smooth surface, weaken the interior, or damage or loosen adjacent parts. Water or water vapour containing salt combines with oxygen in the atmosphere to produce the main source of corrosion in aircraft. Aircraft operating in a marine environment, or in areas where the atmosphere contains industrial fumes that are corrosive, are particularly susceptible to corrosive attacks.

The appearance of corrosion varies with the metal. On the surface of aluminum alloys and magnesium, it appears as pitting and etching, and is often combined with a grey or white powdery deposit. On copper and copper alloys, the corrosion forms a greenish film; on steel, a reddish corrosion by product commonly referred to as rust. When the grey, white, green, or reddish deposits are removed, each of the surfaces may appear etched and pitted, depending upon the length of exposure and severity of attack. If these surface pits are not too deep, they may not significantly alter the strength of the metal; however, the pits may become sites for crack development, particularly if the part is highly stressed. Some types of corrosion can travel between the inside of surface coatings and the metal surface, and can spread until the part fails.

CLASSIFICATION OF CORROSION

There are two general classifications of corrosion that cover most of the specific forms, direct chemical attack and electrochemical attack. In both types of corrosion, the metal is converted into a metallic compound such as an oxide, hydroxide, or sulphate. The corrosion process always involves two simultaneous changes: The metal that is attacked or oxidized suffers what may be called anodic change, and the corrosive agent is reduced and may be considered as undergoing cathodic change.

Direct Chemical Corrosion

Direct chemical attack, or pure chemical corrosion, is an attack resulting from a direct exposure of a bare surface to caustic liquid or gaseous agents. Unlike electrochemical attack where the anodic and cathodic changes may be taking place a measurable distance apart, the changes in direct chemical attack are occurring simultaneously at the same point. The most common agents causing direct chemical attack on aircraft are: (1) spilled battery acid or fumes from batteries; (2) residual flux deposits resulting from in adequately cleaned, welded, brazed, or soldered joints; and (3) entrapped caustic cleaning solutions.

Direct Chemical Attack In A Battery Compartment

With the introduction of sealed lead-acid batteries and the use of nickel-cadmium batteries, spilled battery acid is becoming less of a problem. The use of these closed units lessens the hazards of acid spillage and battery fumes. Many types of fluxes used in brazing, soldering, and welding are corrosive, and they chemically attack the metals or alloys with which they are used. Therefore, it is important to remove residual flux from the metal surface immediately after the joining operation. Flux residues are hygroscopic in nature; that is, they absorb moisture, and unless carefully removed, tend to cause severe pitting. Caustic cleaning solutions in concentrated form should be kept tightly capped and as far from aircraft as possible. Some cleaning solutions used in corrosion removal are, in themselves, potentially corrosive agents; therefore, particular attention should be directed toward their complete removal after use on aircraft. Where entrapment of the cleaning solution is likely to occur, use a noncorrosive cleaning agent, even though it is less efficient.

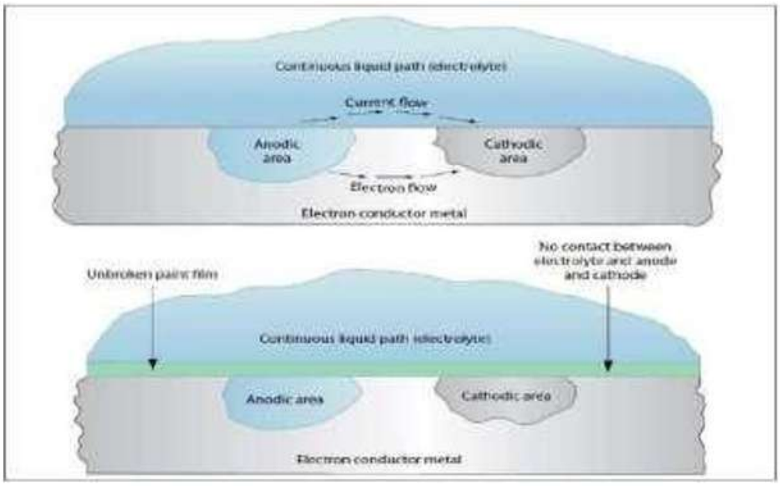
Effect of Temperature

The effect of an increase in temperature usually results in an increase in the rate of oxidation of a metal.

Electrochemical Corrosion

Electrochemical corrosion is similar to the electrolytic action that takes place in a dry cell battery. When the number of electrons matches the number of protons in an atom, the atom is said to be electrically balanced. If there are more or fever electrons than proton, the atom is said to be charged and is called as ion. If there are more electrons than protons it is negative ion and if there are more protons than electrons it is a positive ion.

One of the basic characteristics of the metal is there electrode potential. In other words when the two dissimilar metals are placed in an electrolyte, an electrical potential exist. This potential forces electrons in the more negative material is anode to flow to less negative material ie cathode, when the conductive path is provided. Corrosion occurs when the electrons leave the material. All metals and alloys are electrically active and have a specific electrical potential in a given chemical environment. This potential is commonly referred to as the metal's "nobility." The less noble a metal is, the more easily it can be corroded or in other words the earlier a metal appears in the electrochemical series the more easily it gives up the electrons. The metal that gives up the electron is known as anodic metal and corrodes easily. On the other hand, a metal that appears later in the series do not give up electron easily and are called cathodic metals.



The constituents in an alloy also have specific electrical potentials that are generally different from each other. Exposure of the alloy surface to a conductive, corrosive medium causes the more active metal to become anodic and the less active metal to become cathodic, thereby establishing conditions for corrosion. These are called local cells. The greater the difference in electrical potential between the two metals, the greater will be the severity of a corrosive attack, if the proper conditions are allowed to develop.

The conditions for these corrosion reactions are the presence of a conductive fluid and metals having a difference in potential. If, by regular cleaning and surface refinishing, the medium is removed and the minute electrical circuit eliminated, corrosion cannot occur.

This is the basis for effective corrosion control. The electrochemical attack is responsible for most forms of corrosion on aircraft structure and component parts.

TYPES OF CORROSION

Corrosion is a very general term and may appear in a variety of forms depending on the metal involved and the corrosion producing agents present. We must be familiar with the different types of corrosion and how to identify each.

Oxidation:

One of the simpler forms of corrosion is dry corrosion or, as it is most generally known oxidation. Oxidation corrosion is brought about by direct action of oxygen at low or high temperatures on metals. When the metal such as aluminum is exposed to gas containing oxygen, a chemical reaction takes place on the surface between metal and the gas to form aluminum oxide ($Al2O3$). If the metal is iron or steel iron oxide or rust ($Fe2O3$) is formed on the surface of the metal.

There is one big difference between iron oxide and aluminum oxide. The film of aluminum oxide is unbroken and therefore once it has formed, further reaction of metal with oxygen slows dramatically. Iron oxide on other hand forms porous, interrupted film. Since the film is not airtight the metal continues to react with oxygen in air until the metal is completely eaten away. The best way to protect iron from dry corrosion is to keep oxygen away from coming into contact with its surface. This is done temporarily by covering the surface with oil or grease or permanently with a coat of paint.

Aluminum alloy can be protected from oxidation by the formation of an oxide film on its surface. This film insulates the aluminum from any electrolyte and also prevents further reaction with oxygen. The protection given by an aluminum oxide coating is the principal reason for cladding (Alclad) aluminum alloy used in structural applications.

Uniform Surface Corrosion:

Where an area of unprotected metal is exposed to an atmosphere containing battery fumes, exhaust gases or industrial contaminants a uniform attack over the entire surface occurs. This dulling of surface is caused by microscopic amounts of metal being converted into corrosion salts. If these deposits are not removed and surface protected against further action, the surface becomes so rough that corrosion pits form.

Corrosion sometimes spreads under the surface and cannot be recognized by either roughening of the surface or by powdery deposits. Instead the paint or plating lifts of the surface in small blisters due to the presence of the underlying accumulation of corrosion product.

Pitting Corrosion:

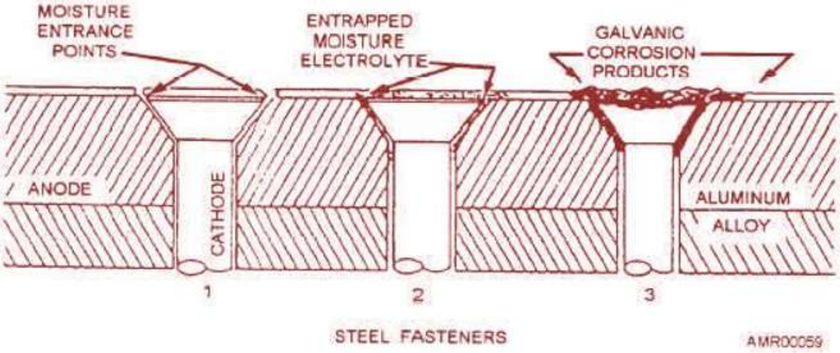
Pitting is a likely result of uniform surface corrosion left untreated. Pits form as localized anodic areas, and corrosive action continues until an appreciable percentage of the metal thickness is converted into salt. In extreme cases this can eat completely through the metal. Pitting corrosion is usually detected by the appearance of clumps of white powder on the surface.

Galvanic Corrosion:

This common type of corrosion occurs any time two dissimilar metals make electrical contact in the presence of an electrolyte. For example a galvanic corrosion can take place where dissimilar metal skins are riveted together or where the aluminum inspection panels are attached to the structure by steel screws.

When the metals of the same galvanic grouping are joined together they show very little tendency for galvanic corrosion. But the metals of one group corrodes when they are held in contact with those in the other group. The further apart the groups more active the corrosion. In addition, corrosion is much more rapid when the anodic metal is smaller than that of the cathodic metal. The reason for this is the greater area of cathode allows higher rate of electron flow accelerating the speed of reaction. On the other hand, if the corroding metal (anode) is larger than less active metal (cathode) corrosion is slow and superficial.

The contamination of a metal’s surface by mechanical means can also induce galvanic corrosion or dissimilar metal corrosion. The improper use of steel cleaning products, such as steel wool or a steel wire brush on aluminum or magnesium, can force small pieces of steel into the metal being cleaned, which will then further corrode and ruin the adjoining surface. Carefully monitor the use of nonwoven abrasive pads, so that pads used on one type of metal are not used again on a different metal surface.



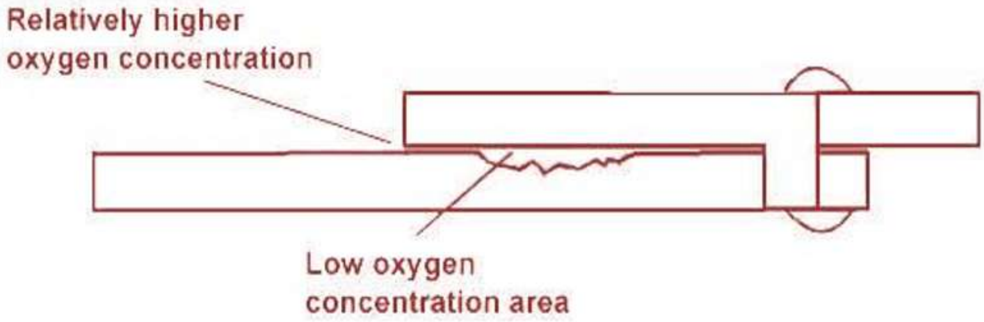
Concentration Cell Corrosion:

Concentration cell corrosion or crevice corrosion is corrosion of metals in a metal to metal joint, corrosion at the edge of joint even though the metals are identical. Concentration cell corrosion occurs when two or more areas of a metal surface are in contact with different concentrations of the same solution. There are three general types of concentration cell corrosion:

1. Oxygen concentration cells
2. Metal ion concentration cells
3. Active-passive cells.

Oxygen concentration cell corrosion:

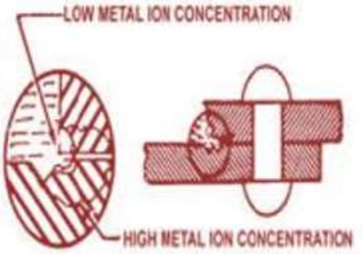
A water solution in contact with the metal surface will normally contain dissolved oxygen. An oxygen cell can develop at any point where the oxygen in the air is not allowed to diffuse uniformly into the solution, thereby creating a difference in oxygen concentration between two points. Typical locations of oxygen concentration cells are under either metallic or non-metallic deposits (dirt) on the metal surface and under faying surfaces such as riveted lap joints. Since the water in an open area readily absorb oxygen from air, it attracts electrons from the metal to form negative hydroxides ions. The area between the skins does not give up the electrons to the water on its surface because there is not enough oxygen there to form hydroxides ions. Instead its electrons flow to the cathodic surface, the open area. The area between the skins having lost electrons now contains positive metal ions and this area becomes anode. These positive metal ions attracts negative hydroxides ions from the open water and the metal corrodes forming metal hydroxides. Corrosion will occur at the area of low-oxygen concentration (anode). This type of corrosion can occur on aluminum, magnesium, or on ferrous metals. The severity of corrosion due to these conditions can be minimized by sealing, maintaining surfaces clean, and avoiding the use of material that permits entry of moisture between faying surfaces.



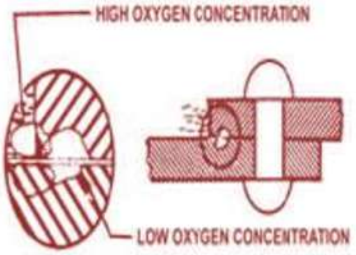
Metal Ion Concentration Cell Corrosion:

The electrode potential within the metal is dependent on the different metals that make up the alloy. However a potential difference can occur if an electrolyte having different or non- uniform concentration of metal ions covers the surface of the metal. For example some metal to metal joint rub against each other creating a high concentration of metal ions adjacent to the low concentration of metal ions.

In the presence of water, the metal area between the faying surfaces where the concentration of the metal ions is highest becomes the cathode and attracts the electrons from the skin in the open area which is anode. As electrons flow from anode to cathode they leave the positive metal ions on the surface near the surface of negative hydroxides ions. These hydroxides ions join the metal ions to form metal hydroxide, a corrosion salt. This condition can be eliminated by sealing the faying surfaces in a manner to exclude moisture. Proper protective coating application with inorganic zinc primers is also effective in reducingfaying surface corrosion



METAL ION CONCENTRATION CELL



OXYGEN CONCENTRATION CELL

The difference between the two types of concentration cell corrosion is the metal ion concentration cell corrosion forms on the open surface whereas oxygen concentration cell corrosion forms in the closed areas between the faying surfaces.

Active Passive Cell Corrosion:

Metals that depend on a tightly adhering passive film (usually an oxide) for corrosion protection; e.g., austenitic corrosion-resistant steel, can be corroded by active-passive cells. The corrosive action usually starts as an oxygen concentration cell; e.g., salt deposits on the metal surface in the presence of water containing oxygen can create the oxygen cell. If the passive film is broken beneath the salt deposit, the active metal beneath the film will be exposed to corrosive attack. An electrical potential will develop between the large area of the cathode (passive film) and the small area of the anode (active metal). Rapid pitting of the active metal will result. This type of corrosion can be avoided by frequent cleaning and by application of protective coatings.

Fili form Corrosion:

It is a special form of oxygen concentration cell corrosion or crevice corrosion which occurs on metals surfaces having an organic coating system. It is recognized by its fine thread like lines under a polyurethane enamel finish. Filiform corrosion often results when the wash primer used on the metal has not been properly cured. A wash primer is a two part metal preparation material in which phosphoric acid converts the surface of the metal into phosphate film that protects the metal from corrosion and provides an excellent bond for paint. This conversion process depends on moisture in the air, if there is not enough moisture to convert all of the acid, some acid remains on the metal. If a dense poly urethane finish is then applied, the acid becomes trapped and reacts with the aluminum alloy to form corrosion. Filiform corrosion does not usually form under acrylic finish because it is porous enough to allow moisture from air to penetrate the film and complete the conversion of any excess acid.