Classification Of Engineering Materials, And Their Properties:

1] **Material classification:**

There are different ways of classifying materials. One way is to describe five groups or families

TABLE 1-1 *Representative examples, applications, and properties for each category of materials*

	Examples of Applications	Properties
Metals and Alloys		
Copper	Electrical conductor wire	High electrical conductivity, good formability
Gray cast iron	Automobile engine blocks	Castable, machinable, vibration-damping
Alloy steels	Wrenches, automobile chassis	Significantly strengthened by heat treatment
Ceramics and Glasses		
SiO_2–Na_2O–CaO	Window glass	Optically transparent, thermally insulating
Al_2O_3, MgO, SiO_2	Refractories (i.e., heat-resistant lining of furnaces) for containing molten metal	Thermally insulating, withstand high temperatures, relatively inert to molten metal
Barium titanate	Capacitors for microelectronics	High ability to store charge
Silica	Optical fibers for information technology	Refractive index, low optical losses
Polymers		
Polyethylene	Food packaging	Easily formed into thin, flexible, airtight film
Epoxy	Encapsulation of integrated circuits	Electrically insulating and moisture-resistant
Phenolics	Adhesives for joining plies in plywood	Strong, moisture resistant
Semiconductors		
Silicon	Transistors and integrated circuits	Unique electrical behavior
GaAs	Optoelectronic systems	Converts electrical signals to light, lasers, laser diodes, etc.
Composites		
Graphite-epoxy	Aircraft components	High strength-to-weight ratio
Tungsten carbide-cobalt (WC-Co)	Carbide cutting tools for machining	High hardness, yet good shock resistance
Titanium-clad steel	Reactor vessels	Low cost and high strength of steel with the corrosion resistance of titanium

- Metals and alloys;
- Ceramics, glasses, and glass-ceramics;
- Polymers (plastics);
- Semiconductors
- Composite materials

Metals and Alloys:

Metals and alloys include steels, aluminum, magnesium, zinc, cast iron, titanium, copper, and nickel. An alloy is a metal that contains additions of one or more metals or non-metals. In general, metals have good electrical and thermal conductivity. Metals and alloys have relatively high strength, high stiffness, ductility or formability, and shock resistance. They are particularly useful for structural or load-bearing applications. Although pure metals are occasionally used, alloys provide improvement in a particular desirable property or permit better combinations of properties.

Ceramics:

Ceramics can be defined as inorganic crystalline materials. Beach sand and rocks are examples of naturally occurring ceramics. Advanced ceramics are materials made by refining naturally occurring ceramics and other special processes. Advanced ceramics are used in substrates that house computer chips, sensors and capacitors, wireless communications, inductors, and electrical insulation. Some ceramics are used as barrier coatings to protect metallic substrates in turbine engines. Ceramics are also used in such consumer products as paints, and tires, and for industrial applications such as the tiles for the space shuttle.

Traditional ceramics are used to make bricks, tableware, toilets, bathroom sinks, refractories (heat-resistant material), and abrasives. In general, due to the presence of porosity (small holes), ceramics do not conduct heat well; they must be heated to very high temperatures before melting. Ceramics are strong and hard, but also very brittle. We normally prepare fine powders of ceramics and convert these into different shapes. New processing techniques make ceramics sufficiently resistant to fracture that they can be used in load-bearing applications, such as impellers in turbine engines. Ceramics have exceptional strength under compression.

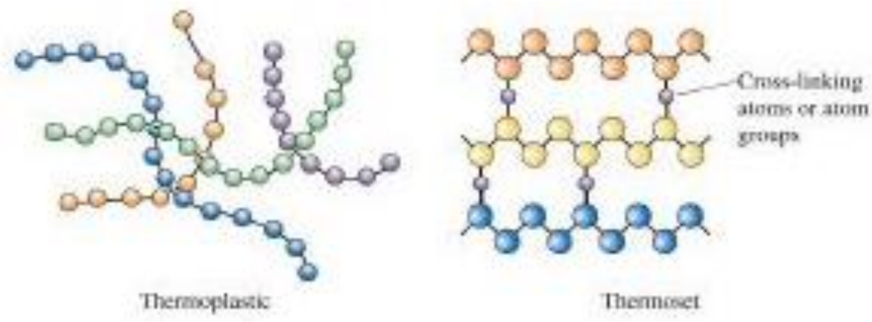
Glasses and Glass-Ceramics:

Glass is an amorphous material, often, but not always, derived from a molten liquid. The term "amorphous" refers to materials that do not have a regular, periodic arrangement of atoms. The fiber optics industry is founded on optical fibers based on high purity silica glass. Glasses are also used in houses, cars, computer and television screens, and hundreds of other applications. Glasses can be thermally treated (tempered) to make them stronger. Forming glasses and nucleating (forming) small crystals within them by a special thermal process creates materials that are known as glass-ceramics. Zerodur™ is an example of a glass-ceramic material that is used to make the mirror substrates for large telescopes (e.g., the Chandra and Hubble telescopes). Glasses and glass-ceramics are usually processed by melting and casting.

Polymers:

Polymers are typically organic materials. They are produced using a process known as polymerization. Polymeric materials include rubber (elastomers) and many types of adhesives. Polymers typically are good electrical and thermal insulators although there are exceptions such as the semiconducting polymers. Although they have lower strength, polymers have a very good strength-to-weight ratio. They are typically not suitable for use at high temperatures. Many polymers have very good resistance to corrosive chemicals. Polymers have thousands of applications ranging from bulletproof vests, compact disks (CDs), ropes, and liquid crystal displays (LCDs) to clothes and coffee cups. Thermoplastic polymers, in which the long molecular chains are not rigidly connected, have good ductility and formability; thermosetting polymers are stronger but more brittle because the molecular chains are tightly linked. Polymers are used in many applications, including electronic devices. Thermoplastics are made by shaping their molten form. Thermosets are typically cast into molds. Plastics contain additives that enhance the properties of polymers.

Polymerization occurs when small molecules, represented by the circles, combine to produce larger molecules, or polymers. The polymer molecules can have a structure that consists of many chains that are entangled but not connected (thermoplastics) or can form three-dimensional networks in which chains are cross-linked (thermosets)



Semiconductors:

Silicon, germanium, and gallium arsenide-based semiconductors such as those used in computers and electronics are part of a broader class of materials known as electronic materials. The electrical conductivity of semiconducting materials is between that of ceramic insulators and metallic conductors. In some semiconductors, the level of conductivity can be controlled to enable electronic devices such as transistors, diodes, etc., that are used to build integrated circuits. In many applications, we need large single crystals of semiconductors. These are grown from molten materials. Often, thin films of semiconducting materials are also made using specialized processes.

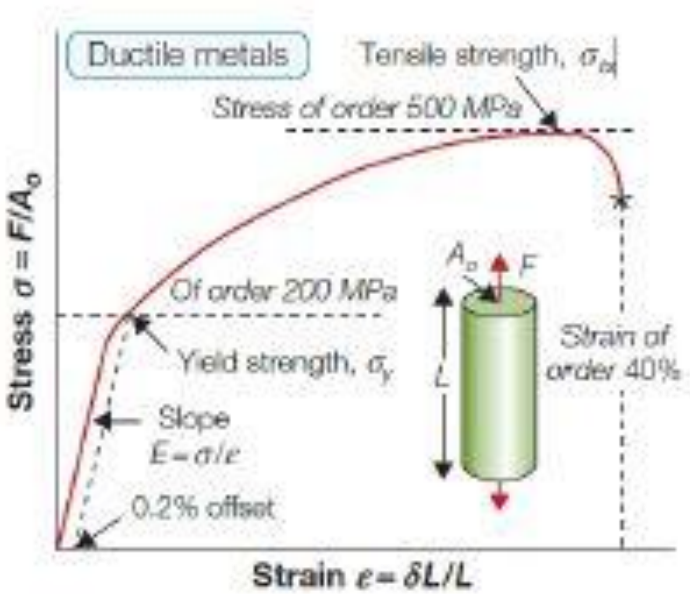
Composite Materials:

The main idea in developing composites is to blend the properties of different materials. These are formed from two or more materials, producing properties not found in any single material. Concrete, plywood, and fiberglass are examples of composite materials. Fiberglass is made by dispersing glass fibers in a polymer matrix. The glass fibers make the polymer stiffer, without significantly increasing its density. With composites, we can produce lightweight, strong, ductile, temperature-resistant materials or we can produce hard, yet shock-resistant, cutting tools that would otherwise shatter. Advanced aircraft and aerospace vehicles rely heavily on composites such as carbon fiber-reinforced polymers. Sports equipment such as bicycles, golf clubs, tennis rackets, and the like also make use of different kinds of composite materials that are light and stiff.

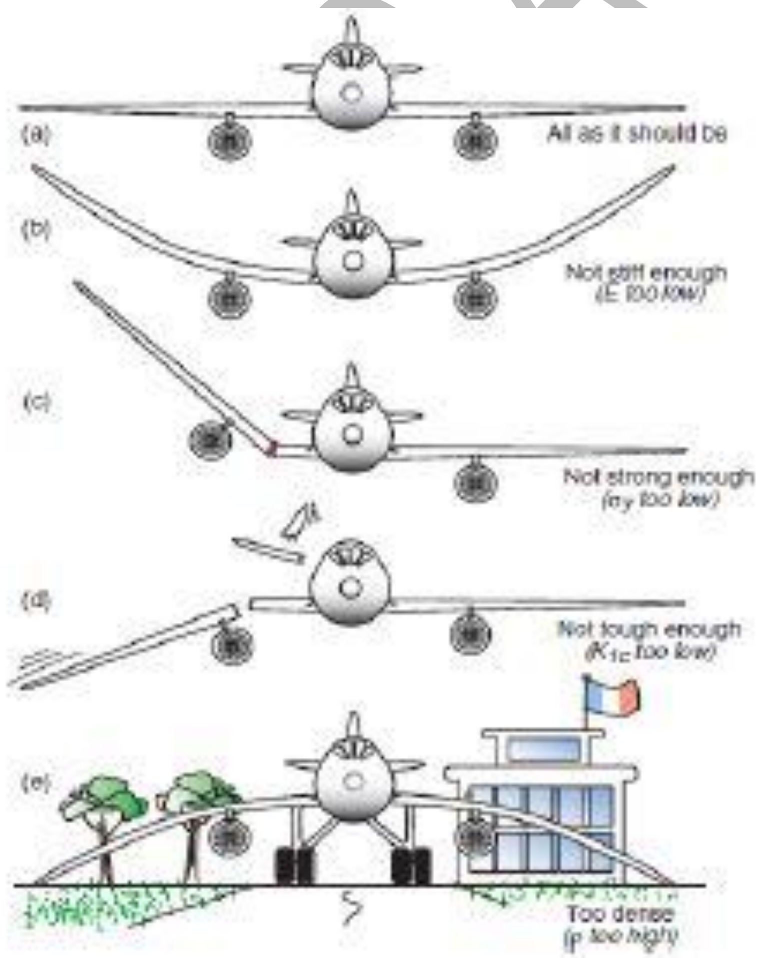
Material properties

Mechanical properties

A steel ruler is easy to bend elastically—'elastic' means that it springs back when released. Its elastic stiffness (here, resistance to bending) is set partly by its shape—thin strips are easy to bend—and partly by a property of the steel itself: their elastic moduli, E. Materials with high E, like steel, are intrinsically stiff; those with low E, like polyethylene, are not. The steel ruler bends elastically, but if it is a good one, it is hard to give it a permanent bend. Permanent deformation has to do with strength, not stiffness. The ease with which a ruler can be permanently bent depends, again, on its shape and on a different property of the steel—its yield strength, σy. Materials with large σy, like titanium alloys, are hard to deform permanently even though their stiffness, coming from E, may not be high; those with low σy, like lead, can be deformed with ease. When metals deform, they generally get stronger (this is called 'work hardening'), but there is an ultimate limit, called the tensile strength, σts, beyond which the material fails (the amount it stretches before it breaks is called the ductility).

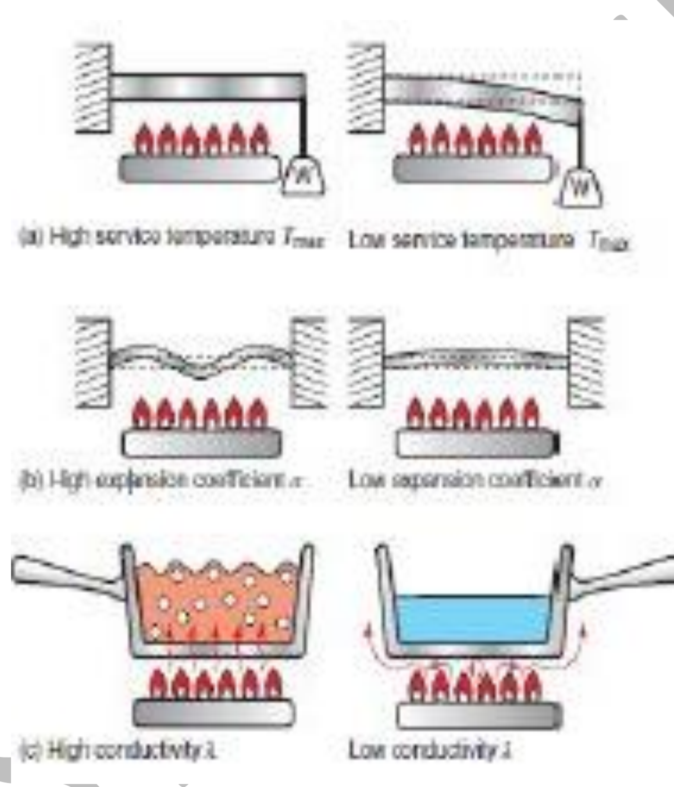


If the ruler were made not of steel but of glass or of PMMA (Plexiglas, Perspex), as transparent rulers are, it is not possible to bend it permanently at all. The ruler will fracture suddenly, without warning, before it acquires a permanent bend. We think of materials that break in this way as brittle, and materials that do not as tough. There is no permanent deformation here, so σy is not the right property. The resistance of materials to cracking and fracture is measured instead by the fracture toughness, K1c. Steels are tough—well, most are (steels can be made brittle)—they have a high K1c. Glass epitomizes brittleness; it has a very low K1c. Figure (d) suggests consequences of inadequate fracture and toughness. We started with the material property density, mass per unit volume, symbol ρ. Density, in a ruler, is irrelevant. But for almost anything that moves, weight carries a fuel penalty, modest for automobiles, greater for trucks and trains, greater still for aircraft, and enormous in space vehicles. Minimizing weight has much to do with clever design is equally to choice of material. Aluminum has a low density, lead a high one. If our little aircraft were made of lead, it would never get off the ground at all (Figure e).These is not the only mechanical properties, but they are the most important ones.



Thermal properties

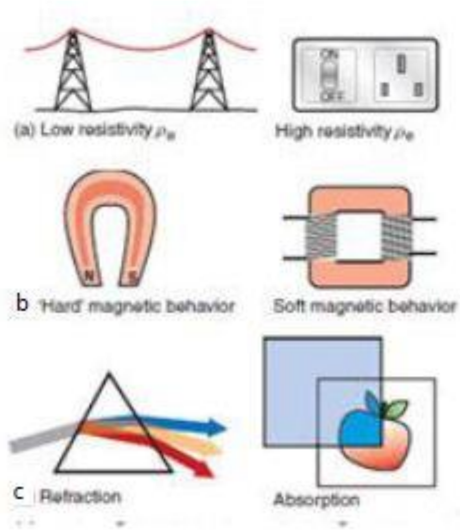
The properties of a material change with temperature, usually for the worse. Its strength falls, it starts to 'creep' (to sag slowly over time), and it may oxidize, degrade or decompose. This means that there is a limiting temperature called the maximum service temperature, Tmax, above which its use is impractical. Stainless steel has a high Tmax—it can be used up to 800°C; most polymers have a low Tmax and are seldom used above 150°C.



Most materials expand when they are heated, but by differing amounts depending on their thermal expansion coefficient, α. The expansion is small, but its consequences can be large. If, for instance, a rod is constrained, as in Figure (b), and then heated, expansion forces the rod against the constraints, causing it to buckle. Railroad track buckles in this way if provision is not made to cope with it. Some materials—metals, for instance—feel cold; others—like woods—feel warm. This feel has to do with two thermal properties of the material: thermal conductivity and heat capacity. The first, thermal conductivity, λ, measures the rate at which heat flows through the material when one side is hot and the other cold. Materials with high λ are what you want if you wish to conduct heat from one place to another, as in cooking pans, radiators and heat exchangers; Figure (c) suggests consequences of high and low λ for the cooking vessel. But low λ is useful too—low λ materials insulate homes, reduce the energy consumption of refrigerators and freezers, and enable space vehicles to re-enter the earth's atmosphere. These applications have to do with long-time, steady, heat flow. When time is limited, that other property—heat capacity, Cp—matters. It measures the Amount of heat that it takes to make the temperature of material rise by a given amount. High heat capacity materials—copper, for instance—require a lot of heat to change their temperature; low heat capacity materials, like polymer foams, take much less

Electrical, magnetic and optical properties

We start with electrical conduction and insulation (Fig a). Without electrical conduction we would lack the easy access to light, heat, power, control and communication that—today—we take for granted. Metals conduct well—copper and aluminum are the best of those that are affordable. But conduction is not always a good thing. Fuse boxes, switch casings, all require insulators. Here the property we want is resistivity, ρe, the inverse of electrical conductivity κe. Most plastics and glass have high resistivity (Figure a)—they are used as insulators—though, by special treatment, they can be made to conduct a little. Electricity and magnetism are closely linked. Electric currents induce magnetic fields; a moving magnet induces, in any nearby conductor, an electric current. The response of most materials to magnetic fields is too small to be of practical value. But a few—called ferromagnets have the capacity to trap a magnetic field permanently. These are called 'hard' magnetic materials because, once magnetized, they are hard to demagnetize. They are used as permanent magnets in headphones, motors and dynamos. Here the key property is the remanence, a measure of the intensity of the retained magnetism.



A few others—'soft Magnet materials—are easy to' magnetize and demagnetize. They are the materials of transformer cores. They have the capacity to conduct a magnetic field, but not retain it permanently (Fig b). For these a key property is the saturation magnetization, which measures how large a field the material can conduct. Materials respond to light as well as to electricity and magnetism—hardly surprising, since light itself is an electromagnetic wave. Materials that are opaque reflect light; those that are transparent refract it, and some have the ability to absorb some wavelengths (colors) while allowing others to pass freely (Figure c).

<u>Chemical properties</u>

Products often have to function in hostile environments, exposed to corrosive fluids, to hot gases or to radiation. Damp air is corrosive, so is water; the sweat of your hand is particularly corrosive, and of course there are far more aggressive environments than these. If the product is to survive for its design life it must be made of materials—or at least coated with materials—that can tolerate the surroundings in which they operate. Figure 2.6 illustrates some of the commonest of these: fresh and salt water, acids and alkalis, organic solvents, oxidizing flames and ultraviolet radiation. We regard the intrinsic resistance of a material to each of these as material properties, measured on a scale of 1 (very poor) to 5 (very good).

Chemical properties: resistance to water, acids, alkalis, organic solvents, oxidation and radiation.

Aircraft Metals

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, the selection of inferior materials may result in the loss of both lives and equipment. The use of unsuitable materials will lead to accidents. The selection of the correct material for a specific job demands familiarity with the most common physical properties of various metals.

Properties of Metals

Of the primary concern in aircraft, the general properties of metals and their alloys are 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 aluminum 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.

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.

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.

Malleability

A metal which can be hammered, rolled, or pressed into various shapes without cracking, breaking, or leaving some other detrimental effect, 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

Ductility is the property of a metal which permits it to be permanently drawn, bent, or twisted into various shapes without breaking. 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, aluminum 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.

Toughness

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.

Brittleness

Brittleness is the property of a metal which allows little bending or deformation without shattering. 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 aluminum, and very hard steel are examples of brittle metals.

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 aluminum alloys at approximately 1,100 °F.

Conductivity

Conductivity is the property which enables a metal to carry heat or electricity. 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.

Selection of Aircraft materials

- High strength to weight ratio
- High specific strength
- High thermal resistance/ low thermal conductivity
- High melting point
- Low cost
- Durable
- High fatigue and creep resistance
- Density should be less
- Good formability, machinability, weld ability
- High Corrosion resistance
- Low thermal expansion

Ferrous Aircraft Metals

The term "ferrous" applies to the group of metals having iron as their principal constituent.

Iron

If carbon is added to iron, in percentages ranging up to approximately 1 percent, the product is vastly superior to iron alone and is classified as carbon steel. 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.

Steel and Steel Alloys

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. The first two digits indicate the type of steel, the second digit also generally (but not always) gives the approximate amount of the major alloying element, and the last two (or three) digits are intended to indicate the approximate middle of the carbon range.

However, a deviation from the rule of indicating the carbon range is sometimes necessary. 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.

The list of standard steels is altered from time to time to accommodate steels of proven merit and to provide for changes in the metallurgical and engineering requirements of industry. Metal stock is manufactured in several forms and shapes, including sheets, bars, rods, tubing, extrusions, forgings, and castings. Sheet metal is made in a number of sizes and thicknesses. Specifications designate thicknesses in thousandths of an inch. Bars and rods are supplied in a variety of shapes, such as round, square, rectangular, hexagonal, and octagonal. Tubing can be obtained in round, oval, rectangular, or streamlined shapes. The size of tubing is generally specified by outside diameter and wall thickness. The sheet metal is usually formed cold in such machines as presses, bending brakes, draw benches, or rolls. Forgings are shaped or formed by pressing or hammering heated metal in dies. Castings are produced by pouring molten metal into molds. The casting is finished by machining.

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. (Few nonferrous metals give off sparks when touched to a grinding stone. Therefore, these metals cannot be successfully identified by the spark test.) Identification by spark testing is often inexact unless performed by an experienced person, or the test pieces differ greatly in their carbon content and alloying constituents.

Wrought iron produces long shafts that are straw colored 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.

Types, Characteristics, and Uses of Alloyed Steels

Steel containing carbon in percentages ranging from 0.10 to 0.30 percent is classed as low carbon steel. The equivalent SAE numbers range from 1010 to 1030. 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.

Steel containing carbon in percentages ranging from 0.30 to 0.50 percent is classed as medium carbon steel. This steel is especially adaptable for machining or forging, and where surface hardness is desirable. Certain rod ends and light forgings are made from SAE 1035 steel.

Steel containing carbon in percentages ranging from 0.50 to 1.05 percent is classed as high carbon steel. The addition of other elements in varying quantities adds to the hardness of this 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. SAE 1095 in sheet form is used for making flat springs and in wire form for making coil springs.

The various nickel steels 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. SAE 2330 steel is used extensively for aircraft parts, such as bolts, terminals, keys, clevises, and pins.

Chromium steel is high in hardness, strength, and corrosion resistant properties, and is particularly adaptable for heat-treated forgings which require greater toughness and strength than may be obtained in plain carbon steel. It can be used for such articles as the balls and rollers of antifriction bearings.

Chrome-nickel or stainless steels are the corrosion resistant metals. 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 chrome-vanadium steels are made of approximately 18 percent vanadium and about 1 percent chromium. When 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.

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. 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.

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.

Inconel is a nickel-chromium-iron alloy closely resembling stainless steel (corrosion resistant steel, CRES) in appearance. Aircraft exhaust systems use both alloys interchangeably. Because the two alloys look very much alike, a distinguishing test is often necessary. One method of identification is to use an electrochemical technique identify the nickel (Ni) content of the alloy. Inconel has a nickel content greater than 50 percent, and the electrochemical test detects nickel. The tensile strength of Inconel is 100,000 psi annealed, and 125,000 psi when hard rolled. It is highly resistant to salt water and is able to withstand temperatures as high as 1,600 °F. Inconel welds readily and has working qualities quite similar to those of corrosion resistant steels.

Nonferrous Aircraft Metals

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 aluminum, titanium, copper, and magnesium, as well as such alloyed metals as Monel and babbit.

Aluminum and Aluminum Alloys

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 as 0.356 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.

The casting alloys are identified by a letter preceding the alloy number. When a letter precedes a number, it indicates a slight variation in the composition of the original alloy. This variation in composition is simply to impart some desirable quality. In casting alloy 214, for example, the addition of zinc to improve its pouring qualities is indicated by the letter A in front of the number, thus creating the designation A214.

When castings have been heat treated, the heat treatment and the composition of the casting is indicated by the letter T, followed by an alloying number. An example of this is the sand casting alloy 355, which has several different compositions and tempers and is designated by 355-T6, 355-T51, or C355-T51.

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.

Effect of Alloying Element

1000 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.

2000 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.

3000 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.

4000 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.

5000 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.

6000 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.

7000 series - Zinc is the principal alloying element. The most popular alloy of the series is 6061. 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.

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.

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.

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 Dowmetal™ 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.

Titanium and Titanium Alloys

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,, 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.

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, sometimes termed “bronze” because of its tin content, is used 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 be added. 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, 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.

Material	**E** **10^9 N/m^2**	**K** **10^9 N/m^2**	**G** **10^9 N/m^2**
Diamond	1120	540	450
Tungsten	390	200	150
Steel	200	160	84
Copper	110	140	44
Aluminum	70	70	70
Glass	55	31	23
Water	55	31	23

Material	**K, thermal conductivity (W/mK)**	**Linear expansion coefficient 10^{-6} m/mK**	**Volume expansion coefficient 10^{-6} m3/m3K**
Aluminum	205	25	75
Brass	109	19	56
Copper	385	17	51
Gold	314	14	42
Steel	50.2	12	35

Stainless steel	Aluminum
Strength more	Strength less
Strength to weight ratio less	Strength to weight ratio more
Corrosion resistance more	High oxidation and corrosion resistance
Electrical conductivity poor	Electrical conductivity high
Thermal conductivity poor	Thermal conductivity high
Can be used at high temperature applications like 800oc	Can be used up to 400oc
Harder to form(workability)	Soft and easy to cut
Weld ability easy	Weld ability difficult
Less reaction with foods	May react with foods
Cost high	Cost less

Hardness Testing

Hardness is defined as the resistance of a material to permanent deformation such as indentation, wear, abrasion, scratch. Principally, the importance of hardness testing has to do with the relationship between hardness and other properties of material. For example, both the hardness test and the tensile test measure the resistance of a metal to plastic flow, and results of these tests may closely parallel each other. The hardness test is preferred because it is simple, easy, and relatively nondestructive.

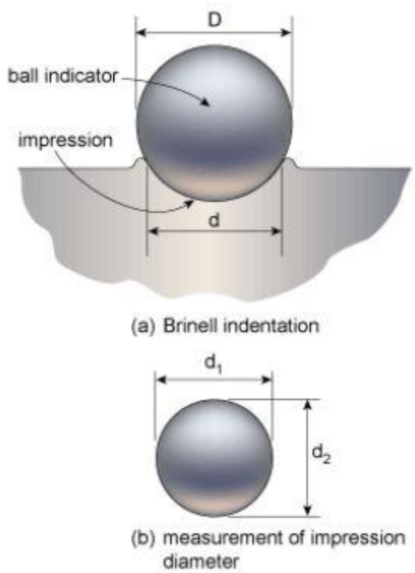
Hardness testing is a method of determining the results of heat treatment as well as the state of a metal prior to heat treatment. Since hardness values can be tied in with tensile strength values and, in part, with wear resistance, hardness tests are a valuable check of heat treat control and of material properties.

Practically all hardness testing equipment now uses the resistance to penetration as a measure of hardness. Included among the better known hardness testers are the Brinell, vicker and Rockwell, all of which are described and illustrated in this section.

Brinell Tester

The Brinell hardness tester uses a hardened spherical ball, which is forced into the surface of the metal. This ball is 10 millimeters (0.3937 inch) in diameter. A pressure of 3,000 kilograms is used for ferrous metals and 500 kilograms for nonferrous metals. The pressure 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.



(a) Brinell indentation
(b) measurement of impression diameter

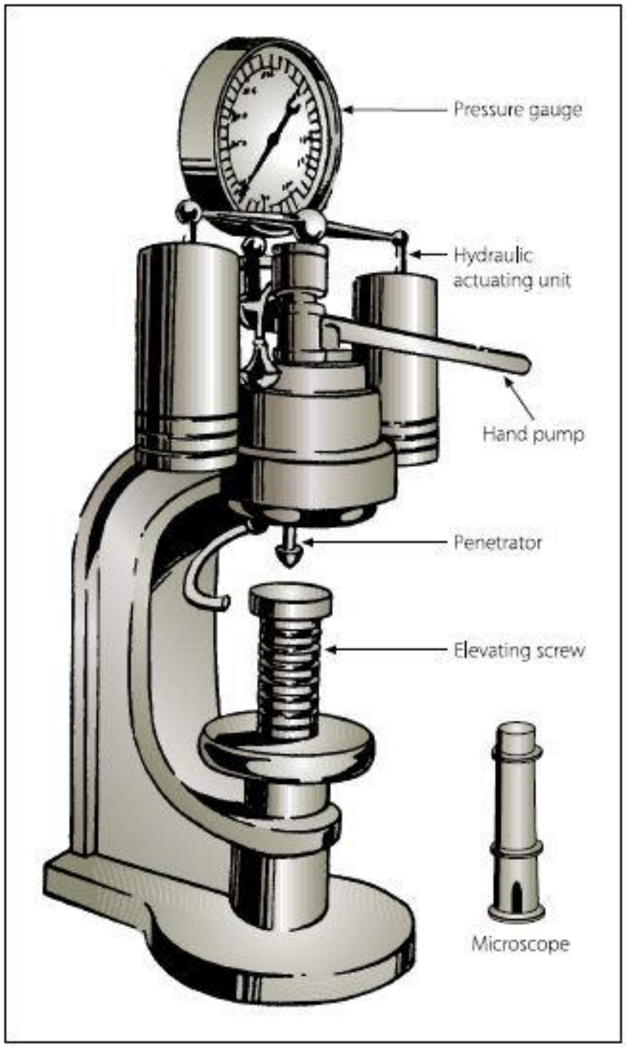
$$BHN = \frac{P}{\frac{\pi D}{2}\left[D - \sqrt{D^2 - d^2}\right]}$$

Where:

P is the test load [kg]

D is the diameter of the ball [mm]

d is the average impression diameter of indentation [mm]



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.

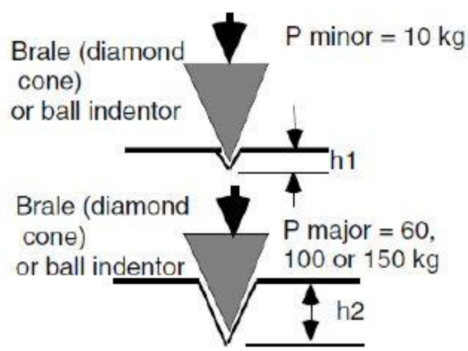
Otherwise, Brinell hardness number is calculated by dividing the load applied by the surface area of the indentation. When the indentor is retracted two diameters of the impression, d1 and d2, are measured using a microscope with a calibrated graticule and then averaged as shown in figure below

The diameter of the impression is the average of two readings at right angles and the use of a Brinell hardness number table can simplify the determination of the Brinell hardness. A well-structured Brinell hardness number reveals the test conditions, and looks like this, "75 HB 10/500/30" which means that a Brinell Hardness of 75 was obtained using a 10mm diameter hardened steel with a 500 kilogram load applied for a period of 30 seconds. On tests of extremely hard metals a tungsten carbide ball is substituted for the steel ball. Compared to the other hardness test methods, the Brinell ball makes the deepest and widest indentation, so the test averages the hardness over a wider amount of material, which will more accurately account for multiple grain structures and any irregularities in the uniformity of the material. This method is the best for achieving the bulk or macro-hardness of a material, particularly those materials with heterogeneous structures.

Rockwell Tester

The Rockwell hardness tester measures the resistance to penetration, as does the Brinell tester. Instead of measuring the diameter of the impression, the Rockwell tester measures the depth, and the hardness is indicated directly on a dial attached to the machine. The dial numbers in the outer circle are black, and the inner numbers are red. 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 the material.

Two types of penetrators are used with the Rockwell tester: a diamond cone and a hardened steel ball. The load which forces the penetrator into the metal is called the major load and is measured in kilograms. The results of each penetrator and load combination are reported on separate scales, designated by letters. The penetrator, the major load, and the scale vary with the kind of metal being tested.

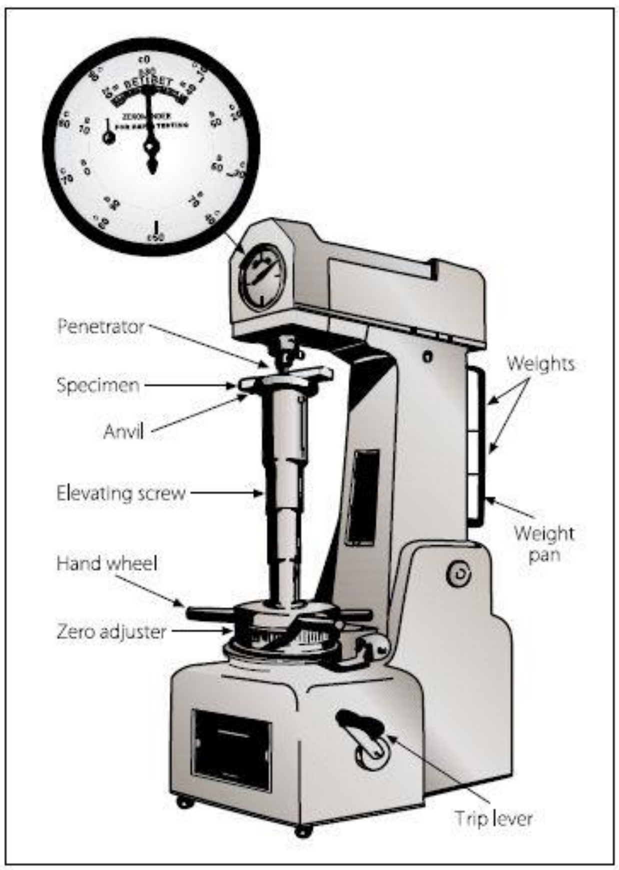


Rockwell Scale (X =)	Indentor	Pmajor (kg)
A	Brale (diamond)	60
B	1/16" ball	100
C	Brale (diamond)	150
D	Brale (diamond)	100
E	1/8" ball	100
F	1/8" ball	60
M	1/4" ball	100
R	1/2" ball	60

$$HRX = R_X = M - \frac{(h_2 - h_1)}{0.002}$$

M = 100 for A, C, and D scales

M = 130 for B, E, M, R, etc. scales



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. In addition to the “C” and “B” scales, there are other setups for special testing. The scales, penetrators, major loads, and dial numbers to be read are listed in Figure.

Scale Symbol	Penetrator	Major Load (kg)	Dial Color/Number
A	Diamond	60	Black
B	1⁄16-inch ball	100	Red
C	Diamond	150	Black
D	Diamond	100	Black
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
K	1⁄8-inch ball	150	Red

The Rockwell tester is equipped with a weight pan, and two weights are supplied with the machine. One weight is marked in red. The other weight is marked in black. With no weight in the weight pan, the machine applies a major load of 60 kilograms. If the scale setup calls for a 100 kilogram load, the red weight is placed in the pan. For a 150 kilogram load, the black weight is added to the red weight. The black weight is always used with the red weight; it is never used alone.

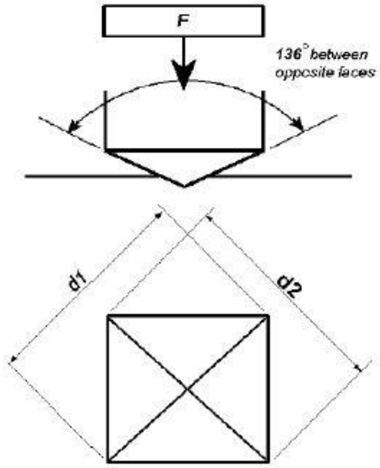
Practically all testing is done with either the B-scale setup or the C-scale setup. For these scales, the colors may be used as a guide in selecting the weight (or weights) and in reading the dial. For the B-scale test, use the red weight and read the red numbers. For a C scale test, add the black weight to the red weight and read the black numbers.

In setting up the Rockwell machine, use the diamond penetrator for testing materials known to be hard. If the hardness is unknown, try the diamond, since the steel ball may be deformed if used for testing hard materials. If the metal tests below C-22, then change to the steel ball. Use the steel ball for all soft materials, those testing less than B-100. Should an overlap occur at the top of the B-scale and the bottom of the C-scale, use the C-scale setup. 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 before the lever is tripped. This preliminary load is called the minor load. The minor load is 10 kilograms regardless of the scale setup. 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 aluminum 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.

Vickers hardness test

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation.



$$HV = \frac{2F \sin \frac{136^o}{2}}{d^2} \qquad HV = 1.854 \frac{F}{d^2} \text{ approximately}$$

F= Load in kgf

d = Arithmetic mean of the two diagonals, $d1$ and $d2$ in mm

HV = Vickers hardness

When the mean diagonal of the indentation has been determined the Vickers hardness may be calculated from the formula, but is more convenient to use conversion tables. The Vickers hardness should be reported like 800 HV/10, which means a Vickers hardness of 800, was obtained using a 10 kgf force. Several different loading settings give practically identical hardness numbers on uniform material, which is much better than the arbitrary changing of scale with the other hardness testing methods. The advantages of the Vickers hardness test are that extremely accurate readings can be taken, and just one type of indenter is used for all types of metals and surface treatments. Although thoroughly adaptable and very precise for testing the softest and hardest of materials, under varying loads, the Vickers machine is a floor standing unit that is more expensive than the Brinell or Rockwell machines.

NON-DESTRUCTIVE TESTING

Objective of NDT are to gain experience with and understanding of the types, advantages and applications of various NDT methods and to be able to choose the best NDT method for a given part.

Up to this point we have learnt various testing methods that somehow destruct the test specimens. These were, tensile testing, hardness testing, etc. In certain applications, the evaluation of engineering materials or structures without impairing their properties is very important, such as the quality control of the products, failure analysis or prevention of the engineered systems in service.

This kind of evaluations can be carried out with Nondestructive test (NDT) methods. It is possible to inspect and/or measure the materials or structures without destroying their surface texture, product integrity and future usefulness.

The field of NDT is a very broad, interdisciplinary field that plays a critical role in inspecting that structural component and systems perform their function in a reliable fashion. Certain standards has been also implemented to assure the reliability of the NDT tests and prevent certain errors due to either the fault in the equipment used, the miss-application of the methods or the skill and the knowledge of the inspectors.

Successful NDT tests allow locating and characterizing material conditions and flaws that might otherwise cause planes to crash, reactors to fail, trains to derail, pipelines to burst, and variety of less visible, but equally troubling events. However, these techniques generally require considerable operator skill and interpreting test results accurately may be difficult because the results can be subjective.

These methods can be performed on metals, plastics, ceramics, composites, cermets, and coatings in order to detect cracks, internal voids, surface cavities, delamination, incomplete c defective welds and any type of flaw that could lead to premature failure. Commonly used

NDT test methods can be seen in table below. These are universal NDT methods; however, very special tests have been developed for specific applications.

Technique	Capabilities	Limitations
Visual Inspection	Macroscopic surface flaws	Small flaws are difficult to detect, no subsurface flaws.
Microscopy	Small surface flaws	Not applicable to larger structures; no subsurface flaws.
Radiography	Subsurface flaws	Smallest defect detectable is 2% of the thickness; radiation protection. No subsurface flaws not for porous materials
Dye penetrate	Surface flaws	No subsurface flaws not for porous materials
Ultrasonic	Subsurface flaws	Material must be good conductor of sound.
Magnetic Particle	Surface / near surface and layer flaws	Limited subsurface capability, only for ferromagnetic materials.
Eddy Current	Surface and near surface flaws	Difficult to interpret in some applications; only for metals.
Acoustic emission	Can analyze entire structure	Difficult to interpret, expensive equipments.

Visual inspection:

VI is particularly effective detecting macroscopic flaws, such as poor welds. Many welding flaws are macroscopic: crater cracking, undercutting, slag inclusion, incomplete penetration welds, and the like. Likewise, VI is also suitable for detecting flaws in composite structures and piping of all types. Essentially, visual inspection should be performed the way that one would inspect a new car prior to delivery, etc. Bad welds or joints, missing fasteners or components, poor fits, wrong dimensions, improper surface finish, delamination’s in coatings, large cracks, cavities, dents, inadequate size, wrong parts, lack of code approval stamps and similar proofs of testing.

Radiography:

Radiography has an advantage over some of the other processes in that the radiography provides a permanent reference for the internal soundness of the object that is radiographed.

The x-ray emitted from a source has an ability to penetrate metals as a function of the accelerating voltage in the x-ray emitting tube. If a void present in the object being radiographed, more x-rays will pass in that area and the film under the part in turn will have more exposure than in the non-void areas. The sensitivity of x-rays is nominally 2% of the materials thickness. Thus for a piece of steel with a 25mm thickness, the smallest void that could be detected would be 0.5mm in dimension. For this reason, parts are often radiographed in different planes. A thin crack does not show up unless the x-rays ran parallel to the plane 0 the crack. Gamma radiography is identical to x-ray radiography in function. The difference is the source of the penetrating electromagnetic radiation which is a radioactive material such m Co 60. However this method is less popular because of the hazards of handling radioactive materials.

Liquid (Dye) penetrant method:

Liquid penetrant inspection (LPI) is one of the most widely used nondestructive evaluation (NDE) methods. Its popularity can be attributed to two main factors, which are its relative ease of use and its flexibility. The technique is based on the ability of a liquid to be drawn into a "clean" surface breaking flaw by capillary action. .

This method is an inexpensive and convenient technique for surface defect inspection. The limitations of the liquid penetrant technique include the inability to inspect subsurface flaws and a loss of resolution on porous materials. Liquid penetrant testing is largely used on nonmagnetic materials for which magnetic particle inspection is not possible.

Materials that are commonly inspected using LPI include the following; metals (aluminum, copper, steel, titanium, etc.), glass, many ceramic materials, rubber, plastics. Liquid penetrant inspection is used to inspect of flaws that break the surface of the sample. Some of these flaws are listed below; fatigue cracks, quench cracks grinding cracks, overload and impact fractures, porosity, laps seams, pin holes in welds, lack of fusion or braising along the edge of the bond line.

Magnetic particles:

Magnetic particle inspection is one of the simple, fast and traditional nondestructive testing methods widely used because of its convenience and low cost. This method uses magnetic fields and small magnetic particles, such as iron filings to detect flaws in components. The only requirement from an inspect ability standpoint is that the component being inspected must be made of a ferromagnetic material such iron, nickel, cobalt, or some of their alloys, since these materials are materials that can be magnetized to a level that will allow the inspection to be effective. On the other hand, an enormous volume of structural steels used in engineering is magnetic. In its simplest application, an electromagnet yoke is placed on the surface of the part to be examined, a kerosene-iron filling suspension is poured on the surface and the electromagnet is energized. If there is a discontinuity such as a crack or a flaw on the surface of the part, magnetic flux will be broken and a new south and north pole will form at each edge of the discontinuity. Then just like if iron particles are scattered on a cracked magnet, the particles will be attracted to and cluster at the pole ends of the magnet, the iron particles will also be attracted at the edges of the crack behaving poles of the magnet. This cluster of particles is much easier to see than the actual crack and this is the basis for magnetic particle inspection. For the best sensitivity, the lines of magnetic force should be perpendicular to the defect.

Eddy current testing:

Eddy currents are created through a process called electromagnetic induction. When alternating current is applied to the conductor, such as copper wire, a magnetic field develops in and around the conductor. This magnetic field expands as the alternating current rises to maximum and collapses as the current is reduced to zero. If another electrical conductor is brought into the close proximity to this changing magnetic field, current will be induced in this second conductor. These currents are influenced by the nature of the material such as voids, cracks, changes in grain size, as well as physical distance between coil and material.

These currents form impedance on a second coil which is used to as a sensor. In practice a probe is placed on the surface of the part to be inspected, and electronic equipment monitors the eddy current in the work piece through the same probe. The sensing circuit is a part of the sending coil.

Eddy currents can be used for crack detection, material thickness measurements, coating thickness measurements, conductivity measurements for material identification, heat damage detection, case depth determination, heat treatment monitoring.

Some of the advantages of eddy current inspection include; sensitivity to small cracks and other defects, ability to detect surface and near surface defects, immediate results, portable equipment, suitability for many different applications, minimum part preparation, no necessity to contact the part under inspection, ability to inspect complex shapes and sizes of conductive materials.

Some limitation of eddy current inspection; applicability just on conductive materials, necessity for an accessible surface to the probe, skillful and trained personal, possible interference of surface finish and roughness, necessity for reference standards for setup, limited depth of penetration, inability to detect of the flaws lying parallel to the probe coil winding and probe scan direction.

Ultrasonic Inspection:

Ultrasonic Testing (UT) uses a high frequency sound energy to conduct examinations and make measurements. Ultrasonic inspection can be used for flaw detection I evaluation, dimensional measurements, material characterization, and more. A typical UT inspection system consists of several functional units, such as the pulser/receiver, transducer, and display devices. A pulser/receiver is an electronic device that can produce high voltage electrical pulse. Driven by the pulser, the transducer of various types and shapes generates high frequency ultrasonic energy operating based on the piezoelectricity technology with using quartz, lithium sulfate, or various ceramics. Most inspections are carried out in the frequency range of 1 to 25MHz. Couplants are used to transmit the ultrasonic waves from the transducer to the test piece; typical couplants are water, oil, glycerin and grease.

The sound energy is introduced and propagates through the materials in the form of waves and reflected from the opposing surface. An internal defect such as crack or void interrupts the waves' propagation and reflects back a portion of the ultrasonic wave. The amplitude of the energy and the time required for return indicate the presence and location of any flaws in the work-piece.

The ultrasonic inspection method has high penetrating power and sensitivity. It can be used from various directions to inspect flaws in large parts, such as rail road wheels pressure vessels and die blocks. This method requires experienced personnel to properly conduct the inspection and to correctly interpret the results.

As a very useful and versatile NDT method, ultrasonic inspection method has the following advantages; sensitivity to both surface and subsurface discontinuities, superior depth of penetration for flaw detection or measurement, ability to single-sided access for pulse-echo technique, high accuracy in determining reflector position and estimating size and shape, minimal part preparation, instantaneous results with electronic equipment, detailed imaging with automated systems, possibility for other uses such as thickness measurements.

Its limitations; necessity for an accessible surface to transmit ultrasound, extensive skill and training, requirement for a coupling medium to promote transfer of sound energy into test specimen, limits for roughness, shape irregularity, smallness, thickness or not homogeneity, difficulty to inspect of coarse grained materials due to low sound transmission and high signal noise, necessity for the linear defects to be oriented parallel to the sound beam, necessity for reference standards for both equipment calibration, and characterization of flaws.

Acoustic Method:

There are two different kind of acoustic methods: (a) acoustic emission; (b) acoustic impact technique.

Acoustic emission:

This technique is typically performed by elastically stressing the part or structure, for example, bending a beam, applying torque to a shaft, or pressurizing a vessel and monitoring the acoustic responses emitted from the material. During the structural changes the material such as plastic deformation, crack initiation, and propagation, phase transformation, abrupt reorientation of grain boundaries, bubble formation during boiling in cavitation, friction and wear of sliding interfaces, are the source of acoustic signals. Acoustic emissions are detected with sensors consisting of piezoelectric ceramic elements. This method is particularly effective for continuous surveillance of load-bearing structures.

Acoustic impact technique:

This technique consists of tapping the surface of an object and listening to and analyzing the signals to detect discontinuities and flaws. The principle is basically the same as when one taps walls, desktops or countertops in various locations with a finger or a hammer and listens to the sound emitted. Vitrified grinding wheels are tested in a similar manner to detect cracks in the wheel that may not be visible to the naked eye. This technique is easy to perform and can be instrumented and automated. However, the results depend on the geometry and mass of the part so a reference standard is necessary for identifying flaws.

Procedure

Liquid penetrant method:

In this method the surfaces to be inspected should be free from any coatings, paint, grease, dirt, dust, etc., therefore, should be cleaned with an appropriate way. Special care should be taken not to give additional damage to the surface to be inspected during the cleaning process. Otherwise, the original nature of surface could be disturbed and the results could be erroneous with the additional interferences of the surface features formed during the cleaning process. Surface cleaning can be performed with alcohol. Special chemicals like cleaner-remover can also be applied if needed. In the experiment, only cleaner-remover will be sufficient. Subsequent to surface cleaning, the surface is let to dry for 2 minutes. Commercially available cans of liquid penetrant dyes with different colors are used to reveal the surface defects.

Steps used in the experiment:

1. Clean the surface with alcohol and let surface dry for 5 min.

2. Apply the liquid penetrant spray (red can) to the surface and brush for further penetration. Then, wait for 20 min.

3. Wipe the surface with a clean textile and subsequently apply remover spray (blue can) to remove excess residues on the surface and wait for a few min.

4. Apply the developer spray (yellow can) at a distance of about 30cm from the surface. The developer will absorb the penetrant that infiltrated to the surface features such as cracks, splits, etc., and then reacted with it to form a geometric shape which is the negative of the geometry of the surface features from which the penetrant is sucked.

5. The polymerized material may be collected on a sticky paper for future evaluation and related documentation, if needed.

Magnetic particle:

In this experiment, commercially available magnetic powder manufactured for NDT inspection will be used. A strong U shape magnet will be used to provide the necessary magnetic field at the inspected area.

The following steps are applied during the experiment;

1. The surface of the specimen will be roughly cleaned wiping with a piece of textile.

2. The fluorescent magnetic spray will be applied on the surface being inspected.

3. Magnetic field will be applied with a strong magnet to the location of interest.

4. The spots where the fluorescent magnetic particles accumulated will be inspected under UV light.

Eddy current inspection:

For this experiment, Magnefest ED-51 0 type unit will be used. A pencil type prop will be used for the inspections. The inspection is performed with 2 MHz frequency and at the related calibration settings. The test blocks were previously prepared for this experiment. Any coatings or paints on the surface of inspected specimens should be treated with special procedures.

The following steps should be applied during the experiment:

l. Inspection area should be clean, smooth, free from any irregular or uneven paint, dirt, grease, etc.

2. There shouldn't be any visible damage or discontinuity.

3. During the inspection procedure the probe will be positioned near the inspection area, on the compensation point and lift off and zero will be adjusted if necessary.

4. The inspection will be carried out by using probe scans. The probe tip will be always at a right angle the inspection surface.

5. Any indication with indicator deflection to the right should be evaluated. All evaluated indications should be measured.

6. After this procedure, all evaluated indications with indicator deflections, will be classified as cracks and be recorded.

Ultrasonic inspection:

For this experiment, USM-2 type ultrasonic unit will be used. The props used supports to work at frequency of 5 MHz. Echo techniques will be employed to find the cracks. Instrument will be tuned to a frequency of 5 MHz. An appropriate couplant used should not cause corrosion or other damage. During the inspection the calibration will be done on the reference standard, if needed. Two different test blocks will be employed in this test, sufficient amount of couplant will be applied to the transducer scan areas on the forward and after sides of the support fitting. The display will be monitored for crack indications. A crack signal will be similar to the following:

The following steps should be applied during the experiment:

1. The couplant should be applied on the inspected area.

2. For the circular test specimen, the prop will be placed in the corresponding space in the supporting fitting tool. Enough couplant should be used between the probe and tool.

3. For the flat specimen, no tool is needed, couplant only applied between the inspected surface and the probe.

4. Special attention should be paid on the location where possible cracks exist.

5. A discontinuity like a crack produces a peak on the screen.

6. Attention should also be given to the movement of the possible peak caused by the cracks on the specimen.

SUPER ALLOYS

Super alloys are heat-resisting alloys based on nickel, nickel-iron, or cobalt that exhibit a combination of mechanical strength and resistance to surface degradation. Super alloys are primarily used in gas turbines, coal conversion plants, and chemical process industries, and for other specialized applications requiring heat and/or corrosion resistance. A noteworthy feature of nickel-base alloys is their use in load-bearing applications at temperatures in excess of 80% of their incipient melting temperatures, a fraction that is higher than for any other class of engineering alloys. Applications of super alloys are categorized below; the bulk of tonnage is used in gas turbines:

• Aircraft gas turbines: disks, combustion chambers, bolts, casings, shafts, exhaust systems, cases, blades, vanes, burner cans, afterburners, thrust reversers

• Steam turbine power plants: bolts, blades, stack gas re-heaters

• Reciprocating engines: turbochargers exhaust valves, hot plugs, valve seat inserts

• Metal processing: hot-work tools and dies, casting dies

• Medical applications: dentistry uses, prosthetic devices

• Space vehicles: aerodynamically heated skins, rocket engine parts

• Heat-treating equipment: trays, fixtures, conveyor belts, baskets, fans, furnace mufflers

• Nuclear power systems: control rod drive mechanisms, valve stems, springs, ducting

• Chemical and petrochemical industries: bolts, fans, valves, reaction vessels, piping, pumps

• Pollution control equipment: scrubbers

• Metals processing mills: ovens, afterburners, exhaust fans

• Coal gasification and liquefaction systems: heat exchangers, re-heaters, piping.

Nickel Base Super alloys

Nickel-base super alloys are the most complex, the most widely used for the hottest parts, and, to many metallurgists, the most interesting of all super alloys. They currently constitute over 50% of the weight of advanced aircraft engines. The principal characteristics of nickel as an alloy base are the high phase stability of the face-centered cubic (FCC) nickel matrix and the capability to be strengthened by a variety of direct and indirect means. Further, the surface stability of nickel is readily improved by alloying with chromium and/or aluminum.

Chemical Composition

The nickel-base super alloys discussed below are considered to be complex because they incorporate as many as a dozen elements. In addition, deleterious elements such as silicon, phosphorus, sulfur, oxygen, and nitrogen must be controlled through appropriate melting practices. Other trace elements such as selenium, bismuth, and lead, must be held to very small (ppm) levels in critical parts. Many wrought nickel-base super alloys contain 10 to 20% Cr, up to about 8% Al and Ti combined, 5 to 15% Co, and small amounts of boron, zirconium, magnesium, and carbon. Other common additions are molybdenum, niobium, and tungsten, all of which play dual roles as strengthening solutes and carbide formers. Chromium and aluminum are also necessary to improve surface stability through the formation of $Cr2O3$ and $Al2O3$, respectively. The functions of the various elements in nickel alloys are as below.

Effect	Iron base	Cobalt base	Nickel base
Solid-solution strengtheners	Cr, Mo	Nb, Cr, Mo, Ni, W, Ta	Co, Cr, Fe, Mo, W, Ta
Fcc matrix stabilizers	C, W, Ni	Ni	. . .
Carbide form			
MC Type	Ti	Ti, Ta, Nb	W, Ta, Ti, Mo, Nb
M_7C_3 type	. . .	Cr	Cr
$M_{23}C_6$ type	Cr	Cr	Cr, Mo, W
M_6C type	Mo	Mo, W	Mo, W
Carbonitrides			
M(CN) type	C, N	C, N	C, N
Forms γ' $Ni_3(Al, Ti)$	Al, Ni, Ti	. . .	Al, Ti
Retards formation of hexagonal $\eta(Ni_3Ti)$	Al, Zr	. . .	. . .
Raises solvus temperature of γ'	. . .	. . .	Co
Hardening precipitates and/or intermetallics	Al, Ti, Nb	Al, Mo, Ti(a) W, Ta	Al, Ti, Nb
Forms γ'' (Ni_3Nb)	. . .	. . .	Nb
Oxidation resistance	Cr	Al, Cr	Al, Cr
Improves hot corrosion resistance	La, Y	La, Y, Th	La, Th
Sulfidation resistance	Cr	Cr	Cr
Increases rupture ductility	B	B, Zr	B(b), Zr
Causes grain-boundary segregation	. . .	. . .	B, C, Zr

Role of elements in super alloys

Iron Base Super alloys

Microstructure

Irons-base super alloys evolved from austenitic stainless steels and are based on the principle of combining a closed-packed fcc matrix with (in most cases) both solid-solution hardening and precipitate-forming elements. The austenitic matrix is based on nickel and iron, with at least 25% Ni needed to stabilize the fcc phase. Other alloying elements, such as chromium, partition primarily to the austenite for solid-solution hardening. The strengthening precipitates are primarily ordered inter metallics, such as γ' Ni3Al, γNi3Ti, and γ" Ni3Nb, although carbides and carbonitrides may also be present. Elements that partition to grain boundaries, such as boron and zirconium, perform a function similar to that which occurs in nickel-base alloys; that is, grain-boundary fracture is suppressed under creep rupture conditions, resulting in significant increases in rupture life. Several groupings of iron-nickel alloys based on composition and strengthening mechanisms have been established. Alloys that are strengthened by ordered fcc γ', such as V-57 and A-286, and contain 25 to 35 wt% Ni, represent one subgroup. The γ' phase is titanium-rich in these alloys, and care must be taken to avoid an excessively high titanium-to aluminum ratio, resulting in the replacement of fcc γ' by hexagonal close-packed (hcp) γ (Ni3Ti), a less effective strengthener. A second iron-rich subgroup, of which Inconel X750 and Incoloy 901 are examples, contains at least 40% Ni, as well as higher levels of solid-solution strengthening and precipitate-forming elements. Boron in quantities of 0.003 to 0.03 wt% and, less frequently, small additions of zirconium are added to improve stress rupture properties and hot workability. Zirconium also forms the MC carbide ZrC. other MC carbide, NbC, is found in alloys that contain niobium, such as Inconel 706 and Inconel 718.

Vanadium also is added in small quantities to iron nickel alloys to improve both notch ductility at service temperatures and hot workability. Manganese and rare earth elements may be present as deoxidizers; rare earths also have been added to improve oxidation resistance. Inconel 718 is one of the strongest (at low temperatures) and most widely used of all super alloys, but it rapidly loses strength in the range of 650 to 815 °C. This is probably due to the high lattice misfit associated with the precipitation of γ" in the austenitic matrix.

Cobalt Base Super alloys

Wrought cobalt-base alloys, unlike other super alloys, are not strengthened by a coherent, ordered precipitate. Rather, they are characterized by a solid solution strengthened austenitic (fcc) matrix in which a small quantity of carbides is distributed. Cobalt crystallizes in the hcp structure below 417 °C. At higher temperatures, it transforms to fcc. To avoid this transformation during service, virtually all cobalt-base alloys are alloyed with nickel in order to stabilize the fcc structure between room temperature and the melting point. Cobalt-base alloys display superior hot corrosion resistance at high temperatures, probably a consequence of the considerably higher chromium contents that are characteristic of these alloys. Cobalt-base alloys generally exhibit better weldability and thermal-fatigue resistance than do nickel-base alloys. Another advantage of cobalt-base alloys is the capability to be melted in air or argon, in contrast to the vacuum melting required for nickel-base and iron-nickel-base alloys containing the reactive metals aluminum and titanium. However, unlike nickel-base alloys, which have a high tolerance for alloying elements in solid solution, cobalt-base alloys are more likely to precipitate undesirable plate-like σ, and TCP phases.

Microstructure

Virtually all cobalt alloys are based on an fcc matrix obtained by alloying with 10% or more nickel. Iron, manganese, and carbon additions also stabilize the fcc phase, while nickel and iron additions improve workability. Exerting the opposite hcp stabilizing tendency are other common alloying elements, such as tungsten, added primarily for solid-solution strengthening, and chromium, added primarily for oxidation and hot corrosion resistance. Improved oxidation and corrosion resistance with 5 wt% Al have been noted in a few cobalt-base alloys.

Titanium additions also have been made in order to precipitate coherent, ordered Co3Ti as a strengthening phase. Unfortunately, this phase is stable only to about 700 °C (1290 °F), which is much lower than for γ' Ni3Al, Ti in Ni-base alloys. As in the case of nickel-base alloys, a variety of carbides have been found in cobalt alloys. These include M23C6, M6C, and MC carbides. In both L-605 and Haynes 188, M6C transforms into M23C6 during exposure to temperatures in the range of 816 to 927 °C for 3000 h. In addition to carbides, small quantities of intermetallic phases such as Co_3W, Co_2W, and Co_7W_6 have been found in L-605. Other alloys display the compounds CoAl, Co_3Ti, and Co_2 (Ta, Nb, Ti). However, it is unlikely that these phases contribute to the strengthening of the γ matrix. On the contrary, Co_7W_6 and Co_2 (Ta, Nb, Ti) are TCP phases that are likely to cause the deterioration of mechanical properties.

POLYMERS, POLYMERIC MATERIALS & PLASTICS AND CERAMICS & GLASS

What is Polymer?

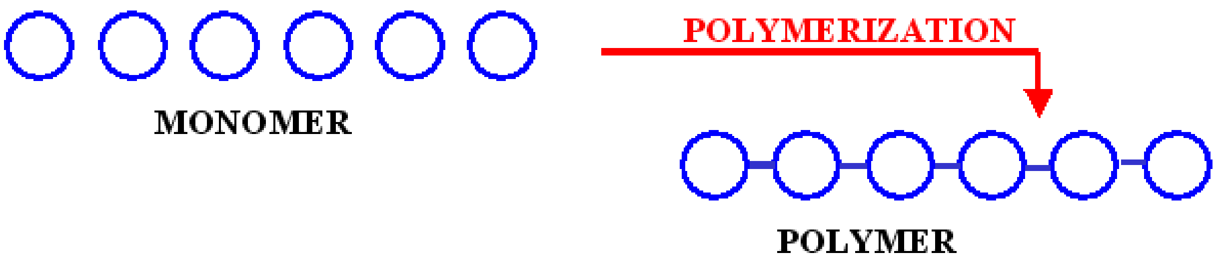
The polymers are defined as macromolecules composed of one or more chemical units (monomers) that are repeated throughout a chain is called polymer. This small molecular unit from which the polymers are used is called Monomers.

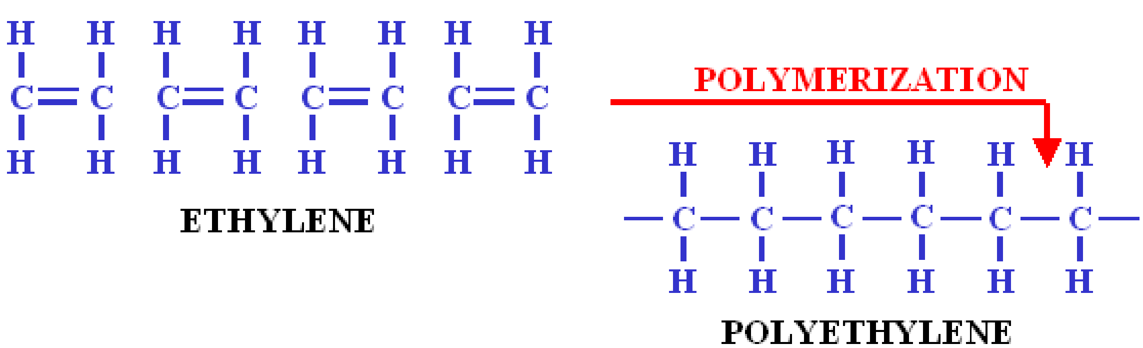
The word, polymer, implies that polymers are constructed from pieces (monomers) that can be easily connected into long chains (polymer).

This process of formation of polymers from respective monomers is called polymerization

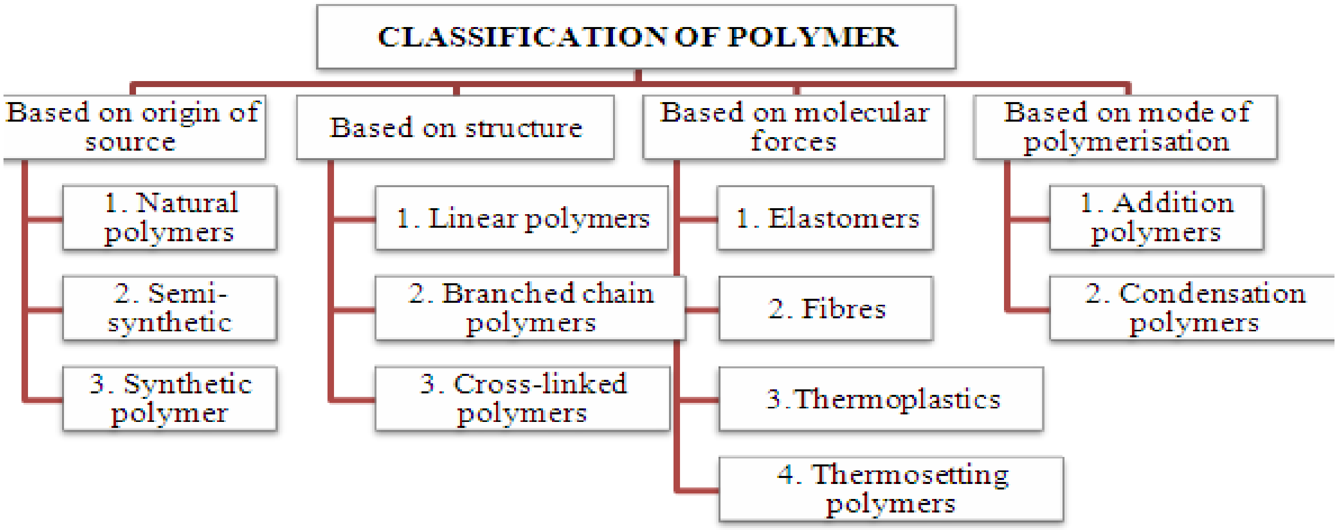
The number of repeating units (n) in the chain so formed is called the “degree of polymerization”

POLYMER:





CLASSIFICATION OF POLYMERS:



CHARACTERISTICS OF POLYMER:

CHARACTERISTICS OF POLYMER:

Polymers can be very resistant to chemicals. Consider all the cleaning fluids in your home that are packaged in plastic. Reading the warning labels that describe what happens when the chemical comes in contact with skin or eyes or is ingested will emphasize the need for chemical resistance in the plastic packaging. While solvents easily dissolve some plastics, other plastics provide safe, non-breakable packages for aggressive solvents.

Polymers can be both thermal and electrical insulators. A walk through your house will reinforce this concept, as you consider all the appliances, cords, electrical outlets and wiring that are made or covered with polymeric materials. Thermal resistance is evident in the kitchen with pot and pan handles made of polymers, the coffee pot handles, the foam core of refrigerators and freezers, insulated cups, coolers, and microwave cookware. The thermal underwear that many skiers wear is made of polypropylene and the fiberfill in winter jackets is acrylic and polyester.

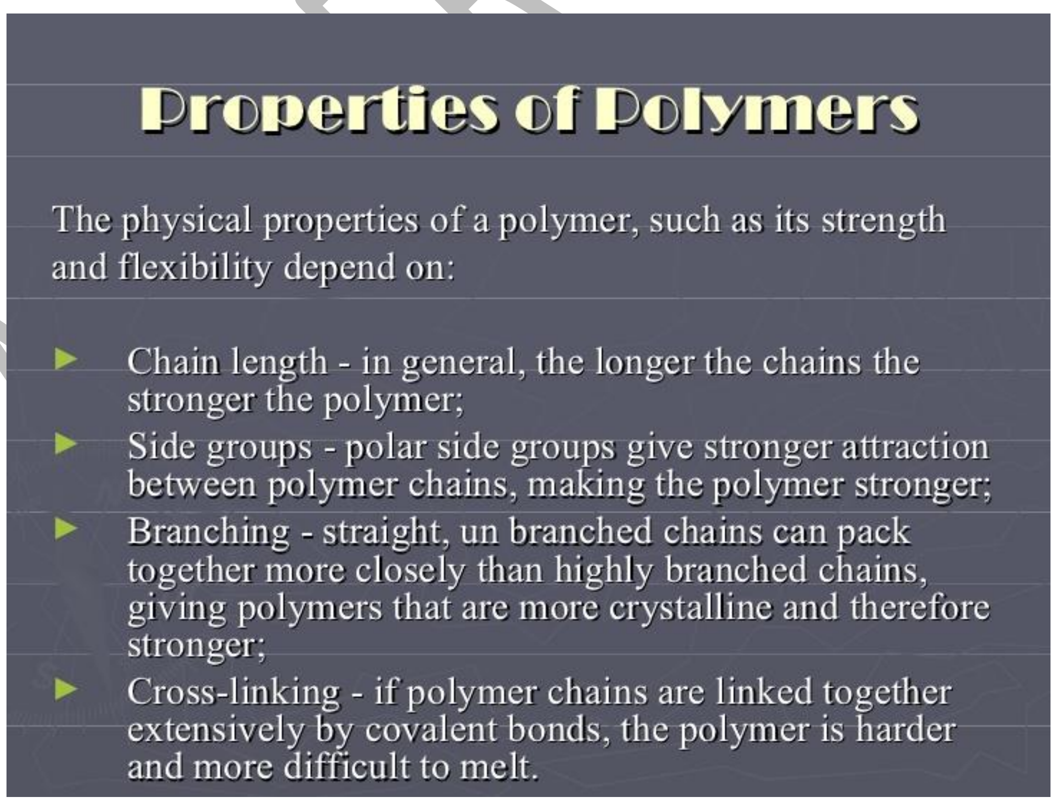
Generally, polymers are very light in weight with significant degrees of strength. Consider the range of applications, from toys to the frame structure of space stations, or from delicate nylon fiber in pantyhose to Kevlar, which is used in bulletproof vests. Some polymers float in water while others sink. But, compared to the density of stone, concrete, steel, copper, or aluminum, all plastics are lightweight materials.

Polymers can be processed in various ways. Extrusion produces thin fibers or heavy pipes or films or food bottles. Injection molding can produce very intricate parts or large car body panels. Plastics can be molded into drums or be mixed with solvents to become adhesives or paints. Elastomers and some plastics stretch and are very flexible. Some plastics are stretched in processing to hold their shape, such as soft drink bottles. Other polymers can be foamed like polystyrene (Styrofoam™), polyurethane and polyethylene.

Polymers are materials with a seemingly limitless range of characteristics and colors. Polymers have many inherent properties that can be further enhanced by a wide range of additives to broaden their uses and applications. Polymers can be made to mimic cotton, silk, and wool fibers; porcelain and marble; and aluminum and zinc. Polymers can also make possible products that do not readily come from the natural world, such as clear sheets and flexible films.

Polymers are usually made of petroleum, but not always. Many polymers are made of repeat units derived from natural gas or coal or crude oil. But building block repeat units can sometimes be made from renewable materials such as polylactic acid from corn or cellulosics from cotton linters. Some plastics have always been made from renewable materials such as cellulose acetate used for screwdriver handles and gift ribbon. When the building blocks can be made more economically from renewable materials than from fossil fuels, either old plastics find new raw materials or new plastics are introduced.

Polymers can be used to make items that have no alternatives from other materials. Polymers can be made into clear, waterproof films. PVC is used to make medical tubing and blood bags that extend the shelf life of blood and blood products. PVC safely delivers flammable oxygen in non-burning flexible tubing. And anti-thrombogenic material, such as heparin, can be incorporated into flexible PVC catheters for open heart surgery, dialysis, and blood collection. Many medical devices rely on polymers to permit effective functioning



Applications of Polymers:

- Polymeric materials are used in and on soil to improve aeration, provide mulch, and promote plant growth and health.

Medicine

- Many biomaterials, especially heart valve replacements and blood vessels, are made of polymers like Dacron, Teflon and polyurethane.

Consumer Science

- Plastic containers of all shapes and sizes are light weight and economically less expensive than the more traditional containers. Clothing, floor coverings, garbage disposal bags, and packaging are other polymer applications.

Industry

- Automobile parts, windshields for fighter planes, pipes, tanks, packing materials, insulation, wood substitutes, adhesives, matrix for composites, and elastomers are all polymer applications used in the industrial market.

Sports

- Playground equipment, various balls, golf clubs, swimming pools, and protective helmets are often produced from polymers.

Why use plastics

Plastic are **easily formed** materials.

The advantage to the manufacturer is that plastic products can be **mass-produced** and require **less skilled staff**.

Plastics require little or **no finishing**, painting, polishing etc. Plastic is referred to as a **self-finishing material**. Particular finishes can be achieved at relatively low cost.

Plastics can be easily printed, decorated or painted.

Plastics are **corrosion resistant**, and **generally waterproof** although certain types of plastics such as UPVC can become brittle and it is possible for the sun's rays to cause the colour of the plastic to fade. It becomes bleached.

Plastics are **lighter than metals**, giving **deeper sections** for a given weight, and hence **stronger sections**.

Origins of Plastics - **synthetic plastics**.

The main source of synthetic plastics is **crude oil**.

Coal and **natural gas** are also used.

Petrol, paraffin, lubricating oils and high petroleum gases are bi-products, produced during the refining of crude oil.

These gases are broken down into **monomers.** Monomers are chemical substances consisting of a single molecule.

A process called **Polymerisation** occurs when thousands of monomers are linked together. The compounds formed as called **polymers**.

Combining the element **carbon** with one or more other elements such as oxygen, hydrogen, chlorine, fluorine and nitrogen makes most polymers.

PLASTICS & ITS CATEGORIES

The two main types are,

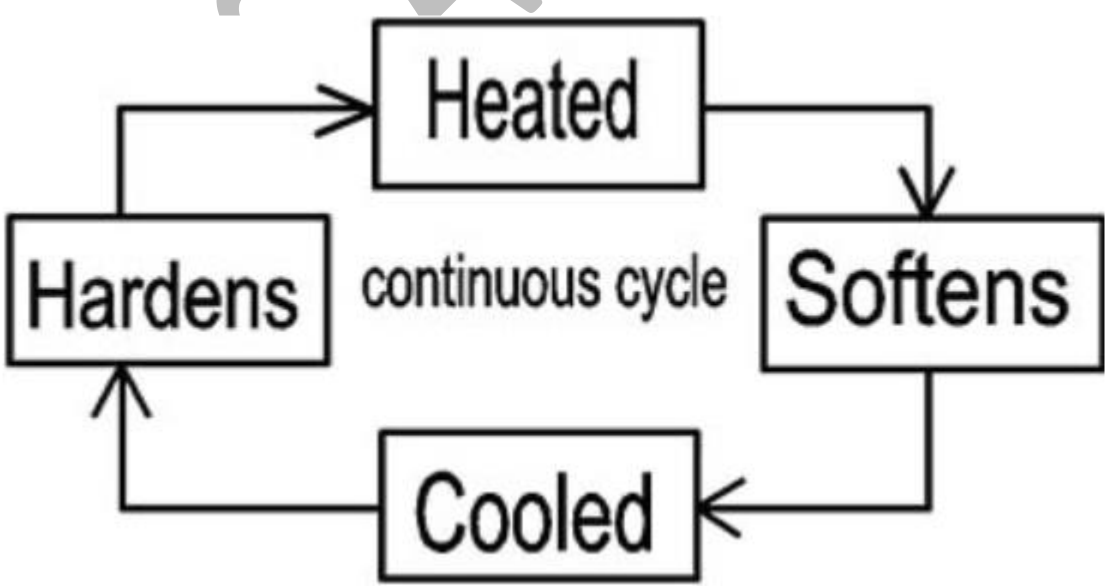
Thermoplastics can be re-melted and essentially returned to their original state—sort of like the way an ice cube can be melted and then cooled again. Thermoplastics usually are produced first in a separate process to create small pellets; these pellets then are heated and formed to make all sorts of consumer and industrial products. Thermoplastics include plastics you're likely familiar with: polyethylene, polypropylene, polyvinyl chloride, polystyrene, nylon, polycarbonate, and others.

Thermosets are usually produced and formed into products at the same time—and they cannot be returned to their original state. They generally are formed using heat ("thermo") and become "set," like a cooked egg. Thermosets include vulcanized synthetic rubber, acrylics, polyurethanes, melamine, silicone, epoxies, and others.

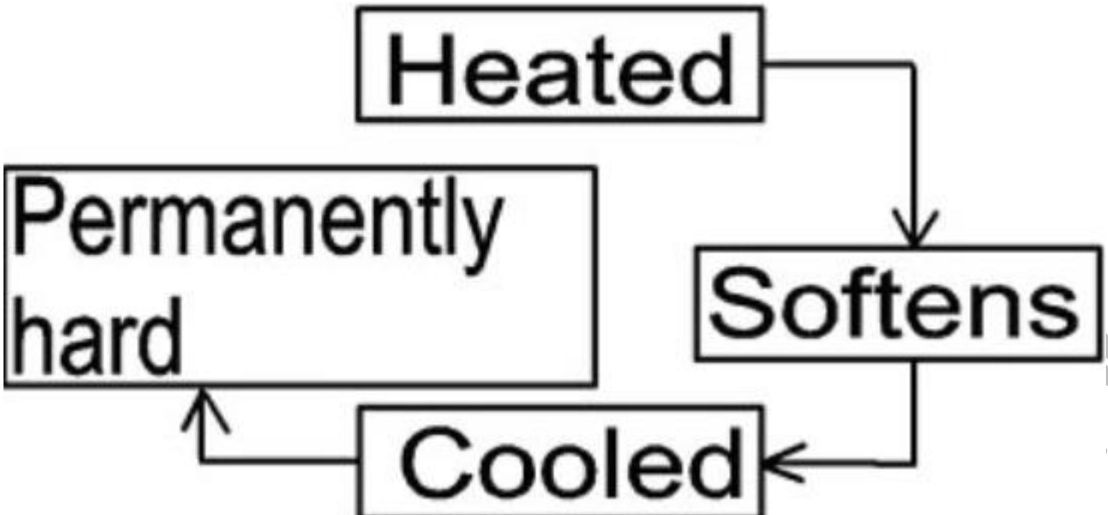
There are other categories of plastics:

1) Synthetic resin plastics
2) Natural resins
3) Cellulose
4) Protein

Thermoplastics



Thermosets

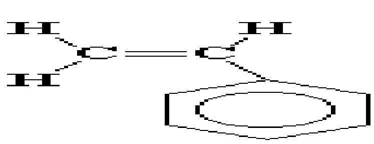


There are other categories of plastics:

Engineering plastics are… well… engineered to have enhanced mechanical properties and often greater durability than other materials. (They often—not always—are thermoplastics.) For example, polycarbonate resists impact. Polyamides like nylon resist abrasion. Some are combinations of plastics, such as incredibly tough ABS (acrylonitrile butadiene styrene). The list of engineering plastics is quite long.

Plastic fibers are precisely that: plastics that have been spun into fibers or filaments that are used to make fabrics, string, ropes, cables—even optical fibers and body armor (such as Kevlar®). Most plastic fibers are strong, stretchable, and stable under heat (so fabrics can be ironed). Some of the most recognizable plastic fibers are polyester, nylon, rayon, acrylic, and spandex, although there are many more. There are many more categories, such as **coatings, adhesives, elastomers and rubbers.**

Polystyrene

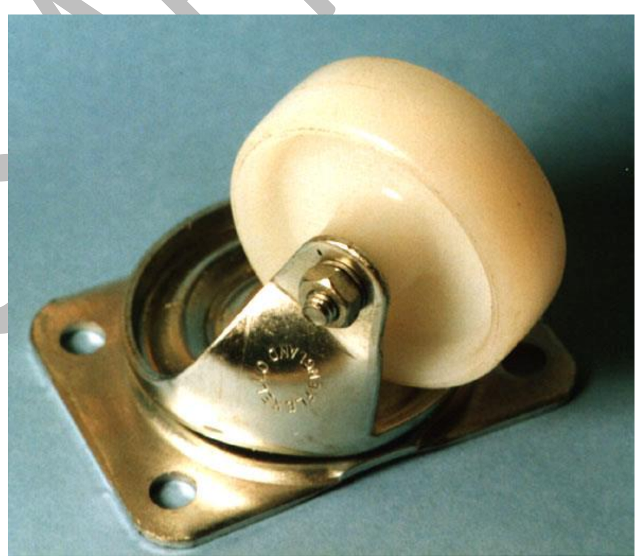


monomer

- Polystyrene is used to make **plates**, cutlery and model kits.
- It is stiff hard and comes in a wide range of colours.
- **Image**: cup and saucer

Nylon

- Nylon is hard, tough, self-lubricating, has a high melting point and has very good resistance to wear and tear.
- It has been used to make clothing, bearings and propellers.
- **Image**: A nylon castor (wheel).



Expanded polystyrene

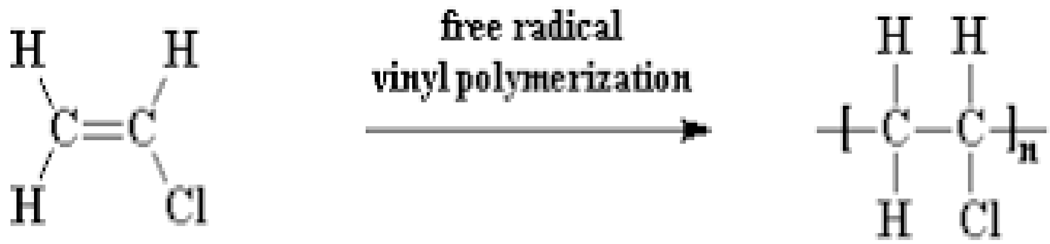
- This is used for disposable food packaging, disposable cups, heat insulation and **protective packaging** for electrical equipment.
- **Image**: Protective packaging

Polythene

Monomer - $(C_2H_4)_n$

- High-density polythene has been used to manufacture milk crates, bottles, buckets, bowl and gear wheels.
- It is stiff, hard, can be sterilised and is dense.

PVC



vinyl chloride poly(vinyl chloride)

- The rigid type is used to make **pipes**, **guttering** and roofing. It is very lightweight and is resistant to acids and alkalis.
- The plasticised type is used for suitcases, hosepipes, electrical wiring and floor coverings.
- **Image**: plumbing U-bend

CERAMIC MATERIALS:

A **ceramic** material is an inorganic, non-metallic, often crystalline oxide, nitride or carbide material. Some elements, such as carbon or silicon, may be considered **ceramics**. **Ceramic** materials are brittle, hard, strong in compression, weak in shearing and tension.

Is glass a ceramic?

A **ceramic** is an inorganic, nonmetallic solid material comprising metal, nonmetal or metalloid atoms primarily held in ionic and covalent bonds. The crystallinity of **ceramic** materials ranges from highly oriented to semi-crystalline, and often completely amorphous (e.g., **glasses**).

What are the properties of ceramic material?

The atoms in ceramic materials are held together by a chemical bond. The two most common chemical bonds for ceramic materials are covalent and ionic. For metals, the chemical bond is called the metallic bond. The bonding of atoms together is much stronger in covalent and ionic bonding than in metallic. That is why, generally speaking, metals are ductile and ceramics are brittle. Due to ceramic materials wide range of properties, they are used for a multitude of applications. In general, most ceramics are:

- Hard & wear-resistant,
- brittle,
- refractory,
- thermal insulators,
- electrical insulators,
- nonmagnetic,
- oxidation resistant,
- prone to thermal shock, and
- chemically stable.

CLASSIFICATION OF CERAMICS:

Technical ceramics can also be classified into three distinct material categories:

- Oxides: alumina, beryllia, ceria, zirconia.
- Nonoxides: carbide, boride, nitride, silicide.
- Composite materials: particulate reinforced, fiber reinforced, combinations of oxides and nonoxides.

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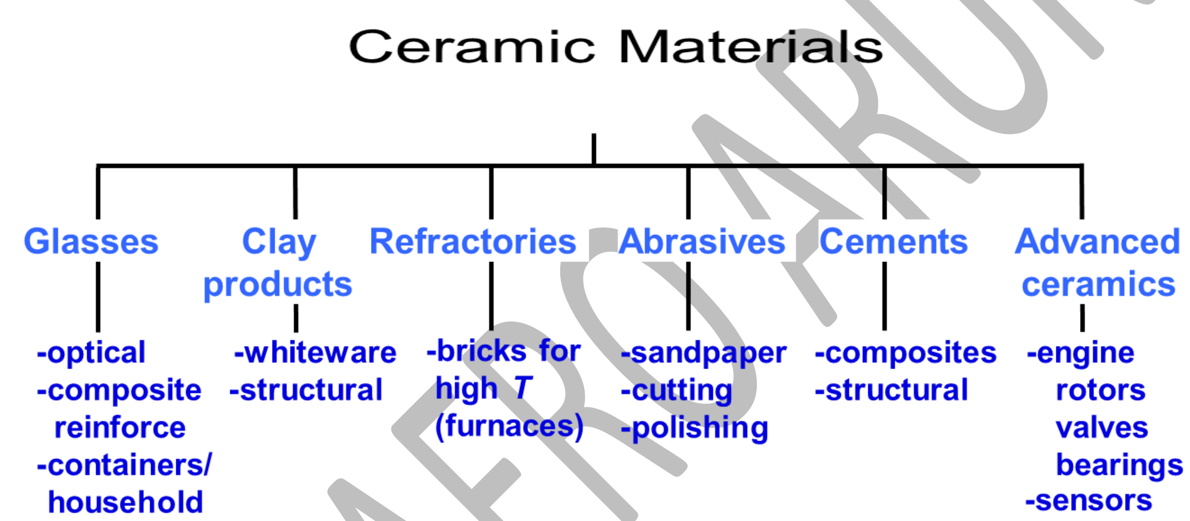
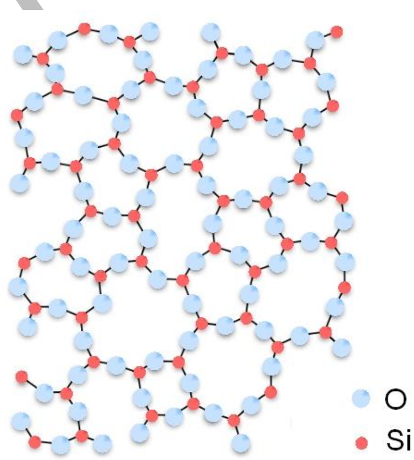


GLASS INGREDIENTS



- Common glass is made from:

- sand or silica (SiO_2)
- sodium carbonate (Na_2CO_3)
- limestone ($CaCO_3$)
- magnesium carbonate ($MgCO_3$)
- additives to improve the glass quality and to colour the glass.

- glass is highly resistant to most chemicals
- its big enemy is hydrofluoric acid
- water can corode glass (depends on temperature)
- good termal conductor
- it is a common material

Transparent Plastics

In a world full of different types of plastics it is perhaps the transparent ones that provide the greatest benefit to our everyday lives. From baby bottles to mobile phones to lenses we are surrounded by clear, tinted or translucent plastic materials that make our lives easier and our products more attractive. The transparent materials offered to the market by Ultra polymers are the result of decades of continuous research and development in product technology as polymer manufacturers strive to create new and exciting applications for transparent plastics.

Transparent plastics in applications

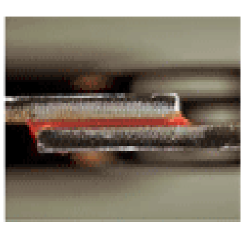
- Polycarbonate is used in a large variety of everyday applications in

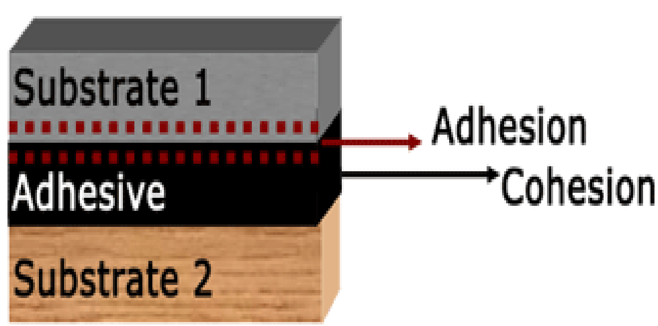
  Electrical and electronics applications (**LED lights**, Connectors, cell phones)
- **PVC is an amorphous thermoplastic** with good transparency.
- **Polyethylene** is a very durable thermoplastic widely used to produce films, tubes, plastic parts, laminates.
- Transparent Polypropylene (PP) Food packaging and storage (Cups, Trays, bottles, jugs, jars…)
- **PMMA** is a rigid, transparent thermoplastic material widely used as a "**shatter-resistant**" alternative to glass

ADHESIVE

Adhesive (or) glue as a non-metallic material which is able to join 2 substrates using adhesion mechanisms (developed between the adhesive and substrate) and cohesive mechanism (developed within the adhesive itself).

As it is set out in the above definition, an adhesive is a non-metallic material, we usually refer to adhesives as the materials which are composed by organic polymers in a liquid state when applied and become a solid state after further curing or hardening.





APPLICATION IN AIRCRAFT INDUSTRY

Master Bond is at the forefront of developing specialty adhesive formulations to meet the stringent specifications of the aerospace industry.

Wide range of products consists of epoxies, polyurethanes, silicones, polysulfides offered in both one and two component systems.

Technologically advanced paste, liquid, film adhesive/sealant systems have met challenging design standards that facilitate improved performance, durability, weight savings, fuel efficiency for commercial/business aircraft, rotorcraft, satellite and UAV's.

Through extensive research and development Master Bond has formulated products that optimize processing efficiency, meet FST requirements for flame, smoke and toxic emission. High strength systems feature protection against extreme temperatures, corrosion, abrasion, noise, vibration, creep, fatigue, humidity/chemicals.

STRUCTURAL ADHESIVE BONDING IN AEROSPACE

Adhesives have been used extensively for structural bonding applications in aerospace.

I assume everyone is aware that the tiles on the space shuttles were attached using a room temperature vulcanizing (RTV) silicone adhesive.

Structural bonding of aircraft has been very important in the history of the industry. Aluminum has been a major substrate for the outer skins, being lightweight while retaining strength and durability. Combining adhesive bonds and rivets has been a typical assembly construction to further optimize weight savings, strength, and durability.

Adhesively bonding the metal components has spread loads over larger areas. Adhesives used in these applications include epoxy-based materials, often applied as a film. The surfaces are cleaned and primed prior to bonding and cure is typically accomplished in an autoclave.

Sandwich structures have further increased strength and durability, while minimizing weight. They consist of outer skins of aluminum or a composite such as fiberglass or carbon fiber with an internal honeycomb structure, often made of aluminum. The most effective assembly method is again adhesive bonding. Foamed cores could also be used.

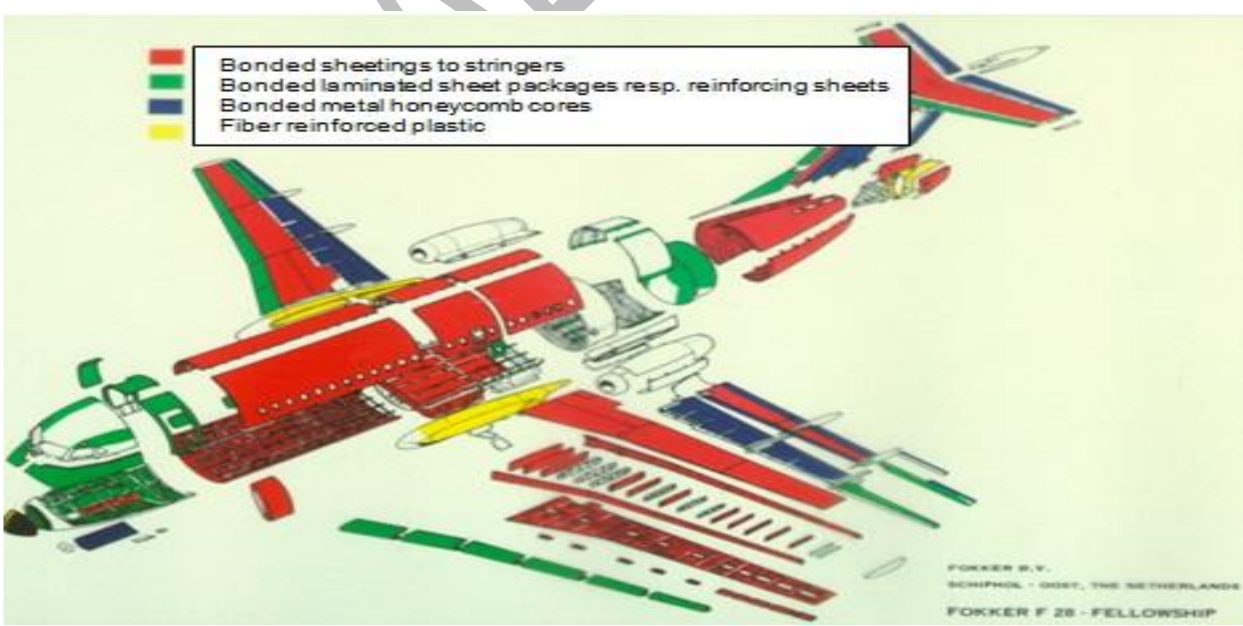
There is a link below to an example of a next generation sandwich structure created from several layers of dissimilar materials.

SAE International is the home for the majority of the standards for aerospace, with over 8000 current standards.

Of those, about 170 are for adhesive and sealants, including material specifications, test methods, and other instructional documents.

The standards are managed by multiple committees within the Aerospace Council, including AMS G9 Aerospace Sealing Committee, AMS P Polymeric Materials Committee, AMS P17 Composite Materials Committee, and AMS G8 Aerospace Organic Coatings Committee.

Unlike the standards from the Automotive Adhesives & Sealant Committee, where the majority of the standards are test methods, the adhesive and sealant standards developed within the Aerospace Council are mostly material specifications.



SEALANTS

Sealant is a substance used to block the passage of fluids through the surface or joints or openings in materials, a type of mechanical seal.

In building construction sealant is sometimes synonymous with caulking and also serves the purposes of blocking dust, sound and heat transmission.

The sealant with adhesive properties is known as adhesive sealants or structural sealants.

Sealants generally contain inert filler material and are usually formulated with an elastomer to give the required flexibility and elongation.

Difference between adhesive and sealant.

The main difference between adhesives and sealants is that sealants typically have lower strength and higher elongation than adhesives does.

When sealants are used between substrates having different thermal coefficients of expansion or differing elongation under stress, they need to have adequate flexibility and elongation.

Sealant: A substance capable of attaching to at least two surfaces, thereby, filling the space between them to provide a barrier or protective coating.

- Adhesives and sealants are often considered together because they both adhere and seal; both must be resistant to their operating environments; and their properties are highly dependent on how they are applied and processed. Adhesives and sealants also share several common characteristics.
- They must behave as a liquid, at some time in the course of bond formation, in order to flow over and wet (make intimate contact with) the adhere ends.
- They form surface attachment through adhesion (the development of intermolecular forces).
- They must harden to carry sometimes continuous, sometimes variable load throughout their lives.

Classification of sealants

1. One-component sealants

Packaged in a cartridge. No special equipment is required to apply

Ex: silicone and urethane

2.Two - component sealants

Composed of two parts — a base component and an activator component

Special equipment's are required

3. Sealant tapes

sealant tapes are supplied as sealant on a flexible backing.

Butyl and silicone tapes (both preformed shape) and urethane tape (supplied in a compressed state).

Aircraft applications of sealant

- Effective is waterproofing
- Thermal insulation
- Acoustic insulation
- Fire barriers
- Simple smoothing or filling
- Caulking
- Physical barrier

Few examples of sealants

1. Silicone
2. Varnish
3. Hot wax

4. Firbin glue
5. Epoxy thermosets
6. Butyl rubber
7. Acrylic Resins

COMPOSITE

Introduction

There is an unabated quest for new materials which will satisfy the specific requirements for various applications like structural, medical, house-hold, industrial, construction, transportation, electrical; electronics, etc. Metals are the most commonly used materials in these applications. In the yore of time, there have been specific requirements on the properties of these materials. It is impossible of any material to fulfill all these properties. Hence, newer materials are developed. In the course, we are going to learn more about composite materials. First, we will deal with primary understanding of these materials and then we will learn the mechanics of these materials.

Definition of a Composite Material

A composite material is defined as a material which is composed of two or more materials at a microscopic scale and has chemically distinct phases. Thus, a composite material is heterogeneous at a microscopic scale but statistically homogeneous at macroscopic scale. The materials which form the composite are also called as constituents or constituent materials. The constituent materials of a composite have significantly different properties.

Further, it should be noted that the properties of the composite formed may not be obtained from these constituents. However, a combination of two or more materials with significant properties will not suffice to be called as a composite material. In general, the following conditions must be satisfied to be called a composite material:

1. The combination of materials should result in significant property changes. One can see significant changes when one of the constituent material is in platelet or fibrous from.

2. The content of the constituents is generally more than 10% (by volume).

3. In general, property of one constituent is much greater than the corresponding property of the other constituent.

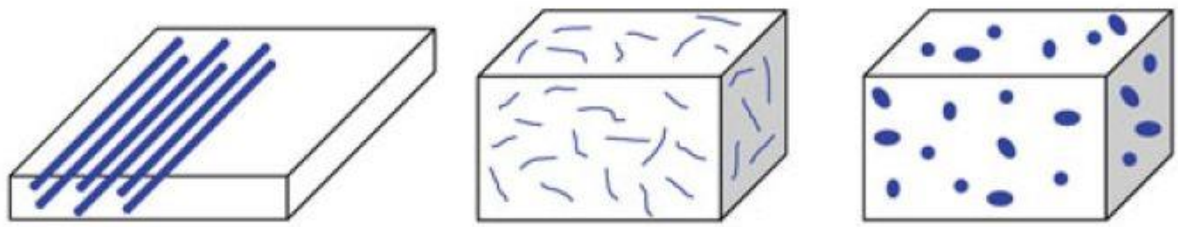
The composite materials can be natural or artificially made materials. In the following section we will see the examples of these materials.

Why we need these materials?

There is unabated thirst for new materials with improved desired properties. All the desired properties are difficult to find in a single material. For example, a material which needs high fatigue life may not be cost effective. The list of the desired properties, depending upon the requirement of the application, is given below.

1. Strength
2. Stiffness
3. Toughness
4. High corrosion resistance
5. High wear resistance
6. High chemical resistance
7. High environmental degradation resistance
8. Reduced weight
9. High fatigue life
10. Thermal insulation or conductivity
11. Electrical insulation or conductivity
12. Acoustic insulation
13. Radar transparency
14. Energy dissipation
15. Reduced cost
16. Attractiveness

The list of desired properties is in-exhaustive. It should be noted that the most important characteristics of composite materials is that their properties are tailorable, that is, one can design the required properties.



Types of reinforcement in a composite

What are the constituents in a typical composite?

In a composite, typically, there are two constituents. One of the constituent acts as a reinforcement and other acts as a matrix. Sometimes, the constituents are also referred as phases.

What are the types of reinforcements?

The reinforcements in a composite material come in various forms. These are depicted in above figure.

1. Fibre: Fibre is an individual filament of the material. A filament with length to diameter ratio above 1000 is called a fibre. The fibrous form of the reinforcement is widely used. The fibres can be in the following two forms:

a. Continuous fibres: If the fibres used in a composite are very long and unbroken or cut then it forms a continuous fibre composite. A composite, thus formed using continuous fibres is called as fibrous composite. The fibrous composite is the most widely used form of composite.

b. Short/chopped fibres: The fibres are chopped into small pieces when used in fabricating a composite. A composite with short fibres as reinforcements is called as short fibre composite. In the fibre reinforced composites, the fibre is the major load carrying constituent.

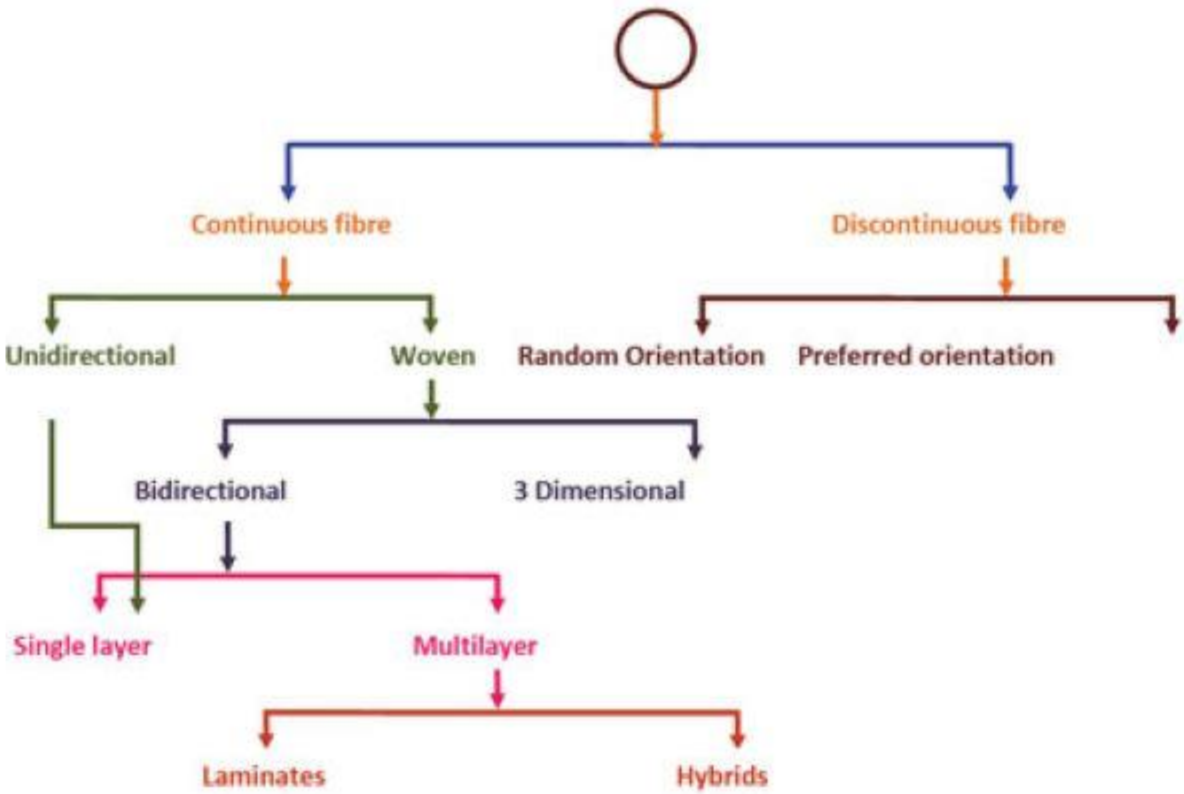
2. Particulate: The reinforcement is in the form of particles which are of the order of a few microns in diameter. The particles are generally added to increase the modulus and decrease the ductility of the matrix materials. In this case, the load is shared by both particles and matrix materials. However, the load shared by the particles is much larger than the matrix material. For example, in an automobile application carbon black (as a particulate reinforcement) is added in rubber (as matrix material). The composite with reinforcement in particle form is called a particulate composite.

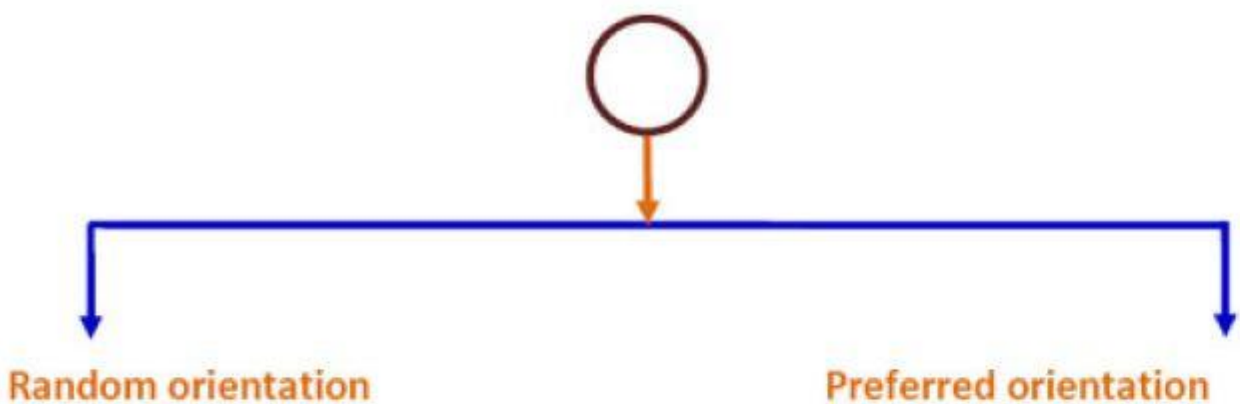
3. Flake: Flake is a small, flat, thin piece or layer (or a chip) that is broken from a larger piece. Since these are two dimensional in geometry, they impart almost equal strength in all directions of their planes. Thus, these are very effective reinforcement components. The flakes can be packed more densely when they are laid parallel, even denser than unidirectional fibres and spheres. For example, aluminum flakes are used in paints. They align themselves parallel to the surface of the coating which imparts the good properties.

4. Whiskers: These are nearly perfect single crystal fibres. These are short, discontinuous and polygonal in cross-section.

The classification of composites based on the form of reinforcement is shown in Figure.

The detailed classification further is given below.





Why are reinforcement made in thin fibre form?

There are various reasons because of which the reinforcement is made in thin fibre form. These reasons are given below.

a) An important experimental study by Leonardo da Vinci on the tensile strength of iron wires of various lengths is well known to us. In this study it was revealed that the wires of same diameter with shorter length showed higher tensile strength than those with longer lengths. The reason for this is the fact that the number of flaws in a shorter length of wire is small as compared longer length. Further, it is well known that the strength of a bulk material is very less than the strength of the same material in wire form.

The same fact has been explored in the composites with reinforcement in fibre form. As the fibres are made of thin diameter, the inherent flaws in the material decrease. Hence, the strength of the fibre increases as the fibre diameter decreases.

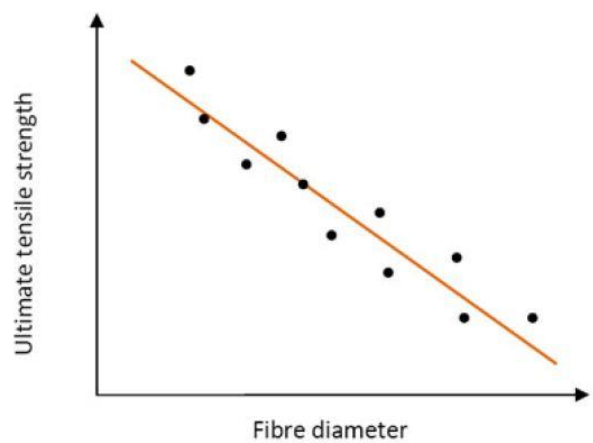


Figure 1.5: Qualitative variation of fibre tensile strength with fibre diameter

b) The quality of load transfer between fibre and matrix depends upon the surface area between fibre and matrix. If the surface area between fibre and matrix is more, better is the load transfer. It can be shown that for given volume of fibres in a composite, the surface area between fibre and matrix increases if the fibre diameter decreases.

c) The fibres should be flexible so that they can be bent easily without breaking. This property of the fibres is very important for woven composites. In woven composites the flexibility of fibres plays an important role. Ultra-thin composites are used in deployable structures.

What are the functions of a reinforcing agent?

The functions of a reinforcing agent are:

1. These are the main load carrying constituents.

2. The reinforcing materials, in general, have significantly higher desired properties. Hence, they contribute the desired properties to the composite.

3. It transfers the strength and stiffness to the matrix material.

What are the functions of a matrix material?

The matrix performs various functions. These functions are listed below:

1. The matrix material holds the fibres together.

2. The matrix plays an important role to keep the fibres at desired positions. The desired distribution of the fibres is very important from micromechanical point of view.

3. The matrix keeps the fibres separate from each other so that the mechanical abrasion between them does not occur.

4. It transfers the load uniformly between fibers. Further, in case a fibre is broken or fibre is discontinuous, then it helps to redistribute the load in the vicinity of the break site.

5. It provides protection to fibers from environmental effects.

6. It provides better finish to the final product.

7. The matrix material enhances some of the properties of the resulting material and structural component (that fibre alone is not able to impart). For example, such properties are: transverse strength of a lamina, impact resistance

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Boron Fiber

This fibre was first introduced by Talley in 1959. In commercial production of boron fibres, the method of Chemical Vapour Deposition (CVD) is used. The CVD is a process in which one material is deposited onto a substrate to produce near theoretical density and small grain size for the deposited material. In CVD the material is deposited on a thin filament. The material grows on this substrate and produces a thicker filament. The size of the final filament is such that it could not be produced by drawing or other conventional methods of producing fibres. It is the fine and dense structure of the deposited material which determines the strength and modulus of the fibre.

The key features of this fibre are listed below:

- These are ceramic monofilament fiber.
- Fiber itself is a composite.
- Circular cross section.

- Fiber diameter ranges between 33-400μm and typical diameter is 140μm.
- Boron is brittle hence large diameter results in lower flexibility.
- Thermal coefficient mismatch between boron and tungsten results in thermal residual stresses during fabrication cool down to room temperature.
- Boron fibres are usually coated with SiC, so that it protects the surface during contact with molten metal when it is used to reinforce light alloys. Further, it avoids the chemical reaction between the molten metal and fibre.
- Strong in both tension and compression.
- Exhibits linear axial stress-strain relationship up to 650^{o}c .
- Since this fibre requires a specialized procedure for fabrication, the cost of production is relatively high.

Carbon Fiber:

The first carbon fibre for commercial use was fabricated by Thomas Edison.

- Sixth lightest element and carbon - carbon covalent bond is the strongest in nature.
- Edison made carbon fiber from bamboo fibers.
- Bamboo fiber is made up of cellulose.
- Precursor fiber is carbonized rather than melting.
- Filaments are made by controlled pyrolysis (chemical deposition by heat) of a precursor material in fiber form by heat treatment at temperature of 1000-3000 ^{o}c
- The carbon content in carbon fibers is about 80-90 % and in Graphite fibers the carbon content is in excess of 99%. Carbon fibre is produced at about 1300 while the graphite fibre is produced in excess of 1900 ^{o}c.
- The carbon fibers become graphitized by heat treatment at temperature above 1800 ^{o}c.
- “Carbon fibers” term is used for both carbon fibers and graphite fibers.
- Different fibers have different morphology, origin, size and shape.
- The size of individual filament ranges from 3 to 147 μm.
- Maximum use of temperature of the fibers ranges from 250 to 2000 ^{o}c.
- The use temperature of a composite is controlled by the use temperature of the matrix.

- Precursor materials: There are two types of precursor materials (i) Polyacrylonitrile (PAN) and (ii) rayon pitch, that is, the residue of petroleum refining.
- Fiber properties vary with varying temperature.
- Fiber diameter ranges from 4 to10 μm.
- A tow consists of about 3000 to 30000 filaments.
- Small diameter results in very flexible fiber and can actually be tied in to a knot without breaking the fiber.
- Modulus and strength is controlled by the process. The procedure involves the thermal decomposition of the organic precursor under well controlled conditions of temperature and stress.
- Cross section of fiber is non-circular; in general, it is kidney bean shape.
- Heterogeneous microstructure consisting of numerous lamellar ribbons.
- Morphology is very dependent on the manufacturing process.
- PAN based carbon fibers typically have an onion skin appearance with the basal planes in more or less circular arcs, whereas the morphology of pitch-based fiber is such that the basal planes lie along radial planes. Thus, carbon fibers are anisotropic.

Glass Fibre

- Fibers of glass are produced by extruding molten glass, at a temperature around 1200 ^{o}c through holes in a spinneret with diameter of 1 or 2 mm and then drawing the filaments to produce fibers having diameters usually between 5 to15 μm.
- The fibres have low modulus but significantly higher stiffness.
- Individual filaments are small in diameters, isotropic and very flexible as the diameter is small.
- The glass fibres come in variety of forms based on silica which is combined with other elements to create speciality glass.

What are the different types of glass fibres? What are their key features?

The types of glass fibres and their key features are as follows:

E glass - high strength and high resistivity.

S2 glass - high strength, modulus and stability under extreme temperature and corrosive environment.

R glass – enhanced mechanical properties.

C glass - resists corrosion in an acid environment.

D glass – good dielectric properties.

Alumina Fibre

- These are ceramics fabricated by spinning a slurry mix of alumina particles and additives to form a yarn which is then subjected to controlled heating.
- Fibers retain strength at high temperature.
- It also shows good electrical insulation at high temperatures.
- It has good wear resistance and high hardness.
- The upper continuous use temperature is about 1700 ^{o}c.
- Fibers of glass, carbon and alumina are supplied in the form of tows (also called rovings or strands) consisting of many individual continuous fiber filaments.
- Du Pont has developed a commercial grade alumina fibre, known as Alumina FP (polycrystalline alumina) fibre. Alumina FP fibres are compatible with both metal and resin matrices. These fibres have a very high melting point of 2100 ^{o}c. They can withstand temperatures up to 1000 ^{o}c without any loss of strength and stiffness properties at this elevated temperature. They exhibit high compressive strengths, when they are set in a matrix.
- The Alumina whiskers are available and they exhibit excellent properties. Alumina whiskers can have the tensile strength of 20700 MPa and the tensile modulus of 427 GPa.

What are the applications of Alumina fibres?

- The Alumina has a unique combination of low thermal expansion, high thermal conductivity and high compressive strength. The combination of these properties gives good thermal shock resistance. These properties make

Alumina suitable for applications in furnace use as crucibles, tubes and thermocouple sheaths.

- The good wear resistance and high hardness properties are harnessed in making the components such as ball valves, piston pumps and deep drawing tools.

Aramid Fibre

- These fibres are from Aromatic polyamide, that is, nylons family.
- Aramid is derived from “Ar” of Aromatric and “amid” of polyamide.
- Examples of fibres from nylon family: Polyamide 6, that is, nylon 6 and Polyamide 6.6, that is, nylon 6.6
- These are organic fibers.
- Melt-spun from a liquid solution.
- Du Pont developed these fibers under the trade name Kevlar. From poly (p-phenylene terephthalamide (PPTA) polymer.
- Morphology – radially arranged crystalline sheets resulting into anisotropic properties.
- Filament diameter about 12 and partially flexible.
- High tensile strength.
- Intermediate modulus.
- Significantly lower strength in compression.
- 5 grades of Kevlar with varying engineering properties are available. Kevlar-29, Kevlar-49, Kevlar-100, Kevlar-119 and Kevlar-129.

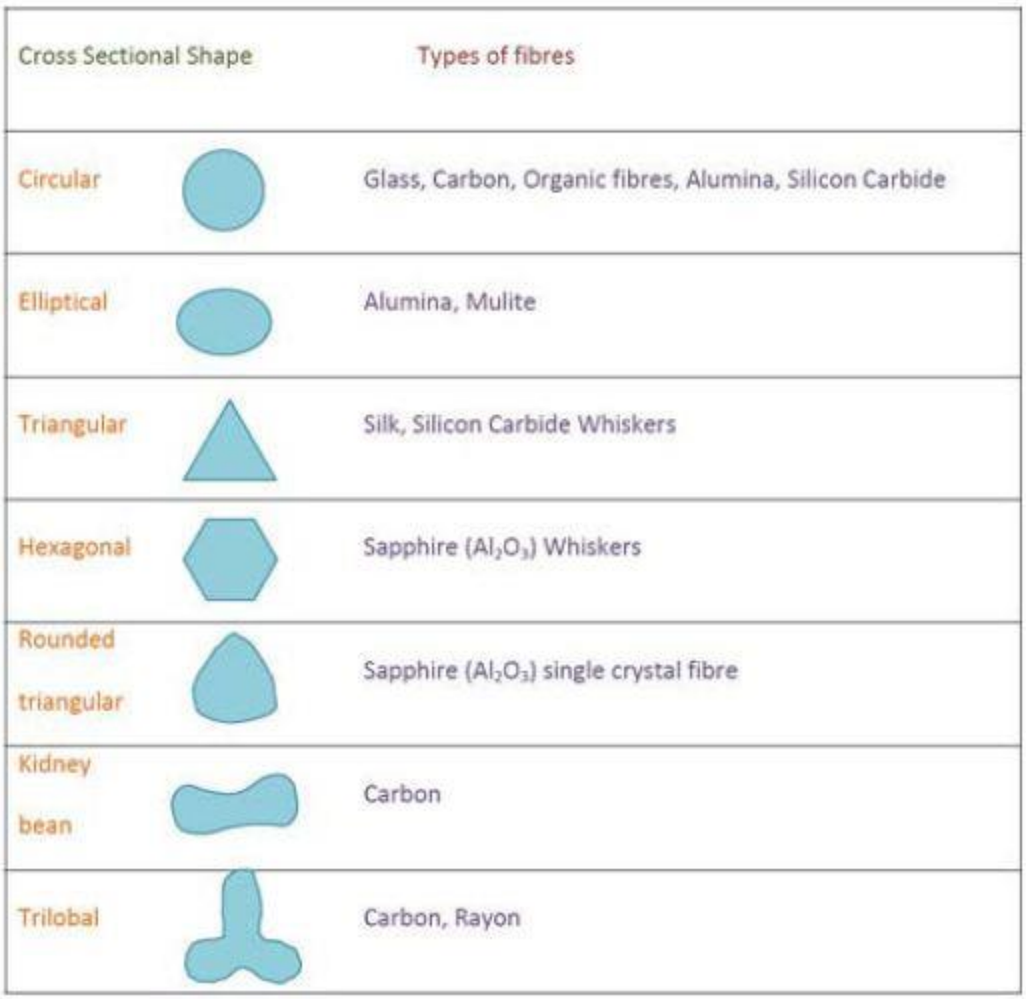
Silicon Carbide Fibre (SiC)

Silicon carbide fibres are ceramic fibers. These fibres are produced in similar fashion as boron fibres are produced. The fibres are produced by two methods as follows:

- CVD on Tungsten or Carbon Core
- NICALON™ by NIPPON Carbon Japan

Cross Sectional Shapes of Fibres

The cross sectional shapes of fibre of various types we have studied above are different. The cross sectional shape of the fibres, although is assumed to be circular, is not circular in general. The various cross sectional shapes of the fibre are shown in Figure 1.10.



Cross Sectional Shape	Types of fibres
Circular	Glass, Carbon, Organic fibres, Alumina, Silicon Carbide
Elliptical	Alumina, Mulite
Triangular	Silk, Silicon Carbide Whiskers
Hexagonal	Sapphire (Al_2O_3) Whiskers
Rounded triangular	Sapphire (Al_2O_3) single crystal fibre
Kidney bean	Carbon
Trilobal	Carbon, Rayon

Fiber Properties

The following are the important points regarding the fibre properties.

- Density, axial modulus, axial Poisson's ratio, axial tensile strength and coefficient of thermal expansion are some of the important properties.
- Advanced fibers exhibit a broad range of properties.
- Properties of carbon fiber can vary significantly depending upon fabrication process.

- For the advanced fibres studied above one can attain either high modulus (> 700 GPa) or high strength (> 5 GPa) but not both attainable simultaneously.
- SCS-6, IM8, boron and sapphire fibers offer the best combination of stiffness and strength but have large diameters and thus limited flexibility. However, IM8 fibers are exception for flexibility.
- The specific stiffness of some of these fibres is almost 13 times of structural metals.
- Similarly, the specific strength of some of these fibres is almost 16 times of structural metals.
- Weight saving, when the composites of these fibres are used, is tremendous due to high specific stiffness and strength.
- Actual properties of composite (fiber + matrix) are reduced.
- Specific properties are reduced even further when the loading is in a direction other than the length direction of fibers.
- Tailorable properties.
- One can get the desired heat transfer or electrical conductivity with proper designing.
- The increased fatigue resistance is attainable with the use of these fibre composites.
- Aging effect can be significantly lowered.

Note: The fibres are classified based on their values of modulus as follows:

1. Ultra-high-modulus, type UHM (modulus > 450 GPa)

2. High-modulus, type HM (modulus between 350-450 GPa)

3. Intermediate-modulus, type IM (modulus between 200-350 GPa)

4. Low modulus and high-tensile, type HT (modulus < 100 GPa, tensile strength > 3.0 GPa)