SURFACE FINISHES

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MODULE 1

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1.01 OBJECT AND SURFACE

ESSENTIAL QUALITIES OF OBJECTS:

We use objects for their many different qualities. Some are used for their structural properties, while others are useful due to their surface quality. We try to find an object with the best combination of such attributes. Where such a combination is not available easily or immediately, we try to change the object appropriately. There are Four categories of essential qualities sought in objects for various purposes:

- **Engineering Attributes:**
  - Chemical -composition, phase, resistance, structure.
  - Physical -thermal, electrical, magnetic, gravimetric, optical, acoustics.
  - Mechanical -stress/strength, formability, rigidity, toughness, durability.
- **Dimensional Features:**
  - Shape -camber, lay/orientation, out of flat, roughness, waviness.
  - Size -scale, proportion, orientation, nature of perception.
- **Surface Properties:**
  - Colour -hue, tone, illumination, refractivity, reflectivity, opacity, transparency, fluorescence.
  - Texture -level and direction of illumination, perceptive organ, nature of contact, scale.
  - Pattern -random, rational, orientation of cut, original, altered.
- **Other Considerations:**
  - Availability -local, seasonal, quality, quantity.
  - Costs -access, procuring, conversion.
  - Conveyance -distance, time, weight, volume.
  - Handling -safety, storage, containment
  - Potential -conversion, processing, manufacturing.

For a material to be purposeful two broad considerations are required.

One: What one does to a material?
Two: How the material responds?

WHAT ONE DOES TO A MATERIAL ?

We seek an object with a perfect combination of many different qualities. Our quest is however further complicated when we require materials in *very large quantities*, and of *equalized quality*. We often need materials *locally and often immediately*.

The quest for a material-object proceeds along these courses.

Strategy 1 We usually have some idea how a particular material will function in a given situation. We *select* the most appropriate material for its probable response. We generally pick such materials off the surface of earth, or mine it. But it would be very rare for anyone to find a **Natural Material** with perfect combination of all the essential qualities.

Strategy 2 Natural materials have certain inherent efficiencies. We retain these while widening our options by *dressing, cutting, and carrying out other modifications*. However, the size of a **Modified Natural Material** either remains the same, or gets decreased.

Strategy 3 Natural and modified materials (and often manufactured materials also) have limitations of *size, and variations of colour, texture, patterns*, etc. So small size materials are amassed or rearranged to form large entities. **Agglomerated Materials** are composed by closely placing the units, with or without an alliance (exchange of ions), or by adhering with an agent. Either way, the agglomerated materials get a new variant, *the joint*. The resultant entity remains as weak as its weakest constituent, usually the joint.

Strategy 4 The qualities of objects (natural, modified or agglomerated) can be further altered by certain treatments and processes, such as: *annealing, hardening, seasoning, wetting, etching, ph balancing etc.* Such **Processed materials** result through treatments that are only surface bound, or affect the whole body of the material.

The term **Synthesis** refers to how materials are made from naturally occurring or manmade chemicals. The term **Processing** means how materials are shaped into useful components to cause changes in the properties of different materials. -*The science and Engineering of Materials : Askeland & Phule*.

Strategy 5 in spite of all the *modifications, processing and aggregation* of material-objects, dimensional limitations and qualitative variations do prevail. An assured quality can only be achieved by producing a new material. **Manufactured materials** have completely different form in comparison to their ingredients. Manufactured Materials also have the added advantage that the even low quality ingredients are used. Manufacturing involves several levels of processing, even then the resultant product may not have any direct or immediate utility. Manufactured materials have some dimensional limitations, as imposed by the methods of production (batch size, machine capacity -eg. textiles, rexine, plywoods). However, coatings and such depositions (which use phase conversion) overcome the size restraints.

Strategy 6 A manufactured material is further formed into **Components**, or several materials are combined to create **Compounded Material-Products**. Natural and manufactured materials are also combined to create **Composites**, or chemically blended to constitute **Synthetics**. Components, compounded material-products, composites and synthetics, all together help generate **Systems**. Systems have dual identities: functional and structural.

We primarily endeavour to create **Single Material Objects**. Objects made of single material, (whether natural or man-made) have inherent efficiencies. We try to achieve the **state of a single material efficiency** by integrating or by synthesizing different components.

A window consists of a structural frame, shutters, glazing system, mosquito nets, curtains, weather sheds, etc. It would be ideal if one integrated system, made up of a single material were to serve all the purposes. Similarly a roof is made of the structural slab, outer side water proofing coat, insulation, and floor finishes, and under side plaster, an acoustic ceiling, etc. It would be very efficient to have one material serving all these functions.

A single material system capable of serving many different purposes is not easy to devise. Such an event takes years of effort. *However, human ingenuity* *outpaces such attempts, by inventing superior but totally a different entity, for the given situation.* The superiority of a newly invented entity may not be due to the *unitary structure or the multi purposiveness of the material*, but for its multiplex system of *simpler and lesser number of elements*.

An automobile, a computer or a building, is formed of as many parts, as it consists of different materials. If one can reduce the number of parts, automatically the number of materials used, will come down. If a conscious attempt is made to reduce, the number materials used, then there will be reduction in number of components.

HOW THE MATERIAL RESPONDS ?

The material response is evident on three counts:

Other Materials,
Environment
User.

Other Materials: A material responds to other materials within its field. The reaction occurs both, in the presence or absence, of the environment and the user.

A material of a higher phase reacts more readily to a material of the lower phase -, e.g. solid to a liquid. Material with an ion charge reacts to a material with opposite ion charge. A material with lower latent energy becomes recipient.

The response of a material, manifests through the surface more emphatically than anywhere else. Materials with their **own surface systems** respond in the same manner as their body would. However, **applied surface systems** of the **same or of foreign material** show different reactions. The surface preparation, application method, and bonding techniques, all play a role in such reactions.

Environment: A material-object is affected by many features of the environment. The effects are local if directional (through specific orientation), or occur comprehensively. The various constituents of the object also respond differently. **Single, or mono material systems** are often inadequate for such multilateral environmental demands. **Multi -material-objects or composites** are conceived to serve such demands, separately as well as unitedly.

A surface material covering an entity, forms its own environment for the entity. Here the situation can also be equated to *material to environment response.*

Effects of the environment substantially relate to the movement of earth-sun, and so have a **time dimension**. The time dimension makes such environmental effects to be *temporary, permanent, recurrent, or variable*. One perhaps cannot terminate the processes of nature, however, the effects of environment can be temporarily delayed or quickened and spatially diffused, or intensified, to programme the functioning of an object.

The effects of environment are *structurally causative* (capable of causing structural changes in a material), and also *sensually attributive* (capable of providing the sensorial experiences).

User: A user perceives a material-object in different terms like: *Engineering attributes, Dimensional features, Surface properties and for Other considerations*. A surface is *the most proximate and tangible part of an object*. A surface, is often the reason, why an object continues to survive in a particular setting. A user **perceives the surface** of a material-object through factors such as:

proximity (closeness, intimacy, distance)
duration (of encounter)
frequency and extent (area) of contact
mode of handling
our past experiences
our sensory capabilities
our physiological state
atmospheric conditions (temperature, humidity)
light (direction and level of illumination)
orientation, or point of observation.

There are more than 20 mathematical parameters applied to **surface description,** and some of the terms are: roughness, irregular features of wave, height, width, lay, and direction on the surface; camber, deviation from straightness; out of flat, measure of macroscopic deviations from flatness of a surface.

FOUR CATEGORIES OF SURFACE SYSTEMS:

- Inherent (original) surfaces

- Modified surfaces
- Applied surfaces
- Applied surface systems at various levels of integration with the base

Inherent and Modified surfaces have to cope up only with the external or the environmental demands, whereas **Applied surfaces** additionally have the operative demands from the base-object. **Integrated surfaces** have only the environmental demands.

A surface system operates in the context of supportive as well as damaging demands. A surface system is analogous to a screen which both retain and filters. A surface system while facilitating the supportive demands, intervenes to debar the damaging demands.

Building stones, pebbles are materials appreciated for their inherent surface qualities. Stones like granite, marble, timber, etc. show very unusual grain patterns, colour and texture with modification processes like cutting, polishing and weathering. Claddings, panelling, coatings, painting, daubing, plasters, etc. are examples of applied surfaces. Oxidization, nitriding, burnishing, and metal plating are examples of surface finishes at various stages of integration with the base entity.

RATIONALIZING THE DEMANDS FOR A SURFACE SYSTEM:

One can rationalize the demands faced by an object or its surface system in many different ways. The processes of rationalizing the demands for surface finish begin with the **object-modification,** but may eventually include **changing the environment**. For a good designer, however, *it is often more efficient (functionally, technologically and economically) to compose a new entity, than expend too much effort in modifying the entity or change its environment.*

There are many fables where the advice is: to cover ones own feet, than cover all the streets of the town, or carry an umbrella than cover up the sun. It is better to buy a new razor blade with a sharp edge, than polish the blunt one.

Objects and the surface systems, if of a single material, the operative demands are simpler, but if composed of many, similar or dissimilar materials, have very complex and often in-specifiable demands.

It is ideal to reform the object entity by *integrating the surface system* with it. Where such direct integration is not possible, the object and its surface system both are individually refashioned, and then integrated into a single material entity.

A surface system can be facilitated by delaying or curtailing the effects of environment, for the functional period of the entity. Environmental effects are from specific orientation or comprehensive, and so one can design a **surface system to be local or total, momentous or everlasting.**

Ordinarily surface finishes are fashioned, only after the object and its relevant environment have been conceived. But sometimes an object could be so hazardous that until an actual workable surface system is designed, it cannot be allowed to occur. Similarly an environment could be so harmful that till an appropriate finish system is devised, the object cannot exist, much less function in it.

Liquids and gases have no stable object boundary, so must be contained, and for such material phases the container becomes the apparent surface system.

The environment influences objects in such a complex way, that any search for logic is impossible. This is the reason why many *surface makers seem to work with their intuitive faculties*. To some people, providing a *surface system is an art or craft, rather than a scientific discipline.*

At any cross section of time, we find *a large number of surface systems either are overtly attached to the object or are in the process of being integrated to the entity base.* It is very necessary that a surface system in such a situation, be singular in constitution or at least be effective in that manner. Finish makers aspire to provide a **singular surface system** in place of a **multi-component system**. However, in a finish maker's world there are very few situations where singular surface system can satisfy all the demands. Multi-component surface systems are reality.

1.02 SURFACE FINISH SYSTEMS

A surface is the outermost part of a material-object. A surface shows how the object has been behaving with the environment, or one can predict, how it will respond to the environment. It also provides a primary comprehension *what one can do to the object*.

CATEGORIES OF SURFACE FINISHES

Self Finishes

- ☐ Natural objects
- ☐ Modified objects
- ☐ Manufactured objects

Applied Finishes

- ☐ Mechanically fixed finishes
- ☐ Adhered finishes
- ☐ Coatings
- ☐ Chemically fixed or Integrated finishes

SELF FINISHES:

Self finish is a surface component of the material itself. Self finishes occur on *Natural, Modified and Manufactured objects*. Since such finishes are integral part of the object, the engineering properties of the object continue to be affective through the surface system.

Natural and Modified objects have inherent limitations, such as: Technologically, one can obtain a surface system *equal to or smaller than the naturally available sizes and shape of the object*. Identical surface qualities (colour, texture, pattern, etc.) are not available in every sliced section of a large object, because deeper or core regions show different surface qualities than the outer parts. Surface properties vary a little within a specie.

One adjusts such qualitative differences by *randomly distributing the variant, as small components in a large composition*. Though agglomerated assemblies have their own problems, of joints and joint materials.

Manufactured objects have self finishes. Bronze statues and outdoor objects have an induced self surface finish consisting of a green, brown, blue, and black patina of copper compounds. Silver is oxidized in an electrolytic liquid and then selectively ground to show a composition of dark (oxidized) and bright (polished) surfaces. Mild steel surfaces are burnished (burnt) to a blue finish. Iron is sometimes allowed to rust until it acquires a satisfactory colour, and then the process is arrested by lacquering. Stone washed jeans are intentionally created finishes.

NATURAL OBJECTS: Natural objects are created through various formative and destructive processes of nature. We pick such objects off the surface of the earth, mine them, or obtain by breaking off from a larger unit. Such objects invariably show some environmental changes, often called **weathering effects**. Freshly opened face of such objects present a surface finish, different from the face already exposed. Objects of the same specie may show up different surface finishes, depending on the angle of cut or cleavage, technique, and tools used for down sizing and finishing. Natural objects have time and space relevance. It may not be possible to amass enough quantity within a set schedule, or may not be economically viable to transport the required type and quantity.

MODIFIED OBJECTS: Natural objects are modified for many different reasons. Large objects are down sized to *equalize the size and shape variations*. Natural objects are also cut to explore patterns through sections. Objects are surface dressed to remove the weathered sections. Minor modifications relate *to, sizing, shaping, texturing (roughing, dressing, polishing)*. Major modifications include *treatments with acids, alkalis, solvents, reducing agents like oxygen, heat and cold processing.* The chemical changes either are on the surface -few molecules deep, or may constitutionally affect the entire mass. Manufactured materials are further processed by the user to modify the quality.

MANUFACTURED OBJECTS: Manufactured materials are often designed to have surface properties appropriate for the use. Manufactured materials are piece, batch or continuously produced. Such materials in a solid phase have finite sizes (length, width, thickness, etc.). Liquid and Gas phase products defy such size limitations. Manufactured materials result from well-defined processes and controls, so quality variations are negligible. Manufactured materials are preferred to natural or modified materials, for their consistent surface properties. Though natural and modified materials sometimes show surface properties that are difficult to emulate in manufactured materials. Large number of manufactured materials are provisioned with surface properties (like colour, texture, pattern, etc.) that are copied from other materials, known as **pseudo-materials or make-believe materials**.

APPLIED FINISHES

Many materials, even if suitable for their engineering performance do not have appropriate surface system, nor are they amenable to modifications towards such needs. Manufactured materials are used for many different purposes and varied environmental conditions, so it is not feasible to design **all purpose surface system**. Large number of objects that we use to day require applied surface systems. Applied surface systems consist of materials, *generically either of the same type, or of different constitution*. The surface system of generically same material is often modified just before the deposition, or changes are induced during or after the process of application. Applied surface systems as a result are sometimes called **foreign material surface systems.**

Foreign material surface systems can be constitutionally singular or composite (layered, etc.). A surface system designer endeavours, first, to achieve *a single material surface system* by integrating all the *surface system components,* i.e. layers, and then tries to integrate the single surface system so achieved, with the object itself.

> A partition is designed to divide a space in terms of visual privacy, safety, stability, sound proofing, fire proofing, heat insulation, provisions for apertures and services, etc. The partitions as a result consist of a structural system and various layers each designed for specific need. The partition is further coloured and textured for use requirements. The structural elements, layers and the surface treatments can be replaced by a **single material-object system**. Composite panels for partitioning, is a first attempt in integrating various sub systems.

There are many methods of applying surface systems to objects. Some surface systems stay in place due to gravity, whereas others may require some degree of fastening, achieved by mechanical fixing, adhesion, chemical reaction, ion attraction, etc. Many surface system use *combination fixing*, i.e. one method to achieve initial anchorage, and another for ultimate fixing. In some instances one system of fixing is operative for normal circumstances, and another one provisioned for extra ordinary stress conditions.

Fixing of a surface system: Fixing makes the applied surface system operate in consonance with the entity. The space between the surface system and the entity is reduced or eliminated by very close packing, or by introducing an intermediary element. It is required for two basic reasons: 1. to prevent the effect of gravity and 2. to stabilize against vibrations, jerks, movements, negative or lifting pressures, suctions, etc.

MECHANICALLY FIXED FINISHES: Of the several techniques available for achieving stable closeness, mechanical fixing is the most simple and universal method. Light weight, mobile (due to the external stimulus), and oppositely charged (ion) surface components need to be anchored mechanically to the base entity. Sufficient friction, surface tension magnetic pull, ionic attraction, presence of kinetic or previously induced stress, may obviate the need for fixing. End (surface) conditions of the base entity also prevent the surface component being destabilized.

Mechanical fixing of a finish component is necessary where its situational stability is insufficient. It is done by positioning, nailing, rivetting, screwing, clamping, keying, etc. As mechanical fixings cause only physical change, mechanically fixed *surface systems are demountable, relocatable and reusable.* There is no need for an interaction between the surface and the base entity. In other words mechanical fixings are ideal where there must not be any interaction between the entity and the surface.

Mechanically fixed surfaces have size limitations. When base objects are larger in extent, than the largest available size of the surface finish component, some joints occur. ***Joints***, however well designed and executed have, properties that are slightly different from the main body of the surface components. Edges of the individual surface components and the edges of the composed surface system, both as a joint require special attention.

Mechanical fixing entails, concentration of stresses at fixing locations, and their accommodation by means of predetermined techniques of stress dissipation. It is also very essential that the surface and the base entity accommodate the *keying elements (nails, rivets, nut-bolts, screws, etc.)*. For mechanical fixing the surface components must have some body (thickness) and stiffness. Mechanical keying occurs at select locations, and their configuration and distribution need pre designing. (For further reading, See chapter: 1.4 Fastening systems).

ADHERED FINISHES: Adhered surface systems cover the object interactively. Adhered surface systems nearly merge with the base entity, and as a result the *transfer of stresses* is evenly distributed. For this reason adhered surface systems could be much thinner, than the body necessary for mechanical fixing. A *thin body surface system* has greater flexibility, ductility, and stretchability, and so better unified behaviour with the base entity. Adhered finishes often require an intermediary agent, the adherent, to achieve the bonding. The adherents have a dual or multilateral qualities, capable of adhering to the singular or multiple components of both, the surface system and the base entity. The adhesion is provided by surface tension, ionic attraction, friction and chemical bonding. Adhered finishes are occasionally removable but not easily demountable and relocatable.

Adhered finishes also have size limitations. Joints in adhered-finishes occur as a thin divide between the two surface components, or as lap-over with a *seam joint (stitched, folded, fused).*

Mechanically fixed and Adhered-finishes, both due to their simplistic technology can be employed on remote locations. The surface components are sometimes designed to have different personalities on the outside and the face to be attached to the base.

COATINGS: *Coatings are thin surfacing, in which a material changes its physical state (phase) to form a film or a coating.* At application-stage the film-forming mediums are in various phases such as liquid, solid or vapour, or a combination thereof like, *suspensions, solutions, dispersions, emulsions, thermoplastic compounds, thixotropic compounds,* etc., but coatings once applied ultimately settle down to a heavier phase, usually (but not necessarily) a solid phase.

At an application stage a lower phase helps in many ways:

1. Easy, uniform and thin level of application.
2. Better dispersion of costly or rare constituents within the mass.
3. Easy and thorough mixing of film forming constituents and other additives.
4. Less energy is required for application.
5. A controlled rate of phase conversion and so deposition.

Coatings are generally capable of forming a film on the relevant surface. But it may be necessary to modify, treat or coat the base object, to make it receptive for the coating. **Surface treatments** form a very important section of coating technology. Some surface treatments are specific for the surface to be coated, such as *cleaning, roughening, smoothening, etching, etc., or moisture proofing, rust inhibiting, barriers, static arresters, etc.* while others are designed for the surface component to be deposited. Some other treatments only facilitate the application, setting or drying of the coating.

Coatings generally do not have joints, except at junctions where coating application is delayed (a dried out portion and a fresh coat touch each other or overlap). Coatings are thin surfacing so are usually malleable and allow the post-forming operations (e.g. coated metal sheets). Coatings are not considered to be adhered-finishes, because the coating film is formed and bonded by a lower to higher phase conversion process.

Coatings are deposited on the entity by many different techniques. (see chapter: Coatings). Coatings require a plant level controlled facility (powder coatings) or equitable environmental conditions for on-site applications.

CHEMICALLY FIXED OR INTEGRATED FINISHES: Coatings, mechanically fixed and adhered surface systems, all have a body that is *foreign to the base entity*, and a variety of problems arise only for this reason. Finish makers desire to integrate the finish components with the entity. To make a foreign finish *fully-resident*, it is necessary to have both of them of the same constituents or at least be mutually very compatible.

Integrated surface finishes develop ionic, covalent or metallic bonds. Once integrated, such finishes have no separable identity. The finish material generally does not affect the mass of the entity, and as a result the base mass retains most of its original structural properties. The surface-system so integrated is just a few molecules in thickness. Very thin deposition allows even very thin objects to retain their characteristics like ductility, malleability, expansion and heat coefficients etc.

Some examples of integrated surface finishes are: Polyester film with metal depositions to create solar films, chrome or gold plating of metals, dyeing of fabrics, paper and leather. There are vast number of such surface systems so well integrated, that we consider them as *surface treatments* rather than as an *integrated surface finish system*.

Further reading

Selection and use of Engineering Materials : Charles, Crane, Furness / Butterworth-Heinemann / CEPT SBST 04536 / 691 /CHA

Engineering Materials : Budinski, Budinski / Prentice Hall / CEPT SBST / 691

Engineering Materials and their Application : Flinn, Trojan / CEPT SBST / 691

Concise Encyclopedia of Science & Technology: Parker P Sybil / Macgrow-Hill

1.03 PROPERTIES OF MATERIALS

State or **phase of a matter** is due to the temperature and pressure. Materials have three common states, namely **Gas, Liquid, and Solid**.

Plasma is the fourth state of matter following solid, liquid, and gas. Plasma is an ionized (electrified) form of gas, a collection of charged gaseous particles containing nearly equal numbers of negative and positive ions, is sometimes called the Fourth State of matter

Most substances are solid at low temperatures, liquid at medium temperatures, and gaseous at high temperatures.

Solids are formed when definite bonds exist between component atoms and molecules. Atoms and molecules are not bonded in liquids and gases. Crystalline Solids (metals and inorganic compounds) have atoms or molecules that are organized, against Amorphous materials (glass, plastics, some organic compounds) which do not have specific and orderly structure.

The state or the changeover of a phase is not always distinct. The temperature at which any given substance changes from solid to liquid is its **Melting point**, and the temperature at which it changes from liquid to gas is its **Boiling point**. In the reverse order the Gas to a Liquid transition is known as **Condensation**, and Liquid to Solid change as **Freezing**.

COMPOUNDS: Objects, materials that we use every day are Compounds, that is a **mix of materials in various phases**. If the compound is uniform, it is called **Homogeneous** and nonuniform compounds are called **Heterogeneous**. Homogenization is a process of distributing one substance, uniformly throughout another (Ice creams, ketch-ups, etc. are homogenized).

Compounded materials occur in following forms

SOLID + SOLID	=alloys
SOLID + LIQUID	=suspension, solution, dispersion
SOLID + GAS	=smoke, airborne dust
LIQUID + SOLID	=gel
LIQUID + LIQUID	=emulsion, mixture
LIQUID + GAS	=fog, aerosols
GAS + SOLID	=solid foams
GAS + LIQUID	=froth, liquid foam

GAS + GAS =atomospheric air.

Some terms that relate to various mixed phase compounds are explained here. Understanding of these terms will help a clearer understanding of *Materials Sciences* and more specifically the *Surface Finishes*.

- **Solution:** Solution is a homogeneous mixture of two or more substances. The substance present in larger quantity is usually called the **solvent**. The other substance called the **solute** is present in smaller quantity and is dissolved. The solute can be either a gas, a liquid, or a solid, and the solvent can be either a liquid or a solid. Carbonated water is an example of a **Gas** (carbon dioxide) dissolved in a **Liquid** (water). Mixtures of gases, such as the atmosphere, are sometimes referred to as solutions as well. Solutions are distinct from **colloids and suspensions** in that the particles of the solute are of molecular size and are evenly dispersed among the molecules of the solvent. Solutions appear homogeneous under the microscope, and the solute cannot be separated by filtration. Salts, acids, and bases ionize when they are dissolved in water. Certain metals are soluble in one into another, in the liquid state and solidify with the mixture of atoms preserved. If such a mixture can solidify for different proportions of the two metals, they are said to form a **Solid solution of metals**.

- **Solubility**: Some liquids, such as water and alcohol, can dissolve in each other, in any proportion. Sugar can be dissolved in water, till the point of saturation. The solubility of a compound in a given solvent at a given temperature and pressure is thus defined as the maximum amount of that compound that can be dissolved in the solution. Solubility increases with the increasing temperature of the solvent for most substances. For some substances, such as gases, solubility in a liquid increases with a lowering of temperature. Usually, solutions with molecules that are structurally similar to the molecules of the solvent have the highest solubility. For example, ethanol (C_2H_5OH) and water (HOH), have structurally similar molecules, and are highly soluble in one-another.

When a solute, is added to a solvent, some physical properties of the solvents change. Its boiling point is raised and its freezing point lowered with increasing concentrations of solute. For example, the cooling water in a car engine, can be prevented from freezing, by adding antifreeze such as ethane-1, 2-diol ($HOCH_2CH_2OH$), as a solute. In addition, the vapour pressure of a solvent is lowered when a solute is added.

- **Solvents:** Solvent is a material that has ability to dissolve other substances, and form a solution. There are three broad classes of solvents - **aqueous, non aqueous and organic**. Organic solvents are further classified by the functional groups like, *alcohols, halogenated hydrocarbons, or hydrocarbons,* present in the molecules. Non aqueous substances are generally inorganic substances, such as *acetic acid, methanol, Hydrogen sulphate and ammonia*. **Hydrocarbon solvents** contain only Carbon and Hydrogen, whereas **Oxygenated solvents** additionally contain Oxygen.

- **Mixtures:** Mixtures are combinations of two or more substances that are not chemically bonded to each other. Gases, liquids, and solids can all mix with each other. When they do, the physical and chemical properties, of the resulting mixture depends on the behaviour of each material in the mixture. Salt can be mixed with sugar, but, no chemical reaction occurs between the two substances. The properties of the mixture are *averages of the properties of the individual substances*. When one substance dissolves in another, it is simply forming a very even mixture with it.

- **Suspension**: When the particles of solid are small, and are not soluble, they can stay suspended in the liquid, and the mixture is then known as a suspension. *Suspensions are chemically more stable than solutions*. Suspensions should not cake on standing, and the solid phase must, readily re-disperse on shaking. Suspensions should pour easily, so the viscosity must not be too high. Lotions, such as calamine lotion, are suspensions. Magmas and milks are thick, viscous, aqueous suspensions of insoluble inorganic compounds.

A barium mineral is opaque to x-rays, so its suspension is given to the patients for taking x-ray of intestine and stomach sections.

- **Colloid**: If the solid particles are much smaller, with diameters in the range 10^{-3} to 10^{-6} mm (40 millionths to 40 billionths of an inch) -they may not settle at all, because they are constantly shaken by movements of the liquid molecules. Such a mixture is called a colloid. Dust particles floating in the air are a colloidal mixture of a solid and a gas. Milk is a colloid consisting of tiny fat droplets (the solid) in a liquid (mainly water). An **aerosol** is a colloidal system consisting of very finely subdivided liquid or solid particles dispersed in a gas.

- **Emulsion**: A mixture of one liquid suspended in another liquid is called an emulsion. In an emulsion, of the two liquids, one is present as droplets of microscopic or ultramicroscopic size, distributed throughout the other. Emulsions are formed either spontaneously, or more often, by mechanical means, such as agitation, if the liquids mixed have no (or a very limited) mutual solubility. However well two immiscible liquids are mixed, on standing they will separate into two layers. To prevent separation, an emulsifying agent is used. Emulsions are stabilized by agents that form films on the surface of the droplets (e.g., soap molecules), or that imparts to them a mechanical stability (e.g., colloidal carbon or bentonite). Unstable emulsions eventually separate into two liquid layers. Stable emulsions can be destroyed by inactivating or destroying the emulsifying agent, e.g. by adding appropriate third substances or also by freezing or heating. **Emulsifying agents** can be divided into three groups: **Finely divided solids** such as *bentonite and magnesium aluminum silicate*, **natural emulsifying agents** such as *cholesterol, gelatin, acacia, methyl cellulose, pectin*, etc. and **synthetic emulsifying agents** such as the *anionic sodium lauryl sulfate, the cationic benzalkonium chloride, and the nonionic polyethylene glycol 400 mono-stearate.*

Some familiar emulsions are milk (a dispersion of fat droplets in an aqueous solution) and butter (a dispersion of droplets of an aqueous solution in fat). Oil-in-water emulsions will mix with water, whereas water-in-oil emulsions only mix with oils. Emulsions are important in many fields, in plastic paints, in the dyeing and tanning industries, in the manufacture of synthetic rubber and plastics, in the preparation of cosmetics such as shampoos.

- **Froth:** The fizz on beer, or soap suds (bubbles) in bath water, are foams, mixtures of gas and liquid. Whisking and cooking egg-whites produces foam, air bubbles with an emulsion. Blasting a gas through a molten plastic fills it with bubbles, when the plastic cools and solidifies the gas bubbles are trapped inside, making a foamed-plastic, used for filling cushions, and pack goods.

- **Gel**: Gel is a coherent mass consisting of a liquid in which particles, (too small to be seen in an ordinary optical microscope) are, either dispersed or arranged in a fine network throughout the mass. A gel may be notably **elastic and jelly like** (as gelatin or fruit jelly), or **solid and rigid** (silica gel, a material that looks like coarse white sand and is used as a de-humidifier). *Gels are colloids* (aggregates of fine particles, dispersed in a continuous medium) in which the liquid medium has become viscous enough to behave almost as a solid. Contraction of a gel, causing separation of liquid from it, is called **syneresis**.

- **Thixotropy:** Reversible behaviour of certain gels that liquefy when shaken, stirred, or otherwise disturbed, and reset after being allowed to stand is called thixotrpy. Thixotropy occurs in paint, such as lithophone in oil, which flows freely when stirred and reverts to a gel-like state on standing. Plastic paints have thixotropic compounds to prevent separation (settlement at bottom of a tin) of pigments and such solid particles. Tixotropic compounds also prevent runoff and dripping of paints during application. Quicksand, a mixture of sand and water, is rendered thixotropic by the presence of certain clays. Drilling mud is made thixotropic by the inclusion of bentonite. It forms a cake on the wall of the drill hole, to keep drilling fluid in the hole and to prevent outside water from entering.

- **Viscosity**: Viscosity denotes opposition to flow. The reciprocal of the viscosity is called the **fluidity**. Viscosity is a major factor in determining the forces that must be overcome when fluids are used in lubrication and transported in pipelines. It controls the liquid flow in such processes as spraying, injection moulding, and surface coating. The viscosity of liquids decreases rapidly with an increase in temperature. The viscosity of gases increases with an increase in temperature. Thus, *upon heating, liquids flow more easily, whereas gases flow more sluggishly*. High-viscosity fluids resist the flow and low viscosity fluids flow easily. The tenacity with which a moving layer of fluid drags adjacent layers of fluid along with it determines its viscosity.

Viscosity is measured through a conical container with a standardized orifice in the bottom (Ford cup-4 for paints, measures in *seconds* to pass 100 ml volume of a liquid). The time / volume rate, the fluid flow through the orifice is a measure of its viscosity.

Silicone oils, for example, change very little in their tendency to flow with changes in temperature. They are valuable as lubricants when machinery is subject to great temperature changes.

- **Aerosols:** Aerosols are colloidal systems consisting of *very finely subdivided liquid or solid particles dispersed in a gas*. Though the term aerosol, is used for **a pressurized package**. *Aerosols include solutions, suspensions, emulsions, powders, and semisolid preparations*. Surface-coating aerosols produce a coarse or wet spray and are used to coat surfaces with a residual film. **Propellants** used in aerosols are of two main types: *Liquefied-gases and compressed-gases*. The former consists of easily liquefiable gases such as *halogenated hydrocarbons*. Drugs are dissolved in the liquefied gas or in a mixture of the gas and a suitable solvent. When these are sealed into the container, the system separates into a liquid and a vapour phase and soon reaches equilibrium. The vapour pressure pushes the liquid phase up the standpipe and against the valve. When the valve is opened by pressing down, the liquid phase is expelled into air at atmospheric pressure and immediately vaporizes, leaving an aerosol of the drug. The pressure inside the container is maintained at a constant value as more liquid changes into vapour. When compressed gases are used as the propellant, the pressure falls steadily as the contents of the aerosol are used, and for this reason liquefied gases are used whenever possible.

- **Classes of Solutions:** Liquid mixtures can be classified as either *solutions of electrolytes or solutions of a non electrolyte*. **Electrolytes** are substances that can dissociate into electrically charged particles called ions, while **non electrolytes** consists of molecules that bear no net electric charge.

Ordinary salt (sodium chloride NaCl) is dissolved in water, it forms an electrolytic solution, dissociating into positive sodium ions ($Na+$) and the negative chloride ions ($Cl-$), whereas sugar dissolved in water maintains its molecular integrity.

Water is the most common solvent for electrolytes. The ocean is a solution of electrolytes. Electrolyte solutions, however, are also formed by other solvents (such as ammonia and sulfur dioxide) that have a large dielectric constant (a measure of the ability of a fluid to decrease the forces of attraction and repulsion between charged particles). The energy required to separate an ion pair (i.e., one ion of positive charge and one ion of negative charge) varies inversely with the dielectric constant, and, therefore, appreciable dissociation into separate ions occurs only in solvents with large dielectric constants. Solutions of electrolytes readily conduct electricity, whereas non electrolyte solutions do not.

- **The state of a surface:** A surface of an object is always in a changing state, though not always apparent over a particular time and space scale. The **changes in the object and its surface occur** due to reactions with the *environment*, stresses set by the *user*, and also from the *stresses set within*. When materials of the same or different phases come into contact with each other, there is an energy transfer, which in certain cases is accompanied by gain or donation of an electron or molecules. There are many such substances which affect the behaviour at a surface level, known as, *retarders, activators, surfactant, emulsifiers, wetting agents, softeners, electrolytes, etc.*

- **Surface preparation:** Application of a surface finish to an object generally involves some type of **surface preparation**. Surface preparations are physical, chemical and mechanical processes, such as *cleaning, rubbing, levelling, sand blasting, washing, etching,* etc. These processes comprise both levelling by removing excess materials and roughing-or etching to remove the material of the surface. Where unwanted particles adhere to the surface through chemical (molecular) bonding or ion attraction, **surface active agents - Surfactant,** are applied. These agents weaken the ion attraction or attack the molecular bond to create a by-product that can be removed easily. Such surface preparation applications generally affect the entity over the surface section only. Some surface preparation agents and their by-products are taken away or washed off the surface. In many instances the by-product is beneficial or neutral and is allowed to remain on the surface. Sometimes **Surface preparation agents** are themselves **primary surface finishes**. Such agents cover the surface area as an intermediary film. Such films help in bonding of the final surface finish.

Further Reading

Concise Encyclopedia of Science & Technology: Parker P Sybil / Macgrow-Hill

1.04 FASTENING SYSTEMS

Surface Finishes, as one ordinarily presupposes are comparatively thin components occurring as **finishing or the outermost layer over an object**. Surface finishes unless made out of the object itself, are **applied finishes**. The application of a finish over an object many times involves some form of **material joining and mechanism**. Surface finish systems are of two types. In the first case a continuous surface layer is formed by depositing a surfacing material, and in the other case, several surfacing components are joined to form an extensive surface layer.

Fastening the Surface Finishes: The fastening of surface finishes is done at two distinct levels: One, when a surfacing component is attached to a base material, and Two, when the edges-ends of the surfacing components are attached to such units. In the first instance, the surfacing component is joined to the base entity. In the second instance, the joining of the edges-ends of the surfacing components apparently enlarges the extent of the assembly, and seals the ends. Edges and joints of surface systems emerge or are formed through design. There are many surface finish compositions (cobble stone or brick flooring) where edge to edge positions do occur, but no joining materials are used. However functional requirements and environment conditions require filling up or sealing of the joints.

Edge to edge joining is, both **created and avoided intentionally**. Wooden floorings for decks (exterior) and stages (interior) have spaced joints to allow the wood to adjust to the **changes in moisture content** of air. Similarly metal assemblies have free joints to accommodate the **movement and expansion caused by the temperature**. Edge joints have an intervening material (such as a ductile or conductive material) or none, to allow or curtail the transmission of energy and vibratory forces (mechanical, sound, electrical, etc.). Structures require **separation joints** to sustain their integrity, and the same are identically placed in their surface finishes.

Very closely placed joints create a virtually continuous surface finish. Stone masonry and wood often have thin or knife edge joints. Thin joints are for sensorial reasons like touch, fill, visual, etc., and for structural or functional causes. Thin joints provide some flexibility to the surface component, but there is insufficient space for displacement (bricks and cobble stone flooring).

Widely spaced joints occur for many different reasons. The prime reasons are: non matting planes at the joint, geometric deviations of the surface components' shapes. Deep joints require greater width for filling up. **Wide unfilled or shallow filled joints** create crevices, enhancing the light-shadow contrast over the surface.

Gravity holding of surface finishes: One of the prime functions of a surface finish is to remain with the base entity in spite of the many destabilizing forces. Gravity is the most pervasive pulling force on the earth and surface-finishes oriented to it, i.e. *with an extensive gravity-parallel surface* do not get easily displaced. Gravity holding is used for laying *Carpets, Durries, Floor spreads, Cobble stone floors, Sand or Pebble spreads, Brick paving, etc.* However, if the surface finish units are small, and if the vibratory and displacing (pullout) thrusts are severe, some additional holding is required. The additional holding is provided by *friction and ion attraction* between the under side of the surface component and the base. *Increase of thickness and weight* improves the holding. Edge to edge joining of the surface components *extends the spread* of the surface finish, and improves its stability.

Surface-finishes are fixed *with or without any additional fixing material*, but through many different techniques. Fixing of **opaque and thicker surface components** have lesser problems in comparison with **transparent materials**. **Surface fixing materials** are unseen in opaque objects but transparent, translucent or ultra thin surface components show off not only the surface fixing materials, but also the quality of the substrate, such as colour, texture, etc.

Surface fixing materials seem to serve only a *technical function* compared to a **joint material**. Joint materials have to be not only *structurally adequate but visually and sensorially appropriate*. A *surface fixing material* and the *joint material* are usually the same in most instances, but not necessarily.

A PVC carpet or floor spread is fixed to the floor with rubber cement, but joints are made by welding. In case of marble or ceramic tiles floor the substrate fixing cement slurry is allowed to flow up the joints and seal it. A brick masonry may have low cement content mortar, but for pointing (joint filling and dressing) work high cement content mortar of different colour or tone is used.

Joints in surface finishes require very careful **design considerations**. These include: colour, texture, form, colour contrasts between the joint material and the surface finish, patterns (geometric configurations) of the joint, orientation of the pattern, proportion of the joint surface area vs. the surface-finish components' area, and density of the joints.

Surface-finishes are applied as a **master surface system** covering the entity assembled out of many components. The master surface system often consists of several surface finish components and systems, all so layered that **a consistent or virtually seamless surface** is available, alternatively it is the coating or deposition that creates a very extensive surface without any breaks or joints.

Joining has been *a followup process* after the components have been devised. Joining was getting a secondary importance. But with **systems design approach** in creation of assembled entities **joining is an integrated effort.** As a result not only **joining, un-joining and rejoining,** all are considered important. At plant or industrial level, the joining of component is inevitable part of manufacturing. This has allowed use of **nano technologies in joining components** of electronics, human body limbs, etc.

CLASSES OF FASTENING SYSTEMS:

Joining begins with the electro magnetic interactions between materials. The interactions are based on mechanical, chemical and physical forces. **Mechanical joining** involves no chemical or physical forces. **Chemical joining** involves chemical reactions arising out of the attraction between the atoms and molecules. **Physical joining** involves no chemical reactions and exploitation of any mechanical arrangement. To a designer fastening systems are more relevant when categorised in terms of the techniques. Important fastening techniques of are:

Mechanical Fastening systems: Such as nails, staples, rivets, nut bolts, screws, keys, snap assemblies, shrink and expansion fittings, friction fittings, crimping, seaming, stitching, tying, etc.

Fusion Joining systems: Such as Soldering, welding, brazing, fusing.

Adhesion fixing: Such as adhesion and cohesion achieved by use of natural adhesives like animal, vegetable or mineral, and synthetic adhesives like elastomers, thermoplastic and thermosetting compounds.

MECHANICAL FASTENING SYSTEMS

Mechanical fastening is the oldest fastening method available to human beings. It has over the years developed into many complex solutions. Mechanical fastening is preferred to all the other techniques because it substantially *depends on the geometry of the component and less on the properties of the materials to joined*.

Mechanical fastening systems are of two types: One, where a component has a **geometric configuration** to receive, accommodate and hold onto another component, and Two, where an **additional fastening device** is employed to endow such qualities. Geometric configurations and additional fastening devices, both also use **friction** to further the mechanical joining. Mechanical fastening systems are many, such as: *Nails, Screws, Nut-bolts, Rivets, Keys, Seaming, Sewing, Stitching, Knotting, Knitting, Paper clips, Safety pins, Zippers, Buttons, Staple pins, Dovetail joints, Tongue-grooves, Punches, Crimping, etc.*

Behaviour of Mechanical joints: Mechanical fastening causes no change in the materials to be joined, so virtually any similar or dissimilar materials can be joined. Mechanical fastening systems are demountable, so offer a flexibility of undoing a joint but also inviting a danger of assembly coming apart accidently. Materials susceptible to deformation may not be good for mechanical joining. Mechanical joining due to the concentration of stresses, causes local failures. Mechanical fastening requires components to be designed with specific geometry. A facility often unavailable in some material forms, e.g. very soft, ductile, brittle or very thin materials.

- **Nails**: Nails are most commonly used to fasten pieces of wood together, but are also used with plastic, drywall components, masonry, and concrete. An assembly to be nailed should be generally static and in a state of compression. A nail on insertion compresses the adjoining material, which upon being stressed causes a bearing pressure and does not allow the nail to escape. The heat generated during hammering and friction insertion may cause annealing of the nail material making it softer. A nail fails, if the holding matter is like a collapsible sponge, or the nail body itself shrinks (e.g. wood pins as used in panelled door shutters). A nail (toe-nailing or toeing) at an inclined angle provides additional shear-resistance.

Nails are made of black steel, galvanized steel, stainless steel, brass, anodized brass, copper, wrought iron, aluminium, bronze, wood and bamboo. The pointed end of a nail is called the **point**, the shaft is called the **shank**, and the flattened part is called the **head**. Nails have various body sections such as round, oval, square, hexagonal or rectangular, come in different lengths and diameters or cross section sizes. Nails have **plain, grooved or threaded shafts**. **Flat heads** make most nails extractable, the **finishing nail and casing nails**, however, are virtually headless.

There are many different types of nails. Two basic classes of nails are **common nails** and **finishing nails**. The most widely used of all nails, the common nail has a large flat head, that is driven in, so that it is flush with the material's surface. A finishing nail has a smaller, narrower head that is driven in below the material's surface with a special tool called a **nail set or punch**. The small depression remaining is filled with putty. Finishing nails are used mostly for interior panelling and cabinetwork, for their neat appearance. **Needle points** are surface-hardened stiff nails of very thin diameters, without head, and lengths not exceeding 25 mm, and are used for fixing veneers, mouldings, floor boards, etc. These points are partially driven by hammer and snapped of to be in level with the surface. **Panel pins** are very small nails, up to 35 mm with a very small head and are used for fixing wood veneers etc. A **box nail** is similar to a common nail but has a slimmer shank and is used on lighter pieces of wood and on boxes. A **casing nail** is similar to a finishing nail but has a slightly thicker shaft and a cone-shaped head. Nails smaller than 25 mm long made from wires are called **wire nails.** They have a small round head. **Brads** have a small side projection, a very small head or none at all. Extremely thick nails are called **spikes.** Nails can be given *specially worked shanks* to give them greater holding power once they have been driven in. The **ring nail** has annular rings on its shaft, while the **spiral shank nail** has a groove running up in a tight spiral, like that of a screw. **Roofing nails** have large, flat heads that can better hold down materials such as roofing felt and fibreboard. Certain specially **hardened nails** are used for attaching wooden members into masonry or concrete. **Tingles**, smallest of all nails, 5 to 8 mm in length, are used for lining, upholstery and leather fixing work. **Tacks** are blue or black finished, short nails (12 to 25 mm), have a square section of shank, and round thin head. Tacks are used for leather as in shoes and upholstery work.

- **Pegs:** :Pegs are like nails, but usually take up the shearing stresses across their cross section, so have a heavier body and are made of mainly hard wood and sometimes metals like copper, carbon steel, etc. Pegs are used for holding tongue-groove assembly in wood and for masonry structures. Traditional stone masonry structures, such as of temples, use no mortars but pegs to prevent displacement of stones. Pegs have round, square or hexagonal sections, usually slightly tapered at one end.

- **Screws:** Screws are made of galvanized mild steel, stainless steel, brass, brass chrome and aluminium. Screws have a spiral groove for partial to full length, and are available with a variety of head formations. Screws are available with a **flat head** or **countersunk top**, **round**, **elliptical, philips or square head and headless.** Screws are generally fixed, with the help of a manual or automatic screw driver, but in some cases with a spanner also.

Screws are superior to nails as their holding power is better for static, vibratory or straight pull off forces (tension). Screws are removable and re installable. However, screws are thicker than nails, so cannot be used for fastening very fine work like veneer or moulding.

○ **Wood screws,** have more open threads but for only part of the length, and are so designed to cut their own threads while being driven. **Sheet metal screws** have small depth close threads for the entire body length. Screw's fixing requires a pre-drilled or punched hole.

◦ **Self tapping screws,** have deep helix groove and can be driven without the need of a pre-drilled hole, in such materials as metals, plastics, glass fibre, asbestos, and resin-impregnated plywood, when driven or screwed into drilled or cored (cast) holes. **Hardened self-tapping screws,** are surface-hardened and can be hammered down a hole in surfaces like plaster, masonry, RCC etc.

◦ **Capped-screws** have a small threaded-hole, in the head, in which a decorative cap can be driven. **Lag-screws,** large wood-screws are, used to fasten heavy objects to wood. Heads are either square or hexagonal. **Setscrews**, fit into threaded-hole in one member when tightened, the cup-shaped point is pressed into a mating member (usually a shaft) and prevents relative motion. Setscrews are also made with conical and cylindrical points that fit in matching holes and with slotted and square heads.

◦ **Machine-screws** are used for fixing metal assemblies where holes have been tapped with threads. A machine screw unlike a wood screw does not require any penetration cone and so have flat but slightly concave bottom. A small tapered edge is provided for primary placement. Compared with a bolt of nut-bolt assembly, the threads of a machine screw are sharper and deeper, because holding (stress transfer) is by the tooth of the grooves within the cylinder of the hole.

- **Nut-Bolts:** Nut-bolts are used to hold two pieces of solid materials having certain amount of thickness and body stiffness. Plain holes are made in both the pieces, and bolt of slightly a smaller diameter is placed through it and fastened with a nut. In some cases only one material has plain hole while the other is internally threaded (tapped). If materials to be fastened, do not have a proper thickness or stiffness capable of distributing the stresses, **washers** are used.

Bolt heads and nut have **Square and Hexagonal shapes**. A **Hexagonal head** is preferred because the wrench movement is of only 60 degrees, whereas in **square head**, though the wrench has to be moved 90 degrees, but has a larger grip area. A hexagonal nut gives a better appearance. A **stud bolt** has no head, and is threaded from end to end, or for some portion at both ends, with a plain, square or hexagonal section in the centre, for tightening. It is permanently screwed into one member and clamped by means of a nut on the other end. A

carriage bolt, is mainly used in timber assemblies, and has smooth oval shaped head and a square shank beneath it, which prevents the bolt from turning as the nut is tightened. A **stove bolt** has an oval or flat head with a slot for a screw driver. Often such bolts have a bevelled countersunk below the head. **Plow bolts** in addition have small projection from the countersunk, which keeps the bolt from turning when the nut is being tightened.

There are many special purpose bolts. **J and U roof bolts** are used for holding corrugated or plain sheets to tubular structure. Long sized **J and L foundation bolts** are used to secure base plates of steel columns, roof-trusses and machineries. **Eye bolts or hooks** are used as hanging or **tying nails** for wires and ropes. **Thumbed bolts** have a butter fly like wings to hold and twist the bolt.

◦ `**Nuts** like bolts, have variety of shapes. Nuts are supposed to remain snugly fit under all types of vibratory conditions. Many **nut-locking and jamming devices** are available. A **jamming nut** is a secondary nut, and is thinner, as it is not required to take the same type of load a primary nut is to carry.

◦ **Lock washers** also function for the same purpose. Lock washers are usually placed below the nut. These washers have cut ends and have a helical shape and exert a spring like pressure to prevent the nut from turning. **Cotter pins** are used for locking the nuts. These are U-shaped spring steel wires of round, half round, oblong or square section. The pin is pushed through a hole in both nut and bolt and ends are rivet-hammered or bent outwards. A **split nut** has horizontal splice, which is deformed or a spike is pushed through it. There are many proprietary locking devices, most of which are mechanical (kinetic), but some work on physical deformations and chemical actions.

◦ **Washers:** Washers are used primarily to distribute the impinging stresses occurring from fastening a screw, nut or bolt into the materials being joined. Nuts also help in allowing and also prevent unfastening. Lock washers or lock nuts prevent unloosening. Washers are also used to prevent thermal and electrical energy transfer, stop vibration transmission and prevent moisture penetration (roof sheet fixing washers). Lock washers have a cut in the ring and slightly deformed edge at the cut ends, or concave ring body. Roof washers are made of soft or fusible materials like bitumen, asphalt, nylon, PVC or rubber.

- **Rivets:** Rivets are used to hold together comparatively thinner plates and sections. It uses very little material and holds well against the vibratory loads. Rivets unlike the nut bolt system are not easily demountable. Rivets are manufactured with one head only, the other head end is formed after inserting it in the assembly. However, in continuous assembly machines both heads may be formed simultaneously. Most ferro alloy rivets are heated for head forming, before the insertion. However, certain aluminium alloy rivets are so delicate that they are kept dry and chilled till being formed.

Rivets have to be of very exact lengths, unlike bolts that can be accommodated. Length of a rivet includes mass required for head formation of appropriate shape and size. **Split rivets** have ends split into two, three or four section, which are pressed outwards. An **explosive rivet** has a small cylindrical cavity for explosive filling, on an explosion the rim of end section bursts and widens. An **eyelet** rivet is like a little cylinder, used for lining holes in leather(belts, shoes, purses), fabric (tents) and paper (files) assemblies.

- **Keys:** Keys are **wedges** placed to fix an object against any movement, or make the object move with another one (wheel on a shaft). The restriction caused maybe unidirectional or multidirectional, linear, planner, circular or helical. The wedge itself may stay put due to a tapered angle, insertion in groove, screw or other fastening mode, gravity, centripetal or magnetic positioning, or by adhesives. Most axle assemblies have **straight pins**, while pistons etc. have **retaining rings** for the same purpose. **Couplers** have multiple saw tooth arrangements with tapered faces for friction holding.

- **Seaming:** Seaming is a joining technique. Seaming is used for very thin malleable sheet materials. Household cans, tins, metal buckets, air-conditioning ducts use these types of joints. Hot seaming is used in assembly work of plastic sheets materials. **Crimping** is a *deformation joint system* for thin malleable sheets formations like pipes. Pipes to be fixed to other tubular and non tubular structures, without welding, have crimped ends. Metal crimped connectors help join electrical cables to fuse boxes and transformers. **Snap assemblies** have at least one material component capable of deformation. **Material deformations** occur in elastomers, while **shape deformations** occur due to mechanical pressures on spring properties of metals. **Expand and shrink methods of assembly** use materials that have high coefficient of expansion, as in case of fitting of an iron rim on a cart wheel, fitting of an iron ring on wooden ice-cream or beer barrels.

- **Stitching and sewing:** Stitching is mainly done on fibre, film or pliable **laminar assemblies**. **Stitching** is a *continuous linear fastening system*, compared to **knotting**, which is of *intermittent stitches*. **Machine Stitching** is common to garments and bags (cement, grains, etc.) packing. Machine stitching is done with *two individual fibers*, on either of the faces, so a fibre pull from the other face (from the machine) may undo the assembly. **Hand stitching** is used for garments repair (*Rafu* work in India) and for preparing *Razais* (Indian cotton stuffed blankets). It is done with *a single fibre* as a continuous stitch, and so is more stable, but not necessarily stronger. **Knotting** is very common in making of cotton mattresses. It is stable and stronger as each knot is tied separately, and even if one of it comes apart, does not affect the entire assembly.

  - **Stitching materials** are threads of cotton, silk, rayon, polyester, and metals (silver, gold, copper, aluminium) Stitching material must have *strength equal or less than the material to be stitched*. A stronger stitching thread otherwise cuts into the material being stitched. Surgeons use stitch materials made of **animal guts** (processed intestines of cats stretched into a fine thread) or fine quality nylon, polyesters and Teflon. **Dissoluble threads** are also used in surgical procedures. **Fusible threads** fuse to form a joint with the fabric, on post stitching heat or chemical treatment. *Rafugars* (Indian -fabric/garment repairers) use very fine threads, or often single fibers to create a **network of stitches** (akin to weaving or knitting) to join torn sections and strengthen weakened areas.

- **Knotting:** Knotting is in many ways similar to stitching but unlike the stitching it is not a continuous process. Knots are created intermittently or at the end of a ductile or flexible linear element like yarn, thread or a rope. **Cross knots** tie up an assembly, **ties** join one linear unit to another, and **Wraps** keep unravelling loose ends of a thread or rope. **Knotted wraps** also do not let a rope or thread go-off, whereas **Unknotted wraps** are created by winding loose ends, or with the help of an extra thread or wire to form a smooth end that can easily slide through a whole, eyelet or sleeve. Elevator metal wire rope ends are rolled over a circular section and secured together by a friction holder. Prestressed wires in RCC structures, wire rope bridges also use similar friction holders of conical shape.

- **Lashes** are straps cut from of leather, polypropylene like plastics, or malleable metals, or knitted threads of round or flat section, used for tying sails, tents, shoes' uppers, paper, bamboos, canes, etc. with or without the use of eyelets. Straps are secured by buckles, knots, rivets or wraps. Metal lashes or straps of annealed mild steel are used for tying bales of cotton and bundles of fabrics. The ends are tied together by crimping a small piece of malleable metal or by rivetting. Fodder grass bundles are tied using metal wires. Here ends are secured by knotting.

FUSION JOINING SYSTEMS

Fusion joining systems are used in fabrication of **metals and thermoplastics**. There are basically *three categories of fusion joining systems*. For **soldering and brazing,** *the work pieces are not melted, yet joined using a meltable filler material*. For **welding** *the work pieces, and in some instances, the filler material, both are melted.* The joint is created with or without application of pressure. Some plastics are joined by solvents that dissolve (soften) the surface areas of the work pieces; this is often termed as a *solvent welding*, but this is truly an *adhesion fixing.*

Fusion joining requires a **heat source**, such as *a gas flame, an electric arc, a laser, an electron beam, friction, or ultrasound*. Fusion joining sometimes requires a slight to very heavy **pressure**. Fusion joining is done under many different **environmental conditions** like *open air, rain, frost, underwater in vacuum or space and sometimes under the shield of inert gases* like Nitrogen, Argon, Helium, Carbon dioxide, etc. Fusion joining in spite of all care is essentially a **hazardous procedure**. It involves risks of *high electric currents, high temperatures, sparks, fumes, and radiation*.

The first fusion joining process used by man was **forge welding**. Blacksmiths used to beat the heated metals for joining. Wood, charcoal and later mineral coals were used to heat the work pieces.

Askokan Iron pillar in Delhi, India, erected about 310 AD, weighs 5.4 metric tons. Such a large one piece casting was not feasible. Forge welding was used in the construction of it.

Soldering and Brazing using **metals softening at low temperature**, like gold, silver, tin, lead, were common in craft work. During 1800s, **DC power sparking, Oxygen-fuel, and arc processes** were developed, and later the 20th C saw production and distribution of AC electric power. After world war II, Plasma, laser and electron welding systems were developed. **Electron beam welding** (1958) made deep and narrow welding possible through the concentrated heat source. Later in the 1960s the **laser beam welding** helped high speed clean profile cutting and automated precision welding. Though both processes are expensive are used for special applications. Today industrial plants have the robotic welding systems, using these technologies.

Heat fusion processes are good for heat fusible substances like metals and some plastics. **Heat fusion processes** induce stresses in the mass, which must be accommodated or some stress-relief processes must be provided. **Electric resistance processes** require electrically conductive mass.

In fusion joining processes the deposited substances are heat-hardened and these are very difficult to grind out. Checking procedures, for completeness of joint fusion are very elaborate (like x ray or sonography scanning) and not always perfect. Most fusing processes require large plant, safety precautions, fire prevention measures and conditioned environments. Fusion joining systems require **power or energy** input, a **filler material**, a **flux** and often a **shield gas**.

Power or energy: Power or energy for forming a fusion type of joints is chiefly from combustible materials (oxyacetylene, petroleum gases, fuels), electric currents, friction, impact, ultrasonic vibrations, electrons, lasers, etc.

Filler material: Welding in certain situations are done without the use of a filler material. Filler materials, for welding where used, are invariably of compatible materials (melting point temperature, alloying capacity, fluxing capacity) added in the form of powders of pure metals, alloys, oxides and such other compounds, ceramics, granules, foils, wires, rods.

Flux: Welding and soldering, require **fluxing agents** to dissolve the existing and to be formed, oxides. **Welding rods** for **steel welding** for example, are coated with borax and aluminum chloride. **Stainless steel welding** requires zinc chloride and hydrochloric acid in equal parts. Soldering of the **Galvanized** surfaces need hydrochloric **acid. Brass**

soldering requires tallow or rosin. Soldering of **tinned** surfaces require hydrochloric acid or rosin. **Copper, Brass and gun metal** need aluminium chloride, hydrochloric acid or ammonium phosphate.

Shield gases: Inert or noble gases constitute O group of a periodic table. Inert gases include Helium, Neon, Argon, Crypton, Xenon, Radon. These gases do not react with other materials so are used for protecting the electric arc so that outside contaminants and other gases do not react with the weld. Some other non-inert gases are used for welding, are Carbon dioxide and Nitrogen.

- **Soldering:** Soldering is a process of joining metal components by a metal or alloy, which melts at a lower temperature than either piece of metals to be joined. The **solder**, liquefies and covers the surfaces and forms an alloy layer, less than 0.1 mm thick, so that when the parts have cooled the two pieces of metal remain firmly joined.

Soldering processes for joining gold and silver can be traced as far back as 4000 BC. The solder than were *alloys of gold with copper, or silver with copper*. Nowadays most familiar **electronic solder** contains *silver, lead and tin*. These can be melted with a blow lamp or heated soldering iron (the iron nose actually being of copper).

Metals that are to be soldered should be clean and free of oxide film. A **flux** of *pine rosin or zinc chloride* is usually applied, which *cleans the surface and seals* it from the tarnishing effect of the atmosphere.

The ease with which **solder flows** over the surface of another metal depends on the characteristics of the metal. For example, *molten lead will not wet a copper surface*, however clean it is, but if a little tin is added to the lead, the resultant alloy will *readily flow over copper*. Aluminium is a difficult metal to solder because the tenacious film of aluminium oxide that forms on the surface, interferers with wetting. Similar problems arise with many other aluminium alloys. With the use of special fluxes, **soldering of aluminium** can be made.

- **Brazing:** Brazing is a process where the joining metal is applied as a metal or alloy having a melting point below that of the pieces to be joined. Tubes or such insertion assemblies and seamed or rimmed joints are coated with a nonferrous metal compound, which is heat treated to form a joint. Alloys are also used to join *ceramic components*.

In **dip brazing** the parts are immersed into molten brass and fitting is made. The **brazing solder** is a form of brass which usually consists of 60 percent zinc and 40 percent of copper. The alloy can be melted at 850 C by a gas torch. Such higher melting-point solder, are often called **hard solders**, in contrast to the **soft solder** made of lead and tin, which melt at 200 to 250 C. A brazed joint is stronger than a soft soldered joint. Another technique similar to brazing is **foil joining**. Two metal parts to be joined, have a metal foil insert, which are then pressed and heated to form a joint.

- **Welding**: Welding is more commonly known as a *fusion joining process*, but it is also used as a *cutting and forming process*. Earliest method of **welding** involved forging, i.e. **heating and pounding** together the metals to be joined. *Brass and copper household utensils are still manufactured by this traditional process.* **Brazing and soldering,** are considered as variants of welding. Welding is performed above temperature of 425° C (irrespective of whether additional metal is used for joining or not), whereas soldering is made at temperatures lower than this.

Weldings are of many types: In case of **gas welding** suitable gaseous substances are burnt to generate the heat for melting the material to be joined, and for liquefying the foreign depository (filler) substance. **Arc welding** uses heat generated by resistance of electric current to melt the electrode and supply the depository substance.

For **gas welding**, the flame condition, gas pressure and mix proportion of gases play a very important role. The primary action of gas flame produces carbon monoxide and hydrogen, which are both reducing gases. The secondary action for complete combustion takes some additional oxygen from the surrounding atmosphere to produce carbon dioxide and water vapour, and reduces the possibility of the molten weld pool becoming oxidized. Further, with complete combustion there is no free carbon to be absorbed by the molten metal.

- **Forge welding:** Forge welding is an ancient process for joining metals. It has many modern versions. In these variants, the heat is created by electrical resistance, friction, laser beams, etc. Continuous pressure or intermittent impaction is done to fuse the heated components. The components are of metals and plastics. The components to be joined are of same constitution or of similar softening properties. Forge welding components are in sheet or small section forms.

- **Resistance welding:** In resistance welding, a current is passed from one component, to another component to be joined. At the cleavage point due to discontinuity the electric resistance is very high, generating sufficient heat to melt the metal at the edge. Two softened edges are brought together and pressed or hammered to form a joint, as in case of window sections. Resistance welding methods are efficient and cause little pollution.

- **Butt or spot welding** is a type of spot resistance welding. A high electric resistance-heat softens the metal close to the melting level, and under pressure (of impact) the thin walls of the assembly, fuse and join. The joint developed has no apparent deformity, except a charred spot. This method of welding is used in manufacturing of steel sheet components like car bodies, cabinets, furniture, etc.

- **Seam or strip welding:** Seam or strip welding is a type of resistance welding method used to join overlapping metal sheets of up to 3 mm thick, as in case of formation of pipes. Instead of pointed electrodes, wheel-shaped electrodes roll along the workpiece, making it a long continuous weld. Weld strength is though lower than other welding methods. The method is suitable for certain applications but is a reliable process.

Seam or strip welding is also used for **joining plastic sheet materials,** as in *raincoats, wind-cheaters, shopping bags, containers*, etc. In one process the sheet materials to be joined are pressed by a preheated point, a straight knife like edge, or a roller. Thicker materials are separately heated, and pressed together to form a fusion as in case of pipe and plate formed assemblies. In another process the joint is created by deposition of a liquified plastic material, (commonly known as PVC welding).

- **Thermit welding** is a method based on the strong affinity of aluminium to oxygen. The joint to be welded is heap lined with *a mix of fine aluminium powder and iron oxide*. The heap is ignited (aluminium) and the metal (iron) liquefies to form a metal joint. In case of **fusion-thermit welding**, the slag and thermit metal are poured over the joint. After cooling the thermit material is taken off as the slag has prevented it to touch the metal. However, during the thermit reaction the temperature is so high that the metals fuse.

- **Submerged arc welding (SAW)**: This is rather like the thermit welding, but here the arc is created under a covering layer of flux. Flux hides the arc and no smoke is produced, it also prevents the contaminants in the atmosphere. Some slag is formed on the weld but comes off easily.

- **Oxyacetylene welding:** This is one of the oldest and most common gas welding process. The equipment is simple and transportable. The combustion of acetylene with oxygen produces a flame with temperature of more than 3000C. It is widely used for site welding of pipes, tubes and sections, as well as repair work in remote locations where electric supply is not available. The flame affects a wide area of the workpiece, causing slower weld cooling. Slow cooling leads to greater residual stresses and weld distortion. However, it facilitates the welding of high alloy steels. The oxyacetylene flames are also used for cutting metals. Other gas welding methods, such as **air acetylene welding, CNG (compressed natural gas), LPG (liquified petroleum gas), oxygen hydrogen welding, etc.** quite similar. A water torch is sometimes used for precision welding of items such as jewellery.

- **Shielded metal arc welding (SMAW):** One of the most common arc welding is the **manual metal arc welding (MMA)** or **stick or rod welding**. Electric current is used to strike an arc between the base material and **consumable electrode rod.** The electrode rod is made of steel and is covered with a **flux** that *protects the weld area from oxidation and contamination by producing CO2 gas during the welding process.* The core of the electrode rod made of steel itself provides the filler metal. The speed of welding is slow and the process is intermittent, as the consumable welding rod must be replaced. The residues of the flux forms slag which has to be removed after welding. The process was limited to welding ferrous materials, though now speciality electrodes have made it possible to weld cast iron, nickel, aluminium, copper, and other metals.

- **TIG Tungsten inert gas welding** is technically a **Gas tungsten arc welding (GTAW)**. It welds with or without a filler metal. There is precise control of heat and no spatter (splash of material). However, it has a lower deposition rate, requires greater care than MIG or stick welding, and is costly for welding thick sections.

In TIG welding an arc is formed between *a non consumable tungsten electrode* and the metal being welded. The diameter of the tungsten electrode determines the range of heat input at different thicknesses. Argon or such inert gases are used as a **shielding gas**. Gas is fed through the torch to shield the electrode and molten weld pool. If a filler wire is used, it is added to the weld pool separately.

Shielding Gases used are: *Argon, Argon + Hydrogen, Argon / Helium*. Helium is added to increase heat input (to increase welding speed or weld penetration). Addition of Hydrogen provides cleaner looking welding work. Hydrogen increases heat input but also may promote porosity (hydrogen cracking).

It is used for welding all types of materials but more often the *stainless steel and light metal* sheets of thicknesses, 0.5 to 3 mm. TIG is a preferred welding process for precision welding such as in *bicycles, aircraft, naval applications*. It is also widely used for welding of *pressure vessels, heat exchanger and pipes*.

TIG-welding with AC current can weld thicknesses down to about 0.5 mm. For larger thicknesses, 0.3 to 12 mm DC TIG-welding can be used. DC TIG (negative electrode) can also be used for welding thin walled structures and profiles.

◦ **Plasma arc welding**: Plasma arc welding uses a tungsten electrode, but uses plasma gas to make the arc. The shielding gas itself forms the plasma arc. This shields the arc and molten weld pool. The arc is more concentrated than the GTAW arc, making transverse control more critical, and thus generally restricting the technique to a mechanical process. Plasma arc welding has stable heat generation so can be used on a wider range of material thicknesses than the GTAW process. It can be applied to all of the same materials as GTAW except magnesium. Stainless steel welding is one important application of the process. A variation of the process is plasma cutting, an efficient steel cutting process.

Plasma: Plasma is an ionized (electrified) form of gas. In plasma cutting and welding, a gas such as Nitrogen is sent under pressure through the torch where it begins to swirl and is forced out of a small orifice at which point it passes through an electric arc and the gas is ionized. The electricity *excites* the electrons of the gas atoms. Plasma equipments use only compressed air (regular air contains enough nitrogen) the most inexpensive and non hazardous gas. It results in a very quick, clean cut or weld. It is also much quicker, easier and economic. Plasma is one step down from a laser. Plasma is better than any traditional oxy-fuel torch. It imparts less heat into the piece being cut and causes very little damage to surrounding material. It leaves no slag deposit to clean up or grind off.

◦ **MIG Metal inert gas welding** is commercially also known as **Gas metal arc welding (GMAW)**. MIG welding is an automatic to semi automatic, high deposition rate welding process. It is not a portable and versatile equipment, yet is still useful for certain industrial applications. It can be handled by a low skill operator.

MIG welding system has a continuous wire feed from a spool, so welds without stops. An inert or semi-inert gas mixture is also fed to protect the weld from contamination. It has all position capability and requires little post welding cleaning. MIG welding is likely to have irregular wire feed, resulting into weld discontinuities, excessive melt-through put, incomplete fusion, porous mass, cracks in weld metal and incomplete joint penetration.

The shielding gasses used for MIG welding are: Argon, Argon +1 to 5% Oxygen, Argon + 3 to 25% CO2, Argon / Helium. CO2 is also used in its pure form in some MIG welding processes. However, in some cases CO2 adversely affects the mechanical properties of the weld.

◦ **FCAW Flux cored arc welding:** It is also referred to as **flux cored welding.** It uses a cored wire (tube) that acts as an electrode and the core powder as a fill material. The cored wire is more expensive than the standard solid wire. Flux cored welding permits higher welding speed and greater metal penetration but generate fumes and/or slag. *Self shielding flux cored arc welding wires* or *gas shielded welding wires* are used. Flux-cored welding has good weld appearance (smooth, uniform welds having a good contour). Flux-cored welding has all position capability.

◦ **EBW Energy beam welding:** Energy beam welding methods such as **laser beam welding** and **electron beam welding**, both have a very focussed energy output which creates a very narrow heat affected zone and slim weld line. High density energy makes it possible to fast weld thick joints in a single pass with deep penetration. Laser welding (and also cutting) employs a highly focussed thin laser beam in ordinary atmosphere.

The electron beam is always generated in a high vacuum, but actual welding occurs at various levels of *vacuums to non vacuum conditions*. Electron beam welding uses no filler material, and due to the high vacuum conditions welding is of maximum purity. **Hybrid laser welding** provides better weld properties by combining the technique of laser beam welding and arc welding.

Electrons (elementary atomic particles with a negative charge, and an extremely small mass) are accelerated to a high energy state, roughly 30 to 70% of the speed of light are focussed to a spot, to produce heat for the weld.

An EBW gun functions similarly to a TV picture tube. The major difference is that a TV picture tube continuously scans the surface of a luminescent screen using a low intensity electron beam to produce a picture.

Energy beam welding equipments' costs are high. Weld preparation such as the vacuum creation takes time. The X-rays produced during welding is a side effect. Rapid solidification rates make the weld susceptibility to thermal cracking.

◦ **Solid-state welding:** Like the forge welding these processes do not melt the materials to be joined. **Ultrasonic welding** uses vibrations of very high frequency and high pressure to join thin sheets and small sections of metal or thermoplastic. For welding metals horizontal mechanical vibrations are used, whereas for welding plastics (both materials with similar melting temperatures) the vibrations are introduced vertically.

◦ **Explosion welding:** In this process materials are pushed together under extremely high pressure, the energy of the impact makes the material plastic, forming a weld, even though only a small amount of heat is generated. The process is commonly used for welding dissimilar materials, such as the welding of aluminum with steel in ship hulls. Other solid-state welding processes include *co-extrusion welding, cold welding, diffusion welding, friction welding (including friction stir welding), high frequency welding, hot pressure welding, induction welding, and roll welding*.

- **Welding Aluminum**: Aluminum is generally used as alloy, and the weld ability of aluminum alloys varies significantly, depending on the chemical composition. Primarily Aluminum comes in **heat treatable** and **non heat treatable** alloys. Heat treatable aluminum alloys get their strength from a process called **ageing**. Substantial reductions in tensile strength occur due to over ageing on application of welding heat.

Aluminum alloys are susceptible to **hot cracking** and to overcome the problem heat input is lowered by faster welding. Preheating helps in decreasing the temperature-gradient, across the weld zone. Preheating of restrained pieces, however, affects the mechanical properties of the base material. The joint design, appropriate selection of base material alloy and the filler alloy, can overcome the problem of hot cracking.

Aluminum components inevitably are covered with oxide and so are most difficult alloys to weld. Aluminum oxide must be cleaned from the surface prior to welding. The series 4xxx has silicon as the major alloying element, (as much as 12%). Aluminum-silicon alloys are used in welding wire and as brazing alloys for joining aluminum, where a lower melting range than that of the base metal is required.

- **Welding steels:** The weld ability of steels is inversely proportional to the **hardenability of the steel**. Larger quantities of carbon, and other alloying elements, result in *higher hardening and so a lower weldability*. Carbon is the key element that affects the hardenability and the weldability, so alloys are judged for their *carbon content*. As the carbon content rises, the weldability of the alloy decreases. Elements such as the chromium and vanadium have compared to carbon less effect on hardenability but more than that of copper and nickel. *High strength, low-alloy steels* were developed specially for welding applications during the 1970s.

- **Welding Stainless steels:** Stainless steels are generally classified by their microstructures: as *ferritic, martensitic, austenitic, or duplex (austenitic and ferritic)*. Iron, carbon, chromium and nickel are the primary elements of stainless steels and substantially determine the microstructures and affect the weld properties. Other alloys change the chromium or nickel equivalents, and also alter welding properties. The choice of base metal, filler metal and welding procedures all are very important factors when fabricating components from stainless steels.

Stainless steels are subject to cracking of the weld metal, and the formation of HAZ (heat-affected-zone) on base metal. The formation of embrittling microstructures and cracking, are the main concerns when welding or fabricating stainless steels.

Many varieties of stainless steels are non rusting (stainless qualities) and this property must be maintained in the joint created through welding. The presence of chromium, if more than 12%, ensures a continuous stable layer of protective chromium-rich oxide cover on the surface.

Generally, 200 and 300 series alloys are mostly austenitic and 400 series alloys are ferritic or martensitic, but exceptions exist.

- **Welding Austenitic Stainless Steels:** Austenitic stainless steels are more complex due to the four alloying elements: iron, chromium (16-26%), carbon and nickel (8-10 %). Cracks can occur in various regions of the weld due to thermal and shrinkage stresses during weld solidification and cooling. Even with these cracking concerns, the austenitic stainless steels are generally considered the most weldable of the stainless steels. The thermal conductivity of austenitic alloys is roughly half that of ferritic alloys, so, the required heat input for welding is less. The coefficient of thermal expansion of an austenite is 30 to 40 percent greater than that of ferrite, which can enhance both distortion and residual stresses, due to welding. The molten weld pool of the austenitic stainless steel is commonly more viscous, or sluggish, than ferritic and martensitic alloys. This slows down the metal flow and wet ability of welds in austenitic alloys, which may promote lack-of-fusion defects when poor welding procedures are employed.

- **Welding Ferritic Stainless Steels:** 400 series stainless steels are substantially made of Ferritic stainless steels. These steels contain from 16 to 20 % chromium along with other alloying elements, particularly molybdenum. Ferritic stainless steels have poor weldability and cannot be formed in sections thicker than sheet metal. Due to their brittleness at very high temperature (540-870 C), these are not used for chemical reaction vessels. The ferritic stainless steels are noted for their resistance to stress-corrosion cracking (SCC), pitting and crevice corrosion in chloride environments, but has poor toughness, especially in the welded condition.

- **Welding Martensitic Stainless Steels:** Martensitic stainless steels are considered to be the most difficult of the stainless steel alloys to weld. Higher carbon contents will produce greater hardness and, therefore, an increased susceptibility to cracking. The most commonly used alloy within this stainless steel family is type 410, (chromium 12 % and carbon 0.1%). The risk of cracking increases when hydrogen from various sources is present in the weld metal. A complete and appropriate welding process is needed to prevent cracking and produce a sound weld.

- **Welding joints**: Welding requires specific joint shape. The shape and size depend largely on the welding process, strength properties desired, thickness of the material to be welded, position of work pieces and type of filler material. Common welding joints are *butt joint, lap joint, corner joint, edge joint, and T-joint*. There are many other variations as well. Resistance spot welding, laser beam welding, and electron beam welding are performed on lap joints, whereas shielded metal arc welding is very versatile and can weld virtually any type of joint.

- **Quality:** Quality of the weld is judged on two counts: the strength of the weld itself and the strength of the surrounding material. Many factors govern this, such as the welding method, the amount and concentration of heat, the base material, the filler material, the flux material, the design of the joint, the cooling rate, and the interactions among all these factors. Quality is verified by both destructive or nondestructive methods.

- **HAZ heat-affected zone:** The amount of heat input during the welding, plays an important role. Oxyacetylene weldings have a wide unconcentrated heat input and so a large **Heat affected zone HAZ** Arc welding has a smaller HAZ. Laser beams have a concentrated spread resulting in a very small HAZ.

- **Distortion and cracking**: Welding methods where material melts at the joint, expand and shrink causing residual stresses of longitudinal and torque distortion. Distortions result into misshaping of the piece and often cracking. Clamping the work pieces in place, causes the buildup of residual stress in the HAZ of the base material, resulting like **cold cracking**. The distortion and residual stresses can be taken care of by reducing the amount of heat input and by welding the piece in small segments, rather than in long stretches. On the other hand **hot cracking or solidification cracking** occurs in the fusion zone of a weld. By avoiding Excessive restraining of the material and use of a proper filler material this can be eliminated.

Cold cracking is limited to steels, and is associated with the formation of martensite as the weld cools. The cracking occurs in the **heat-affected zone** of the base material. USA produced several war and cargo ships popularly known as **Liberty Ships**. These class of ships had unusual breakdowns, often as birthed in the port breaking down into two pieces. This was investigated, and found that cracking was at heat-affected zones.

- **Underwater welding**: While many welding applications are done in controlled environments such as factories and repair shops, some welding processes are commonly used in a wide variety of environmental conditions, such as open air, underwater, and vacuums (such as space). In open-air applications, such as construction and outdoors repairs, *shielded metal arc welding* is the most common process. Processes that employ inert gases to protect the weld cannot be readily used in such site-based situations, because unpredictable atmospheric movements can result in a faulty weld. Shielded metal arc welding is also often used in underwater welding in the construction and repair of ships, offshore platforms, and pipelines, but others, such as flux cored arc welding and gas tungsten arc welding, are also common.

Outer space welding was first tried out in 1969 by Russians by experimenting the shielded metal arc welding, plasma arc welding, and electron beam welding in a non pressure condition. Efforts continued for developing methods for using other welding processes such as laser beam welding, resistance welding, and friction welding. Other new areas of research and development include the welding of dissimilar materials such as steel and aluminum, and new joining processes, such as *friction stir, magnetic pulse, conductive heat seam, and laser-hybrid welding*.

ADHESIVES

History: Earliest adhesives were plant exudates like gums and resins, and of animal origin like hide-gums. The adhesives were used for joining broken ceramic vessels and for waterproofing boats and canoes. Limes and natural cementing materials like pozzolana-volcanic ash, calcium carbonate and sulphate were used as mortars in masonry work. Bitumen, tar pitches, beeswax, etc. were used as caulk or sealants. These were also as adhesive for fixing statues and other repair work. Adhesive materials like gums, glue, starches, egg whites, casein and other proteins, have been used in art work painting to fix various types of colourants. The Egyptians have extensively used animal-glues in tombs, furniture, ivory and papyrus items. Adhesives made of starch flour were used for bonding non-woven fabrics from fibers of reed plant -papyrus, by the Egyptians dating back 3,300 years. Many societies have used adhesive materials to fix decorations on adornments, ornaments, etc. In Europe during the middle ages, egg whites were used to decorate parchments with gold leaves. Wooden objects were bonded with glues from fish, horn and cheese. Hide glue factories were operational in Holland in the 1700s, and Fish glue was produced by the British in the 1750s. Rubber, and nitrocellulose-based cement, were introduced, soon thereafter. Adhesive technology advanced substantially during the 20th C. Synthetic adhesives began to replace the natural adhesives. The demand for adhesives with high degree of structural strength and resistant to severe environmental conditions helped the development of high-performance adhesives. With greater environmental concern the natural adhesives are once again being appreciated.

Adhesives are used for joining a wide variety of similar and dissimilar materials such as: paper, wood, leather, glass, fabrics, ceramics, plastics, rubbers and metals. However, masonry buildings constitute the largest sector for adhesives, where large variety of cementing materials like, clays, portland cement, lime, plaster of paris (gypsum plasters), etc. are used. Another field akin to adhesives is of sealants, putties, mastic compounds, waterproofing agents, noise dampening coatings. Structural adhesives are expected to provide properties equal or often better than possessed by the materials being joined. The **failure of a structural adhesive** occurs as yield (ductile) or fracture (brittle) of the adhesive material. Structural adhesives thus transmit the stresses without losing their integrity.

An adhesive is a substance capable of joining two or more materials by surface attachment. It includes cements, glues, mucilage, etc. **Adhesive bonding**, like the **fusion joining**, is alternative to **mechanical fixing**. Fusion joining heats up the interface of materials to be joined to the melting point (very impracticable for materials like wood, paper and many types of plastics). Fusion joining requires material to be joined to be the same, or almost similar, whereas adhesives are useful for joining vastly different materials (like metal-plastic, glass-paper, etc.).

Adhesives perform many other functions. Silicone and poly sulfide rubber are used for dampening vibration (glass to window frames). Aircraft and automobile frame components are bonded by adhesives to save labour, weight and expense of rivets and other fasteners. Components joined with an adhesive cannot be separated but some demountable adhesives are available.

Advantages of adhesives are many. Adhesives can join substances that are materially and dimensionally different and form-wise very difficult. Adhesive joints are overlapping though are very smooth. Adhesives allow uniform stress distribution, unlike screws and nuts which create localized stress points. Adhesive Joints may be designed as required, to be elastic or rigid. Relatively low process temperature involved in adhesive bonding does not affect the crystallographic structure of the metal. *Adhesives can create very extensive, multi layered laminar compositions without physically cutting or puncturing the materials*.

Limitations of adhesives are few but important. Adhesives require elaborate surface treatments, specific application conditions, curing procedures and considerable expense of time for setting. Inspection of the joint is difficult. Joint design becomes very critical compared with other mechanical and thermal processes. The adhesive itself may corrode the materials it is joining, or induce stresses during curing.

Adhesive failures: There are three ways in which an adhesive bonded joint can fail:

1. A *very strong adhesive* will not allow a joint to open out, so there is a rupture elsewhere in the material.
2. *Very weak adhesive* fails and separates into two distinct layers.
3. An adhesive may *fail to adhere* to one face.

Prevention of Adhesive failures:

careful design of the joint,
correct selection of the adhesive,
careful preparation of the joint surfaces,
controlled application
environment at the joint (cleanliness, temperature and humidity).

With correctly prepared surfaces, the *adhesion at the interface is usually greater than the strength of the adhesive itself*, and failures occur within the adhesive film. Failure of the adhesive film is usually caused by the propagation of cracks accelerated by the presence of discontinuities and flaws. Therefore, **thin layered adhesives** provide the strongest joints. Usually the adhesive selected should have similar strength characteristics to be adherends being bonded together. An exception would be where boding is only temporary pending another joining processes to be used. Most adhesives show optimum **strength characteristics** when in tension or compression closely followed by, shear. Often the high strength, thermosetting adhesives form brittle bonds that are adversely affected by vibration and impact loading, causing the bond to crack or shatter. Under such conditions a slightly weaker but more resilient adhesives may perform more satisfactorily. Adhesives may show a satisfactory strength characteristic under test conditions, but will tend to creep under sustained loads in service.

Adhesion and Cohesion: The strength of the bond depends on two factors: Adhesion and Cohesion.

- **Adhesion** is the ability of the bonding material -**the adhesive** to stick -**adhere** to the materials being joined -**the adherends**. The development of an adhesive bond occurs through more than one of these processes. First, a **mechanical interlocking**, occurs when the adhesive flows into pores and micro projections on the surface. Second, **interdiffusion** results when liquid adhesive dissolves and diffuses into the adherend materials. The third mechanism occurs through, **adsorption and surface reaction**, when adhesive molecules adsorb onto a solid surface and chemically react with it. Finally, **electrostatic attraction,** forces develop at an interface between materials.

- **Cohesion** is the ability of the adhesive and/or the adherend to resist the applied forces within itself. Cohesion could occur even without an adhesive material if there is molecular attraction between surfaces that are in very intimate contact, as happens between two panes of glass. Materials with good surface wetting qualities, like water, also can help in cohesion. Cohesive failure is a constitutional failure of the adhesive, when two items separate out with adhesive remaining on both the substrate surfaces.

Bonding of Adhesives: In order to form a bond adhesives harden via processes such as evaporation of the solvent or water, reaction with radiation such as heat or UV, polymerization, chemical reaction, or phase change.

Bonding mechanisms of adhesives: The adhesive bonding of two materials depends on **mechanical adhesion**, in which the **surface roughness or absorption properties** of the adherents provide a key for the adhesive to grip. Adhesion for **smooth materials** such as metals, plastics and ceramics depends on the molecules of the adhesive and the surface molecules of the adherents. **Rough surfaces** have greater contact area. Mechanical adhesion can be increased by special **surface treatments**.

> Polyethylene surfaces need to be modified by flame treatment for adhesive bonding. Aluminium requires anodizing with phosphoric acid. Carbon steel parts are coated with a zinc or iron phosphate conversion coating as an alternative to sand blasting or hand cleaning to roughen up the surface.

In the formation of an adhesive bond, a **transitional zone** arises in the interface between adherend and adhesive. In this zone, called **the inter-phase**, the chemical and physical properties of the adhesive may be considerably different from those in the non contact portions. The inter-phase composition controls the durability and strength of an adhesive joint and is primarily responsible for the transference of stress from one adherend to another. The inter-phase region is frequently the site of environmental attack, leading to joint failure.

The mechanical behaviour of the bonded structure is also influenced by the **joint design**, and by the way in which the applied loads are transferred from one adherend to the other. The quality of an adhesive is usually judged against the adherend (i.e., the components being joined -metal alloys, plastics, composites, etc.) and the surface (that is the nature of the surface and its treatment).

Selection of an adhesive: This depends on several factors such as:

Economics, batch size, and quantity,
Impermeable joints to seal liquids and gases,
Thermal or electrical insulation requirements,
Vibration and fatigue resistance,
Corrosion capacity.

An adhesive generally should have strength not greater than the strength of the adherends. It should be as rigid or flexible as the adherends. Adhesive should have a high bonding strength than a high structural strength and thermal expansion properties similar to the surfaces being joined. Adhesives must not contain solvents or volatile that can affect the adherends. Adhesives must not adversely affect the plasticizer or any constituents of the adherends.

Most woodwork adhesives are stronger than the wood, so it is the convenience of viscosity, hardening time, cost, durability, etc. that play important role in the selection. A gap of 0.076 to 0.15 mm in wood joints suffices for a thin adhesive layer to give optimum results.

Adhesive materials: Adhesives are of basically two classes. Natural and Synthetic.

Natural adhesives

Natural adhesives are of three broad classes: **Plant materials and exudates**, such as starches, plant saps and resins, natural rubber, gum arabic, colophons, oils like linseed oil, wax like carnauba wax, and proteins like the soybean, carbohydrates like starch. **Animal products**, like casein, milk proteins, wax, glues, other gelatinous substances, and shellac. **Mineral products** like pozzolana and other natural cement products, silicates, asphalt, bitumen pitch. To these materials, a range of **modified natural products**, typically various derivatives like chlorinated rubber, cyclized rubber and rubber hydrochloride, can be added.

The demand for natural adhesives has declined since the mid 20th C., though some of them continue to be used with wood and paper products, particularly in corrugated board, envelopes, bottle labels, book bindings, cartons, furniture, and laminated film and foils. In addition, due to various environmental regulations, *natural adhesives derived from renewable resources are receiving fresh attention*.

Some important natural adhesive products are described below.

- **Animal Glue**: The term animal glue is usually confined to glue prepared from mammalian collagen, the principal protein constituent of skin, bone, and muscle. When treated with acids, alkalies, or hot water, the normally insoluble collagen slowly becomes soluble. If the original protein is pure and the conversion process is mild, the high-molecular-weight product is called **gelatin** and may be used for food or photographic products. The low molecular weight material produced by more vigorous processing is normally less pure and darker in colour and is called **animal glue** (Gujarati: *Saresh*). Animal-glues are available in solid and gel forms. Joints with animal glue work well in dry to moderately moist weather, but with high humidity (80 % or more) growth of micro organisms weakens the adhesive. In spite of its advantage of high initial tack (stickiness), animal glue is being replaced by synthetic adhesives.

> Animal glue has been traditionally used for wood joining, book binding, sandpaper manufacture, gummed tapes (brown paper packing tapes), leather shoes, luggage items and similar applications.

- **Protein Glue**: Casein is made by dissolving, a protein obtained from milk (soured milk curd, dried and ground to powder), in an aqueous alkaline solvent. The degree and the type of alkali, both influence the product behaviour. **Casein** is used to improve the adhering characteristics of paints (calcimine, distemper coatings). In wood bonding, casein-glues are generally superior to animal-glues in moisture resistance and aging characteristics. Casein is now getting replaced by urea formaldehyde resins.

- **Blood Albumin Glue**: This is made from **serum albumin**, a blood component obtainable from either fresh animal blood or dried soluble blood powder to which water is added. Addition of an *alkali to albumen-water mixtures* improves adhesive properties. Some considerable quantities of glue products from blood are used in the plywood industry (not much in India).

- **Starch and Dextrin:** These are soluble or dispersible in water. Vegetable adhesives are obtained from plant sources throughout the world. Starch and dextrin, are extracted from corn, wheat, potatoes, tamarind, mango seeds and rice. Starch and dextrin glues are used in corrugated board, packaging, and as a wallpaper adhesive. Kite flying threads are treated with starches.

- **Natural Gums**: These gums are extracted from the natural sources. **Agar-agar or Calcium Alginate**, is a marine-plant colloid (suspension of extremely minute-particles). It is extracted by hot water treatment, and subsequently frozen for purification. **Algin,** is obtained by digesting a seaweed in alkali, and precipitating either the calcium salt, or alginic acid. **Gum-arabic** is harvested from *acacia trees* that are artificially wounded to cause the gum to exude. In India Babool, Neem trees, provide such gum exudates (Hindi-*Gund*), some of which are also used in sweets, ayurvedic-herbal preparations and as incense. Another plant exudate is **natural rubber latex**, which is harvested from Hevea trees. Natural gums are used chiefly in **water re-wetable products** (postal stamps and envelopes).

- **Bituminous Adhesives:** Bitumen and coal tar derivatives are available as hot melt or softening, emulsion and solvent diluted materials. The hot melt or softening materials have a tendency to run at high temperatures. Bituminous materials are used for fixing waterproofing felt and roof insulation boards.

Synthetic adhesives

Natural adhesives are *less expensive to produce or process*, but synthetic adhesives based on synthetic resins and rubbers excel in *versatility and performance*. Synthetic adhesives can be produced in a constant supply and with uniform properties. In addition, they can be modified in many different ways and are often combined to obtain the best set of characteristics for a particular application.

Synthetic adhesives, used either alone or as modifiers of natural adhesives, perform better, and have a greater range of application than the natural products. Most of them are in the form of polymers. The polymers form strong chains and nets that link surfaces in a firm bond. The formation of the adhesive-bond occurs simultaneously with the polymerization (as happens with epoxy resins and cyanoacrylate), or the polymer is applied as an adhesive like thermoplastic elastomers.

Classes of Synthetic adhesives

- **Thermoplastics** provide strong, durable adhesion at normal temperatures. Thermoplastics can be *softened for application by heating* without undergoing degradation. These are used for bonding wood, glass, rubber, metal, and paper products. Thermoplastic resins employed as adhesives include *nitrocellulose, polyvinyl acetate, vinyl acetate-ethylene copolymer, polyethylene, polypropylene, polyamides, polyesters, acrylics, and cyanoacrylics.*

- **Thermosetting adhesives** get transformed into tough, permanent, heat-resistant, insoluble solids by the *addition of a catalyst or the application of heat*. These are mainly used in structural functions such as bonding of metallic parts of aircraft and space vehicles. Adhesives based on thermosetting polymers include *phenol-formaldehyde, urea-formaldehyde, unsaturated polyesters, epoxies, and polyurethane.*

- **Elastomer-based Adhesives** are of both types thermoplastic, as well as thermosetting types. The characteristics of elastomeric adhesives include quick assembly, flexibility, variety of type, economy, high peel strength, ease of modification, and versatility. The major elastomers employed as adhesives are *natural rubber, butyl rubber, butadiene rubber, styrene-butadiene rubber, nitrile rubber, silicone, and neoprene*. Elastomeric adhesives, such as synthetic or natural rubber cements, are used for bonding flexible materials to rigid materials.

The adhesive manufacturers and users face a challenge to replace adhesive systems based on organic solvents with **Adhesive systems based on water.** Environmental regulations to minimise the use of volatile organic compounds VOC that contribute to the depletion of ozone in atmosphere have forced use of adhesives based on aqueous emulsions and dispersions.

Different types of adhesives

- **Structural Adhesives**. Structural adhesives exhibit good load-carrying capability, long-term durability, and resistance to heat, solvents, and fatigue. Six structural-adhesive families are: **Epoxies** exhibit high strength, good temperature and solvent resistance. **Polyurethanes** are flexible, have good peeling characteristics, and resistant to shock and fatigue. **Acrylics** are very versatile adhesives with good overall properties, cure quickly and even bond to oily parts. **Anaerobic, or Surface-activated acrylics** are good for bonding threaded metal parts and cylindrical shapes. **Cyanoacrylates** bond quickly to plastics and rubber, but have limited temperature and moisture resistance. **Silicones** are flexible, weather out-of-doors condition, and provide good sealing properties. Each of these families can be modified to provide adhesives with a range of physical and mechanical properties, cure systems, and application techniques. Polyesters, polyvinyl, and phenolic resins are also used in industrial applications but have, processing or performance limitations. High-temperature adhesives, such as polyamide, have a limited market.

- **Contact-cements**: Contact adhesives or cements are usually based on solvent solutions of neoprene. These are applied to both surfaces to be bonded. Following evaporation of the solvent, the two surfaces join to form a strong bond with high resistance to shearing forces. Contact cements are used extensively in the assembly of automotive parts, furniture, leather goods, and decorative laminates. They are effective in the bonding of plastics.

- **Hot-melt Adhesives**: Hot-melt adhesives are employed in many nonstructural applications. Based on thermoplastic resins, which melt at elevated temperatures without degrading, these adhesives are applied as hot liquids to the adherend. Commonly used polymers include *polyamides, polyesters, ethylene-vinyl acetate, Polyurethanes, and a variety of block copolymers and elastomers such as butyl rubber, ethyl ene-propylene copolymer, and styrene-butadiene rubber*. Hot-melts find wide application in the automotive and home-appliance fields. These have poor strength beyond 40-65 C. To improve this aspect, thermoplastics modified with reactive urethane, moisture-curable urethane, or silane-modified polyethylene are used. Such modifications can provide higher heat capability (in the range of 70-95 C) and also enhanced peel adhesion and improved resistance to ultraviolet radiation.

- **PSA Pressure-sensitive Adhesives:** These form a bond because the pressure increases the proximity of adhesive and the adherend, and provides for the molecular interactions. The adhesive is just stiff enough to support the bond and soft enough to wet the surface and yet not flow out. PSAs are used for permanent or removable uses. Examples of **permanent applications** include water proofing tapes and automobile trimmings. Temporary applications include fixing tags for picture frames and hooks. Some high performance permanent PSAs can support large weights with a small contact area. Permanent PSAs may be initially removable but set to a permanent bond after several hours or days, as in case of solar films for glass windows. **Removable adhesives** come off easily without leaving any residual damage or product. Removable adhesives are: *electrical insulation tapes, bookmarks, product labels on crockery, graphical rendering patterns for architectural drawings and medical tapes*. Some temporary adhesives are removable once only, whereas others are designed for several operations of stick-unstick. *The difference* *between these adhesives and contact-cement is that the latter require no pressure to bond*. Materials used to formulate PSA systems include: *natural and synthetic rubbers, thermoplastic elastomers, polyacrylate, polyvinylalkyl ethers, and silicones.* These polymers, in both solvent-based and hot-melt formulations, are applied as a coating onto a substrate of paper, cellophane, plastic film, fabric or metal foil.

- **Temporary adhesives:** These are removable adhesives designed for repeated action of stick-unstick. Many of these are used on *ready-made tags, labels, tapes, sheets and films*. *Cello tapes are cellophane, paper or plastic film tapes. Sterilised and/or medicated tapes and sheets of paper and cotton are used for medical dressing, surgical covering, and orthopaedic muscle restraining.* Other common applications of temporary adhesives are in binding loose pack of paper. Plants and equipments are adhesive film wrapped for temporary protection against scratches, dust and moisture.

- **Ultraviolet-cured Adhesives:** These types of adhesives normally consist of a monomer (which also can serve as the solvent) and a low-molecular-weight pre polymer combined with a photo initiator. **Photo initiators** are compounds that break down into free radicals upon exposure to ultraviolet radiation. The radicals induce polymerization of the monomer and pre polymer. Thus, completing the chain extension and cross-linking required for the adhesive to form. Because of the low process temperatures and very rapid polymerization (from 2 to 60 seconds), ultraviolet-cured adhesives are making rapid advances in the *electronic, automotive, dental and medical areas.* They consist mainly of *acrylated formulations of silicones, urethanes, and methacrylate*. Combined ultraviolet-heat-curing formulations also exist.

Some common adhesive formulations

- **Air drying adhesives:** Glues, NC lacquer based, synthetic resins based and rubber cements are mixtures of ingredients dissolved in a solvent (including water) are air drying adhesives. As the solvent evaporates, the adhesive hardens. Some air drying adhesives on drying (through solvent evaporation) further polymerise, resulting into a product that cannot be dissolved again. These adhesives are typically weak and are used for household applications. Some intended for small children are now made nontoxic.

- **White Adhesives:** Popularly known **white adhesives** are used for paper, leather, fabric and wood work. These **Polyvinyl acetate PVA emulsions** are white liquids, and transparent when set. These are available in various viscosities and hardening time.

- **Super glues:** These are instant gums, setting instantly and capable of joining any types of surfaces. These are at cheaper level *NC lacquer or rubber-solvent formulations*, but at higher cost level are adhesive of *cyanoacrylate* (more commonly known by the brand name "super glue") which reacts with trace moisture on the surfaces being bonded and therefore does not need any mixing before application.

- **Hot adhesives:** Hot melt adhesives are applied hot, and on cooling harden. These adhesives require specific tools, such as glue gun for application.

- **Reactive adhesives:** Reactive adhesives are mainly thermosetting plastics. *Epoxy resins* (Araldite, M-Seal, etc.) are common examples of this type of adhesives. Reactive adhesives are two-pack systems. The two ingredients of the adhesive must be mixed in recommended proportions just before the application. Generally one ingredient is a monomer, or resin, and the second is a reaction initiator. When the two are mixed together, a polymerisation reaction occurs which solidifies the adhesive. Some epoxies, when mixed, (due to the resultant lowering of viscosity) have a tendency to *run* and leave the joint. Some reaction adhesives may also react with the substrate to form a bond. Some adhesives are (the catalyst) acidic and may react with the base mass, before reacting with the main resin. Reactive adhesives are very strong and are used for high-stress applications such as attaching wings to an aircraft. Reactive adhesives are not very useful as a filler material, because the strength of a reactive-adhesive result from the chemical bonding with the substrate requiring a very thin film application.

- **Amino resin adhesives:** These groups of adhesives include chiefly Phenol (Resorcinol, Cashew Nut Shell liquid CNSL. Etc.), Urea and Melamine compounded with formaldehyde. The adhesives are: *water soluble systems* (typically urea), *heat cured systems* (typically phenol), and also *catalysts cured systems* (typically melamine). Urea resins are colourless, and so used for commercial quality plywood and veneer production. Water proof plywoods though has a phenol bonding. Melamine resins have toughness, and so are used for laminate top sides, though here bottom layers may be formed with a phenol compound.

- **Neoprene Styrene and Butadiene rubber compounds:** These are called rubber cements, chiefly solvent-based systems, and used where moisture may affect the adherend, such as with paper, leather, etc. Contact-cements form bonds, to almost all types of adherends, by the Van de Waals forces, and do not require holding or clamping.

Using adhesives

Adhesives do not achieve their full bond strength instantaneously, so it is necessary to press them for some time. However excessive pressure displaces the adhesive mass all together, adversely affecting the strength. Depending on the type of adhesive used, a specific temperature range is provided or created. In case of thermosetting adhesives the temperature of the joint must be sufficient to ensure a complete curing of the adhesive. The joint is usually heated in an autoclave or, if the assembly is too large, radiant heaters are used. Even cold setting adhesives, require the exothermic reaction of a hardener to ensure curing. In the case of thermoplastic adhesive the ambient temperature must be sufficiently high to ensure complete evaporation of the solvent. Usually a warm dry, working environment around 20° C. is suitable for both cold setting thermosetting and thermoplastic adhesives.

For joining plastics, Ref to Chapter: POLYMERS / joining plastics.

Mastic, Caulking Compounds, Putties, etc.

These are heavy consistency compounds used for several purposes: *for filling in cracks and gaps, levelling the surface, and for fixing objects on surfaces*. Due to their heavy consistency these compounds do not run. *High viscosity* is achieved by *heavier phase formation, foaming or by addition of bulky filler materials*. Some are designed to dry out completely slowly or quickly, whereas many are designed to remain *green* (wet or soft) so as to be removable, or to absorb the vibrations and movements.

One of the most commons of such compound is **glass fixing putty or mastic**. This is made from china clay, water and alkyd resin or bodied linseed oil. Other commercial compounds in this category include *butadiene, poly-sulphide and silicone* compounds. Some of these are two pack (resin + hardener), high strength and high bonding materials often used as industrial **crack filler or sealant**. These are also used for temporary bonding so that clamps may not be required for assembly work (e.g. truss erection), and also to eliminate mechanical fastenings like nut-bolts and rivets. Such industrial sealants offer greater assurance of the joint, better distribution of stresses.

Epoxy putty compounds such as *M-seal* etc., are also of this category. Asphalt-based **water proofing caulking compounds** are widely used in filling roof or terrace cracks, for sealing pipe and duct joints, and lining the joints in sheet structures. Epoxy based caulking compounds are also used in fixing composite aluminium sheets, frameless glass facades, fibre glass sheets, PVC door frames, and aluminium sections to masonry faces. Polymer-based water soluble compounds help fix tiles and panels as floors or claddings. Caulking compounds being heavier in viscosity give assured fixing than low viscosity contact adhesives. Mastics are sold in cans, tubes, or canisters that fit into hand-operated or air-operated caulking guns.

Further reading

Joining of Materials and Structures: Messler Robert W. / Butterworth-Heinemann CEPT SA 15650 / 694.6 / MES

Selection and use of Engineering Materials : Charles, Crane, Furness / Butterworth-Heinemann / CEPT SBST 04536 / 691 /CHA

Engineering Materials : Budinski, Budinski / Prentice Hall / CEPT SBST / 691

Engineering Materials and their Application : Flinn, Trojan / CEPT SBST / 691

1.05 COMPOSITES

Differentiating Composites and Structural Compositions

Natural and manufactured raw materials are invariably compounds, made of many materials. Many of the such compounded materials are in the form of **Composites**. The composite materials come into being, by *putting together natural and manufactured materials* in such a special way that the strength and other qualities are different from the constituents, individually and cumulatively.

The term -different, is considered here as an improved quality, because man-made composites are designed and created towards specific performance requirements only.

Natural materials, manufactured materials and composites, all are further *shaped, re-formed and geometrically integrated* to create **components** as well as **Structural Compositions**.

A **composite** is a *designed material entity* with potential utility, but has no *operational functionality*. A **component**, on the other hand is a *configuration of many materials into a utilitarian product*. **Component manufacturing** employs processes that are many times similar to a **composite formation**. As a matter of fact for component manufacturing, the 'composite formation' and the 'component creation' both occur simultaneously. **Structural compositions** (trusses, bridges, buildings) are *geometric-configuration of materials*, often assisted by components (nuts, rivets, pins, bearings, etc.). Structural compositions use composites to form the constituent elements.

Definitions of Composites:

1 Consisting of two or more physically distinct and conceptually separable or visually identifiable materials.

2 Products that can be made by mixing separate materials so the dispersion of one material in the other can be done in a controlled way to achieve optimum properties.

3 Products with properties that are superior and possibly unique in some specific respects compared to the properties of their individual components.

Classes of Composites:

Natural composites	Wood, Bamboo Bone, Muscle and other tissues
Macro composites (engineering products)	Galvanized steel Reinforced cement concrete (beams, etc.) Helicopter blades Skis, Tennis rackets
Microscopic composites	Metallic alloys Toughened plastic (impact polystyrene, ABS) Sheet moulding compounds Reinforced plastics
Nano composites	Electronics circuits, diodes, transistors

Some **natural composites** are easy to identify, such as: wood, bamboo, bones, muscles, etc. First **manmade composites** were related to the bronze, as man tried to fix *natural stones and ceramic pieces by hammering into the bronze*. *Layered wood* composites have been used by Egyptians. *Mud bricks reinforced with hay, hair, and rice husk* have been used. *Cow-dung is also reinforced with granular sand particles for wall plaster*. Gypsum (Plaster of Paris) has been applied on a *lattice of jute, papyrus and such other fibres*.

Macro, Micro and Nano Composites: Composites can be categorized in terms of the size of constituent particulate matter. Ingredients of **macro composites** can be distinguished by naked eye, whereas one may need an electron microscope to understand the constituents of **micro composites** and **nano composites**. Nano composites are created by introducing nanoparticulates, which drastically add to the electrical, thermal, and mechanical properties of the original material.

Categorization of Composites on the basis of strengthening mechanisms.

Composite materials can be distinguished into three categories based on the **strengthening mechanism**. These categories are: Dispersion strengthened, Particle reinforced and Fiber reinforced.

- **Dispersion Strengthened Composites** have a fine distribution of secondary particles (filler) in the matrix of the material. These particles impede the mechanisms that allow a material to deform. Many Metal-matrix composites would fall into the dispersion strengthened composites' category.
- **Particle reinforced composites** have a large volume of particles dispersed in the matrix. The load is shared by the particles and the matrix. Most commercial ceramics and many filled polymers are particle-reinforced composites.
- **Fiber-reinforced composites** have fibre as the main load-bearing component. Fiberglass and carbon fibre composites are examples of fiber-reinforced composites.

Matrix, Filler and Interface

The constituents of a composite are ordinarily classified as **Matrix and Filler**. It is the *nature of relationship between the filler and matrix*, or the **Interface** that defines the composite. Fillers serve to resist stresses, mainly tension, and the matrix serves to resist the shear, and all materials present including any aggregates, serve to resist the compression.

Matrix and filler each are of three types: **Metals, Ceramics and Polymers**. This set provides nine possible combinations.

Composite materials' combinations: Possibilities of combinations and type-examples.

Matrix	+	Filler	= Composite Type-Examples
Metal matrix composites MMC			
Metal	+	Metal	Aluminium-Tin are non miscible metals, yet can be alloyed as a composite
Metal	+	Ceramic	Electrical semi conductors, Carbide cutting tool tips, Scissors, knives
Metal	+	Polymer	Not feasible, Metals become soft at very high temperature -unsuitable for polymer filler
Ceramic matrix composites CMC			
Ceramic	+	Ceramic	Carbon-carbon composites
Ceramic	+	Metal	Metal sprayed optic glass fiber cables
Ceramic	+	Polymer	Not feasible, Ceramics require high temperature for formation -unsuitable for polymer filler
Polymer matrix composites PMC			
Polymer	+	Polymer	Polyester or rayon fibre reinforced plastics
Polymer	+	Metal	Grinding and polishing abrasives
Polymer	+	Ceramic	Fibreglass, Fibre reinforced plastic FRP Asphalt roads, imitation granite, cultured marble sinks and counter tops

Interface of Matrix and Filler

In a composite material the Filler in the form of **particles, fibres and sheets**, is expected to take up the stresses in unison with the matrix because of the strong interface provided by the later. Composite materials with **weak interfaces** have low strength and stiffness, but high resistance to fracture, On the other hand materials with **strong interfaces** have high strength and stiffness but are brittle. The bonding between the matrix and the filler is dependent on the atomic arrangement and chemical properties of filler and on the molecular conformation and chemical constitution of the matrix. A crack that starts in a monolithic material generally continues to propagate until that material fails, whereas the *filler-matrix combination reduces the potential for a complete fracture*.

Bonding at the interface: In a simple system the bonding is due to adhesion between filler and the matrix. Adhesion can be attributed to following five main mechanisms:

1 **Adsorption and wetting**: When two electrically neutral surfaces are brought sufficiently close, there is a physical attraction. Most solids have surfaces that are rarely perfectly in level and without any contamination. So a wetting agent that substantially covers every hill and valley displaces all air and overcome effects of contamination, is required.

2 **Interdiffusion**: It is possible to form a bond between two polymer surfaces by the diffusion of the polymer molecules on one surface into a molecular network of the other surface. The bond strength will depend on the amount of molecular entanglement and the number of molecules involved. Interdiffusion may be promoted by the presence of solvents and plasticising agents.

3 **Electrostatic attraction**: When one surface carries a net positive charge and the other surface, a net negative charge, electrostatic attraction occurs (as in acid+base reaction). Electrostatic attraction does not play any major role in contribution of bond strength, but has importance on how things initially begin to get mixed.

4 **Chemical bonding**: It is formed between a chemical group of filler and a chemical group of a matrix. The bond formation or breakage usually involves thermal activity.

5 **Mechanical adhesion**: Some bonding occurs by the mechanical interlocking of two surfaces (e.g. fibre shape-section).

Shocks, impact, loadings or repeated cyclic stresses can cause the Individual fibers to separate from the matrix, e.g. **a fibre pullout**. In case of laminated or layered construction there could be a separation at the interface between two layers, a condition known as **de-lamination**.

Matrices

A matrix is an environment or material within which something develops. A matrix surrounds a Filler material while creating a bond with it. A matrix thus creates a network within which the filler components are supported by maintaining or reinforcing their intended positions. For a matrix to be affective, it must at some stage have a lower phase than the filler material. The lower phase may occur *before or while* the filler material is being formed or introduced. The matrix material may turn to a higher phase by evaporation of the solvent, removal of the heat or pressure, and polymerization or action of a catalyst. Polymer matrices are most common, followed by metals and ceramics. However, paper pulp, mud, wax, etc. are some matrix materials that do not fit into any of the above-mentioned categories. Ceramic matrix composites though difficult to form, show greatest promise in material sciences.

Portland cement, Gypsum plaster, mud (clay), and Bitumens are widely used matrix materials. Polymer matrix materials are thermosetting resins such as polymers, polyamides, epoxies, or thermoplastic resins such as polycarbonate or polysulphones. Typically a polymer matrix composite of Epoxy and carbon fibers is of two thirds the weight of aluminum, and two and a half times as stiff.

For metal matrices most commonly used metals are aluminum, titanium, magnesium, and copper. Composites with metal matrices generally have metal or ceramic as filler materials. Aluminum reinforced with fibers of the ceramic silicon carbide is a classic example of a metal matrix with ceramic filler. The composite material combines the strength and stiffness of a silicon carbide with the ductility of aluminum. Metal to metal composites consist of two immiscible metals (metals that do not form alloys), such as magnesium and titanium. Such metal-metal composites with bronze matrixes have been in use since Bronze Age to create many useful materials.

Fillers:

Fillers are inevitable constituents of composites. Fillers, besides providing the reinforcement, also impart special properties to the new material. Fillers have many forms, such as fine particulates, staple fibre (whiskers or short fibres), filaments (long or continuous fibres), unwoven (felt) and woven fabrics, knit textiles, aggregates, and sheets. Filler materials are natural (wood, plant, hair), minerals (asbestos, sand, stones, powders), and man-made (polymers, metals, ceramics).

Straw, hair, coir, hemp, jute, papyruses, rice-husk etc., have been mixed with clay to form bricks. Sand, ash, and mineral dust were added to mud to reduce the plasticity for plaster work. Wood planks were glued together to form block board or plywood like construction in 15th C BC.

Man-made materials include: Fiberglass, quartz, kevlar, Dyneema or carbon fibre, graphite, carbon-graphite, silicon carbide, titanium carbide, aluminum oxide, boron, coated boron, boron carbide, alumina, alumina-silica, niobium-titanium, niobium-tin, etc.

Fillers Particles (of 10 t0 250 μm in diameter) help block the movement of dislocations in the composites and provide distinctive strength properties. *Staple fibres* used as fillers have high length to a diameter ratio and are generally in their random orientations. Whereas *filaments* are used for high performance structural applications and are prearranged (for a particular structural use) before introduction of matrix, or in certain cases a fixing compound. Depending on the load conditions the reinforcement is **random, unidirectional** (align ed in a single direction), or **multidirectional** (oriented in two or three directions). **Continuous fibers** are more efficient at resisting loads than are short ones, but it is more difficult to fabricate complex shapes from materials containing continuous fibers than from short-fibre or particle-reinforced materials.

Particles (fillers) of one material are dispersed in another material (matrix) in many different ways. Particles are mixed in a liquid phase of the matrix and allowed to harden to a solid phase, the particles are allowed to grow in the matrix or particles are pressed into the matrix and interdiffusion is encouraged by mechanical working or other energy input. Particulate fillers in ceramic matrices enhance characteristics such as electrical conductivity, thermal conductivity, thermal expansion, and hardness. Particles of Alumina, Silicon carbide and Boron nitride embedded in a polymer matrix formed abrasives are used for grinding and polishing stone floors, tools etc. Carbon black (as powder) added to vulcanised rubber provides hardness and toughness for automobile tyres. The rubber is further reinforced with metal, rayon, polyester and other threads as continuous fibre filler.

High-performan ceramic composites are strengthened with filaments that are bundled into yarns. Each yarn, strand or tow may contain thousands of filaments, each of which with a diameter of approximately 10 micrometers (0.01 millimetres).

Often components are formed that are strong in all directions, by creating a three-dimensional lattice of filler component. The filler component itself could be a composite material.

Fillers affect the quality of a composite. Fillers are usually combined with *ductile matrix materials*, such as metals and polymers, to make them stiffer. Fillers are added to *brittle-matrix materials* like ceramics to increase toughness. The *length-to diameter ratio of the fibre*, the strength of the bond between the fibre and the matrix, and the amounts of fibre are variables that affect the mechanical properties. It is important to have a high length-to-diameter aspect ratio so that the applied load is effectively transferred from the matrix to the fibre.

A variety of reinforcements can be used, including particles, whiskers (very fine single crystals), discontinuous (short) fibers, continuous fibers, and textiles perform (made by braiding, weaving, or knitting fibers together in specified designs).

Glass is the most common and inexpensive fibre and is usually use for the reinforcement of polymer matrices. Glass has a high tensile strength and fairly low density (2.5 g/cc).

Carbon-graphite: In advance composites, carbon fibers are the material of choice. Carbon is a very light element, with a density of about 2.3 g/cc and its stiffness is considerable higher than glass. Carbon fibers can have up to 3 times the stiffness of steel and up to 15 times the strength of construction steel. The graphitic structure is preferred to the diamond-like crystalline forms for making carbon fibre because the graphitic structure is made of densely packed hexagonal layers, stacked in a lamellar style. This structure results in mechanical and thermal properties are highly anisotropic and this gives component designers the ability to control the strength and stiffness of components by varying the orientation of the fibre.

Polymers: A variety of polymer materials are used as filler material for composites. The strong covalent bonds of polymers offer tailor-made properties in the form of bristles, whiskers, staple fibers, filaments, yarns or tows, spun yarns, threads, ropes, unwoven and woven fabrics, knitted compositions. Nylons, polyesters, rayon, acrylic, Kevlar and many other fibers are used for composite formation.

Ceramics Ceramic fibers made from materials such as Alumina and Silicon carbides are used in very high temperature applications, and also where environmental attacks are severe. Tungsten-boron filaments, Ceramics have poor properties in tension and shear, so most applications as reinforcement are in the particulate form.

Metallic: Metallic fibers have high strengths but since their density is very high they are of little use in weight critical applications. Drawing very thin metallic fibers (less than 100 microns) is also very expensive.

- **MMC -Metal Matrix Composites:**

Metal matrix composites have either Metal or Ceramic as the filler material. Polymer fillers are nominally not feasible, because at processing temperature of metal matrix material, most polymers cannot survive. Majority MMCs are aluminum matrix composites, but a growing number of composites are produced with the matrix of superalloys, titanium, copper, magnesium, or iron. Lightest metal-matrix composite is heavier than any other polymer or polymer matrix composite and are comparatively complex to process.

Metal matrix composites are as old as the Bronze age. However, work on modern MMC began in the late 1950s. A copper-clad 316 stainless steel shell was manufactured by electroforming, possessing an outer skin of nickel and a reflective platinum final surface, for aerospace industry in USA. Today, metal cladding (a layered metal composite) is very common, as seen in coins, cooking ware, armour, and other items. Metal-matrix composites are used for the space shuttles, commercial airliners, electronic substrates, bicycles, automobiles, golf clubs, and a variety of other applications. Superalloy composites reinforced with tungsten alloy fibers are used for components of jet turbine engines that operate at temperatures above 1000 °C. Under sea cables for communication and cables for shipping and elevators are invariably of composite materials.

Compared to monolithic metals, MMCs have higher strength-to-density ratios, higher strength and stiffness, better wear resistance, fatigue resistance and elevated temperature properties, a lower creep rate and coefficients of thermal expansion. MMCs have higher cost, involve difficult to use technologies but provide wonderful super alloys and super-conductive materials.

Carbide drill bits are a metal matrix composite. Tungsten carbide powder is mixed with cobalt powder, and then pressed and sintered together, the tungsten carbide retains its identity. The resulting material has a soft cobalt matrix with tough tungsten carbide particles inside.

Metal Matrix composites in comparison to other materials: Compared to monolithic metals and polymer matrix composites, MMCs are high cost systems with relatively newer and immature technology. However, MMCs have better temperature capability, superior fire resistance, higher electrical and thermal conductivities.

MMC reinforcements are metal wires, and ceramic materials like particulates, whiskers, filaments, fibers. Key continuous fibers include boron, graphite (carbon), alumina, alumina-silica, boron carbide and silicon carbide.

○ **Aluminium Matrix composites** have the advantage of low cost over most other MMCs. Aluminium matrix composites have excellent thermal conductivity, high shear strength, excellent abrasion resistance, high-temperature operation, nonflameability, minimal attack by fuels and solvents, and the ability to be formed and treated on conventional equipment. Aluminum MMCs are produced by casting, powder metallurgy, in situ development of reinforcements, and foil-and-fiber pressing techniques. Aluminium matrix composites are used in brake rotors, pistons, and other automotive components, golf clubs, bicycles, machinery components, electronic substrates, extruded angles and channels, and many structural and electronic applications.

◦ **Copper Matrix composites** have metal wires and filaments of tungsten, beryllium, titanium, and molybdenum for reinforcement. Ductile superconductors are fabricated with a matrix of copper and superconducting filaments of niobium-titanium and niobium-tin. Copper matrices are also fortified with fine tungsten wires. Copper matrix reinforced with tungsten particles or aluminum oxide particles, is used in heat sinks and electronic packaging. Copper-Graphite composites can be designed to have very specific qualities such as high temperatures in air, excellent mechanical characteristics, as well as high electrical and thermal conductivity. Copper matrix materials are easier to process compared to titanium. Copper matrix composites have lower density compared with steel.

◦ **Titanium Matrix composites** are new age composites. Titanium reinforced with silicon carbide fibers is under development as skin material for the National Aerospace Plane. Stainless steels, tool steels, and Inconel are among the matrix materials reinforced with titanium carbide particles.

- **PMC -Polymer-Matrix Composites:**

These are most widely used types of composite materials. PMC consists of a polymer matrix of thermosetting and thermoplastic materials with nearly all types of fillers. Most popular fillers are wood, glass and carbon fibers.

◦ **Thermosetting Materials for Polymer Matrix:** Thermosetting polymer molecules develop interlinks during the curing process which usually occurs at room temperature, but can have temperature input to achieve the optimum results. Shrinkage during curing and thermal contraction on cooling, can lead to inbuilt stresses in the composite material. Thermoset materials have a shelf life problem, often requiring freezing to retard the changes that continuously occur in the resin. Thermosets are recyclable so are considered to be environment friendly. Epoxies and polyester resins cover a broad range of thermoplastic resins for composites.

Thermosetting composites are manufactured through many different processes. In all these processes wetting of fibre with the resin material is an important aspect. Fibres in the form of a mat are impregnated with resin, tows or bundles of fibers are wetted and laid to shape a component, Paper-covered sheets or narrow stripes (pre-preg) of resin impregnated fibers are partially cured, and pressed to form the final shape of the component, or resin and fibres, are mixed and co-extruded, or hot pressed.

○ **Thermoplastic Materials for Polymer Matrix:** Thermoplastics can be repeatedly melted and solidified for reprocessing. Thermoplastics as a result are considered recyclable and preferred from the environment point of view. Manufacturing technologies for thermoplastics are not as advanced as those for thermosets.

Thermoplastics derive their strength and stiffness from the inherent properties of the monomer units and very high molecular weight. In amorphous thermoplastics there is high concentration of molecular entanglements, which acts like cross links, and in crystalline materials there is high degree of molecular order and alignment. In amorphous materials heating reduces entanglement and the material turn from solid to viscous liquid. With crystalline materials heating melts the crystalline phase, to give an amorphous viscous liquid.

Thermoplastics are structurally very sensitive to temperature conditions, as under constant load conditions these materials show an increase in strain with time, i.e. materials creep under loads. This means that in composite material with thermoplastics a redistribution of the load between the resin (matrix) and the fibres occur during the deformation.

Thermoplastics are more expensive, and they generally do not resist heat as well as thermosets, however, some thermoplastics with higher melting temperatures are available. Three common thermoplastics matrix polymers are polypropylene, nylon and polycarbonate.

- **CMC -Ceramic Matrix Composites:**

Ceramic matrix composites have evolved from needs that certain *components must maintain their structural integrity at very high temperatures*, yet remain operative. Temperatures in boilers, chimneys, exhausts, heat sinks, combustion engines, furnaces, etc. are such that *metal materials become soft, whereas polymer materials get degraded.* Here traditional ceramic materials work well with their superior heat resistance, low abrasive and non corrosive properties, but brittleness is a major drawback. **Ceramic Matrix Composites reinforced with ceramic or metal fibers** provide better structural properties against not only traditional ceramics but also metals and alloys. Ceramics by themselves are often not conductive of heat, electricity, etc. but this can be altered by suitable addition of a filler material. The desirable characteristics of CMCs include: *high-temperature stability, high thermal-shock resistance, high hardness, high corrosion resistance, light weight, nonmagnetic and nonconductive properties.*

Unlike polymers and metals, which are processed by techniques that involve melting (or softening) followed by solidification, *constituents of high-temperature ceramics cannot be melted*. They are generally produced by some variation of **sintering**, a technique that renders a *combination of materials into a coherent mass by heating to high temperatures without complete melting*. In some instances a polymer-filler mixture, on **pyrolysis**, is converted to a ceramic matrix (consisting of silicon carbide, boron carbide, boron nitride, and a silicon oxy-carbide -SiOC glass), without reacting with the carbon fibre. Where continuous fibers or textile weaves (as opposed to short fibers or whiskers) are involved, sintering is preceded by impregnating the assembly of fibers with a slurry of ceramic particles dispersed in a liquid.

Technologies for CMC are still new compared to PMC, but technological achievements are very remarkable. Major barriers to wide use of ceramic matrix composites are: *lack of detailed specifications, information, problems of fixing other materials to ceramic matrix components, in-service repair methodology, high cost.*

Ceramic matrices can be categorized as either *oxides or non oxides* and in some cases may contain residual metal after processing. *Common oxide matrices* include alumina, silica, mullite, barium aluminosilicate, lithium aluminosilicate and calcium aluminosilicate. *Common non oxide ceramics* include, SiC, Si3N4, boron carbide, and AlN. Oxide matrices are considered environmentally stable yet non oxide ceramics, with their superior structural properties, hardness, and corrosion resistance are considered commercially better.

Ceramic reinforcements in the form of discontinuous fibre include whiskers, platelets, and particulates having compositions of Si3N4, SiC, AlN, titanium di boride, boron carbide, and boron nitride are commonly used. Of these, SiC is most prominent because of its stability with a broad range of ceramic oxide and non oxide matrices. Discontinuous oxide ceramic reinforcements are less prevalent because of their incompatibility with many common ceramic matrices.

Some of the more common continuous reinforcements of ceramics include: *glass, mullite, alumina, carbon, and SiC*. Of these, SiC-fibres are commonly used because of their high strength, stiffness and thermal stability.

Common trade names for *silicon carbide* fibre include Nicalon™, Hi-Nicalon™, SCS, Sylramic™, and Tyranno. For applications where temperature is lower (< 1100°C) or exposure times limited, mullite fibers are used because of their lower cost. Nextel is a common trade name for both mullite and alumina fibre. Continuous ceramic fibers are favoured because of their ability to provide pseudo-ductile characteristics to otherwise brittle ceramic materials.

Advanced Composites:

'Advanced-composites' is a misleading term. In case of composites it could mean different concepts. It could mean composites requiring: *high tuned multiple processing, composites of uncommon materials, or composites with very specific material properties.*

Advanced composites had come of age in the early 1960s with the development of high-modulus whiskers and filaments. While whiskers were easily made, their composites were of poor quality. But the 60 million modulus strength boron filaments with reinforcing epoxy, were very successful and were used in fighter aircraft and, later, in golf-club shafts, fly-rods, and tennis rackets.

But it was the improvement of graphite fibre that led to the major jump in mechanical advantages for military and sports applications. A sprinkling of boron now turned up but, just like the early gasoline with boron, its contribution was minor; still, it sold. The large modulus differences for fibre and matrix were also accompanied by large differences in expansion coefficients and consequent residual thermal stresses.

In the First category, as an example, one can include, Carbon-carbon composites which are closely related to Ceramic Matrix Composites, but differ in the methods by which they are produced. Carbon-carbon composites consist of semi-crystalline carbon fibers embedded in a matrix of amorphous carbon. The composite begins as a PMC, with semi-crystalline carbon fibers impregnated with a polymeric phenolic resin. The resin-soaked system is heated in an inert atmosphere to pyrolyze, or char the polymer to a carbon residue. The composite is re-impregnated with a polymer, and the pyrolysis is repeated. Continued repetition of this impregnation/pyrolysis process yields a structure with least voids. Carbon-carbon composites retain their strength at 2500 C and are used in the nose cones of re-entry vehicles. However, because they are vulnerable to oxidation at such high temperatures, they must be protected by a thin layer of ceramic.

In the Second group, as an example, one can include composites of **piezoelectric materials** which generate an electrical current when they are bent, conversely, when an electrical current is passed through these materials, they stiffen. This property can be used to suppress vibration, the electrical current generated during vibration could be detected, amplified, and sent back, causing the material to stiffen and stop vibrating. Other examples are efforts to develop smart or responsive material systems, that mimic a living organism by reacting to stimuli generates a desired response.

In the third group, for example, materials are needed with a near-zero coefficient of thermal expansion can be included. These materials have to be thermally stable and should not expand and contract when exposed to extreme changes in temperature.

Manufacturing Methods for Composites

Composites to be extra efficient are engineered to form or shape of the component. This involves strategically placing the reinforcements while manipulating the matrix properties to achieve a perfect combination. These fabrication methods are commonly named moulding, casting, injection and extrusion processes. Other processes include curing (through catalysts, radiation, exothermic reactions and heat), heat treatments like baking, melting, sintering, forging, pressing and rolling.

Each matrix system requires specific manufacturing method. Polymer matrices, need no or low heat input, followed by metal matrices. Ceramic matrices need very high temperatures for composite formation.

The most common form of material used for the fabrication of composite structures is the **pre-impregnated tape, or Pre-Preg.** There are two types commercial pre-preg materials, Tapes (of 75 ml width) and Broad goods (of several metres widths) intended for hand lay-up and large sheet applications. To make a composite pre-preg with surface treated fibres are passed through a resin bath and laid on to a component form or sheet form. For thermosetting polymers, the resin coated structure of tape or broad goods are autoclaved or baked. Thermoplastic systems do not require heat input, so prove to be less costly and easier to handle.

Pultrusion is a continuous process where fibres and the resin are pushed through a heated die for manufacturing long shapes. Resin transfer moulding is generally limited to low viscosity materials. Fibres are laid in a mould and resin is injected in the closed mould.

To make a low temperature super conductor, Niobium-tin alloys (Nb3 Sn), are found to be brittle. However, Copper and Niobium nominally immiscible, when melted together provides a ductile material. The new material has Niobium solidified within the copper into structures called dendrites. When drawn into a thin wire, the Niobium dendrites form small filaments within the copper. After these stage the wire is passed through molten tin. The tin combines with the copper to provide a wind able wire of super-conducting properties.

Short comings of composites:

Although composite materials have certain advantages over conventional materials, composites also have some disadvantages. For example, PMC and other composite materials tend to be highly **anisotropic**, that is, their strength, stiffness, and other engineering properties are different depending on the orientation of the filler material. Joining composite components is difficult. Advanced composites have not only high manufacturing costs but require very exact quality controls. The composite material must result into a definite component, which makes the processes very much labour-intensive, and not easily amenable to automation.

Further reading:

An Introduction to Composite Materials: Hull Derek / Cambridge University Press / 620.1

Selection and use of Engineering Materials : Charles, Crane, Furness / Butterworth-Heinemann / CEPT SBST 04536 / 691 /CHA

Engineering Materials : Budinski, Budinski / Prentice Hall / CEPT SBST / 691

Engineering Materials and their Application : Flinn, Trojan / CEPT SBST / 691

1.06 MATERIAL PROCESSES

Surface Finish materials result from **natural causes and human effort**. Materials produced by natural causes are *occasional, usually very slowly formed and with no quality control*. Just the same, nature often presents *spectacular and impossible to duplicate finishes*. As natural finishes are *rare and available in very limited quantity*, some degree of **quality generalization and equalization** are required. Natural finishes require, minor to substantial modifications, such as **physical conversions** like cutting, dressing and polishing, to **chemical alterations** such as baking, bleaching and sintering. Materials modified out of the natural raw materials retain many of their original characteristics. **Manufactured or man-made materials** as raw materials have their own appearance, or after **secondary processing,** acquire a designed form and facet.

Since prehistoric times certain finishes have been collectively associated with specific *materials, tools and techniques* employed. A new product results with a variation in any one of these parameters. **Materials** provide vast options in their natural, processed and manufactured forms. **Tools** extend human limb abilities and also endow new capacities, so are continuously improvised through learning. **Techniques** of employing tools and processes relate to quality refinement, efficiency and productivity through scheduling, task management, planning, all leading to some form of automation.

Tools and techniques together create **rational manufacturing processes,** a strategy of for replicating specific end results. A manufacturing process could be very personal initially, but gradually spreads across the locality, and then becomes universal. **Personal manufacturing processes** reflect the personal skills of the originator or the inheritor of the knowledge. **Craft-products** as a result are very *individualistic, local and ethnic*. **Industrial products** on the other hand are *universal, unless patented or copyright protected* by the inventor. Industrial products come with assurance of consistency.

Creation of a surface finish is a cumulative consequence of all, *the Processes, Techniques and Tools*. There are many types of processes, techniques and tools. Some are more commonly associated with *specific materials or end products*, but many are common, i.e. applicable to many different materials and towards variety of end products. The *difference between a process and a technique may not seem very obvious, unless when either of them, are specific to a material or end product.*

Processes	for processing materials
	for specific end product, e.g. surface finishes
Techniques	for materials, using tools, etc.
	for surface finishing
Tools	Hand tools
	Power tools

This chapter covers **Material Processes**. Other sections are covered in subsequent chapters.

PROCESSES:

Processing of Materials: Materials are processed with following three main objectives:

1 Shape and size formation
2 Alteration and induction of properties
3 Endowing finishes

1 Shape and size formation:

Body forming processes change the dimensional format of the material through *phase-change of the material* (solid to liquid to gas, or vice versa), within the *same material phase* (heat treatments, hot and cold working, and through mechanical work like mixing, stirring), and through *material compositions* (structuring, assembly).

Grains or dust mixed with a binder material can be cast into solids, or melted-fused as alloy, or sintered to a ceramic. Solids can be rolled into sheets or melt-spun into fibers, blown to powders, or drawn into wires. Fibres and wires are woven into fabric sheets.

Shaping processes can be categorized as:

Solid forming: Forging, beating, pressing, rolling, drawing, casting, extrusion, moulding.

Sheet forming: Bending, punching, stamping, cutting, seaming, forming, moulding.

Linear forming: Drawing, spinning, entwining, weaving.

Grain forming: Blowing or granulation, chopping, grinding.

These processes can also be classed as:

1a Flow processes: casting, moulding, extruding, drawing, rolling, forging, hammering, beating, powder-technology, material deposition, stamping, punching, pressing, bending, folding, seaming.

1b Additive processes: lamination, crystal growth, foaming (lower phase material dispersion in a higher phase material), plating, cladding, mounting, joining, material deposition, fabrication, joining, supporting, holding, keying, positioning, plugging, arranging.

1c Reducing processes: cutting, chopping, sizing, splicing, scooping, drilling, boring, machining, planning, chiselling, engraving, etching, de-layering, chipping, grinding, rubbing, sand blasting, cleaning, washing, melting, dissolving.

1d Other forming processes: spinning, weaving, knitting.

2 Alteration and Induction of properties:

Alteration and Induction of properties cause a change in the engineering or structural quality of the material, frequently accompanied by the modification of the surface characteristics. The alteration processes are also designed to regain the lost or the reduced properties during other processing.

2a Heat treatments: boiling, liquidizing, melting, softening, sintering, baking, drying, fusing, welding, soldering, forging, annealing, heating, hardening, crystal forming, blowing.

2b Non heat treatments: magnetizing, static discharging, infection proofing, cleaning, washing, earthing, wetting, drying, stretching, strenting, stressing, compressing, tensiling, twisting, filling.

2c Material applications: coatings, depositions, claddings, panelling, enamelling, inlaying, gilding, printing, moisture proofing, fuming.

2d Non material processes: embossing, engraving, polishing, burring, charring, burnishing, chasing, buffing.

2e Chemical treatments: dyeing, bleaching, etching.

3 Endowing finishes:

Finishes are provided: By **altering** the surface properties of the materials at a raw material stage and also after formation of the object, By **reforming** the objects, and By **applying** other materials at a raw material stage or at an object formation stage.

The **need for a peculiar finish** could be varied, but essentially for:

> Imparting specific sensorial characteristics, for survival of the object in an environment, for changing the structural properties, as an aid in material processing and forming operations, for storage and handling of the raw materials or components, and for efficient operation of the system.

Processes for Natural Surface Finishes: Natural Finishes result due to many different factors, such as:

> Elemental conditions of formation, subsequent responses like weathering, cognitive affectations, and later, natural or man-made interventions (angle of cut, tools and techniques used, etc.).

Natural surface finishes have three main **cognitive affectations**: *Colour, Pattern and Texture*. The **colours** are of *original formation, subsequent weathering, readjustment of stresses, or induced by physical and chemical changes*. The **patterns** result from the *stresses, mixing of constituents, weathering, and the varied reactivity of different parts and constituents*. Patterns also result from *granular or fibrous orientation, method of cut, cyclic nature of growth, formation of residual products, deposition of contaminants, and tools-techniques of handling and processing*. **Textures** primarily result from the *degree of homogeneity, angle of cut, differential weathering, and various formative processes*.

Processes for Manufactured Surface Finishes

Manufactured Surface Finishes result at three levels: *Raw material stage, Product formation stage, and later, through Application of surface finish on Completion of the system*. In *an integrated production setup* all three could be a **single stage or plant process**, but in most other *fabrication shops* only the last two processes are combined. For *a site fabricated systems* like buildings, the last process, i.e. surface finish application, is a distinct process as it is carried out at a site. Manufactured surface finishes as a result are of two categories: **Plant based and Site-based systems**. Though lot of preparatory work may occur in the industrial plant for the site-based surface finish application. Products fully surface finished in industrial plants require very careful handling (transportation, loading, storage, delivery and positioning), and so may carry **protective but removable coatings or shields**.

Make-believe or pseudo finishes: These finishes are of two basic types:

1. Surface finishes that **duplicate the natural materials**, such as: wood figure or texture effects in polymers, stone like effects in ceramics, cotton like fabrics made out of polyester, or synthetic gems and diamonds.
2. Surface finishes that **copy the effects of other manufactured finishes**, such as: chrome polymers for metals, white metal ornaments for silver, or acrylic for glass. Future possibilities include flexible glass, elastomeric metals, polymers with programmable colouring or texture

forming system, metals lighter than ceramics or polymers, biodegradable ceramics, etc.

Surface finishes can be considered as:

Inherent Finishes
Applied Finishes
Integrated Finishes

(for discussion: see chapter: 1.02 Surface Finish Systems)

PROCESSES FOR SURFACE FINISHES:

Materials have some surface finish qualities at a raw material stage, and these are either maintained or changed during the conversion to a product. **Shaping of solid materials** is done primarily to reformat the shape, and to convert them into a planer or linear forms, but surface finishes begin to evident at this stage.

Note: Common surface finishing techniques are dealt in the next *chapter 1.07 Techniques*. Surface Finishing techniques for specific materials are detailed in *relevant chapters on Materials*. Surface finishes resulting from use of distinctive tools are discussed in *chapter 1.08 Tools*.

- **Hammering or Beating:** This is a very ancient process for shaping materials. Chipping by hammering stones to shape sharp edges was perhaps the most primitive of all processes. Hammering was also used to grind food stuffs, ceramic forming raw materials and metal ores. Even today hammering and beating, are mother processes for surface finishing.

Hammering was used to flatten-out the natural pure nodules of copper, and shape them into ornaments, tools and utensils. Hammering a copper nodule made it brittle, but frequent heating and graduated cooling -annealing made the mass ductile. Similarly sudden cooling by quenching in oil or water, caused surface hardening of the metal. Annealed and surface hardened materials had not only different structural properties but also had special surface qualities, (e.g. colour). Beating was also carried out to grind, and wet-mix materials, such as for ceramics.

- **Forging:** The ancient process of **Hammering** to shape a material is now a rational process. **Forging** is a process of shaping iron and other malleable metals by hammering or pressing them after making them plastic by application of heat. Forging not only provides a desired form, but also refines the grain size and arrangement and by that improves the structure of the metal. Forged metal is stronger and more ductile than cast metal, and exhibits greater resistance to fatigue and impact. Forging is also used to compact materials by removing gases and by packing the cavities.

There are six basic **Types of Forgings**:

Upsetting: Decreasing the length and increasing the diameter of the metal.
Swaging: Decreasing the diameter of the metal on concave tools called swages.
Bending: It is done by hammering the work around a form or by levering it against a support.
Weld forging: It joins two pieces of metals together by hammering them together at high temperature with the help of a flux such as a borax.
Punching: It forms small depressions or openings in the metal by a punch of the proper shape on a base of a ring-shaped piece of metal.
Cutting: It cuts out large holes, apertures or niches in the metal with heavy, sharp chisels.

Forging can also be categorized, depending on the equipment used in the process.

- **Hand Forging:** Sometimes called **smithing, or black smithing** is the simplest and oldest of all forging techniques. It uses a hammer and a beating block, called an anvil. An anvil has slightly tapered or a convex surface that allows precise hammering angles. Often concave shaped tools like swages are used to cover or hold the material (to restrict the flow of metal). A drop-forging uses force of gravity to drop heavy weight over the work piece instead of hammering.

- **Machine Forging**: various types of machine-powered hammers or presses are used instead of a hand-held sledgehammer. These machines provide, heavy and rapid blows for production of large size and high quality objects. Forging-compression is obtained through the entire piece, compared to the hand-forging where mainly the surface is deformed. **Drop forging or Impact-die forging** involves placing a ductile, or heat softened metal in a single die or between two **shaping dies**. The upper of these dies, is dropped onto the lower one forcing the heated metal into the shaped die cavities, as in coin-making. For reducing part of a piece of metal stock to a predetermined size, **forging rolls** are used. These consist of a pair of grooved, cam-shaped rollers through which the metal is passed. Machine-forging operations are frequently accomplished by use of a **series of dies** mounted on the same press or hammer. The dies are arranged in sequence to form the finished forging in a series of steps. After the piece has been partially formed by one stroke, it is moved to the next die for further shaping on the next stroke.

- **Shaping by Rolling:** Materials are shaped by passing through rollers. Rolling not only compresses, levels and stretches the material but it can emboss patterns (e.g. checkered aluminium plates of bus floors) and textures, cut shapes, polish the surface. Hot rolling, joins or fuses the layers of materials. Hot and cold rolling of metal sheets are done to provide specific surface qualities.

- **Shaping by Drawing and Stretching:** Materials are drawn out through apertures or orifices to reduce the cross sectional shape and size, but elongate its length dimension. Wires, seamless pipes and filaments are drawn products. Drawing is often accompanied by twisting-spinning, entwining, thread or rope forming, etc. Extrusion of plastic is also a drawing process. Opposite to this, materials are stretched to increase their sectional shape and size, often slightly decreasing the length dimension. During drawing and stretching constituents like molecules, grains and fibers get rationally realigned, providing different surface qualities. Drawing and stretching, are also carried out to mix new ingredients such as colours, liquids, plasticizers, lubricants, etc.

  Fabrics, Paper, Leather, Glass, Elastomers (rubbers), Polymers, Filaments, etc. are some of the materials receiving specific surface qualities (creased-crinkled, corrugations, gloss, matt, hardness, softness, evenness, etc.) through Drawing and Stretching processes. Most of the commercial metal forms (annealed, surface-hardened, ribbed, fluted and corrugations) are produced through such processes.

- **Shaping by Shear cutting, Stamping (die forming), Punching:** In spite of simpler options these processes are used to achieve special surface qualities. Ordinary cutting by toothed saw leaves cut marks but shearing provides a smooth cut. Ruptures can be performed on materials with substantial stiffness (density) but softer materials shear cutting is required. Stamping allows stretching the material into a shape cast. The quality of a surface is determined by: nature of die surface, lubricants, force, nature of material (cold or hot workable, for stainless steel austenitic or martensitic), etc. Punching is faster than drilling, but stresses the edges of the hole rim.

- **Bending and Folding:** are processes used for shaping ductile materials. Bending and folding can be done by controlled hammering, but today mechanical systems are used. Edge shaped tools provide linear shaping (almirah -cupboard shelves), solid shaped-ends create shaped deformations (spoons, frying pans, automobile bodies), balls are used for forming curved shapes (concave-convex as in wok or chemical vessels bottoms). Bending and folding operations are also used for shear-cutting. **Bending** relates to smooth curving whereas, folding relates to a sharp or angular turning. In **Sheet metal fabrication** bending and folding generally increases the planner stiffness, as in AC ducts, cans and tins, barrels, corrugated sheets, purlins, pipe etc.

See Chapters: Polymers, Coatings, Metal treatments, Fabrics, Fabric crafts, for material specific processes

1.07 TECHNIQUES

SURFACE FINISHING TECHNIQUES:

Many techniques of achieving surface finishes in use today are essentially the same as those employed in ancient times. These have been refined in terms of the tools used and rationalized in terms of procedures. Many processes are now highly mechanised saving time and energy, and some even are fully automatized, using robotics that allows faster, accurate and safer production.

Some important techniques of associated with surface finishes are briefly discussed in following four groups.

1 Techniques for surface finishing **objects' own material**.
2 Techniques for surface finishing with **foreign materials**.
3 Techniques of **material deposition** for surface finishing.
4 **Surface modification** techniques.

1 TECHNIQUES FOR SURFACE FINISHING OBJECTS' OWN MATERIAL.

- **Cutting:** Cutting is the oldest of all techniques. First cutting edges were made of sharp edged flint stone chips. Cutting stone chips were tied to wood or bone handles which not only improved tool holding, but leveraged greater force. Cutting Axes were reasonable for medium strength materials like wood, but for harder materials like stone, cutting and beating separated into **hammer and chisel** (for tools: see next chapter). Cutting is used for fast division of materials and quicker removal of parts of materials (skinning, debarking, chopping, mining). Cutting is the crude but primary technique of material processing.

- **Carving:** Carving is a controlled cutting technique requiring use of a chisel and only occasionally pounding by a hammer. Carving is associated with fine but soft grain materials like *ivory, horn, bones and wood*. Carving is also done to pliable metals like copper, silver-based alloys, and also hard but fracture-able materials like stones.

- **Engraving:** Engraving is a delicate and shallower material removal technique than carving, using a chisel or sharp pointed tools with hand pressure, or very light pounding of the hammer. Engraving is today done by fine rotary tools similar to the dentist's pneumatic drill. A computer controlled, diamond bit engraving is now done to ultra thin materials also.

  In **Intaglio, or Gravure, printing**, the image to be printed is etched or incised into the surface of the printing plate or cylinder. Gramophone records have engraved and embossed grooves.

- **Chasing:** For chasing, the material is depressed or displaced by a fine tool as *dots, small length linear-strokes or in continuous linear patterns*. Wet ceramic pieces, and plastered-surfaces are patterns rendered by chasing. Braille writing on a thick paper sheet is a form of chasing.

Engraving and chasing techniques are frequently used to provide a matt finish, onto normally very glossy stainless steel surfaces. *Chasing* techniques are also used for relieving as well as introducing stresses at the surface section, allow moisture and heat transfer, and improve the ductility of the material.

- **Embossing:** Embossing introduces a texture through pounding, beating or by pressing of the surface. The pressure may be applied from one face or both faces of a sheet, locally as spots, or continuously under a plate or roller, creating repeat patterns or random designs. *Pounding or beating,* compacts the surface-sections of the material, and thereby increasing its density and integrity. Embossing techniques are used to reduce the gloss by matting the surface. Embossing is done to increase the thickness bulk of very thin surface materials and make them apparently stiffer. Synthetic fabrics and fibers are emboss-deformed and permanently set (perma-set and texturizing) through heat or chemical treatment.

- **Repousse:** Repousse is a method of raising a design in relief from the reverse side. The design is first drawn on the surface of the metal and the motifs outlined with a tracer, which transfers the essential parts of the drawing to the back of the plate. The plate is then embedded face down in an asphalt block and the portions to be raised are hammered down into the soft asphalt. Next the plate is removed and re embedded with the face uppermost. The hammering is continued, this time forcing the background of the design into the asphalt. By a series of hammering and re embedding, followed finally by chasing, the metal sheet attains the finished appearance. There are three essential types of tools used: -for tracing, -for bossing, -for chasing.

Ornaments in relief are also produced by mechanical means. A thin, pliable sheet of metal is pressed into moulds, between set of dies, or over the stamps. Embossed utensils of copper and brass, statuettes of gods formed of thin silver and gold plates are very much part of every Indian house. Today Aluminium craft pieces are similarly embossed and black anodized.

> Traditional Indian Brass and copper utensils have hammered finish on the outside. The same is often copied on aluminium utensils but reducing the strength due to 'cold working' of the metal. Leather and paper surfaces are rolled embossed to create textured patterns. Timber veneered surfaces are pressed for texture creation. Rendering of a wet plaster face by variety of pressing and chasing tools is very common. Chasing is very common with copper and brass pots (e.g. Peshwai Lotas and glasses).

- **Matting and Etching:** These are mainly used for creating textured surfaces. Matting is generally a mechanical technique compared to etching where a chemically active substance is used. Mating and etching, are also achieved by metal removal processes (reversing the metal deposition by changing the cathode charge) in the final stage of plating.

> Parallel, crossed, irregular, concentric, circular and other geometric configurations are carved or embossed on the surface. Line and spacing between them are often less than 1/100 part of a millimetre, depending on the compactness of the material mass. Another method of surface decoration is to impress it with repeating patterns of hatched lines (used on precious metals), thus matting or breaking up areas to contrast with other areas left polished and reflective.

- **Etching:** Etching is usually done by an active substance that will either eat away part of the surface or change its colour quality. Acid and alkali treatments also provide etched surfaces. Etching is also an artwork technique (see: chapter: Coatings) Glass surfaces are etched with Hydrofluoric acid.

- **Surface levelling:** Surface levelling is a major field of surface finishing. Surfaces are levelled by chipping away very thin sections off the surface. The material must have layered formation (e.g. Kotah -ladi stones, bamboo, cane) or fracturable or brittle constitution (e.g. stones). Surfaces are ground and polished for a levelling.

- **Grinding:** Grinding removes material from the surface to roughen a normally glossy surface like glass, or polishes a rough surface like stone. Grinding requires material of higher hardness than the surface material, and is done by rubbing down with a graded series of coarse to fine abrasives, such as carborundum, sandstone, emery, pumice, sand, glass and diamond powders. Where a material constitution permits, very fine grinding may polish the surface. Grinding is a cutting operation in which each grit that comes in contact with the material cuts out a minute chip, or swarf.

Grinding wheels usually consist of particles of a synthetic abrasive, such as silicon carbide or aluminium oxide, mixed with a vitrified or resinoid bonding material. Grinding can be coarse or fine, depending on the size of the grit used in the grinding wheel. Metal and glass can be ground to a **mirror finish** and an accuracy of 0.0000025 cm. Abrasive are used as grinding wheels, sandpapers, honing stones, polish, cutoff wheels, tumbling and vibratory mass-finishing media, sandblasting, pulp-stones, ball mills, and many other tools and products.

Stone surfaces are chiselled to split the material into thinner sections, to remove the weathered crust and also to level out the surface. Grinding and polishing is done to: Hard materials such as building stones, marbles, granites, metals, glass; Precious and Semiprecious stones like gems, diamonds; Animal products like ivory, bones, horns, teeth, leather; Plant products like timbers, seeds; Ceramics like pottery products, bricks, cement concrete and other cement products.

- **Polishing, Honing, Lapping, Buffing:** Polishing uses extremely fine abrasive substances, such as jewellers rouge, Tripoli, whiting, putty powder and emery dust to rub or burnish an extremely smooth and brilliant finish on the surface of a material. The polishing materials are coated on the surface of cloth, felt, leather, rubber pr polymer wheels or as belts. Metal surfaces are levelled and finished by honing and lapping. **Honing** removes less than 0.0125 millimetres of material from the surface to eliminate micro scratches and machine marks from ground machine parts. It is done with bonded abrasive sticks or stones that are mounted in a honing head. **Lapping** is a process in which a soft cloth (wool, linen and chamois-leather) impregnated with abrasive pastes (rubbing compounds), is rubbed against the surface of a workpiece. Honing and lapping, are essentially metal finishing techniques. **Buffing** is a term used for polishing of metals. Buffing is done with polishing compounds and brushes of various shapes, and materials, like: (animal hair, synthetic fibers, plant fibers -coir), flex, wool and leather. Barber polishing the razor on a leather stripe is a buffing process that levels out small nicks on the blade.

There are four types of precision grinding machines: Center-type grinders used for tiny valve spools to steel mill roles. Center-less grinders used for bowling balls, surgical sutures, and tapered roller bearings. Internal grinders are employed for inside diameters of gears, bearing races, and similar parts. Surface grinders are used for die tops, bench surfaces.

Lapping is used to produce a high-quality surface finish or to finish a workpiece within close size limits. Dimensional tolerances of 0.00005 millimetres can be achieved in the hand or machine lapping of precision parts such as gauges or gauge blocks.

- **Shaving and Splitting**: Shaving is done to remove material's components such as outward hair or fibers, layers, etc. Leather surfaces are **shaved** for thinning and to remove the surface hair. Leathers are also **surface-split** to separate leather suitable for uppers and soles. The palm leaves are shaved to remove the stems and make them smoother for writing. Tree-barks are removed by axes and choppers to retard insect attack and increase moisture removal. Timbers are re-cut or planned with finer tools to achieve a smoother surface. Timbers are split very finely to create veneers. **Wood planning** is also a shaving technique. Carpets and rugs require close shearing by scissors to shave of protruding fibers.

- **Burnishing**: Burnishing is controlled burning (or a heat treatment) at the surface section to remove part of the material and to change the colour or texture properties of the surface. Burnishing is both a process of surface finish and **surface cleaning**. Most of the organic materials can be surface-treated directly with fire or indirectly with high heat to achieve a burnished or ironed effect. Textiles, paper, leather, leaves, wood, etc. are some materials that can be burnished. High temperature burnishing removes the surface fibers and hair, and chars or burns (sinter) the top part of the surface, creating a burnt colour + texture effect. Textiles are Ironed, i.e. de creased or perma-set, i.e. creased with pressurized heat treatment. Synthetics or composite textiles are selectively or locally burnished to fuse the fibers or filaments, create texturized effects and also alter the transparency, opacity, etc. Wood surfaces on burnishing, creates a dehydrated or an old **shrivelled or shrunk surface**, similar to an old wood. Metal surfaces also burnished not only to harden or anneal the top surface but to burn the oily residues, dehydrate, and descale the surface. Burnished metal surfaces often attain peculiar colour and pattern effects.

2 TECHNIQUES FOR SURFACE FINISHING WITH FOREIGN MATERIALS.

Surface finishing or decorating with a foreign material is a very ancient technology. Some important and traditional methods are described here. Other Material relevant techniques are dealt in chapters on *Materials*.

- **Damascening**: Damascening is a technique of encrusting gold, silver or copper wire on the surface of iron, steel, or bronze objects. The metal base surface is finely chased or engraved with a sharp tool. The decorative metal thread is forced into the minute grooves by hammering.

- **Niello**: Niello is made by fusing together silver, copper and lead, and then mixing the molten alloy with sulfur. The black product is powdered. Chased or the engraved metal surface is wetted with a flux compound and black powder is spread on it. On heating the niello melts and runs into the depressions or channels. Excess niello is scraped and the surface is polished, giving a dual metallic effect or pattern.

- **Granulation:** Granulation is mainly used for gold jewellery. In granulation, beads of gold are soldered onto gold surfaces. Etruscans produced such jewellery in 5^{th} BC. The beads were minute and provided an effect of a bloom to the gold surface, rather than of a beaded surface.

- **Filigree:** Filigree can be made of either gold or silver. Open-work patterns are worked from minute wires or cables made of two or three gold or silver wires twined or braided together. In the 16^{th} and 17^{th} C. filigree was extremely popular for decorating vases and drinking vessels, especially in Italy and Germany, and in the 18th- and 19^{th} AD in South America. In Russian and Scandinavian countries filigree has survived as a provincial craft and is used for boxes, mirror cases, and peasant jewellery. It is obviously very delicate and fragile work and, except jewellery, usually has a backing material. In India, **Orissa** is the main centre for filigree work in India.

- **Ajouré:** Ajouré are achieved by cutting or piercing patterns in the metal. Raised patterns were also affixed by soldering small castings or cut out motifs onto a flat surface.

- **Embellishments with Other Materials**: These include fixing or embedding precious and semiprecious gemstones, enamels, a variety of exotic substances such as rare woods, metals, ivory, horn, beads, sea shells, jade, and amber, and niello (a black finish on silverware) into chased cavities, heat or solvent softened materials. Fixing is also done by wire or thread knitting and knotting (Kutch Mirror work and embroidery on fabrics). In ancient times ceremonial furnishings were almost as exotically decorated as personal jewellery and cult implements.

- **Inlay:** Inlay works are of many varieties, with metal into wood, stones and metal, and wood into wood, ivory into wood, more recently high grade plastics into wood, metal, and plastics, glass beads into ceramics, etc. Floral patterns and scripts on Taj Mahal are examples of Marble inlay work. Inlay work involves incising a pattern's shape and filling it up with a cutout of material to be laid in. The fixing is done with tight fitting, adhesives, or by hammering a ductile metal.

- **Gilding**: is the art of decorating wood, metal, plaster, stone, glass, or other objects with a covering or design of gold in leaf or powder form. The term also covers similar application of silver, palladium, aluminum, and copper alloys. Thin sheets of gold and silver are beaten in leather sheet folders to create leaves (foils) as thin as 0.00001 millimetre. After being cut to a standard 90 to 100mm square, the leaves are packed between sheets of tissue-paper as small books, ready for the gilder's use. Gilding by gold or silver sheets requires as no adhesives as sufficient electrical charges attract the foil to the base, however for permanent fixing (exterior use) some form of adhesives are used. To day commercial guilders used **aluminum powders** in a variety of metallic shades such aluminium in different shades of oxidation, bronze, copper, gold, etc. These powders are dry sprayed on an adhesive or varnish-covered surface or mixed with a carrier varnish or lacquer.

- **Overlays:** Overlays use slightly heavier sheets of metal than gilding, otherwise it is the same as gilding. Egyptian mummy cases and furniture were gold covered. The Chinese ornamented wood, pottery, and textiles with designs in gold. The Greeks not only gilded wood, masonry, and marble sculpture but also **fire-gilded metal** by applying a gold amalgam (gold+mercury) to it and removing the mercury with heat, leaving a coating of gold on the metal surface. The Romans acquired from the Greeks the art, and covered their temples and palaces with gold. Jain and Buddhist statues are covered by **gold and silver foils and sheets**. Ancient gilding shows that gold was applied to a ground prepared with chalk or marble dust and an animal size or glue. Today lacquers, epoxies and rubber-based adhesives are used to fix the foils and sheets. Temple statues are decorated by gold foil without any adhesive, by the electric (ion) charge, which makes it removable it. **Silver gilding** gets tarnished in moist weather. Gilding requires careful surface preparation. To day flat paints, lacquers, or sealing glues are used, depending on the nature of the substrate.

Metals surfaces prone to corrosion may be primed (and protected) by red lead or iron oxide coatings. The area to be gilded is covered with an adhesive. When it has dried enough so that it just adheres to the fingertips, it is ready to receive and retain the gold leaf or powder. After fixing the foil, it is rubbed gently (burnishing) with a dry cotton swab, to achieve high luster. Other **materials for burnishing** include agate. Loose bits of gold, or skewing are removed from the finished work with a camel's hair brush.

- **Enamelling:** Enamelling is technique of providing a lustrous finish on any surface such as metal, ceramic or wood. A vitreous paste consisting of mixture of silica (from quartz or sand), soda or potash, and lead, is deposited on to metal objects such as jewellery, small metal boxes, utensils, ceramics or glass, and fused by heat. A resultant surface is chemically **identical to glass or highly vitrified ceramic**. The ingredients are made opaque and coloured by the addition of other metallic oxides. Enamel work is also known as **Minakari** in jewellery field. Enamel finishes were very popular as coatings for steel items when alternative rust-free materials like aluminium and stainless steel, were not available. So **hospital-ware** such as gandy, urine pot, kidney tray, instruments' tray, camping-ware like tumbler, bowls, dishes, and decorative items like ceiling panels, signboards, watch or clock panels, etc. were made with enamelling.

> Bombay suburban trains' stations and street' name boards were created by ceramic enamelling on wrought iron plates (slightly puffed-embossed in the centre). Similar Multi coloured enamelled ceiling plates were used in many rich homes in Europe and India. Some such plates still survive after 100 to 175 years.

Five main types of enamelling are in use: **Champlevé, Cloisonne, Basse-taille, Plique-à-jour, and Encrusted.**

- **Champlevé** (French= raised field): Champlevé enamels are done by scratching or etching a metal surface, usually copper, leaving hollows or troughs with raised lines between them. The hollows are filled with pulverized enamel that is then fired. The hard-finished enamel is subsequently filed down until the glossy surface and the metal surface can be polished simultaneously, with crocus powder and jewellers rouge.

- **Cloisonne** (French= partitioned): In the cloisonne process, very small partitions, or cloisonne, consisting of thin metal strips are built up on the surface of the metal. They may describe a pattern and are fixed to the surface by solder or the enamel itself. The partitions are filled with pulverized enamel, and the subsequent procedure is the same as for champleve. The Cloisonne technique is usually applied to silver, although gold or copper may also be used as bases.

- **Basse-Taille** (French= low cutting): The Basse-taille process is a kind of champlevé but is applied to silver or gold. The metal is engraved or hammered to various depths according to the design. The depressions are then filled with translucent enamel, through which the design beneath it can be seen.

- **Plique-à-jour** (French=open braids): Plique-à-jour enamelling resembles cloisonne, but differs from it in that the partitions are soldered to each other rather than to the metal base, which is removed after firing. The remaining shell of translucent enamel gives the effect of stained glass. Because it has no metal base, Plique-à-jour enamel is exceptionally fragile.

- **Encrusted Enamel**: Encrusted enamel or **enamel *en ronde bosse*** is prepared by spreading of an opaque enamel paste over slightly roughened surfaces of objects such as small figures.

- **Painted Enamel** Painted enamels resemble small oil paintings. These are made traditionally on a metal plaque covered with a layer of white enamel and fired. The design, in coloured enamels, is then applied on the white ground, by painting, spraying, screen printing, or block printing. A separate firing may be required for each colour because each may fuse at a different temperature.

(Techniques of art work painting and other coatings are covered in Chapter: Coatings) (Techniques of knitting etc. covered in Chapter: Fabric Crafts) (Metal related techniques are further detailed in Chapter: Metal Crafts, and Chapter: Metal Treatments) (Wood related techniques are further detailed in Chapter: Wood crafts).

3 TECHNIQUES OF MATERIAL DEPOSITION FOR SURFACE FINISHING.

Material Depositions: There are many techniques of depositing materials. These techniques implant or deposit a material or combination of materials onto a substrate to make it an integrated surface. This is done without the use of *mechanical joining or adhesive fixing*. Chemical reactions, if any are only at the surface level.

Form of materials to be deposited: Metals, metalloids, alloys, ceramics, polymers, composites, and other material compounds in intermediate or a nascent stage.

Phase Stage of the material to be deposited: Gas, Liquid, Solid or Plasma.

State of the material to be deposited: Powders, granules, solids, liquids, plasma, gases and vapours, molecules and ions.

Production Status of the recipient object: Raw material, partially formed, fully composed objects, or operative systems.

Form of the recipient object: The *recipient object* and *material to be deposited* are of vastly different forms, such as: *Ceramics deposited with* metals or polymers, *Metals loaded with* alloying metals, metalloids, ceramics, composites, polymers, etc., *Polymers receiving depositions of* metals, metalloids, ceramics and composites. Biotic materials like bones, skins, and other natural materials are deposited with ceramic materials.

- **Electroplating:** This is a method of electrically depositing a metal or a mix of metals (as alloy) on conductive surfaces (metals), as well as on nonconductive materials such as plastics, wood, leather, etc.; after these have been rendered conductive by processes such as coating with graphite, conductive lacquer, etc. Metal alloy compounds that nominally cannot be produced can be alloyed and electroplated on a surface (e.g. tin-nickel compound).

Modern Electroplating started with the discovery of battery, sometime in 1800. It all started when it was seen that a nodule of copper deposited on a silver cathode could not be easily removed. The battery current was used to deposit the lead, copper, and silver. During the same period zinc, copper and silver were deposited on themselves, and on other electroplating worthy metals including gold and silver. Commercial scale electroplating began in 1840s when cyanide copper solution was discovered. Iron, cobalt, nickel, copper, zinc, ruthenium, rhodium, palladium, silver, cadmium, tin, iridium, platinum, gold, and lead are commonly used for plating. During 1925, introduction chromium plating changed the face of many automobile and household gadgets completely. Chromium plating provided a permanently glossy surface. Soon nickel-chromium or copper-nickel-chromium strengthened the plating industry.

Chrome plating on nonconductive materials is in use since 19th C. However, in 1963 ABS plastic was found suitable for chrome plating. The plastic part is first etched chemically by dipping in a hot chromic acid–sulfuric acid mixture. It is then activated by dipping in stannous chloride solution and palladium chloride solution. It is then coated with an electro less copper or nickel before further plating.

- **Melt deposition:** Melt deposition is a very broad term, and includes many different technologies of applying or depositing a material by melting through *radiant heat, friction heat, pressure and solvents*. Traditional processes use radiant heat, but today *infra red, microwave, high velocity oxy-fuel-TIG, electron beam, laser and plasma systems* are used for fast and controlled heat input. Pressure is caused by direct *pressing, impact loading, pressure exerted through gas and liquid surroundings*. Melt depositions are made in ambient environments, under pressure, in near vacuum conditions, electrically charged enclosures, and also in presence of inert gases and ionised materials.

- **Direct Material Deposition** is one of the most common of methods to *build up 3D objects*, and also a *method of surfacing*. It uses feed from a wire or powder, which are melted before deposition. It, in a simple and economic way affords a very fast buildup, but causes distortions in the component. Melt deposition creates comparatively substantial (heavier-thicker) surface, or heavier-solid buildups. It is used to repair worn out surfaces, add features to an object, fill up cracks, level out the machined surfaces to a very fine finish. Metal deposition is also used in building up planner or solid prototypes.

Household tinning of brass and copperware is a metal deposition process. Gold and silver plating is a metal deposition process.

Deposition of the metal powders: Metal or an alloying-agent in the powder form, are sprayed through a nozzle that is coaxial to the CO_2 laser beam. The metal powder gets deposited on the molten mass on the object's surface. The process is fast and occurs on top surface section so does not affect the basic mass properties of the object.

- **Vapour Deposition Technologies:** Vapour deposition technologies include processes that put *materials into a vapour state via condensation, chemical reaction, or phase conversion.* Manufacturers use these to alter the mechanical, electrical, thermal, optical, corrosion resistance, and wear properties of substrates. Vapour deposition technologies are used *to form freestanding bodies, films, and fibers and to infiltrate fabric-forming composite materials.* There are two main sub techniques: **Physical vapour deposition** and **Chemical vapour deposition**. In physical vapour deposition the object is placed in plasma (of active gas like nitrogen, oxygen, or methane) bombardment, whereas in the chemical vapour deposition, thermal energy heats the material to vaporise in a chamber, and initiates a deposition reaction. Physical vapour deposition involves dry vacuum deposition methods in which a coating is deposited over the entire object rather than in certain areas.

Commercial **physical vapour deposition** methods are Ion plating, Ion implantation, Sputtering, and Laser alloying of surfaces.

Plasma-based Ion Plating: Ions are accelerated from the plasma and high energy neutrons through a negative bias deposit metals and alloys (titanium, aluminum, copper, gold, palladium, etc.) on a closely placed substrate. Plasma ion plating is used for production of X-ray tubes, piping threads used in chemical environments, aircraft engine turbine blades, steel drill bits, gear teeth, high-tolerance injection moulds, aluminium vacuum-sealing flanges, decorative coatings and for corrosion protection in nuclear reactors.

Ion Implantation: Ion implantation does not produce a discrete coating. A beam of charged ions of the desired element changes the elemental chemical composition of the surface by forming an alloy. There are three different processes of ion implantation: *beam implementation, direct ion implantation, and plasma source implementation*. Iron implantation is used as an *anti-wear treatment for components of high value such as biomedical devices like prostheses, tools like moulds, dies, punches, cutting tools, and inserts, and gears and balls used in the aerospace industry. Other industrial applications include depositing gold, ceramics, and other materials into plastic, ceramic, and silicon and gallium arsenide substrates for the semiconductor industry.*

Commercial **Chemical vapour deposition** methods include *sputtering, ion plating, plasma-enhanced CVD, low-pressure CVD, laser-enhanced CVD, active reactive evaporation, ion beam, laser evaporation, and other variations.* The variations are in the manner the coating is delivered by a material known as a reactive vapour that can be dispensed in either a gas, liquid, or solid form.

The CVD methods are used for coating metals like: nickel, tungsten, chromium, and titanium carbide. CVD is used to deposit coatings and to form foils, powders, composite materials, freestanding bodies, spherical particles, filaments, and whiskers. The majority of applications are in electronics production including structural applications, optical, opto-electrical, photovoltaic, and chemical industries.

- **Metallizing:** Metalizing is essentially a surface metal deposition technique used to change the appearance (gloss, colour, texture), to alter the surface properties (rust proofing, protective coating, spark or erosion proofing, wettability, conductivity, etc.), to fix or clad new materials, components, etc. Metalizing creates a very thin surface where inter particle boundaries are not very important. Though the density of particles spread is very critical.

Metallized Polyester films control the solar radiation. Gold Metallized glass, are used in windows of outer space vehicles to eliminate radiation penetration. Metallized films are used as mirrors. Metallized glass is used as mirror. Metallized films split into a very narrow-stripes are used in place of gold or silver Jari. Metalizing is also done through special mixtures - amalgam of gold or silver+ mercury in craft work such as gilding, Sankheda and Chinese lacquer work patterning.

- **Alternative Methods of Metal Deposition:** Traditional methods of metal deposition such as electroplating (chromium, nickel, cadmium, copper) use toxic substances like cyanides that cause pollution problem. These alternative technologies include *thermal spray coating, vapour deposition, and chemical vapour deposition.*

- **Sputtering:** Sputtering is used for etching and deposition of metals. In both instances it changes the physical properties of the surface. A gas plasma discharge is set up between two electrodes, a cathode plating material, and anode substrate. Positively charged gas ions are attracted to and accelerated into the cathode. The impact knocks the atoms off the cathode, which impact the anode substrate while coating it. A film forms as atoms adhere to the substrate. The deposits are thin, ranging from 0.00005 to 0.01 mm. The materials deposited are *chromium, titanium, aluminum, copper, molybdenum, tungsten, gold, and silver*. Three techniques for sputtering are available: Diode plasmas, RF diodes, and Magnetron-enhanced sputtering.

Sputter-deposited films are used in watch bands, eye glasses, and jewellery. The electronics industry uses sputtered coatings and films for thin film wiring on chips, recording heads, magnetic and magneto-optic recording media. Architectural glass, solar radiation control films, reflective films and food packaging films produced by sputtering.

- **Infiltration:** Infiltration is a technique of filling in the cracks, pores and voids of various, micro to macro sizes. The infiltration is done with particulates of smaller size than the cavities that exist. Filling in of pores is caused by reaction with or deposition from a liquid or vapour. In the case of liquid reaction, the technique is called *melt infiltration,* and in the case of vapour phases, it is called chemical *vapour infiltration*. Many composites are formed by infiltration of the matrix forming compound, into the filler.

Typically in a cement concrete mass, the voids in the stone aggregates are filled in by sand, voids in sand granules are filled in by cement, voids in cement particles are filled in by water. Stone aggregates and sands stay deposited but cement and water react.

- **Laser Surface Alloying/Laser Cladding** Lasers are very suitable for surface modifications. Lasers can soften or melt a surface mass for a controlled depth, in a localized spot and very quickly. Laser generating equipments operate to synchronize injection of feed material. One of many methods of laser surface alloying is **laser cladding**. In this, a thin layer of metal or ceramic, or powders thereof, are bonded with a base metal through heat and pressure. Materials that are easily oxidized are difficult to deposit without using inert gas streams and envelopes.

- **Thermal Spray Coatings:** Coatings are sprayed from rod, wire or granules or powder stock. The molten stock is heat melted and atomized by a high-velocity stream of compressed air or other gases, and sprayed on the substrate. The substrate is often both, charged and heated.

- **Ceramic coatings by thermal spraying:** Ceramic forming materials are heated fused and sprayed, or are deposited and allowed to form a ceramic surface.

  Ceramic coated surfaces are tougher, and highly scratch resistant besides are non static charging and better wettable than chrome sprayed surfaces. Ceramic rolls are now replacing the chrome rolls for offset and such printing techniques.

- **Electric Arc Spraying:** An electric arc is formed between two ends of coating material feeds (wires, etc.). They continuously melt at the arc point is blown by a jet of gas like air or nitrogen, as droplets towards the substrate.

- **Plasma Spraying**: A DC current passing between a water-cooled copper anode and tungsten cathode forms an arc ionizing to form plasma. The plasma heats the powder coating to a molten state. Compressed gas propels the molten mass at very high speed towards the substrate. Materials for plasma spraying are: *zinc, aluminum, copper alloys, tin, molybdenum, steels, and ceramics.*

4 SURFACE MODIFICATION TECHNIQUES:

- **Patina forming:** Patina is a rust layer formed on bronze objects, either naturally over a period of time or intentionally by chemical treatment. Sculptures exposed to different kinds of atmosphere or buried in soil or immersed in seawater for some time acquire attractive patina. Bronze can have a wide variety of green, brown, blue, and black patinas. Iron is sometimes allowed to rust until it acquires a satisfactory colour, and then the process is arrested by lacquering.

- `**Anodising:** Anodising is a technique of creating an oxide film on a metal surface. The film is intended for purposes such as corrosion resistance, electrical insulation, thermal control, abrasion resistance, sealing, improving paint adhesion, and as a decorative finish. Anodizing-process consist of electrically depositing an oxide film from aqueous solution onto the surface of a metal, often aluminum, which serves as the anode in an electrolytic cell. Plate properties such as porousness, abrasion resistance, colour, and flexibility, depend on the type, concentration, and temperature of the electrolyte, the strength of the electrical current and the processing time, and the type of metal being plated. Dyes can be added into the oxidation process to achieve a coloured surface. Coloured anodised aluminum is used in gift ware, home appliances, and architectural windows sections and trimmings.

- **Carburizing:** Carburizing is one of the oldest methods of surface hardening iron-based metals, next only to fast cooling by quenching in oil or water. Iron or steel products heated to a very high temperature are placed in a carbonaceous environment for long duration. The carbon diffuses into the surface of the object, making it harder. The depth of the carbon penetration depends on the exposure time and temperature. In *gas carburizing* the parts are heated in contact with such carbon-bearing gases such as carbon monoxide, carbon dioxide, methane, or propane.

- **Carbunitriding:** The same process is used in Carbunitriding except that ammonia is added.and it takes place at lower temperatures that produce less distortion in the steel. Gears, ball and roller bearings, and piston pins are among the products made by carburizing.

- **Nitriding:** These surface hardening technique uses utilizes nitrogen and heat. Cam shafts, fuel injection pumps, and valve stems are typically hardened by this process.

- **Flame hardening and induction hardening:** in which high heat is applied for a short time, (by gas flame or high-frequency electric current, respectively) and then the steel is immediately quenched. These processes are used generally for larger implements.

- **Peening:** Peening is mechanical technique of *hardening the surface* by rolling, hammering, drawing or hammering of the surface at temperatures that do not affect the composition of the steel.

- **Sintering:** Sintering is a high pressure and high temperature baking process. It is used for production of alloys, ceramics and composites. Pressure increases the densification and decreases the heat requirement by nearly half the melting point of ceramic. High pressure or impact load helps in shape formation. Simple hot pressing does not allow forming of complex shapes. In another process, called *hot isostatic pressing* (HIP), a ceramic is pre sintered to squeeze out the porosity (so that interconnected pores are eliminated) or encapsulated with a viscous coating such as glass. The ceramic is further processed under a high pressure fluid such as argon or helium, and at high temperature, so that residual gases from the object bubble out. Very complex objects can be formed by this method.

For sintering conventional radiant heat input are too slow. For rapid heating two sources are used: *Plasma and microwave*. In plasma heating energized and ionized particles deposit large quantity of energy on the surfaces of the ceramic being sintered. **Plasma sintering** takes place in an ionized gas. In **microwave sintering**, electromagnetic radiations at microwave frequencies penetrate and deposit the heat in the interior of a sintering ceramic first rather than on the exterior surface. A combination of radiant and microwave heating can be used to obtain thorough heating of the object.

Reaction sintering or reaction bonding is a process for production of dense ceramics. Typically a reaction-bonded silicon carbide (RBSC) is produced from finely divided mixture of *silicon carbide and carbon*. Pieces formed from this mixture are exposed to liquid or vapour silicon at high temperature. The silicon reacts with the carbon to form additional silicon carbides, which bonds the original particles together. Silicon also fills any residual open pores.

Reaction-bonded silicon nitride (RBSN) is made from finely divided silicon powders that are formed to shape and subsequently reacted in mixed nitrogen/hydrogen or nitrogen/helium atmosphere at 1,200° to 1,250° C (2,200° to 2,300° F). The nitrogen permeates the porous body and reacts with the silicon to form *a silicon nitride* within the pores. The piece is then heated to 1,400° C (2,550° F), just below the melting point of silicon.

- **Glazing:** Glazing is a very common term, used for many different processes and purposes. In building construction it means providing and fixing glass, including roof lights, clerestory windows, curtain wall constructions and as figured-glass. Glazing is also used in ceramics as a process that provide gloss and colour through a pre-firing *coating of slip* and *salt spray during firing.* Glazing is used as *polishing or asa glaze achieving* process by coating (wax, oil, lacquer, silicon, etc.) and rubbing or roll pressing a surface. In *textile glazing* as a term is used for a process that provides slight gloss with sealing of the surface by a starch or polymer *sizing composition*. The term glazing is used with paper in the same manner.

for Material specific techniques, See Chapters: on various materials such as Wood, Metal treatments, Fabrics, Fabric crafts, Polymers, Coatings, etc.

1.08 TOOLS AND DEVICES

HISTORY

The oldest known tools date back to 26 00 000 years. For 20 00 000 years, **rock chopper** was the only tool for cutting through the skin and sinews of the hunted animal, until **a hand axe**, a superior version of the chopper appeared.

> The chopper was just a fist-sized rock, chipped on one face, to form a roughly toothed but a sharp edge. Later the chopper was tied to a stick or narrow bone for greater leverage, and became the axe. The stone edge of the handled axe was chipped all around, so was sharper and more effective than earlier chopper.

About 110,000 years back Neanderthal man began to use many different types of **handled tools** like *axes, borers, knives and spears*. In all these tools, the edges were heavily notched (due to chipping of the stone) but a toothed edge helped in carving, cutting and boring processes for materials like horn, bone, skins, wood, stones, etc. Wood, natural fibers and bones complimented the edge stones for handling and gripping.

Approximately 35 000 years back, Cro-Magnon man devised newer tools. **Burin**, an engraving tool, was made from a sharp narrow flint blade, for incising and burrowing. This made it possible to work the horn and bone into combs, needles, beads and such other small items. Tools similar to a burin were used for cleaning and shaving hides.

Early tools were used for many different materials and equally varied tasks. **Specialized tools** emerged as materials technology advanced from stone age, bronze age, to iron age. **Complementary tools** such as for gripping tools, holding the work pieces, for sharpening used tools, and for measuring, were now produced. By Neolithic period, about 7000 BC, **chipped stone** edges and points were replaced by **ground tools**. Sharper ground tools were now used for agricultural operations, fuel conversion and for better shelter building.

First **metal age tools** were made about 5,000 years ago, by beating the naturally occurring copper nodules. People knew how to make bronze -a copper+tin alloy, though smelting of copper alone occurred nearly a millennium later, during the iron ages. Iron offered many different qualitative variations, making it possible to manufacture specialized tools for particular tasks.

Hand tools of many different varieties were in use by 1500 BC. The **stone age hand tools** like: *adze, auger, axe, knife, hammer, and chisel*, had now bronze versions. Primitive forms of drill and saw were also in use. **Bronze age** saw development of an array of devices such as for *domesticated animals, fire, metallurgical, ceramics, spinning and weaving processes*. Later part of bronze age also saw new tools and devices for building construction, water management, etc. **Medieval period** gave the *brace, tenon saw, and spoke-shave*, besides **mechanization of many tool-devices**, using *the screw, pulley, lever, wedge, wheel and axle*. By 18th and 19th C, **the industrial revolution period**, **mechanised tools** began to be integrated as **devices or machines** capable of performing tasks through the use of power. The powered devices or machines also prompted the development of **powered hand-held tools or portable tools.** Portable tools made it possible to execute many tasks on the site then in workshops.

Machine devices made work faster, and heavy duty jobs very easy. But machines had many moving parts. The movements were of two types: Ones that replaced the human labour of lifting, moving, pushing, etc. The other category of movements related, to transferring the power to various task locations in the required force and with speed regulations. This was done with reduction gears, timing belts, pulleys, etc.

> A textile plant had a steam boiler to operate a piston set which in turn rotated a shaft. The shaft passed through the plant, rotating several belt pulleys, which in turn rendered the mechanical power to the carding machines, spinnerets and looms. In mechanical workshops machine tools such as lathes, shapers, planers, grinders, saws, and milling, drilling, and boring machines were powered through common a shaft.

The linear position of the **power shaft** forced organization of workshops. The **line production methods** enforced by the power shafts promoted productivity through time management and sequencing of task procedures. Mechanical power drives allowed heavy duty job work, as well as precision and micro work. In many instances tasks began to be assimilated and handled simultaneously in a single time slot and location.

> Multi point drilling, Dual or multi face machining, Simultaneous wood planning and rebating, Concurrent wetting, Sizing (starching) and ironing of the fabrics, Single operation cutting, forming, punching and fusion joining of sheet metal assemblies are some of the multi tasking processes, conducted in same time and space.

Mechanical power transmission systems were noisy, inflexible for process planning, had many moving parts, lot of energy wastage and too dependent on the single source of power. These disabilities were removed with the electric power. **Electrical power** offered local control through electric motors (horse power) rating, speed variation through voltage control, and operational control like start-stop, etc. Independent electric powered machines with faster and multi tasking capabilities were often beyond the human supervision capacity.

Earlier, the middle age workshops were crafts person oriented, but powered machines provided standardized products on a massive scale, often using low skilled labour. During the early part of the 20th C. **machines** became **multi tasking**, and adjuncts to **assembly-line production systems.** The machine became a device to handle a variety of tools, often simultaneously. The machines were operating at a faster speed requiring equally fast control system.

Control devices have been with us since very early ages. First control devices were **actuators**, capable of letting an action occur, for example a very heavy fort door closes by gravity on removal of the holding peg. A firecracker sets off as the wick gets burnt. The rate of combustion in a furnace is controlled by the size of the air intake aperture.

Primary control devices are reading devices that convey information about the working of a system, such as temperature, air pressure, speed or voltage rating gauges. Electric power allowed remote reading of such devices, and also afforded the supervisor to take requisite action, remotely. The devices later had parametric definitions that would generate a signal or warning, and actuate certain responses like stoppage of the power.

Continuously variable speed motors and gears actuated by the *operative loading conditions* were mechanical control devices (servomechanisms) soon to be converted into electric power variable drives.

Control devices or systems are considered to be of two types:

A **Feed-forward system** would input necessary information to initiate a set of actions, but would not oversee or govern the actualization of the action. Examples for Feed-forward systems: Jacquard weaving loom uses a feed-forward control as a programmed punched card to weave a pattern, but cannot stop the loom if there is a short feed of thread. Similarly a cutting machine cuts a large sized shape by moving the cutter tracing a small scale pattern through the arm of a pantograph.

A **Feedback system** would continuously monitor the action taking place, control or terminate it according to preset parameters. Examples for Feedback systems: A wind mill keeps facing the wind with the help of a tail wane. A pressure cooker seals itself with heightened internal pressure of steam. Pressure valves are weight calibrated opening themselves at certain pressure levels only.

Automation began in the late 1940s with the development of the mechanical devices for moving and positioning objects on a production line, though observation and manual intervention were necessary. During 1960s digital computers began to offer control systems in three different manners: *For supervisory or optimizing control, Direct digital control, and Hierarchy control.* In the first instance, for the **supervisory control** a computer sets parametric levels for optimizing the operations. In the second instance, for the **direct-digital control**, several devices feed data to a single processor, which then decides a strategy of operation. The advantage is a very fast and objective evaluation of the data. The third system the **hierarchy control** applies to all the plant-control situations concurrently, often with the actuation of the control mechanisms.

Machines were now becoming **large scale integrated device systems** capable of handling several tools in a variety of programmable modes. **Automats** (a composite machine capable of delivering manufactured products from the raw material) and **robots** (capable of assembling a variety of components into an entity), have been developed since 1960s. It is now possible to go from a CAD programme to production, without the human interface.

TOOLS: Hand tools and Machine tools:

- **Hand tools:** A hand tool is a small instrument traditionally operated by the muscular power of the user. Hand Tools are of following categories:
  - **Percussive tools**: deliver blows, axe, adz, and hammer, etc.
  - **Cutting, drilling, and abrading tools**: knife, awl, drill, saw, file, chisel, and plane.
  - **Screw-based tools**: screwdrivers and wrenches.
  - **Measuring tools**: ruler, plumb line, level, square, compass.
  - **Accessory tools**: workbench, vice, tongs, and pliers, anvil.

- **Machine tools:** Machine tools are power driven utilities, and are of two types:

- **Hand held or mobile machine tools** are apparently small and lightweight, whereas **Stationary tools** (often called machines) are large and so fixed to a position.

There are seven types of **Engineering machine tools**: *Turning machines, Shapers and Planers, Drillers and borers, Milling machines, Grinding machines, Saws and shear cutting machines, and Presses.* These tools are **autonomous systems**. All machine tools have, **work-holding and supplementary devices,** and means for accurately controlling the scale (size, depth, input rates, etc.) of the operations. The *relative motion between the operative tool and the work object* is called the **operational speed**, the speed with which a work object is brought into contact with the tool is called the **feed motion**. Both can be varied independently.

Machine tools often have supplementary facility of **cooling and quenching** the work pieces, besides **self cooling system** for moving parts including the motor. Temperature at the point of contact between the tool and the work object goes up and affects the quality of both. The temperature rise is influenced by the rigidity of the machine, the shape of the work piece, and the depth of the operation. Temperature is controlled by a **cooling system**, such as: Ventilation by evacuation of surrounding air, supply of fresh air or a chilled gas, and **Quenching** through oil, water or other mediums. The temperature is also controlled by the operative speed and feed motion. **Cutting oils** are used for lubrication, cooling and removal of cut-material.

DIFFERENT CATEGORIES OF HAND TOOLS

- **Percussive tools:** Percussive tools deliver concentrated blows or impact in swift motion and so are also called **dynamic tools**. The prime tools in this category are the **ax and hammer**.

- **Hammers:** A hammer is a striking tool also known as a **pounder, beetle, mallet, maul, pestle, sledge**, etc. There are many **trade specific hammers**, like, the *carpenter's claw type, smith's rivetting, boiler-maker's, bricklayer's, blacksmith's, machinist's ball peen and cross peen, goldsmith's, smith's stone (or spalling), prospecting, and tack hammers*. Each hammer has a distinctive form, with minor variations in terms of weight, length and angle of the handle, and the shape of the face. A **pounder, or hammer stone**, was the first tool to have a handle, marking a great technological advance. A long handle, even if not needed for dynamic effect (as in a tool used only for light blows), makes the tool easier to control and generally reduces operator's fatigue. **Club like pounders or mallet**, with a handle of the same material are widely used. The hammer as a tool, for nailing, rivetting, and smithing, originated in the Metal Age. For beating lumps of metal into strips and sheet, heavy and compact hammers with flat faces are needed, whereas lighter ones are more suited to rivetting and driving nails and wooden pegs. Hammers with dual heads are in use since Roman age. Hammers with dual heads include: **clawed hammers** for pulling out nails, hammers with a chisel or pointed ends to dig out shafts, toothed edges to smoothen the stone surfaces. Other special forms of the **peen** (-the end opposite the flat face) like hemispherical, round-edged, and wedge like shapes helped the metalworker stretch and bend metal or the mason to chip or break stone or bricks. A **file maker's hammer** has two chisel-like heads, to score flat pieces of lead (file blanks) that were subsequently hardened by heating and quenching. **Heavy hammers** are used as part of power tools, and largest are the **pile drivers**. **Trip-hammers** are gravity impulse based but **steam hammers** use, besides gravity a downward thrust from a steam-pushed piston. **Pneumatic hammers** driven by air include the **hammer drill**, used on rock and concrete. The **rivetting hammer** is used in steel construction with girders and plates.

- **Cutting tools:** These are used for cutting through, fracturing (shearing), to chip-out or remove material in granules.

◦ **Chisels** have been the chief cutting tools often combined with a hammering device. Chipped flints were used in 8000 BC, till neolithic period. Rectangular flint and obsidian chisels were used on soft stone and timber. **Chisels with concave heads** were used to create deeper sections. **Chisels and gouges of very hard stone** were used to dig out the bowls out of soft stones such as *alabaster, gypsum, soapstone, and volcanic rock*. The earliest **copper and bronze chisels** were long compared to flint chisels, and were used by the Egyptians to dress limestone and sandstone for their monuments. Use of wooden handles saved the chisel metal to half length, while causing less damage to the mallet. The chisel has since then taken on many shapes, and is being put to many different uses.

◦ **Edge tools or cutting edge tools** do not require impact or percussion. A **sharp edge** is pulled or pushed to pierce and slice a soft material; or a **blank edge** is used to pressure, shear-cut or cause a cleavage in a glass or ceramic like material. Primitive cutting edges were made from chipped stones, and later from ground stones. However, with metals it was possible to cast a cutting edge with the holder or handle. Iron in carburized and quench-hardened form was very revolutionary technology. **Knives** *for domestic and craft uses* led the way for **scythes, sickles,** and such other *agricultural cutting tools*. Many *defence tools* like **daggers, swords**, etc. have originated from edge tools. Cutting tools like **razor and surgical blades** now consist of a micro thin edges of ceramic coated metals and diamond bits. Diamond bits are used in cutting glass.

◦ **Scissors** are also called **shears**. Scissors have two independent cutting edges of various lengths but with handle formation at the other end. Scissors with *short cutting edges and long handles* are used for harder work like metal sheet cutting (tin shears). **Tailor scissors** for cutting of fabrics have *larger blades compared to the size of the handle*. *Small cutting blades with a small handle* are used for cutting fine work like knitting, embroidery, branches, stems, for carpet shearing, and for shaving animal hair. *Large blade and large handle* scissors are used for hedge cutting and other garden trimming and pruning work. Surgeons use *bent blade scissors* to reach inside cavities. **Betel nut cutters and nut crackers** are ends bolted for highest leverage action, and may have a spring for releasing the open. Similar tools are used for sniffing cigars butt ends. **Toothed scissors** are used for cropping massive hair growth.

• **Toothed Edge cutting devices:** These include saws, toothed chisels and knives. The primitive chipped flint stone tools had V shaped section, but too thick for a penetrative cut. A toothed cutting device is efficient, if, it has a thin edge. First **thin body, toothed cutting tools** were made from castable metals like bronze and copper. These tools were handy or of comparatively short length. Toothed edge cutting tools were used for cutting across the fibrous sections of materials like *bamboo, wood, bone, horn and also freshly mined* *stones* (before weathering hardens a calcium-lime stone, as is the case with Porbandar stones).

Egyptians used blunt bronze thin section edges to cut hard stone, by pushing it over wetted abrasive particles like quartz sand.

- **Saws** have basically two forms of teeth formations that allow either **push or pull cutting.** A **push saw** holds the work piece down, so is better to work with compared to a **pull saw** that pulls the workpiece towards the worker, so must be properly held. A pull saw could be thinner than a push saw and would waste less material. **Tooth size** is determined by the *nature of homogeneity of the material* to be cut, and the required fineness of the cut surface.

It was during the 1st century AD that Pliny (elder) found that by bending the teeth sideways, (alternatively on either of the sides) widens the thickness of the blade but helps in faster cutting due to lesser friction in wider slots and in discharge the cutting dust.

Several types of saws are used for various purposes. The familiar, **crosscut saw** is used to cut across the grain of wood and the **ripsaw** for cutting along the grain. Curves are cut with the **coping saw or framed saw**, which consists of a metal frame that keeps a narrow blade under tension. The precise cutting of joints can be done by hand with the aid of the **backsaw**, a thin rectangular blade stiffened by a metal bar along its back. Thermocole, rubber, PU foam, acrylic and such other materials are cut by very small width teethed blades. Household knives have a serrated edge to aid in cutting.

- **Broach:** A broach is a toothed tool for removing material. It has a series of progressively taller chisel points mounted on a single piece of steel. It is used to reformat a circular hole into a larger, but non circular sections, such as square, hexagonal, etc. Another typical use of a broach is to cut splines or square keyways on objects such as gears, drive shafts, pulleys etc. A wobble broach is slightly a different tool, used for the irregular hole shapes.

- **Abrading tools:** The first abrading tools were sand stones and hard grained abrasive sands. Tough fibers like asbestos, wool, and coir were also used for buffing purposes. Today sandpapers in sheet, stripes and tape forms are available with paper and cloth backing and bonded with water-based gums and synthetic resins. Carborundum and other man-made ceramic granules are embedded or cast in various base materials and shaped as discs, wheels, cones, rings, etc. for use with various machines. Such abrading tools are also used for drilling, edge dressing, tunnelling, boring, etc. Automobile and other lacquer finishes are buff-polished with very fine abrading media mixed with wax and silicon oil base (rubbing compounds). Abrading materials also included soft particles used in household utensil cleansers and jewellers polish to the hardest known material, the diamond. Abrasives are used in the form of tumbling and vibratory mass-finishing media as in polishing for nails, sandblasting, flour mill stones, ball mills. Abrasive materials and tools can cut through hardest materials at a faster speed than metal saws, while generating less heat and providing smoother cut face. New alloys and ceramics can only be cut by abrasives. Granite, marble, slate, and highly vitrified tiles are cut to size with diamond abrasive wheels. Grooves for expansion joints in runways and roads, holes in RCC structures are made by metal blades with embedded diamond abrasives.

○ **Files:** Files are abrading tools. Files are of many different cross sections, lengths, notch configurations and the coarseness of the cut (density -teeth per area). A file could be very thin, almost like a knife with a serrated cutting edge, to a wide chequered figured plate. The most common sections are rectangular, triangular, round and half round. Most files have reduced size of section at their tail end. There are three tooth forms: The *single-cut* file has rows of parallel teeth cut diagonally across the working surfaces. The *double-cut* file has rows of teeth crossing each other. *Rasp teeth* are disconnected round top notches. Rasp files, or rasps, are usually very coarse and are used primarily on wood and also soft materials like leather, aluminum, lead, etc. Files are used for many different purposes: to smoothen nails, cut injection vials of glass, removing human skin blemishes and birthmarks, for shaping bones during plastic surgery, removing spots and discolourations from suede fabrics, and for levelling teeth.

- **Dies**: Dies are shaped tools used for cutting a form. The simplest are **punching dies**, used for piercing holes or embossing patterns. **Cutting dies** cut a thin material in shapes often while forming it. **Bending and folding dies** are designed to make single or compound bends in a material. **Drawing-dies,** are used for stretching and forming the material into hollow and cupped-shapes (kitchen utensils). **Reducing dies** are used to produce a reduced section on a hollow part, such as the neck of a rifle cartridge. When a finished part must have a bulge at the bottom or in the middle, **hydraulic dies** are usually employed. The punch is replaced by a ram that forces oil or water into the part under pressure, thus forcing the metal outward against the matrix. **Curling dies** form a curved edge, or flange, on a hollow part. A special kind of curling die called a **wiring die** is used to form a wired edge in which the outside edges of the metal are tightly wound around a wire inserted for strength. A **combination die** is designed to perform more than one of the above operations in one stroke of the press, whereas a **progressive die** permits successive forming operations with the same die. **Wire drawing Dies** have a metal plate containing a number of tapered or bell-shaped openings, successively finer in diameter. For cutting threads on bolts or on the outside pipe, a **thread-cutting die** is used. The corresponding tool for cutting an inner thread, such as that inside a nut or pipe is called a **tapping die**.

- **Planes:** Planes are material cutting tools that remove material off the surface. Materials are removed as dust, chips or layers depending on the constituents of the material. The depth of the cut is variable but the angle and projection of the blade. Wide planes are used for wood planks, whereas narrow blades are used for creating rebates, grooves, fillets and linear mouldings. The **flat-edged chisel** and the **semicircular gouge** are used in to remove unwanted wood for creating joint formations.

- **Drills:** Prehistorically materials like shell, ivory, antler, bone, and tooth, have been pierced through to make adornments. Soft materials like skins (hides, leather) were punched for stitching. Flint blades slimmed to a sharp point were used for piercing holes. Another method could have been to grind a hole with abrasive sand under the point of a stick. Strap or thong of leather or twine was used to rotate the stick.

Drills have been used for producing new holes, enlarging existing holes and also for shaping cavities to various forms of circular sections. Drills with special attachments are also used for creating threads inside cylindrical forms. Common drills have a single cutting tip of steel made of hardened, carbon steel or tipped with cemented carbide or diamond. A carpenter’s hand held wooden drill takes forward and backward motion from the thong or bow-thread. The dual movement helps in drilling as well as evacuation of dust. Dual movement require double edged drilling bit, compared to a single direction movement bit, which are easy to make and re-sharpen. Drilling bits with spirally fluted columns came into practice much later, in 19^{th} C.

Drilling is done with a small diameter-axial movement so requires high speed and low torque. Drilling removes very little material per rotation. **Boring** is done with a large diameter so requires low speed but high torque. For finishing large bores grinding wheels are used. **Grinding-wheel cutters** have a planetary motion, rotating rapidly on their own axes, which in turn rotates on the internal face of the bore.

An **awl** and the **needle** were the first hole making tools. These create a hole by shifting the material to sides rather than removing it. Small, shallow holes in stone, concrete, brick, and similar materials are usually drilled by hand with a **star drill**, a steel rod with an X-shaped cutting point. The point is held against the object to be drilled, and the other end of the rod is struck with a hammer or sledge. The drill is revolved slightly after each stroke. A hardened metal **punch** is used even today to push a hole in fragile materials like plaster, bricks. Punch is also used to mark a small indentation, so that drilling bit has a homing mark. Metal sheets cannot be drilled properly so are holed by a pointed punch or a **punching die**.

◦ **Augers:** Augers are large size hole making tools. Initially in the Iron Age it had a cutting bar or plate joined to an axle which could be rotated. Later it was like a length split pipe. The auger was used for boring softer materials. It removed large quantity of material due to its wide size capacity, so had to be taken out to remove the cut material. Middle age Augers with spiral or helical flutes helped the evacuation of the cut material to the surface. Augurs are now used for pile foundation boring work, tree planting etc.

The other hand boring tools include the **brace,** a crank shaped device that can be held by one hand and rotated by another (action similar to car lifting jack), the **push drill** has a spiral flute along which a trunk moves down creating rotations but bounces back, on release of the compressed spring.

- **Auxiliary Hand tools:** Auxiliary hand tools are not directly involved in actual manufacturing processes, but rather facilitate such tasks. However mechanisms or systems like heating, cooling, quenching, conveying, etc. are excluded from this category.

    - **Holding devices:** Holding devices hold and stabilize a work piece against the vibratory and gravity forces. Holding devices also control the feed rate of the work piece or the tool. **Vices** of different types are used for holding work pieces. **Tongs** are used for holding hot pieces. **Buckled straps** are used for bulk massing sticks like materials. Work that requires gluing is usually clamped with the **C-clamp**, the **bar clamp**, and the **hand screw** or **gluing clamps**. **Chain clamps** hold circular sections like pipes. Drilling machines and lathes use **chucks** to position the work piece and also hold the tool.

    - **Safety devices:** Safety devices are of three categories: to protect the worker, to guard the work piece and the equipment. Movement, sparking, heating, visual distractions, noise, radiation, electric shocks, etc. are some common hazards, for which safety devices are required.

    - **Measuring Devices:** Measuring tools are used to mark and check work for size and alignment. These tools include the steel tape measure, the folding wood rule, and the steel rules. The square and the tri-square are used to align or test right angles, the spirit level is used primarily to test horizontal and plumb for vertical alignment. A **calliper** is a mechanical device used for determining micro sizes with reasonable accuracy. Simple callipers have two movable legs of some desired shape to meet the surfaces whose separation is to be measured. The measured width between the leg tips is then amplified mechanically against some length scale. The **vernier calliper** is wrench-like and has a scale that allows direct reading of the adjusted width between the jaws of the wrench.

POWER TOOLS -PORTABLE

- **Portable power tools** are power operated tools. Mechanically powered tools like push drills, watch and clocks were the forerunners of powered tools. Battery pack tools can operate minor motors capable of doing low energy tasks, but continuous electric power is required for heavy duty tasks. Electric power devices have smaller volumes so many hand-operated tools were converted to electric power while achieving reduced size and weight. The most important of electric power operated tools are like: drill, saw, router, sander.

Tools such as **portable electric drills** perform variety of other functions by changing the bit or attachment, such as screw fixing, nailing, rotary sanding, polishing, and filing.

◦ **Portable electric saws** are available in circular and also linear reciprocating movements. The **chain saw** has several spikes mounted on a circular chain, and is used for cutting tree trunks and logs. The **sabre saw** employs a narrow blade mounted vertically, which operates in an up-and-down motion, to cut curves and straight lines in relatively thin wood. The **router**, a very high-speed device, is used for cutting grooves and channels of many types, shaping straight or curved edges, and making decorative moulding.

Two types of **portable electric sanders** are used to smooth surfaces and to remove the marks left by cutting tools before a finish is applied. The **orbital sander** causes sandpaper to vibrate in either a reciprocal or circular manner at a high frequency against the work piece. It is less effective for many purposes than the **belt sander**, which runs a sandpaper loop at high speed against the work piece.

Other portable workshop tools include chipping tools, air-less spray guns, staple pin fixing machines, gumming devices, can or tin openers, vacuum cleaners, etc.

CONVENTIONAL MACHINE TOOLS

Timber yards, furniture factories, and other sites where large volumes of manufacturing takes place employ large stationary machines designed for both, batch and continuous operations. The **radial saw** moves back and forth on runners above the work piece to make many types of cuts: **cross-cut, rip cut, mitre, and bevel cut** for creating many types of joints. The **circular bench saw**, which is sometimes used in the home workshop, cuts with a circular blade positioned in a slot on the surface of a metal table. This type of saw is used for many different types of cuts. The **band saw** employs a large flexible steel blade as a loop tensioned by means of two large pulleys positioned one over the other. Bandsaws are used for such heavy work as ripping logs into boards and cutting very thick wood.

Power planers, known variously as **surface planers, thicknessers, and joinder**, are used to speed the planing operation. On power planers, the work piece is moved against rapidly rotating cutting edges. **Lathes** are used for creating circular sections or shapes, straight or curvilinear groves.

- **Table or platform drills** are used for cutting holes in wood, metal, rock, or other hard materials. Table mounting is required where jobs are heavy, repetitive and precise. Platform mounting is used for simultaneous or multi drill operations. Tools for drilling holes in wood are commonly known as **bits**. A number of special forms of bits are also employed, including the **expanding bit**, which has a central guide screw and a radial cutting arm that can be adjusted to widen already drilled holes. For drilling metal, twist drills rotated by motor-drives are employed. **Chucks** are holding devices to drills of various sizes. **Rock drills** are hammered by pneumatic devices for creating holes to place explosive charges in mining and quarrying. A **rotary drill** consists of a single auger-like bit, or three inclined positioned circular sets of multiple bits moved by a toothed gear, and the gear rotated by a series of connected steel pipes. Rotary drills are used in drilling oil wells.

MACHINES:

Manufacturing units have two basic sets of tasks. Tasks that are very specific to the process are executed within the integrated setup. The machine tools are generally customised for the process. However, there are other nonspecific tasks like repair, maintenance, tooling etc., which are conducted by using standard machine tools. (first category of machines have been discussed in chapters of relevant materials, in other modules of this series). Among the basic machine-tools are: **lathes, shapers, planer, and milling machines**. Auxiliary to these are **drilling and boring machines, grinders, saws, and various material forming machines**.

- **Lathes**: A Lathe is a prime machine for workshop. Lathes are used for cutting, drilling, boring, planning, polishing, threading and many other processes, on virtually all types of solid materials. Lathes are turning machines where either the work piece or the tool remains stationary, and the other rotates against it. Lathes are used for wood, ivory, metals, plastics, ceramics and glass.

A lathe could be a hand-held device, a table top resting machine, or one with elaborate structure. Lathes have a horizontal base -'bed' except in CNC lathes and automats, where the bed could be inclined or vertical. The left side of the bed has a head stock supplying the rotation. The right end of the bed stock may have a tail stock to support the work piece. Metalworking lathes have a cross slide to hold tools and other measuring and dividing devices. Wood turning and metal spinning lathes do not have cross slides, but have a flat piece to support the tools. Cutting fluids are pumped to the cutting site to provide cooling, lubrication and clearing of cut from the metal working.

- **Woodworking lathes** are the oldest variety. One of the simplest is the **hand lathe** (Sanghadi-**Thada**: Hindi/Gujarati). The work piece is axially rotated by a thong (bow) and a non rotating tool is moved against it. The same lathe is used for applying lac finish to turned wooden components (e.g. Toys of Idar, and Sankheda furniture of Guj. India). Thadas are used for making bangles out of Ivory and acrylic tubes.

- **Ornamental lathes:** These began to be used in 19^{th} C AD. It had several accessories for cutting, elliptical chucks and off centric turning. These lathes had complex dividing arrangements to allow the exact rotation of the mandrel. The ornamental lathes were used in turning out embellishments, adornments, inlay pieces, hardware, fittings, etc.

- **Metalworking lathes:** Metal working lathe is the most common machine in a workshop. It has a variable ratio gear train to drive the main lead screw to enable cutting of different pitches of threads. Gears are manually changeable or have a quick change box to select frequently used ratios through a lever. The workpiece is supported between either a pair of points called centres, or it may be bolted to a faceplate or held in a chuck.

- **Metal spinning lathes:** Metal spinning lathes are used for moulding a sheet metal into bowl type of shape. A rotating wooden shape serves as a template against the sheet is pressed by a variety of wooden shapes (called spoons). This operation can be done on a large press with a metal forming die, but the lathe provides an economic solution

- **Glass working lathes:** Glass working lathes are similar to many other lathes. The glass work piece is slowly rotated over a flame. The flame softened glass piece becomes malleable and is formed by glassblowing or by a tool.
- **Diamond Lathes:** The diamond being too small is embedded on a holder tip. The tool is held against a rotating disk for shaping and polishing.

For boring work the tool is rotated and moved into the stationary work piece. On a **speed lathe** the tool is mounted on a slider that controls the direction and rate of 'feed' of the tool. On a **screw cutting lathe** the work piece rotation and horizontal tool feed synchronised to match the screw or spiral needs. **Gear hobbing or gear cutting machines** are similar to lathe machines. The stationary work piece is turned manually or automatically following preset positions, and the cutting two-wheel rotating on its own axis cuts a hob or gap.

> Turning operations involve cutting excess material, in the form of chips or dust. Lathes remove material from the external sides of a workpiece to develop straight or tapered cylindrical shapes, grooves, shoulders, and screw threads and also for creating flat surfaces on the ends of cylindrical parts. Internal operations include operations such as drilling, boring, reaming, counterboring, countersinking, and threading.

- **Shaping machines:** Shapers are used primarily to produce flat surfaces. A *tool slides against a stationary work piece*, cuts on one stroke, returns to its starting position, and then cuts on the next stroke after small lateral displacement. The parallel strokes produce almost a levelled surface composed. It uses a single-point tool and depends on reciprocating (alternating forward and return) strokes so is relatively slow. For this reason, the shapers are seldom found on a production line. It is, however, a valuable tool for machining varied sizes of surfaces such as for die making.

- **Planing machines**: The planer is the largest of the reciprocating machine tools. The planer *moves the work piece past a fixed tool*, unlike a shaper, which moves a tool past a fixed work piece. After each reciprocating cycle, the work piece is advanced laterally to expose a new section to the tool. Like the shaper, the planer also produces vertical, horizontal, or diagonal cuts. It is also possible to mount several tools at once in any or all tool holders of a planer to execute multiple forms cuts, simultaneously.

- **Milling Machines**: In a milling machine, the work piece is fed against a cylindrical tool with a series of cutting edges on its circumference. The work piece is held on a table that controls the feed against the cutter. The table conventionally has three possible movements: longitudinal, horizontal, and vertical; in some cases it can also rotate. Milling machines are the most versatile of all machine tools. Flat or contoured surfaces may be machined with excellent finish and accuracy. Angles, slots, gear teeth, and recess cuts can be made by using various cutters. Milling machines have rotating cutting surfaces that abrade substances with which they come into contact. In standard milling machines, a sliding table with a work piece on top is pushed against the whirling cutter.

- **Routers, drilling and boring Machines**: Motorised drill machines not only drill new holes, and alter the existing holes by *boring or reaming* to enlarge it, cut screw threads by *tapping* it, or *lap or hone* a hole for accurate sizing (tolerances) and to provide a smooth finish. **Drilling machines** vary in size and function, ranging from portable to very large **radial drilling machines**, **multi-spindle units**, **automats or automatic production machines**, and **deep-hole-drilling machines**. **Routers** are machines with drilling spindles but are moved sideways (similar to a dentist's drill) to cut shallow to deep grooves with square or rounded sections to create engraved patterns in materials like wood, plastics and metals. Drilling machines are also operated with pressurized gas - pneumatically, to achieve very high speeds.

- **Grinders**: Grinding is the removal of material by a rotating abrasive wheel on the face or sideways, the action is similar to that of a milling cutter. The wheel is composed bonded abrasive material. The process produces extremely smooth and accurate finishes. With this machine fragile material like glass can be roughened or polished. Belt and disc grinders are only surface grinders. Disc grinders are used for marble, granite, wood veneers, etc.

- **Power saws**: Power saws cut in reciprocal, circular and continuous ribbon or band motions. Band-motions saws, besides cutting teeth, also have spikes to cut across wood knots etc. Marble and other stone slabs are cut simultaneously by a **gang of saws**.

- **Presses**: Presses are used for **shaping** work pieces. Presses are also used in **adhesive bonding** to remove air between layers to be bonded and spread the adhesive to thinnest film. First presses were impact presses. **Impact presses** flatten thin metal sheets, and if used with forming dies, can mould or cut shapes. Impact-presses are also used for forging. Presses are **flat bed or inclined to vertical**. A **roller press** is used for flattening thin sheets like paper, cloth, leaves, parchment, bakery dough, and also for printing. A press consists of a platten bed, a ram and a mechanism (hydraulic, pneumatic, counter balance, kinetic, or direct power) to lift or move the ram.

- **Cutting Tools materials:**

Metal cutting processes involve high local stresses, friction, and considerable heat generation. **Cutting-tools** must combine strength, toughness, hardness, and wear-resistance for working at elevated temperatures. To meet these requirements special constituents and surface treatments are required for tool making. **Carbon steel tools** (1 to 1.2 % carbon) are low cost, but lose cutting capacity at temperatures at about 200 C. **High-speed steel tools** (typically 18% tungsten, 4% chromium, 1% vanadium and 0.6 % carbon) allow cutting at nearly 3 times the speed of carbon steel. **Cast alloy cutting-tools** are nonferrous alloys containing cobalt, chromium, and tungsten. Cast steel alloys have the capacity to machine very hard and very hot surfaces like cast iron. **Cemented tungsten carbide tools** are of recent origin (1926) but very common now. The tools have hardness nearly close to the diamond, but are not as expensive. Carbide tools have cutting speed even higher than high speed tools. **Ceramic or oxide tipped tools** (e.g. scissors like Fiscars) are now used in many applications. These are mainly made of fine aluminum oxide particles bonded together. **Diamonds bits** are used for their hardness. Since these are very small sized, are embedded in other materials. For cutting applications they are used largely for low depth cutting or final finishing at very high speeds on hard or abrading surfaces and for working with bronze and babbitt-metal components.

- **Cutting fluids:**

Cutting tools, the work areas and the work pieces, all are affected by the high heat. In many cutting operations fluids are used for cooling and lubrication. **Cooling** increases tool life and helps stabilize the size of the finished part. **Lubrication** reduces friction, decreases the heat generation and the power required for a cutting. Cutting fluids include water-based solutions, chemically inactive oils, and synthetic fluids.

OTHER TOOLS:

Every building trade requires specific tools to measure, cut, shape, dress and finish the materials. Many of the wood working tools are variants of tools used in other trades such as metal or stone. A **plasterer** uses **trowels, musters, embossed or recessed rollers**, etc. to achieve a suitable finish. However, new materials require different sort of tool. For example **acrylics and other plastic sheets** need tools different from a sheet metal working. **Foam materials** need tools different from coir-based materials. **Upholstery or lining work** was based on hand or machine stitching of leather or tapestry, but with adhesive or fusible joint system and rexine materials, required tools are now of very different nature. There are many material specific tools like for paper industry (manufacturing, conversion, printing and binding), coatings, textiles, ceramics, etc. (Many of these are included in relevant chapters, in other modules of this series.)

UNCONVENTIONAL MACHINE TOOLS:

Many machine tools are now used in the manufacturing. These machines are unconventional either in their sources of energy or the manner of their process. These machine tools were developed primarily to shape the **ultra-hard alloys** used in heavy industry and aerospace applications. The tools were also devised to work with ultra-thin materials micro sections such as used in electronic devices and microprocessors. New machine tools were also required to handle new materials such as high end ceramics, composites, etc. It was possible to devise new tools because new sources of energy like micro waves, infra reds, Uvs, plasmas, lasers, electrons began to be available.

Plasma has changed how materials are heat processed, including for liquidization, vaporization, melting and sintering. Lasers have provided a very compact radiation source and are used for both, cutting, joining and very localized heat treatments.

Some such machines are described here. (See also: in this module chapter 1.7 Techniques, and in other modules, chapters: Fabrics, Metal treatments, Coatings, etc.)

- **Plasma-arc machining** (PAM) employs a high-velocity jet of high-temperature gas to melt and displace material in its path. The materials cut by PAM are generally those that are difficult to cut by any other means, such as stainless steels and aluminium alloys.

- **Laser-beam machining** (LBM) is accomplished by precisely manipulating a beam of coherent light to vaporize unwanted material. LBM is particularly suited to making accurately placed holes. LBM is also used to cut odd shape profiles through digitized data input. The LBM process can make **holes in refractory metals and ceramics** and in **very thin materials** without warping the work piece. Extremely fine wires can also be welded using LBM equipment.

- **Electro-discharge**: Electro-discharge machining (EDM), is primarily used for hard metals or those that would be impossible to machine with traditional techniques. It is also known as **spark erosion machine**, as it employs electrical energy to remove metal from the work piece without touching it. A pulsating high-frequency electric current is applied between the tool point and the work piece, causing sparks to jump the gap and vaporize small areas of the work piece. Because no cutting forces are involved, light, delicate operations can be performed on thin work pieces. EDM can be used with materials that are electrically conductive. EDM can produce shapes unobtainable by any conventional machining process. It can cut small or odd-shaped angles, intricate contours or cavities in extremely hard steel and exotic metals such as titanium, kovar, inconel and carbide. EDM. It is also used to provide a texture on the insides of mould tools used for injection moulding a wide variety of plastic products.

- **Electrochemical machining** (ECM) also uses electrical energy to remove material. An electrolytic cell is created in an electrolyte medium, with the tool as the cathode and the work piece as the anode. A high-amperage, low-voltage current is used to dissolve the metal and to remove it from the work piece, which must be electrically conductive. A variety of operations can be performed by ECM including: matting, dulling, texturization, etching, marking, hole-making, and milling.

- **Ultrasonic**: Ultrasonic machining (USM) employs high-frequency, low-amplitude vibrations to create holes and other cavities. A relatively soft tool is shaped as desired and vibrated against the work piece while a mixture of fine abrasive and water flows between them. The friction of the abrasive particles gradually cuts the work piece. Materials such as **hardened steel, carbides, rubies, quartz, diamonds, and glass** can easily be machined by USM. Ultrasound is also used to cleanup surfaces.

- **Electron Beam**: In **electron-beam machining** (EBM), electrons are accelerated to a velocity nearly three quarters that of light. The process is performed in a vacuum chamber to reduce the scattering of electrons by gas molecules in the atmosphere. The stream of electrons is directed against a precisely limited area of the work piece, on impact, the kinetic energy of the electrons is converted into thermal energy that melts and vaporizes the material to be removed, forming holes or cuts. EBM equipment is commonly used by the electronics industry to aid the **etching of circuits in microprocessors**.