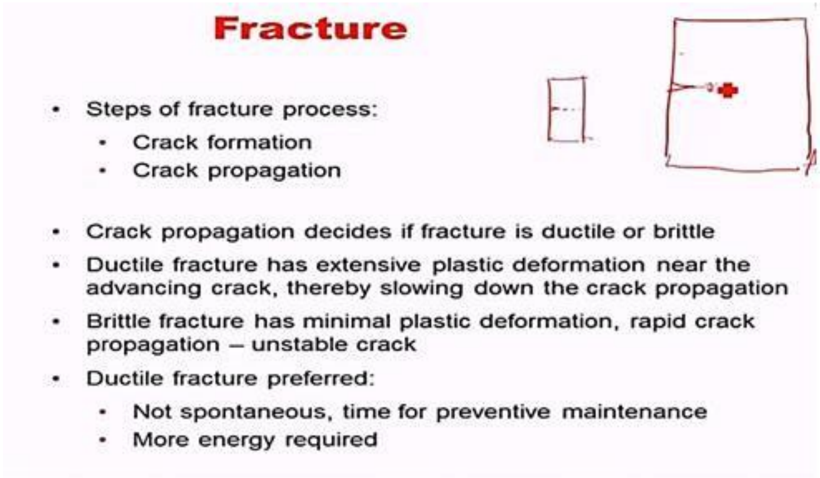
UNIT II MATERIAL PROPERTIES

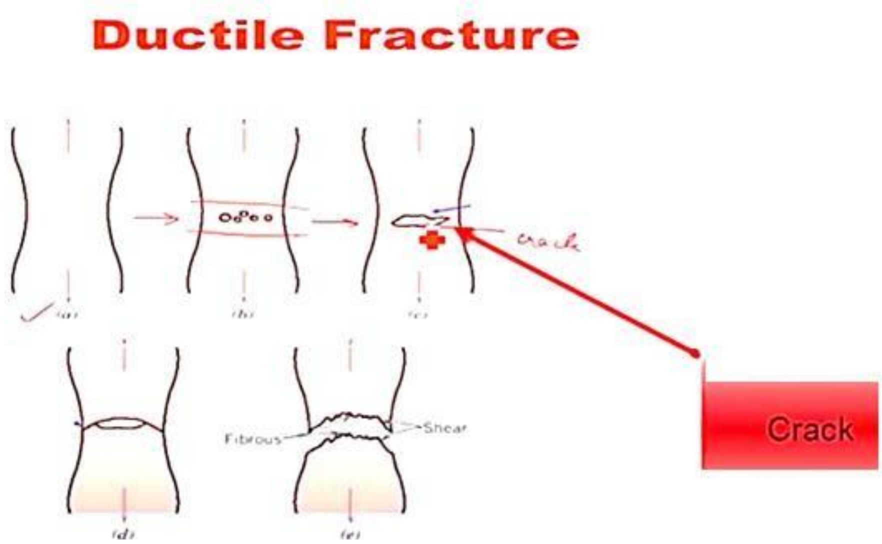
Mechanical properties – fatigue strength – fracture Toughness - Thermal Properties – Magnetic Properties - Fabrication Properties –electrical , optical properties - Environmental Properties , Corrosion properties –shape and size - Material Cost and Availability– failure analysis.

Fracture Toughness

Fracture toughness refers to a property which describes the ability of a material containing a crack to resist further fracture. Fracture toughness is a quantitative way of expressing a material's resistance to brittle fracture when a crack is present. If a material has high fracture toughness, it is more prone to ductile fracture. Brittle fracture is characteristic of materials with less fracture toughness.

- Fracture toughness values may serve as a basis for:
- Material comparison
- Selection
- Structural flaw tolerance assessment
- Quality assurance
- Tensile strength is a measure of the maximum stress that a metal can support before starting to fracture. Fracture toughness is a measure of the energy required to fracture a material that contains a crack.





Fracture toughness is strongly dependent on geometry and loading conditions. The thick line represents the fracture toughness, such as the material property, while the thin lines represent the applied crack driving force. The structure is expected to fracture when the applied force exceeds the material resistance.

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Environmental Properties Corrosion properties

Corrosion involves the deterioration of a material as it reacts with its environment. Corrosion is the primary means by which metals deteriorate. Corrosion literally consumes the material reducing load carrying capability and causing stress concentrations. Corrosion is often a major part of maintenance cost and corrosion prevention is vital in many designs

Corrosion can be either dry or wet type:

Dry corrosion: *it involves the direct attack of dry gases (air and oxygen) on the metals through chemical reactions.*

As a result an oxide layer is formed over the surface.

This type of corrosion is not common.

Wet corrosion: *it involves the direct attack of aqueous media (strong or dilute, acidic or alkaline) on metal through electrochemical reactions.*

The moisture and oxygen are also responsible.

This type of corrosion is quite common.

FACTORS INFLUENCING CORROSION

A number processing factors affect rate of corrosion.

1. **Solution pH**
2. **Oxidizing agents**
3. **Temperature**
4. **Velocity**
5. **Surface films**
6. **Other factors** [concentration of corrosive chemicals]

Material Cost and Availability

- Material cost is the cost of materials used to manufacture a product or provide a service. Excluded from the material cost is all indirect materials, such as cleaning supplies used in the production process. Material is the most important element of cost. In most of the manufacturing concerns, 50% to 70% of the total cost of a product is represented by the cost of the material. Material may be direct materials or indirect materials. Direct materials comprise:
- (i) Materials which can be directly related to and identified with cost centers or cost units. In other words, these are the items which form part of the product itself, e.g., cotton used for spinning cotton yarn, cotton yarn used in weaving cotton textile, wood used in making furniture, the leather used in making shoes and bricks and cement used in construction buildings.
- (ii) Materials which are purchased specifically for a particular job, work order or contract.
- (iii) Finished product of a particular process which forms the raw material of the succeeding process e.g., cost of yarn transferred from the spinning process to weaving process.

Indirect materials comprise:

- (i) Materials which cannot be allocated but can be apportioned to or absorbed by cost centers or cost units e.g., cotton waste for cleaning the machinery, lubricants for oiling the machinery, diesel oil for generating power etc.
- (ii) Materials which are used in such a small quantity that it is not possible to ascertain their per unit cost exactly e.g., cost of thread and nails used in shoe-making.

The procedure for estimation of material cost is as follows:

- Break up the final product into simple parts so that their areas and volumes can be calculated easily.

- Neglect small fillets and rounded comers but take into consideration scrap involved. Suitable approximations whenever necessary may be adopted
  - By applying the formulas of mensuration calculate area and volume of each part.
  - In order to determine the volume of the product, the volumes of the all parts calculated above in step 3, are added.
  - In order to calculate weight of the material constituting the product, multiply the product volume by the density of the material of which the product is made.
  - Lastly determine the material cost by multiplying the cost per unit weight to the weight of material.

Raw material, whether wood, minerals, crude oil or even meat, all often have varying price points rising and dropping like the stock exchange. There are many variables at play causing this to happen. Each variable affects the price point of raw materials, causing it to increase or decrease for manufacturers, distributors and consumers. Here are several contributing factors to the shifting price of such materials.

- **Sourcing the Material**
- **Transportation**
- **Labor**

Sourcing the Material

One of the most expensive aspects of obtaining and distributing raw materials is sourcing it. If a mine runs low on the source material, if a harsh winter kills crops or if a forest fire takes down acres of lumber, readily available material is reduced, which in turn causes the price of raw material to go up. The demand remains, but as the supply is reduced, prices increase.

Transportation

The transportation of goods is another major expense to moving raw materials to different regions both within a country and around the world. This is especially true when importing or exporting the goods. As new levies and taxes are placed on goods brought in from other countries, the price for the raw material goes up. Additionally, if transporting lumber by truck or train, an increase in the cost of fuel will increase the cost to transport the goods, which causes the cost of raw material to shift.

Labor

Between transportation, sourcing the material, carrying for the material before it is ready to harvest or any other labor position along the way, if there is a shift in the work force there can be a shift in raw material pricing. If a union goes on strike, it affects raw material pricing as less of it can be transported or sourced from the earth. Other times, if the labor union reaches a deal and this includes an increase in pay, benefits or other aspects of their work, it in turn increases the price of raw material. Just about any shift in labor will have an impact on the cost of raw material.

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Fabrication

Fabrication is the act of taking raw stock material and turning it into a part for use in assembly process.

Metal fabrication is the creation of metal structures by cutting, bending and assembling processes. It is a value-added process involving the creation of machines, parts, and structures from various raw materials.

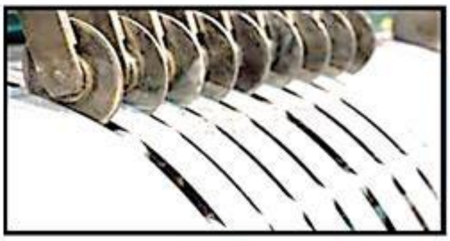
Typically, a fabrication shop bids on a job, usually based on engineering drawings, and if awarded the contract, builds the product. Large fab shops employ a multitude of value-added processes, including welding, cutting, forming and machining.

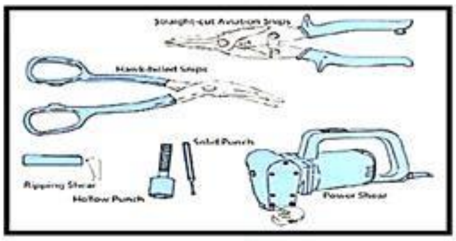
As with other manufacturing processes, both human labor and automation are commonly used. A fabricated product may be called a *fabrication*, and shops specializing in this type of work are called *fab shops*. The end products of other common types of metalworking, such as machining, metal stamping, forging, and casting, may be similar in shape and function, but those processes are not classified as fabrication.

There are many different types of fabrication processes.

1. Cutting
2. Folding
3. Machining
4. Punching
5. Shearing
6. Stamping
7. Welding

1. Cutting:- There are many ways to cut nowadays. The old standby is the saw. Others now include plasma torches, water jets, and lasers. There is a wide range of complexity and price, with some machines costing in the millions.



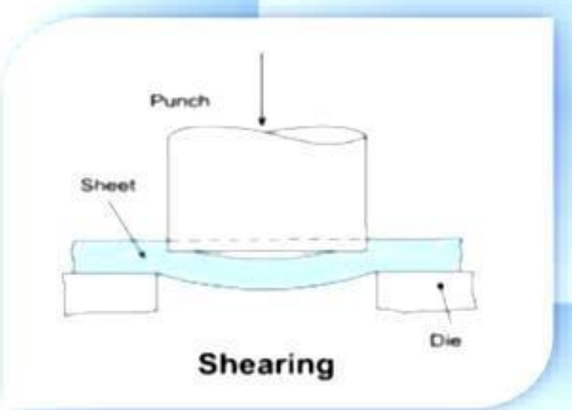


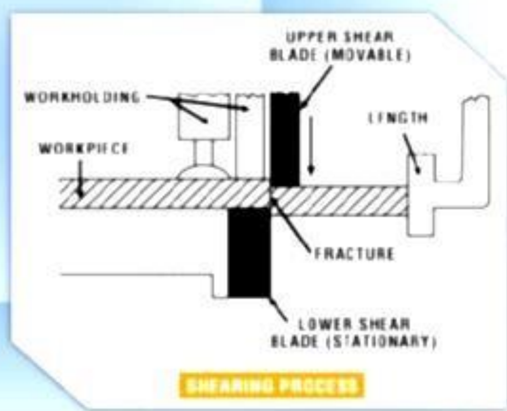
2.Folding:- Some parts need to be bent. The most common method is a press brake (or brake press). It has a set of dies that pinches the metal to form a crease. This operation can only be performed in very specific cases due to the movement of the part and the possible shape of the dies.

3.Machining:- This is the process of removing metal from a piece of material. It might be done on a lathe, where the material rotates against a cutting tool, or in some other cutting machine where a rotating tool is moved in a variety of ways against a stationary piece. Drills fall into this latter category.

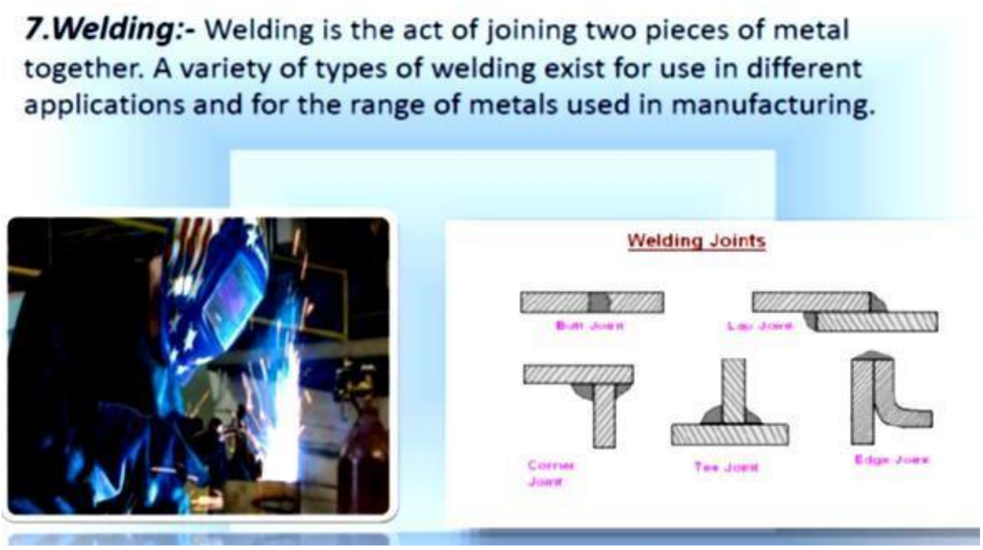
4.Punching:- Punching is the act of a punch and a die forming a 'scissor' effect on a piece of metal to make a hole in it. Obviously, the punch and die must be the same shape and size of the desired hole. In some cases, the main piece of material is kept, as in when holes are added for fasteners. In other cases, the piece that is removed is the desired product- this is called 'blanking'.

5.*Shearing:-* Shearing is the process of making a long cut on a piece of metal. It is, in effect, just like the action of one of those paper cutters with the long chop-handle. This is done on sheet metal.





6.Stamping:- Stamping is very similar to punching, except the material is not cut. The die is shaped to make a raised portion of material rather than penetrating.



Fabrication Properties

- Castability
- Machinability
- speeds and feeds

Castability

Castability is the ease of forming a quality casting. A very castable part design is easily developed, incurs minimal tooling costs, requires minimal energy, and has few rejections. Castability can refer to a part design or a material property. Material properties that influence their castability include their pouring temperature, fluidity, solidification shrinkage, and slag/dross formation tendencies

Machinability

- **Machinability** is the ease with which a metal can be cut (machined) permitting the removal of the material with a satisfactory finish at low cost.
- Materials with good machinability (**free machining** materials) require little power to cut, can be cut quickly, easily obtain a good finish, and do not wear the tooling much.
- The factors that typically improve a material's performance often degrade its machinability. Therefore, to manufacture components economically, engineers are challenged to find ways to improve machinability without harming performance.

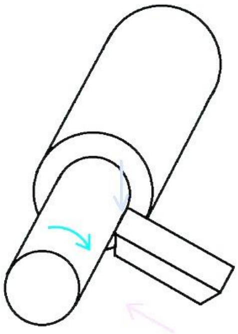
- Machinability can be difficult to predict because machining has so many variables. Two sets of factors are the condition of work materials and the physical properties of work materials.
- The condition of the work material includes eight factors: microstructure, grain size, heat treatment, chemical composition, fabrication, hardness, yield strength, and tensile strength. Physical properties are those of the individual material groups, such as the modulus of elasticity, thermal conductivity, thermal expansion, and work hardening. Other important factors are operating conditions, cutting tool material and geometry, and the machining process parameters.

There are many factors affecting machinability, but no widely accepted way to quantify it. Instead, machinability is often assessed on a case-by-case basis, and tests are tailored to the needs of a specific manufacturing process. Common metrics for comparison include tool life, surface finish, cutting temperature, and tool forces and power consumption

speeds and feeds

- The phrase **speeds and feeds** or **feeds and speeds** refers to two separate velocities in machine tool practice, **cutting speed** and **feed rate**. They are often considered as a pair because of their combined effect on the cutting process. Each, however, can also be considered and analyzed in its own right.
- Cutting speed (also called surface speed or simply speed) is the speed difference (relative velocity) between the cutting tool and the surface of the workpiece it is operating on.
- It is expressed in units of distance across the workpiece surface per unit of time, typically surface feet per minute or meters per minute (m/min). *Feed rate* (also often styled as a solid compound, *feed rate*, or called simply *feed*) is the relative velocity at which the cutter is advanced along the workpiece; its vector is perpendicular to the vector of cutting speed. Feed rate units depend on the motion of the tool and workpiece; when the workpiece rotates (*e.g.*, in turning and boring), the units are almost always distance per spindle revolution

(inches per revolution] or millimeters per revolution [mm/rev]). When the workpiece does not rotate (*e.g.*, in milling), the units are typically distance per time (inches per minute] or millimeters per minute), although distance per revolution or per cutter tooth are also sometimes used.



- If variables such as cutter geometry and the rigidity of the machine tool and its tooling setup could be ideally maximized (and reduced to negligible constants), then only a lack of power (that is, kilowatts or horsepower) available to the spindle would prevent the use of the maximum possible speeds and feeds for any given workpiece material and cutter material. Of course, in reality those other variables are dynamic and not negligible, but there is still a correlation between power available and feeds and speeds employed. In practice, lack of rigidity is usually the limiting constraint.

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Every product or process has modes of failure. An analysis of potential failures helps designers focus on and understand the impact of potential process or product risks and failures. Several systematic methodologies have been develop to quantify the effects and impacts of failures.

The occurrence of unexpected failure of components in a structure usually calls for some follow-up study to determine the cause and possible ways to avoid further loss. In such cases it is inevitable that such failure analysis will involve both (a) a review of the old databases used to design the part and (b) a search for or the development of new data sources that may shed more light on the material's response to conditions that developed during the life of the structure that had not been anticipated beforehand. The types of databases sought in this case will likely be those containing statistically reliable data, but recognizing the unexpected nature of some problems, an interest in a wider range of data sources and a willingness to consider a lower level of data quality may result. Databases for failure analysis studies may need to be wider in scope and to cover subjects such as corrosion that are not always easily treated by statistical means. In fact, sources covering failure experience may be the most valuable, though hardest to find because historically engineers and scientists do not publish much detail about their mistakes. The net result is that when dealing with failure analysis, the search may be quite broad in terms of data quality, and the focus most likely will be more on applicability to the problem than on the quality and structure of the compilation. As in the case of maintenance engineers and technicians needing databases comprised of service experience, failure analysts may well be faced with building new data sources based upon their organization's production and service experience Product Development

Prevent product malfunctions

- Insure product life.
- Prevent safety hazards while using the product.
- Process Development
- Insure product quality
- Achieve process reliability
- Prevent customer dissatisfaction
- Prevent safety or environmental hazards

Common Failure Analysis Techniques

- Cause-Consequence Analysis •
- Checklist
- Event Tree Analysis
- Failure Modes & Effects Analysis (FMEA)
- Failure Modes, Effects and Criticality Analysis (FMECA)
- Fault Tree Analysis (FTA)
- Hazard & Operability Analysis (HAZOP)
- Human Reliability
- Preliminary Hazard Analysis (PHA)
- Relative Ranking
- Safety Review
- What-If / Checklist Analysis
- What-If Analysis

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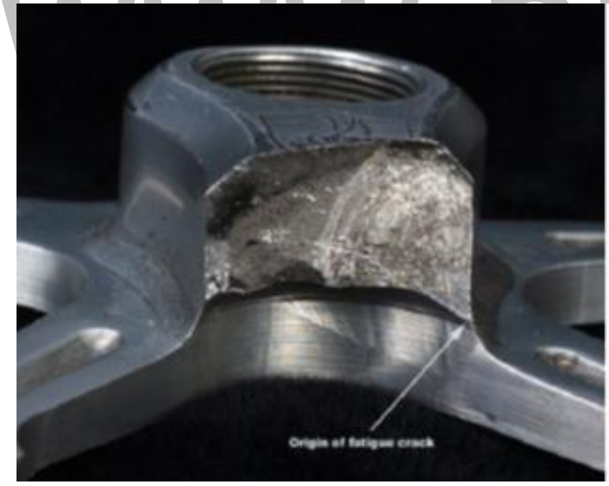
Fatigue

Fatigue is the weakening of material caused by the repeated loading of the material. When a material is subjected to cyclic loading, and loading greater than certain threshold value but much below the strength of material (ultimate tensile strength limit or yield stress limit), microscopic cracks begin to form at grain boundaries and interfaces. Eventually the crack reaches to a critical size. This crack propagates suddenly and the structure gets fractured. The shape of structure affects the fatigue very much. Square holes and sharp corners lead to elevated stresses where the fatigue crack initiates.



Factors causing fatigue failure Basic factors

- A maximum tensile stress of sufficiently high value.
- A large amount of variation or fluctuation in the applied stress.
- A sufficiently large number of cycles of the applied stress

Additional factors

- Stress concentration
- Corrosion
- Temperature
- Overload
- Metallurgical structure
- Residual stress
- Combined stress

Characteristics of fatigue

- The process starts with dislocation movements, eventually forming persistent slip bands that nucleate short cracks.
- The greater the applied stress, the shorter the life.
- Damage is cumulative. Materials do not recover when rested.
- Fatigue is a stochastic process, often showing considerable scatter. Fatigue life scatter tends to increase for longer fatigue lives.
- Fatigue life is influenced by a variety of factors, such as temperature, surface finish
- Number of cycles of stress of a specific character that a specimen of material can withstand before failure of a specific nature occurs. Number of cycles required (usually 10 million) to cause a failure decreases as the level of stress increases. Also called fatigue limit, it is affected by the environmental factors such as corrosion.

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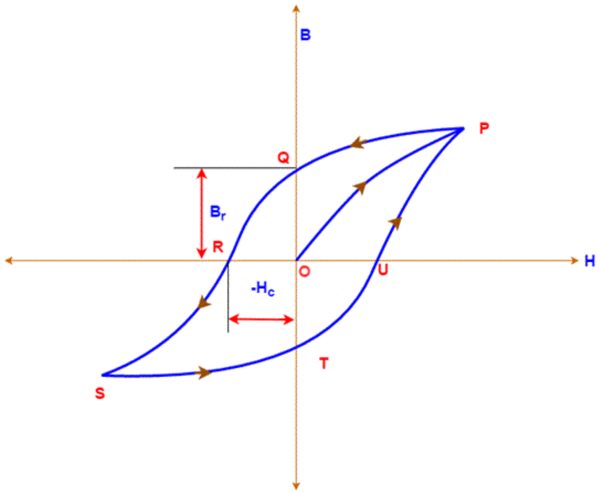
Retentivity or Magnetic Hysteresis

When a magnetic material is placed in an external magnetic field, its grains get oriented in the direction of magnetic field. Which results in magnetization of material in the direction of external magnetic field. Now, even after removal of external magnetic field, some magnetization exists, which is called residual magnetism. This property of material is called Magnetic retentively of material. A hysteresis loop or B-H cure of a typical magnetic material is shown in figure below. Magnetization B_r in below hysteresis loop represents the residual magnetism of material.



B-H Curve of a typical magnetic material

Coercive force

Due to retentivity of material, even after removal of external magnetic field some magnetization exists in material. This magnetism is called residual magnetism of material. To remove this residual magnetization, we have to apply some external magnetic field in opposite direction. This external magnetic motive force (ATs) required to overcome the residual magnetism is called "coercive force" of material. In above hysteresis loop, – H_c represents the coercive force. The material having large value of residual magnetization and coercive force are called magnetically hard materials. The material having very low vale of residual magnetization and coercive force are called magnetically soft materials.

Reluctance

- It is a property of magnetic material which resists to buildup of magnetic flux in material. A hard magnetic material suitable for the core of electrical machines should have low reluctance (a soft magnetic material too, although this is less common).

All materials are diamagnetic, even if their diamagnetism is hidden by their greater para- or ferromagnetism. Diamagnetism makes itself evident in atoms and molecules that have no permanent magnetic moment. Some atoms or molecules, however, do have a permanent magnetic moment, and such materials are paramagnetic. Magnetism is a phenomenon by which a material exerts either attractive or repulsive force on another. Basic source of magnetic force is movement of electrically charged particles. Thus magnetic behavior of a material can be traced to the structure of atoms. Electrons in atoms have a planetary motion in that they go around the nucleus. This orbital motion and its own spin cause separate magnetic moments, which contribute to the magnetic behavior of materials. Thus, every material can respond to a magnetic field. However, the manner in which a material responds depend much on its atomic structure, and determines whether a material will be strongly or weakly magnetic.

Types of Magnetism •

A material is magnetically characterized based on the way it can be magnetized. This depends on the material's magnetic susceptibility – its magnitude and sign.

Three basic magnetisms are:

- Dia-magnetism
- Para-magnetism
- Ferro-magnetism. Anti-ferro-magnetism and ferri-magnetisms are considered as subclasses of ferro-magnetism.

Dia-magnetism

Very weak; exists ONLY in presence of an external field, non-permanent. Applied external field acts on atoms of a material, slightly unbalancing their orbiting electrons, and creates small magnetic dipoles within atoms which oppose the applied field. This action produces a negative magnetic effect known as diamagnetism. The induced magnetic moment is small, and the magnetization (M) direction is opposite to the direction of applied field (H). Materials such as Cu, Ag, Si, Ag and alumina are diamagnetic at room temperature.

Para-magnetism

Slightly stronger; when an external field is applied dipoles line-up with the field, resulting in a positive magnetization. However, the dipoles do not interact. Materials which exhibit a small positive magnetic susceptibility in the presence of a magnetic field are called para-magnetic, and the effect is termed as para-magnetism. In the absence of an external field, the orientations of atomic magnetic moments are random leading to no net magnetization. When an external field is applied dipoles line-up with the field, resulting in a positive magnetization. However, because the dipoles do not interact, extremely large magnetic fields are required to align all of the dipoles. In addition, the effect is lost as soon as the magnetic field is removed. Since thermal agitation randomizes the directions of the magnetic dipoles, an increase in temperature decreases the paramagnetic effect. Para-magnetism is produced in many materials like aluminium, calcium, titanium, alloys of copper.

Ferro-magnetism

Both dia- and para- magnetic materials are considered as non-magnetic because they exhibit magnetization only in presence of an external field. •Certain materials possess permanent magnetic moments even in the absence of an external field. This is result of reinforcement of the dipoles. These are chrematistics of ferromagnetism.

Ferro Magnets are very strong; dipoles line-up permanently upon application of external field. Has two sub-classes:-

- Anti-ferro-magnetism:
- Ferri-magnetism:

Anti-ferro-magnetism

Dipoles line-up, but in opposite directions, resulting in zero magnetization. Eg: Mn, Cr, MnO, NiO, CoO, $MnCl_2$ Exchange interaction which is responsible for parallel alignment of spins is extremely sensitive to inter-atomic spacing and to the atomic positions. This sensitivity causes anti-parallel alignment of spins. When the strength of anti-parallel spin magnetic moments is equal, no net spin moment exists, and resulting susceptibilities are quite small.

Ferri-magnetism

Some ceramic materials exhibit net magnetization. In a magnetic field, the dipoles of a cation may line up with the field, while dipoles of other cation may not. These ceramics are called ferrites, and the effect is known as ferri-magnetism. Ferri-magnetism is similar to anti-ferro-magnetism in that the spins of different atoms or ions line up anti-parallel. However, the spins do not cancel each other out, and a net spin moment exists.

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Mechanical properties

To finalize the material for an engineering product or application, is it important to understand the mechanical properties of the material. The mechanical properties of a material are those which affect the mechanical strength and ability of a material to be molded in suitable shape. Some of the typical mechanical properties of a material include:

- Strength
- Toughness
- Hardness
- Hardenability
- Brittleness
- Malleability
- Ductility
- Creep and Slip
  - Resilience
  - Fatigue

Strength

It is the property of a material which opposes the deformation or breakdown of material in presence of external forces or load. Materials which we finalize for our engineering products, must have suitable mechanical strength to be capable to work under different mechanical forces or loads.

Toughness

It is the ability of a material to absorb the energy and gets plastically deformed without fracturing. Its numerical value is determined by the amount of energy per unit volume. Its unit is Joule/ m^3. Value of toughness of a material can be determined by stress-strain characteristics of a material. For good toughness, materials should have good strength as well as ductility.

For example: brittle materials, having good strength but limited ductility are not tough enough. Conversely, materials having good ductility but low strength are also not tough enough. Therefore, to be tough, a material should be capable to withstand both high stress and strain.

Hardness

It is the ability of a material to resist to permanent shape change due to external stress. There are various measure of hardness – Scratch Hardness, Indentation Hardness and Rebound Hardness.

1. Scratch Hardness

   Scratch Hardness is the ability of materials to the oppose the scratches to outer surface layer due to external force.

2. Indentation Hardness

   It is the ability of materials to oppose the dent due to punch of external hard and sharp objects.

3. Rebound Hardness

   Rebound hardness is also called as dynamic hardness. It is determined by the height of "bounce" of a diamond tipped hammer dropped from a fixed height on the material.

Hardenability

It is the ability of a material to attain the hardness by heat treatment processing. It is determined by the depth up to which the material becomes hard. The SI unit of hardenability is meter (similar to length). Hardenability of material is inversely proportional to the weld-ability of material.

Brittleness

Brittleness of a material indicates that how easily it gets fractured when it is subjected to a force or load. When a brittle material is subjected to a stress it observes very less energy and gets fractures without significant strain. Brittleness is converse to ductility of material. Brittleness of material is temperature dependent. Some metals which are ductile at normal temperature become brittle at low temperature.

Malleability

Malleability is a property of solid materials which indicates that how easily a material gets deformed under compressive stress. Malleability is often categorized by the ability of material to be formed in the form of a thin sheet by hammering or rolling. This mechanical property is an aspect of plasticity of material. Malleability of material is temperature dependent. With rise in temperature, the malleability of material increases.

Ductility

Ductility is a property of a solid material which indicates that how easily a material gets deformed under tensile stress. Ductility is often categorized by the ability of material to get stretched into a wire by pulling or drawing. This mechanical property is also an aspect of plasticity of material and is temperature dependent. With rise in temperature, the ductility of material increases.

Creep and Slip

Creep is the property of a material which indicates the tendency of material to move slowly and deform permanently under the influence of external mechanical stress. It results due to long time exposure to large external mechanical stress with in limit of yielding. Creep is more severe in material that are subjected to heat for long time. Slip in material is a plane with high density of atoms.

Resilience

Resilience is the ability of material to absorb the energy when it is deformed elastically by applying stress and release the energy when stress is removed. Proof resilience is defined as the maximum energy that can be absorbed without permanent deformation. The modulus of resilience is defined as the maximum energy that can be absorbed per unit volume without permanent deformation. It can be determined by integrating the stress-strain cure from zero to elastic limit. Its unit is joule/m^3.

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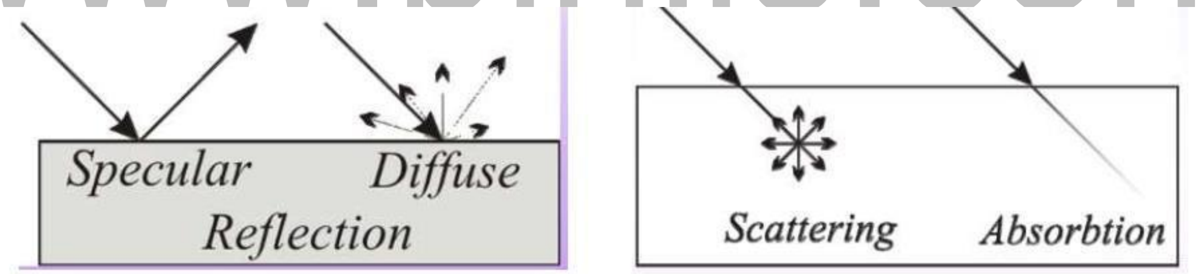
Optical Properties

The reflection could be specular or diffusion. From more fundamental perspective., there are only two possibilities of interaction of a medium with electromagnetic radiation

i. Scattering
ii. Absorption

If one considers a wider spectrum of frequencies, the some part of the spectrum could be absorbed while the other frequencies could be scattered.



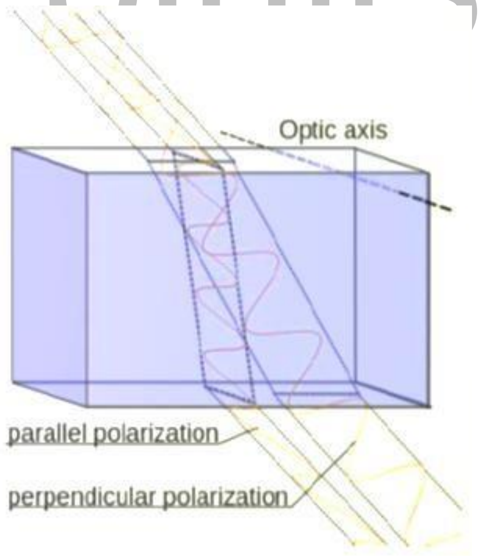
List of Properties

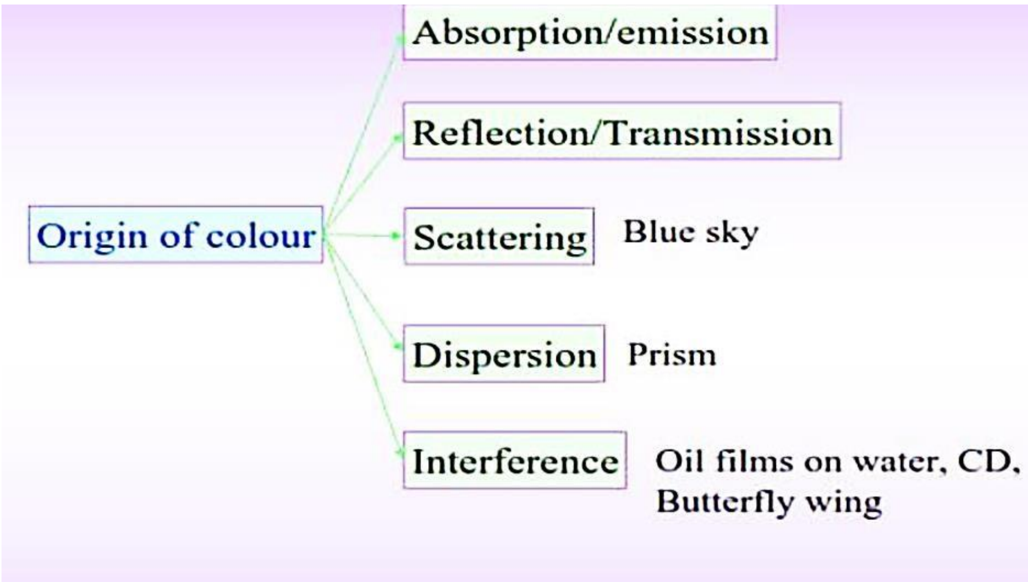
- Absorbance – How strongly a chemical attenuates light
- Bire fringence – is the optical property of a material having a refractive index that depends on the polarization and propagation direction of light.
- Luminosity – It is the amount of electromagnetic energy a body radiates per unit time. It is most frequently measured in two forms :
  - a) Visual (visible light only)
  - b) Bolometric (Total radiant energy)

- Photosensitivity – is the amount to which an object reacts upon receiving photons, especially visible light.
- Refractive Index (n) – is a dimensionless number that describes how light propagates through the medium.

$$n = \frac{c\,(Velocity\ in\ Vaccum)}{V(Velocity\ in\ Medium)}$$

- Scattering – is a general physical process where some forms of radiation, such as light, sound, or moving particles, are forced to deviate from a straight trajectory by one or more path due to localized no-uniformities in the medium through which they pass.
- Transmittance – of the surface of a material is its effectiveness in transmitting radiant energy. It is the fraction of incident electromagnetic power that is transmitted through a sample, in contrast to the transmission coefficient, which is the ratio of the transmitted to incident electric field.





- Absorption essentially involves activating some process in the material to make it to an excited state (from the ground state). ´ These Processes are :

  i. Electronics

  ii. Vibrational

  iii. Rotational Excitations

Further part of the absorbed energy could be **re-emitted**.If the absorbed energy is dissipated as heat, this is called **dissipative absorption.**When an electromagnetic wave impinges on an atom, the electron cloud is set into oscillation. This situation is like a dipole oscillator which emits radiation of the same frequency in all directions. This is the process of scattering. Similar to absorption, scattering is also frequency dependent. When a wave is being transmitted from one medium to another, its frequency remains constant, but its velocity decreases (the wave being slower in the medium). The ratio of the velocities **c/v medium** is called the **refractive index (n)**

$$n = \frac{c}{v} = \sqrt{\frac{\varepsilon\mu}{\varepsilon_0\mu_0}} = \sqrt{K_E K_M} \qquad K_M = \frac{\mu}{\mu_0}$$

$$K_E = \frac{\varepsilon}{\varepsilon_0}$$

Where, **ε** is permittivity of the medium and **μ** is the permeability of the medium. The subscript **'0'** refers to these values in vacuum. KE is the relative permittivity (dielectric constant) KM is the relative permeability of the medium

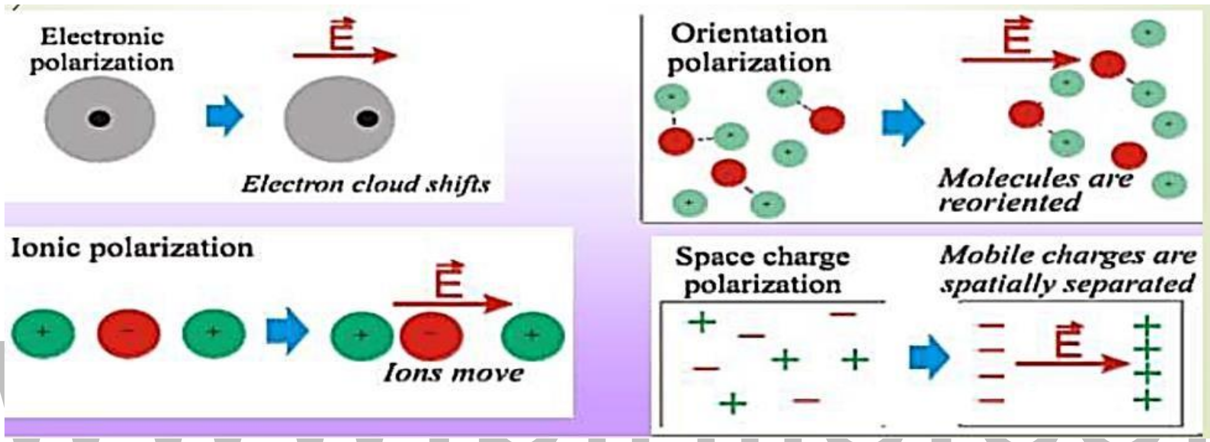
Usually KM is close to unity. KE is a function of the frequency of the electromagnetic wave and leads to the phenomenon of dispersion (e.g. dispersion of white light by a prism into 'VIBGYOR' colors. Physically, the origin of the dependence of 'n' on frequency is due to four factors:

(i) Orientational Polarization

(ii) Electronic Polarization

(iii) Ionic Polarization

(iv) Space Charge



- Usually the refractive index (n) is greater than one **(n>1),** but under certain circumstances it can be less than one **(n<1)** or even be negative **(n<0)**.

  n<1 implies that light is travelling faster than speed of light which is in apparent contradiction to the theory of relativity. ´ In cases, where **n<1**, the velocity which one needs to consider (instead of the 'phase velocity') is the 'group velocity(vg)'' (or in still other cases the 'signal velocity', which will be less than 'c'. ´ In negative refractive index materials (or typically structures) the refracted beam will be on the other side of the normal.

UNIT II MATERIAL PROPERTIES

Mechanical properties – fatigue strength – fracture Toughness - Thermal Properties – Magnetic Properties - Fabrication Properties –electrical , optical properties - Environmental Properties , Corrosion properties –shape and size - Material Cost and Availability– failure analysis.

Thermal Properties

- When a material undergoes a change in temperature, it either elongates or contracts depending upon whether heat is added to or removed from the material. If the elongation or contraction is not restricted, then the material does not experience any stress despite the fact that it undergoes a strain.
- The strain due to temperature change is called thermal strain and is expressed as

$$\varepsilon_T = \alpha(\Delta T)$$

Thermal properties of engineering materials comprise the following:

1. Specific heat.
2. Thermal conductivity
3. Thermal expansion
4. Melting point or heat resistance
5. Thermal shock.
6. Thermal diffusivity
7. Thermal effect

Specific Heat (Heat Capacity):

The heat capacity of a material is defined as the amount of heat required to raise its temperature by 1°. The heat capacity per unit mass, of material is defined as its specific heat. Heat capacity per mole is defined as its molar heat capacity.

Thermal Conductivity:

It is defined as the amount of heat conducted in a unit time through a unit area normal to the direction of heat.

Thermal Expansion:

Thermal expansion arises from the addition of heat energy in the atoms and their subsequent movement away from their equilibrium positions as the temperature rises in solid. This expansion or contraction resulting from increase or decrease in temperature is three dimensional but in practice linear thermal expansion is used for simplicity instead of volume expansion.

Melting Point:

Melting point or softening point is a significant temperature level as it represents transition point between solid and liquid phases having different structural arrangement of the atoms within the material. As heat is added to a solid, its thermal energy increases until the atoms or molecules on the surface begin to break away from their equilibrium positions.

Thermal Shock:

Thermal shock is the effect of a sudden change of temperature on a material whereas thermal shock resistance can be defined as the ability of material to withstand thermal stresses due to sudden and severe changes in the temperature at the surface of a solid body.

Thermal Diffusivity:

Thermal diffusivity is therefore associated with the diffusion of thermal energy and may be taken to represent an energy flux arising from the motion of phonons through a relatively stationary atomic array. As phonons are in the nature of waveform, the atoms vibrate in unison but are not physically transported.

Thermal Stresses:

When expansion or contraction of a body due to temperature change is wholly or partially prevented, thermal stress will be developed in body. Thermal stress may arise from external bodies connected to one under stress as for example, welded structure, railway line shrink fit components. Or, it may be due to non-uniform expansion of the body itself, for example bimetallic strips used in thermostatic controls. The value of thermal stress, expansion or contraction can be calculated by applying simple stress calculation theory.

Thermo-Elastic Effect:

When a solid is subjected to a load, work is done on it and it changes in volume. If this work is done at constant temperature, an adiabatic temperature rise (without transfer of heat to or from the surroundings) occurs. This will appear in the form of rise of temperature of solid when it is in stretched condition. Similarly when the solid is rapidly relaxed, -it will feel. cool. This warming or cooling phenomenon is called thermoelastic effect.

Magnetic properties of materials

To finalize the material for an engineering product / application, we should have the knowledge of **magnetic properties of materials**. The magnetic properties of a material are those which determine the ability of material to be suitable for a particular magnetic Application. Some of the typical **magnetic properties of engineering materials** are listed below-

- Permeability
- Retentivity or Magnetic Hysteresis
- Coercive force
- Reluctance

Permeability

- It is the property of magnetic material which indicates that how easily the magnetic flux is build up in the material. Some time is also called as the magnetic susceptibility of material.