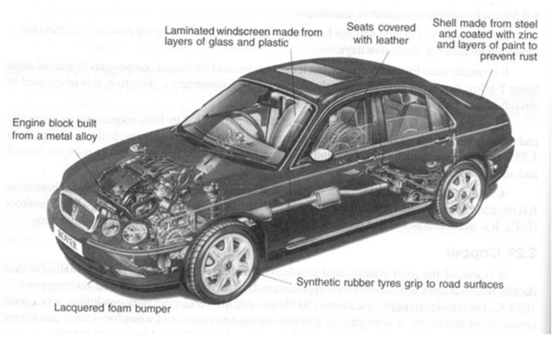
Engineering Materials



Engineering Materials

- Engineering Materials
  - Metal & its alloy
    - *Ferrous*
    - *Non-ferrous*
  - Non-metal
  - Composite
  - Nano-material
  - Smart material

Important Factors for Selecting the Material for Machine Elements

- Physical & Mechanical Properties
- Cost
- Availability
- Manufacturing consideration

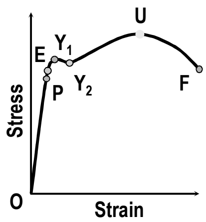
Properties of Metals

Physical Properties
- Density
- Melting point
- Thermal Conductivity
- Electrical Conductivity
- Colour, luster, etc.

Metal	*Density (Kg/ m^3)*	*Melting Point (°C)*	*Thermal Conductivity (W/ m °C)*
Aluminium	**2700**	**660**	**220**
Cast Iron	**7250**	**1300**	**54.5**
Steel	**7850**	**1510**	**50.2**
Copper	**8900**	**1083**	**393.5**
Brass	**8450**	**950**	**130**
Bronze	**8730**	**1040**	**67**
Tin	**7400**	**232**	**67**

Properties of Metals

Mechanical Properties
- **Strength**
- **Elasticity**
- **Plasticity**
- **Stiffness**
- **Ductility**
- **Brittleness**
- **Malleability**
- **Toughness**
- **Resilience**
- **Hardness**
- **Creep**



Mechanical Properties of Metals

Strength
- is a inherent property of the material (depends on treatment & processing)
- ability of the material to resist the external forces without breaking

The internal resistance per unit area offered by a part to an externally applied force is called Stress

- Stress is depends on geometry of the component, independent of material & its processing

Elasticity - ability of the material to regain its original shape and size after the deformation when external forces are removed.

Plasticity - ability of the material to retain the deformation produced under the load on permanent basis.

Stiffness - ability of the material to resist deformation under the action of external load.

Modulus of Elasticity is the measure of Stiffness

Mechanical Properties of Metals

Ductility - ability of the material to deform to a greater extent before the sign of crack, when it is subjected to ***tensile force***.

Ductility is measured by means of % elongation & % reduction of area in tensile test

Brittleness
- is that property of the material which shows negligible plastic deformation before fracture takes place.
- Is the property opposite to ductility.

Ductile materials	***Brittle materials***
- deform to a greater extent before fracture in tension test	- show negligible plastic deformation prior to fracture
- Tensile strain > 5% at fracture (approx.)	- Tensile strain < 5% at fracture (approx.)
- Failure takes place by gradual yielding	- Fails by sudden fracture
- Energy absorbed before fracture in tension test is more	- Energy absorbed before brittle fracture is Negligible

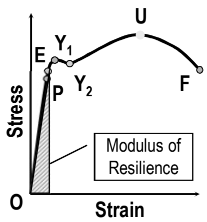
Mechanical Properties of Metals

Malleability - ability of the material to deform to a greater extent before the sign of crack, when it is subjected to ***compressive force***.

Ductility	***Malleability***
- ability to deform under a tensile force	- ability to deform under a compressive force
- Ductility decreases with increasing temperature	- Malleability increases with increase in temperature
- is desirable when the component is formed or drawn & component is subjected to shock load	- Is desirable when the component is forged, rolled or extruded

Mechanical Properties of Metals

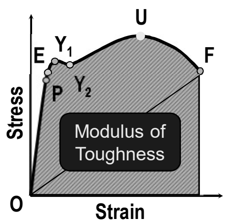
Resilience - ability of the material to absorb energy when deformed elastically & to release this energy when unloaded.



Resilience is measured by a quantity called ***Modulus of Resilience***, which is the ***strain energy per unit volume*** within elastic limit

Toughness

- ability of the material to absorb the energy before fracture has taken place.
- Property of the material to resist fracture due to high impact load



Toughness is measured by a quantity called ***Modulus of Toughness***, which is the ***strain energy per unit volume*** upto the point of fracture

Mechanical Properties of Metals

Toughness is measured by the ***Izod & Charpy Impact test***

Toughness decreases as the temperature increases

Resilience	***Toughness***
- Is the ability of the material to absorb energy within elastic range	- Is the ability to absorb energy within elastic & plastic range
- Modulus of resilience is the area below stress-strain curve in tension test up to elastic limit	- Modulus of toughness is the total area below stress-strain curve
- Resilience is essential in spring applications	- Toughness is required for components subjected to bending, twisting, stretching or to impact loads
- Example : spring steels are resilient	- Example : structural steel are tough

Mechanical Properties of Metals

Hardness

- is defined as the resistance of the material to penetration
- It indicates many different properties like resistance to wear, scratching, and machinability etc.
- Is an important property in selection of material for parts which rub on one another such as gear & pinion, cam & follower, rail & wheel, parts of ball bearing etc.

Primary Method of measuring Hardness

- Brinell Hardness Test
- Rockwell Hardness Test
- Vickers Hardness Test
- Shore Hardness Test

Creep

- When a part is subjected to a constant stress at high temperature for a long period of time, it will undergo a slow & permanent deformation.

Ferrous Metal

- Cast Iron (CI)
  - Grey Cast Iron
  - Malleable Cast Iron
  - Spheriodal Graphite Cast Iron | Ductile Cast Iron | Nodular Cast Iron
  - Alloy Cast Iron
- Wrought Iron
- Steel
  - Plain Carbon Steel
  - Free Cutting Steel
  - Alloy Steel
  - Cast Steel
  - Stainless Steel
  - High Speed Tool Steel
  - Spring Steel

Non-Ferrous Metal

- Aluminium & Aluminium Alloy
- Copper & Copper Alloy
- Nickel base Alloy
  - Monel
  - Inconel
  - Nichrome
  - Nimonic
- Zinc base Alloy

Cast Iron (CI)

- is primarily an alloy of Iron & Carbon
- Carbon contents in cast iron varies from ***2% to 4.5%*** (approx.)
- It also contains small amount of Silicon (*1-3%*), Manganese (*0.5-1%*), Sulphur (upto *0.1%*), Phosphorous (upto *0.1%*)
- Cast Iron is a **brittle material**

Other Element	***Effect***
Silicon	provides formation of free graphite which makes soft & easily machinable, produces sound casting because of its high affinity for O_2
Sulphur	makes CI hard & brittle, Too much sulphur gives unsound casting
Manganese	makes CI white & hard, helps to exert a controlling influence over the harmful effect of sulphur
Phosphorous	aids fusibility & fluidity in CI, but induces brittleness

Cast Iron

Advantages

- ✓ CI has a higher compressive strength (3 to 5 times that of steel)
- ✓ **CI has an excellent ability to damp vibrations** ---used for m/c tool bed, frames, guide
- ✓ CI has more resistance to wear even under the conditions of boundary lubrication
- ✓ CI has good casting characteristics --- complex shape can be manufactured without involving costly operations & tooling

Disadvantages

- ➢ CI has poor tensile strength if compared to steel
- ➢ CI is brittle & has poor impact resistance
- ➢ The machinability of CI parts is poor if compared to steel parts
- ➢ CI doesn't offer any plastic deformation before failure & exhibits no yield point. The failure of CI parts is sudden & total

Cast Iron

Type of Cast Iron	*B.I.S*	*I.S Designation*	*Tensile Strength [Min.] (MPa)*	*BHN*	*Applications*	*Remarks*
Grey CI	**IS 210** - 1993	FG 150	150	130-180	Auto-parts : cylinder block, brake drum, clutch plate, cylinder head, housing of gearbox, flywheel, m/c bed, frame & guide	
		FG 200	200	160-220		
		FG 300	300	180-230		
		FG 400	400	207-270		
Malleable	**IS 14329** - 1995	WM 400	400	220 (Max)	Brake shoe, lever, wheel hub, housing & door hinges, pipe fittings, fitting for motor cycle frame	Whiteheart
		BM 350	350	150 (Max)		Blackheart
		PM 700	700	240-290		Pearlitic
Spheroidal Graphite	**IS 1865** - 1991	SG 900/2	900	280-360	Crank shaft, heavy duty gears, furnace components, pipelines & its fitting	
		SG 600/3	600	190-270		
		SG 400/15	400	130-180		
		SG 350/22	350	150 (Max)		

Compressive Strength = 400 to 1000 MPa

Steel

Steel

- is primarily an alloy (solid solution) of Iron & Carbon
- Carbon contents in steel is upto ***1.5%***
- It also contains small amount of Silicon, Manganese, Sulphur, Phosphorous
- Steel is a ductile material

According to Indian Standard [IS : 1762 (Part-I)-1974], Steels are designated on the following two basis:

-- On the basis of Mechanical Properties (Tensile Strength)

-- On the basis of Chemical Composition

- ***Carbon content***
- ***Composition of alloying elements***

Steel

Indian Standard designation of steel [*IS : 1570 (Part-I)- 1993*]

Type of Steel	*I.S Designation*	*Tensile Strength [Min.] (MPa)*	*Yield Strength [Min.] (MPa)*	*% Elongation [Min.]*
Wrought Steel	Fe 290	290	170	27
	Fe E 220	290	220	27
	Fe 490	490	290	21
	Fe E 370	490	370	21
	Fe 690	690	410	12
	Fe E 520	690	520	12
	Fe 870	870	520	8
	Fe E 650	870	650	8

Symbol '**Fe**' : Steel has been specified on the basis of ***Minimum Tensile Strength***

Symbol '**Fe E**' : Steel has been specified on the basis of ***Minimum Yield Strength***

Steel

Plain Carbon Steel

Type of Carbon Steel	*Carbon content (approx.)*	*Remarks*
Low Carbon Steel or **Mild Steel**	C < 0.3%	- are soft & very ductile, can be machined & welded easily, unresponsive to heat treatment due to low C - content
Medium Carbon Steel	0.3% ≤ C < 0.6%	- are stronger & tougher as compared with low C –Steel, respond readily to heat treatment, easily hardened by heat treatment
High Carbon Steel	0.6% ≤ C < 1.5%	- respond readily to heat treatment, heat treated high C-steel have very high strength combined with hardness, - do not have much ductility as compared with low & high C-steel, difficult to weld, excessive hardness often accompanied by excessive brittleness

Carbon Steel

Indian Standard designation of Carbon Steel [*IS : 1570 (Part-II/Sec 1)- 1991*]

Type of Steel	*I.S Designation*	*Composition (%)*		*Tensile Strength [Min.] (MPa)*	*Yield Strength [Min.] (MPa)*	*% Elongation [Min.]*	*BHN*
		% C	*% Mn*				
Low Carbon Steel	30C8	0.25-0.35	0.7-0.9	500	400	21	179
	40C8	0.35-0.45	0.7-0.9	580	380	18	217
Medium Carbon Steel	50C4	0.45-0.55	0.3-0.5	660	460	13	241
	60C4	0.55-0.65	0.3-0.5	750	470	11	255
High Carbon Steel	80C6	0.75-0.85	0.5-0.7	790	510	9	265
	85C6	0.8-0.9	0.5-0.7	820	520	8	265

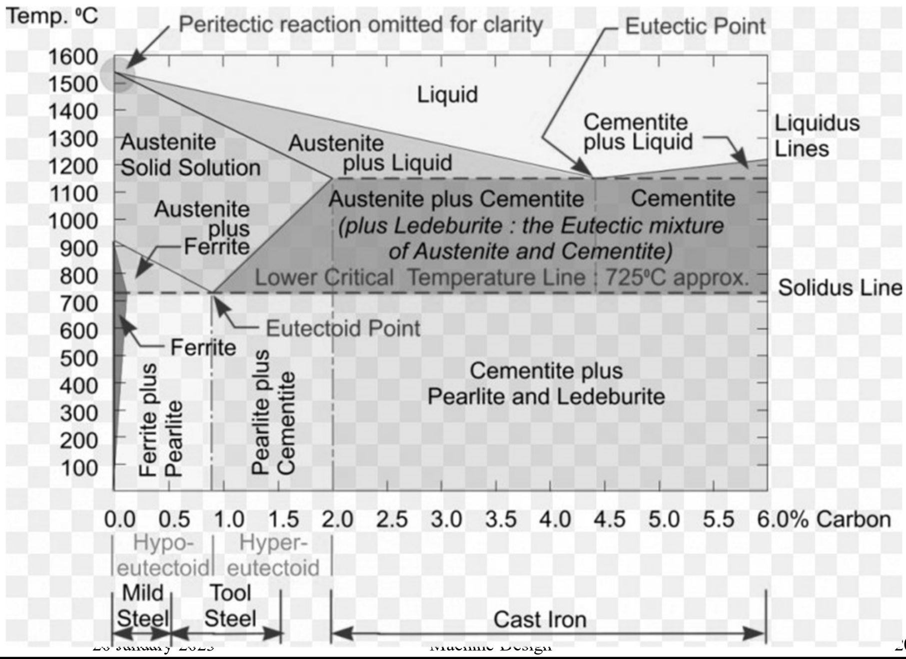
The designation of Plain Carbon Steel consists of the following three quantities:

(i) figure indicating **100** times the average **% of Carbon**

(ii) Letter ‘C’

(iii) figure indicating **10** times the average **% of Manganese**

Iron-Carbon Phase Diagram



Free Cutting Steels

- steel of this group include carbon steel with higher sulphur content than plain C-steel & phosphorous content.
- Carbon contents vary from 0.1 to 0.45% & sulphur from 0.08 to 0.3%
- the machinability of these steels is improved due to addition of sulphur
- **40C10S18** : C:- 0.35-0.45%; Mn:- 0.8-1.2%; S:-0.14-0.22%

Limitations of Plain Carbon Steel

- The tensile strength of plain carbon steels cannot be increased beyond 700 MPa without substantial loss in ductility & impact resistance
- Plain C - Steel have low corrosion resistance
- Plain C - Steel are not deep hardenable
- Plain C - Steel have poor impact resistance at low temperatures

Alloy Steel

Alloy Steels

- steel to which one or more elements other than carbon are added in significant amount to produce an improvement in properties (strength, wear & corrosion resistance etc.)
- Carbon contents in steel is upto ***1.5%***
- The chief alloying elements used in steel are Silicon, Manganese, Nickel, Chromium, Molybdenum, Tungsten, Cobalt, Vanadium

Advantages of Alloy Steels

- ✓ Alloy steel have higher Strength, Hardness & Toughness
- ✓ High values of hardness & strength can be achieved for components will large section thickness
- ✓ Alloy steels retain their strength & hardness at elevated temperatures
- ✓ Alloy steel have higher resistance to corrosion & oxidation compared with plain carbon steels

Alloy Steel

Effects of Chief Alloying Elements on Steel

Alloying Element	Effects	Remarks
Silicon	- Increases strength & hardness w/o lowering the ductility	
Manganese	- Increases strength, hardness & depth of hardening	
Nickel	- Increases strength, hardness & toughness w/o sacrificing ductility, increases hardenability & impact resistance at low temperature	25% Ni – boiler tube, IC engine valve, spark plug. 36% Ni – Invar – precision measuring instrument
Chromium	- Increases hardness & wear resistance, retain strength & hardness at high temperature, Excellent corrosion resistance (Cr > 4%)	- 0.5-2% Cr - balls, rollers & races for bearing, - nickel-chrome steel (3.25% Ni, 1.5% Cr) for crank shaft, axle, gears

Alloy Steel

Effects of Chief Alloying Elements on Steel

Alloying Element	Effects	Remarks
Molybdenum	- Increases wear resistance & hardness, resists softening of steel during tempering & heating	-used for air-plane fuselage & auto-parts
Tungsten	- Increases depth of hardening & retain hardness at elevated temperature	- Mainly used in cutting tools, die, tap etc.
Vanadium	- Increases tensile strength & elastic limit	
Cobalt	- Increases hot hardness	

Alloy Steel

Indian Standard designation of Alloy Steel [*IS : 1762 (Part-I)- 1993*]

The designation of **Low & Medium Alloy Steel** (*total alloying element <10%*) consists of the following quantities:

(i) figure indicating **100** times the average **% of Carbon**

(ii) Chemical symbol for alloying elements each followed by the figure for its average % content multiplied by a factor as given below

Element	*Multiplying factor*
Cr, Co, Ni, Mn, Si & W	4
Al, V, Pb, Cu, Nb, Ti, Mo,	10
S	100

IS designation	Average % Composition					
	C	Ni	Cr	Mo	V	
25Cr4Mo2	0.25		1	0.2		
40Ni8Cr8V2	0.40	2	2		0.2	

Alloy Steel

The designation of **High Alloy Steel** (*total alloying element >10%*) consists of the following quantities:

(i) a Letter ‘X’

(ii) a figure indicating **100** times the average **% of Carbon**

(ii) Chemical symbol for alloying elements each followed by the figure for its average % content round off to nearest integer

IS designation	Average % Composition		
	C	Ni	Cr
X15Cr25Ni12	0.15	12	25
X20Cr18Ni2	0.20	2	18

Overseas Equivalent Designations of Steel

India	British	USA		German
I.S	En	S.A.E	A.I.S.I	D.I.N
10C4	32 A	1012	C 1012	17155
45C8	43 B	1045	C 1045	17200
60C4	43 D	1060	C 1060	17200
65C6	42 B	1064	C 1064	17222
35Ni5Cr2	111	3140	3140	1662

Heat Treatment of Steels

Heat treatment process consists of controlled heating & cooling of plain C-Steel or alloy steel in the solid state for the purpose of changing their *metallurgical structure* in order to obtain certain desirable properties (*like hardness, strength, ductility etc*.) without changing in *chemical composition*.**

Aims of heat treatment

- To increase strength & hardness of metals
- To improve ductility of metals
- To relieve the stresses set up in the metal after hot or cold working
- To improve machinability
- To increase the qualities of a metal to provide better resistance to heat, corrosion & wear
- To improve its electrical & magnetic properties.

Heat Treatment of Steels

Major Heat Treatment Processes

- Annealing
- Normalising
- Quenching / Hardening
- Tempering

Surface hardening / Case hardening

- Carburishing
- Cyaniding
- Nitriding
- Induction hardening
- Flame hardening

Annealing

- Heating the steel component to a temperature 30° to 50°C above the critical temperature or transformation temperature, holding it at this temperature for sometime (approx. 3 to 4 min. for each mm of thickness of the largest section), followed by cooling slowly in the furnace. The rate of cooling varies from 30 to 200°C per hour depending upon the composition of steel.

Normalising

- Heating the steel component to a temperature 30° to 50°C above the critical temperature or transformation temperature, holding it at this temperature for about 15 min. & then allowed to cool down in air.

Quenching / Hardening

- Heating the steel component to a temperature slightly above the critical temperature, holding it at this temperature for sometime & then cooling it rapidly in water, oil or brine.

Tempering

- reheating the quenched/ hardened steel component to a temperature below the critical temperature, followed by cooling at a desired rate.

The recommended hardening & tempering treatments & temperature ranges can be obtained from the standards

Steel

- **Stainless Steel**
  - Martensitic Stainless Steel
  - Ferritic Stainless Steel
  - Austenitic Stainless Steel or 18/8 steel
- **High Speed Tool Steel**
  - 18-4-1 High Speed Steel — 18% W + 4% Cr + 1% V
  - Molybdenum High Speed Steel
  - Super High Speed Steel
- **Spring Steel**
  - High Carbon Steel
  - Chrome-vanadium Steel
  - Silicon- manganese Steel

Non-Ferrous Metals

- **Aluminium Alloy**
- **Copper Alloy**
  - **Brass** — 50-70% Copper + 50-30% Zinc
  - **Bronze** — 75-95% Copper + 25-5% Tin
  - **Gun metal** — 88% Copper + 10% Tin + 2% Zinc
- **Nickel base Alloy**
  - **Monel** — 65% Nickel + 32% Copper + 3% Others
  - **Inconel** — 80% Nickel + 14% Chromium + 6% iron
  - **Nichrome** — 65% Nickel + 15% Chromium + 20% iron
  - **Nimonic** — 80% Nickel + 20% Chromium
- **Zinc base Alloy**

Non-Ferrous Metals

- it contain a metal other than iron as their chief constituent

Aluminium & Aluminium Alloy

Alloying Elements : Copper, Manganese, Silicon, Magnesium, Zinc etc.

Type of Al. Alloy
- Cast Aluminium Alloy
- Wrought Aluminium Alloy

Advantages

- ✓ **Low Specific Gravity**
- ✓ **Corrosion Resistance**
- ✓ **Ease of fabrication**
- ✓ **High Thermal Conductivity**

Non-Ferrous Metals

Ceramics

- Compound of metallic & non-metallic elements with predominantly 'ionic' inter atomic bonding.

Examples:
- Alumina (Al_2O_3)
- Tungsten Carbide (TiC)
- Magnesia (MgO)
- Zirconia (ZrO_2)
- Silicon Carbide (SiC)

Advantages

- ✓ **High hardness**
- ✓ **High melting point**
- ✓ **Good thermal insulators**
- ✓ **High electrical resistivity**
- ✓ **Low density**
- ✓ **Chemically resistant to acids**

Disadvantages

- ✓ **Brittle in nature**
- ✓ **Poor tensile strength**
- ✓ **Difficult to shape & machine**

Plastics

- Synthetic materials & perhaps the most widely used group of polymers.

- A polymer is a non-metallic organic compound of high molecular weight consisting of a very long chain of monomers
- A monomer is a group of atoms that constitutes one unit of a polymer chain.
- When monomers are subjected to heat & pressure, they join together to form a chain called polymer
- The process of combining monomers into polymers is called polymerization

When short polymer chain is lengthened by adding more & more monomer units, material becomes more dense & passes from gaseous state to liquid state, from liquid state to semi-solid state & finally becomes a tough solid material.

Monomer	Polymer
Ethylene	Polyethylene
Propylene	Polypropylene
Vinyl chloride	Polyvinyl chloride (PVC)
Styrene	Polystyrene
Tetrafluoroethylene	Polytetrafluoroethylene (PTFE) (Teflon)

Methane gas (CH_4)
↓
Ethane gas (C_2H_6)
↓
Paraffin wax ($C_{18}H_{38}$)
↓
Polyethylene ($C_{100}H_{102}$)

Plastics

Plastic can be defined as a solid material consisting of an organic polymer of a long molecular chain & high molecular weight.

Additives
→ Fillers
→ Plasticisers
→ Flame retardants
→ Pigments or Colourant

Additive	*Purpose*
Filler	An inert foreign substance added to polymer to improve certain mechanical properties (tensile, compressive strength, abrasion resistance, toughness, thermal stability etc.) - Finely powdered silica floor, limestone, saw dust, sand etc.)
Plasticisers	Low molecular weight polymer additive that improves flexibility, ductility & toughness & reduces brittleness & stiffness. - Polyvinyl chloride, acetate copolymers
Flame retardants	Increases flammability resistance & interfers with combustion process & prevents burning
Pigments or Colourant	Imparts a specific colour to the plastic parts

Plastics

Plastic can be defined as a solid material consisting of an organic polymer of a long molecular chain & high molecular weight.

- **Plastics**
  - **Thermoplastics** - Polymeric material which softens when heated & hardens upon cooling
  - **Thermosetting Plastics** - Polymeric material which once having cured or hardened by chemical reaction does not soften or melt upon subsequent heating

Thermoplastics	*Thermosetting Plastics*
- Has linear polymer chain (molecular structure)	- Has cross-linked polymer chain
- Softens with heat. Heating & cooling can reshape	- Once set & hardened, cannot be remelted or reshaped
- Can be recycled	- Cannot be recycled
- Are flexible (molecules in a linear chain can slide over each other)	- More rigid (rigidity increases with the no. of cross-links)
- Polyethylene, polypropylene, PVC, polyamide (nylon), PTFE (Teflon)	- phenolics, aminos, polyesters, expoxies

Plastics

Advantages

- ✓ Low specific gravity so light weight
- ✓ High corrosion resistance
- ✓ Easy fabrication
- ✓ Some plastic acid-resistant
- ✓ Some plastic have low coefficient of friction & self-lubricating property

Disadvantages

- ✓ Poor tensile strength
- ✓ Mechanical properties vary considerably with temp. in ambient region
- ✓ Susceptible to time-dependent deformation when the stress level is maintained constant.

Plastics (trade name)	Application	
Polyamide (Nylon)	Gears, conveyor roller, bearing, cooling fan	- Excellent toughness & wear resistance
Acetal (Delrin)	Cams, gears, self-lubricating bearing	- High wear resistance
Polyurethane (Texin)	Gears, gaskets, seals, bearings	- tough, abrasion resistant & impact resistant
PTFE (Teflon)	self-lubricating bearing	- Low coeff. of friction & self-lubricating
Polyethylene (Polythene)	Gasket, washers, pipes	-flexible & tough
Phenolic	pulleys	

Fibre Reinforced Plastics (FRP)

FRP - Composite material in which the low strength of the polymetric material is increased by means of high strength fibres.

Main constituents of FRP:

- **Matrix** - is to provide a rigid base for holding fibres in position
- **Fibre** - is to transmit the load acting on the component

Advantages

- Low specific gravity resulting in light weight construction .
- High specific strength & modulus of elasticity.
- Good resistance to fatigue failure & to corrosion

Glass Reinforced Plastics (GRP)	*Carbon Reinforced Plastics (CRP)*
- Glass fibre is relatively strong	- Carbon fibre has maximum strength
- Glass is chemically inert w.r.t plastic materials	- Carbon fibre retains its strength at elevated temperature
- Glass is Cheaper & available	- Relatively Cheap
- Automobile bodies, valve bodies, pump casing storage containers	- Pressure vessels, aircraft components, casings of rocket motors

Selection of Material

Important Factors for Selecting the Material for Machine Elements

- Physical & Mechanical Properties
- Cost
  - Cost of material
  - cost of material processing
- Availability
- Manufacturing consideration

Past experience & Design data book are good guide for the selection of material.
However, a designer should not overlook the possibilities of new materials.