NIT JAMSHEDPUR

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SELECTION OF ENGINEERING MATERIALS:

COMMON ENGG. MATERIALS INCLUDING METALS AND ALLOYS

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● MATERIAL SELECTION

INTRODUCTION

The engineering profession may be defined as “the art and science of harnessing the information, materials and energy resources that occur in nature, for the benefit of mankind.” Moreover, on little reflection, it should be evident that the basic ingredients of any technology are energy, information and materials. Materials, therefore, must be of great interest to the engineer. The engineers’ interest in materials may be drawn to diverse aspects such as The Materials Science Aspect, and The Materials Management Aspect. However, to design and manufacturing engineers, it is The Materials Selection Aspect that should be of most interest .Until recently, this particular aspect has often not been adequately addressed in the common literature on engineering design.

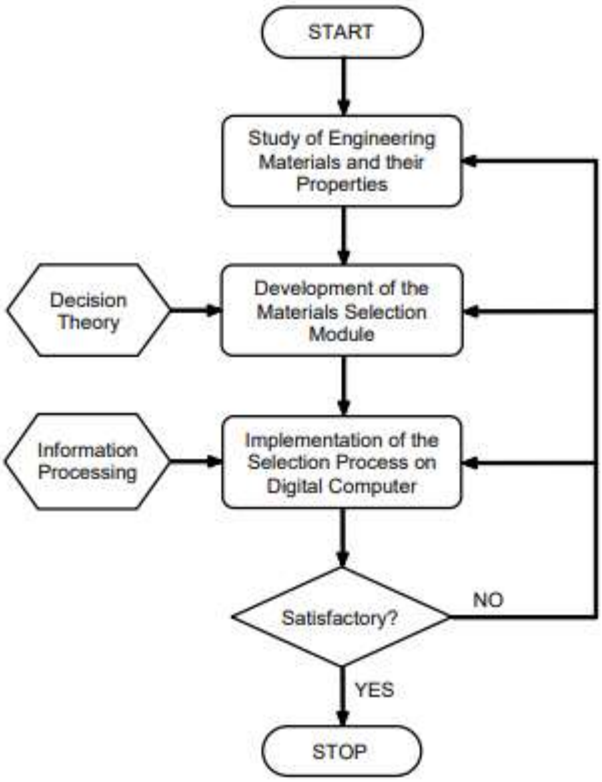


Fig. 5 – Development of the Materials Selection Process

THE GROWING SGNIFICANCE OF MATERIAL SELECTION

1.The Significance of Materials Selection in Design and Manufacturing

The importance of prudent materials selection in design and manufacturing may be summed up in the following statements:

● The number of materials available to the engineer is large and continually increasing. Since the properties and cost of these materials vary widely, it is imperative that materials be selected prudently if the functional and service requirements on products are to be met in the most beneficial manner.

● Some manufacturing technologies may not be successfully applied to all materials. Therefore, the rational choice of material has to be made with the manufacturing process in mind.

● To be competitive requires the timely manufacture and sale of high quality products. The quality of products is generally dependent on the materials from which the product is made.

● In many cases, materials have a direct relationship with the appearance of a product, and therefore its sales appeal.

● The cost of a product has a direct relationship with the cost of the materials of which it is made. Furthermore, the choice of materials frequently influences the cost of processing. Improper choice of material may lead to very costly processing.

● Failure of a product can result in injury or even loss of the lives of people. These may also lead to very costly litigation. In many cases of such failure, improper choice of materials is a significant causal factor.

2. Materials and Conservation of the Environment and Our Natural Resources

Design requirements are getting more stringent by the day. One reason for this is the need to conserve our dwindling natural resources and physical environment. There is an absolute limit to the quantities of many of the materials available here on earth. Therefore, these resources must be utilized efficiently and be recycled whenever possible.

Prudent selection and use of materials should help to achieve these ends.

For instance:

● The high demand for timber in the construction industry may be depleting our forests. We can conserve these forests through development and use of materials other than timber. It would be even better if such alternatives to timber happened to be recycled or waste materials such as sawdust.

● In recent years, the increased use of plastics, such as the polyethylene bags used for packaging, has posed the menace of littering and polluting our environment. The use of bio-degradable alternatives such as sisal and paper bags should eliminate this menace.

3. Materials and Technological Breakthroughs

In some instances revolutionary technological advances are brought about by breakthroughs in materials technology. Consider the following examples:

● The modern digital computer and the information revolution could not have been possible without the discovery of the group of materials known as semiconductors.

● The reciprocating piston internal combustion engine is one of the most important technological developments of our times. The thermal efficiency of this device can be substantially increased through the development of what is known as the "adiabatic" engine. The adiabatic engine would require that the cylinder block be made of a material with the thermal insulation of ceramics and, perhaps, the mechanical properties of cast iron. Clearly then, development of the adiabatic engine awaits a breakthrough in materials technology.

Thus, the ever growing significance of prudent selection and use of materials is clearly evident and therefore ever greater attention must be paid to the selection of materials.

CONCLUSIONS

1.All manufactured products are made of materials. All constructed structures are made of materials. All infrastructure is made of materials. Thus, the prudent selection of materials is critical in modern engineering design and manufacturing.

2.The engineering design process, including the selection of materials in design, is essentially a decision making process in which choices are made from among the available alternatives.

3. In its essence, the materials selection process is an information-processing task. As such it can be implemented on digital computer, taking advantage of the computer's immense power in the processing of information. Then, materials selection will comprise an important component of computer-aided engineering.

4. The development of rational materials selection processes is called for. The necessary research and development work should require substantial expenditure of time and effort, but should not necessarily be expensive in material terms since it would mainly consist of acquisition and utilization of information so as to develop the necessary software. Once developed, the use of such software should be easy, inexpensive and expeditious. This is an area in which universities and industry can collaborate for the benefit of all.

• IRON

FERROUS MATERIALS

<u>Cast iron</u>

It is an alloy of iron, carbon and silicon and it is hard and brittle. Carbon content may be within 1.7% to 3% and carbon may be present as free carbon (graphite) or iron carbide Fe C.

In general the types of cast iron are:

(a) Grey cast iron
(b) White cast iron
(c) Malleable cast iron
(d) Spheroidal or nodular cast iron
(e) Austenitic cast iron
(f) Abrasion resistant cast iron.

<u>GREY CAST IRON</u>

Grey cast iron Carbon content is 3 to 3.5%. Carbon here is mainly in the form of graphite. This type of cast iron is inexpensive and has high compressive strength. It has low tensile strength and low ductility. Graphite is an excellent solid lubricant and this makes it easily machinable but brittle. Some examples of this type of cast iron are FG20, FG35 or FG35SI15. The numbers indicate ultimate tensile strength in MPa and 15 indicates 0.15% silicon.

Gray Cast Iron

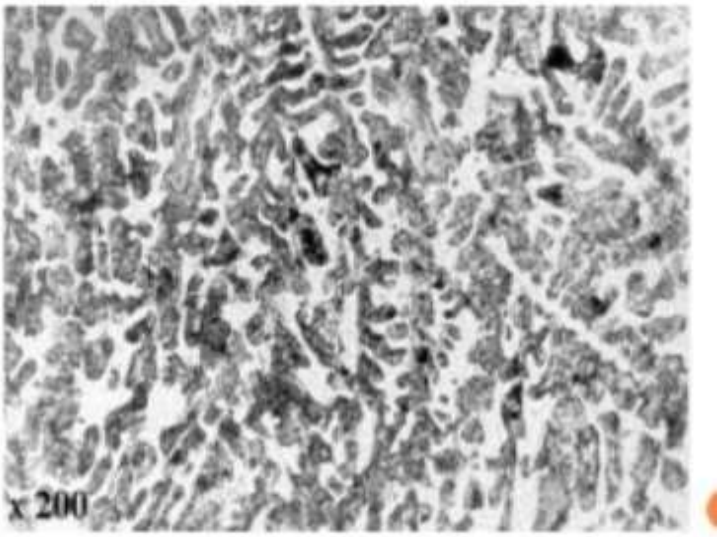
Due to lubricating action it is very suitable for parts where sliding action is desired. They are machine tool bodies, automotive cylinder blocks, heads, housings, fly-wheels, pipes and pipe fittings and agricultural implements.

AUSTENITIC CAST IRON

Depending on the form of graphite present this cast iron can be classified broadly under two headings: Austenitic flake graphite iron, Austenitic spheroidal or nodular graphite iron These are alloy cast irons and they contain small percentages of silicon, manganese, sulphur, phosphorus etc. They may be produced by adding alloying elements viz. nickel, chromium, molybdenum, copper and manganese in sufficient quantities. These elements give more strength and improved properties. They are used for making automobile parts such as cylinders, pistons, piston rings, brake drums etc.

WHITE CAST IRON

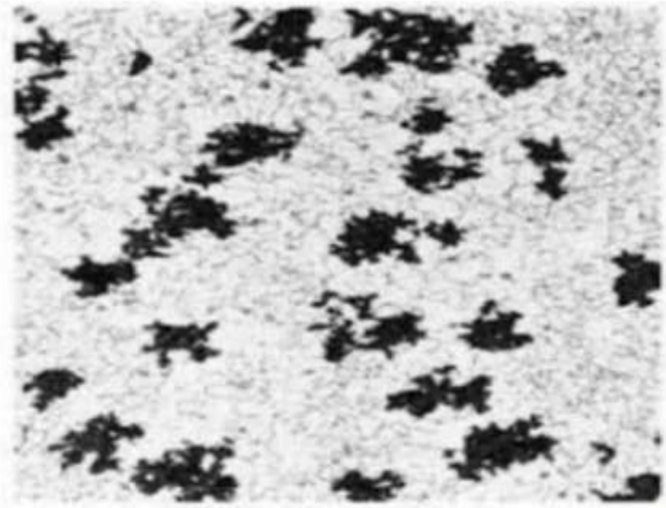
White cast iron- Carbon content is 1.75 to 2.3%.In these cast irons carbon is present in the form of iron carbide (Fe,C) which is hard and brittle. White cast iron has high tensile strength and low compressive strength. The presence of iron carbide increases hardness and makes it difficult to machine. Consequently these cast irons are abrasion resistant.



Due to wear resisting characteristics it is used for car wheels, rolls for crushing grains and jaw crusher plates. These are alloy cast iron and the alloying elements render abrasion resistance. A typical designation is ABR33 Ni4 Cr2 which indicates a tensile strength in kg/mm with 4% nickel and 2% chromium.

MALLEABLE CAST IRON

Malleable cast iron- These are white cast irons rendered malleable by annealing. These are tougher than grey cast iron and they can be twisted or bent without fracture. They have excellent machining properties and are inexpensive. Depending on the method of processing they may be designated as black heart BM32, BM30 or white heart WM42, WM35 etc.

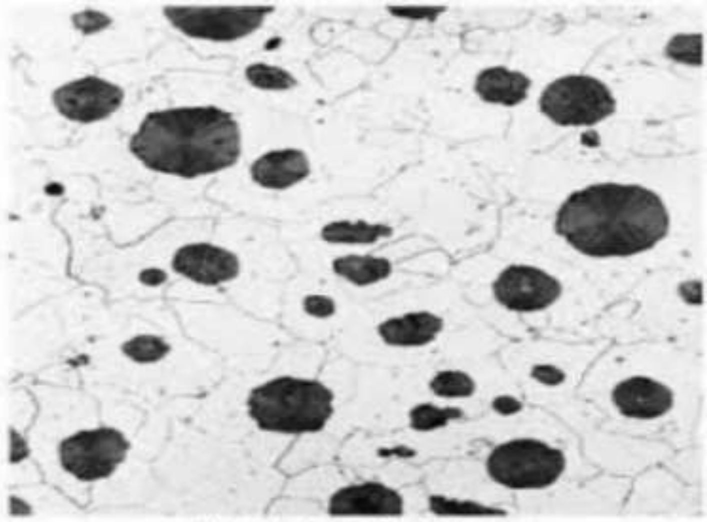


Malleable Cast Iron

Malleable cast iron is used for making parts where forging is expensive such as hubs for wagon wheels, brake supports.

SPHEROIDAL OR NODULAR GRAPHITE CAST IRON

In these cast irons graphite is present in the form of spheres or nodules. This type of cast iron is formed by adding small amounts of magnesium (0.1 to 0.8%) to the molten grey iron. The addition of magnesium causes the graphite to take form of nodules or spheroids instead of normal angular flakes. They have high tensile strength and good elongation properties. They are designated as, for example, SG50/7, SG80/2 etc where the first number gives the tensile strength in MPa and the second number indicates percentage elongation.



Nodular Cast Iron

Nodular cast iron is generally used for casting requires shock and impact resistance along with good machinability, such as hydraulic cylinders, cylinder heads rolls for rolling mills and centrifugally products.

WROUGHT IRON

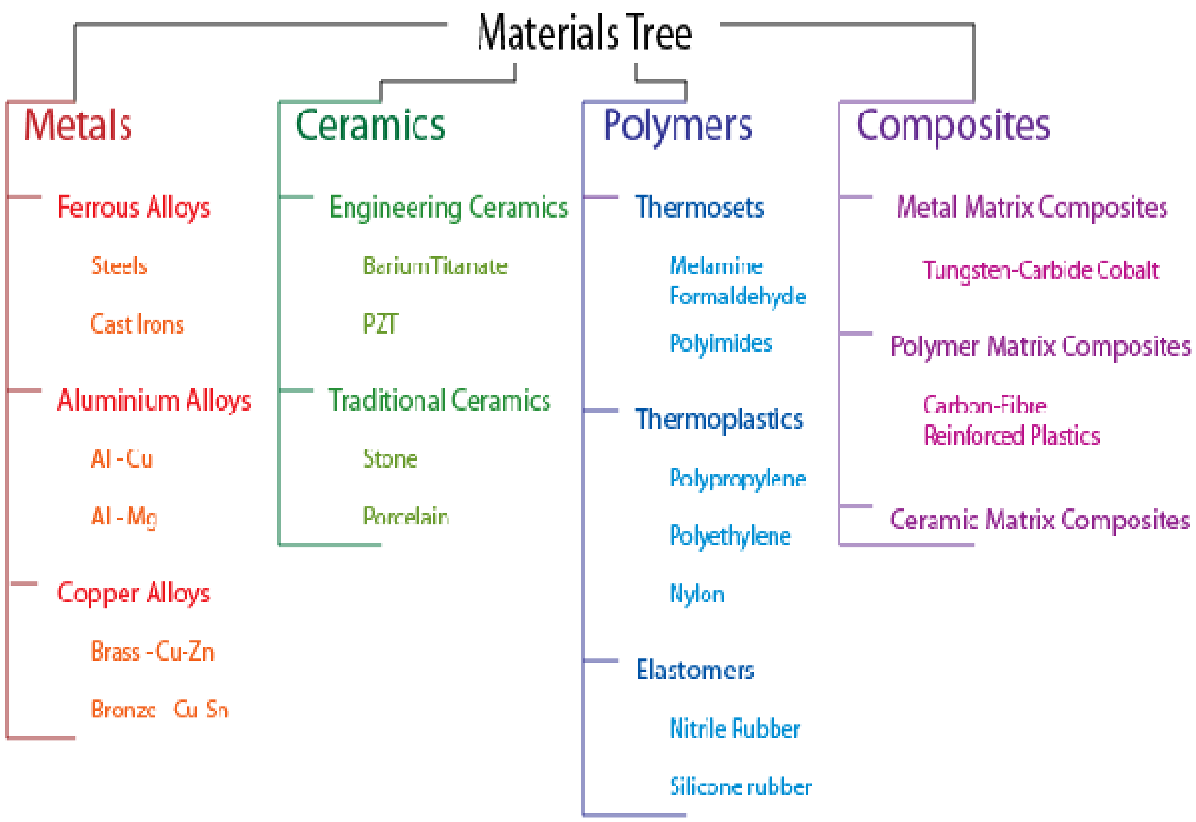
This is a very pure iron where the iron content is of the order of 99.5%. It is produced by re melting pig iron and some small amount of silicon, sulphur, or phosphorus may be present. It is tough, malleable and ductile and can easily be forged or welded. It cannot however take sudden shock.

Applications- Chains, crane hooks, railway couplings and such other components may be made of this iron.

• STEEL

Types of metals and alloys

Metallic materials are broadly of two kinds – ferrous and non-ferrous materials. This classification is primarily based on tonnage of materials used all around the world. Ferrous materials are those in which iron (Fe) is the principle constituent. All other materials are categorized as non-ferrous materials. Another classification is made based on their formability. If materials are hard to form, components with these materials are fabricated by casting, thus they are called cast alloys. If material can be deformed, they are known as wrought alloys. Materials are usually strengthened by two methods – cold work and heat treatment. Strengthening by heat treatment involves either precipitation hardening or martensitic transformation, both of which constitute specific heat treating procedure. When a material can not be strengthened by heat treatment, it is referred as non-heat-treatable alloys.



Ferrous materials

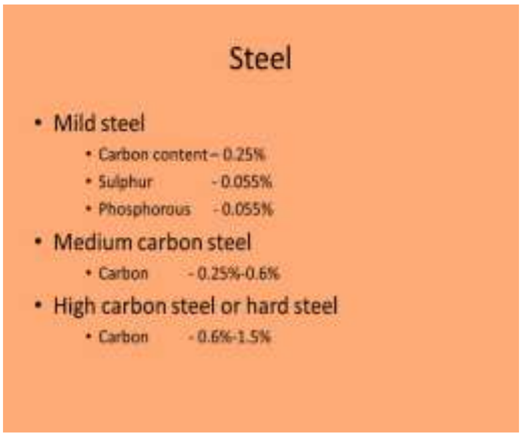
Ferrous materials are produced in larger quantities than any other metallic material. Three factors account for it:

- availability of abundant raw materials combined with economical extraction,
- ease of forming and
- their versatile mechanical and physical properties.

One main drawback of ferrous alloys is their *environmental degradation* i.e. poor corrosion resistance.

STEELS:

Steels are alloys of iron and carbon plus other alloying elements. In steels, carbon present in atomic form, and occupies interstitial sites of Fe microstructure. Alloying additions are necessary for many reasons including: improving properties, improving corrosion resistance, etc.



Mechanical properties of steels are very sensitive to carbon content. Hence, it is practical to classify steels based on their carbon content. Thus steels are basically three kinds: lowcarbon steels (% wt of C < 0.3), medium carbon steels (0.3< % wt of C <0.6) and high carbon steels (% wt of C >0.6).

<u>Low carbon steels</u>: These are arguably produced in the greatest quantities than other alloys. Carbon present in these alloys is limited, and is not enough to strengthen these materials by heat treatment; hence these alloys are strengthened by cold work. Their microstructure consists of ferrite and pearlite, and these alloys are thus relatively soft, ductile combined with high toughness. Common alloying elements are: Cu, V, Ni, W, Cr, Mo, etc. Typical applications of these alloys include: structural shapes, tin cans, automobile body components, buildings, etc.

<u>Medium carbon steels</u>: These are stronger than low carbon steels. However these are of less ductile than low carbon steels. These alloys can be heat treated to improve their strength. Usual heat treatment cycle consists of *austenitizing, quenching, and tempering* at suitable conditions to acquire required hardness. Ni, Cr and Mo alloying additions improve their hardenability. Typical applications include: railway tracks & wheels, gears, other machine parts which may require good combination of strength and toughness.

<u>High carbon steels</u>: These are strongest and hardest of carbon steels, and of course their ductility is very limited. These are heat treatable, and mostly used in hardened and tempered conditions. They possess very high wear resistance, and capable of holding sharp edges. Thus these are used for tool application such as knives, razors, hacksaw blades, etc. With addition of alloying element like Cr, V, Mo, W which forms hard carbides by reacting with carbon present, wear resistance of high carbon steels can be improved considerably.

STAINLESS STEEL:

The name comes from their high resistance to corrosion i.e. they are rustless (stain-less). Steels are made highly corrosion resistant by addition of special alloying elements, especially a minimum of 12% Cr along with Ni and Mo. Stainless steels are mainly three kinds:

i. **Ferritic stainless steels** are principally Fe-Cr-C alloys with 12-14% Cr. They also contain small additions of Mo, V, Nb, and Ni.
ii. **Austenitic stainless steels** usually contain 18% Cr and 8% Ni in addition to other minor alloying element. Other alloying additions include Ti , Nb , Mo (prevent weld decay), Mn and Cu (helps in stabilizing austenite).
iii. By alloying additions, for **martensitic steels** Ms is made to be above the room temperature. These alloys are heat treatable. Major alloying elements are: Cr, Mn and Mo.

Ferritic and austenitic steels are hardened and strengthened by cold work because they are not heat treatable. On the other hand martensitic steels are heat treatable.

• ALLOYS

Ferrous Alloys

Ferrous alloys nave iron as the base element. These alloys and include steels and cast irons. Ferrous alloys are the most common metal alloys in use due to the abundance of iron. ease of production. and high versatility of the material. The biggest disadvantage of man~ ferrous alloys is low corrosion resistance. Carbon is an important alloying element in all ferrous alloys. In general. nigher levels of carbon increase strength and hardness. and decrease ductility and weldability.

Non-ferrous materials have specific advantages over ferrous materials. They can be fabricated with ease, high relatively low density, and high electrical and thermal conductivities. However different materials have distinct characteristics, and are used for specific purposes. This section introduces some typical non-ferrous metals and their alloys of commercial importance.

Aluminium alloys

These are characterized by low density, high thermal & electrical conductivities, and good corrosion resistant characteristics. As Al has FCC crystal structure, these alloys are ductile even at low temperatures and can be formed easily. However, the great limitation of these alloys is their low melting point (660 C), which restricts their use at elevated temperatures. Strength of these alloys can be increased by both cold and heat treatment – based on these alloys are designated in to two groups, cast and wrought. Chief alloying elements include: Cu, Si, Mn, Mg, Zn. Recently, alloys of Al and other low-density metals like Li, Mg, Ti gained much attention as there is much concern about vehicle weight reduction. Al-Li alloys enjoy much more attention especially as they are very useful in aircraft and aerospace industries. Common applications of Al alloys include: beverage cans, automotive parts, bus bodies, aircraft structures, etc. Some of the Al alloys are capable of strengthening by precipitation, while others have to be strengthened by cold work or solid solution methods.

Nickel Alloys

Nickel alloys have high temperature and corrosion resistance. Common alloying ingredients include copper, chromium, and iron. Common nickel alloys include Monel, k-Monel, lnconel, and Hastelloy.

Copper alloys

As history goes by, bronze has been used for thousands of years. It is actually an alloy of Cu and Sn. Unalloyed Cu is soft, ductile thus hard to machine, and has virtually unlimited capacity for cold work. One special feature of most of these alloys is their corrosion resistant in diverse atmospheres. Most of these alloys are strengthened by either cold work or solid solution method. Common most Cu alloys: Brass, alloys of Cu and Zn where Zn is substitutional addition (e.g.: yellow brass, catridge brass, muntz metal, gilding metal); Bronze, alloys of Cu and other alloying additions like Sn, Al, Si and Ni. Bronzes are stronger and more corrosion resistant than brasses. Mention has to be made about Beryllium coppers who possess combination of relatively high strength, excellent electrical and corrosion properties, wear resistance, can be cast, hot worked and cold worked. Applications of Cu alloys include: costume jewelery, coins, musical instruments, electronics, springs, bushes, surgical and dental instruments, radiators, etc.

Magnesium alloys

The most sticking property of Mg is its low density among all structural metals. Mg has HCP structure, thus Mg alloys are difficult to form at room temperatures. Hence Mg alloys are usually fabricated by casting or hot working. As in case of Al, alloys are cast or wrought type, and some of them are heat treatable. Major alloying additions are: Al, Zn, Mn and rare earths. Common applications of Mg alloys include: hand-held devices like saws, tools, automotive parts like steering wheels, seat frames, electronics like casing for laptops, camcoders, cell phones etc.

Titanium alloys

Ti and its alloys are of relatively low density, high strength and have very high melting point. At the same time they are easy to machine and forge. However the major limitation is Ti's chemical reactivity at high temperatures, which necessitated special techniques to extract. Thus these alloys are expensive. They also possess excellent corrosion resistance in diverse atmospheres, and wear properties.

Common applications include: space vehicles, airplane structures, surgical implants, and petroleum & chemical industries.