

AIRCRAFT MATERIALS AND PRODUCTION TECHNOLOGY

(R17A2102)

COURSE FILE

II B. Tech II Semester

(2017-2018)

Prepared By

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Department of Aeronautical Engineering



**MALLA REDDY COLLEGE OF
ENGINEERING & TECHNOLOGY**

(Autonomous Institution – UGC, Govt. of India)

Affiliated to JNTU, Hyderabad, Approved by AICTE - Accredited by NBA & NAAC – 'A' Grade - ISO 9001:2015
Certified)

Maisammaguda, Dhulapally (Post Via. Kompally), Secunderabad – 500100, Telangana State, India.

MRCET VISION

- To become a model institution in the fields of Engineering, Technology and Management.
- To have a perfect synchronization of the ideologies of MRCET with challenging demands of International Pioneering Organizations.

MRCET MISSION

To establish a pedestal for the integral innovation, team spirit, originality and competence in the students, expose them to face the global challenges and become pioneers of Indian vision of modern society.

MRCET QUALITY POLICY.

- To pursue continual improvement of teaching learning process of Undergraduate and Post Graduate programs in Engineering & Management vigorously.
- To provide state of art infrastructure and expertise to impart the quality education.

PROGRAM OUTCOMES (PO's)

Engineering Graduates will be able to:

1. **Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis:** Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design / development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems:** Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multi disciplinary environments.
12. **Life- long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

DEPARTMENT OF AERONAUTICAL ENGINEERING

VISION

Department of Aeronautical Engineering aims to be indispensable source in Aeronautical Engineering which has a zeal to provide the value driven platform for the students to acquire knowledge and empower themselves to shoulder higher responsibility in building a strong nation.

MISSION

The primary mission of the department is to promote engineering education and research. To strive consistently to provide quality education, keeping in pace with time and technology. Department passions to integrate the intellectual, spiritual, ethical and social development of the students for shaping them into dynamic engineers.

QUALITY POLICY STATEMENT

Impart up-to-date knowledge to the students in Aeronautical area to make them quality engineers. Make the students experience the applications on quality equipment and tools. Provide systems, resources and training opportunities to achieve continuous improvement. Maintain global standards in education, training and services.

PROGRAM EDUCATIONAL OBJECTIVES

Aeronautical Engineering

1. **PEO1 (PROFESSIONALISM & CITIZENSHIP):** To create and sustain a community of learning in which students acquire knowledge and learn to apply it professionally with due consideration for ethical, ecological and economic issues.
2. **PEO2 (TECHNICAL ACCOMPLISHMENTS):** To provide knowledge based services to satisfy the needs of society and the industry by providing hands on experience in various technologies in core field.
3. **PEO3 (INVENTION, INNOVATION AND CREATIVITY):** To make the students to design, experiment, analyze, and interpret in the core field with the help of other multi disciplinary concepts wherever applicable.
4. **PEO4 (PROFESSIONAL DEVELOPMENT):** To educate the students to disseminate research findings with good soft skills and become a successful entrepreneur.
5. **PEO5 (HUMAN RESOURCE DEVELOPMENT):** To graduate the students in building national capabilities in technology, education and research

PROGRAM SPECIFIC OUTCOMES – Aeronautical Engineering

1. To mould students to become a professional with all necessary skills, personality and sound knowledge in basic and advance technological areas.
2. To promote understanding of concepts and develop ability in design manufacture and maintenance of aircraft, aerospace vehicles and associated equipment and develop application capability of the concepts sciences to engineering design and processes.
3. Understanding the current scenario in the field of aeronautics and acquire ability to apply knowledge of engineering, science and mathematics to design and conduct experiments in the field of Aeronautical Engineering.
4. To develop leadership skills in our students necessary to shape the social, intellectual, business and technical worlds.

MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY
II Year B. Tech, ANE-I Sem
R17A2103 - AIRCRAFT MATERIALS AND PRODUCTION
TECHNOLOGY

OBJECTIVES :

On completion of the course, the student will have knowledge about the selection of aircraft materials and process involved during production.

UNIT-I INTRODUCTION:

Classification of aircraft materials, properties of flight vehicle materials and their significant, factors affecting the selection of material for different parts of airplanes, Process associated to conventional materials.

UNIT-II METALS AND ALLOYS:

Aluminum and its alloys, high strength and high corrosion alloys. Titanium and its alloys: applications, machining, forming, welding and heat treatment; Classification of steels alloys, effect of alloying elements, magnesium alloys and their properties, heat treatment processes, maraging steels: properties and applications.

UNIT-III HIGH STRENGTH AND HEAT RESISTANT ALLOYS:

Classification of heat resistant materials, iron, nickel and cobalt based alloys, refractory materials, ceramics, properties of inconel, monal, nimonic and super alloys; application of heat resistant alloy in aircrafts. Heat treatment of steel and its alloys. Case hardening, initial stresses and stress alleviation procedures, corrosion prevention and protective treatments.

UNIT-IV COMPOSITE MATERIALS:

Classification, characteristics of composite materials, volume fraction, laminated composites, particulate composites and fibrous composites. Types of reinforcements, their shape and size, production and properties of fiber reinforced plastics. Application of Composite materials.

UNIT-V AIRCRAFT MANUFACTURING PROCESSES:

Profiling, hydro forming, spar milling, spark erosion and powered metal parts, integral machining, contour etching, high energy rate forming and manufacturing of honeycomb structures and general methods of construction of aircraft engine parts.

Text Books:

1. G. F. Titterton, Aircraft Materials and Processes, 5/e, Sterling Book House, 1998.
2. F. C. Campbell, Manufacturing Technology for Aerospace Structural Materials, 1/e, Elsevier Publications, 2006.
3. Agarwal, B.D., and Broutman, L.J., "Analysis and Performance of Fibre Composites," John Wiley and sons. Inc., New York, 1995.

LESSON PLANNER**DEPARTMENT OF AERONAUTICAL ENGINEERING****SUB: AIRCRAFT MATERIALS AND PRODUCTION TECHNOLOGY****SEMMESTER – II Year I Sem.****FACULTY: L.SUSHMA, Asst PROF**

S.no	UNIT NO	TOPICS PLANNED TO COVER	NO OF CLASSES
1	INTRODUCTION	Classification of aircraft materials, , ,	3
		properties of flight vehicle materials and their significant	2
		factors affecting the selection of material for different parts of airplanes	3
		Process associated to conventional materials.	3
		Unit 1 Total no of classes	11
2	METALS AND ALLOYS	Aluminum and its alloys, , , ,	1
		high strength and high corrosion alloys	1
		Titanium and its alloys: applications	1
		machining, forming, welding and heat treatment	2
		Classification of steels alloys, effect of alloying elements	1
		magnesium alloys and their properties	2
		heat treatment processes, maraging steels: properties and applications	2
		Unit 2 Total no of classes	12
3	HIGH STRENGTH AND HEAT RESISTANT ALLOYS	Classification of heat resistant materials, iron, nickel and cobalt based alloys, refractory materials, ceramics, , ,	3
		properties of inconel, monal, nimonic and super alloys; application of heat resistant alloy in aircrafts	2
		Heat treatment of steel and its alloys	2
		Case hardening, initial stresses and stress alleviation procedures	2
		corrosion prevention and protective treatments	2
		Unit 3 Total no of classes	11
4	COMPOSITE MATERIALS	Classification, characteristics of composite materials, , , ,	2
		volume fraction, laminated composites	2
		particulate composites and fibrous composites. Types of reinforcements	2
		their shape and size	2
		production and properties of fiber reinforced plastics.	2
		Application of Composite materials.	2
			14

5	AIRCRAFT MANUFACTURING PROCESSES	Profiling, hydro forming, spar milling, spark erosion	3
		powered metal parts, integral machining, contour etching	2
		high energy rate forming and manufacturing of honeycomb structures	2
		general methods of construction of aircraft engine parts.	1
			10
		TOTAL NO OF CLASSES FOR COURSE	61

Text Books:

1. G. F. Titterton, Aircraft Materials and Processes, 5/e, Sterling Book House, 1998.
2. F. C. Campbell, Manufacturing Technology for Aerospace Structural Materials, 1/e, Elsevier Publications, 2006.
3. Agarwal, B.D., and Broutman, L.J., "Analysis and Performance of Fibre Composites," John Wiley and sons. Inc., New York, 1995.
4. L. Gupta, Advanced Composite Materials, 2/e, Himalayan Books, 2006.

UNIT I

INTRODUCTION TO AIRCRAFT MATERIALS



Copper



Lead



Tin



Nickel



Aluminium



Zinc

INTRODUCTION

The development of new materials and better exertion of existing materials has been central to the advancement of aerospace engineering. Advances in the structural performance, safety, fuel economy, speed, range and operating life of aircraft has been reliant on improvements to the airframe and engine materials. Aircraft materials have changed greatly in terms of mechanical performance, durability, functionality and quality since the first powered flight by the Wright Brothers in 1903. Furthermore, the criteria which are used to select materials for aircraft have also changed over the past 100 years.

The main criteria for materials selection for the earliest aircraft (c. 1903–1920) was minimum weight and maximum strength. The earliest aircraft were designed to be light and strong; other design criteria such as cost, toughness and durability were given less importance in the quest for high strength-to-weight. At the time the best material to achieve the strength-to-weight requirement was **wood**.

The situation changed during the 1920s/1930s when the criteria for materials selection widened to consider a greater number of factors affecting aircraft performance and capability. The design of aircraft changed considerably as commercial and commuter aviation became more popular and the military began to recognise the tactical advantages of fast fighters and heavy bombers. Improved performance from the 1930s led to aircraft capable of flying at fast speeds over long distances while carrying heavy payloads. The requirement for high strength-to-weight remained central to the choice of material, as it had with earlier aircraft, but other criteria such as high stiffness and durability also became important. Higher stiffness allowed sleeker and more compact designs, and hence improved performance. These new criteria not only required new materials but also the development of new production methods for transforming these materials into aircraft components. **Aluminium alloys** processed using new heat treatments and shaped using new metal-forming processes were developed to meet the expanding number of selection criteria.

Major advances in aerospace technology, particularly jet aircraft, first generation helicopters and rockets/missiles, occurred shortly after World War II. These advances placed greater demands on the performance requirements of the the airframe and engine materials. Another significant milestone was the introduction of pressurised cabin aircraft for high altitude flight during the 1940s. The increased pressure loads exerted on the fuselage led to the development of **stressed skin panels** made using high-strength material.

Around the same time, the need for materials with fatigue and fracture properties emerged as a critical safety issue, and represents the introduction of the damage tolerance criterion. Damage tolerance is the capability of an aircraft structure to contain cracks and other damage below a critical size without catastrophic failure. The unexpected failure of aircraft structures was common before and, in some instances, during World War II. Aviation was considered a high risk industry and aircraft crashes caused by catastrophic structural failures were common. Designers attempted to minimize the risk by building bulky structures which made the aircraft heavy, but structural failures continued leading to many crashes. Fracture toughness and fatigue resistance joined other important properties such as weight, stiffness and strength as essential properties in the choice of aircraft materials.

The development of supersonic aircraft together with advances in rocket technology during the 1960s prompted the need for high-temperature materials. The aerospace industry invested heavily in the development of new materials for supersonic airliners such as Concorde, high-speed fighters and surveillance aircraft for the Cold War, and spacecraft and satellites for the Space Race. The investments led to the development of heat-resistant airframe materials such as titanium alloys and special aluminium alloys that were capable of withstanding frictional heating effects during supersonic flight without softening. The need for more powerful engines for aircraft and rockets also drove the development of high-temperature materials capable of operating above 800 °C. New types of nickel-based alloys and other heat-resistant materials were developed to survive within the hottest sections of jet engines.

The need for damage-tolerant materials became more intense in the late 1970s when unexpected failures occurred in ultra-high-strength steel components in United States Air Force (USAF) aircraft. It became clear that the failures involved manufacturing defects and fatigue cracks so small that they could not be found reliably. The USAF introduced a damage tolerant design philosophy which accepted the presence of cracks in aircraft and managed this by achieving an acceptable life by a combination of design and inspection. Achieving this required the use of materials that were resistant to fatigue cracking and failure.

The aerospace industry implemented new measures to minimize weight and maximize structural performance, and this included the greater use of higher-strength aluminium alloys and the introduction of carbon-epoxy fibre composite materials into secondary structures such as engine cowlings and undercarriage doors.

Aircraft Manufacturing involves various materials for their own unique applications. The specialist property may be the most important consideration in materials selection, and other properties such as the:

- cost
- ease of manufacture or mechanical performance (For example, resistance against cracking and spalling owing to rapid heating, known as thermal shock resistance, is an essential property for materials used in the exhaust casing of rocket engines.) Listed below are several specialist properties which may be considered in materials selection:
- Electrical conductivity is an important property for materials used in the outer skin of aircraft. The material must have the ability to conduct an electrical charge in the event of lightning strike.
- Thermal conductivity is a consideration for materials used in high-temperature applications such as heat shields and engine components. Heat-shield materials require low thermal conductivity to protect the airframe structure from excessive heating.
- Thermal expansion is also a consideration for high-temperature materials. Materials with a low thermal expansion coefficient are often required to avoid excessive expansion and contraction during heating and cooling.
- Flammability is a consideration for materials where there is the risk of fire, such as aircraft cabins and jet engines. Flammability properties such as ignition temperature, flame spread rate and smoke may need to be considered.
- Stealth is an important property for materials used in the external surface of covert military aircraft. Materials with the capability to absorb radar waves and/or reduce the infrared visibility are important for stealth aircraft.

Various Materials used in aircraft construction are:

- Wood
- Metals
- Alloys
- Plastics
- Composites

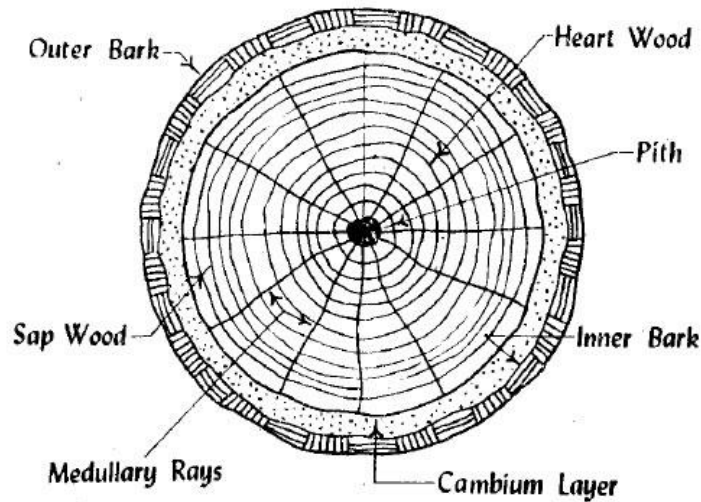
I. **Wood:**

- Structure and composition of wood:** The properties of wood that make it a useful aircraft material (i.e. lightness, strength and toughness), are controlled by its structure and composition.

Macrostructure of wood:

- The macrostructure of wood consists of several distinct zones that occur across a tree trunk.
- The outer layer, or bark, provides some protection for the inside of a tree against birds, insects, fungi and other organisms.
- Just beneath the bark is a zone called the cambium that contains new growing cells for both the bark and inner region of the tree. During the warmer months of each year, the cambium grows new wood cells on its inner surface and new bark cells on its outer surface. The sapwood is a region adjoining the cambium that contains cells where nutrients are stored and sap (containing water and minerals) is transported along the trunk and into the branches and twigs.
- The inner core of the tree is called the heartwood, and is composed entirely of dead cells. The heartwood is denser and stronger than the cambium and sapwood, and provides most of the mechanical support for a tree. Only wood taken from the heartwood of a mature, fully grown tree is used for aircraft construction.

Wood is a highly anisotropic material. Three axes are used to describe the directionality of cut timber. The axes are mutually perpendicular to each other. The longitudinal axis (L) is parallel with the axis of the trunk, and is also known as the fibre or grain direction. The radial axis (R) is across the diameter of the trunk and the tangential axis (T) is normal to the radial direction. The mechanical properties are different along each axis, and therefore it is important that timber used in aircraft construction is cut in the direction that maximises structural performance. For example, stiffness and strength are highest when timber is loaded parallel with the longitudinal axis and lowest in the radial direction for reasons that are explained in 17.5.2. Wood is toughest when cracking occurs in the radial direction and is more susceptible to splitting in the other directions. Care is needed when constructing structures to ensure the wood grain is aligned with the major loads acting on the aircraft.



Microstructure of wood

The microstructure of heartwood consists of long and thin hollow cells that are extended in the longitudinal direction.

The microstructure consists of long, hollow cells squeezed together like drinking straws. These cells are called fibres or fibrils because of their very high aspect ratio (length-to-width) of 100 or more.

Fibre cells are less than 0.01 mm wide and roughly 1 mm long in hardwoods and 5 mm long in softwoods. The fibres provide wood with most of its stiffness, strength and toughness.

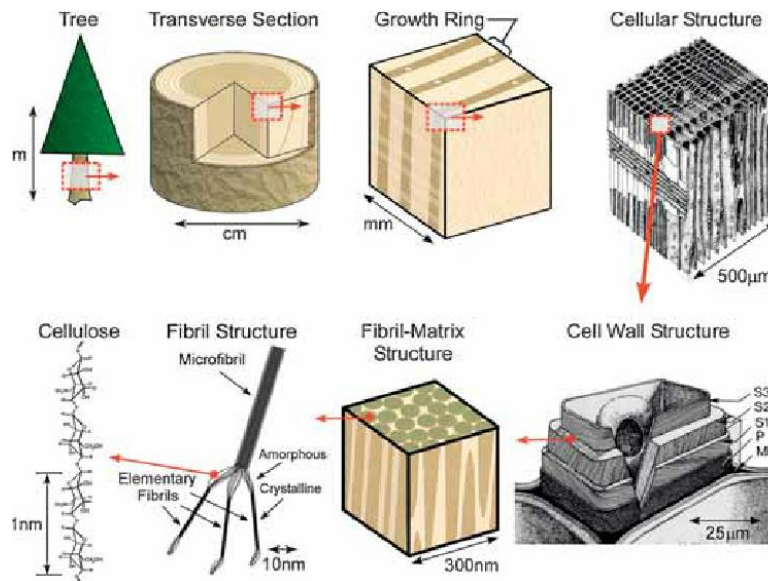
The microstructure of wood is often considered in the materials engineering context as a unidirectional fibre–polymer composite.

Wood consists of long fibre cells aligned in the same direction, which is analogous to the fibres in a composite, which are bonded together in an organic matrix. Most of the wood fibres are roughly parallel with the longitudinal axis, and this is called the grain direction. The term grain describes both the cell direction and the wood texture; the grain direction has a major influence on the mechanical properties of wood.

Cell structure of wood

- The structure and composition of cells in the heartwood are similar for most hardwoods and softwoods. Cell consists of a hollow core and multilayer wall structure. The wall consists of several layers of microfibrils, which are crystalline cellulose ($(C_6H_{10}O_5)_n$) molecules clumped together into long strands.

- Each molecular chain consists of long segments of linear, crystalline cellulose separated by shorter segments of amorphous cellulose. Cellulose is a linear molecule with no cumbersome sidegroups, and so it crystallises easily into strands of great stiffness and strength. The crystalline cellulose strands are encased in a layer of hemicellulose. This is a semicrystalline polymer of glucose that acts as a binding agent to the cellulose strands.
- The hemicellulose is covered with lignin, which is an amorphous polymer (phenol–propane) that also acts as a binder. A microfibril then consists of a bundle of crystalline cellulose chains that are encased with hemicellulose and lignin. This structure is somewhat analogous to a fibre–polymer composite, where the cellulose strands act as the fibres and the hemicellulose and lignin are the matrix binding phase.



II. **Elements:** The elements can be **classified** as

- Metals:** Metals are good conductors of heat and electricity, and are malleable (they can be hammered into sheets) and ductile (they can be drawn into wire) are (usually) poor conductors of heat and electricity, and are not malleable or ductile.
- Nonmetals** are (usually) poor conductors of heat and electricity, and are not malleable or ductile; many of the elemental nonmetals are gases at room temperature, while others are liquids and others are solids.
- The metalloids** are intermediate in their properties. In their physical properties, they are more like the nonmetals, but under certain circumstances, several of

them can be made to conduct electricity. These semiconductors are extremely important in computers and other electronic devices.

Metals are used in aircraft construction. Metals are classified as

- i. **Ferrous:** The metal in which iron is the principal element is known as ferrous metal. These are directly attracted by magnets.

Ferrous metals are those that contain iron as the base metal. The properties of ferrous metals may be changed by adding various alloying elements. The chemical and mechanical properties need to be combined to produce a metal to serve a specific purpose.

The basic ferrous metal form is pig iron. Pig iron is produced in a blast furnace that is charged with an iron ore, coke, and limestone. The four principal iron ores are hematite, limonite, magnetite and faconite.

Manipulation of **atom-to-atom relationships between iron, carbon and various alloying elements establishes the specific properties of ferrous metals.** As atoms transform from one specific arrangement, or crystallite lattice, to another, strength, toughness, impact resistance, hardness, ductility and other properties are altered. Ferrous metals include:

- cast iron and steel
- stainless steels
- special steels

General Information: Ferrous Metals

Material selection for a mechanical or structural application requires some important considerations, including how easily the material can be shaped into a finished part and how its properties can be either intentionally or inadvertently altered in the process. Depending on the end of use, metals can be simply cast into the finished part or cast into an intermediate form, such as an ingot, then worked, wrought by rolling, or processed by forging, extruding or another deformation process.

Although the same operations are used with ferrous as well as non-ferrous metals and alloys, the reaction of nonferrous metals to these forming processes is often more severe. Consequently, properties may differ considerably between the cast and wrought forms of the same metal or alloy.

To shape both non-ferrous and ferrous metals, designers use processes that range from casting and sintered powder metallurgy (P/M) to hot and cold working. Each

forming method imparts unique physical and mechanical characteristics to the final component. As the more abundant of all commercial metals, alloys of iron and steel continue to cover a broad range of structural applications. Iron ore is readily available, constituting about 5% of the earth's crust and is easy to convert to a useful form. Iron is obtained by fusing the ore to drive off oxygen, sulfur and other impurities. The ore is melted in a furnace in direct contact with the fuel using limestone as a flux. The limestone combines with impurities and forms a slag, which is easily removed.

Adding carbon in small amounts reduces the melting point of iron. All commercial forms of iron and steel contain carbon, which is an integral part of the metallurgy of iron and steel.

The various properties of materials can be assessed, by accurate laboratory tests on sample pieces.

SOME FERROUS METALS AND THEIR PROPERTIES

NAME	ALLOY OF	PROPERTIES	USES
Mild Steel	Carbon 0.1 - 0.3% Iron 99.9 - 99.7%	Tough. High tensile strength. Can be case hardened. Rusts very easily.	Most common metal used in school workshops. Used in general metal products and engineering.
Carbon Steel	Carbon 0.6 - 1.4% Iron 99.4 - 98.6%	Tough. Can be hardened and tempered.	Cutting tools such as drills.
Stainless Steel	Iron, nickel and chromium	Tough, resistant to rust and stains.	Cutlery, medical instruments.
Cast Iron	Carbon 2 - 6% Iron 98 - 94%	Strong but brittle. Compressive strength very high.	Castings, manhole covers, engines.
Wrought Iron	Almost 100% iron	Fibrous, tough, ductile, resistant to rusting.	Ornamental gates and railings. Not in much use today.

CARBON CONTENT The carbon content affects the properties. We have

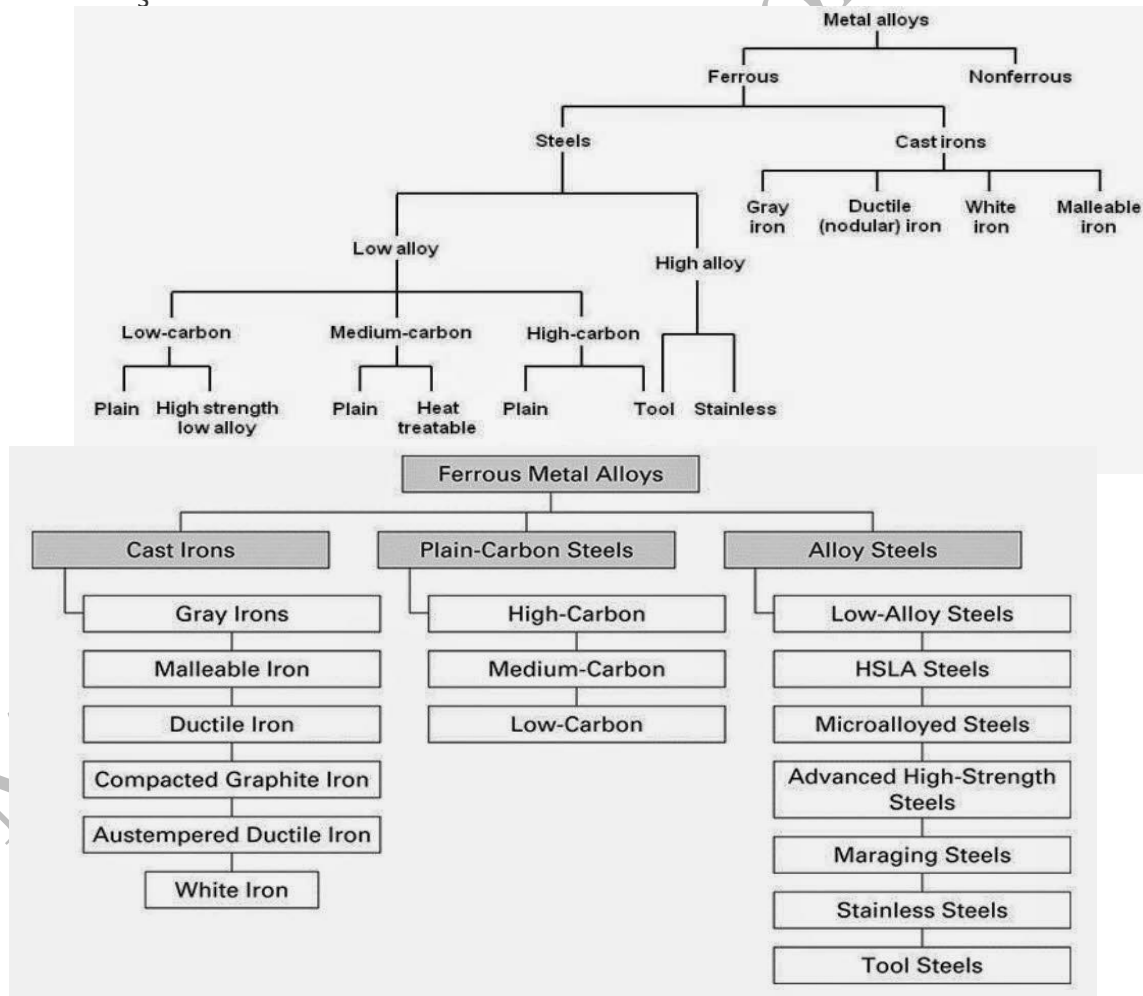
Pure Iron: The cast iron with carbon content of less than 0.2% is called wrought iron or pure iron. Wrought iron is an iron alloy with a very low carbon content. it is commercially known as "pure iron"

Medium Carbon Steel:

High Carbon Steel: High-Carbon is much harder so High-Carbon Steel can cut Low-Carbon Steel

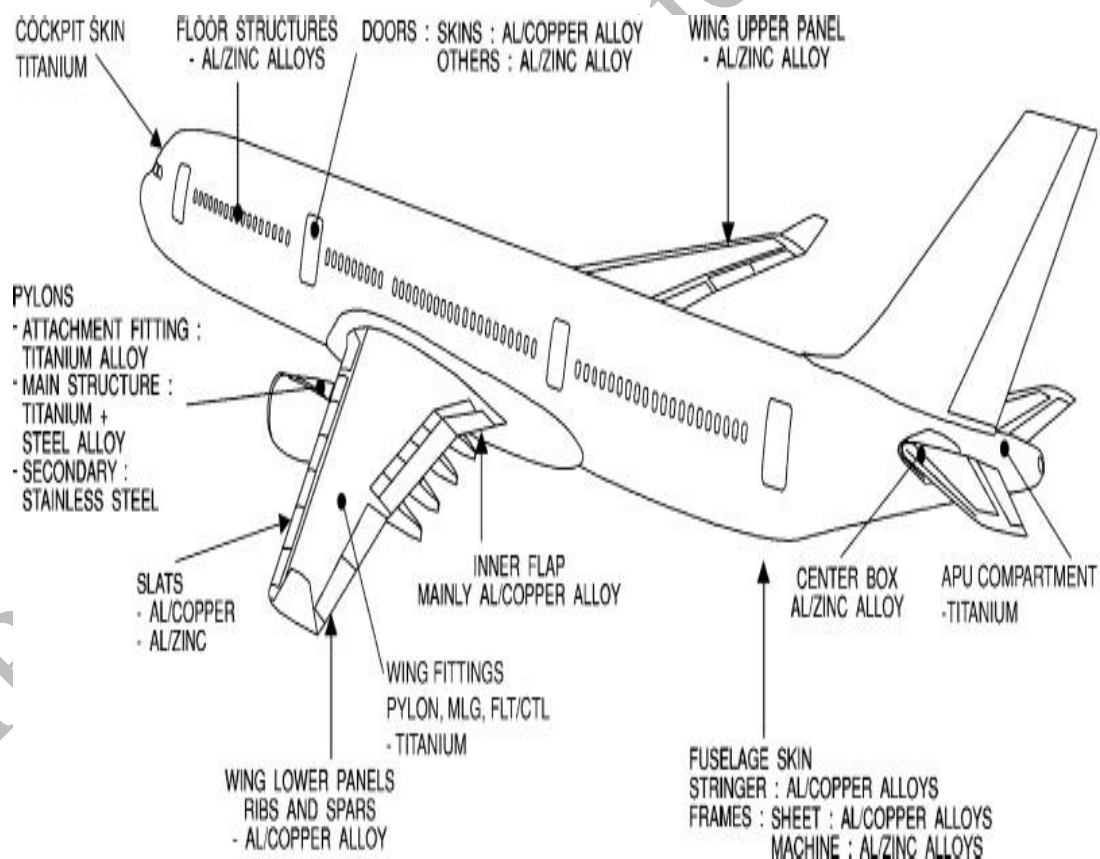
Cast Iron: The cast iron with carbon content of 0.2-1.7% is called cast steel. So, cast steel is a kind of special cast iron. More than 2% of content is called pig iron. Wrought iron is very soft, plastic and easily deformed, but its strength and hardness are lower, so not widely used.

Low Carbon Steel (mild steel): The Low-Carbon (Mild) Steel is soft and easily



ii. **Non Ferrous:** The metal which does not contain iron is called non-ferrous metals. Eg : copper, Aluminum ,Tin ,Lead.

- a) **Aluminum:** Commercially pure aluminum is a white lustrous metal which stands second in the scale of malleability, sixth in ductility, and ranks high in its resistance to corrosion. Aluminum combined with various percentages of other metals forms alloys which are used in aircraft construction. Several aluminum alloys as for example 2024 and 7075 are very susceptible to corrosion. Sheets of such material are clad with a thin layer of pure aluminum with 1 % zinc on both sides as a mean of corrosion protection. These layers are permanently welded to the base material in a rolling process at high temperature. Other than electroplated stock, clad material can be formed. The thickness of the clad layers is about 3 or 5% of the material thickness. An ink print on US sheet metal that reads Alclad, Clad or Alc indicates that such sheet is clad.



b) Magnesium

Magnesium alloys are used frequently in structures in cast, forged, and sheet form. The greatest advantage of magnesium is that it is one of the lightest metals for its strength. The disadvantages in the use of magnesium sheet are that it is more subject to corrosion than many metals, it is not easily worked at room temperatures, and if it becomes ignited, it is extremely difficult to extinguish. When magnesium is used in an airplane structure, it can often be recognized by the fact that it has a yellowish surface due to the chromate treatment used to pre-vent corrosion and furnish a suitable paint base.

c) Titanium

Titanium is a metal that has been developed within the past fifty years into an important aircraft structural material. It is lightweight and corrosion resistant, and has high structural strength which it retains to a high temperature. It is used in turbine engines, and for aircraft skins in areas where the temperature is high. Titanium may be worked by methods similar to those used with stainless steel, but it requires some special techniques, and the tools used must be kept very sharp. It may be welded, but because it reacts with oxygen at high temperatures, it must be protected from the air with a blanket of helium or argon gas. For this reason, inert-gas arc welding is used.

d) **Nickel Alloys:** nickel alloys used in aerospace. The alloy provides strength and structural reliability at high temperatures, as this alloy remains structurally sound at temperatures as high as 870°C. As a result of Wasaploy's great temperature resistance, it is routinely used in the exhaust section of an aircraft where burning jet fuel can cause parts to become immensely hot for extended periods of time. Other nickel alloys commonly used in the 'hot section' are Alloy 25, 188, 282®, 625, 718, X and Rene 41. (* 'hot section' refers to combustion chambers and exhaust systems of an aircraft).

- Alloy 230, C263, 617, 625, X, X-750 and 75 have superb resistance in extremely high-stressed and high temperature environments, such as those found in pressure vessels, rocket engines, gas turbines and other aircraft structures.
- Alloy X-750 for example, being precipitation hardened with elements such as aluminium and titanium, can withstand very high levels of oxidation and corrosion which are often commonplace in numerous parts of an aircraft engine.

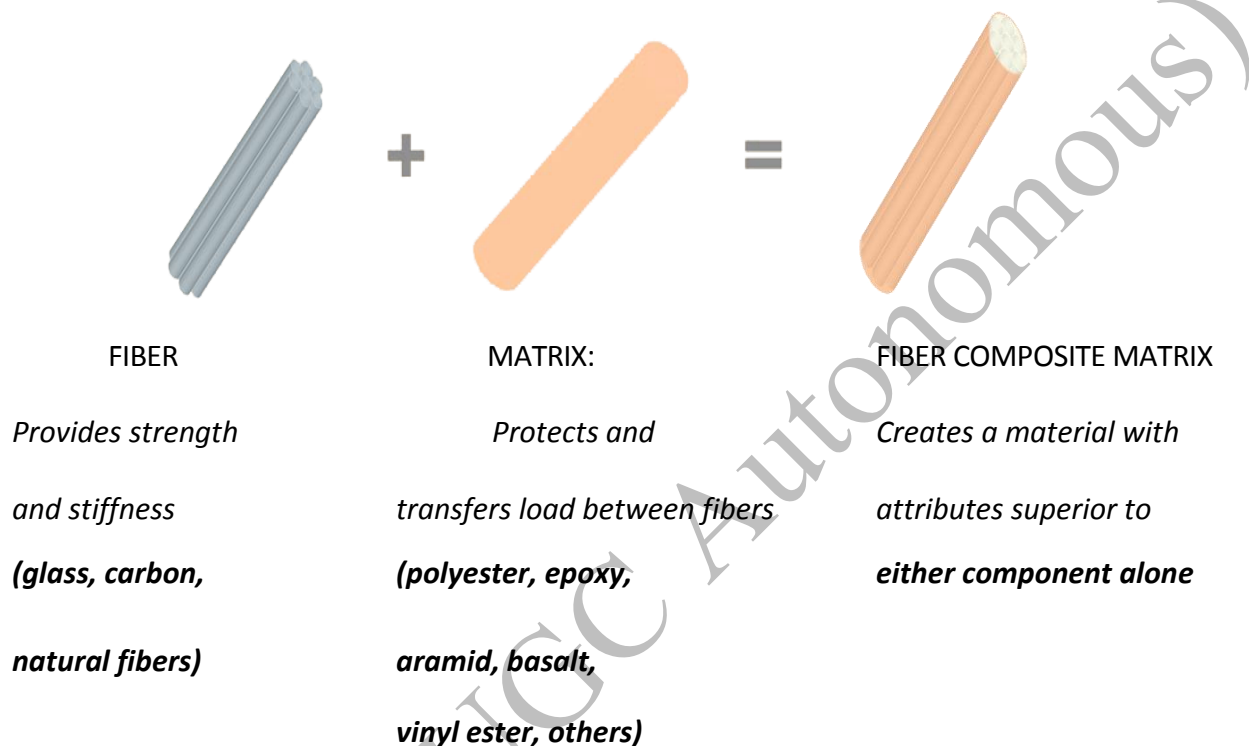
- Alloys 230, C263, 617, 625, X, X-750 and 75 are alloys of choice for the 'cold section' of an aircraft engine where air inlet gets compressed before being combusted.
- CREEP RESISTANCE UNDER HIGH STRESS CONDITIONS Apart from the super alloy mentioned above, other nickel alloys for aerospace applications such as Nimonic®80A and Nimonic®90 have exceptional creep resistance and stress-rupture properties. This alloys' ability to retain its fortitude under high degrees of stress and at temperatures from 815-920°C makes it extremely useful for the construction of aircraft exhaust valves, turbine rotors and other rotating parts.
- WEIGHT-SAVING ALLOYS Because you cannot afford to add any unnecessary weight on an aircraft, strong but light-weight alloys such as titanium grade 5 or Ti 6AL-4V and Ti 6-2-4-2 are a popular choice for a manufacture of discs, ducts, fans and front bearing housing in the turbine engine.
- LOW-EXPANSION AT HIGH TEMPERATURES Alloy 36 is a nickel and iron based alloy (containing 36% nickel) which is used mainly in lay-up tooling for aerospace composite parts and structures. Alloy 36's main advantage is its extremely low levels of expansion at temperatures of 260°C and above, allowing this alloy to consistently retain its shape and strength in the moulding process. Its application within the field of aerospace includes the formation of composites, thermostat rods, measuring devices, laser components and tanks and piping for liquefied gas storage.

III. Composite Materials:

Composites, also known as Fiber-Reinforced Polymer (FRP) composites, are made from a polymer matrix that is reinforced with an engineered, man-made or natural fiber (like glass, carbon or aramid) or other reinforcing material. The matrix protects the fibers from environmental and external damage and transfers the load between the fibers. The fibers, in turn, provide strength and stiffness to reinforce the matrix—and help it resist cracks and fractures.

In many of our industry's products, polyester resin is the matrix and glass fiber is the reinforcement. But many combinations of resins and reinforcements are used in composites—and each material contributes to the unique properties of the finished

product: Fiber, powerful but brittle, provides strength and stiffness, while more flexible resin provides shape and protects the fiber. FRP composites may also contain fillers, additives, core materials or surface finishes designed to improve the manufacturing process, appearance and performance of the final product.



a) Natural and synthetic composites

Composites can be natural or synthetic. Wood, a natural composite, is a combination of cellulose or wood fibers and a substance called lignin. The fibers give wood its strength; lignin is the matrix or natural glue that binds and stabilizes them. Other composites are synthetic (man-made).

Plywood is a man-made composite that combines natural and synthetic materials. Thin layers of wood veneer are bonded together with adhesive to form flat sheets of *laminated* wood that are stronger than natural wood.

Not all plastics are composites. In fact, most plastics—the ones used in toys, water bottles and other familiar items—are *not* composites. They're pure plastics. But many types of plastic can be reinforced to make them stronger. This combination of plastic and reinforcement can produce some of the strongest, most versatile materials (for their weight) ever developed by technology.

Polymer resins (such as polyester, vinyl ester, epoxy or phenolic) are sometimes referred to as plastic.

Many terms are used to define FRP composites. Modifiers have been used to identify a specific fiber such as Glass Fiber Reinforced Polymer (GFRP), Carbon Fiber Reinforced Polymer (CFRP), and Aramid Fiber Reinforced Polymer (AFRP). Another familiar term used is Fiber Reinforced Plastics. In addition, other acronyms have been developed over the years and their use depended on geographical location or market use. For example, Fiber Reinforced Composites (FRC), Glass Reinforced Plastics (GRP), and Polymer Matrix Composites (PMC) can be found in many references. Each of the aforementioned terms means the same thing: FRP composites.

MRCET (UGC Autonomous)

MRCET (UGC Autonomous)

Process associated with conventional metals

Aircraft production technology

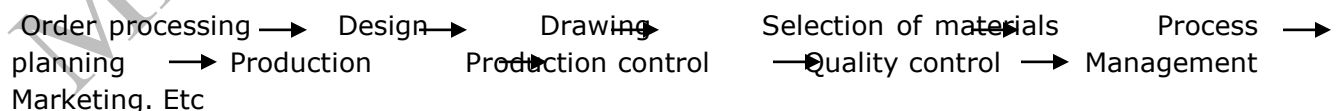
Production of modern aircrafts involves the manufacture of several thousands of individual parts to precise dimensions and assembling them together with brought out components. The parts to be manufactured include those required for the airframe structure and bracketry, pipelines, electric cable runs etc for installing aircraft systems. The individual parts of the aircraft structure are assembled in several stages such as minor subassemblies, sub assemblies and major assemblies to form the aircraft structure.

Unlike mass manufacturing practices prevalent in general engineering industries, aircraft are produced in relatively small quantities. Very high standards of quality control are required to meet the stringent design specifications and ensure safety of human lives. All raw material and components should comply with airworthiness standards and traceable throughout the process of manufacture and service usage to enable proper analysis of defects / flying accidents. Extensive specific to type production tooling is employed for achieving the required close dimensions and tolerances, surface finish and interchangeability of components. Many manufacturing processes and production machines have been specially developed for aircraft industry, such as, heat treatment and surface treatment processes, CNC machines etc. some of these are later adopted in general engineering industries. Sophisticated management system has been evolved in aircraft industry to cope with the complex technologies, high risk and investment, long gestation periods for design, development and production for series preparation and prolonged pay back periods.

Manufacturing:

Manufacturing implies making of articles or goods and providing services to meet the human needs. It creates value by useful application of physical and mental labour in the process. This, however, is too inadequate a definition to give a clear picture of domain of manufacturing which is more complex and broad based than what it appears from this definition.

It can be defined as a chain of interrelated activities and operations as



Most of the metals used in industry are obtained as ores. These ores are subjected to suitable reducing or refining processes which convert the metal into a molten form. This molten metal is poured into moulds to give commercial castings, called ingots. These ingots are further subjected to one or more processes to obtain usable metal products of different

shapes and sizes. All these further processes used for changing the ingots into usable products can be classified as follows

Classification Manufacturing Process

They are mainly classified into six groups:

- **Primary Shaping (or) forming process:** Primary shaping is manufacturing of a solid body from molten or gaseous state or forms an amorphous material. Amorphous materials are liquid, gaseous, powders, fibers, chips, melts and like. A primary shaping or forming tool contains a hollow space, which, with the allowance for contraction usually corresponds to the form of the product. Here, cohesion is normally created among particles. Some of the important primary shaping processes are;

1. Casting
2. Powder metallurgy
3. Plastic technology

- **Deforming processes:** Deforming processes make use of suitable stresses like compression, tension, and shear or combined stresses to cause deformation of the materials to produce required shapes without changing its mass or material composition. In forming, no material is removed; they deformed and displaced. Some of the deforming processes are;

- | | |
|------------------------|----------------------------|
| 1. Forging | 5. Rotary swaging |
| 2. Extrusion | 6. Thread Rolling |
| 3. Rolling | 7. Explosive forming |
| 4. Sheet metal working | 8. Electromagnetic forming |

- **Machining (or) removing processes:** The principle used in all machining processes is to generate the surface required by providing suitable relative motion between the work piece and the tool. In these processes material is removed from the unwanted regions of the input material. In this work material is subjected to a lower stress as compared to forming processes. Some of the machining processes are;

- | | |
|-------------|-------------------------|
| 1. Turning | 5. EDM |
| 2. Drilling | 6. ECM |
| 3. Milling | 7. Shaping & Planning |
| 4. Grinding | 8. Ultrasonic machining |

- **Joining processes:** In this two or more metal parts are united together to make sub-assembly or final product. The joining processes are carried out by

fusing, pressing, rubbing, riveting or any other means of assembling. Some of the joining processes are;

- | | |
|----------------------|-----------------------|
| 1. Pressure welding | 4. Resistance Welding |
| 2. Diffusion welding | 5. Explosive welding |
| 3. Brazing | |
| 6. Soldering | |

- **Surface finish processes:** These processes are utilized to provide intended surface finish on the metal surface of a job. By imparting surface finishing processes, dimension of the part is not changed functionally, either negligible amount of the metal is removed from or certain material is added to the surface of the job. Surface cleaning processes is also accepted as surface finishing processes. Some of the surface finishing processes are

- | | |
|-----------------------|--------------------|
| 1. Plastic coating | 7. Honing |
| 2. Metallic coating | 8. Tumbling |
| 3. Organic finishes | 9. Electro-plating |
| 4. Anodizing | 10. Lapping |
| 5. Buffing | 11. Sanding |
| 6. Inorganic finishes | |

- **Material properties modification processes**

1. Heat and surface treatment
2. Annealing
3. Stress relieving

The selection of manufacturing process depends on:

- i. Type & nature of the starting material.
- ii. Volume of production.
- iii. Expected quality & properties of the components.
- iv. Technical viability of the process.
- v. Economy.
- vi. Other factors influencing are – Geometric shape, tooling, jigs fixtures, gauges, equipment and delivery date.

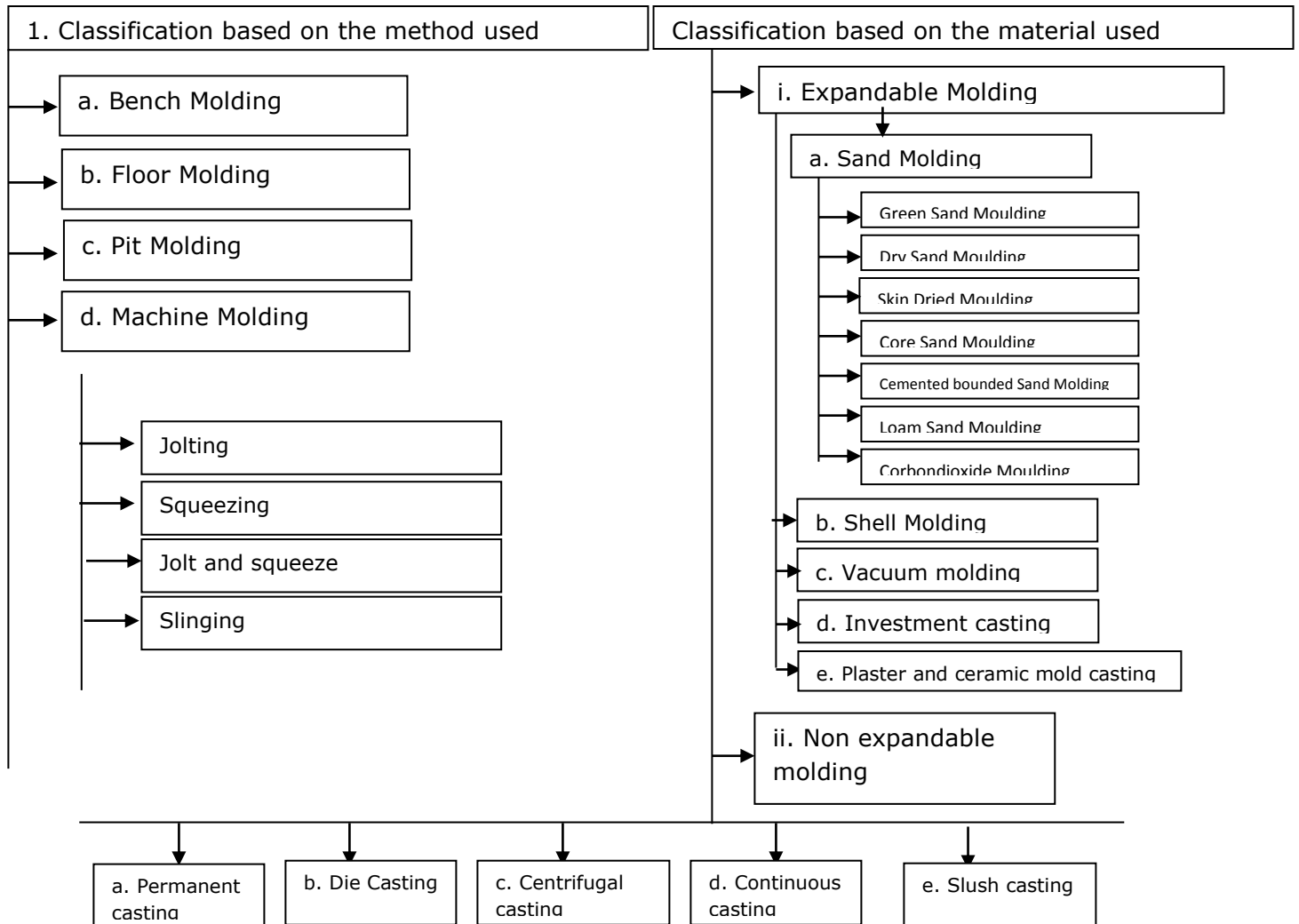
Selection of material is based on the processing factors and functional requirements referred in table 1.1 to 1.3.

Type of material is whether to select a brittle or ductile material. And whether they are casted or machined.

Ex:

1. Cold work renders a stronger, harder and brittle material. And surface finish, tolerances can be obtained when compared to hot working.
2. Very thin sections can not be casted and complex parts can't be mechanically worked easily.
3. Lead time: time to start the work. If larger volumes are manufactured it must be economical and reduce the cost per unit.
4. Able to complete by the delivery date or possible before that and check for quality.
5. Cost must be optimum.

MOULDING



a. BENCH MOLDING: is for small work, done on a bench of a height convenient to the molder.

b. FLOOR MOLDING: When castings increase in size, with resultant difficulty in handling, the work is done on the foundry floor. This type of molding is used for practically all medium and large size castings.

c. PIT MOLDING: Extremely large castings are frequently molded in a pit instead of a flask. The pit acts as the drag part of the flask and a separate cope is used above it. The sides of the pit are brick kind, and on the bottom there

d. MACHINE MOLDING: Machines have been developed to do a number of operations that the molder ordinarily does by hand. Ramming the sand, rolling the mold, forming the gate and drawing the pattern can be done by these machines.

There are three main types of machines:

Jolting

Squeezing

Sand slinger

Or combination of above three

JOLTING: In the jolting molding machine, the pattern and flask are mounted on a mould plate and flask is filled with sand. The entire assembly is raised a small amount by means of a cylinder and is then dropped against a fixed stop. The compacting of sand is achieved by the decelerating forces acting on it.

SQUEEZING: this machine has a fixed flask and movable flask which compresses the sand in the molding flask.

SAND SLINGER: in this machine the sand is thrown out by centrifugal force from a rapidly rotating single laded impeller and directed over the pattern in the flask.

i PERMANENT MOULD

In this method the same mould is used for large numbers of castings. Each casting is released by opening the mould rather than by destroying it. Permanent moulds need to be made of a material which can withstand the temperature fluctuations and wear associated with repeated casting. A good example of a product made with methods such of this is the ubiquitous 'die-cast' child's toy ('die' is another word for 'mould').

ii EXPENDABLE MOULD AND PATTERN

With this type of casting, a pattern is made from a low melting point material and the mould is built around it. The pattern is then melted or burnt out as the metal is poured in. The mould has to be destroyed to retrieve the casting. This method is used to make moulds for casting high melting-point alloys like those used for jet engine turbine blades. A model (the pattern) of the blade is made in wax. The pattern is then coated in a thick slurry containing ceramic particles. The slurry dries, and is then fired in an oven: this hardens the ceramic (like firing a pot) and melts out the wax, leaving a hollow ceramic mould. The metal is then poured in to the mould, which is broken away after the metal has solidified and cooled.

CASTING is a manufacturing process by which a liquid material is (usually) poured into a mold, which contains a hollow cavity of the desired shape, and then allowed to solidify. The solid casting is then ejected or broken out to complete the process. Casting may be used to form hot liquid metals or various materials that *cold set* after mixing of components (such as epoxies, concrete, plaster and clay). Casting is a 6000 year old process. The casting process is subdivided into two distinct subgroups: **expendable and non-expendable mold casting**.

Advantages of Castings

- Intricate can be achieved, molten metal can be made to flow into any small section in the mould cavity and as such any intricate shapes internal or external can be made with the casting process
- Castings of ferrous and nonferrous metals are practically possible
- Necessary tools required for casting mould are simple and inexpensive. As a result, for trial production or of a small lot, it is an ideal method it is possible in casting process, to the amount of material where exactly require. As a result, weight reduction in design can be achieved

- Castings are generally cooled uniformly from all sides and therefore they are expected to have no directional properties
- Castings of and weight, even up to two hundred tones can be made.

Steps involved in Casting are

- 1) Pattern making
- 2) Mould and core preparation (or) making
- 3) Making the provisions like gating, riser, runner, sprue
- 4) Melting and pouring the metal
- 5) Allow the mould to solidify
- 6) Fettling i.e. Cleaning
- 7) Testing and inspection of the casting

CASTING TERMS:

PATTERN: Pattern is the replica of the final object to be made with some modifications. The mould cavity is made with the help of the pattern.

PARTING LINE: This is a line dividing the molding flasks that makes up the sand mould. In split pattern it is also the dividing between the two halves of the pattern

BOTTOM BOARD: This the board normally made of wood which is used at the start of the mould making. The pattern is first kept on the board, sand is sprinkled on it and then ramming is done in the drag.

FACING SAND: Small amount of carbonaceous material sprinkled on the inner surface of the mould cavity to give a better surface finish to the castings.

MOULDING SAND: Mixture of silica, clay and moisture in appropriate proportions to get the desired results and it surrounds the pattern while making the mould cavity.

BACKING SAND: It constitutes the refractory material found in the mould. This is made up of burnt sand.

FLASK: A moulding flask is one which holds the sand mould intact. Depending upon the position of the flask in mould structure it is referred to by various names

drag – lower moulding flask

cope – upper moulding flask

cheek – intermediate moulding flask

CHILLS: To control the solidification and metallurgical structure of the metal, it is possible to place metal plates—chills—in the mold. The associated rapid local cooling will form a finer-grained structure and may form a somewhat harder metal at these locations. In ferrous castings the effect is similar to quenching metals in forge work.

CORES: Cores are separate shapes of sand that are generally required to form hollow interiors of the casting or a hole through the casting. To produce cavities within the casting—such as for liquid cooling in engine blocks and cylinder heads—negative forms are used to produce cores. Usually sand-molded, cores are inserted into the casting box after removal of the pattern. Whenever possible, designs are made that avoid the use of cores, due to the additional set-up time and thus greater cost.



Requirements:

1. Cores must be strong enough to retain its shape without deforming, to withstand handling and to resist erosion and deformation during filling of the mould
2. Cores must be permeable to allow the core gases to escape easily
3. Cores should be highly refractory in nature to withstand high temperature of the molten metal
4. Cores must be sufficiently low in residual gas-forming materials to prevent excess gas entering the metal
5. Cores must be stable with a minimum of contraction and expansion to make a true form of casting
6. Cores should be sufficiently collapsible, i.e., they should disintegrate and collapsible after the metal solidifies, to minimize strains on the castings and to facilitate removal of the core from the castings during shakeout.

PATTERN → Pattern is the replica of the component to be produced by casting process and is used to prepare mould cavity. The success of a casting process depends a lot on the quality and the design of pattern.

PATTERN MATERIALS → generally pattern is prepared using any of the following

1. Wood
2. Metal
3. Plastic
4. Plaster & Polyurethane foam
5. Wax or Mercury.

Types of patterns**PATTERNS**

There are various types of patterns depending upon the complexity of the job, the no of castings require and the molding procedure adopted

- Single piece pattern
- Split pattern
- Match plate pattern
- Cope and drag pattern
- Gated pattern
- Loose piece pattern
- Sweep pattern
- Follow board pattern
- Skeleton pattern
- Segmental pattern
- Shell pattern
- Built-up pattern
- Boxed-up pattern
- Lagged-up pattern
- Left and right hand pattern

Single piece pattern:

MOLDING MATERIAL AND PROPERTIES

A large variety of molding materials is used in foundries for manufacturing molds and cores. They include molding sand, system sand or backing sand, facing sand, parting sand, and core sand. The choice of molding materials is based on their processing properties. The properties that are generally required in molding materials are: Table 4

- **Refractoriness:** It is the ability of the molding material to resist the temperature of the liquid metal to be poured so that it does not get fused with the metal. The refractoriness of the silica sand is highest.
- **Permeability:** During pouring and subsequent solidification of a casting, a large amount of gases and steam is generated. These gases are those that have been absorbed by the metal during melting, air absorbed from the atmosphere and the steam generated by the molding and core sand. If these gases are not allowed to escape from the mold, they would be entrapped inside the casting and cause casting defects. To overcome this problem the molding material must be porous. Proper venting of the mold also helps in escaping the gases that are generated inside the mold cavity.
- **Green Strength:** The molding sand that contains moisture is termed as green sand. The green sand particles must have the ability to cling to each other to impart sufficient strength to the mold. The green sand must have enough strength so that the constructed mold retains its shape.
- **Dry Strength:** When the molten metal is poured in the mold, the sand around the mold cavity is quickly converted into dry sand as the moisture in the sand evaporates due to the heat of the molten metal. At this stage the molding sand must possess the sufficient strength to retain the exact shape of the mold cavity and at the same time it must be able to withstand the metallostatic pressure of the liquid material.
- **Hot Strength:** As soon as the moisture is eliminated, the sand would reach at a high temperature when the metal in the mold is still in liquid state. The strength of the sand that is required to hold the shape of the cavity is called hot strength.
- **Collapsibility:** The molding sand should also have collapsibility so that during the contraction of the solidified casting it does not provide any resistance, which may result in cracks in the castings. Besides these specific properties the molding material should be cheap, reusable and should have good thermal conductivity.

Molding Sand Composition: The main ingredients of any molding sand are:

1. Base Sand: Silica sand is most commonly used base sand. Other base sands that are also used for making mold are zircon sand, Chromite sand, and olivine sand. Silica sand is cheapest among all types of base sand and it is easily available.

2. Binder: Binders are of many types such as:

1. Clay binders,

2. Organic binders

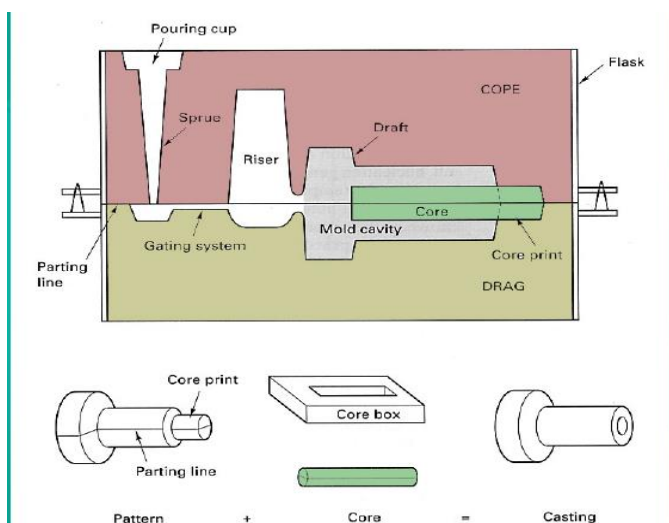
3. Inorganic binders

Clay binders are most commonly used binding agents mixed with the molding sands to provide the strength. The most popular clay types are: Kaolinite or fire clay ($\text{Al}_2\text{O}_3 \cdot 2 \text{SiO}_2 \cdot 2 \text{H}_2\text{O}$) and Bentonite ($\text{Al}_2\text{O}_3 \cdot 4 \text{SiO}_2 \cdot n\text{H}_2\text{O}$) of the two the Bentonite can absorb more water which increases its bonding power.

3. Moisture: Clay acquires its bonding action only in the presence of the required amount of moisture. When water is added to clay, it penetrates the mixture and forms a microfilm, which coats the surface of each flake of the clay. The amount of water used should be properly controlled. This is because a part of the water, which coats the surface of the clay flakes, helps in bonding, while the remainder helps in improving the plasticity. A typical composition of molding sand is given in (Table 4).

ELEMENTS OF GATING SYSTEMS: Gating system provides the way for the molten metal to flow in to the mould cavity when poured from the ladle. It comprises of

1. Pouring basin
2. Sprue
3. Sprue base well
4. Runner
5. Runner extension
6. In gate
7. Riser
8. Core



DIFFERENT PATTERN ALLOWANCES:**1. Shrinkage allowance:**

Castings shrink when they cool. Like nearly all materials, metals are less dense as a liquid than a solid. During solidification (freezing), the metal density dramatically increases. This results in a volume decrease for the metal in a mold. Solidification shrinkage is the term used for this contraction. Cooling from the freezing temperature to room temperature also involves a contraction. The easiest way to explain this contraction is that is the reverse of thermal expansion. Compensation for this natural phenomenon must be considered in two ways. Shrinkage after solidification can be dealt with by using an oversized pattern designed for the relevant alloy. Pattern makers use special "contraction rulers" (also called "shrink rules") to make the patterns used by the foundry to make castings to the design size required.

2. Machine allowance: Castings may oxidised in the mould during heat treatment so scales etc are formed, even rough surfaces are seen, therefore machining is to be done,therefore the dimensions must be slightly higher to compensate this decrease in dimensions.

- Machine finish allowance should be given on pattern in order to compensate the amount of metal that is lost in machining or finishing the casting to obtain the final casting of required dimensions and surface finish.
- The amount of this allowance depends upon the size of casting, type of machining operation such as grinding, turning, milling, boring etc.
- Type of moulding process such as sand casting, die casting etc, and the degree of surface finish

3. Draft allowance:

At the time of withdrawing the pattern from the sand mould, the vertical faces of the pattern are in continual contact with the sand, which may damage the mould cavity, as shown in figure 1. To reduce the chances of this happening, the vertical faces of the pattern are always tapered from the parting line as shown in figure 2. This provision is called draft allowance. Draft allowance varies with the complexity of the job.

- In general inner details of the pattern require higher draft than outer surfaces.
- More draft is needed in case of hand moulding compare to machine moulding.

4. Distortion allowance:

- Weaker section such as long flat portions, U, V, Sections are distortion prone.
- Foundry practice should be given extra material provision for reducing the distortion. Alternatively, the shape of pattern itself should be given a distortion of equal amounts in the opposite direction of the likely distortion direction.

5. Shake or Rapping allowance:

Before withdrawal from the sand mould, the pattern is rapped all around the vertical faces to enlarge the mould cavity slightly which facilitates its removal. Since it enlarges the final casting made, it is desirable that the original pattern dimensions should be reduced to account for this increase.

- No quantifying method is available.
- Depends on the personnel and practices involved.

It is the negative allowance and is to be applied only to those dimensions which are parallel to the [parting plane](#).

MELTING PRACTICES

Melting is an equally important parameter for obtaining a quality castings. A number of furnaces can be used for melting the metal, to be used, to make a metal casting. The choice of furnace depends on the type of metal to be melted. Some of the furnaces used in metal casting are as following.

- Crucible furnaces
- Cupola
- Induction furnace
- Reverberatory furnace

1. CRUCIBLE FURNACE.

Crucible furnaces are small capacity typically used for small melting applications. Crucible furnace is suitable for the batch type foundries where the metal requirement is intermittent. The metal is placed in a crucible which is made of clay and graphite. The energy is applied indirectly to the metal by heating the crucible by coke, oil or gas. The heating of crucible is done by coke, oil or gas. .

2. COKE-FIRED FURNACE.

- Primarily used for non-ferrous metals
- Furnace is of a cylindrical shape
- Also known as pit furnace
- Preparation involves: first to make a deep bed of coke in the furnace
- Burn the coke till it attains the state of maximum combustion
- Insert the crucible in the coke bed
- Remove the crucible when the melt reaches to desired temperature

3. OIL-FIRED FURNACE.

- Primarily used for non-ferrous metals
- Furnace is of a cylindrical shape
- Advantages include: no wastage of fuel
- Less contamination of the metal
- Absorption of water vapor is least as the metal melts inside the closed metallic furnace

4. CUPOLA FURNACE

Cupola furnaces are tall, cylindrical furnaces used to melt iron and ferrous alloys in foundry operations. Alternating layers of metal and ferrous alloys, coke, and limestone are fed into the furnace from the top. A schematic diagram of a cupola is shown in Figure. This diagram of a cupola illustrates the furnace's cylindrical shaft lined with refractory and the alternating layers of coke and metal scrap. The molten metal flows out of a spout at the bottom of the cupola. .

Gas defects:-

- **Blow holes and open blows:** These are the spherical, flattened or elongated cavities present inside the casting or on the surface as shown on the surface they are called open blows and inside, they are called blow holes. Because of the heat in the molten metal, the moisture is converted into steam, part of which when entrapped in the reaches the surface.
- **Air inclusions:** The atmospheric and other gases absorbed by the molten metal in the furnace, in the ladle, and during the flow in the mould, when not allowed to escape, would be trapped inside the casting and weaken it.
- **Pin hole porosity:** This is caused by hydrogen in the molten metal. This could have been picked up in the furnace or by the dissociation of water inside the mould cavity.
- **Shrinkage cavities:** These are caused by the liquid shrinkage occurring during the solidification of the casting.

Causes:

Excessive moisture & Organic content of sand, Moisture on chills, chaplets or metal inserts, Poor venting and Less permeability of sand if used (hard ramming), High gas content of molten metal and improper feeding & Insufficient drying of mould and cores

Molding material defects:

- **Cuts and washes:** These appear as rough spots and areas of excess metal, and are caused by the erosion of molding sand by the flowing molten metal. It appears as a low projection on the drag face of a casting that extends along the surface, decreasing the height as it extends from one side of the casting to the other end. It generally occurs in bottom gating in which the sand is not of sufficient hot strength and when too much metal is allowed to flow.
- **Metal penetration:** When the molten enters the gaps between the sand grains, the result would be a rough casting surface. The main reason for this is that, either the grain size of the sand is too coarse, or no mould wash has been applied to the mould cavity.
- **Fusion:-** This is caused by the fusion of sand grains with the molten metal, giving a brittle, glassy appearance on the casting surface.
 - **Run out:-** A run out is caused when the molten metal leaks out of the mould. This may be caused either due to faulty mould making or because of the faulty molding flask.
 - **Buckles:-** It appears as a long, fairly, shallow, broad, vee depression occurring in the surface of flat castings. It extends in a straight line across the entire flat surface. Rat tail is caused by the compression failure of the skin of the mould cavity because of the excessive heat in the molten metal. This as molding sand has got poor expansion properties and hot strength or the heat in the pouring metal is too high.
 - **Rat tails:** It appears as a long, fairly, shallow, broad, angular depression occurring in the surface of flat castings. It extends in a straight line across the entire flat surface.
 - **Swell:** this occurs as slight smooth bulge usually found on vertical faces of castings resulting from liquid metal pressure. Under the influence of the metallostatic forces, the mould wall may move back causing a swell in the dimensions of the casting. This is caused due to low strength of mould because of too high water content or when sand not rammed properly.
 - **Drop:** The dropping of loose molding sand or lumps normally from the cope surface into the mould cavity is responsible for this defect.
 - **Scab:** Caused when portion of the face of a mould lifts or break downs thus the recess is filled by the molten metal.

Pouring metal defects:-

- **Mis-runs:** Mis-run is caused when the metal is unable to fill the mould cavity completely and thus leaves unfilled cavities.
- **Cold shuts:** A cold shut is caused when two metal streams while meeting in the mould cavity, did not fuse together properly, thus causing a discontinuity or weak spot in the casting.

Causes:

1. Sometimes a condition leading to cold shuts can be observed when no sharp corners exist in a casting.
2. These defects are caused essentially, by the lower fluidity of the molten metal or when the section thickness of the casting is too small.

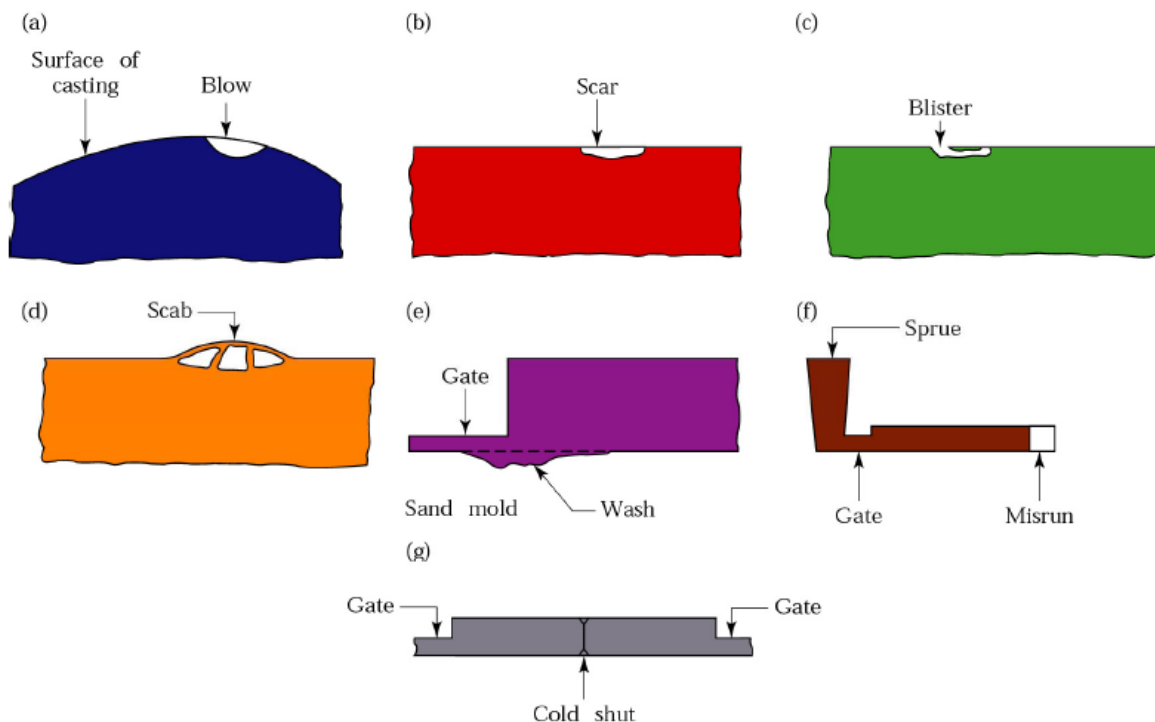
Metallurgical defects:-

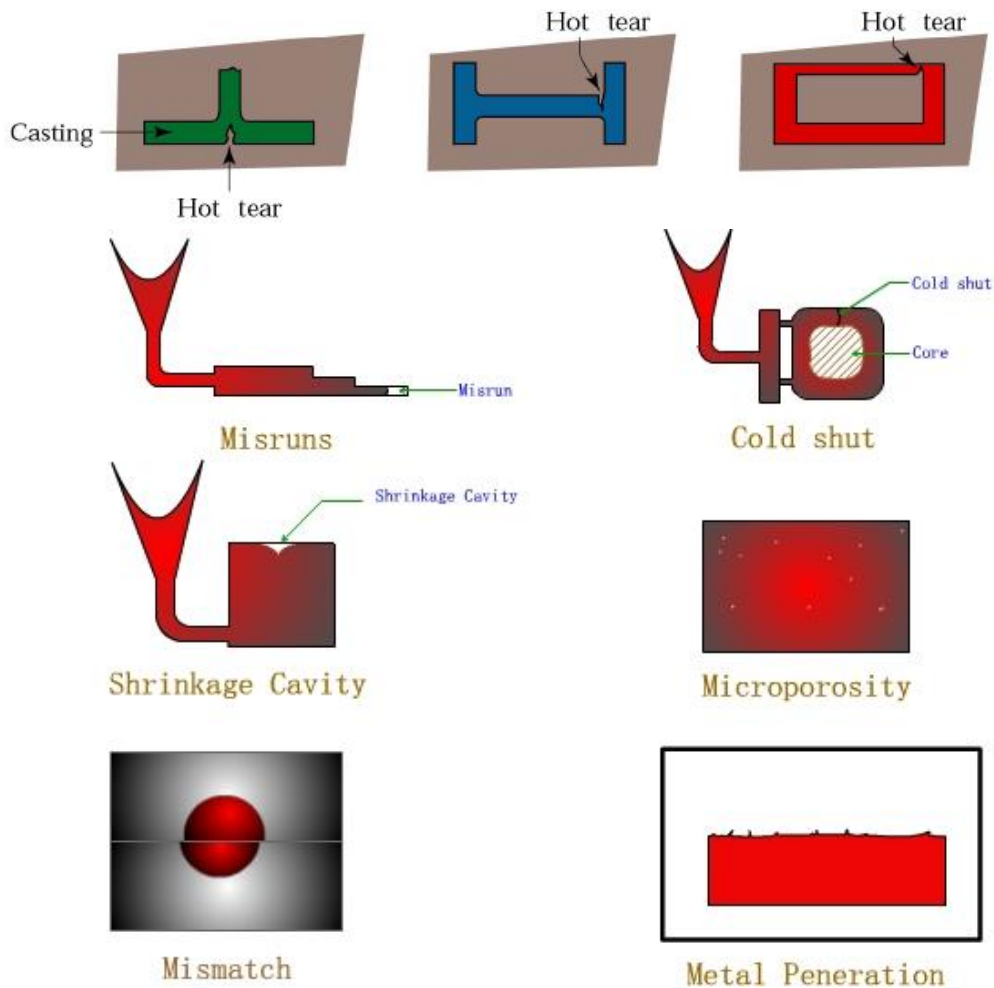
- **Hot tears:-** Hot tears are hot cracks which appear in the form of irregular crevices with dark oxidized fracture surface.

Causes:

Since metal has low strength at higher temperature, any unwanted cooling stress may cause the rupture of the casting, If the metal does not have sufficient strength to resist ensile forces produced during solidification & Non uniform cooling and incorrect gating design

- **Hot spots:-** These are caused by the chilling of the casting. For example, with grey cast iron having small amounts of silicon, very hard white cast iron may result at the chilled surface.





FETTING

The complete process of the cleaning of casting, called 'fettling', involves the removal of the cores, gates and risers, cleaning of the casting surface and chipping of the unnecessary projections on surfaces.

The dry sand cores can be removed simply by knocking off with an iron bar, by means of core vibrator, or by means of hydro blasting. The method depends on the size, complexity and the core material used.

The gates and risers can be removed by hammering, chipping, hack sawing, abrasive cutoff or by flame or arc cutting. For brittle materials such as grey cast iron, the gates can easily be broken by hitting with a hammer. For steel and other similar materials, sawing with any metal cutting saw like hack saw and band saw would be more convenient. For large size gates and risers, it may be necessary to use flame or arc cutting to remove them. Similarly, abrasive cut off may also be used for removal of gates.

For cleaning the sand particles sticking to the casting surface, sand blasting normally used. The casting is kept in a closed box and a jet of compressed air with a blast of sand grains or steel grit is directed against the surface, which thoroughly cleans the casting surface. The typical shot speeds reached of the order of 80 m/s.

Another useful method for cleaning the casting surface is the tumbling. Here the castings are kept in a barrel which is completely closed and then slowly rotated on a horizontal axis 30 to 40 rpm. The barrel is reasonably packed, with enough room for castings to move so that they will be able to remove the sand and unwanted fins and projections. However one precaution to be taken for tumbling is that, the casting should all be rigid with non frail or overhung segments which may get knocked off during the tumbling operation.

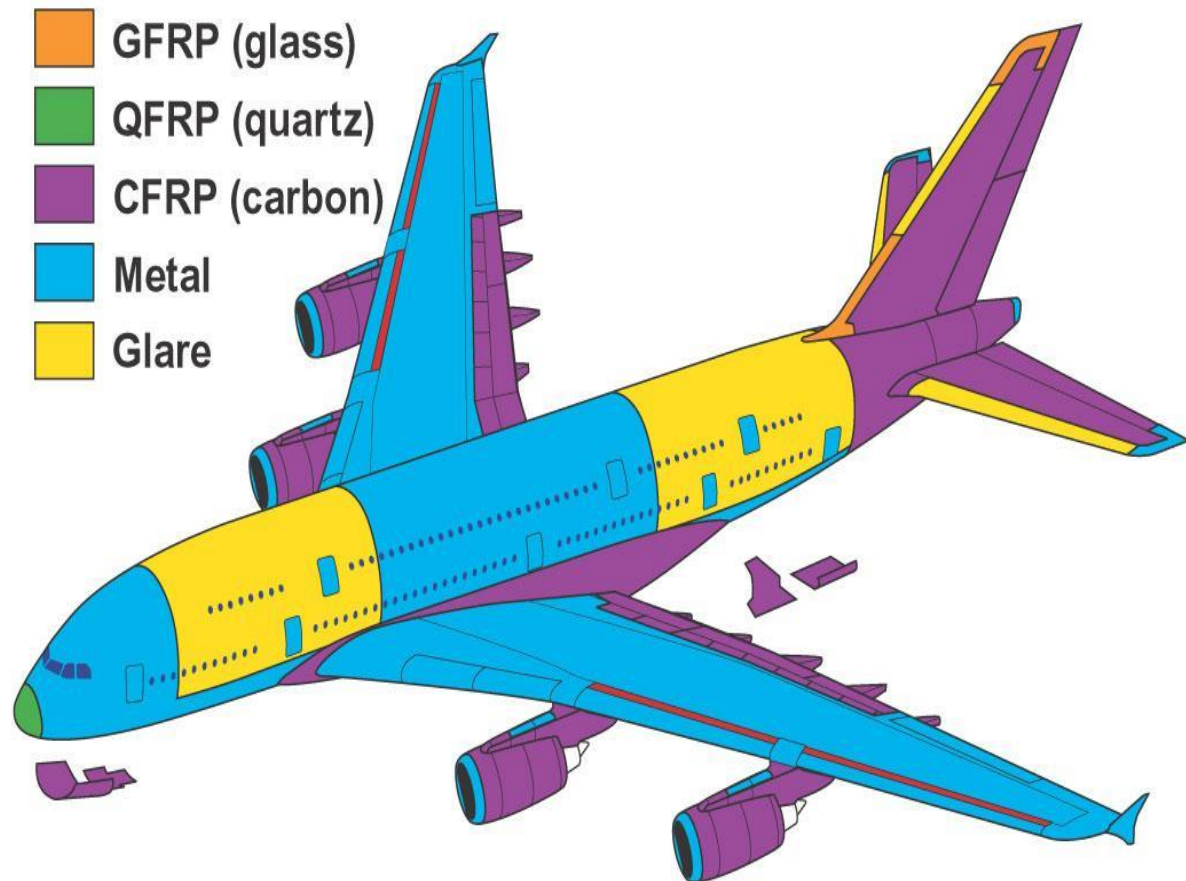
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UNIT II

METALS AND ALLOYS

A380-800 MATERIALS OVERVIEW



2.1 ALUMINIUM & ITS ALLOYS

Aluminium alloys have been the main airframe materials since they started replacing wood in the late 1920s. Even though the role of aluminium in future aircraft will probably be somewhat diminished by the increasing use of composite materials, high-strength aluminium alloys are, and will remain, important airframe materials. The attractiveness of aluminium is that it is a

- Relatively low cost
- light weight metal
- They can be heat treated to fairly high-strength levels;
- easily fabricated of the high-performance materials,

Disadvantages of aluminium alloys include

- a low modulus of elasticity,
- low elevated-temperature capability (130 °C),
- in high-strength alloys the susceptibility to corrosion

Dramatic improvements in aluminium alloys have occurred since they were first introduced in the 1920s. These improvements, shown in Fig. 2.1, are a result of increasing understanding of chemical composition, impurity control and the effects of processing and heat treatment. The data in Fig. 2.1 pertain to established aerospace aluminium alloys; newer ones (such as AA7085) are under evaluation, as are the third-generation aluminium–lithium (Al–Li) alloys. The chemical compositions of some aerospace grade aluminium alloys [2] are given in Table 2.1. One of the earliest aerospace Al alloys was Duralumin (AA2017) which had a yield strength of 280 MPa. Property improvements have come through development of new alloy systems, modifications to compositions within particular systems, and from the use of a range of multistage ageing treatments (tempers) [3].

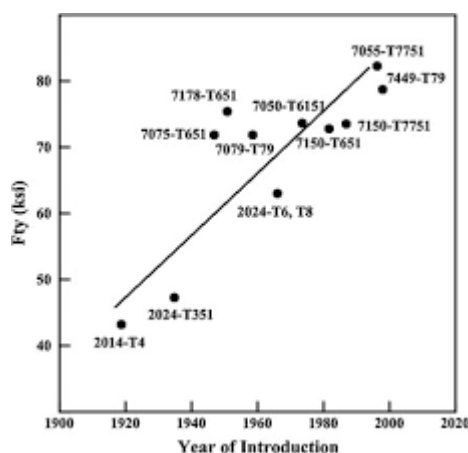
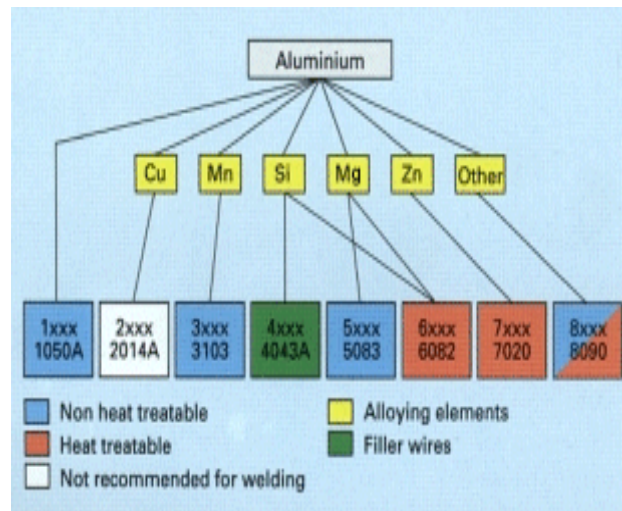


Figure 2.1: Yield strengths versus year of introduction of Al alloys



I. Classification and Designation:

Aluminium alloys are classified as

Heat treatable

Non-heat treatable,

The heat treatable alloys contain elements that decrease in solid solubility with decreasing temperature, and in concentrations that exceed their equilibrium solid solubility at room temperature and moderately higher temperatures. The most important alloying elements in this group include copper, lithium, magnesium and zinc. A large number of other compositions rely instead on work hardening through mechanical reduction, usually in combination with various annealing procedures for property developments.

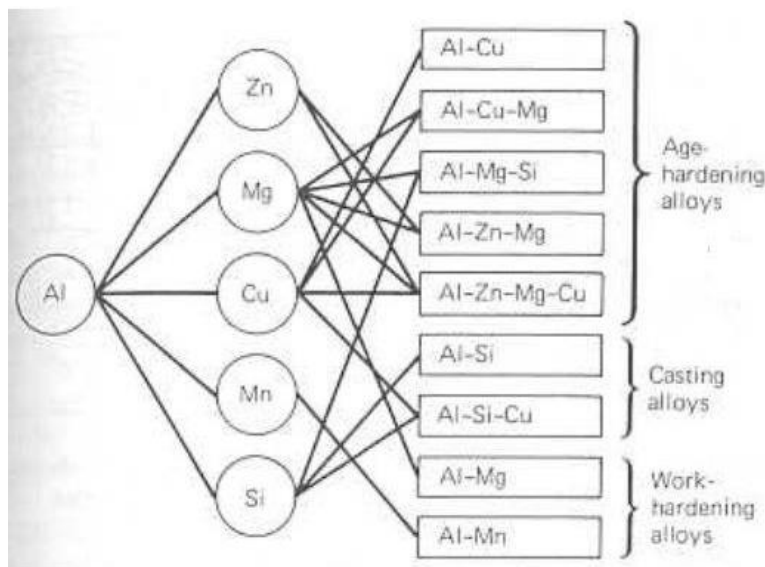
These alloys are referred to as non-heat-treatable or work-hardening alloys. Some casting alloys are essentially non-heat-treatable and are used as-cast or in thermally modified conditions uninfluenced by solutionizing or precipitation effects.

Figure 2.2 gives an overview of the principal types of aluminium alloys.

A. Wrought Alloys A four-digit numerical designation system is used to identify wrought aluminium and aluminium alloys. As shown below, the first digit of the four-digit designation indicates the group. Aluminium, >99.00 %—1XXX.

Aluminium alloys grouped by major alloying element(s);

Copper	—	2XXX;
Manganese	—	3XXX;
Silicon	—	4XXX;
Magnesium	—	5XXX;
Magnesium and Silicon	—	6XXX;
Zinc	—	7XXX;
Other elements	—	8XXX;
Unused series	—	9XXX.



B. Cast Alloys A system of four-digit numerical designations incorporating a decimal point is used to identify aluminium and aluminium alloys in the form of castings and foundry ingots. The first digit indicates the alloy group. Aluminium, >99.00 %—1XX.X.

Aluminium alloys grouped by major alloying element(s);

Copper	—	2XX.X;
Silicon with added copper and/or magnesium	—	3XX.X;
Silicon	—	4XX.X;
Magnesium	—	5XX.X;
Zinc	—	7XX.X;
Tin	—	8XX.X;
Other elements	—	9XX.X;
Unused series	—	6XX.X

C. Temper Designations

The temper designation system is used for all product forms (both wrought and cast), with the exception of ingots. The system is based on the sequences of mechanical or thermal treatments, or both, used to produce the various tempers.

The temper designation follows the alloy designation and is separated from it by hyphen. Basic temper designations consist of individual capital letters. Major subdivisions of basic tempers, where required, are indicated by one or more digits following the letter. These digits designate sequences of treatments that produce specific combinations of characteristics in the product. Variations in treatment conditions within major subdivisions are identified by additional digits.

- **T1—cooled from an elevated-temperature shaping process and naturally aged to a substantially stable condition.** This designation applies to products that are not cold-worked after an elevated-temperature shaping process such as casting or extrusion, and for which mechanical properties have been stabilized by room temperature ageing. This designation also applies to products that are flattened or straightened after cooling from the shaping process, whereby the cold-work effects imparted by flattening or straightening are not accounted for in the specified property limits.
- **T2—Cooled from an elevated-temperature shaping process, cold-worked, and naturally aged to a substantially stable condition.** This designation refers to products that are cold-worked specifically to improve strength after cooling from a hot-working process such as rolling or extrusion, and for which the mechanical properties have been stabilized by room temperature ageing. This designation also applies to products in which the effects of cold-work, imparted by flattening or straightening, are accounted for in the specified property limits.
- **T3—Solution heat treated, cold-worked, and naturally aged to a substantially stable condition.** T3 applies to products that are cold-worked specifically to improve strength after solution heat treatment and for which mechanical properties have been stabilized by room temperature ageing. This designation also applies to products in which the effects of cold work, imparted by flattening or straightening, are accounted for in the specified property limits.
- **T4—Solution heat treated and naturally aged to a substantially stable condition.** This designation signifies products that are not cold-worked after solution heat treatment and for which mechanical properties have been stabilized by room temperature ageing. If the products are flattened or

straightened, the effects of the cold-work imparted by flattening or straightening are not accounted for in the specified property limits.

- **T5—Cooled from an elevated-temperature shaping process and artificially aged.** T5 includes products that are not cold-worked after an elevated-temperature shaping process such as casting or extrusion and for which the mechanical properties have been substantially improved by precipitation heat treatment. If the products are flattened or straightened after cooling from the shaping process, the effects of the cold-work imparted by flattening or straightening are not accounted for in the specified property limits.
- **T7—Solution heat treated and overaged or stabilized.** T7 applies to wrought products that have been precipitation heat treated beyond the point of maximum strength to provide some special characteristics, such as enhanced resistance to stress corrosion cracking or exfoliation corrosion. This designation also applies to cast products that are artificially aged after solution heat treatment to provide dimensional and strength stability.
- **T8—Solution heat treated, cold-worked, and artificially aged.** This designation applies to products that are cold-worked specifically to improve strength after solution heat treatment and for which mechanical properties or dimensional stability, or both, have been substantially improved by precipitation heat treatment. The effects of cold work, including any cold work imparted by flattening or straightening, are accounted for in the specified property limits.
- **T9—Solution heat treated, artificially aged, and cold-worked.** This group is comprised of products that are cold-worked specifically to improve strength after they have been precipitation heat treated.
- **T10—Cooled from an elevated-temperature shaping process, cold-worked, and artificially aged.** T10 identifies products that are cold-worked specifically to improve strength after cooling from a hot-working process such as rolling or extrusion and for which the mechanical properties have been substantially improved by precipitation heat treatment. The effects of cold work, including any cold work imparted by flattening or straightening, are accounted for in the specified property limits.

II. Age-Hardenable Aluminium Alloys: Although most metals will alloy with aluminium, comparatively few have sufficient solid solubility to serve as major alloying additions, see Table 2.2. Some of the transition metals, e.g. chromium, manganese and zirconium, which have solid solubilities below 1 at.% confer important improvements to alloy properties by forming intermetallic compounds that control the grain structure. Apart

from tin, which is sparingly soluble, the maximum solid solubilities in binary aluminium alloys occur at the eutectic and peritectic temperatures.

The heat treatment given to aluminium alloys to increase strength is age hardening. As stated at the beginning of Sect. 2.2, the basic requirement for an alloy to be amenable to age-hardening is a decrease in solid solubility of one or more of the alloying elements with decreasing temperature. Heat treatment normally involves the following stages:

1. Solution treatment at a relatively high temperature within the single-phase region.
2. Rapid cooling or quenching, usually to room temperature to obtain a supersaturated solid solution (SSSS) of the age-hardening elements in aluminium.
3. Controlled decomposition of the SSSS to form a finely dispersed precipitate, usually by ageing for convenient times at one and sometimes two intermediate temperatures.

The complete decomposition of an SSSS is usually a complex process which may involve several stages. Typically, Guinier–Preston (GP) zones and an intermediate precipitate may be formed in addition to the equilibrium phase. Most aluminium alloys that respond to ageing will undergo some hardening at ambient temperatures. This is called ‘natural ageing’ and may continue almost indefinitely, although the rate of change becomes extremely slow after months or years. Ageing at sufficiently elevated temperature (artificial ageing) is characterized by a different behaviour in which the hardness usually increases to a maximum and then decreases. The highest value of hardness occurs at one particular temperature, which varies with each alloy. Maximum hardening in commercial alloys normally occurs when a critical dispersion of GP zones, or an intermediate precipitate, or a combination of both, are present. In some alloys more than one intermediate precipitate may be formed. The softening that occurs on prolonged artificial ageing is known as ‘overageing’. For commercial heat treatments an ageing schedule is usually selected to give the desired response to hardening (strengthening) within a convenient period of time. Some alloys are cold-worked (e.g. stretching or compression, up to 5 %) after quenching and before ageing. The cold-work increases the dislocation density and provides more sites at which heterogeneous nucleation of intermediate precipitates may occur during ageing [6]. The result is an improvement in the strength properties.

III. **Effects of Alloying Elements** The effect(s) of various alloying elements are given below.

Some of the effects, particularly with respect to impurities, are not well documented and are specific to particular alloys or conditions.

- **Chromium:** Is a common addition to many alloys of the aluminium–magnesium, aluminium–magnesium–silicon, and aluminium–magnesium–zinc groups, in which it is added in amounts generally not exceeding 0.35 wt%. Above this limit chromium tends to form very coarse constituents with other impurities or additions such as manganese and titanium. Chromium has a low diffusion rate and forms a fine dispersed phase in

wrought products. The dispersed phase inhibits nucleation and grain growth. Hence during hot working or heat treatment, chromium prevents grain growth in aluminium–magnesium alloys and recrystallization in aluminium–magnesium–silicon or aluminium–magnesium–zinc alloys. The main drawback of chromium in heat treatable alloys is the increase in quench sensitivity when the hardening phase tends to precipitate on the preexisting chromium-phase particles.

- **Copper:** Aluminium–copper alloys containing 2–10 wt% Cu, generally with other additions, form an important family of Al alloys. Both cast and wrought aluminium–copper alloys respond to solution heat treatment and subsequent ageing, with an increase in strength and hardness and a decrease in elongation. The strengthening is maximum between 4 and 6 wt% Cu, depending upon the influence of other constituents. N.B: the ageing characteristics of binary aluminium–copper alloys have been studied in greater detail than for any other system, but all commercial aerospace alloys contain other alloying elements.
- **Copper–Magnesium:** The main benefit of adding magnesium to aluminium–copper alloys is the increased strength following solution heat treatment and quenching. In certain wrought alloys of this type, ageing at room temperature (natural ageing) causes an increase in strength accompanied by high ductility. Artificial ageing, at elevated temperatures, results in a further increase in strength, especially the yield strength, but at a substantial sacrifice in tensile elongation. For both cast and wrought aluminium–copper alloys, as little as about 0.5 wt % Mg is effective in changing the ageing characteristics. In wrought products the effect of magnesium additions on strength can be maximized in artificially aged materials by cold-working prior to ageing. In naturally aged materials, however, the benefit to strength from magnesium additions can decrease with cold-working. The effect of magnesium on the corrosion resistance of aluminium–copper alloys depends on the type of product and thermal treatment.
- **Copper–Magnesium plus Other Elements:** Al–Cu–Mg alloys containing manganese are the most important and versatile class of commercial high-strength wrought aluminium–copper–magnesium alloys. In general, tensile strength increases with separate or simultaneous increases in magnesium and manganese, and the yield strength also increases, but to a lesser extent. Further increases in tensile strength and particularly yield strength occur on cold-working after heat treatment. Additions of manganese and magnesium decrease the fabrication characteristics of aluminium–copper alloys, and manganese also causes a loss in ductility. Hence the concentration of manganese does not exceed about 1 wt% in commercial alloys. Additions of cobalt, chromium, or molybdenum to the wrought Al-4 wt% Cu-0.5 wt% Mg type of alloy increase the tensile properties on heat treatment, but none offers a distinct advantage over manganese. The cast aluminium–copper–magnesium alloys containing iron are

characterized by dimensional stability and improved bearing characteristics, as well as high strength and hardness at elevated temperatures. However, in a wrought Al-4 wt% Cu-0.5 wt% Mg alloy, iron in concentrations as low as 0.5 wt% lowers the tensile properties in the heat-treated condition unless the silicon content is sufficient to sequester the iron as FeSi intermetallic particles. When sufficient silicon is present to combine with the iron, the strength properties are unaffected, although the FeSi particles are detrimental to fracture toughness, see Sect. 2.5.1. However, if there is excess iron, it unites with copper to form the Cu_2FeAl_7 constituent, thereby reducing the amount of copper available for heat-treating effects. Silicon also combines with magnesium to form Mg_2Si precipitates that contribute to the age-hardening process, see below. Silver substantially increases the strength of heat treated and aged aluminium–copper–magnesium alloys. Nickel improves the strength and hardness of cast and wrought aluminium–copper–magnesium alloys at elevated temperatures. However, addition of about 0.5 wt% Ni lowers the tensile properties of the heat-treated wrought Al-4 %Cu-0.5 %Mg alloy at room temperature.

- **Magnesium–Silicon:** Wrought alloys of the 6XXX group contain up to 1.5 wt% each of magnesium and silicon in the approximate ratio to form Mg_2Si , i.e. 1.73:1. The maximum solubility of Mg_2Si in Al is 1.85 wt%, and this decreases with temperature. Precipitation upon age-hardening occurs by formation of Guinier–Preston zones and a very fine precipitate. Both confer an increase in strength to these alloys, though not as great as in the case of the 2XXX or the 7XXX alloys. Al– Mg_2Si alloys can be divided into three groups. In the first group the total amount of magnesium and silicon does not exceed 1.5 wt%. These elements are in a nearly balanced ratio or with a slight excess of silicon. Typical of this group is AA6063, which nominally contains 1.1 wt% Mg_2Si and is widely used for extruded sections. Its solution heat-treating temperature of just over 500 °C and its low quench sensitivity are such that this alloy does not need a separate solution treatment after extrusion, but may be air quenched at the press and artificially aged to achieve moderate strength, good ductility, and excellent corrosion resistance. The second group nominally contains 1.5 wt% or more of magnesium + silicon and other additions such as 0.3 wt% Cu, which increases strength in the T6 temper. Elements such as manganese, chromium, and zirconium are used for controlling grain structure. Alloys of this group, such as AA6061, achieve strengths about 70 MPa higher than in the first group in the T6 temper. However, this second group requires a higher solution treating temperature than the first and they are quench sensitive. Therefore they generally require a separate solution treatment followed by rapid quenching and artificial ageing. The third group contains an amount of Mg_2Si overlapping the first two but with substantial excess silicon. An excess of 0.2 wt% Si increases the strength of an alloy containing 0.8 wt% Mg_2Si by about 70 MPa. Larger amounts of excess silicon are

less beneficial. Excess magnesium, however, is of benefit only at low Mg_2Si contents because magnesium lowers the solubility of Mg_2Si . In excess silicon alloys, segregation of silicon to the grain boundaries causes grain-boundary fracture in recrystallized structures. Additions of manganese, chromium, or zirconium counteract the effect of silicon by preventing recrystallization during heat treatment. Common alloys of this group are AA6351 and the more recently introduced alloys AA6009 and AA6010. An addition of lead and bismuth to an alloy of this series (AA6262) improves machinability.

- **Silicon:** In wrought alloys silicon is used with magnesium at levels up to 1.5 wt % to produce Mg_2Si in the 6XXX series of heat treatable alloys. High-purity aluminium–silicon casting alloys exhibit hot shortness up to 3 wt% Si, the most critical range being 0.17–0.8 wt% Si. However, in aluminium–copper–magnesium alloys silicon additions (0.5–4.0 wt%) reduce the cracking tendency. Small amounts of magnesium added to any silicon-containing alloy will render it heat treatable, but the converse is not true, since excess magnesium over that required to form Mg_2Si sharply reduces the solid solubility of this compound. Modification of the silicon morphology in casting alloys can be achieved through the addition of sodium in eutectic and hypoeutectic alloys and by phosphorus in hypereutectic alloys.
- **Titanium:** Is used primarily as a grain refiner of aluminium alloy castings and ingots. When used alone, the effect of titanium decreases with time of holding in the molten state and with repeated remelting. The grain-refining effect is enhanced if boron is present in the melt or if it is added as a master alloy containing boron largely combined with titanium as TiB_2 .
- **Zinc–Magnesium:** Addition of magnesium to aluminium–zinc alloys develops the strength potential of this alloy system, especially in the range of 3–7.5 wt% Zn. Magnesium and zinc form $MgZn_2$, which produces a far greater response to heat treatment than occurs in the binary aluminium–zinc system. On the negative side, increasing additions of both zinc and magnesium decrease the overall corrosion resistance of aluminium, such that close control over the microstructure, heat treatment, and composition are often necessary to maintain adequate resistance to stress corrosion and exfoliation corrosion. For example, depending upon the alloy, stress corrosion is controlled by some or all of the following: overageing; cooling rate after solution treatment; maintaining an unrecrystallized structure via additions such as zirconium, copper or chromium (see zinc–magnesium–copper alloys); and adjusting the zinc–magnesium ratio closer to 3:1.
- **Zinc–Magnesium–Copper:** Addition of copper to the aluminium–zinc–magnesium system, together with small but important amounts of chromium and manganese, results in the highest strength aluminium-base alloys (7XXX series) commercially available.

and magnesium control the ageing process. The effect of copper is to increase the ageing rate by increasing the degree of supersaturation and perhaps through nucleation of the CuMgAl_2 phase. Copper also increases the quench sensitivity upon heat treatment. In general, copper reduces the resistance to general corrosion of aluminium–zinc–magnesium alloys, but increases the resistance to stress corrosion. Minor alloy additions, such as chromium and zirconium, have a marked effect on mechanical properties and corrosion resistance.

- **Zirconium:** Additions in the range 0.1–0.3 wt% are used to form a fine precipitate of intermetallic particles that inhibit recovery and recrystallization. An increasing number of alloys, particularly in the aluminium–zinc–magnesium family, use zirconium additions to increase the recrystallization temperature and to control the grain structure in wrought products. Zirconium additions render this family of alloys less quench sensitive compared to chromium additions. Higher levels of zirconium are employed in some superplastic alloys to retain the required fine substructure during elevated temperature forming. Zirconium additions have been used to reduce the as-cast grain size, but the effect is less than that of titanium. In addition, zirconium tends to reduce the grain-refining effect of titanium plus boron additions so that it is necessary to use more titanium and boron to grain refine zirconium-containing alloys.

IV. Mechanical Properties 2.5.1 Strength and Fracture Toughness

- **Strength and Fracture Toughness:** Aluminium alloys may be divided into two groups depending upon whether or not they respond to precipitation hardening. For alloys that do not respond to ageing treatments, it is the finely dispersed precipitates that have the dominant effect in inhibiting dislocation motion and thereby raising yield and tensile strengths. For the other group the grain size of cast alloys and the dislocation structures produced by cold-working in the case of wrought alloys are of prime importance. Some of the mechanical properties of wrought age-hardening aerospace aluminium alloys are given in Table 2.3. Coarse intermetallic compounds have relatively little effect on yield or tensile strength but they can cause a marked loss of ductility in both cast and wrought products. The particles may crack at small plastic strains forming internal voids which, under the action of further plastic strain, coalesce leading to premature fracture. Early work on the higher strength aluminium alloys was directed primarily at maximizing tensile properties in aerospace materials. Since the 1960s the emphasis in alloy development has shifted away from tensile strength as the primary consideration, and more attention is given to optimizing a combination of properties and the alloys' behaviour under a variety of service loadings and environmental conditions. Yield strength is important for resisting deformation under service loads, but in the presence

of cracks and other flaws it is the fracture toughness that generally becomes the more important parameter. Minimum fracture toughness requirements have become mandatory, and in the high-strength alloys the generally inverse relationship between strength and toughness, see Fig. 2.3, limits the level of yield strength that can be safely employed by the designer. The major step in the development of aluminium alloys with greatly improved fracture toughness has come from controlling the levels of the impurity elements iron and silicon. This effect is shown in Fig. 2.3a for alloys based on the Al–Cu–Mg system: it can be seen that plane-strain fracture toughness values may be doubled by maintaining the combined levels of these elements below 0.5 wt% as compared with similar alloys in which this value exceeds 1.0 wt%. Consequently, some high-toughness versions of older alloy compositions are now commercially used with reduced impurity levels [3]. Figure 2.3b shows that in general the 7XXX series of alloys can attain superior combinations of strength and fracture toughness compared with 2XXX alloys.

- **Fatigue:** Fatigue life and strength properties are always important design data for aircraft structures. The practical significance is, however, restricted to notched fatigue, since cracks start at stress concentrations, especially fastener holes. Unlike steels, the unnotched fatigue strengths of wrought aluminium alloys are not proportional to the static strengths, i.e. stronger alloys do not necessarily have a higher fatigue strength, see Fig. 2.4. This is even more marked for notched fatigue, and there is actually little difference in the high-cycle notched fatigue strengths of IM wrought alloys, for example Fig. 2.5.
- **Fatigue Crack Growth Conventional** (non-lithium-containing) 2XXX series alloys are generally superior to 7XXX series alloys under constant amplitude loading, for example Fig. 2.6, and gust spectrum loading (typical for transport aircraft), but not necessarily under maneuver spectrum loading representative for tactical (fighter) aircraft [8]. Also, for constant amplitude loading at low DK values, the alloy rankings depend strongly on the ageing treatment: naturally aged (T3X) and artificially aged (T8X) treatments for 2XXX series alloys, and artificially peak aged (T6X) and overaged (T7X) treatments for 7XXX series alloys [7]. Thus, summarizing, fatigue crack growth testing, even at the basic materials level, when selecting candidate materials for further evaluation, should include realistic load histories and representative stress levels [8].
- **Corrosion Resistance** The corrosion resistance of any specific aluminium alloy depends on the environment as well as the alloy. Both chemical and physical environmental variables affect corrosion. The influence of the environment depends on its composition and the presence of impurities, such as heavy metal ions. Physical variables are temperature, degree of movement and agitation, and pressure. Alloy variables that affect corrosion are composition and fabrication practice. These

determine the microstructure, which controls whether localized corrosion occurs and the method of attack [9]. Conventional (non-lithium-containing) aerospace alloys always require some form of corrosion protection. This can be cladding with (nearly) pure aluminium and anodizing for sheet alloys; anodizing or ion vapour deposition for other types of products; and primer and paint systems. Some aluminium alloys are susceptible to stress corrosion cracking (SCC), which occurs under the combined action of a continuous tensile stress and a specific corrosive environment. The most important aerospace aluminium alloys susceptible to SCC are the 2XXX-T8XX, 7XXX-T6XX and 7XXX-T7XX tempers [12]. Very rarely, SCC occurs in aluminium–magnesium–silicon alloys (6XXX).

V. Typical Aerospace Applications of Aluminium Alloys

Even though the role of aluminium in future commercial aircraft will probably be ‘threatened’ by the increasing use of composite materials, the high-strength aluminium alloys are, and will remain, important airframe materials. Even in fighter aircraft, which already have composite material percentages in the range of 40– 50 %, aluminium still plays a significant role [1]. The attractiveness of aluminium is that it is a relatively low cost, lightweight metal that can be heat treated to fairly high-strength levels, and it is one of the most easily fabricated high performance materials, i.e. the manufacturing costs are relatively low. Improvements in aluminium manufacturing technology include high-speed machining and friction stir welding (FSR):

- Although higher metal removal rates are an immediate benefit of high-speed machining, an additional cost saving is the ability to machine extremely thin walls and webs. This allows the design of weight competitive high-speed machined assemblies, in which sheet metal parts that were formally assembled with mechanical fasteners can now be machined from a single or several blocks of aluminium plate.
- FSR is a solid state joining process that has the ability to weld the 2XXX and 7XXX alloys, which are not suited to conventional fusion welding. FSR also allows the design of weight competitive assemblies with a minimum number of mechanical fasteners.

More specifically, the alloy property requirements vary depending on the application. A generic example is given in Fig. 2.7, which illustrates the engineering property requirements for several of the main structural areas in a transport aircraft, namely (i) fuselage and pressure cabins, (ii) wings and (iii) empennage (horizontal and vertical stabilizers). The engineering properties required for these structures are strength (TS, CYS), stiffness (E), damage tolerance (DT: fatigue, fatigue crack growth, fracture toughness), and corrosion (general and stress corrosion). The rankings of the requirements differ for different areas, but there is much commonality. Table 2.4 presents a survey of the actual and proposed uses of conventional 2XXX and 7XXX aluminium alloys in airframe structures. Alloy producers develop basically similar alloys for

different product forms and applications. The most important contribution to this flexibility is the development of a range of alloy tempers that allow optimizations and trade-offs of properties, and hence the ability to match the alloys to particular applications.

VI. Indian Scenario

4 % of the global primary Al production of about 50 million tons is produced in India by three large manufacturers: NALCO, HINDALCO and the Vedanta Group. Comparable quantities are produced by recycling (using domestic as well as imported scrap, mostly by thousands of small units). About 80 % of the primary aluminium is consumed domestically, while the rest is exported, making India an Al-surplus country. This deceptive surplus is essentially due to the very low per capita consumption of aluminium (under 1 kg) compared to the US and Europe (25–30 kg), and even China (3 kg). The domestic consumption pattern gives a clue to the reasons for this situation: the Power Industry (mainly overhead cables and other conductors) is the principal consumer of domestic aluminium (48 %). Other sectors lag far behind: Transport 15 %; Construction 13 %; Machinery and Equipment 7 %; Consumer Durables 7 %; Packaging: 4 %; Others 6 %. From the foregoing list it is clear that only very small amounts of aluminium and its alloys made in India go into the aerospace industry, which itself is at an early stage of development, particularly in the private sector. The only primary aircraft manufacturer is the public sector Hindustan Aeronautics Limited (HAL), which produces military aircraft, either of its own design or under licence from a foreign Table 2.4 Actual and proposed uses of conventional aerospace aluminium alloys in airframe structures [13]

Product	Strength levels	Alloy/temper	Applications
Sheet	Damage tolerant	2024-T3, 2524-T3/351	Fuselage/pressure cabin skins
Plate	Damage tolerant	2024-T351, 2324-T39, 2624-T351, 2624-T39	Lower wing covers
	Medium strength	2024-T62	Tactical aircraft fuselage panels
	Medium strength	2124-T851	Tactical aircraft bulkheads
	High strength	7050-T7451, 7X75-T7XXX	Internal fuselage structures
	Medium strength	7150-T7751, 7055-T7751, 7055-T7951, 7255-T7951	Upper wing covers
	Medium strength	7050-T7451	Spars, ribs, other internal structures
	High strength	7175-T7351, 7050-T7452	Forgings
	Damage tolerant	2024-T3511, 2026-T3511, 2024-T4312, 6110-T6511	Wing/fuselage attachments
	Medium/high strength	7075-T73511, 7075-T79511, 7150-T6511, 7175-T79511, 7055-T77511, 7055-T79511	Fuselage stringers and frames, upper wing stringers, floor beams, seat rails

2 Aluminium Alloys for Aerospace Applications 47 manufacturer. The other major aerospace organization is the Indian Space Research Organization (ISRO). This is a research establishment producing highly advanced Space Vehicles that serve as technology demonstrators. Nonetheless these have high commercial potential. Several hundred ancillary units fabricate component parts for aerospace applications. Two examples are Hindalco-Almex Aerospace Ltd (HAAL), Aurangabad, and PMI Engineering Exports Pvt Ltd, Chennai. The aluminium alloys they state they are able to produce include AA2014, AA2618, AA5083, AA6061, AA7010, AA7020, AA7050, AA7075 and AA7175: in

short, a considerable variety. Besides industry, there is considerable aerospace R&D activity in other institutions in India, led by several prestigious DRDO laboratories. Missile development programs at several of these laboratories are supplemented by extensive work on manufacture and property studies for a range of Al alloys including Al–Li alloys (see Chap. 3 of this Volume) at the Defence Metallurgical Research Laboratory, Hyderabad. Some CSIR labs like the National Aerospace Laboratory (NAL), Bengaluru, and the Regional Research Laboratory, Trivandrum, a few University Departments and Research Institutions like the celebrated Indian Institute of Science, Bengaluru, complete the R&D picture.

2.2 Titanium Alloys

The high strength and low density of titanium and its alloys have from the first ensured a positive role for the metal in aero-engine and airframe applications. It is difficult to imagine how current levels of performance, engine power to weight ratios, airframe strength, aircraft speed and range and other critical factors could be achieved without titanium.

Aircraft Engines

Titanium alloys capable of operating at temperatures from sub zero to 600°C are used in engines for discs, blades, shafts and casings from the front fan to the last stage of the high pressure compressor, and at the rear end of the engine for lightly loaded fabrications such as plug and nozzle assemblies.

Airframes

Alloys with strength up to 1200MPa are used in a wide variety of airframe applications from small fasteners weighing a few grams to landing gear trucks and large wing beams weighing up to 1 ton. Currently titanium makes up to 10% of empty weight of aircraft such as the Boeing 777.

Titanium Alloys for Aircraft Applications

Some of the alloys available for aircraft applications are outlined in the following tables. The alloys are grouped by their relative usages.

Table 1. More widely used titanium alloys in aircraft applications.

Alloy	Attributes/Applications
Ti6Al4V	Workhorse, general purpose high strength alloy

Ti6Al2Sn4Zr2Mo (6-2-4-2)	Creep and oxidation resistant engine alloy
Ti6Al2Sn4Zr6Mo (6-2-4-6)	Creep and oxidation resistant engine alloy
Ti3Al8V6Cr4Zr4Mo (Beta C)	Beta alloy with established spring applications
Ti10V2Fe3Al (10-2-3)	Beta forging alloy used for 777 landing gear
Ti15V3Cr3Sn3Al (15-3-3-3)	High strength heat treatable beta sheet alloy
Ti3Al2.5V	Medium strength alloy used for hydraulic tubing
Ti4Al4Mo2Sn (550)	Higher strength heat treatable airframe and engine alloy
Ti5.5Al3.5Sn3Zr1Nb (829)	Advanced engine alloy, creep and oxidation resistant
Ti5.8Al4Sn3.5Zr0.7Nb (834)	Advanced engine alloy, creep and oxidation resistant
Ti5Al2Sn4Mo2Zr4Cr (Ti17)	Advanced engine alloy, creep and oxidation resistant
Ti15Mo3Nb3Al0.2Si (21S)	Oxidation and corrosion resistant beta sheet alloy

Table 2. Titanium alloys of increasing importance in aircraft applications.

Alloy	Attributes/Applications
Ti6Al2Zr2Sn2Mo2Cr0.25Si (6.22.22)	Airframe alloy for F22 and JSF projects
Ti4.5Al4Mo4Sn0.5Si (SP 700)	Competitor for Ti6Al4V for SPF and general use

Table 3. Less widely used titanium alloys in aircraft applications, but alloys that may be critical in their application to specific fully validated components.

Alloy	Attributes/Applications
Ti2Cu	Heat treatable sheet alloy
Ti4Al4Mo4Sn0.5Si (551)	High strength airframe alloy, very limited availability
Ti8Al1Mo1V	Early alloy now mainly used for spares and replacements
Ti-6-6-2	High strength alloy with specific earlier applications
Ti11Sn5Zr2.5Al1Mo0.2Si (679)	Earlier engine alloy rarely specified in new programmes
Ti6Al5Zr0.5Mo0.25Si (685)	Engine alloy now mainly for spares and replacements

iron has few practical uses in its pure state. However, adding small amounts of other materials to molten iron dramatically changes its properties. Some of the more common alloying elements include carbon, sulphur, silicon, phosphorus, nickel and chromium (also referred to as chrome).

2.3 Steel

Steel is essentially an alloy of iron and less than 2.5% carbon, usually with a few impurities. (In practice, most steels do not have more than 1.5% carbon).

Steel is produced by refining pig iron (removing excess carbon and other unwanted impurities). The excess carbon is extracted by blowing oxygen or air through the molten metal and/or adding iron oxide. Slag, containing other impurities is skimmed off. The most common furnace used for this process was the 'Bessemer Converter', developed in 1856. It reduced the cost of steel to one fifth of its original cost. Bessemer converters were loaded with 20-50 tons of pig iron and air was blown from the bottom for approximately 15 minutes.

The high quality steels that are used in aircraft construction are usually produced in electric furnaces, which allow better control than gas furnaces, when alloying. The carbon electrodes produce an intense arc and the steel (when molten) can have impurities removed and measured amounts of alloying materials added.

I. Classification of Steels

When carbon is alloyed with iron, the hardness and strength of the metal increases. The effect of varying amounts of carbon is truly dramatic. If carbon is progressively added to pure iron, the following occurs:

- Initially, the strength and hardness increases – Steel containing 0.4% carbon has twice the strength of pure iron.
- When 1% of carbon is added, the strength and hardness show a further increase but ductility is reduced.
- If 1% to 1.5% of carbon is added, the hardness continues to increase. But there is no further increase in strength and there is even less ductility. Steels containing such high amounts of carbon are seldom used for anything except cutting implements *e.g.* razor blades and scissors.

The (American) Society of Automotive Engineers (SAE) has classified steel alloys with a four-digit numerical index system. A small extract from the SAE classification system is shown in table below, where it can be seen. For example, that one common steel alloy is identified by the designation SAE 1030. The first digit identifies it as a Carbon-Steel, while the second digit shows that it is a Plain Carbon-Steel. The last two digits denote the percentage of carbon in the steel (0.30%). It should be noted that the British Standards Institute (BS) has a different classification system.

II. Metallurgical Structure of Steel

The amount of carbon present in steel has a major effect on the mechanical properties. The form in which the carbon is present is also important.

➤ Structure and Properties – Slow-cooled Steels

Carbon can be present in these steels in the following forms:

- When the carbon is fully dissolved and uniformly distributed in a solid solution, the metallurgical structure is called ferrite. At room temperature, only a very small amount of carbon (0.006%) can be contained in solid solution. Therefore, this ferrite structure is almost pure iron, which is soft, weak and ductile.
- When 1 carbon atom chemically combines with 3 iron atoms, the result is called cementite or iron carbide, which is very hard and brittle.
- Cementite can be present either as free cementite or laminated with ferrite (in alternate layers) to produce a metallurgical structure called pearlite. As pearlite is half cementite and half ferrite, it is not surprising to find that pearlite combines the properties of ferrite and cementite *i.e.* pearlite is strong without being brittle.

The amount of carbon necessary to produce a totally pearlite structure is 0.83%, but this material is a little too hard for general structural use. If the carbon content exceeds this value, the excess carbon forms carbon-rich cementite areas along the grain boundaries, and this is known as free cementite. Such high-carbon steels as already stated are very hard and strong but very brittle. Mild steel has a metallurgical structure comprising approximately one third pearlite and two thirds ferrite.

➤ ***Effects of Cooling Rates on Steels***

Previously, the effect of carbon on the properties of a slowly cooled steel has been considered. However, if such steels are rapidly cooled from relatively high temperature the metallurgical structure and properties can be somewhat different.

➤ ***Heat-Treatment of Carbon Steels***

If a 'straight' carbon steel is progressively heated from cold, a steady rise in temperature occurs. However, at approximately 700°C, there is a reduction in the rate of temperature rise (a 'hesitation'), even though the heating is continued (refer to figure below). This hesitation starts at 700°C and finishes at up to 200°C higher (depending on the percentage of carbon present) and eventually, the temperature rise speeds up and the rate of rise is similar to that which occurred before the hesitation.

The start of the hesitation is known as the 'lower critical point' and the end is called the 'upper critical point'. And the phenomenon of the temperature response is due to a change in the crystalline structure of the steel in between the two critical points.

If carbon steel is heated to just above its Upper Critical Point, the structure is called 'Austenitic'. This structure is a solid solution of carbon in iron (*i.e.* all the carbon is uniformly distributed throughout the iron). If the steel contains above 0.3% carbon, and it is rapidly cooled (*i.e.* quenched) from above the Upper Critical Point it becomes hardened.

The more the carbon is present, the harder the steel will be after quenching. This rapid cooling causes a change in the metallurgical structure and is called 'Martensite'. Martensite is extremely hard, but is not suitable for most engineering purposes due to it being very brittle. For most applications, it is necessary to carry out a further heat-treatment to reduce the brittleness of the steel and this is called 'tempering'.

To temper hardened carbon steel, it is necessary to heat it to a suitable temperature below its Lower Critical Point followed by cooling (usually quenching). The effect of this heat-treatment is to slightly reduce the

hardness whilst at the same time greatly increasing the toughness. The actual tempering temperature used depends on the requirements of strength, hardness and toughness.

The higher the tempering temperature, the lower will be strength and hardness, but the toughness will be greater. The maximum tensile strength of hardened carbon steel is achievable when 0.83% carbon is present. If an even greater amount of carbon is present, the hardness continues to increase but strength will decrease.

Associated Problems - Hardening Process

The effective hardening of carbon steels depends not only on the amount of carbon present but also on very rapid cooling from high temperature. The cooling rate mainly depends on the cooling medium, the size of tank and the mass of the object to be cooled.

Agitation in the cooling bath can also speed up the cooling rate and in terms of cooling severity, brine is more effective than water, followed by oil and finally air.

Carbon steels require an extremely rapid cooling phase. So brine or water is normally used, whereas oil or air-cooling is used on certain alloy steels. The rapid cooling rates, involved in the hardening of carbon steel, cause enormous thermal stresses in the component and distortion is commonplace. Cracking may also occur in some cases.

To achieve relatively uniform cooling, it is sometimes necessary to immerse the object in a specific way because of its shape and mass.

- ***Tempering***

As already stated, tempering is carried out to improve the toughness of hardened steel whilst suffering only a modest drop in strength. In addition to well-equipped facilities, accurate temperature measuring equipment are required to do these procedures on aerospace metals.

However, the following table shows that, when carbon steel is polished and then slowly heated, a range of colours appears due to a thin oxide film formation during the heating process. These colours are related fairly closely to temperatures. The higher the temperature achieved during the tempering process, the softer and tougher the material will become and vice-versa.

- **Annealing**

The annealing of steel may be for one of the following purposes:

- To soften the steel for forming or to improve machinability.
- To relieve internal stresses induced by a previous process (rolling, forging, or unequal cooling).
- To remove coarseness of grain.

Annealing is normally achieved on carbon steel by heating to just above the Upper Critical Limit, followed by very slow cooling. In practise, the slow cooling rates are achieved by cooling in the furnace or by immersing in a poor thermal conductor such as ashes. The end result is a stress-free, fully softened material, suitable for major forming operations such as deep pressing, drawing, extruding etc.

- **Normalising**

This process is similar to annealing, except that the cooling is done in still air. Again, the end result is a stress-free, soft material with uniform fine grain structure. Normalising is commonly used on actual components after heavy machining operations (or welding), prior to the final hardening and tempering processes.

Surface Hardening of Steels

- Unlike conventional through-hardening of steel, it is sometimes desirable to retain a relatively tough (relatively less brittle) inner core, coupled with a very hard surface. This would, typically, be required of a component, which is subjected to high dynamic stresses, yet also has to resist surface wear and would include:
 - Gears (where the teeth need to be hardened)
 - Camshafts and crankshafts (bearing surfaces)
 - Cylinder barrels of piston engines (or landing gear legs)

Some materials can be 'case-hardened' to achieve this aim. Several methods are used, depending on the parent material and the particular application.

- **Carburising**

This is the most common method of case-hardening low-carbon steels and consists of heating the metal to approximately 900°C, while the component is in contact with a carbon-rich medium followed by a suitable heat-treatment.

Carbon is generally absorbed into the surface of the heated steel and the rate of penetration is approximately 1mm in 5-6 hours. Low-carbon steels are particularly suited to this type of treatment, as it increases the carbon content and hence the hardness locally. Various methods of carburising are used, the most common ones being:

- **Pack Carburising:** The object is sealed in a container containing a carbon-rich (charcoal based) powder and heated in a furnace. The metal is then quenched in oil (not water, which would cause the hard case to peel off). The depth of the hard skin depends on the length of time that the metal is heated.
- **Gas Carburising:** The object is placed in a basket in a furnace, through which is passed a suitable, carbon-rich gas (e.g. methane, propane).
- **Liquid Carburising:** The object is heated to a suitable temperature and then immersed in a hot, salt bath at 900°C. The salts are usually based on sodium cyanide and the process is often called 'cyanide hardening'. The metal is quenched in water (not oil, which would react unfavourably with the salts).

- **Nitriding**

This process involves the absorption of nitrogen (instead of carbon) into the surface of the steel. Suitable "Nitalloy" steels are necessary for this process and they usually contain 1% Aluminium, 1.5% Chromium and 0.2% Molybdenum.

A special furnace is used and ammonia gas is circulated through it. The furnace temperature of 500°C converts the ammonia into a nitrogen-rich gas and forms hard iron nitride in the surface of the steel.

The resulting case depth is less than that by pack carburising, but the major advantage of nitriding is that no hardening or tempering is necessary to achieve the final hardness and no finish machining is required after nitriding. This relatively low-temperature process results in negligible distortion and is much cleaner than the carbon methods. Aircraft piston engine cylinder barrels are particularly suitable for nitriding, as are some crankshaft bearing surfaces and the stems of some aero-engine induction and exhaust valves.

Nitrided surfaces must be protected against pitting corrosion, usually (as with engine gears and shafts) by keeping the surface oiled.

Note: If certain surfaces of a component are not to be case-hardened, it is necessary to protect them during the carburising or nitriding processes, to locally prevent the hardening agent from being absorbed. Copper plating, nickel plating or a proprietary paste are generally used in such areas.

- **Flame/Induction Hardening**

Unlike carburising and nitriding, flame and induction hardening do not add a hardening agent into the surface of a basically softer material. Instead, they are merely techniques for hardening the surface of material by a 'local heat-treatment'. Steels suitable for these processes already contain sufficient carbon (or other elements) to attain a high degree of hardness if heated and quenched.

Only the surface is locally heated (by a flame or electrical induction coil), and the heated surface is then immediately quenched by water jets. The flame or induction coil is positioned so that it only heats the area required to be hardened.

Other Surface Hardening Techniques

In addition to case-hardening, there are other methods of producing hard surfaces on metals, such as by electro-plating, welding, bonding, and metal spraying. All usually involve adding a harder surface metal to the parent material.

III. Alloying Elements in Steel

➤ Carbon

Carbon is the most common alloying element found in steel. When mixed with iron, compounds of iron carbide form and it is the carbon in steel that allows it to be heat-treated to obtain varying degrees of hardness, strength and toughness. The greater the carbon content, the more receptive the steel becomes to heat-treatment and, while its strength and hardness increases, its malleability and weldability decreases.

- **Low-Carbon Steel:** Low-carbon steels contain between 0.1% and 0.3% carbon and are classified as SAE 1010 to SAE 1030 steels. They are used in such items as locking wire and cable bushings. And in sheet form, they are used for low-load applications. Low-carbon steels weld easily but do not accept heat-treatment very well.
- **Medium-Carbon Steel:** These steels contain between 0.3% and 0.7% carbon. The increased carbon assists in heat-treatment while still

retaining reasonable ductility. Medium-carbon steels are used for machining or forging and where surface hardness is required.

- **High-Carbon Steel:** The carbon content of these steels, ranges between 0.5% and 1.5% and this makes them very hard. High-carbon steels are primarily used in springs, files and in most cutting tools.

➤ **Sulphur**

Sulphur causes steel to be brittle when rolled or forged and so it must be removed during the refining process. If it proves impossible to remove all of the sulphur, then manganese can be added to the metal (to form manganese sulphide). The manganese also improves forging by making the steel less brittle during the forming processes.

➤ **Silicon**

When silicon is alloyed with steel, it acts as a hardener. When used in small quantities, it also improves ductility.

➤ **Phosphorus**

Phosphorus raises the yield strength of steel and improves a low-carbon steel's resistance to atmospheric corrosion. The steel tends to be brittle when cold. So, no more than 0.05% phosphorus is normally used in steel production.

➤ **Nickel**

Nickel is used extensively for alloying with steel as follows:

- In the range of 1-5%, there is a marked improvement in strength and hardness without lowering ductility. This high-strength, tough steel is widely used for highly stressed parts.
- At about 25% nickel, the steel becomes highly corrosion-resistant, heat-resistant and non-magnetic.
- At 36% nickel, a unique steel (known under its trade name as 'Invar') is created. This has the lowest coefficient of expansion of any metal ($1/20^{\text{th}}$ that of steel) and is excellent for master gauges and instruments.
- Because of the effect of such amounts of nickel on the expansion properties of steel, a range of nickel-steels can be purpose-made, to trim the coefficient of expansion to specific needs. These alloys are used in thermostats, spark plug electrodes etc.

- **Nickel Alloys:** When the amount of nickel present is predominant, then the material becomes known as a Nickel Alloy, many of which are widely used in industry.

One of the most important nickel-based alloy groups is the *nimonics*. These are a family of alloys, containing 50-80% nickel, with the balance being mainly chromium (chrome) with some titanium and aluminium.

Nimonic alloys are used in hot air control ducting, for gas turbine engine combustion chambers and turbine blades because of their extremely low coefficient of expansion at elevated temperatures.

Other ranges of nickel-based alloys come under the trade names of Inconel and *Hastelloy*, which are also temperature-resistant and corrosion-resistant.

Another common nickel alloy is *Monel*. This metal (68% nickel and 29% copper, with iron, manganese, silicon and carbon) has excellent resistance to both corrosion and chemical attack. It is tough, ductile, reasonably strong (equivalent to mild steel) and is non-magnetic. It is used in many marine applications for surgical apparatus and for aircraft rivets. Normally, Monel does not respond to heat treatment but, when alloyed with a small amount of aluminium (2-4%), it can be hardened to double its strength. This version is known as '*K-Monel*'.

Nickel adds strength and hardness to steel as well as increasing its yield strength. By slowing the rate of hardening during heat-treatment, the depth of hardening can be increased and the steel's grain structure made finer. SAE 2330 steel, containing 3% nickel and 0.3% carbon is used in the manufacture of bolts, nuts, rod ends and pins.

➤ **Chromium (Chrome)**

When small amounts of chrome are added to steel, the strength and hardness increases, but there is some loss of ductility. 1.5% chrome in a high-carbon (1%) steel, results in a very hard material, which is used extensively for instrument pivots and in ball and roller bearings. Low chrome (1.5-3%) steels are used for high tensile fasteners and are suitable for nitriding. Chromium can also be electrolytically deposited onto metals, to provide hardwearing surfaces, such as those required in cylinder bores.

Steels containing 12% or more chrome are very corrosion-resistant. Stainless (SS) Steels or Corrosion Resistant Steels (CRS) come into this category. One particular stainless steel is designated '*18/8 Stainless*', which contains approximately 18% chrome and 8% nickel. These stainless steels are used extensively in engine parts, particularly for hot applications and for exhaust areas where their corrosion resistance is vital.

➤ **Nickel-Chrome Steel and Its Alloys:**

This term is used when the amount of nickel present is greater than the chrome content. A wide range of such steels exists, but the low nickel-chrome alloys are suitable for through-hardening or case-hardening. The nickel content is around 3-5% and the chrome ranges from 0.5-1.5%. Crankshafts and connecting rods are often made from this group. High nickel-chrome alloys (65-85% nickel, 15-20% chrome) have a high electrical resistance and are often used as heater elements.

By adding both metals in appropriate percentages, steel is produced. Nickel-chromium steels are used for forged and machined parts requiring high strength, ductility, shock resistance and toughness.

➤ **Cobalt**

Cobalt is often included in High-Speed Steel (HSS) in addition to chrome, vanadium, molybdenum and tungsten, to improve still further the ability to cut at high working temperatures. Cobalt is included in high-strength, permanent magnets in some of the nimonic alloys used for high-temperature components in gas turbine engines. It is also found in a range of temperature-resistant alloys called 'Stellite' (used in piston engine valves and for cutting tools).

➤ **Vanadium**

When added to steel, vanadium improves the strength, without the loss of ductility. But also greatly improves its toughness and its resistance to fatigue. Because of the improved tensile and elastic properties, valve (and many types of other) springs usually include vanadium. Small amounts of vanadium are included in certain nickel-chrome steels and good quality engineering tools.

Vanadium, when combined with chromium, produces a strong, tough, ductile steel-alloy. Amounts of up to 0.2% vanadium improve grain structure, ultimate tensile strength and toughness. Ball bearings are also made from chrome vanadium steel.

➤ **Manganese**

When small amounts of manganese are added to steel (up to 1.5%), the result is a steel which is strong and hard (similar to nickel-chrome steel). Such steel is often used for shafts and axles. 11-14% manganese steel has very unusual properties and is extremely useful. When this material is heated to approximately 1000°C and water-quenched, its structure becomes austenitic and although it is only moderately hard, any attempt to

cut it or abrade it, results in the local formation of hard Martensite. Thus, it becomes highly resistant to cutting or abrasion. Because of this peculiar property, it is used extensively for rock drills, stone crushers, and railway lines at junctions etc. Small amounts of manganese are used in steel production and in welding rods since it acts as a purifying agent by reducing oxidation.

➤ ***Molybdenum***

One of the most widely used alloying elements for aircraft structural steel is molybdenum. It reduces the grain size of steel, which increases its impact strength and elastic limit. Other advantages are an increase in wear-resistance and high fatigue-resistance, which is the reason why molybdenum-steels are found in structural members and engine parts.

➤ ***Chrome and Molybdenum***

Chrome-molybdenum steel is probably the most commonly used alloy steel in the aircraft industry. Its SAE 4130 designation denotes an alloy of 0.8-1.10% Cr, 0.15-0.25% Mo, 0.28-0.33% C and other elements, such as Mn, P, S and Si. It machines well and is easily welded by gas or electric arc methods, as well as responding well to heat-treatment. Its use in aircraft construction includes landing gear, engine mountings and many engine components.

➤ ***Tungsten***

Tungsten has an extremely high melting point and adds this characteristic to the steel with which it is alloyed. Tungsten steels retain their hardness at elevated temperatures, and are typically used for contact-breaker contacts (in magnetos), and also for high-speed cutting tools.

2.4 MAGNESIUM

Use of Magnesium in Aircraft Parts casting In recent years, new Magnesium alloy castings has demonstrated superior corrosion performance. This advantage has lead magnesium and magnesium alloys for aerospace applications.

Magnesium Alloy Offers:

- Light weight.
- Low density (Just two thirds of aluminium).
- Excellent high temperature mechanical properties.
- Good to medium corrosion resistance.

I. Application of Magnesium Alloy in Aircraft Parts:

They are used for helicopter transmission casings, main rotor gearbox castings, applications can have auxiliary gearboxes, generator housings, canopies, intermediate compressor casings for turbine engines. Airframe mounted auxiliary drive systems (AMADS) as in fighter jets etc.

- Magnesium is an excellent metal as it is readily available commercially and it is the lightest of all the structural metals having a density of 1.7g/cm^3 ;
- It also has good heat dissipation, good damping and good electro-magnetic shield. It is most commonly found in the earth's ocean.
- At room temperature magnesium and its alloys are difficult to deform due to the crystal structure which is hexagonal close packed (Figure 1). This structure restricts its ability to deform because it has fewer slip systems at lower temperatures.
- Magnesium has a moderately low melting temperature making it easier to melt for casting. Additionally it is relatively unstable chemically and extremely susceptible to corrosion in a marine environment.
- It is thought that the corrosion is due more to impurities in the metal versus an inherent characteristic. Finally magnesium powder ignites easily when heated in air and must be handled very carefully in a powder form.
- Figure 1: Example of Hexagonal Close Packed Crystalline Structure Pure magnesium is rarely used in the manufacturing of aerospace and automotive parts. In order to be used in manufacturing, it is alloyed with other metals.
- Some of the most common alloyed elements in commercial alloys are: aluminum, zinc, cerium, silver, thorium, yttrium and zirconium.

There are three main groups of magnesium alloys (both wrought and cast):

1. Magnesium-Manganese Alloys.

These alloys have good weldability and are used for manufacturing thin plates.

2. Magnesium-Aluminum-Zinc Alloys.

These alloys are manufactured by Die casting, Sand casting, Permanent mold casting, Forging and Extrusion. The alloys are heat-treatable.

3. Magnesium-Zinc-Zirconium-Thorium Alloys.

These alloys have high impact toughness, good corrosion resistance and machinability. The alloys are heat-treatable.

The designation system uses the following combination of letters and numbers for identification of the alloys:

The **first two letters** indicate the major alloying elements in the alloy according to the following codes:

A – Aluminum (Al),
B – Bismuth (Bi),
C – Copper (Cu),
D – Cadmium (Cd),
E – Rare earth elements,
F – Iron (Fe),
H – Thorium (Th),
K – Zirconium (Zr),
L – Beryllium (Be),
M – Manganese (Mn),
N – Nickel (Ni),
P – Lead (Pb),
Q – Arsenic (As),
R – Chromium (Cr),
S – Silicon (Si),
T – Tin (Sn),
Z – Zinc (Zn).

The two letters are followed by **two numbers**, indicating the concentration of the major alloying elements.

The **fifth symbol** is a letter, signifying the alloy modification.

The alloy code is followed by a **designation of temper**. The temper designation system of magnesium alloys is similar to the Temper designation of aluminum alloys:

F – As fabricated;
O – Annealed;
H – Cold worked;
T4 – Solution treatment;
T5 – Artificial aging;
T6 – Solution treatment followed by artificial aging.

Example:

Alloy designated as ZE63A-T6 is magnesium alloy, containing 6% (rounded off) of zinc (symbol Z) and about 3% (rounded off) of rare earth elements (symbol E).

Modification of the alloy – A.

The temper of the alloy is solution treatment followed by artificial aging (T6).

Alloy Characteristics

AZ63	Good room temperature strength and ductility
AZ81	Tough, leak tight castings with 0.0015 Be, used for pressure die-casting
AZ91	General-purpose alloy used for sand and die castings
AM50	High-pressure die castings
AM20	Good ductility and impact strength
AS41	Good creep properties to 150°C
AS21	Good creep properties to 150°C
AE42	Good creep properties to 150°C
ZK51	Sand castings, good room temperature strength and ductility
ZK61	As for ZK51
ZE41	Sand castings, good room temperature strength, improved castability
ZC63	Pressure-tight castings, good elevated temperature strength, weldable
EZ33	Good castability, pressure-tight, weldable, creep resistant to 250°F
HK31	Sand castings, good castability, weldable, creep resistant to 350°C
HZ32	As for HK31
QE22	Pressure tight and weldable, high proof stress to 250°C
QH21	Pressure-tight, weldable, good creep resistance and proof stress to 300°C
WE54	High strength at room and elevated temperatures
WE43	Good corrosion resistance, weldable
M1	Low-to medium- strength alloy, weldable, corrosion resistant
AZ31	Medium-strength alloy, weldable, good formability
AZ61	High-strength alloy, weldable 13
AZ80	High-strength alloy
ZM21	Medium-strength alloy, good formability, good damping capacity
ZK30	High-strength alloys ZK60 Good formability
ZMC711	High-strength alloy
HK31	High creep resistance to 350°C, weldable
HM21	High creep resistance to 350°C, short time exposure to 425°C, weldable
WE43	High temperature creep resistance
WE54	High temperature creep resistance
LA141	Ultra-light weight

II. Types of Heat Treatment

Magnesium alloy castings respond readily to heat treatment, and about 95 percent of the magnesium used in aircraft construction is in the cast form. The heat treatment of magnesium alloy castings is similar to the heat treatment of aluminum alloys in that there are two types of heat treatment: Magnesium, however, develops a negligible change in its properties when allowed to age naturally at room temperatures.

➤ Solution Heat Treatment

Magnesium alloy castings are solution heat treated to improve tensile strength, ductility, and shock resistance. This heat-treatment condition is indicated by using the symbol -T4 following the alloy designation. Solution heat treatment plus artificial aging is designated -T6. Artificial aging is necessary to develop the full properties of the metal.

Solution heat-treatment temperatures for magnesium alloy castings range from 730 °F to 780 °F, the exact range depending upon the type of alloy. The temperature range for each type of alloy is listed in Specification MIL-H-6857. The upper limit of each range listed in the specification is the maximum temperature to which the alloy may be heated without danger of melting the metal.

The soaking time ranges from 10 to 18 hours, the exact time depending upon the type of alloy as well as the thickness of the part. Soaking periods longer than 18 hours may be necessary for castings over 2 inches in thickness. NEVER heat magnesium alloys in a salt bath as this may result in an explosion.

A serious potential fire hazard exists in the heat treatment of magnesium alloys. If through oversight or malfunctioning of equipment, the maximum temperatures are exceeded, the casting may ignite and burn freely. For this reason, the furnace used should be equipped with a safety cutoff that will turn off the power to the heating elements and blowers if the regular control equipment malfunctions or fails. Some magnesium alloys require a protective atmosphere of sulfur dioxide gas during solution heat treatment. This aids in preventing the start of a fire even if the temperature limits are slightly exceeded.

Air quenching is used after solution heat treatment of magnesium alloys since there appears to be no advantage in liquid cooling.

➤ **Precipitation Heat Treatment**

After solution treatment, magnesium alloys may be given an aging treatment to increase hardness and yield strength. Generally, the aging treatments are used merely to relieve stress and stabilize the alloys in order to prevent dimensional changes later, especially during or after machining. Both yield strength and hardness are improved somewhat by this treatment at the expense of a slight amount of ductility. The corrosion resistance is also improved, making it closer to the “as cast” alloy.

Precipitation heat treatment temperatures are considerably lower than solution heat-treatment temperatures and range from 325 °F to 500 °F. Soaking time ranges from 4 to 18 hours.

Annealing:

Wrought magnesium alloys in various conditions of strain hardening or temper can be annealed by being heated at 290 to 455°C (550 to 850°F), depending on alloy, for one or more hours. This procedure usually will provide a product with the maximum anneal that is practical.

Because most forming operations on magnesium are done at elevated temperature, the need for fully annealed wrought material is less than with many other metals.

Stress Relieving of Wrought Alloys:

Stress relieving is used to remove or reduce residual stresses induced in wrought magnesium products by cold and hot working, shaping and forming, straightening, and welding.

When extrusions are welded to hard rolled sheet, the lower stress-relieving temperature and the longer time should be used to minimize distortion-for example, 150°C (300°F) for 60 min, rather than 260°C (500°F) for 15 min.

Stress Relieving of Castings:

The precision machining of castings to close dimensional limits, the necessity of avoiding warp age and distortion, and the desirability of preventing stress-corrosion cracking in welded magnesium-aluminum casting alloys make it mandatory that cast components be substantially free from residual stresses. Although magnesium castings do not normally contain high residual stresses, the low modulus of elasticity of magnesium alloys means that comparatively low stresses can produce appreciable elastic strains.

Residual stresses may arise from contraction due to mold restraint during solidification, from non uniform cooling after heat treatment, or from quenching. Machining operations also can result in residual stress and require intermediate stress relieving prior to final machining.

Solution Treating and Aging:

In solution treating of magnesium-aluminum-zinc alloys, parts should be loaded into the furnace at approximately 260°C (500°F) and then raised to the appropriate solution-treating temperature slowly, to avoid fusion of eutectic compounds and resultant formation of voids. The time required to bring the load from 260°C to the solution-treating temperature is determined by the size of the load and by the composition, size, weight and section thickness of the parts, but 2 h is a typical time.

During aging, magnesium alloy parts should be loaded into the furnace at the treatment temperature, held for the appropriate period of time, and then cooled in still air. There is a choice of artificial aging treatments for some alloys; results are closely similar for the alternative treatments given.

Reheat Treating:

Under normal circumstances, when mechanical properties are within expected ranges and the prescribed best treatment has been carried out, reheat treating is seldom necessary. However, if the microstructures of heat treated castings indicate too high a compound rating or if the castings have been aged excessively by slow cooling after solution treating, reheat treating is called for. Most magnesium alloys can be reheating treated with little danger of germination.

UNIT III

HIGH STRENGTH

AND HEAT

RESISTANT

ALLOYS

I. HEAT RESISTANT ALLOYS

Heat resistant alloys of iron, nickel and cobalt are used where high temperature performance, particularly creep resistance, is required. These alloys have been typically selected for gas turbine components such as blades, turbine wheels and latter stage compressor disks, which are subjected to long term rotational stresses and high temperatures. Increased understanding of the alloy systems has permitted the upgrading of forgings by mechanical and thermal treatment to satisfy requirements for high strength in applications other than creep resistance, such as low and high cycle fatigue and crack growth resistance.

Such alloys are designed to offer high strength at elevated temperatures. These characteristics, which are desirable in the end product, make forging very difficult. Furthermore, any additive that improves service temperature performance tends to decrease workability. Alloy cleanliness also has a significant effect on hot forgeability.

Alloy selection is generally directed at optimizing one or more of seven properties:

- Creep strength
- Tensile strength
- Low-cycle fatigue response
- High-cycle fatigue response
- Fracture toughness
- Creep rupture behavior
- Cyclic rupture (creep-fatigue interaction) behavior.

An example of a forged iron-based heat resistance alloy is A286 (AMS 5737). This and similar alloys are forged with practices similar in many respects to those used for 18-8 austenitic stainless grades. Because they are alloyed with reactive elements such as titanium, aluminum, boron, or columbium, they respond to solution and aging cycles similar to the specialty stainless grades.

Cobalt based forging alloys such as L605, Alloy 188 and N-155 continue to be used. S-816 alloys are still used for exhaust valves on gasoline and diesel engines.

The most widely forged true heat resistant alloys are Ni-Cr-Fe-based, such as alloys 718, 706 and 625. More highly alloyed Ni-Cr-Co based materials like Waspaloy, alloy 41 and alloy 500, which are very high strength and very difficult to forge, are less widely used. Forging process for heat resistant alloys are highly refined to control temperatures,

strain rate, strain and alloy condition. These controls are necessary to achieve uniform critical properties, such as grain size, and other characteristics after heat treatment.

Some "super-superalloys" such as Rene 95, IN 100, Merl 76 and low-carbon Astroloy are best forged with a more complex process that includes the initial consolidation of compacted billets of powder, followed by sintering, canning, and then hot extrusion to develop the starting billets for forging. This P/M (powder metallurgy) route precedes the use of isothermal or hot die forging process to near-net shapes. These alloys contain less cobalt and more reactive metals like titanium, aluminum, columbium, or tungsten. They tend to form stable carbides that improve creep resistance at higher service temperatures.

Heat resistant alloy forgings and processes are often computer modeled using various commercial codes. Modeling reduces costly tryout and costly inputs, such as material and die preparations, prior to tooling and process development. This practice has led to some remarkable refinements in the forgings processes and quality improvements.

Typical forging grades and nominal compositions are:

IronBasedHeatResistantAlloy	
A286	AM5737
Nickel-IronBasedHeatResistantAlloy	
Alloy 901	AMS 5660
CobaltBasedHeatResistantAlloys	
L605	AMS 5758
188	AMS 5772
N-155	AMS 5769
NickelBasedHeatResistantAlloys	

Ni-600	AMS 5665
Ni-625	AMS 5666
Ni-706	AMS 570
Ni-718	AMS 5663
Ni-X750	AMS 5667
Waspaloy	AMS 5708
Alloy 41	AMS 5712

Following are nominal compositions for several heat resistant alloys.

AlloyDesignation	PrincipalElement	Percentcomposition								
		AL	Cb	Co	Cr	Fe	Mo	Ni	Ti	W
A286	Iron	0.2			15	54	1	26	2	
Stellite	Cobalt			Bal	30	3	1	23		4
L605	Cobalt			53	20			0		15
S-816	Cobalt			Bal.	20	3	4	20		
IN 901	Nickel	0.2	4		12	36	6	43	3	
Astroloy	Nickel	4		17	15		5	55	4	
IN 718	Nickel	1	5		19	18	3	52	3	
Rene 41	Nickel	2		11	19		1	55	3	
Rene 95	Nickel	4	4	8	14		3	61	3	4
Udimet 700	Nickel	4		17	15		5	55	3	
Waspaloy	Nickel	1		13	19		4	58	3	
MERL 76	Nickel	5		18	12		3	59	4	v

II. Role of refractory

Refractory materials have a crucial impact on the cost and quality of steel products. The diversification on steel products and their cleanliness requirement in recent years have increased the demand for high quality refractory. Steelmaking requires high temperatures of the order of 1600 degree centigrade. In addition steelmaking handles high temperature phases like molten steel, slag and hot gases. These phases are chemically reactive; refractory materials are required to produce steels. High quality refractory at a cheaper cost is the main requirement because cost of refractory adds into the cost of product.

What is a refractory?

Refractories are inorganic nonmetallic material which can withstand high temperature without undergoing physico – chemical changes while remaining in contact with molten slag, metal and gases. It is necessary to produce range of refractory materials with different properties to meet range of processing conditions. The refractory range incorporates fired, chemically and carbon bonded materials that are made in different combinations and shapes for diversified applications.

Why required?

- To minimize heat losses from the reaction chamber
- To allow thermal energy dependent conversion of chemically reactive reactants into products because metallic vessels are not suitable.

In steelmaking, the physico- chemical properties of the following phases are important: Slag: Mixture of acidic and basic inorganic oxides like SiO_2 , P_2O_5 , CaO , MgO , FeO , etc.; temperature varies in between 1400°C to 1600°C .

Molten steel: Iron containing carbon, silicon, manganese, phosphorous, tramp elements, non metallic inclusions, dissolved gases like nitrogen, oxygen and hydrogen and different alloying elements like Cr, Ni, Nb, Mo, W, Mo etc.; temperature 1600°C Gases: CO, CO_2 , N_2 , Ar containing solid particles of Fe_2O_3 , Fe_3O_4 etc.; temperature 1300°C to 1600°C . The above phases are continuously and constantly in contact with each other and are in turbulent motion.

Refractory requirements:

The refractory materials should be able to withstand

- High temperature
- Sudden changes of temperature
- Load at service conditions
- Chemical and abrasive action of phases

The refractory material should not contaminate the material with which it is in contact.

Melting point of some pure compounds used to Manufacture refractory Compounds Melting point (°C)

MgO (pure sintered) 2800

CaO(limit) 2571

SiC pure 2248

MgO (90-95%) 2193

Cr₂O₃ 2138

Al₂O₃(pure sintered) 2050

Fireclay 1871

SiO₂ 1715

Kaolin (Al₂O₃. SiO₂) 1816

Chromite (FeO. Cr₂O₃) 2182

Properties required in a refractory

The diversified applications of refractory materials in several different types of industries require diversified properties to meet the physico-chemical and thermal requirements of different phases. In some industrial units more than one phase are present e.g. in steel-making vessels slag /metal /gases are simultaneously present in the vessel at high temperatures. In the heat treating furnaces solid/reducing or oxidizing gases are simultaneously present.

Below are briefly described the properties of the refractory materials:

Refractoriness:

Refractoriness is a property at which a refractory will deform under its own load. The refractoriness is indicated by PCE (Pyrometric cone equivalent). It should be higher than the application temperatures. Refractoriness decreases when refractory is under load. Therefore more important is refractoriness under load (RUL) rather than refractoriness. Porosity and Slag permeability Porosity affects chemical attack by molten slag, metal and gases. Decrease in porosity increases strength and thermal

Conductivity:

Strength It is the resistance of the refractory to compressive loads, tension and shear stresses. In taller furnaces, the refractory has to support a heavy load; hence strength under the combined effect of temperature and load, i.e. refractoriness under load is important. Specific gravity Specific gravity of the refractory is important to consider the weight of a brick. Cost of bricks of higher specific gravity is more that of lower specific gravity. But strength of bricks of higher specific gravity is greater than one with lower specific gravity.

Spalling:

Spalling relates to fracture of refractory brick which may occur due to the following reasons:

- A temperature gradient in the brick which is caused by sudden heating or cooling.
- Compression in a structure of refractory due to expansion
- Variation in coefficient of thermal expansion between the surface layer and the body of the brick
- Variation in coefficient of thermal expansion between the surface layer and the body of the brick is due to slag penetration or due to structural change.

On sudden heating Spalling tendency $\propto$ coeff. of thermal expansion max m shearing strain

◆ thermal diffusivity On sudden cooling Spalling tendency $\propto$ coeff. of thermal expansion max m tensile strength

◆ thermal diffusivity Permanent Linear change (PLC) on reheating In materials certain permanent changes occur during heating and these changes may be due to

- Change in the allotropic form
- Chemical reaction
- Liquid phase formative
- Sintering reactions

$PLC(\%)_{linear} = \frac{\text{Increase /decrease in length}}{\text{original length}} \times 100$ $PLC(\%)_{volume} = \frac{\text{Increase /decrease in volume}}{\text{original volume}} \times 100$ These changes determine the volume stability and expansion and shrinkage of the refractory at high temperatures.

Thermal conductivity Thermal conductivity of the bricks determines heat losses. Increase in porosity decreases thermal conductivity but at the same time decreases strength also. Bulk density: Decrease in bulk density increases volume stability, heat capacity. Types of refractory materials This can be discussed in several ways, for example chemical composition of refractory or use of refractory or method of manufacture or in terms of physical shape. Below is given type of refractory depending on its chemical composition and physical shape. A) Chemical composition

Refractories are composed of either single or multi-component inorganic compounds with non-metallic elements. Acid refractory The main raw materials used are SiO_2 , ZrO_2 and aluminosilicate. They are used where slag and atmosphere are acidic. They cannot be used under basic conditions. Typical refractories are fireclay, quartz and silica. Basic refractory Raw materials used are CaO , MgO , dolomite and chrome-magnesite. Basic refractories are produced from a composition of dead burnt magnesite, dolomite, chrome ore.

a) Magnesite: Chrome combinations have good resistance to chemical action of basic slag and mechanical strength and volume stability at high temperatures.

- b) Magnesite: Carbon refractory with varying amount of carbon has excellent resistance to chemical attack by steelmaking slags.
- c) Chromite- Magnesite refractory: used in inner lining of BOF and side walls of soaking pits.(basic refractory)
- d) Magnesite: Basic refractory in nature.

Magnesite bricks cannot resist thermal shock, lose strength at high temperature and are not resistant to abrasion. Neutral refractory Neutral refractory is chemically stable to both acids and bases. They are manufactured from Al_2O_3 , Cr_2O_3 and carbon.

B) Physical form broadly speaking refractory materials are either bricks or monolithic. Shaped refractories are in the form of the bricks of some standard dimensions. These refractories are machine pressed and have uniform properties. Special shapes with required dimensions are hand molded and are used for particular kilns and furnaces.

Different types are:

- i. Ramming refractory material is in loose dry form with graded particle size. They are mixed with water for use. Wet ramming masses are used immediately on opening.
- ii. Castables refractory materials contain binder such as aluminate cement which imparts hydraulic setting properties when mixed with water. These materials are installed by casting and are also known as refractory concretes.
- iii. Mortars are finely ground refractory materials, which become plastic when mixed with water. These are used to fill the gap created by a deformed shell, and to make wall gas tight to prevent slag penetration. Bricks are joined with mortars to provide a structure.
- iv. Plastic refractories are packed in moisture proof packing and pickings are opened at the time of use.

Plastic refractories have high resistance to corrosion.

Monolithic refractories Monolithic refractories are replacing conventional brick refractories in steelmaking and other metal extraction industries. Monolithic refractories are loose materials which can be used to form joint free lining. The main advantages of monolithic linings are

- Greater volume stability
- Better spalling tendency
- Elimination of joint compared with brick lining
- Can be installed in hot standby mode
- Transportation is easier

Monolithic refractories can be installed by casting, spraying etc. Ramming masses are used mostly in cold condition so that desired shapes can be obtained with accuracy. Insulating materials The role of insulating materials is to minimize heat losses from the high temperature reactors. These materials have low thermal conductivity while their heat capacity depends on the bulk density and specific heat. Insulating materials are porous in structure; excessive heat affects all insulating materials. Choice of insulating materials would depend upon its effectiveness to resist heat conductivity and upon temperature. High alumina with thermal conductivity $0.028 \text{ kcal m}^\circ\text{C}$, and silica with thermal conductivity $0.04 \text{ kcal m}^\circ\text{C}$ etc are amongst others, used as insulating materials. Ceramic fibres are important insulating materials and are produced from molten silica, titania, Zirconia etc in the form of wool, short fibres and long fibres. They have excellent insulation efficiency. They are long weight.

