COURSE MATERIAL

II Year B. Tech I- Semester

MECHANICAL ENGINEERING

Materials Engineering

R18A0305

MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

DEPARTMENT OF MECHANICAL ENGINEERING

(Autonomous Institution-UGC, Govt. of India)
Secunderabad-500100, Telangana State, India.
www.mrcet.ac.in

CONTENTS

MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

(Autonomous Institution – UGC, Govt. of India)

VISION

- 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 technology leaders of Indian vision of modern society.

MISSION

- To become a model institution in the fields of Engineering, Technology and Management.
- To impart holistic education to the students to render them as industry ready engineers.
- To ensure synchronization of MRCET ideologies with challenging demands of International Pioneering Organizations.

QUALITY POLICY

- To implement best practices in Teaching and Learning process for both UG and PG courses meticulously.
- To provide state of art infrastructure and expertise to impart quality education.
- To groom the students to become intellectually creative and professionally competitive.
- To channelize the activities and tune them in heights of commitment and sincerity, the requisites to claim the never - ending ladder of **SUCCESS** year after year.

For more information: www.mrcet.ac.in

VISION

To become an innovative knowledge center in mechanical engineering through state-of-the-art teaching-learning and research practices, promoting creative thinking professionals.

MISSION

The Department of Mechanical Engineering is dedicated for transforming the students into highly competent Mechanical engineers to meet the needs of the industry, in a changing and challenging technical environment, by strongly focusing in the fundamentals of engineering sciences for achieving excellent results in their professional pursuits.

Quality Policy

- ✓ To pursuit global Standards of excellence in all our endeavors namely teaching, research and continuing education and to remain accountable in our core and support functions, through processes of self-evaluation and continuous improvement.
- ✓ To create a midst of excellence for imparting state of art education, industry-oriented training research in the field of technical education.

PROGRAM OUTCOMES

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 teamwork**: 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 multidisciplinary 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.

PROGRAM SPECIFIC OUTCOMES (PSOs)

PSO1	Ability to analyze, design and develop Mechanical systems to solve the Engineering problems by integrating thermal, design and manufacturing Domains.
PSO2	Ability to succeed in competitive examinations or to pursue higher studies or research.
PSO3	Ability to apply the learned Mechanical Engineering knowledge for the Development of society and self.

Program Educational Objectives (PEOs)

The Program Educational Objectives of the program offered by the department are broadly listed below:

PEO1: PREPARATION

To provide sound foundation in mathematical, scientific and engineering fundamentals necessary to analyze, formulate and solve engineering problems.

PEO2: CORE COMPETANCE

To provide thorough knowledge in Mechanical Engineering subjects including theoretical knowledge and practical training for preparing physical models pertaining to Thermodynamics, Hydraulics, Heat and Mass Transfer, Dynamics of Machinery, Jet Propulsion, Automobile Engineering, Element Analysis, Production Technology, Mechatronics etc.

PEO3: INVENTION, INNOVATION AND CREATIVITY

To make the students to design, experiment, analyze, interpret in the core field with the help of other inter disciplinary concepts wherever applicable.

PEO4: CAREER DEVELOPMENT

To inculcate the habit of lifelong learning for career development through successful completion of advanced degrees, professional development courses, industrial training etc.

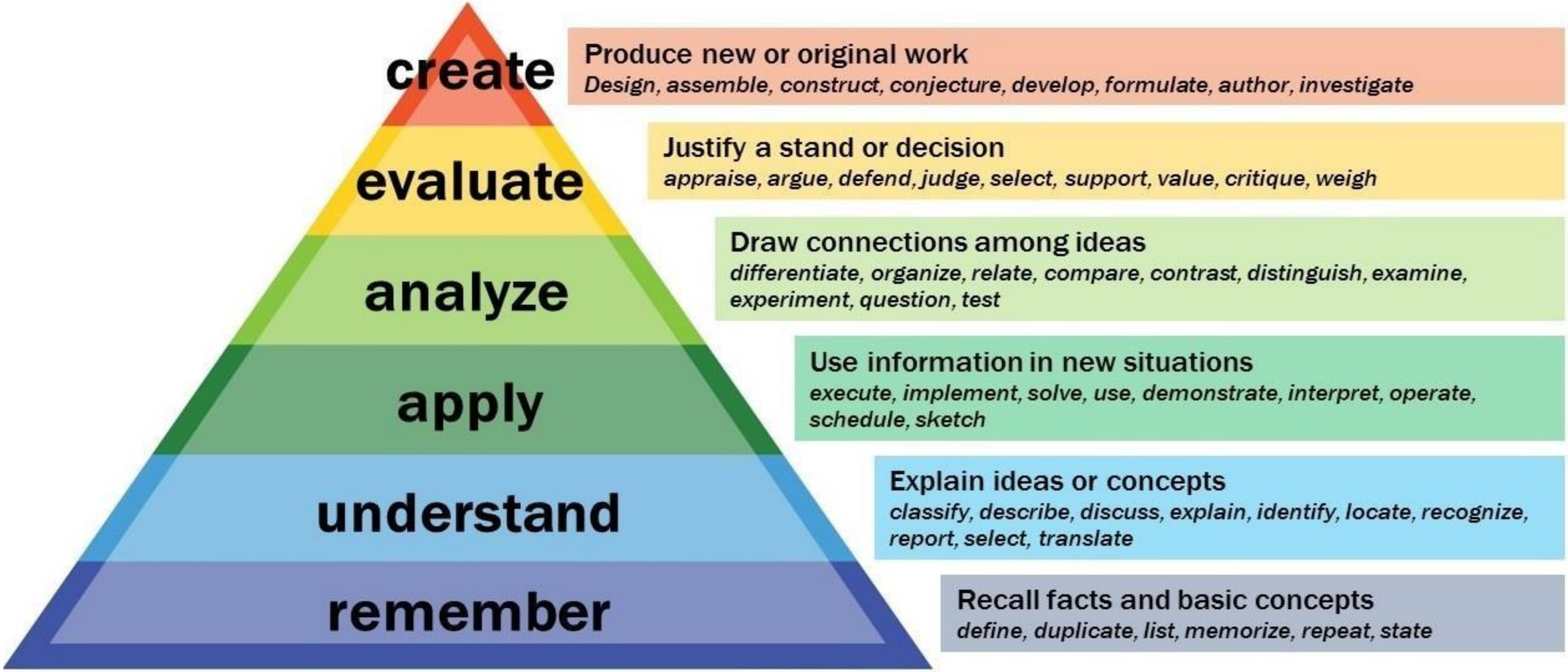
PEO5: PROFESSIONALISM

To impart technical knowledge, ethical values for professional development of the student to solve complex problems and to work in multi-disciplinary ambience, whose solutions lead to significant societal benefits.

Blooms Taxonomy

Bloom's Taxonomy is a classification of the different objectives and skills that educators set for their students (learning objectives). The terminology has been updated to include the following six levels of learning. These 6 levels can be used to structure the learning objectives, lessons, and assessments of a course.

1. **Remembering**: Retrieving, recognizing, and recalling relevant knowledge from long- term memory.
2. **Understanding**: Constructing meaning from oral, written, and graphic messages through interpreting, exemplifying, classifying, summarizing, inferring, comparing, and explaining.
3. **Applying**: Carrying out or using a procedure for executing or implementing.
4. **Analyzing**: Breaking material into constituent parts, determining how the parts relate to one another and to an overall structure or purpose through differentiating, organizing, and attributing.
5. **Evaluating**: Making judgments based on criteria and standard through checking and critiquing.
6. **Creating**: Putting elements together to form a coherent or functional whole; reorganizing elements into a new pattern or structure through generating, planning, or producing.



Produce new or original work
Design, assemble, construct, conjecture, develop, formulate, author, investigate

Justify a stand or decision
appraise, argue, defend, judge, select, support, value, critique, weigh

Draw connections among ideas
differentiate, organize, relate, compare, contrast, distinguish, examine, experiment, question, test

Use information in new situations
execute, implement, solve, use, demonstrate, interpret, operate, schedule, sketch

Explain ideas or concepts
classify, describe, discuss, explain, identify, locate, recognize, report, select, translate

Recall facts and basic concepts
define, duplicate, list, memorize, repeat, state

Course Syllabus

MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

II Year B. Tech, ME-I Sem

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(R18A0305) MATERIALS ENGINEERING

Course Objectives:

1. To understand various mechanical properties of materials.
2. To understand how and why the properties of materials are controlled by its structure at the microscopic and macroscopic levels.
3. To understand how and why the structure and composition of a material may be controlled by processing.
4. To create different types of composite materials and its applications.
5. To remember polymer material classifications and applications.

UNIT-I

Structure of Materials: Structure of atom – Atomic models – Bonding in solids – Bonding forces and energies – Ionic, Covalent, metallic and van der Waals Bond - Crystal structure - Unit Cell – Bravais lattice – BCC – FCC – HCP - Interstitial sites – NaCl crystal – CsCl crystal – Perovskite structure – Diamond structure – Graphite – Crystal directions and planes.

UNIT-II

Structure of Metals and Alloys - Imperfection in crystals – Point defects – Dislocations – Slip plane – Movement of dislocations – Planar defects and grain boundaries – solid solutions – Hume Rothery rule – Phase diagram – Lever rule – Gibb's phase rule – Phase diagram for binary alloys – Eutectic – Peritectic – Eutectoid – Zone refining, Solidification of pure metals and alloys, Short and long freeze range alloys, basic concepts of powder metallurgy.

UNIT-III

Ferrous and Non Ferrous Alloys: Allotropy and phase change of pure iron – Classification of steels and cast iron – iron – carbon equilibrium diagram – Microstructure of iron and steel - Ferrous alloys and their applications, High Resistivity alloys – nichrome, manganin, constantan and kanthal and their composition and applications – Super hard materials - Tungsten carbide and Boron nitrides.

Heat Treatment Methods: Annealing, hardening, tempering, normalizing, surface hardening

UNIT-IV

Ceramic Materials:Introduction to Ceramics, Advanced Ceramic Materials - Crystal Structures –Silicate ceramics, glass and its manufacturing process, Functional properties and applications of ceramic materials.

Composites Materials: Introduction,Classification of composites - Fiber reinforced materials – Law of mixtures – Continuous fibers – discontinuous fibers – Particle-reinforced materials – Cermets – Dispersion strengthened materials – Laminates - Application of composites in electrical and mechanical components – nuclear industry.

UNIT-V

Polymer Materials: Polymers,Classification of polymer – Mechanisms of polymerization - Some commercially important individual polymer – Thermoplastics - Elastomers – Thermosets – Engineering plastics - Liquid crystal polymers - Conductive polymers – High Performance fibers - Biomedical applications – Photonic polymers.

TEXT BOOKS:

1. Material Science by Dr. Kodgire, Everest publications,Pune.
2. V.Raghavan, Material Science and Engineering, Prentice –Hall of India Pvt. Ltd., 2007
3. Sidney H. Avner, Introduction to physical metallurgy, Tata Mc-Graw-Hill, Inc. 1997.

REFERENCE BOOKS:

1. Donald R. Askeland, Pradeep P. Phule, The Science and Engineering of Materials 4th Edition,Thomson/Brooks/Cole,2003.
2. William F.Smith, Structural Properties of Engineering Alloys, Tata Mc-Graw-Hill, Inc., 1993.
3. Kingery. W.D., Bowen H.K. and Uhlmann D.R., Introduction to Ceramics, 2nd Edition, John Wiley & Sons, New York, 1976.

Course Outcomes:

1. Summarizing the concepts of material science properties in the design and development of mechanical systems.
2. Creativeness in new systems components and processes in the field of engineering.
3. Interpreting the heat treatment process and types of alloys for mechanical engineering applications useful to the society.
4. Produce different methods of composite materials for automobile and aeronautical applications.
5. To recalling relevant knowledge from long term memory in types of polymers.

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Units	Chapter No's	Author	Text Book Title	Publishers	Edition
Unit-I STRUCTURE OF MATERIALS	2,3,4	GK NARULA, KS NARULA & VK GUPTA	MATERIAL SCIENCE	TATA McGRAW-HILL	19
Unit-II STRUCTURE OF METALS &ALLOYS	5,6,17	GK NARULA, KS NARULA & VK GUPTA	MATERIAL SCIENCE	TATA McGRAW-HILL	19
Unit-III FERROUS & NON FERROUS ALLOYS	9,10,11	GK NARULA, KS NARULA & VK GUPTA	MATERIAL SCIENCE	TATA McGRAW-HILL	19
Unit-IV CERAMIC MATERIALS	13,15	BK AGRAWAL	ENGINEERING MATERIALS	TATA McGRAW-HILL	36
Unit-V POLYMER MATERIALS	12	GK NARULA, KS NARULA & VK GUPTA	MATERIAL SCIENCE	TATA McGRAW-HILL	19

UNIT - I

Historical Perspective and Materials Science

Materials are so important in the development of human civilization that the historians have identified early periods of civilization by the name of most significantly used material,

e.g.: Stone Age, Bronze Age. This is just an observation made to showcase the importance of materials and their impact on human civilization. It is obvious that materials have affected and controlling a broad range of human activities through thousands of decades.

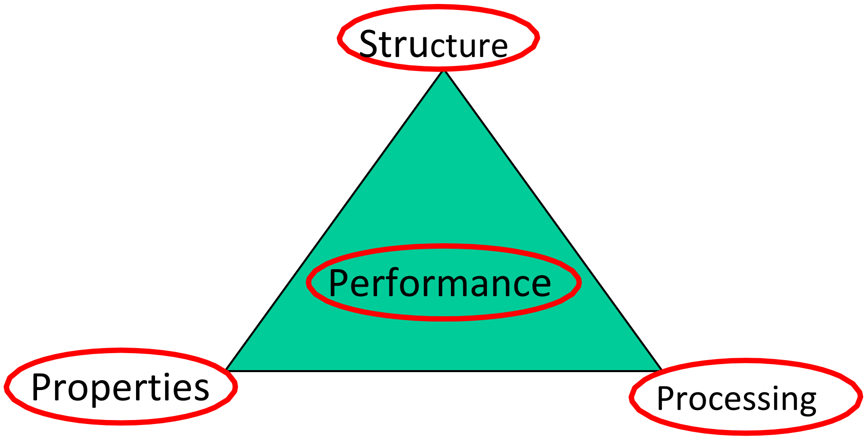
From the historical point of view, it can be said that human civilization started with *Stone Age* where people used only natural materials, like stone, clay, skin, and wood for the purposes like to make weapons, instruments, shelter, etc. Thus the sites of deposits for better quality stones became early colonies of human civilization. However, the increasing need for better quality tools brought forth exploration that led to *Bronze Age*, followed by *Iron Age*. When people found copper and how to make it harder by alloying, the *Bronze Age* started about 3000 BC. The use of iron and steel, a stronger material that gave advantage in wars started at about 1200 BC. Iron was abundant and thus availability is not limited to the affluent. This commonness of the material affected every person in many aspects, gaining the name *democratic material*. The next big step in human civilization was the discovery of a cheap process to make steel around 1850 AD, which enabled the railroads and the building of the modern infrastructure of the industrial world. One of the most significant features of the *democratic material* is that number of users just exploded. Thus there has been a need for human and material resources for centuries, which still going strong. It’s being said and agreed that we are presently in *Space Age* marked by many technological developments towards development materials resulting in stronger and light materials like composites, electronic materials like semiconductors, materials for space voyage like high temperature ceramics, bio materials, etc

In summary, materials constitute foundation of technology. The history of human civilization evolved from the Stone Age to the Bronze Age, the Iron Age, the Steel Age, and to the Space Age (contemporaneous with the Electronic Age). Each age is marked by the advent of certain materials. The Iron Age brought tools and utensils. The Steel Age brought railroads, instruments, and the Industrial Revolution. The Space Age brought the materials for stronger and light structures (e.g., composite materials). The Electronic Age brought semiconductors, and thus many varieties of electronic gadgets.

Materials Science

As engineering materials constitute foundation of technology, it’s not only necessary but a must to understand how materials behave like they do and why they differ in properties. This is only possible with the atomistic understanding allowed by quantum mechanics that first explained atoms and then solids starting in the 1930s. The combination of physics, chemistry, and the focus on the relationship between the properties of a material and its microstructure is the domain of Materials Science. The development of this science allowed designing materials and provided a knowledge base for the engineering applications (Materials Engineering).

Important components of the subject Materials Science are structure, properties, processing, and performance. A schematic interrelation between these four components is shown in figure 1.1.



Interrelation between four components of Materials Science.

Fig no:1.1

Why Study Materials Science and Engineering? and Classification of Materials? All engineers need to know about materials. Even the most "immaterial", like software or system engineering depend on the development of new materials, which in turn alter the economics, like software-hardware trade-offs. Increasing applications of system engineering are in materials manufacturing (industrial engineering) and complex environmental systems.

Innovation in engineering often means the clever use of a new material for a specific application. For example: plastic containers in place of age-old metallic containers. It is well learnt lesion that engineering disasters are frequently caused by the misuse of materials. So it is vital that the professional engineer should know how to select materials which best fit the demands of the design - economic and aesthetic demands, as well as demands of strength and durability. Beforehand the designer must understand the properties of materials, and their limitations. Thus it is very important that every engineer must study and understand the concepts of Materials Science and Engineering. This enables the engineer.

- To select a material for a given use based on considerations of cost and performance.
- To understand the limits of materials and the change of their properties with use.
- To be able to create a new material that will have some desirable properties.
- To be able to use the material for different application.

Classification of Materials

Like many other things, materials are classified in groups, so that our brain can handle the complexity. One can classify them based on many criteria, for example crystal structure (arrangement of atoms and bonds between them), or properties, or use.

Metals, Ceramics, Polymers, Composites, Semiconductors, and Biomaterials constitute

The main classes of present engineering materials.

Metals: These materials are characterized by high thermal and electrical conductivity; strong yet deformable under applied mechanical loads; opaque to light (shiny if polished). These characteristics are due to valence electrons that are detached from atoms, and spread in an *electron sea* that *glues* the ions together, i.e. atoms are bound together by metallic bonds and weaker van der Waalls forces. Pure metals are not good enough for many applications, especially structural applications. Thus metals are used in alloy form i.e. a metal mixed with another metal to improve the desired qualities. E.g.: aluminum, steel, brass, gold.

Ceramics: These are inorganic compounds, and usually made either of oxides, carbides, nitrides, or silicates of metals. Ceramics are typically partly crystalline and partly amorphous. Atoms (ions often) in ceramic materials behave mostly like either positive or negative ions, and are bound by very strong Coulomb forces between them. These materials are characterized by very high strength under compression, low ductility; usually insulators to heat and electricity. Examples: glass, porcelain, many minerals.

Polymers: Polymers in the form of thermo-plastics (nylon, polyethylene, polyvinyl chloride, rubber, etc.) consist of molecules that have covalent bonding within each molecule and van der Waals forces between them. Polymers in the form of thermo-sets (e.g., epoxy, phenolics, etc.) consist of a network of covalent bonds. They are based on H, C and other non-metallic elements. Polymers are amorphous, except for a minority of thermoplastics. Due to the kind of bonding, polymers are typically electrical and thermal insulators. However, conducting polymers can be obtained by doping, and conducting polymer-matrix composites can be obtained by the use of conducting fillers. They decompose at moderate temperatures (100 – 400 C), and are lightweight. Other properties vary greatly.

Composite materials: Composite materials are multiphase materials obtained by artificial combination of different materials to attain properties that the individual components cannot attain. An example is a lightweight brake disc obtained by embedding SiC particles in Al-alloy matrix. Another example is reinforced cement concrete, a structural composite obtained by combining cement (the matrix, i.e., the binder, obtained by a reaction known as hydration, between cement and water), sand (fine aggregate), gravel (coarse aggregate), and, thick steel fibers. However, there are some natural composites available in nature, for example – wood. In general, composites are classified according to their matrix materials. The main classes of composites are metal-matrix, polymer-matrix, and ceramic-matrix.

Semiconductors: Semiconductors are covalent in nature. Their atomic structure is characterized by the highest occupied energy band (the valence band, where the valence electrons reside energetically) full such that the energy gap between the top of the valence band and the bottom of the empty energy band (the conduction band) is small enough for some fraction of the valence electrons to be excited from the valence band to the conduction band by thermal, optical, or other forms of energy. Theirelectrical properties depend extremely strongly on minute proportions of contaminants. They are usually doped in order to enhance electrical conductivity. They are used in the form of single crystals without dislocations because grain boundaries and dislocations would degrade electrical behavior. They are opaque to visible light but transparent to the infrared. Examples: silicon (Si), germanium (Ge), and gallium arsenide (GaAs, a compound semiconductor).

Biomaterials: These are any type material that can be used for replacement of damaged or diseased human body parts. Primary requirement of these materials is that they must be biocompatible with body tissues, and must not produce toxic substances. Other important material factors are: ability to support forces; low friction, wear, density, and cost; reproducibility. Typical applications involve heart valves, hip joints, dental implants, intraocular lenses. Examples: Stainless steel, Co-28Cr-6Mo, Ti-6Al-4V, ultra high molecular weight poly-ethelene, high purity dense Al-oxide, etc.

Advanced Materials, Future Materials, and Modern Materials needs

Advanced Materials

These are materials used in *High-Tech* devices those operate based on relatively intricate and sophisticated principles (e.g. computers, air/space-crafts, electronic gadgets, etc.). These materials are either traditional materials with enhanced properties or newly developed materials with high-performance capabilities. Hence these are relatively expensive. Typical applications: integrated circuits, lasers, LCDs, fiber optics, thermal protection for space shuttle, etc. Examples: Metallic foams, inter-metallic compounds, multi-component alloys, magnetic alloys, special ceramics and high temperature materials, etc.

Future Materials

Group of new and state-of-the-art materials now being developed, and expected to have significant influence on present-day technologies, especially in the fields of medicine, manufacturing and defense. Smart/Intelligent material system consists some type of sensor (*detects an input*) and an actuator (*performs responsive and adaptive function*). Actuators may be called upon to change shape, position, natural frequency, mechanical characteristics in response to changes in temperature, electric/magnetic fields, moisture, pH, etc.

Four types of materials used as actuators: Shape memory alloys, Piezo-electric ceramics, Magnetostrictive materials, Electro-/Magneto-rheological fluids. Materials / Devices used as sensors: Optical fibers, Piezo-electric materials, Micro-electro-mechanical systems (MEMS), etc.

Typical applications: By incorporating sensors, actuators and chip processors into system, researchers are able to stimulate biological human-like behavior; Fibers for bridges, buildings, and wood utility poles; They also help in fast moving and accurate robot parts, high speed helicopter rotor blades; Actuators that control chatter in precision machine tools; Small microelectronic circuits in machines ranging from computers to photolithography prints; Health monitoring detecting the success or failure of a product.

Modern Materials needs

Though there has been tremendous progress over the decades in the field of materials science and engineering, innovation of new technologies, and need for better performances of existing technologies demands much more from the materials field. Moreover it is evident that new materials/technologies are needed to be environmental friendly. Some typical needs, thus, of modern materials needs are listed in the following:

- Engine efficiency increases at high temperatures: requires high temperature structural materials
- Use of nuclear energy requires solving problem with residues, or advances in nuclear waste processing.
- Hypersonic flight requires materials that are light, strong and resist high temperatures.
- Optical communications require optical fibers that absorb light negligibly.
- Civil construction – materials for unbreakable windows.
- Structures: materials that are strong like metals and resist corrosion like plastics.

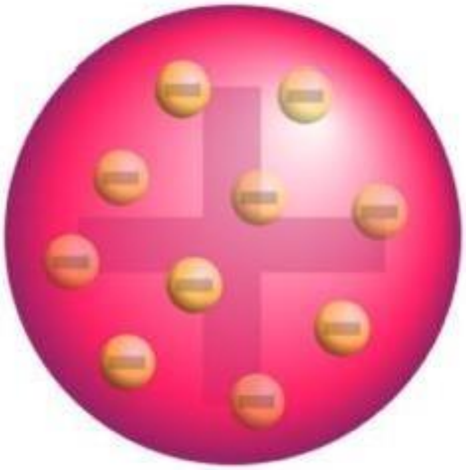
Atomic Structure and Atomic Bonding in Solids

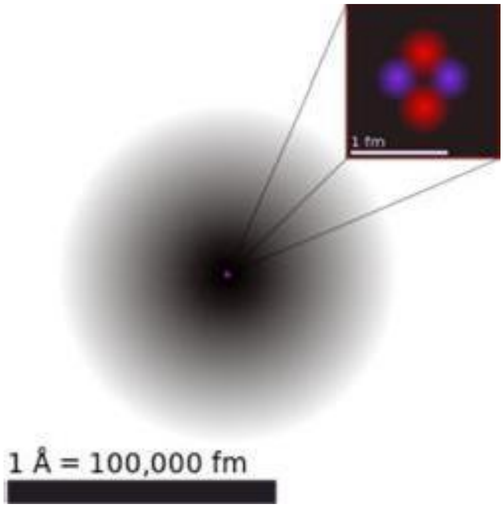
Atomic Model

Thomson atomic model

A schematic presentation of the plum pudding model of the atom; in Thomson's mathematical model the "corpuscles" (or modern electrons) were arranged non-randomly, in rotating rings

The current model of the sub-atomic structure involves a dense nucleus surrounded by a probabilistic "cloud" of electrons





The **plum pudding model** was a model of the atom that incorporated the recently discovered electron, and was proposed by J. J. Thomson in 1904. Thomson had discovered the electron in 1897. The plum pudding model was abandoned after discovery of the atomic nucleus. The plum pudding model of the atom is also known as the "Blueberry Muffin" model.

In this model, the atom is composed of electrons (which Thomson still called "corpuscles", though G. J. Stoney had proposed that atoms of electricity be called electrons in 1894) surrounded by a soup of positive charge to balance the electrons' negative charges, like negatively charged "raisins" surrounded by positively charged "pudding". The electrons (as we know them today) were thought to be positioned throughout the atom, but with many structures possible for positioning multiple electrons, particularly rotating rings of electrons (see below). Instead of a soup, the atom was also sometimes said to have had a "cloud" of positive charge.

With this model, Thomson abandoned his earlier "nebular atom" hypothesis in which the atom was composed of immaterial vortices. Now, at least part of the atom was to be composed of Thomson's particulate negative "corpuscles", although the rest of positively charged part of the atom remained some what nebulous and I ill defined.

The 1904 Thomson model was disproved by the 1909 gold foil experiment of Hans Geiger and Ernest Marsden. This was interpreted by Ernest Rutherford in 1911 to imply a very small nucleus of the atom containing a very high positive charge (in the case of gold, enough to balance about 100 electrons), thus leading to the Rutherford model of the atom. Although gold has an atomic number of 79, immediately after Rutherford's paper appeared in 1911 Antonius Van den Broek made the intuitive suggestion that atomic number is nuclear charge. The matter required experiment to decide. Henry Moseley's work showed experimentally in 1913 (see Moseley's law) that the effective nuclear charge was very close to the atomic number (Moseley found only one unit difference), and Moseley referenced only the papers of Van den Broek and Rutherford. This work culminated in the solar-system-like (but quantum-limited) Bohr model of the atom in the same year, in which a nucleus containing an atomic number of positive charge is surrounded by an equal number of electrons in orbital shells. Bohr had also inspired Moseley's work. Thomson's model was compared (though not by Thomson) to a British dessert called plum pudding, hence the name. Thomson's paper was published in the March 1904 edition of the Philosophical Magazine, the leading British science journal of the day. In Thomson's view: the atoms of the elements consist of a number of negatively electrified corpuscles enclosed in a sphere of uniform positive electrification.

In this model, the electrons were free to rotate within the blob or cloud of positive substance. These orbits were stabilized in the model by the fact that when an electron moved farther from the center of the positive cloud, it felt a larger net positive inward force, because there was more material of opposite charge, inside its orbit (see Gauss's law). In Thomson's model, electrons were free to rotate in rings which were further stabilized by interactions between the electrons, and spectra were to be accounted for by energy differences of different ring orbits. Thomson attempted to make his model account for some of the major spectral lines known for some elements, but was not notably successful at this. Still, Thomson's model (along with a similar Saturnian ring model for atomic electrons, also put forward in 1904 by Nagaoka after James Clerk Maxwell's model of Saturn's rings), were earlier harbingers of the later and more successful solar-system-like Bohr model of the atom.

Rutherford model

Rutherford overturned Thomson's model in 1911 with his well-known gold foil experiment in which he demonstrated that the atom has a tiny, heavy nucleus. Rutherford designed an experiment to use the alpha particles emitted by a radioactive element as probes to the unseen world of atomic structure.

Rutherford presented his own physical model for subatomic structure, as an interpretation for the unexpected experimental results. In it, the atom is made up of a central charge (this is the modern atomic nucleus, though Rutherford did not use the term "nucleus" in his paper) surrounded by a cloud of (presumably) orbiting electrons. In this May 1911 paper, Rutherford only commits himself to a small central region of very high positive or negative charge in the atom.

Bohr model

In the early 20th century, experiments by Ernest Rutherford established that atoms consisted of a diffuse cloud of negatively charged electrons surrounding a small, dense, positively charged nucleus. Given this experimental data, Rutherford naturally considered a planetary-model atom, the Rutherford model of 1911 – electrons orbiting a solar nucleus – however, said planetary- model atom has a technical difficulty. The laws of classical mechanics (i.e. the Larmor formula), predict that the electron will release electromagnetic radiation while orbiting a nucleus. Because the electron would lose energy, it would rapidly spiral inwards, collapsing into the nucleus on a timescale of around 16 picoseconds. This atom model is disastrous, because it predicts that all atoms are unstable.

Also, as the electron spirals inward, the emission would rapidly increase in frequency as the orbit got smaller and faster. This would produce a continuous smear, in frequency, of electromagnetic radiation. However, late 19th century experiments with electric discharges have shown that atoms will only emit light (that is, electromagnetic radiation) at certain discrete frequencies.

To overcome this difficulty, Niels Bohr proposed, in 1913, what is now called the Bohr model of the atom. He suggested that electrons could only have certain classical motions:

1. Electrons in atoms orbit the nucleus.
2. The electrons can only orbit stably, without radiating, in certain orbits (called by Bohr the "stationary orbits") at a certain discrete set of distances from the nucleus. These orbits are associated with definite energies and are also called energy shells or energy levels. In theseorbits, the electron's acceleration does not result in radiation and energy loss as required by classical electromagnetics.
3. Electrons can only gain and lose energy by jumping from one allowed orbit to another, absorbing or emitting electromagnetic radiation with a frequency ν determined by the energy difference of the levels according to the Planck relation

where h is Planck's constant. The frequency of the radiation emitted at an orbit of period T is as it would be in classical mechanics; it is the reciprocal of the classical orbit period:

The significance of the Bohr model is that the laws of classical mechanics apply to the motion of the electron about the nucleus only when restricted by a quantum rule. Although rule 3 is not completely well defined for small orbits, because the emission process involves two orbits with two different periods, Bohr could determine the energy spacing between levels using rule 3 and come to an exactly correct quantum rule: the angular momentum L is restricted to be an integer multiple of a fixed unit:

$$L = n\frac{h}{2\pi} = n\hbar$$

where n = 1, 2, 3, ... is called the principal quantum number, and ħ = h/2π. The lowest value of n is 1; this gives a smallest possible orbital radius of 0.0529 nm known as the Bohr radius. Once an electron is in this lowest orbit, it can get no closer to the proton. Starting from the angular momentum quantum rule, Bohr was able to calculate the energies of the allowed orbits of the hydrogen atom and other hydrogen-like atoms and ions. Other points are:

1. Like Einstein's theory of the Photoelectric effect, Bohr's formula assumes that during a quantum jump a discrete amount of energy is radiated. However, unlike Einstein, Bohr stuck to the classical Maxwell theory of the electromagnetic field. Quantization of the electromagnetic field was explained by the discreteness of the atomic energy levels; Bohr did not believe in the existence of photons.
2. According to the Maxwell theory the frequency ν of classical radiation is equal to the rotation frequency ν_{rot} of the electron in its orbit, with harmonics at integer multiples of this frequency. This result is obtained from the Bohr model for jumps between energy levels E_n and E_{n-k} when k is much smaller than n. These jumps reproduce the frequency of the k-th harmonic of orbit n. For sufficiently large values of n (so-called Rydberg states), the two orbits involved in the emission process have nearly the same rotation frequency, so that the classical orbital frequency is not ambiguous. But for small n (or large k), the radiation frequency has no unambiguous classical interpretation. This marks the birth of the correspondence principle, requiring quantum theory to agree with the classical theory only in the limit of large quantum numbers.
3. The Bohr-Kramers-Slater theory (BKS theory) is a failed attempt to extend the Bohr model which

   $$n\lambda = 2\pi r.$$

   violates the conservation of energy and momentum in quantum jumps, with the conservation laws only holding on average. Bohr's condition, that the angular momentum is an integer multiple of $\hbar$ was later reinterpreted in 1924 by de Broglie as a standing wave condition: the electron is described by a wave and a whole number of wavelengths must fit along the circumference of the electron's orbitSubstituting de Broglie's wavelength of h/p reproduces Bohr's rule. In 1913, however, Bohr justified his rule by appealing to the correspondence principle, without providing any sort of wave interpretation. In 1913, the wave behavior of matter particles such as the electron (i.e., matter waves) was not suspected.

Modern concept of atomic model (De- Broglie's atomic model)

In 1925 a new kind of mechanics was proposed, quantum mechanics, in which Bohr's model of electrons traveling in quantized orbits was extended into a more accurate model of electron motion. The new theory was proposed by Werner Heisenberg. Another form of the same theory, wave mechanics, was discovered by the Austrian physicist Erwin Schrödinger independently, and by different reasoning. Schrödinger employed de Broglie's matter waves, but sought wave solutions of a three-dimensional wave equation describing electrons that were constrained to move about the nucleus of a hydrogen-like atom, by being trapped by the potential of the positive nuclear charge.

The shapes of atomic orbitals can be understood qualitatively by considering the analogous case of standing waves on a circular drum. To see the analogy, the mean vibrational displacement of each bit of drum membrane from the equilibrium point over many cycles (a measure of average drum membrane velocity and momentum at that point) must be considered relative to that point's distance from the center of the drum head. If this displacement is taken as being analogous to the probability of finding an electron at a given distance from the nucleus, then it will be seen that the many modes of the vibrating disk form patterns that trace the various shapes of atomic orbitals. The basic reason for this correspondence lies in the fact that the distribution of kinetic energy and momentum in a matter-wave is predictive of where the particle associated with the wave will be. That is, the probability of finding an electron at a given place is also a function of the electron's average momentum at that point, since high electron momentum at a given position tends to "localize" the electron in that position, via the properties of electron wave-packets (see the Heisenberg uncertainty principle for details of the mechanism).

This relationship means that certain key features can be observed in both drum membrane modes and atomic orbitals. For example, in all of the modes analogous to s orbitals (the top row in the animated illustration below), it can be seen that the very center of the drumembrane vibrates most strongly, corresponding to the anti node in all s orbitals in an atom. This antinode means the electron is most likely to be at the physical position of the nucleus (which it passes straight through without scattering or striking it), since it is moving (on average) most rapidly at that point, giving it maximal momentum. A mental "planetary orbit" picture closest to the behavior of electrons in s orbitals, all of which have no angular momentum, might perhaps be that of a Keplerian orbit with the orbital eccentricity of 1 but a finite major axis, not physically possible (because particles were to collide), but can be imagined as a limit of orbits with equal major axes but increasing eccentricity.

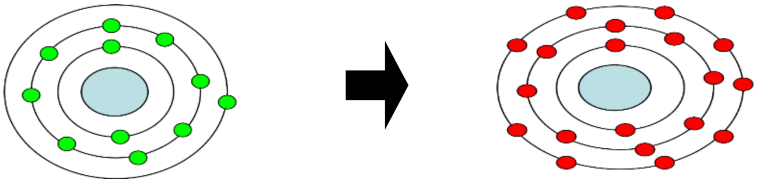
Below, a number of drum membrane vibration modes are shown. The analogous wave functions of the hydrogen atom are indicated. A correspondence can be considered where the wave functions of a vibrating drum head are for a two-coordinate system $\psi(r, \theta)$ and the wave functions for a vibrating sphere are three-coordinate $\psi(r, \theta, \phi)$.

Atomic bonding in solids

In order to understand the why materials behave like they do and why they differ in properties, it is necessary that one should look at atomic level. The study primarily concentrates on two issues: what made the atoms to cluster together, and how atoms are arranged. As mentioned in earlier chapter, atoms are bound to each other by number of bonds. These inter-atomic bonds are primarily of two kinds: Primary bonds and Secondary bonds. Ionic, Covalent and Metallic bonds are relatively very strong, and grouped as primary bonds, whereas van der Waals and hydrogen bonds are relatively weak, and termed as secondary bonds. Metals and Ceramics are entirely held together by primary bonds - the ionic and covalent bonds in ceramics, and the metallic and covalent bonds in metals. Although much weaker than primary bonds, secondary bonds are still very important. They provide the links between polymer molecules in polyethylene (and other polymers) which make them solids. Without them, water would boil at -80˚C, and life as we know it on earth would not exist.

Ionic Bonding:

This bond exists between two atoms when one of the atoms is negative (has an extra electron) and another is positive (has lost an electron). Then there is a strong, direct Coulomb attraction. Basically ionic bonds are non-directional in nature. An example is NaCl. In the molecule, there are more electrons around Cl, forming Cl^- and fewer electrons around Na, forming Na^+. Ionic bonds are the strongest bonds. In real solids, ionic bonding is usually exists along with covalent bonding.



Schematic representation of ioning bonding.

Here, Na is giving an electron to Cl to have stable structure

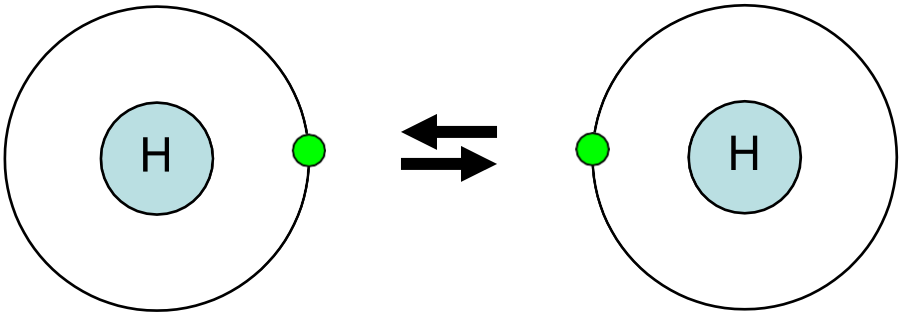


Fig 1.3 Schematic representation of covalent bond in Hydrogen molecule

Covalent Bonding:

In covalent bonding, electrons are shared between the atoms, to saturate the valency. The simplest example is the H_2 molecule, where the electrons spend more time in between the nuclei of two atoms than outside, thus producing bonding. Covalent bonds are stereo-specific i.e. each bond is between a specific pair of atoms, which share a pair of electrons (of opposite magnetic pins). Typically, covalent bonds are very strong, and directional in nature. The hardness of diamond is a result of the fact that each carbon atom is covalently bonded with four neighboring atoms, and each neighbor is bonded with an equal number of atoms to form a rigid three- dimensional structure.

Metallic Bonding:

Metals are characterized by high thermal and electrical conductivities. Thus, neither covalent nor ionic bondings are realized because both types of bonding localize the valence electrons and preclude conduction. However, strong bonding does occur in metals. The valence electrons of metals also are delocalized. Thus metallic bonding can be viewed as metal containing a periodic structure of positive ions surrounded by a sea of delocalized electrons. The attraction between the two provides the bond, which is non-directional.

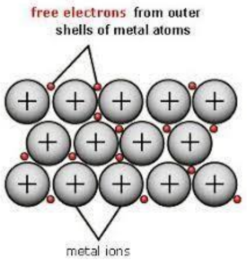


Fig 1.4 Metallic bonding

Fluctuating Induced Dipole Bonds:

Since the electrons may be on one side of the atom or the other, a dipole is formed: the + nucleus at the center, and the electron outside. Since the electron moves, the dipole fluctuates. This fluctuation in atom A produces a fluctuating electric field that is felt by the electrons of an adjacent atom, B. Atom B then polarizes so that its outer electrons are on the side of the atom closest to the + side (or opposite to the – side) of the dipole in A.

Polar Molecule-Induced Dipole Bonds:

Another type of secondary bond exists with asymmetric molecules, also called polar molecules because of positively and negatively charged regions. A permanent dipole moment arises from net positive and negative charges that are respectively associated with the hydrogen and chlorine ends of the HCl molecule, leading to bonding. The magnitude of this bond will be greater than for fluctuating induced dipoles.

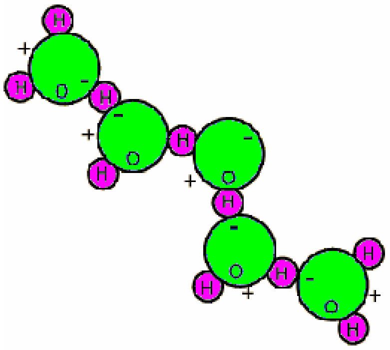


Fig 1.5 Dipole bond in water

These two kinds of bonds are also called van der Waals bonds. Third type of secondary bond is the hydrogen bond. It is categorized separately because it produces the strongest forces of attraction in this category.

Permanent Dipole Bonds / Hydrogen bonding: It occurs between molecules as covalently bonded hydrogen atoms – for example C-H, O-H, F-H – share single electron with other atom essentially resulting in positively charged proton that is not shielded any electrons. This highly positively charged end of the molecule is capable of strong attractive force with the negative end of an adjacent molecule. The properties of water are influenced significantly by the hydrogen bonds/bridges. The bridges are of sufficient strength, and as a consequence water has the highest melting point of any molecule of its size. Likewise, its heat of vaporization is very high.

Crystal Structures, Crystalline and Non-Crystalline materials

Crystal structures

All metals, a major fraction of ceramics, and certain polymers acquire crystalline form when solidify, i.e. in solid state atoms self-organize to form *crystals*. Crystals possess a long-range order of atomic arrangement through repeated periodicity at regular intervals in three dimensions of space. When the solid is not crystalline, it is called amorphous. Examples of crystalline solids are metals, diamond and other precious stones, ice, graphite. Examples of amorphous solids are glass, amorphous carbon (a-C), amorphous Si, most plastics.

There is very large number of different crystal structures all having long-range atomic order; these vary from relatively simple structures for metals to exceedingly complex structures for ceramics and some polymers. To discuss crystalline structures it is useful to consider atoms as being hard spheres, with well-defined radii. In this scheme, the shortest distance between two like atoms is one diameter. In this context, use of terms *lattice* and *unit cell* will be handy. *Lattice* is used to represent a three-dimensional periodic array of points coinciding with atom positions. *Unit cell* is smallest repeatable entity that can be used to completely represent a crystal structure. Thus it can be considered that a unit cell is the building block of the crystal structure and defines the crystal structure by virtue of its geometry and the atom positions within.

Important properties of the unit cells are

- The type of atoms and their radii *R*.
- Cell dimensions (Lattice spacing a, b and c) in terms of *R* and
- Angle between the axis α, β, γ
- a*, b*, c* - lattice distances in reciprocal lattice , α*, β*, γ* - angle in reciprocal lattice
- *n*, number of atoms per unit cell. For an atom that is shared with *m* adjacent unit cells, we only count a fraction of the atom, 1/*m*.
- *CN*, the coordination number, which is the number of closest neighbors to which an atom is bonded.
- *APF*, the atomic packing factor, which is the fraction of the volume of the cell actually occupied by the hard spheres. *APF* = Sum of atomic volumes/Volume of cell.

Some very common crystal structures and relevant properties are listed in table below.

Unit Cell	*n*	*CN*	*a/R*	*APF*
Simple Cubic	1	6	4/[illegible]	0.52
Body-Centered Cubic	2	8	$4/\sqrt{3}$	0.68
Face-Centered Cubic	4	12	$4/\sqrt{2}$	0.74

Hexagonal Close Packed	6	12		0.74

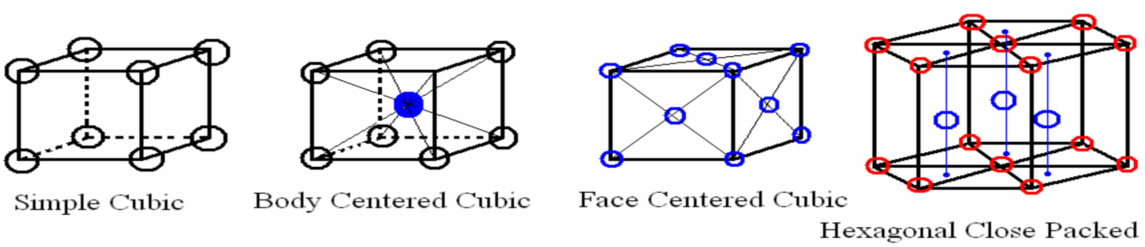


Fig 1.6Common metallic crystal structures

Crystalline and Non-crystalline materials

Single Crystals: Crystals can be *single crystals* where the whole solid is one crystal. Then it has a regular geometric structure with flat faces.

Polycrystalline Materials: A solid can be composed of many crystalline grains, not aligned with each other. It is called *polycrystalline*. The grains can be more or less aligned with respect to each other. Where they meet is called a *grain boundary*.

Non-Crystalline Solids: In amorphous solids, there is no long-range order. But amorphous does not mean random, since the distance between atoms cannot be smaller than the size of the hard spheres. Also, in many cases there is some form of short-range order. For instance, the tetragonal order of crystalline SiO_2 (quartz) is still apparent in amorphous SiO_2 (silica glass).

Miller Indices, Anisotropy, and Elastic behavior of composites

Miller indices:

It is understood that properties of materials depend on their crystal structure, and many of these properties are directional in nature. For example: elastic modulus of BCC iron is greater parallel to the body diagonal than it is to the cube edge. Thus it is necessary to characterize the crystal to identify specific directions and planes. Specific methods are employed to define crystal directions and crystal planes.

Methodology to define crystallographic directions in cubic crystal:

- a vector of convenient length is placed parallel to the required direction.
- the length of the vector projection on each of three axes are measured in unit cell dimensions.
- these three numbers are made to smallest integer values, known as indices, by multiplying or dividing by a common factor.
- the three indices are enclosed in square brackets, *[uvw]*. A family of directions is represented by *<uvw>*.

Methodology to define crystallographic planes in cubic crystal:

- Determine the intercepts of the plane along the crystallographic axes, *in terms of unit cell dimensions*. If plane is passing through origin, there is a need to construct a plane parallel to original plane.
- Take the reciprocals of these intercept numbers.
- Clear fractions.
- Reduce to set of smallest integers.
- The three indices are enclosed in parenthesis, *(hkl)*. A family of planes is represented by *{hkl}*.

For example, if the x-, y-, and z- intercepts of a plane are 2, 1, and 3. The Miller indices are calculated as:

- Take reciprocals: 1/2, 1/1, 1/3.
- Clear fractions (multiply by 6): 3, 6, 2.
- Reduce to lowest terms (already there). => Miller indices of the plane are (362). Figure 2.2 depicts Miller indices for number of directions and planes in a cubic crystal.

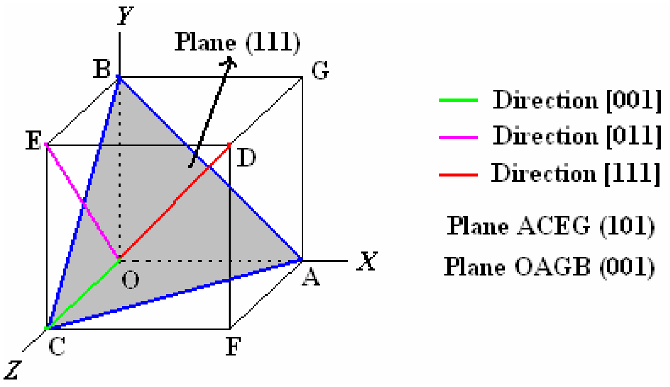


Fig 1.7 Miller indices in a cubic crystal.

Some useful conventions of Miller notation:

- If a plane is parallel to an axis, its intercept is at infinity and its Miller index will be zero.
- If a plane has negative intercept, the negative number is denoted by a bar above the number. *Never alter negative numbers.* For example, do not divide -1, -1, -1 by -1 to get 1,1,1. This implies symmetry that the crystal may not have!
- The crystal directions of a family are not necessarily parallel to each other.
- Similarly, not all planes of a family are parallel to each other.
- By changing signs of all indices of a direction, we obtain opposite direction. Similarly, by changing all signs of a plane, a plane at same distance in other side of the origin can be obtained.
- Multiplying or dividing a Miller index by constant has no effect on the orientation of the plane.
- The smaller the Miller index, more nearly parallel the plane to that axis, and vice versa.
- When the integers used in the Miller indices contain more than one digit, the indices must be separated by commas. E.g.: (3,10,13)

- By changing the signs of all the indices of (a) a direction, we obtain opposite direction, and (b) a plane, we obtain a plane located at the same distance on the other side of the origin.

Why Miller indices are calculated in that way?

- Using reciprocals spares us the complication of infinite intercepts.
- Formulas involving Miller indices are very similar to related formulas from analytical geometry.
- Specifying dimensions in unit cell terms means that the same label can be applied to any plane with a similar stacking pattern, regardless of the crystal class of the crystal. Plane (111) always steps the same way regardless of crystal system.

Miller-Bravis indices

Though Miller indices can describe all possible planes through any crystal, Miller-Bravis indices are used in hexagonal crystal systems. This is because they reveal hexagonal symmetry more clearly. Although partially redundant, they are used exclusively for hexagonal systems.

Direction indices are obtained as above where first three indices are representative of projections of the direction over three co-planar axes in the plane called basal plane while the last index denotes the projection over the axis perpendicular to the basal plane. Miller-Bravis indices for a plane are denoted as *[uvtw]*, where $t = -(u+v)$

In the same procedure, planes in a hexagonal crystal are denoted by *(hkil)*, where $i =- (h+k)$.

Structure and properties of polymers

Polymers are common in nature, in the form of wood, rubber, cotton, leather, wood, silk, proteins, enzymes, starches, cellulose. Artificial polymers are made mostly from oil. Their use has grown exponentially, especially after WW2 (World War-2). The key factor is the very low production cost and useful properties (e.g., combination of transparency and flexibility, long elongation, etc.).

Most polymers are organic, and formed from hydrocarbon molecules. These molecules can have single, double, or triple carbon bonds. A *saturated hydrocarbon* is one where all bonds are single, i.e. the number of atoms is maximum (or saturated). Among this type are the paraffin compounds, C_nH_{2n+2}. In contrast, non-saturated hydrocarbons contain some double and triple bonds.

Isomers are molecules that contain the same molecules but in a different arrangement. An example is butane and iso-butane. Some physical properties of hydrocarbons depend on the isomeric state.

Polymer molecules

Polymer molecules are huge, macro molecules that have internal covalent bonds. For most polymers, these molecules form very long chains. The backbone is a string of carbon atoms, often single bonded. Polymers are composed of basic structures called ***mer*** units. A molecule with just one mer is a monomer. Within each molecule / mer atoms are bonding together by strong covalent bonds. When many mers are together, they form polymer. Bi-functional monomers may bond with two other units in forming 2-D chain- like structures; while Tri-functional monomers can form three active bonds, and thus 3-D molecular network. Examples of polymers are polyvinyl chloride (PVC), poly-tetra- fluoro-ethylene (PTFE or Teflon), polypropylene, nylon and polystyrene. When all the mers are the same, the molecule is called a *homopolymer*. When there is more than one type of mer present, the molecule is a *copolymer*.

The mass of a polymer is not fixed, but is distributed around a mean value, since not all polymer chains will grow same extent. The average molecular weight can be obtained by averaging the masses with the fraction of times they appear (*number-average*) or with the weight fraction of the molecules (*weight-average*). Another representation of average chain size is *degree of polymerization* (*n*) – average number of mer units in a chain. It is obtained by dividing the average mass of the polymer by the mass of a mer unit. Numbers of polymer characteristics are affected by the magnitude of the molecular weight. Short chain polymers usually exist in form of gases or liquids at room temperature; where as medium range polymers are waxy solids and soft resins. Solid polymers are commonly having weights ranging between 10K and several million g/mol.

Polymer structures

Polymers consist of large number of molecular chains which are usually not linear; bending and rotations can occur around single C-C bonds (double and triple bonds are very rigid). Random kinks and coils in chains along with bending of chains lead to intertwining and entanglement of neighboring chains, situation like in the spaghetti structure. These characteristic entanglements are responsible for a number of properties specific to polymers, e.g.: large elastic extension. However, physical properties of polymers depend not only on molecular weight and shape, but also on differences in structure of the chains. It should be remembered that polymers are not usually of only one distinctive structural type, though they are classified into different groups. Typical polymer chain structures are: (a) *linear*, where mer units are joined together end to end in single chains. E.g.: PVC, nylon. (b) *branched*, where side-branch chains are connected to main ones. Branching of polymers lowers polymer density because of lower packing efficiency. (c) *cross-linked*, where chains are joined one to another at various positions by covalent bonds.

This cross-linking is usually achieved at elevated temperatures by additive atoms. E.g.: vulcanization of rubber. (d) *network*, trifunctional mer units with 3- D networks comes under this category. E.g.: epoxies, phenol-formaldehyde.

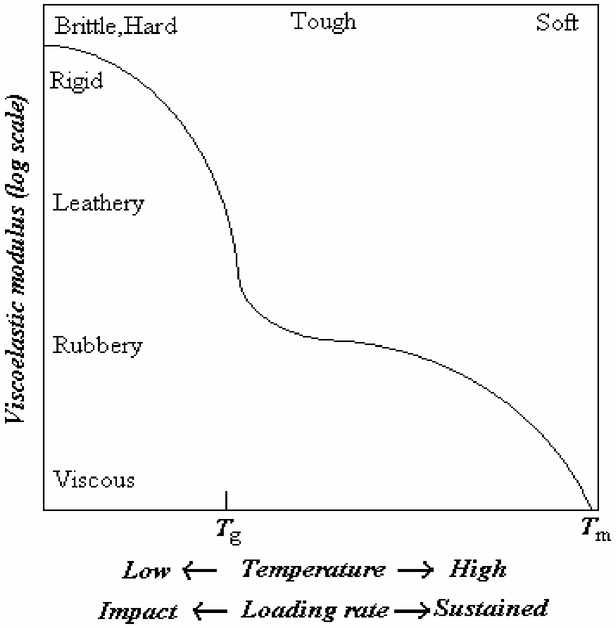
Polymer crystallinity

Crystallinity in polymers is more complex than in metals. Polymer molecules are often partially crystalline (*semicrystalline*), with crystalline regions dispersed within amorphous material. The degree of crystallinity may range from completely amorphous to almost entirely crystalline; on the other hand metals are almost always crystalline whereas ceramics are either completely crystalline or noncrystalline. The degree of crystallinity of a polymer depends on cooling path, and also on chain configuration. For copolymers, the more irregular and random the mer arrangement, the greater is probability for noncrystalline nature. Crystalline polymers are denser than amorphous polymers, so the degree of crystallinity can be obtained from the measurement of density.

Different models have been proposed to describe the arrangement of molecules in semicrytalline polymers. In the fringed-micelle model, the crystallites (micelles) are embedded in an amorphous matrix. Polymer single crystals grown are shaped in regular platelets (lamellae). Spherulites are chain-folded crystallites in an amorphous matrix that grow radially in spherical shape "grains". These are considered to be the polymer analogue of grains in polycrystalline metals and ceramics. Many semicrystalline polymers form spherulites; each spherulite consists of a collection of ribbonlike chain- folded lamellar crystallites that radiate outward from its center. E.g.: polyethelene, PVC.

A polymer's response to mechanical forces under elevated temperatures is related to its molecular structure. Based on this response, polymers are classified as: *thermoplasts* (soften when heated and harden when cooled), and *thermosets* (become permanently hard when heat is applied and do not soften upon subsequent heating). Thermosets are generally harder and stronger than thermoplasts, and have better dimensional stability. Most of the cross-linked and network polymers are thermosets; whereas linear and some branched polymers are thermoplastic.

Properties of polymers



Fluids and amorphous solids undergo viscous flow when external forces are applied. It is well known that polymers exhibit very high viscosity in order of 10^{12} Pa.s at room temperature. Polymers are non-

Newtonian in nature, and formed into plastic products at a temperature above their glass-transition temperature. It is evident that temperature has very strong influence on mechanical behavior of polymers. Elastic strain occurs simultaneously with viscous flow, resulting in visco-elastic deformation of polymers under externally applied loads. Below the glass transition temperature elastic deformation dominates and the material behaves rigid. In the range of glass temperature, the materials is leathery; in the rubber plateau, polymers deform readily but quickly regain their previous shape if the stress in removed. At still higher temperatures, under sustained loads, the polymer deforms extensively by viscous flow. Figure below depicts temperature effect on deformation behavior of polymers.

Structure and properties of ceramics

Ceramics are inorganic and non-metallic materials that are commonly electrical and thermal insulators, brittle and composed of more than one element (e.g., two in Al_2O_3). As ceramics are composed of two or more elements, their crystal structures are generally more complex than those of metals. Ceramic bonds are mixed, ionic and covalent, with a proportion that depends on the particular ceramics. The ionic character is given by the difference of electronegativity between the cations (+) and anions (-). Covalent bonds involve sharing of valence electrons. Very ionic crystals usually involve cations which are alkalis or alkaline-earths (first two columns of the periodic table) and oxygen or halogens as anions.

The building criteria for the ceramic crystal structure are as follows:

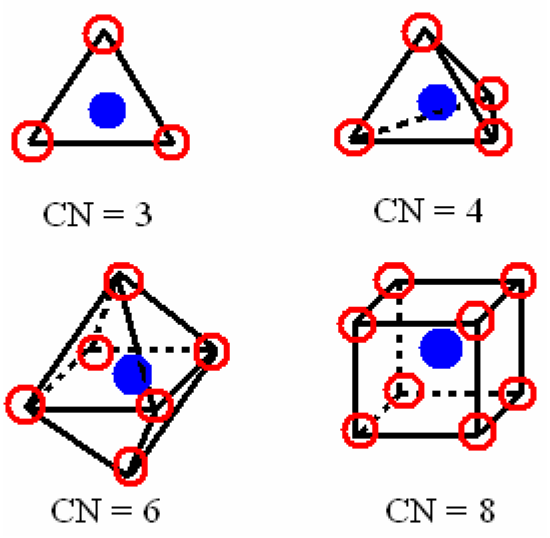
- maintain neutrality (charge balance dictates chemical formula)
- achieve closest packing

The crystal stability condition i.e. condition of minimum energy implies maximum attraction and minimum repulsion. This leads to contact and configurations such that anions have the highest number of cation neighbors (coordination number) and vice versa. The coordination number is dependent on cation-anion radius ratio, which can be determined from geometric relations. Table 2.2 presents relevant coordination numbers and radius ratios.

Co-ordination number dependency on cation-anion radius ratio.

Cation-anion radius ratio (r_c/r_a)	< 0.155	0.155 – 0.225	0.225 – 0.414	0.414 – 0.732	0.732 – 1.000	> 1.000
Coordination number	2	3	4	6	8	12

Fig no: 1.8 Ion arrangements for different coordination numbers.



Ceramic crystal structures

AX-type ceramic crystal structures: Most common ceramics are made of equal number of cations and anions, and are referred to as AX compounds (A-cation, and X-anion). These ceramics assume many different structures, named after a common material that possesses the particular structure.

Rock salt structure: here the coordination number is 6, i.e. $r_c/r_a = 0.414\text{-}0.732$. This structure can be viewed as an FCC of anions with cations occupying center of each edge and the center of the cell. Thus it can be said that lattice is made of two interpenetrating FCC lattices, one composed of cations, and the other of anions. E.g.: NaCl, MgO, FeO.

Cesium Chloride structure: here the coordination number is 8. Crystal structure consists of anions at corners of a cube while a cation occupies the center, and vice versa. E.g.: CsCl.

Zinc Blende structure: here the coordination number is 4. Unit cell is composed of one kind of ions occupying corners and face centers of a cube, while the other kind of ions occupies the interior tetrahedral positions. E.g.: ZnS, SiC.

A_mX_p- type structures: when the charges of cation and anions are not the same, to maintain the neutrality, ceramic structures with chemical formula would exist. For example – CaF_2 with $r_c/r_a = 0.8$, and thus coordination number of 8. It can be expected that crystal structure could be the same as that of CsCl. However cations are half many as anions, thus only half the center positions are occupied. One unit cell shall be made of eight cubes. E.g.: UO_2, ThO_2, PuO_2.

$A_mB_nX_p$-type structures: it is possible that ceramics do have more than one kind of cations. E.g.: $BaTiO_3$. unit cell is made of cube where Ba^{2+} ions occupies all eight corners, T^{4+} occupies cube center, while O^{2-} are at center of each face. This structure is called *perovskite crystal structure*.

It is worth to understand and know more about some common most common ceramic in nature. For example: silicates and carbon.

Silicates

Oxygen and Silicon are the most abundant elements in Earth's crust. Their combination (silicates) occurs in rocks, soils, clays and sand. The bond is weekly ionic, with Si^{4+} as the cation and O^{2-} as the anion. However the bonds in silicates are strongly of covalent character with strong directional Si-O bonds. Basic unit of silicates structures are thus is SiO_4^{4-} tetrahedron that consists of four oxygen atoms at corners of tetrahedron, and silicon atom at the center of it. Various

silicate structures consists SiO $^{4-}$ unit bonded in 1, 2-, and 3- dimensions. 4

In silica (SiO_2) every oxygen atom is shared by adjacent tetrahedra. Silica can either be crystalline (e.g., quartz) or amorphous, as in glass. Crystalline forms of silica are known to be complicated and comparatively open, thus of low densities compared with amorphous glasses. Soda glasses melt at lower temperature than amorphous SiO_2 because the addition of Na_2O (soda) that act as *network modifier* breaks the tetrahedral network. Addition of *intermediates* such as Al_2O_3, TiO_2 substitute of silicon atoms and become part of stabilized network. Addition of network modifiers and intermediates lowers melting point, and thus it is easy to form glass, for instance, bottles.

In complicated silicate structure, corner oxygen atom of basic unit is shared by other tetrahedra, resulting in formulas such as SiO_4^{4-}, $Si_2O_7^{6-}$, $Si_3O_9^{6-}$, etc. The repeating unit of 2-D sheet or layered structure is represented as $Si_2O_5^{2-}$. Such layered structures are characteristics of clays and other minerals.

Carbon

Carbon is not really a ceramic, but one of its allotropic form, diamond may be considered as a ceramic. *Diamond* has very interesting and even unusual properties such as:

- possesses diamond-cubic structure (like Si, Ge)
- consists covalent C-C bonds
- having highest hardness of any material known
- very high thermal conductivity (unlike ceramics)
- transparent in the visible and infrared, with high index of refraction
- semiconductor (can be doped to make electronic devices)
- meta-stable (transforms to carbon when heated)

Synthetic diamonds are made by application of high temperatures and pressures or by chemical vapor deposition. Future applications of this latter, cheaper production method include hard coatings for metal tools, ultra-low friction coatings for space applications, and microelectronics.

Graphite, another allotropic form of carbon, has a layered structure with very strong hexagonal bonding within the planar layers (using 3 of the 3 bonding electrons) and weak, van der Waals bonding between layers using the fourth electron. This leads to easy inter-planar cleavage and applications as a lubricant and for writing (pencils). Graphite is a good electrical conductor and chemically stable even at high temperatures. Applications include furnaces, rocket nozzles, electrodes in batteries, etc.

Recently (1985) discovered allotropic form of carbon is the C_{60} molecule, also known as *fullerene* or *bucky-ball* (after the architect Buckminster Fuller who designed the geodesic structure that C_{60} resembles.). Structure of this form resembles a hallow spherical cluster of 60 atoms, and is found to consist of 20 hexagons and 12 pentagons where no two pentagons share a common edge. Fullerenes and related structures like nanotubes are exceptionally stiff, strong, and ductile. Future applications of fullerenes are as a structural material and possibly in microelectronics, due to the unusual properties that result when fullerenes are doped with other atoms.

Imperfections in ceramics

Imperfections in ceramics include point defects and impurities. Their formation is strongly affected by the condition of charge neutrality (creation of unbalanced charges requires the expenditure of a large amount of energy). Both vacancies and interstitials are possible in ceramics as in metals; however as ceramics have more then one element these defects can be associated with each of these elements. Neutral charge defects include the Frenkel and Schottky defects. A *Frenkel-defect* is a vacancy- interstitial pair of cations (placing large anions in an interstitial position requires a lot of energy in lattice distortion). A *Schottky-defect* is a pair of nearby cation and anion vacancies.

Non-stoichiometry refers to a change in composition so that the elements in the ceramic are not in the proportion appropriate for the compound (condition known as stoichiometry). To minimize energy, the effect of non-stoichiometry is a redistribution of the atomic charges. Introduction of impurity atoms in the lattice is likely in conditions where the charge is maintained. This is the case of electronegative impurities that substitute lattice anions or electropositive substitutional impurities. This is more likely for similar ionic radii since this minimizes the energy required for lattice distortion. Defects will appear if the charge of the impurities is not balanced.

Mechanical response of ceramics

Brittle Fracture of Ceramics: The brittle fracture of ceramics limits their engineering applications. It occurs due to the unavoidable presence of microscopic flaws (micro- cracks, internal pores, and atmospheric contaminants) that result during cooling from the melt. The flaws need to crack initiation, and crack propagation (perpendicular to the applied stress) is usually trans-granular, along cleavage planes. The flaws cannot be closely controlled in manufacturing; this leads to a large scatter in the fracture strength of ceramic materials.

Under compressive stresses, however, flaws do not associate with amplification of stress. Hence, the compressive strength of ceramics is typically ten times to their tensile strength. This makes ceramics good structural materials under compression (e.g., bricks in houses, stone blocks in the pyramids), but not in conditions of tensile stress, such as under flexure.

Plastic deformation in crystalline ceramics is by slip, which is difficult due to the structure and the strong local (electrostatic) potentials. There is very little plastic deformation before fracture. Non-crystalline ceramics, like common glass, deform by viscous flow (like very high-density liquids) as deformation can not occur by slip because of absence of regular atomic structure, which occurs in metals. Characteristic property of viscous flow, viscosity, is a measure of non-crystalline material’s resistance to deformation. It was found to decrease with increasing temperature. At room temperature, the viscosity of many non-crystalline ceramics is extremely high.

Perovskites

The terms "perovskite" and "perovskite structure" are often used interchangeably. Technically, a perovskite is a type of mineral that was first found in the Ural Mountains and named after Lev Perovski who was the founder of the Russian Geographical Society. A perovskite structure is any compound that has the same structure as the perovskite mineral.

True perovskite (the mineral) is composed of calcium, titanium and oxygen in the form CaTiO3. Meanwhile, a perovskite structure is anything that has the generic form ABX3 and the same crystallographic structure as perovskite (the mineral). However, since most people in the solar cell world aren’t involved with minerals and geology, perovskite and perovskite structure are used interchangeably.

The perovskite lattice arrangement is demonstrated below. As with many structures in crystallography, it can be represented in multiple ways. The simplest way to think about a perovskite is as a large atomic or molecular cation (positively-charged) of type A in the centre of a cube. The corners of the cube are then occupied by atoms B (also positively-charged cations) and the faces of the cube are occupied by a smaller atom X with negative charge (anion).

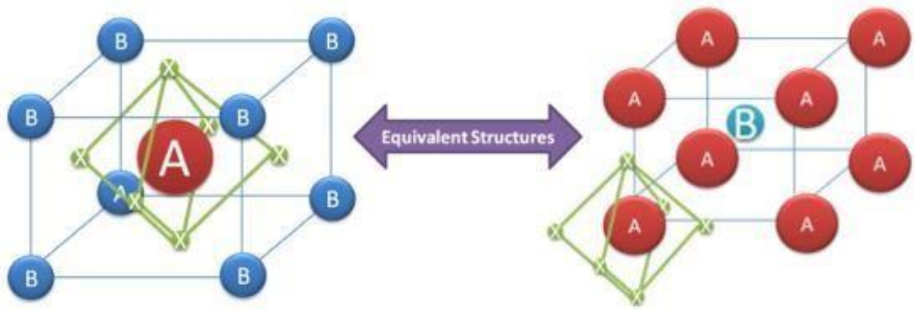


Fig no 1.9 A generic perovskite crystal structure of the form ABX3. Note however that the two structures are equivalent

The left hand structure is drawn so that atom B is at the <0,0,0> position while the right hand structure is drawn so that atom (or molecule) A is at the <0,0,0> position. Also note that the lines are a guide to represent crystal orientation rather than bonding patterns.

Depending on which atoms/molecules are used in the structure, perovskites can have an impressive array of interesting properties including superconductivity, giant magnetoresistance, spin-dependent transport (spintronics) and catalytic properties. Perovskites therefore represent an exciting playground for physicists, chemists and material scientists.

In the case of perovskite solar cells, the most efficient devices so far have been produced with the following combination of materials in the usual perovskite form ABX_3:

- A = An organic cation - methylammonium $(CH_3NH_3)^+$
- B = A big inorganic cation - usually lead(II) (Pb^{2+})

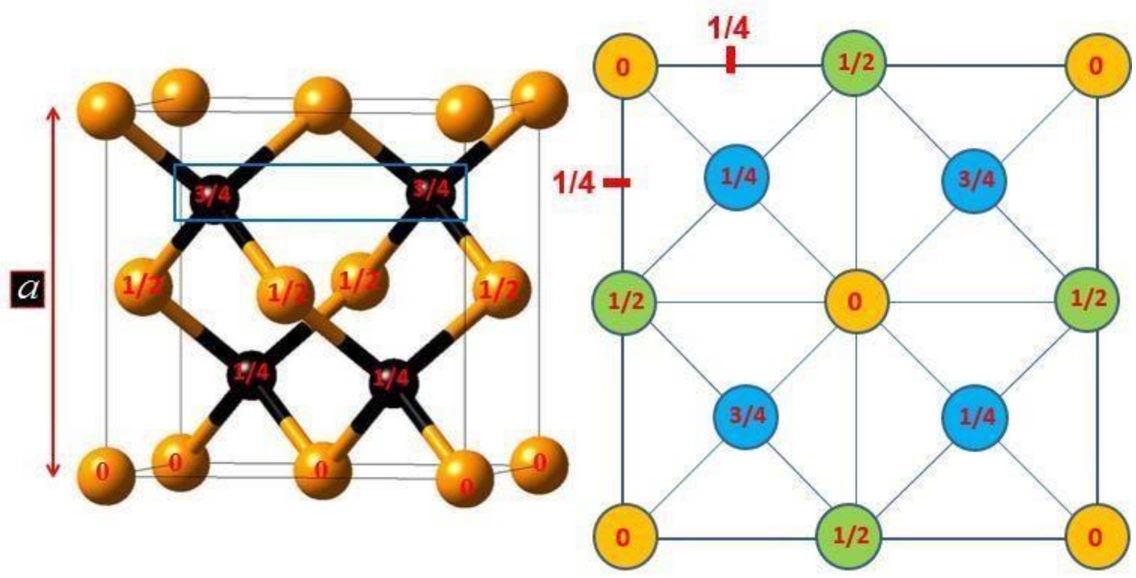
  X_3= A slightly smaller halogen anion – usually chloride (Cl^-) or iodide (I^-)

Since this is a relatively general structure, these perovskite-based devices can also be given a number of different names, which can either refer to a more general class of materials or a specific combination. As an example of this, we’ve created the below table to highlight how many names can be formed from one basic structure.

A	**B**	**X3**
Organo	Metal	Trihalide (or trihalide)
Methylammonium	Lead	Iodide (or triiodide)
	Plumbate	Chloride (or trichloride)

Diamond Structure

Diamond Crystal Structure is a metastable allotrope of carbon where the each carbon atom is bonded covalently with other surrounding four carbon atoms and are arranged in a variation of the face centered cubic crystal structure called a diamond lattice. Diamond is a transparent crystal of tetrahedrally bonded carbon atoms (sp^3) that crystallizes into the diamond lattice which is a variation of the face centered cubic structure. Each carbon atom joins four other carbon atoms in regular tetrahedrons (triangular prisms). Based on the cubic form and its highly symmetrical arrangement of atoms, diamond crystals can develop into several different shapes, known as 'crystal habits'.

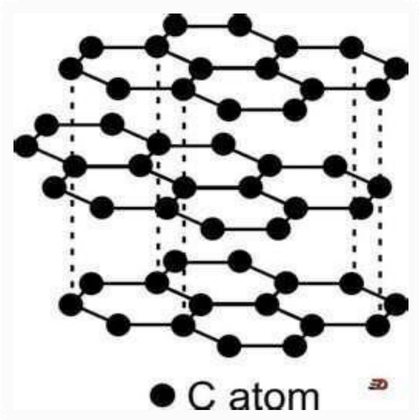


The number '0' and fractions '½', '¼' and '¾' denote the height above the base.

Fig no :1.10

Graphite Structure

Graphite is a greyish black opaque substance. It is lighter than diamond and is soft and slippery to touch. It conduct electricity. It is made up of carbon atoms only. The structure of graphite is very different from that of diamond. It consists of layers of carbon atoms or sheet of carbon atoms.



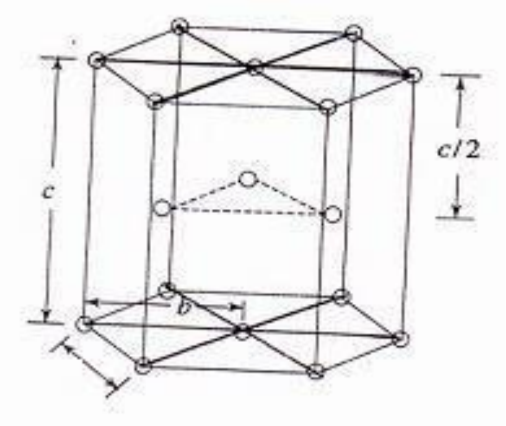
Each carbon atoms in a graphite layer is joined to three other carbon atoms by strong covalent bonds to form flat hexagonal rings. The various layers of carbon atoms in graphite are held together by weak van der waals forces. The structure of graphite is very different from that of diamond. It consists of layers of carbon atoms or sheet of carbon atoms. Each carbon atoms in a graphite layer is joined to three other carbon atoms by strong covalent bonds to form flat hexagonal rings. The various layers of carbon atoms in graphite are held together by weak van der waals forces. Due to the sheet like structure, graphite is comparatively soft substance. Graphite is good conductor of electricity because due to the presence of free electrons.

Uses of Graphite:

- Graphite can be used for lubricating those machine parts which operate at very high temperature.
- Graphite is used for making graphite electrodes in dry cells and electric arcs.
- Graphite is used for making the cores of our pencils called pencil leads.

– **Hexagonal Closed Packed Structure**

Fig no:1.11 It consists of three layers of atoms.



- The bottom layer has six corner atoms and one face centred atom.
- The middle layer has three full atoms.
- The upper layer has six corner atoms and one face centred atom.
- Each and every corner atom contributes 1/6 of its part to one unit cell.
- The number of total atoms contributed by the corner atoms of both top and bottom layers is 1/6 ⍰ 12 = 2.
- The face centred atom contributes 1/2 of its part to one unit cell.
- Since there are 2 face centred atoms, one in the top and the other in the bottom layers, the number of atoms contributed by face centred atoms is 1/2⍰2 = 1.
- Besides these atoms, there are 3 full atoms in the middle layer.
- Total number of atoms present in an HCP unit cell is 2+1+3 = 6.

CO-ORDINATION NUMBER (CN)

- The face centered atom touches 6 corner atoms in its plane.
- The middle layer has 3 atoms.
- There are three more atoms, which are in the middle layer of the unit cell.
- Therefore the total number of nearest neighbours is 6+3+3=12.

References

1. William D. Callister, Jr, Materials Science and Engineering – An introduction, sixth edition, John Wiley & Sons, Inc. 2004.

2. B. D. Cullity and S. R. Stock, Elements of X-Ray Diffraction, Third Edition, Prentice Hall, Upper Saddle River, NJ, 2001
3. Lawrence H. Van Vlack, Elements of Materials Science and Engineering, sixth edition, Addison Wesley Longman, Inc. New York, 1998.

UNIT- II

Phase Diagrams

Equilibrium Phase Diagrams

Give the relationship of composition of a solution as a function of temperatures and the quantities of phases in equilibrium. These diagrams do not indicate the dynamics when one phase transforms into another. Sometimes diagrams are given with pressure as one of the variables. In the phase diagrams we will discuss, pressure is assumed to be constant at one atmosphere.

Binary Isomorphous Systems

This very simple case is one complete liquid and solid solubility, an *isomorphous* system. The example is the Cu-Ni alloy of Fig. 9.2a. The complete solubility occurs because both Cu and Ni have the same crystal structure (FCC), near the same radii, electronegativity and valence. The *liquidus line* separates the liquid phase from solid or solid + liquid phases. That is, the solution is liquid above the liquidus line. The *solidus line* is that below which the solution is completely solid (does not contain a liquid phase.)

Interpretation of phase diagrams

Concentrations: Tie-line method

a) locate composition and temperature in diagram
b) In two phase region draw tie line or isotherm
c) note intersection with phase boundaries. Read compositions.

Fractions: lever rule

a) construct tie line (isotherm)
b) obtain ratios of line segments lengths.

Development of microstructure in isomorphous alloys

a) Equilibrium cooling

Solidification in the solid + liquid phase occurs gradually upon cooling from the liquidus line. The composition of the solid and the liquid change gradually during cooling (as can be determined by the tie-line method.) Nuclei of the solid phase form and they grow to consume all the liquid at the solidus line.

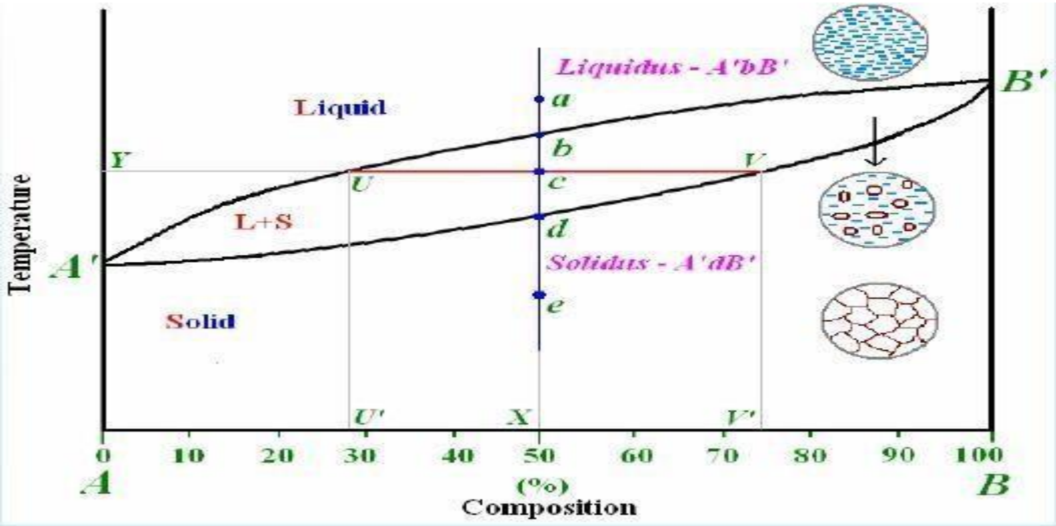
b) Non-equilibrium cooling

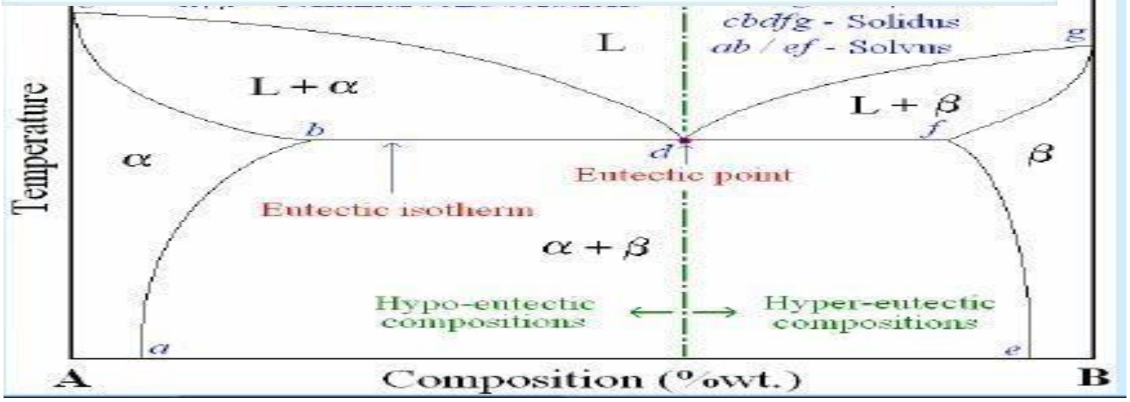
Solidification in the solid + liquid phase also occurs gradually. The composition of the liquid phase evolves by diffusion, following the equilibrium values that can be derived from the tie- line method. However, diffusion in the solid state is very slow. Hence, the new layers that solidify on top of the grains have the equilibrium composition at that temperature but once they are solid their composition does not change. This lead to the formation of layered (cored)

grains (Fig. 9.14) and to the invalidity of the tie-line method to determine the composition of the solid phase (it still works for the liquid phase, where diffusion is fast.)

Binary Eutectic Systems

Interpretation: Obtain phases present, concentration of phases and their fraction (%). *Solvus line*: limit of solubility ***Eutectic*** or invariant point. Liquid and two solid phases exist in equilibrium at the *eutectic composition* and the *eutectic temperature.* The melting point of the eutectic alloy islower than that of the components (eutectic = easy to melt in Greek).• At most





two phases can be in equilibrium within a phase field.• Single-phase regions are separated by 2-pe regions.

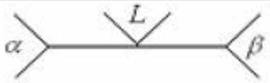
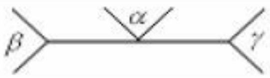
Development of microstructure in eutectic alloys

Case of lead-tin alloys, A layered, eutectic structure develops when cooling below the eutectic temperature. Alloys which are to the left of the eutectic concentration (*hipoeutectic*) or to the right (*hypereutectic*) form a *proeutectic* phase before reaching the eutectic temperature, while in the solid + liquid region. The eutectic structure then adds when the remaining liquid is solidified when cooling further. The eutectic microstructure is lamellar (layered) due to the reduced diffusion distances in the solid state. To obtain the concentration of the eutectic microstructure in the final solid solution, one draws a vertical line at the eutectic concentration and applies the lever rule treating the eutectic as a separate phase.

Eutectoid and Peritectic Reactions

The *eutectoid* (eutectic-like) reaction is similar to the eutectic reaction but occurs from one solid phase to two *new* solid phases. It also shows as V on top of a horizontal line in the phase diagram. There are associated eutectoid temperature (or temperature), eutectoid phase, eutectoid and proeutectoid microstructures.

The *peritectic* reaction also involves three solid in equilibrium, the transition is from a solid + liquid phase to a *different* solid phase when cooling. The inverse reaction occurs when heating.

Reaction	Symbolic equation	Schematic presentation	Example
Eutectic	$L \rightarrow \alpha + \beta$		Fe-C, 4.27% C, 1147°C
Eutectoid	$\alpha \rightarrow \beta + \gamma$		Fe-C, 0.80% C, 723°C
Peritectic	$L + \alpha \rightarrow \beta$		Fe-C, 0.16%C, 1495°C
Peritectoid	$\alpha + \beta \rightarrow \gamma$		

Particle strengthening by precipitation

The strength and hardness of some metal and alloys may be enhanced by the formation of extremely small uniformly dispersed particles of a second phase within the original phase matrix; this must be accomplished by phase transformations that are induced by appropriate heat treatments. The process is called precipitation hardening because the small particles of the new phase are termed "precipitates".

Precipitation hardening and the treating of steel to form tempered matrensite are totally different phenomena, even though the heat treatment procedures are similar.

Precipitation reactions

A precipitation reaction is a reaction in which soluble ions in separate solutions are mixed together to form an insoluble compound that settles out of solution as a solid. That insoluble compound is called a precipitate

Kinetics of nucleation and growth

From a micro structural standpoint, the first process to accompany a phase transformation **is nucleation**- the formation of very small particles or nuclei, of the new phase which are capable of growing. The second stage is **growth**, in which the nuclei increase in size; during this process, some volume of the parent phase disappears. The transformation reaches completion if growth of these new phase particles is allowed to proceed until the equilibrium fraction is attained.

As would be expected, the time dependence of the transformations rate (which is often termed the **kinetics** of a transformation) is an important consideration in the heat treatment of materials. With many investigations, the fraction of reaction that has occurred is measured as a function of time, while the temperature is maintained constant. Transformation progress is usually ascertained by either microscopic examination or measurement of some physical property. Data are plotted as the fraction of transformed material versus the logarithm of time; an S-shaped curve, represents the typical kinetic behavior for most solid state reactions.

Solid Solutions

A solid solution may be formed when impurity atoms are added to a solid, in which case the original crystal structure is retained and no new phases are formed.

- **Substitutional solid solutions:** impurity atoms substitute for host atoms, and appreciable solubility is possible only when atomic diameters and electronegativities for both atom types are similar, when both elements have the same crystal structure, and when the impurity atoms have a valence that is the same as or less than the host material.

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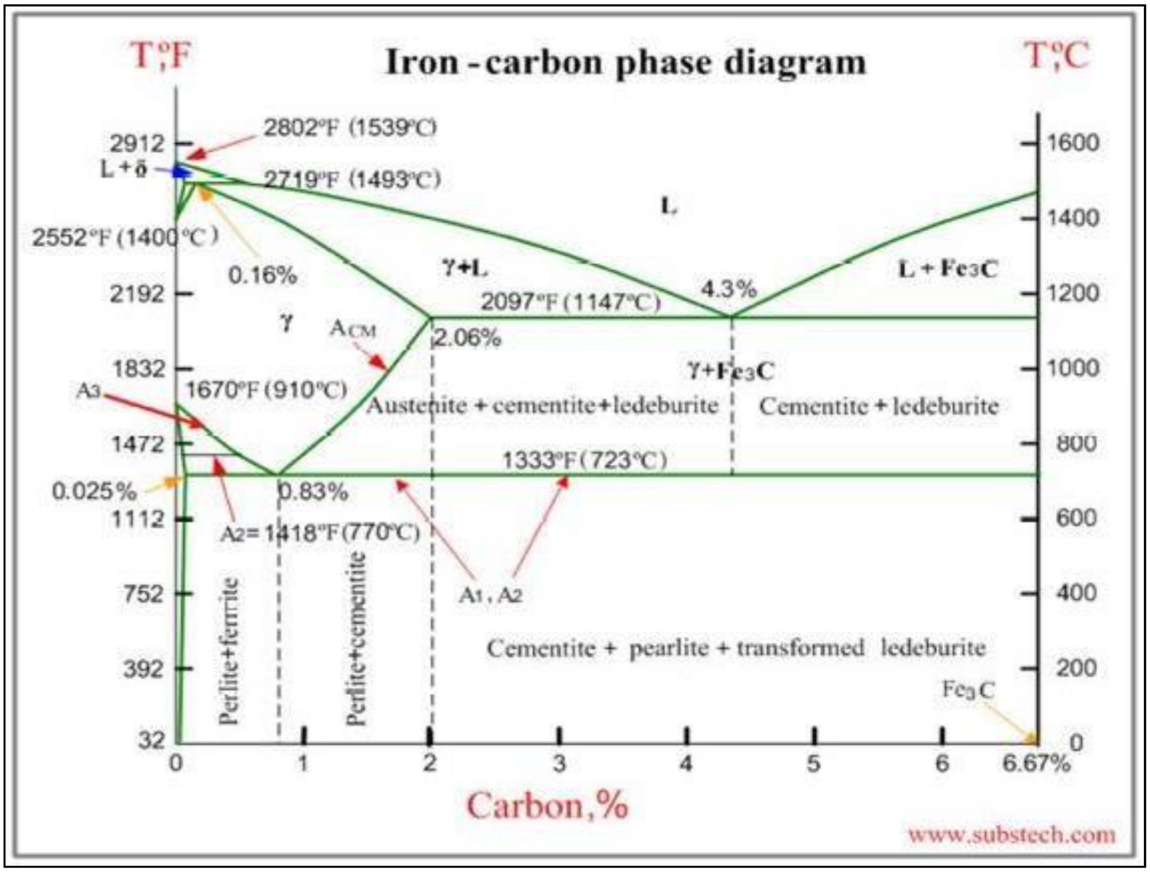
- **Interstitial solid solutions:** These form for relatively small impurity atoms that occupy interstitial sites among the host atoms

The Iron–Iron Carbide (Fe–Fe_3C) Phase Diagram

This is one of the most important alloys for structural applications. The diagram Fe—C is simplified at low carbon concentrations by assuming it is the Fe—Fe_3C diagram. Concentrations are usually given in weight percent. The possible phases are:

- α-ferrite (BCC) Fe-C solution
- γ-austenite (FCC) Fe-C solution
- δ-ferrite (BCC) Fe-C solution
- liquid Fe-C solution
- Fe_3C (iron carbide) or cementite. An intermetallic compound.



The maximum solubility of C in α- ferrite is 0.022 wt%. δ−ferrite is only stable at high temperatures. It is not important in practice. Austenite has a maximum C concentration of 2.14

wt %. It is not stable below the eutectic temperature (727 C) unless cooled rapidly (Chapter 10). Cementite is in reality metastable, decomposing into α-Fe and C when heated for several years between 650 and 770 C.

← **δ-ferrite:** – It is solid solution of carbon in δ-iron. Maximum concentration of carbon in δ-ferrite is 0.09% at 2719 ºF (1493ºC) which is the temperature of the peritectic transformation. The crystal structure of δ-ferrite is BCC (cubic body centered).

← **Austenite:** – Austenite is interstitial solid solution of carbon in γ-iron. Austenite has FCC (cubic face centered) crystal structure, permitting high solubility of carbon i.e. up to 2.06% at 2097 ºF (1147 ºC). Austenite does not exist below 1333 ºF (723ºC) and maximum carbon concentration at this temperature is 0.83%.

← **α-ferrite:** – It is solid solution of carbon in α-iron. α-ferrite has BCC crystal structure and low solubility of carbon – up to 0.025% at 1333 ºF (723ºC). α-ferrite exists at room temperature.

← **Cementite** – Cementite is also known as iron carbide, is an intermetallic compound of iron and carbon, having fixed composition Fe_3C. Cementite is a hard and brittle substance, influencing the properties of steels and cast irons.

Critical temperatures

← **Upper critical temperature (point) A_3** is the temperature, below which ferrite starts to form as a result of ejection from austenite in the hypo-eutectoid alloys.

← **Upper critical temperature (point) A_{CM}** is the temperature, below which cementite starts to form as a result of ejection from austenite in the hyper-eutectoid alloys.

← **Lower critical temperature (point) A_1** is the temperature of the austenite-to-Pearlite eutectoid transformation. Below this temperature austenite does not exist.

← **Magnetic transformation temperature A_2** is the temperature below which α-ferrite is ferromagnetic.

Phase compositions of the iron-carbon alloys at room temperature

← **Hypoeutectoid steels** (carbon content from 0 to 0.83%) consist of primary (proeutectoid) ferrite (according to the curve A3) and Pearlite.

← **Eutectoid steel** (carbon content 0.83%) entirely consists of Pearlite.

← **Hypereutectoid steels** (carbon content from 0.83 to 2.06%) consist of primary (proeutectoid) cementite (according to the curve A_{CM}) and Pearlite.

← **Cast irons** (carbon content from 2.06% to 4.3%) consist of cementite ejected from austenite according to the curve A_{CM} , Pearlite and transformed ledeburite (ledeburite in which austenite transformed to pearlite).

When the liquid of eutectic composition is cooled, at or below eutectic temperature this liquid transforms simultaneously into two solid phases (two terminal solid solutions, represented by αand β). This transformation is known as eutectic reactionand is written symbolically as:

Liquid (L) ↔solid solution-1 (α) + solid solution-2 (β)

In the solid state analog of a eutectic reaction, called a eutectoid reaction, one solid phase having eutectoid composition transforms into two different solid phases. Another set of invariant reactions that occur often in binary systems are - peritectic reaction where a solid phase reacts with a liquid phase to produce a new solid phase.

For their role in mechanical properties of the alloy, it is important to note that: ***Ferrite is soft and ductile Cementite is hard and brittle.*** Thus, combining these two phases in solution an alloy can be obtained with intermediate properties. (Mechanical properties also depend on the microstructure, that is, how ferrite and cementite are mixed.)

Development of Microstructures in Iron—Carbon Alloys

The eutectoid composition of austenite is 0.8 wt %. When it cools *slowly* it forms *perlite*, a lamellar or layered structure of two phases: α-ferrite and cementite (Fe3C). Hypoeutectoid alloys contain *proeutectoid ferrite* plus the eutectoid pearlite. Hypereutectoid alloys contain *proeutectoid cementite* plus pearlite. Since reactions below the eutectoid temperature are in the solid phase, the equilibrium is not achieved by usual cooling from austenite.

The Influence of Other Alloying Elements

Alloying strengthens metals by hindering the motion of dislocations. Thus, the strength of Fe–C alloys increase with C content and also with the addition of other elements.

Time-temperature transformation (TTT) diagrams measure the rate of transformation at a constant temperature. In other words a sample is austenitised and then cooled rapidly to a lower temperature and held at that temperature whilst the rate of transformation is measured, for example by dilatometry. Obviously a large number of experiments is required to build up a complete TTT diagram.

- An increase in carbon content shifts the TTT curve to the right (this corresponds to an increase in hardenability as it increases the ease of forming martensite - i.e. the cooling rate required to attain martensite is less severe).
- An increase in carbon content decreases the martensite start temperature.
- An increase in Mo content shifts the TTT curve to the right and also separates the ferrite + pearlite region from the bainite region making the attainment ofa bainitic structure more controllable.

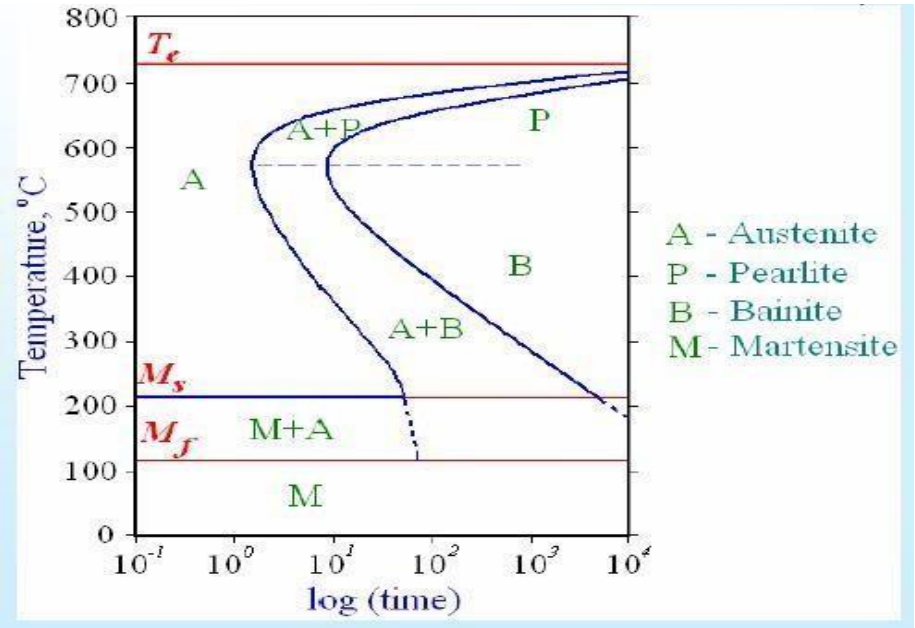


Fig 2.3 Microstructure and Property Changes in Fe-C Alloys IsothermalTransformation Diagrams

UNIT – III

Various types of carbon steel

Carbon steel is steel in which the main interstitial alloying constituent is carbon in the range of 0.12–2.0%. The American Iron and Steel Institute (AISI) defines carbon steel as the following: "Steel is considered to be carbon steel when no minimum content is specified or required for chromium, cobalt, molybdenum, nickel, niobium, titanium, tungsten, vanadium or zirconium, or any other element to be added to obtain a desired alloying effect; when the specified minimum for copper does not exceed 0.40 percent; or when the maximum content specified for any of the following elements does not exceed the percentages noted: manganese 1.65, silicon 0.60, copper 0.60.

Types:

Carbon steel is broken down into four classes based on carbon content:

Mild and low-carbon steel

Mild steel also known as plain-carbon steel, is the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications, more so than iron. Low-carbon steel contains approximately 0.05–0.320 % carbon making it malleable and ductile. Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing.

It is often used when large quantities of steel are needed, for example as structural steel. The density of mild steel is approximately 7.85 g/cm^3 (7850 kg/m^3 or 0.284 lb/in^3) and the Young's modulus is 210 GPa (30,000,000 psi).

Low-carbon steels suffer from yield-point run out where the material has two yield points. The first yield point (or upper yield point) is higher than the second and the yield drops dramatically after the upper yield point. If low-carbon steel is only stressed to some point between the upper and lower yield point then the surface may develop louder bands. Low-carbon steels contain less carbon than other steels and are easier to cold-form, making them easier to handle.

Higher carbon steels

Carbon steels which can successfully undergo heat-treatment have carbon content in the range of 0.30–1.70% by weight. Trace impurities of various other elements can have a significant effect on the quality of the resulting steel. Trace amounts of sulfur in particular make the steel red- short, that is, brittle and crumbly at working temperatures. Low-alloy carbon steel, such as A36 grade, contains about 0.05% sulfur and melts around 1,426–1,53°C (2,599–2,800°F). Manganese is often added to improve the harden ability of low-carbon steels. These additions turn the material into low-alloy steel by some definitions, but AISI's definition of carbon steel allows up to 1.65% manganese by weight.

Low carbon steel

Less than 0.3% carbon content

Medium carbon steel

Approximately 0.30–0.59% carbon content. Balances ductility and strength and has good wear resistance; used for large parts, forging and automotive components.

High-carbon steel

Approximately 0.6–0.99% carbon content. Very strong, used for springs and high-strength wires.

Ultra-high-carbon steel

Approximately 1.0–2.0% carbon content. Steels that can be tempered to great hardness. Used for special purposes like (non-industrial-purpose) knives, axles or punches. Most steels with more than 1.2% carbon content are made using powder metallurgy. Note that steel with carbon content above 2.14% is considered cast iron.

Alloy steel

Alloy steel is steel that is alloyed with a variety of elements in total amounts between 1.0% and 50% by weight to improve its mechanical properties. Alloy steels are broken down into two groups: low-alloy steels and high-alloy steels. The difference between the two is somewhat arbitrary: Smith and Has hemi define the difference at 4.0%, while Degarmo, et al., define it at 8.0%. Most commonly, the phrase "alloy steel" refers to low-alloy steels.

Types:

According to the World Steel Association, there are over 3,500 different grades of steel, encompassing unique physical, chemical and environmental properties. In essence, steel is composed of iron and carbon, although it is the amount of carbon, as well as the level of impurities and additional alloying elements that determines the properties of each steel grade.

The carbon content in steel can range from 0.1-1.5%, but the most widely used grades of steel contain only 0.1-0.25% carbon. Elements such as manganese, phosphorus and sulphur are found in all grades of steel, but, whereas manganese provides beneficial effects, phosphorus and sulphur are deleterious to steel's strength and durability.

Different types of steel are produced according to the properties required for their application, and various grading systems are used to distinguish steels based on these properties. According to the American Iron and Steel Institute (AISI), steels can be broadly categorized into four groups based on their chemical compositions:

1. Carbon Steels
2. Alloy Steels
3. Stainless Steels
4. Tool Steels

1) Carbon Steels:

Carbon steels contain trace amounts of alloying elements and account for 90% of total steel production. Carbon steels can be further categorized into three groups depending on their carbon content:

- Low Carbon Steels/Mild Steels contain up to 0.3% carbon
- Medium Carbon Steels contain 0.3 – 0.6% carbon
- High Carbon Steels contain more than 0.6% carbon

2) Alloy Steels:

Alloy steels contain alloying elements (e.g. manganese, silicon, nickel, titanium, copper, chromium and aluminum) in varying proportions in order to manipulate the steel's properties, such as its hardenability, corrosion resistance, strength, formability, weldability or ductility. Applications for alloys steel include pipelines, auto parts, transformers, power generators and electric motors.

3) Stainless Steels:

Stainless steels generally contain between 10-20% chromium as the main alloying element and are valued for high corrosion resistance. With over 11% chromium, steel is about 200 times more resistant to corrosion than mild steel. These steels can be divided into three groups based on their crystalline structure:

- **Austenitic**: Austenitic steels are non-magnetic and non heat-treatable, and generally contain 18% chromium, 8% nickel and less than 0.8% carbon. Austenitic steels form the largest portion of the global stainless steel market and are often used in food processing equipment, kitchen utensils and piping.
- **Ferritic:** Ferritic steels contain trace amounts of nickel, 12-17% chromium, less than 0.1% carbon, along with other alloying elements, such as molybdenum, aluminum or titanium. These magnetic steels cannot be hardened with heat treatment, but can be strengthened by cold works.
- **Martensitic**: Martensitic steels contain 11-17% chromium, less than 0.4% nickel and up to 1.2% carbon. These magnetic and heat-treatable steels are used in knives, cutting tools, as well as dental and surgical equipment.

4) Tool Steels:

Tool steels contain tungsten, molybdenum, cobalt and vanadium in varying quantities to increase heat resistance and durability, making them ideal for cutting and drilling equipment.

Steel products can also be divided by their shapes and related applications:

- Long/Tubular Products include bars and rods, rails, wires, angles, pipes, and shapes and sections. These products are commonly used in the automotive and construction sectors.
- Flat Products include plates, sheets, coils and strips. These materials are mainly used in automotive parts, appliances, packaging, shipbuilding, and construction.
- Other Products include valves, fittings, and flanges and are mainly used as piping materials.

Cast iron

Cast iron is iron or a ferrous alloy which has been heated until it liquefies, and is then poured into a mould to solidify. It is usually made from pig iron. The alloy constituents affect its colour when fractured: white cast iron has carbide impurities which allow cracks to pass straight through. Grey cast iron has graphite flakes which deflect a passing crack and initiate countless new cracks as the material breaks.

Carbon (C) and silicon (Si) are the main alloying elements, with the amount ranging from 2.1–4 wt% and 1–3 wt%, respectively. Iron alloys with less carbon content are known as steel. While this technically makes these base alloys ternary Fe–C–Si alloys, the principle of cast iron solidification is understood from the binary iron–carbon phase diagram. Since the compositions of most cast irons are around the eutectic point of the iron–carbon system, the melting temperatures closely correlate, usually ranging from 1,150 to 1,200 °C (2,100 to 2,190 °F), which is about 300 °C (572 °F) lower than the melting point of pure iron.

Cast iron's properties are changed by adding various alloying elements, or alloyants. Next to carbon, silicon is the most important alloying because it forces carbon out of solution. Instead the carbon forms graphite which results in a softer iron, reduces shrinkage, lowers strength, and decreases density. Sulfur, when present, forms iron sulfide, which prevents the formation of graphite and increases hardness. The problem with sulfur is that it makes molten cast iron sluggish, which causes short run defects. To counter the effects of sulfur, manganese is added because the two form into manganese sulfide instead of iron sulfide.

The manganese sulfide is lighter than the melt so it tends to float out of the melt and into the slag. The amount of manganese required to neutralize sulfur is 1.7 × sulfur content + 0.3%. If more than this amount

of manganese is added, then manganese carbide forms, which increases hardness and chilling, except in grey iron, where up to 1% of manganese increases strength and density.

Nickel is one of the most common alloying elements because it refines the pearlite and graphite structure, improves toughness, and evens out hardness differences between section thicknesses. Chromium is added in small amounts to the ladle to reduce free graphite, produce chill, and because it is a powerful carbide stabilizer; nickel is often added in conjunction. A small amount of tin can is added as a substitute for 0.5% chromium. Copper is added in the ladle or in the furnace, on the order of 0.5–2.5%, to decrease chill, refine graphite, and increase fluidity. Molybdenum is added on the order of 0.3–1% to increase chill and refine the graphite and pearlite structure; it is often added in conjunction with nickel, copper, and chromium to form high strength irons. Titanium is added as a degasser and deoxidizer, but it also increases fluidity. 0.15–0.5% vanadium is added to cast iron to stabilize cementite, increase hardness, and increase resistance to wear and heat. 0.1–0.3% zirconium helps to form graphite, deoxidize, and increase fluidity.

In malleable iron melts, bismuth is added, on the scale of 0.002–0.01%, to increase how much silicon can be added. In white iron, boron is added to aid in the production of malleable iron; it also reduces the coarsening effect of bismuth.

Grey cast iron

Grey cast iron is characterised by its graphitic microstructure, which causes fractures of the material to have a grey appearance. It is the most commonly used cast iron and the most widely used cast material based on weight. Most cast irons have a chemical composition of 2.5–4.0% carbon, 1–3% silicon, and the remainder is iron. Grey cast iron has less tensile strength and shock resistance than steel, but its compressive strength is comparable to low and medium carbon steel.

White cast iron

It is the cast iron that displays white fractured surface due to the presence of cementite. With a lower silicon content (graphitizing agent) and faster cooling rate, the carbon in white cast iron precipitates out of the melt as the metastable phase cementite, Fe3C, rather than graphite. The cementite which precipitates from the melt forms as relatively large particles, usually in a eutectic mixture, where the other phase is austenite (which on cooling might transform to martensite). These eutectic carbides are much too large to provide precipitation hardening (as in some steels, where cementite precipitates might inhibit plastic deformation by impeding the movement of dislocations through the ferrite matrix). Rather, they increase the bulk hardness of the cast iron simply by virtue of their own very high hardness and their substantial volume fraction, such that the bulk hardness can be approximated by a rule of mixtures. In any case, they offer hardness at the expense of toughness. Since carbide makes up a large fraction of the material, white cast iron could reasonably be classified as a cermet. White iron is too brittle for use in many structural components, but with good hardness and abrasion resistance and relatively low cost, it finds use in such applications as the wear surfaces (impeller and volute) of slurry pumps, shell liners and lifter bars in ball mills and autogenous grinding mills, balls and rings in coal pulverisers, and the teeth of a backhoe's digging bucket (although cast medium- carbon martensitic steel is more common for this application).

It is difficult to cool thick castings fast enough to solidify the melt as white cast iron all the way through. However, rapid cooling can be used to solidify a shell of white cast iron, after which the remainder cools more slowly to form a core of grey cast iron. The resulting casting, called a chilled casting, has the benefits of a hard surface and a somewhat tougher interior.

High-chromium white iron alloys allow massive castings (for example, a 10-tonne impeller) to be sand cast, i.e., a high cooling rate is not required, as well as providing impressive abrasion resistance. These high-chromium alloys attribute their superior hardness to the presence of chromium carbides. The main form of these carbides are the eutectic or primary M7C3 carbides, where "M" represents iron or chromium and can vary depending on the alloy's composition. The eutectic carbides form as bundles of hollow hexagonal rods and grow perpendicular to the to the hexagonal basal plane. The hardness of these carbides are within the range of 1500-1800HV

Malleable cast iron

Malleable iron starts as a white iron casting that is then heat treated at about 900 °C (1,650 °F). Graphite separates out much more slowly in this case, so that surface tension has time to form it into spheroidal particles rather than flakes. Due to their lower aspect ratio, spheroids are relatively short and far from one another, and have a lower cross section vis-a-vis a propagating crack or phonon. They also have blunt boundaries, as opposed to flakes, which alleviates the stress concentration problems faced by grey cast iron. In general, the properties of malleable cast iron are more like mild steel. There is a limit to how large a part can be cast in malleable iron, since it is made from white cast iron.

Ductile cast iron

A more recent development is nodular or ductile cast iron. Tiny amounts of magnesium or cerium added to these alloys slow down the growth of graphite precipitates by bonding to the edges of the graphite planes. Along with careful control of other elements and timing, this allows the carbon to separate as spheroidal particles as the material solidifies. The properties are similar to malleable iron, but parts can be cast with larger sections.

TYPICAL USES

Cast iron is used in a wide variety of structural and decorative applications, because it is relatively inexpensive, durable and easily cast into a variety of shapes.

Most of the typical uses include:

- Historic Markers And Plaques
- Hardware: Hinges, Latches
- Columns, Balusters
- Stairs
- Structural Connectors In Buildings And Monuments
- Decorative Features
- Fences
- Tools And Utensils
- Ordnance
- Stoves And Firebacks.
- Piping.

The basic cast iron material in all of these applications may appear to be the same, or very similar, however, the component size, composition, use, condition, relationship to adjacent materials, exposure and other factors may dictate that different treatments be used to correct

similar problems. Any material in question should be evaluated as a part of a larger system and treatment plans should be based upon consideration of all relevant factors.

Heat Treatment

Heat Treatment is the controlled heating and cooling of metals to alter their physical and mechanical properties without changing the product shape. Heat treatment is sometimes done inadvertently due to manufacturing processes that either heat or cool the metal such as welding or forming. Heat Treatment is often associated with increasing the strength of material, but it can also be used to alter certain manufacturability objectives such as improve machining, improve formability, restore ductility after a cold working operation. Thus it is a very enabling manufacturing process that can not only help other manufacturing process, but can also improve product performance by increasing strength or other desirable characteristics.

Steels are particularly suitable for heat treatment, since they respond well to heat treatment and the commercial use of steels exceeds that of any other material.

Steels are heat treated for one of the following reasons:

1. Softening
2. Hardening
3. Material modification

Softening: Softening is done to reduce strength or hardness, remove residual stresses, improve toughness, restore ductility, refine grain size or change the electromagnetic properties of the steel. Restoring ductility or removing residual stresses is a necessary operation when a large amount of cold working is to be performed, such as in a cold-rolling operation or wiredrawing. Annealing — full Process, spheroidizing, normalizing and tempering austempering, martempering are the principal ways by which steel is softened.

Hardening: Hardening of steels is done to increase the strength and wear properties. One of the pre-requisites for hardening is sufficient carbon and alloy content. If there is sufficient Carbon content then the steel can be directly hardened. Otherwise the surface of the part has to be Carbon enriched using some diffusion treatment hardening techniques.

Material Modification: Heat treatment is used to modify properties of materials in addition to hardening and softening. These processes modify the behavior of the steels in a beneficial manner to maximize service life, e.g., stress relieving, or strength properties, e.g., cryogenic treatment, or some other desirable properties

Full annealing is the process of slowly raising the temperature about 50 ºC (90 ºF) above the *Austenitic temperature* line A_3 or line A_{CM} in the case of Hypoeutectoid steels (steels with < 0.77% Carbon) and 50 ºC (90 ºF) into the Austenite-Cementite region in the case of Hypereutectoid steels (steels with > 0.77% Carbon).

It is held at this temperature for sufficient time for all the material to transform into Austenite or Austenite-Cementite as the case may be. It is then slowly cooled at the rate of about 20

ºC/hr (36 ºF/hr) in a furnace to about 50 ºC (90 ºF) into the Ferrite-Cementite range. At this point, it can be cooled in room temperature air with natural convection. The grain structure has coarse Pearlite with ferrite or Cementite (depending on whether hypo or hyper eutectoid). The steel becomes soft and ductile.

Normalizing is the process of raising the temperature to over 60 º C (108 ºF), above line A_3 or line A_{CM} fully into the Austenite range. It is held at this temperature to fully convert the structure into Austenite, and then removed form the furnace and cooled at room temperature under natural convection. This results in a grain structure of fine Pearlite with excess of Ferrite or Cementite. The resulting material is soft; the degree of softness depends on the actual ambient conditions of cooling. This process is considerably cheaper than full annealing since there is not the added cost of controlled furnace cooling.

Process Annealing is used to treat work-hardened parts made out of low-Carbon steels (< 0.25% Carbon). This allows the parts to be soft enough to undergo further cold working without fracturing. Process annealing is done by raising the temperature to just below the Ferrite-Austenite region, line A_1on the diagram. This temperature is about 727 ºC (1341 ºF) so heating it to about 700 ºC (1292 ºF) should suffice. This is held long enough to allow recrystallization of the ferrite phase, and then cooled in still air. Since the material stays in the same phase through out the process, the only change that occurs is the size, shape and distribution of the grain structure. This process is cheaper than either full annealing or normalizing since the material is not heated to a very high temperature or cooled in a furnace.

Stress Relief Anneal is used to reduce residual stresses in large castings, welded parts and cold-formed parts. Such parts tend to have stresses due to thermal cycling or work hardening. Parts are heated to temperatures of up to 600 - 650 ºC (1112 - 1202 ºF), and held for an extended time (about 1 hour or more) and then slowly cooled in still air.

Spheroidization is an annealing process used for high carbon steels (Carbon > 0.6%) that will be machined or cold formed subsequently. This is done by one of the following ways: Heat the part to a temperature just below the Ferrite-Austenite line, line A_1 or below the Austenite-Cementite line, essentially below the 727 ºC (1340 ºF) line. Hold the temperature for a prolonged time and follow by fairly slow cooling.

or

Cycle multiple times between temperatures slightly above and slightly below the 727 ºC (1340 Offline, say for example between 700 and 750 ºC (1292 - 1382 ºF), and slow cool.)

or

For tool and alloy steels heat to 750 to 800 ºC (1382-1472 ºF) and hold for several hours followed by slow cooling.

All these methods result in a structure in which all the Cementite is in the form of small globules (spheroids) dispersed throughout the ferrite matrix. This structure allows for improved machining in continuous cutting operations such as lathes and screw machines. Spheroidization also improves resistance to abrasion.

Tempering is a process done subsequent to quench hardening. Quench-hardened parts are often too brittle. This brittleness is caused by a predominance of Martensite. This brittleness is removed by tempering. Tempering results in a desired combination of hardness, ductility, toughness, strength, and structural stability. Tempering is not to be confused with tempers on rolled stock-these tempers are an indication of the degree of cold work performed.

The mechanism of tempering depends on the steel and the tempering temperature. The prevalent Martensite is a somewhat unstable structure. When heated, the Carbon atoms diffuse from Martensite to form a carbide precipitate and the concurrent formation of Ferrite and Cementite, which is the stable form. Tool steels for example, lose about 2 to 4 points of hardness on the Rockwell C scale. Even though a little strength is sacrificed, toughness (as measured by impact strength) is increased substantially. Springs and such parts need to be much tougher — these are tempered to a much lower hardness.

Tempering is done immediately after quench hardening. When the steel cools to about 40 ºC (104 ºF) after quenching, it is ready to be tempered. The part is reheated to a temperature of 150 to 400 ºC (302 to 752 ºF). In this region a softer and tougher structure Troostite is formed. Alternatively, the steel can be heated to a temperature of 400 to 700 ºC (752 to 1292 ºF) that results in a softer structure known as Sorbite. This has less strength than Troostite but more ductility and toughness.

The heating for tempering is best done by immersing the parts in oil, for tempering upto 350 ºC (662 ºF) and then heating the oil with the parts to the appropriate temperature. Heating in a bath also ensures that the entire part has the same temperature and will undergo the same tempering. For temperatures above 350 ºC (662 ºF) it is best to use a bath of nitrate salts. The salt baths can be heated upto 625

ºC (1157 ºF). Regardless of the bath, gradual heating is important to avoid cracking the steel. After reaching the desired temperature, the parts are held at that temperature for about 2 hours, then removed from the bath and cooled in still air.

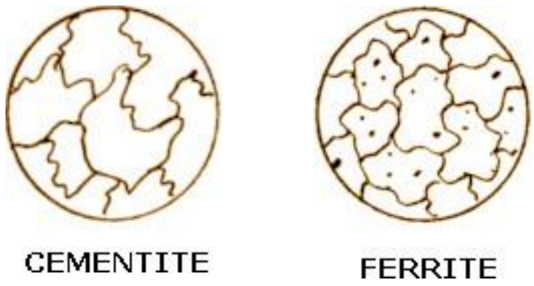
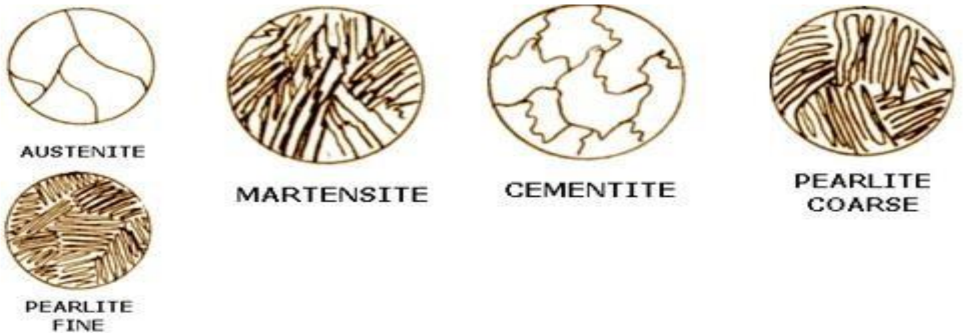

CEMENTITE FERRITE

Fig no: 3.1

Hardening

Hardness is a function of the Carbon content of the steel. Hardening of a steel requires a change in structure from the body-centered cubic structure found at room temperature to the face- centered cubic structure found in the Austenitic region. The steel is heated to Autenitic region. When suddenly quenched, the Martensite is formed. This is a very strong and brittle structure. When slowly quenched it would form Austenite and Pearlite which is a partly hard and partly soft structure. When the cooling rate is extremely slow then it would be mostly Pearlite which is extremely soft.

Fig No 3.2



AUSTENITE

MARTENSITE

CEMENTITE

PEARLITE COARSE

PEARLITE FINE

Usually when hot steel is quenched, most of the cooling happens at the surface, as does the hardening. This propagates into the depth of the material. Alloying helps in the hardening and by determining the right alloy one can achieve the desired properties for the particular application.

Quench Media

Water: Quenching can be done by plunging the hot steel in water. The water adjacent to the hot steel vaporizes, and there is no direct contact of the water with the steel. This slows down cooling until the bubbles break and allow water contact with the hot steel. As the water contacts and boils, a great amount of heat is removed from the steel. With good agitation, bubbles can be prevented from sticking to the steel, and thereby prevent soft spots.

Water is a good rapid quenching medium, provided good agitation is done. However, water is corrosive with steel, and the rapid cooling can sometimes cause distortion or cracking.

Salt Water: Salt water is a more rapid quench medium than plain water because the bubbles are broken easily and allow for rapid cooling of the part. However, salt water is even more corrosive than plain water, and hence must be rinsed off immediately.

Oil: Oil is used when a slower cooling rate is desired. Since oil has a very high boiling point, the transition from start of Martensite formation to the finish is slow and this reduces the likelihood of cracking. Oil quenching results in fumes, spills, and sometimes a fire hazard.

Precipitation hardening is achieved by:

1. solution heat treatment where all the solute atoms are dissolved to form a single-phase solution.
2. rapid cooling across the solvus line to exceed the solubility limit. This leads to a supersaturated solid solution that remains stable (metastable) due to the low temperatures, which prevent diffusion.
3. precipitation heat treatment where the supersaturated solution is heated to an intermediate temperature to induce precipitation and kept there for some time

   (aging). If the process is continued for a very long time, eventually the hardness decreases. This is called over aging.

The requirements for precipitation hardening are:

- appreciable maximum solubility
- solubility curve that falls fast with temperature
- composition of the alloy that is less than the maximum solubility

Precipitation Hardening

Hardening can be enhanced by extremely small precipitates that hinder dislocation motion. The precipitates form when the solubility limit is exceeded. Precipitation hardening is also called age hardening because it involves the hardening of the material over a prolonged time.

Case Hardening

Case hardening produces a hard, wear-resistant sur- face or case over a strong, tough core. The principal forms of casehardening are carburizing, cyaniding, and nitriding. Only ferrous metals are case-hardened. Case hardening is ideal for parts that require a wear-resistant surface and must be tough enough interally to withstand heavy loading. The steels best suited for case hardening are the low-carbon and low- alloy series. When high-carbon steels are case hardened, the hardness penetrates the core and causes brittleness. In case hardening, you change the surface of the metal chemically by introducing a high carbide or nitride content. The core remains chemically unaffected. When heat-treated, the high-carbon surface responds to hardening, and the core toughens.

Carburizing

Carburizing is a case-harden- ing process by which carbon is added to the surface of low-carbon steel. This results in a carburized steel that has a high-carbon surface and a low-carbon interior. When the carburized steel is heat-treated, the case be- comes hardened and the core remains soft and tough. Two methods are used for carburizing steel. One method consists of heating the steel in a furnace containing a carbon monoxide atmosphere. The other method has the steel placed in a container packed with charcoal or some other carbon-rich material and then heated in a furnace. To cool the parts, you can leave the container in the furnace to cool or remove it and let it air cool. In both cases, the parts become annealed during the slow cooling. The depth of the carbon penetration depends on the length of the soaking period. With to- day's methods, carburizing is almost exclusively done by gas atmospheres.

Cyaniding

This process is a type of case hardening that is fast and efficient. Preheated steel is dipped into a heated cyanide bath and allowed to soak. Upon removal, it is quenched and then rinsed to remove any residual cyanide. This process produces a thin, hard shell that is harder than the one produced by carburizing and can be completed in 20 to 30 minutes vice several hours. The major drawback is that cyanide salts are a deadly poison.

Nitriding

This case-hardening method produces the hardest surface of any of the hardening processes. It differs from the other methods in that the individual parts have been heat-treated and tempered before nitriding. The parts are then heated in a furnace that has an ammonia gas atmosphere. No quenching is required so there is no worry about warping or other types of distortion. This process is used to case harden items, such as gears, cylinder sleeves, camshafts and other engine parts, that need to be wear resistant and operate in high-heat areas.

Flame Hardening

Flame hardening is another procedure that is used to harden the surface of metal parts. When you use an oxyacetylene flame, a thin layer at the surface of the part is rapidly heated to its critical temperature and then immediately quenched by a combination of a water spray and the cold base metal. This process produces a thin, hardened surface, and at the same time, the internal parts

retain their original properties. Whether the process is manual or mechanical, a close watch must be maintained, since the torches heat the metal rapidly and the temperatures are usually determined visually. Flame hardening may be either manual or automatic. Automatic equipment produces uniform results and is more desirable. Most automatic machines have variable travel speeds and can be adapted to parts of various sizes and shapes. The size and shape of the torch depends on the part. The torch consists of a mixing head, straight extension tube, 90-degree extension head, an adjustable yoke, and a water-cooled tip. Practically any shape or size flame- hardening tip is available. Tips are produced that can be used for hardening flats, rounds, gears, cams, cylinders, and other regular or irregular shapes. In hardening localized areas, you should heat the metal with a standard hand-held welding torch. Adjust the torch flame to neutral for normal heating; however, in corners and grooves, use a slightly oxidizing flame to keep the torch from sputtering. You also should particularly guard against overheating in comers and grooves. If dark streaks appear on the metal surface, this is a sign of overheating, and you need to increase the distance between the flame and the metal. For the best heating results, hold the torch with the tip of the inner cone about an eighth of an inch from the surface and direct the flame at right angles to the metal. Sometimes it is necessary to change this angle to obtain better results; however, you rarely find a deviation of more than 30 degrees. Regulate the speed of torch travel according to the type of metal, the mass and shape of the part, and the depth of hardness desired. In addition, you must select the steel according to the properties desired. Select carbon steel when surface hardness is the primary factor and alloy steel when the physical properties of the core are also factors. Plain carbon steels should contain more than 0.35% carbon for good results inflame hardening. For water quench- ing, the effective carbon range is from 0.40% to 0.70%. Parts with a carbon content of more than 0.70% are likely to surface crack unless the heating and quenching rate are carefully controlled. The surface hardness of a flame-hardened section is equal to a section that was hardened by furnace heating and quenching. The decrease in hardness between the case and the core is gradual. Since the core is not affected by flame hardening, there is little danger of spalling or flaking while the part is in use. Thus flame hardening produces a hard case that is highly resistant to wear and a core that retains its original properties. Flame hardening can be divided into five general methods: stationary, circular band progressive, straight- line progressive, spiral band progressive, and circular band spinning.

Diffusion

Diffusion Mechanisms

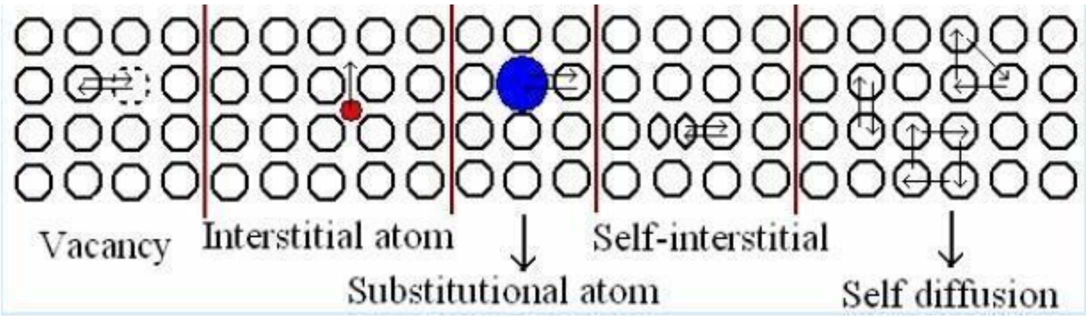


Fig no: 3.4

Diffusion is the process of mass flow in which atoms change their positions relative to neighbors in a given phase under the influence of thermal and a gradient. The gradient can be a compositional gradient, an electric or magnetic gradient, or stress gradient. Many reactions in solids and liquids are diffusion dependent. Diffusion is very important in many industrial and domestic applications. E.g.: Carburizing the steel, annealing homogenization after solidification, coffee mixing, etc. From an atomic perceptive, diffusion is a step wise migration of atoms from one lattice position to another. Migration of atoms in metals/alloys can occur in many ways, and thus corresponding diffusion mechanism is defined.

Atom diffusion can occur by the motion of vacancies (vacancy diffusion) or impurities (impurity diffusion). The energy barrier is that due to nearby atoms which need to move to let the atoms go by. This is more easily achieved when the atoms vibrate strongly, that is, at high temperatures. There is a difference between diffusion and net diffusion. In a homogeneous material, atoms also diffuse but this motion is hard to detect. This is because atoms move randomly and there will be an equal number of atoms moving in one direction than in another. In inhomogeneous materials, the effect of diffusion is readily seen by a change in concentration with time. In this case there is a *net* diffusion. Net diffusion occurs because, although all atoms are moving randomly, there are more atoms moving in regions where their concentration is higher.

Steady-State Diffusion

The flux of diffusing atoms, J, is expressed either in number of atoms per unit area and per unit time (e.g., atoms/m_2-second) or in terms of mass flux (e.g., kg/m_2-second).Steady state diffusion means that J does not depend on time. In this case, ***Fick's first law*** holds that the flux along direction x is:

$$J = - D\, dC/dx$$

Where dC/dx is the gradient of the concentration C, and D is the diffusion constant.

The concentration gradient is often called the *driving force* in diffusion (but it is not a force in the mechanistic sense). The minus sign in the equation means that diffusion is down the concentration gradient.

Nonsteady-State Diffusion

This is the case when the diffusion flux depends on time, which means that a type of atoms accumulates in a region or that it is depleted from a region (which may cause them to accumulate in another region).

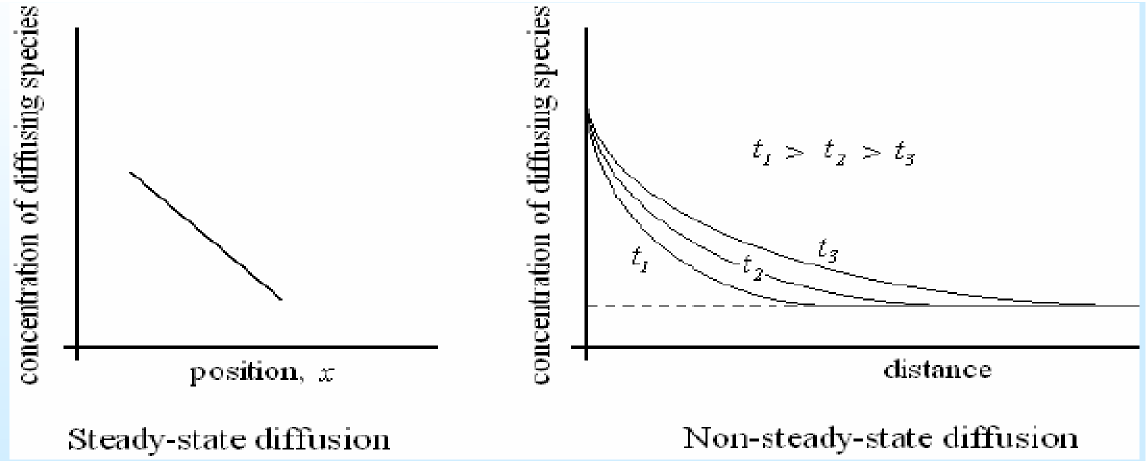


Fig no :3.5

Factors that influence diffusion

As stated above, there is a barrier to diffusion created by neighboring atoms that need to move to let the diffusing atom pass. Thus, atomic vibrations created by temperature assist diffusion. Also, smaller atoms diffuse more readily than big ones, and diffusion is faster in open lattices or in open directions. Similar to the case of vacancy formation, the effect of temperature in diffusion is given by a Boltzmann factor: $D = D_0 \times \exp(-Q_d/kT)$.

NON FERROUS METAL & ALLOYS

Copper

- Copper is one of the earliest metals discovered by man.
- The boilers on early steamboats were made from copper.
- The copper tubing used in water plumbing in Pyramids was found in serviceable condition after more than 5,000 years.
- Cu is a ductile metal. Pure Cu is soft and malleable, difficult to machine.
- Very high electrical conductivity – second only to silver.
- Copper is refined to high purity for many electrical

Applications

- Excellent thermal conductivity – Copper cookware most highly regarded – fast and uniform heating.
- Electrical and construction industries are the largest users of Cu.

Copper Alloys

- Brasses and Bronzes are most commonly used alloys of Cu. Brass is an alloy with Zn. Bronzes contain tin, aluminum, silicon or beryllium.
- Other copper alloy families include copper-nickels and nickel silvers. More than 400 copper- base alloys are recognized.

Applications

- Electrical wires,
- roofing, nails, rivets
- Automotive radiator
- core, lamp fixture,
- clutch disk,
- diaphragm, fuse clips,
- springs
- Furniture, radiator
- fittings, battery clamps,
- light fixtures
- Bearings, bushings,
- valve seats and guards
- Electrical, valves,
- pumps
- Condenser, heat exchanger
- piping,
- valves
- Tin bronze Sn,

- Bearings, bushing,
- piston rings, gears

Aluminum

- Aluminum is a light metal & easily machinable; has wide variety of surface finishes; good electrical and thermal conductivities; highly reflective to heat and light.
- Versatile metal - can be cast, rolled, stamped, drawn, spun, roll-formed, hammered, extruded and forged into many shapes.
- Aluminum can be riveted, welded, brazed, or resin bonded.
- Corrosion resistant - no protective coating needed, however it is often anodized to improve surface finish, appearance.
- Al and its alloys - high strength-to-weight ratio (high specific strength) owing to low density.
- Such materials are widely used in aerospace and automotive applications where weight savings are needed for better fuel efficiency and performance.
- Al-Li alloys are lightest among all Al alloys and find wide applications in the aerospace industry.

Application of some Al Alloys

- Food/chemical handling
- equipment, heat exchangers
- light reflectors

- Utensils, pressure vessels and
- piping
- Strain-hardn.
- Bellows, clutch disk,
- diaphragm, fuse clips, springs
- Heat treated
- Aircraft structure, rivets, truck
- wheels, screw
- Trucks, canoes, railroad cars,
- furniture, pipelines
- Peak-aged
- Aircraft structures and other
- highly loaded applications
- Aircraft pump parts,
- automotive transmission
- cases, cylinder blocks

Zinc

Zinc (symbol Zn), in commerce also spelter, is a metallic chemical element. It has atomic number 30. It is the first element of group 12 of the periodic table. In some respects zinc is chemically similar to magnesium: its ion is of similar size and its only common oxidation state is

+2. Zinc is the 24th most abundant element in the Earth's crust and has five stable isotopes. The most common zinc ore is sphalerite (zinc blende), a zinc sulfide mineral. The largest mineable amounts are found in Australia, Asia, and the United States. Zinc production includes froth flotation of the ore, roasting, and final extraction using electricity (electrowinning).

Brass, which is an alloy of copper and zinc, has been used since at least the 10th century BC in Judea and by the 7th century BC in Ancient Greece. Zinc metal was not produced on a large scale until the 12th century in India and was unknown to Europe until the end of the 16th century. The mines of Rajasthan have given definite evidence of zinc production going back to 6th century BC. To date, the oldest evidence of pure zinc comes from Zawar, in Rajasthan, as early as the 9th century AD when a distillation process was employed to make pure zinc. Alchemists burned zinc in air to form what they called "philosopher's wool" or "white snow".

Applications

Major applications of zinc include

- Galvanizing (55%)
- Alloys (21%)
- Brass and bronze (16%)
- Miscellaneous (8%)

The metal is most commonly used as an anti-corrosion agent. Galvanization, which is

the coating of iron or steel to protect the metals against corrosion, is the most familiar form of using zinc in this way. In 2009 in the United States, 55% or 893 thousand tonnes of the zinc metal was used for galvanization.

Zinc is more reactive than iron or steel and thus will attract almost all local oxidation until it completely corrodes away. A protective surface layer of oxide and carbonate forms as the zinc corrodes. This protection lasts even after the zinc layer is scratched but degrades through time as

the zinc corrodes away. The zinc is applied electrochemically or as molten zinc by hot-dip galvanizing or spraying. Galvanization is used on chain-link fencing, guard rails, suspension bridges, light posts, metal roofs, heat exchangers, and car bodies.

The relative reactivity of zinc and its ability to attract oxidation to itself makes it an efficient sacrificial anode in catholic protection (CP). For example, cathodic protection of a buried pipeline can be achieved by connecting anodes made from zinc to the pipe. Zinc acts as the anode (negative terminus) by slowly corroding away as it passes electric current to the steel pipeline. Zinc is also used to catholically protect metals that are exposed to sea water from corrosion. A zinc disc attached to a ship's iron rudder will slowly corrode while the rudder stays unattacked. Other similar uses include a plug of zinc attached to a propeller or the metal protective guard for the keel of the ship.

With a standard electrode potential (SEP) of −0.76 volts, zinc is used as an anode material for batteries. (More reactive lithium (SEP −3.04 V) is used for anodes in lithium batteries). Powdered zinc is used in this way in alkaline batteries and sheets of zinc metal form the cases for and act as anodes in zinc–carbon batteries.[98][99] Zinc is used as the anode or fuel of the zinc- air battery/fuel cell. The zinc-cerium redox flow battery also relies on a zinc-based negative half- cell.

Alloys

A widely used alloy which contains zinc is brass, in which copper is alloyed with anywhere from 3% to 45% zinc, depending upon the type of brass. Brass is generally more ductile and stronger than copper and has superior corrosion resistance.These properties make it useful in communication equipment, hardware, musical instruments, and water valves.

Other widely used alloys that contain zinc include nickel silver, typewriter metal, soft and aluminium solder, and commercial bronze. Zinc is also used in contemporary pipe organs as a substitute for the traditional lead/tin alloy in pipes.[104] Alloys of 85–88% zinc, 4–10% copper, and 2–8% aluminium find limited use in certain types of machine bearings. Zinc is the primary metal used in making American one cent coins since 1982.The zinc core is coated with a thin layer of copper to give the impression of a copper coin. In 1994, 33,200 tonnes (36,600 short tons) of zinc were used to produce 13.6 billion pennies in the United States. Alloys of primarily zinc with small amounts of copper, aluminium, and magnesium are useful in die casting as well as spin casting, especially in the automotive, electrical, and hardware industries. These alloys are marketed under the name Zamak. An example of this is zinc aluminium. The low melting point together with the low viscosity of the alloy makes the production of small and intricate shapes possible. The low working temperature leads to rapid cooling of the cast products and therefore fast assembly is possible. Another alloy, marketed under the brand name Prestal, contains 78% zinc and 22% aluminium and is reported to be nearly as strong as steel but as malleable as plastic. This superplasticity of the alloy allows it to be molded using die casts made of ceramics and cement.

Similar alloys with the addition of a small amount of lead can be cold-rolled into sheets. An alloy of 96% zinc and 4% aluminium is used to make stamping dies for low production run applications for which ferrous metal dies would be too expensiveIn building facades, roofs or other applications in which zinc is used as sheet metal and for methods such as deep drawing, roll forming or bending, zinc alloys with titanium and copper are usedUnalloyed zinc is too brittle for these kinds of manufacturing processes.

As a dense, inexpensive, easily worked material, zinc is used as a lead replacement. In the wake of lead concerns, zinc appears in weights for various applications ranging from fishing to tire balances and flywheels.

Cadmium zinc telluride (CZT) is a semi conductive alloy that can be divided into an array of small sensing devices. These devices are similar to an integrated circuit and can detect the energy of incoming gamma ray photons. When placed behind an absorbing mask, the CZT sensor array can also be used to determine the direction of the rays.

Other industrial uses

Zinc oxide is used as a white pigment in paints. Roughly one quarter of all zinc output in the United States (2009), is consumed in the form of zinc compounds; a variety of which are used industrially. Zinc oxide is widely used as a white pigment in paints, and as a catalyst in the manufacture of rubber. It is also used as a heat disperser for the rubber and acts to protect its polymers from ultraviolet radiation (the same UV protection is conferred to plastics containing zinc oxide) The semiconductor properties of zinc oxide make it useful invaristors and

photocopying products. The zinc zinc-oxide cycle is a two step thermochemical process based on zinc and zinc oxide for hydrogen production.

Zinc chloride is often added to lumber as a fire retardant and can be used as a wood preservative. It is also used to make other chemicals.

Crystals of ZnS are used in lasers that operate in the mid-infrared part of the spectrum. Zinc sulfate is a chemical in dyes and pigments. Zinc pyrithione is used in antifouling paints.

Zinc powder is sometimes used as a propellant in model rockets. When a compressed mixture of 70% zinc and 30% sulfur powder is ignited there is a violent chemical reaction. This produces zinc sulfide, together with large amounts of hot gas, heat, and light. Zinc sheet metal is used to make zinc bars.

Zn, the most abundant isotope of zinc, is very susceptible to neutron activation, being transmuted into the highly radioactive

Zn, which has a half-life of 244 days and produces intense gamma radiation. Because of this, Zinc Oxide used in nuclear reactors as an anti-corrosion agent is depleted of

Zn before use, this is calleddepleted zinc oxide. For the same reason, zinc has been proposed as a salting material for nuclear weapons (cobalt is another, better-known salting material). A jacket of isotopically enriched

Zn would be irradiated by the intense high-energy neutron flux from an exploding thermonuclear weapon, forming a large amount of

Zn significantly increasing the radioactivity of the weapon's fallout. Such a weapon is not known to have ever been built, tested, or used.

Zn is also used as a tracer to study how alloys that contain zinc wear out, or the path and the role of zinc in organisms.

Chromium

Chromium is a chemical element which has the symbol Cr and atomic number 24. It is the first element in Group 6. It is a steely-gray, lustrous, hard and brittle metal which takes a high polish,

resists tarnishing, and has a high melting point. Chromium oxide was used by the Chinese in the Qin dynasty over 2,000 years ago to coat metal weapons found with the Terracotta Army. Chromium was discovered as an element after it came to the attention of the western world in the red crystalline mineral crocoite (lead(II) chromate), discovered in 1761 and initially used as a pigment. Louis Nicolas Vauquelin first isolated chromium metal from this mineral in 1797. Since Vauquelin's first production of metallic chromium, small amounts of native (free) chromium metal have been discovered in rare minerals, but these are not used commercially. Instead, nearly all chromium is commercially extracted from the single commercially viable orechromite, which is iron chromium oxide Chromite is also now the chief source of chromium for chromium pigments.

Applications

The strengthening effect of forming stable metal carbides at the grain boundaries and the strong increase in corrosion resistance made chromium an important alloying material for steel. The high-speed tool steels contain between 3 and 5% chromium. Stainless steel, the main corrosion- proof metal alloy, is formed when chromium is added to iron in sufficient concentrations, usually above 11%. For its formation, ferrochromium is added to the molten iron. Also nickel-based alloys increase in strength due to the formation of discrete, stable metal carbide particles at the grain boundaries. For example, Inconel 718 contains 18.6% chromium. Because of the excellent high-temperature properties of these nickel superalloys, they are used in jet engines and gas turbines in lieu of common structural materials.

The relative high hardness and corrosion resistance of unalloyed chromium makes it a good surface coating, being still the most "popular" metal coating with unparalleled combined durability. A thin layer of chromium is deposited on pretreated metallic surfaces by electroplating techniques. There are two deposition methods: Thin, below 1 µm thickness, layers are deposited by chrome plating, and are used for decorative surfaces. If wear-resistant surfaces are needed then thicker chromium layers are deposited. Both methods normally use acidic chromate or dichromate solutions. To prevent the energy-consuming change in oxidation state, the use of chromium(III) sulfate is under development, but for most applications, the established process is used.

In the chromate conversion coating process, the strong oxidative properties of chromates are used to deposit a protective oxide layer on metals like aluminium, zinc and cadmium. This passivation and the self-healing properties by the chromate stored in the chromate conversion coating, which is able to migrate to local defects, are the benefits of this coating methodBecause of environmental and health regulations on chromates, alternative coating method are under development.

Anodizing of aluminium is another electrochemical process, which does not lead to the deposition of chromium, but uses chromic acid as electrolyte in the solution. During anodization, an oxide layer is formed on the aluminium. The use of chromic acid, instead of the normally used sulfuric acid, leads to a slight difference of these oxide layers. The high toxicity of Cr(VI) compounds, used in the established chromium electroplating process, and the strengthening of safety and environmental regulations demand a search for substitutes for chromium or at least a change to less toxic chromium(III) compounds.

Dye and pigment

The mineral crocoite (lead chromate $PbCrO4$) was used as a yellow pigment shortly after its discovery. After a synthesis method became available starting from the more abundant chromite, chrome yellow was, together with cadmium yellow, one of the most used yellow pigments. Chromium oxides are also used as a green color in glassmaking and as a glaze in ceramics. Green chromium oxide is extremely light-fast and as such is used in cladding coatings. It is also the main ingredient in IR reflecting paints, used by the armed forces, to paint vehicles, to give them the same IR reflectance as green leaves.

Synthetic ruby and the first laser

Natural rubies are corundum (aluminum oxide) crystals that are colored red (the rarest type) due to chromium (III) ions (other colors of corundum gems are termedsapphires). A red-colored artificial ruby may also be achieved by doping chromium(III) into artificial corundum crystals, thus making chromium a requirement for making synthetic rubies

Wood preservative

Because of their toxicity, chromium(VI) salts are used for the preservation of wood. For example, chromated copper arsenate (CCA) is used in timber treatment to protect wood from decay fungi, wood attacking insects, including termites, and marine borers.

Refractory material

The high heat resistivity and high melting point makes chromite and chromium(III) oxide a material for high temperature refractory applications, like blast furnaces, cement kilns, molds for the firing of bricks and as foundry sands for the casting of metals. In these applications, the refractory materials are made from mixtures of chromite and magnesite. The use is declining because of the environmental regulations due to the possibility of the formation of chromium(VI).

Brasses & Bronzes

Brass is an alloy made of copper and zinc; the proportions of zinc and copper can be varied to create a range of brasses with varying properties. Bronze is an alloy consisting primarily of copper, usually with tin as the main additive. It is hard and tough, and it was so significant in antiquity that the Bronze Age was named after the metal.

Admiralty brass contains 30% zinc, with 1% tin to inhibit dezincification in many environments. Alpha brasses with less than 35% zinc, are malleable, can be worked cold, and are used in pressing, forging, or similar applications. They contain only one phase, with face-centered cubic crystal structure. Alpha-beta brass (Muntz metal), also called duplex brass, is 35–45% zinc and is suited for hot working. It contains both α and β' phase; the β'-phase is body-centered cubic and is harder and stronger than α. Alpha-beta brasses are usually worked hot. Aluminium brass contains aluminium, which improves its corrosion resistance. Red brass is both an American term for the copper-zinc-tin alloy known as gunmetal, and an alloy which is considered both a brass and a bronze. It typically contains 85% copper, 5% tin, 5% lead, and 5% zinc.

Aluminium Bronze

A type of BRONZE in which aluminium is the main alloying metal added to copper. Small amounts of other elements such as iron, manganese, nickel and silicon are added to impart various properties such as corrosion resistance or malubility. It fairs well in the marine enviroment.

Typical compostion:

- Copper 80%

- Aluminium 10%
- Nickel 5%
- Iron 5%

Silicon Bronze

Has small amounts of silicon to allow it to be wrought or cold worked into a stronger alloy such as by rolling. It is also resistant to corrosion and therefore good for use in the marine enviroment. Typical compostion:

- Copper 96%
- Silicon 3%
- Manganase 1%

Phosphor bronze

Well this one is different! Rather than Phosphor being the main alloy metal, it is used during manufacture to purify the melt and create a purer stronger type of bronze. Usually not more than 0.2% of the Phosphur is left in the metal. It is very corrosion resistant and therefore good in the marine environment.

Typical compostion:

- Copper 94.8%
- Tin 5%
- Phosphorus 0.2%

Leaded Bronze

Leaded Gunmetal (LG2) Is a type of copper alloy that has a small amount of lead, tin and zinc added in similar quantities. It is not considered to be brass due to the amount of zinc being small. It has widespread use as a valve and through hull fitting material due to it's good seawater resistance. It does not de-zincify in seawater despite having a zinc content. It is good for use in the marine environment.

Typical composition:

- Copper 85%
- Lead 5%
- Tin 5%
- Zinc 5%

Bronze was especially suitable for use in boat and ship fittings prior to the wide employment of stainless steel owing to its combination of toughness and resistance to salt water corrosion. Bronze is still commonly used in ship propellers and submerged bearings.

In the 20th century, silicon was introduced as the primary alloying element, creating an alloy with wide application in industry and the major form used in contemporary statuary. Sculptors may prefer silicon bronze because of the ready availability of silicon bronze brazing rod, which allows color-matched repair of defects in castings. Aluminium is also used for the structural metal aluminium bronze.

It is also widely used for cast bronze sculpture. Many common bronze alloys have the unusual and very desirable property of expanding slightly just before they set, thus filling in the finest details of a mold. Bronze parts are tough and typically used forbearings, clips, electrical connectors and springs.

Bronze also has very low metal-on-metal friction, which made it invaluable for the building of cannon where iron cannonballs would otherwise stick in the barrel. It is still widely used today for springs, bearings, bushings, automobile transmission pilot bearings, and similar fittings, and is particularly common in the bearings of small electric motors. Phosphor bronze is particularly suited to precision-grade bearings and springs. It is also used in guitar and piano strings.

Unlike steel, bronze struck against a hard surface will not generate sparks, so it (along with beryllium copper) is used to make hammers, mallets, wrenches and other durable tools to be used in explosive atmospheres or in the presence of flammable vapors.

Bronze is used to make bronze wool for woodworking applications where steel wool would discolor oak.

Bearing Materials - Ceramics, Chrome Steels, Stainless Steels, and Plastics

The bearing industry uses different materials for the production of the various bearing components. The materials are processed to achieve desirable properties to maximize bearing performance and life. The materials described here are the most commonly used. Additional information can be found in the Technical Information

Sheets for Balls, Closures, and Retainers.

UNIT IV

Introduction

Ceramics can be defined as heat-resistant, non-metallic, inorganic solids that are (generally) made up of compounds formed from metallic and non-metallic elements. Although different types of ceramics can have very different properties, in general ceramics are corrosion-resistant and hard, but brittle. Most ceramics are also good insulators and can withstand high temperatures. These properties have led to their use in virtually every aspect of modern life.

The two main categories of ceramics are traditional and advanced. Traditional ceramics include objects made of clay and cements that have been hardened by heating at high temperatures. Traditional ceramics are used in dishes, crockery, flowerpots, and roof and wall tiles. Advanced ceramics include carbides, such as silicon carbide, SiC; oxides, such as aluminum oxide, Al2O3; nitrides, such as silicon nitride, Si3N4; and many other materials, including the mixed oxide ceramics that can act as superconductors. Advanced ceramics require modern processing techniques, and the development of these techniques has led to advances in medicine and engineering.

Glass is sometimes considered a type of ceramic. However, glasses and ceramics differ in that ceramics have a crystalline structure while glasses contain impurities that prevent crystallization. The structure of glasses is amorphous, like that of liquids. Ceramics tend to have high, well-defined melting points, while glasses tend to soften over a range of temperatures before becoming liquids. In addition, most ceramics are opaque to visible light, and glasses tend to be translucent. Glass ceramics have a structure that consists of many tiny crystalline regions within a noncrystalline matrix. This structure gives them some properties of ceramics and some of glasses. In general, glass ceramics expand less when heated than most glasses, making them useful in windows, for wood stoves, or as radiant glass-ceramic cooktop surfaces.

Composition

Some ceramics are composed of only two elements. For example, alumina is aluminum oxide, Al2O3; zirconia is zirconium oxide, ZrO2; Ceramics are good insulators and can withstand high temperatures. A popular use of ceramics is in artwork. silicon dioxide, SiO2. Other ceramic materials, including many minerals, have complex and even variable compositions. For example, the ceramic mineral feldspar, one of the components of granite, has the formula KAlSi3O8.

The chemical bonds in ceramics can be covalent, ionic, or polar covalent, depending on the chemical composition of the ceramic. When the components of the ceramic are a metal and a nonmetal, the bonding is primarily ionic; examples are magnesium oxide (magnesia), MgO, and barium titanate, $BaTiO_3$. In ceramics composed of a metalloid and a nonmetal, bonding is primarily covalent; examples are boron nitride, BN, and silicon carbide, SiC. Most ceramics have a highly crystalline structure, in which a three-dimensional unit, called a unit cell, is repeated throughout the material. For example, magnesium oxide crystallizes in the rock salt structure. In this structure, Mg^{2+} ions alternate with O^{2-} ions along each perpendicular axis.

Manufacture of Traditional Ceramics

Traditional ceramics are made from natural materials such as clay that have been hardened by heating at high temperatures (driving out water and allowing strong chemical bonds to form between the flakes of clay). In fact, the word "ceramic" comes from the Greek keramos, whose original meaning was "burnt earth." When artists make ceramic works of art, they first mold clay, often mixed with other raw materials, into the desired shape. Special ovens called kilns are used to "fire" (heat) the shaped object until it hardens.

Clay consists of a large number of very tiny flat plates, stacked together but separated by thin layers of water. The water allows the plates to cling together, but also acts as a lubricant, allowing the plates to slide past one another. As a result, clay is easily molded into shapes. High temperatures drive out water and allow bonds to form between plates, holding them in place and promoting the formation of a hard solid. Binders such as bone ash are sometimes added to the clay to promote strong bond formation, which makes the ceramic resistant to breakage. The common clay used to make flowerpots and roof tiles is usually red-orange because of the presence of iron oxides. White ceramics are made from rarer (and thus more expensive) white clays, primarily kaolin.

The oldest known ceramics made by humans are figurines found in the former Czechoslovakia that are thought to date from around 27,000 B.C.E. It was determined that the figurines were made by mixing clay with bone, animal fat, earth, and bone ash (the ash that results when animal bones are heated to a high temperature), molding the mixture into a desired shape, and heating it in a domed pit. The manufacture of functional objects such as pots, dishes, and storage vessels, was developed in ancient Greece and Egypt during the period 9000 to 6000 B.C.E.

An important advance was the development of white porcelain. Porcelain is a hard, tough ceramic that is less brittle than the ceramics that preceded it. Its strength allows it to be fashioned into beautiful vessels with walls so thin they can even be translucent. It is made from kaolin mixed with china stone, and the mixture is heated to a very high temperature (1,300°C, or 2,372°F). Porcelain was developed in China around C.E. 600 during the T'ang dynasty and was perfected during the Ming dynasty, famous for its blue and white porcelain. The porcelain process was introduced to the Arab world in the ninth century; later Arabs brought porcelain to Spain, from where the process spread throughout Europe.

Bone china has a composition similar to that of porcelain, but at least 50 percent of the material is finely powdered bone ash. Like porcelain, bone china is strong and can be formed into dishes with very thin, translucent walls. Stoneware is a dense, hard, gray or tan ceramic that is less expensive than bone china and porcelain, but it is not as strong. As a result, stoneware dishes are usually thicker and heavier than bone china or porcelain dishes.

Manufacture of Advanced Ceramics

The preparation of an advanced ceramic material usually begins with a finely divided powder that is mixed with an organic binder to help the powder consolidate, so that it can be molded into the desired shape. Before it is fired, the ceramic body is called "green." The green body is first heated at a low temperature in order to decompose or oxidize the binder. It is then heated to a high temperature until it is "sintered," or hardened, into a dense, strong ceramic. At this time, individual particles of the original powder fuse together as chemical bonds form between them. During sintering the ceramic may shrink by as much as 10 to 40 percent. Because shrinkage is not uniform, additional machining of the ceramicmay be required in order to obtain a precise shape.

Sol-gel technology allows better mixing of the ceramic components at the molecular level, and hence yields more homogeneous ceramics, because the ions are mixed while in solution. In the sol-gel process, a solution of an organometallic compound is hydrolyzed to produce a "sol," a colloidal suspension of a solid in a liquid. Typically the solution is a metal alkoxide such as tetramethoxysilane in an alcohol solvent. The sol forms when the individual formula units polymerize (link together to form chains and networks). The sol can then be spread into a thin film, precipitated into tiny uniform spheres called microspheres, or further processed to form a gel inside a mold that will yield a final ceramic object in the desired shape. The many crosslinks between the formula units result in a ceramic that is less brittle than typical ceramics.

Although the sol-gel process is very expensive, it has many advantages, including low temperature requirements; the ceramist's ability to control porosity and to form films, spheres, and other structures that are difficult to form in molds; and the attainment of specialized ceramic compositions and high product purity. Porous ceramics are made by the sol-gel process. These ceramics have sponge like structures, with many porelike lacunae, or openings, that can make up from 25 to 70 percent of the volume. The pore size can be large, or as small as 50 nanometers (2×10^{-6} inches) in diameter. Because of the large number of pores, porous ceramics have enormous surface areas (up to 500 square meters, or 5,382 square feet, per gram of ceramic), and so can make excellent catalysts. For example, zirconium oxide is a ceramic oxygen sensor that monitors the air-to- fuel ratio in the exhaust systems of automobiles.

Aerogels are solid foams prepared by removing the liquid from the gel during a sol-gel process at high temperatures and low pressures. Because aerogels are good insulators, have very low densities, and do not melt at high temperatures, they are attractive for use in spacecraft.

Properties and Uses

For centuries ceramics were used by those who had little knowledge of their structure. Today, understanding of the structure and properties of ceramics is making it possible to design and engineer new kinds of ceramics.

Most ceramics are hard, chemically inert, refractory (can withstand very high heat without deformation), and poor conductors of heat and electricity. Ceramics also have low densities. These properties make ceramics attractive for many applications. Ceramics are used as refractories in furnaces and as durable building materials (in the form of bricks, tiles, cinder blocks, and other hard, strong solids). They are also used as common electrical and thermal insulators in the manufacture of spark plugs, telephone poles, electronic devices, and the nose cones of spacecraft. However, ceramics also tend to be brittle. A major difficulty with the use of ceramics is their tendency to acquire tiny cracks that slowly become larger until the material falls apart. To prevent ceramic materials from cracking, they are often appliedas coatings on inexpensive materials that are resistant to cracks. For example, engineparts are sometimes coated with ceramics to reduce heat transfer.

Composite materials that contain ceramic fibers embedded in polymer matrices possess many of the properties of ceramics; these materials have low densities and are resistant to corrosion, yet are tough and flexible rather than brittle. They are used in tennis rackets, bicycles, and automobiles. Ceramic composites may also be made from two distinct ceramic materials that exist as two separate ceramic phases in the composite material. Cracks generated in one phase will not be transferred to the other. As a result, the resistance of the composite material to cracking is considerable. Composite ceramics made from diborides and/or carbides of zirconium and hafnium mixed with silicon carbide are used to create the nose cones of spacecraft. Break-resistant cookware (with outstanding thermal shock resistance) is also made from ceramic composites.

Structure and Properties

The properties of ceramic materials, like all materials, are dictated by the types of atoms present, the types of bonding between the atoms, and the way the atoms are packed together. This is known as the atomic scale structure. Most ceramics are made up of two or more elements. This is called a compound. For example, alumina ($Al2O3$), is a compound made up of aluminum atoms and oxygen atoms.

The atoms in ceramic materials are held together by a chemical bond. The two most common chemical bonds for ceramic materials are covalent and ionic. For metals, the chemical bond is called the metallic bond. The bonding of atoms together is much stronger in covalent and ionic bonding than in metallic. That is why, generally speaking, metals are ductile and ceramics are brittle.

Another structure that plays an important factor in the final property of a material is called microstructure. The microstructure of a material is the structure that can be seen using a microscope, but seldom with the naked eye. For ceramics, the microstructure can be entirely glassy (glasses only); entirely crystalline; or a combination of crystalline and glassy. In the last case, the glassy phase usually surrounds small crystals, bonding them together.

The atomic structure primarily effects the chemical, physical, thermal, electrical, magnetic, and optical properties. The microstructure also can effect these properties but has its major effect on mechanical properties and on the rate of chemical reaction. Due to ceramic materials wide range of properties, they are used for a multitude of applications. In general, most ceramics are:

- Hard,
- wear-resistant,
- brittle,
- refractory,
- thermal insulators,
- electrical insulators,
- nonmagnetic,
- oxidation resistant,
- prone to thermal shock, and chemically stable.

Of course there are many exceptions to these generalizations. For example, borosilicate glasses (glasses that contain silica and boron as major ingredients) and certain glass ceramics (glasses that contain a crystalline phase) and NZP ceramics are very resistant to thermal shock and are used in applications such as ovenware, stove tops and kiln furniture

respectively. Also, some ceramics are excellent electrical conductors and an entire commercial market is based on the fact that certain ceramics (ferrites) are magnetic.

Overview of Ceramic and Glass Manufacturing

Ceramics are typically produced by the application of heat upon processed clays and other natural raw materials to form a rigid product. Ceramic products that use naturally occurring rocks and minerals as a starting material must undergo special processing in order to control purity, particle size, particle size distribution, and heterogeneity. These attributes play a big role in the final properties of the finished ceramic. Chemically prepared powders also are used as starting materials for some ceramic products. These synthetic materials can be controlled to produce powders with precise chemical compositions and particle size.

The next step is to form the ceramic particles into a desired shape. This is accomplished by the addition of water and/or additives such as binders, followed by a shape forming process. Some of the most common forming methods for ceramics include extrusion, slip casting, pressing, tape casting and injection molding. After the particles are formed, these "green" ceramics undergo a heat-treatment (called firing or sintering) to produce a rigid, finished product. Some ceramic products such as electrical insulators, dinnerware and tile may then undergo a glazing process. Some ceramics for advanced applications may undergo a machining and/or polishing step in order meet specific engineering design criteria.

The processing of glass products is different than for ceramics. In glass production, raw materials such as silica, lime, and soda ash are melted in a furnace, then formed into the desired shape (i.e.; pressed plate, fibers, molded bottle, plate glass, etc.) while still molten. After the molten glass is formed, it is quickly cooled, "freezing" the glass into place to form the finished product. The glass typically undergoes additional processing steps such as cutting, etching, coating, grinding, decorating, or heat treating (tempering).

Some of the challenges that face ceramic and glass manufacturers, and suppliers include availability and cost of raw materials, quality and cost of labor, changing markets, quality control, capital for expansion, import pressure, and environmental, health and safety standards.

Introduction of Composites

Historical Development / Historical overview:

After making and controlling fire and inventing the wheel, spinning of continuous yarns is probably the most important development of mankind, enabling him to survive outside the tropical climate zones and spread across the surface of the Earth. Flexible fabrics made of locally grown and spun fibres as cotton; flax and jute were a big step forward compared to animal skins. More and more natural resources were used, soon resulting in the first composites; straw reinforced walls, and bows (Figure M1.1.1 (a)) and chariots made of glued layers of wood, bone and horn. More durable materials as wood and metal soon replaced these antique composites.

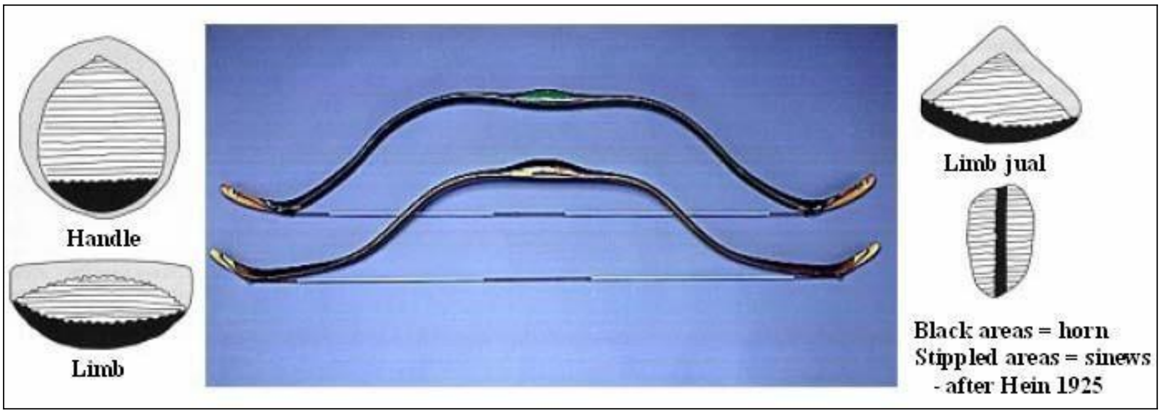


Fig no 4.1: Composite Korean bow

Present:

Originating from early agricultural societies and being almost forgotten after centuries, a true revival started of using lightweight composite structures for many technical solutions during the second half of the 20th century. After being solely used for their electromagnetic properties (insulators and radar-domes), using composites to improve the structural performance of spacecraft and military aircraft became popular in the last two decades of the previous century. First at any costs, with development of improved materials with increasing costs, nowadays cost reduction during manufacturing and operation are the main technology drivers. Latest development is the use of composites to protect man against fire and impact (Figure M1.1.1 (b)) and a tendency to a more environmental friendly design, leading to the reintroduction of natural fibres in the composite technology, see Figure M1.1.1 (c). Increasingly nowadays, the success of composites in applications, by volume and by numbers, can be ranked by accessibility and reproducibility of the applied manufacturing techniques. Some examples of use of natural fibers are shown in Figure M1.1.1 (d) and Figure M1.1.1 (e).

Figure M1.1 (d): Manufacturing of a basket using indigenous knowledge (Bangladesh)

Figure M1.1 (e): Traditional clay product/pottery in Zimbabwe

Fig no :4.2

Figure M1.1.1 (b): Lightweight composite military helmet

Figure M1.1.1 (c): Interior part of the Mercedes A–200 (Generation of A - classes)

Fig no: 4.3

Future:

In future, composites will be manufactured even more according to an integrated design process resulting in the optimum construction according to parameters such as shape, mass, strength, stiffness, durability, costs, etc. Newly developed design tools must be able to instantaneously show customers the influence of a design change on each one of these parameters.

Concept of Composite:

Fibers or particles embedded in **matrix** of another material are the best example of modern-day composite materials, which are mostly structural.

Laminates are composite material where different layers of materials give them the specific character of a composite material having a specific function to perform. **Fabrics** have no matrix to fall back on, but in them, fibers of different compositions combine to give them a specific character. **Reinforcing materials** generally withstand maximum load and serve the desirable properties.

Further, though composite types are often distinguishable from one another, no clear determination can be really made. To facilitate definition, the accent is often shifted to the levels at which differentiation take place viz., **microscopic** or **macroscopic**.

In **matrix**-based structural composites, the matrix serves two paramount purposes viz., binding the **reinforcement phases** in place and deforming to distribute the stresses among the constituent **reinforcement materials** under an applied force.

The demands on matrices are many. They may need to temperature variations, be conductors or resistors of electricity, have **moisture sensitivity** etc. This may offer weight advantages, ease of handling and other merits which may also become applicable depending on the purpose for which matrices are chosen.

Solids that accommodate stress to incorporate other constituents provide strong bonds for the reinforcing phase are potential **matrix materials**. A few inorganic materials, polymers and metals have found applications as matrix materials in the designing of structural composites, with commendable success. These materials remain elastic till failure occurs and show decreased failure strain, when loaded in tension and compression.

Composites cannot be made from constituents with divergent linear expansion characteristics. The interface is the area of contact between the reinforcement and the matrix materials. In some cases, the region is a distinct added phase. Whenever there is **interphase**, there has to be two interphases between each side of the interphase and its **adjoint constituent**. Some composites provide interphases when surfaces dissimilar constituents interact with each other. Choice of fabrication method depends on matrix properties and the effect of matrix on properties of reinforcements. One of the prime considerations in the selection and fabrication of composites is that the constituents should be chemically inert non-reactive. Figure 1.1 (f) helps to classify matrices.

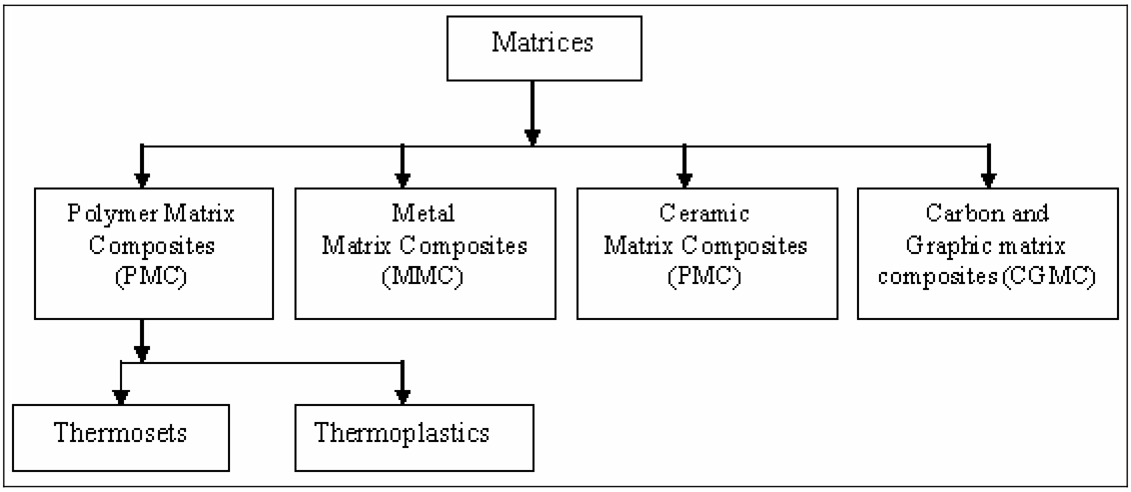


Fig:4.4 Classification of Matrix Materials

Basic Definitions and Classifications of Composites

1.2.1 Classification of Composites

Composite materials are commonly classified at following two distinct levels:

- The first level of classification is usually made with respect to the matrix constituent. The major composite classes include Organic Matrix Composites (OMCs), Metal Matrix Composites (MMCs) and Ceramic Matrix Composites (CMCs). The term organic matrix composite is generally assumed to include two classes of composites, namely Polymer Matrix Composites (PMCs) and carbon matrix composites commonly referred to as carbon- carbon composites.
- The second level of classification refers to the reinforcement form - fibre **reinforced composites**, **laminar composites** and **particulate composites**. Fibre Reinforced composites (FRP) can be further divided into those containing discontinuous or continuous fibres.
- **Fibre Reinforced Composites** are composed of fibres embedded in matrix material. Such a composite is considered to be a discontinuous fibre or short fibre composite if

its properties vary with fibre length. On the other hand, when the length of the fibre is such that any further increase in length does not further increase, the elastic modulus of the composite, the composite is considered to be continuous fibre reinforced. Fibres are small in diameter and when pushed axially, they bend easily although they have very good tensile properties. These fibres must be supported to keep individual

fibres from bending and buckling.

- **Laminar Composites** are composed of layers of materials held together by matrix. Sandwich structures fall under this category.
- **Particulate Composites** are composed of particles distributed or embedded in a matrix body. The particles may be flakes or in powder form. Concrete and wood particle boards are examples of this category.

Organic Matrix Composites

Polymer Matrix Composites (PMC)/Carbon Matrix Composites or Carbon- Carbon Composites

Polymers make ideal materials as they can be processed easily, possess lightweight, and desirable mechanical properties. It follows, therefore, that high temperature resins are extensively used in aeronautical applications.

Two main kinds of polymers are **thermosets** and **thermoplastics**. Thermosets have qualities such as a well-bonded three-dimensional molecular structure after curing. They decompose instead of melting on hardening. Merely changing the basic composition of the resin is enough to alter the conditions suitably for curing and determine its other characteristics. They can be retained in a partially cured condition too over prolonged periods of time, rendering Thermosets very flexible. Thus, they are most suited as matrix bases for advanced conditions fiber reinforced composites. Thermosets find wide ranging applications in the **chopped fiber composites** form particularly when a premixed or moulding compound with fibers of specific quality and aspect ratio happens to be starting material as in epoxy, polymer and phenolic polyamide resins.

Thermoplastics have one- or two-dimensional molecular structure and they tend to at an elevated temperature and show exaggerated melting point. Another advantage is that the process of softening at elevated temperatures can reversed to regain its properties during cooling, facilitating applications of **conventional compress techniques** to mould the compounds.

Resins reinforced with thermoplastics now comprised an emerging group of composites. The theme of most experiments in this area to improve the base properties of the resins and extract the greatest functional advantages from them in new avenues, including attempts to replace metals in die-casting processes. In crystalline thermoplastics, the reinforcement affects the **morphology** to a considerable extent, prompting the reinforcement to empower nucleation. Whenever **crystalline** or **amorphous**, these resins possess the facility to alter their **creep** over an extensive range of temperature. But this range includes the point at which the usage of resins is constrained, and the reinforcement in such systems can increase the failure load as well as creep resistance. Figure M1.2.1 shows kinds of thermoplastics.

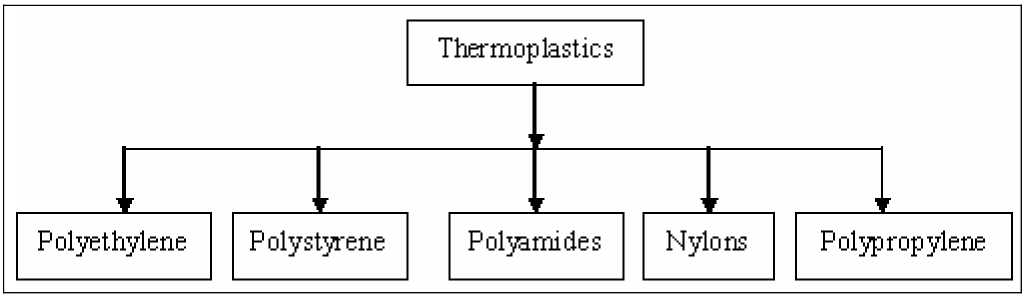


Fig:4.5 Thermoplastics

A small quantum of shrinkage and the tendency of the shape to retain its original form are also to be accounted for. But **reinforcements** can change this condition too. The advantage of thermoplastics systems over thermosets are that there are no chemical reactions involved, which often result in the release of gases or heat. Manufacturing is limited by the time required for heating, shaping and cooling the structures.

Thermoplastics resins are sold as **moulding compounds**. Fiber reinforcement is apt for these resins. Since the fibers are randomly dispersed, the reinforcement will be almost **isotropic**. However, when subjected to moulding processes, they can be aligned directionally.

There are a few options to increase heat resistance in thermoplastics. Addition of fillers raises the heat resistance. But all thermoplastic composites tend loose their strength at elevated temperatures. However, their **redeeming qualities** like **rigidity**, **toughness** and ability to **repudiate creep**, place thermoplastics in the important composite materials bracket. They are used in automotive control panels, electronic products encasement etc.

Newer developments augur the broadening of the scope of applications of thermoplastics. Huge sheets of reinforced thermoplastics are now available and they only require sampling and heating to be moulded into the required shapes. This has facilitated easy fabrication of bulky components, doing away with the more cumbersome moulding compounds.

Thermosets are the most popular of the fiber composite matrices without which, research and development in structural engineering field could get truncated. Aerospace components, automobile parts, defense systems etc., use a great deal of this type of fiber composites. **Epoxy matrix materials** are used in printed circuit boards and similar areas. Figure M1.2.2 shows some kinds of thermosets.

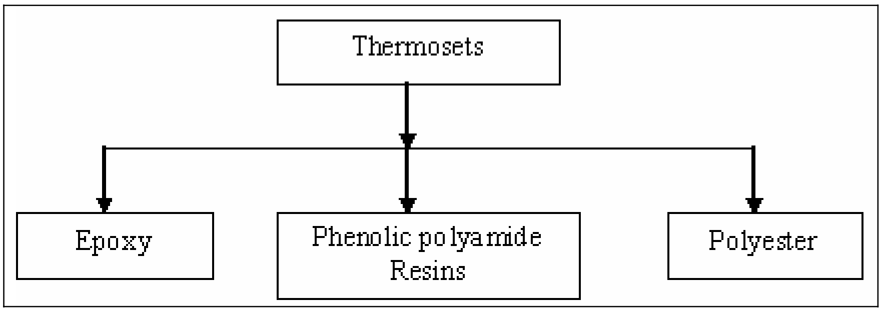


Fig:4.6 Thermoset Materials

Direct condensation **polymerization** followed by rearrangement reactions to form **heterocyclic entities** is the method generally used to produce thermoset resins. Water, a product of the reaction, in both methods, hinders production of void-free composites. These voids have a negative effect on properties of the composites in terms of strength and dielectric properties. **Polyesters phenolic** and **Epoxies** are the two important classes of thermoset resins.

Epoxy resins are widely used in filament-wound composites and are suitable for **moulding prepress**. They are reasonably stable to chemical attacks and are excellent **adherents** having slow shrinkage during curing and no emission of volatile gases. These advantages, however, make the use of epoxies rather expensive. Also, they cannot be expected beyond a temperature of 140ºC. Their use in high technology areas where service temperatures are higher, as a result, is ruled out.

Polyester resins on the other hand are quite easily accessible, cheap and find use in a wide range of fields. **Liquid polyesters** are stored at room temperature for months, sometimes for years and the mere addition of a catalyst can cure the matrix material within a short time. They are used in automobile and structural applications.

The **cured polyester** is usually rigid or flexible as the case may be and transparent. Polyesters withstand the variations of environment and stable against chemicals. Depending on the formulation of the resin or service requirement of application, they can be used up to about 75ºC or higher. Other advantages of polyesters include easy **compatibility** with few glass fibers and can be used with verify of reinforced plastic accoutrey.

Aromatic Polyamides are the most sought after candidates as the matrices of advanced fiber composites for structural applications demanding long duration exposure for continuous service at around 200-250ºC .

Metal Matrix Composites (MMC)

Metal matrix composites, at present though generating a wide interest in research fraternity, are not as widely in use as their plastic counterparts. High **strength**, **fracture toughness** and **stiffness** are offered by metal matrices than those offered by their polymer counterparts. They can withstand elevated temperature in corrosive environment than polymer composites. Most metals and alloys could be used as matrices and they require reinforcement materials which need to be stable over a range of temperature and non-reactive too. However the guiding aspect for the choice depends essentially on the matrix material. Light metals form the matrix for temperature application and the reinforcements in addition to the aforementioned reasons are characterized by high moduli.

Most metals and alloys make good matrices. However, practically, the choices for low temperature applications are not many. Only light metals are responsive, with their low density proving an advantage. Titanium, Aluminium and magnesium are the popular matrix metals currently in vogue, which are particularly useful for aircraft applications. If metallic matrix materials have to offer high strength, they require high modulus reinforcements. The strength-to- weight ratios of resulting composites can be higher than most alloys.

The melting point, physical and mechanical properties of the composite at various

temperatures determine the service temperature of composites. Most metals, ceramics and compounds can be used with matrices of low melting point alloys. The choice of reinforcements becomes more stunted with increase in the melting temperature of matrix materials.

Ceramic Matrix Materials (CMM)

Ceramics can be described as solid materials which exhibit very strong **ionic bonding** in general and in few cases **covalent bonding**. High melting points, good corrosion resistance, stability at elevated temperatures and high compressive strength, render ceramic-based matrix materials a favourite for applications requiring a structural material that doesn’t give way at temperatures

above 1500ºC. Naturally, ceramic matrices are the obvious choice for high temperature applications.

High **modulus of elasticity** and low tensile strain, which most ceramics posses, have combined to cause the failure of attempts to add reinforcements to obtain strength improvement. This is because at the stress levels at which ceramics rupture, there is insufficient elongation of the matrix which keeps composite from transferring an effective **quantum of load** to the reinforcement and the composite may fail unless the percentage of fiber volume is high enough. A material is reinforcement to utilize the higher tensile strength of the fiber, to produce an increase in load bearing capacity of the matrix. Addition of high-strength fiber to a weaker ceramic has not always been successful and often the resultant composite has proved to be weaker.

The use of reinforcement with high modulus of elasticity may take care of the problem to some extent and presents **pre-stressing** of the fiber in the ceramic matrix is being increasingly resorted to as an option.

When ceramics have a higher **thermal expansion coefficient** than reinforcement materials, the resultant composite is unlikely to have a superior level of strength. In that case, the composite will develop strength within ceramic at the time of cooling resulting in microcracks extending from fiber to fiber within the matrix. Microcracking can result in a composite with tensile strength lower than that of the matrix.

Classification Based on Reinforcements

Introduction to Reinforcements

Reinforcements for the composites can be fibers, fabrics particles or **whiskers**. Fibers are essentially characterized by one very long axis with other two axes either often circular or near circular. Particles have no preferred orientation and so does their shape. Whiskers have a preferred shape but are small both in diameter and length as compared to fibers. Figure M1.2.3 shows types of reinforcements in composites.

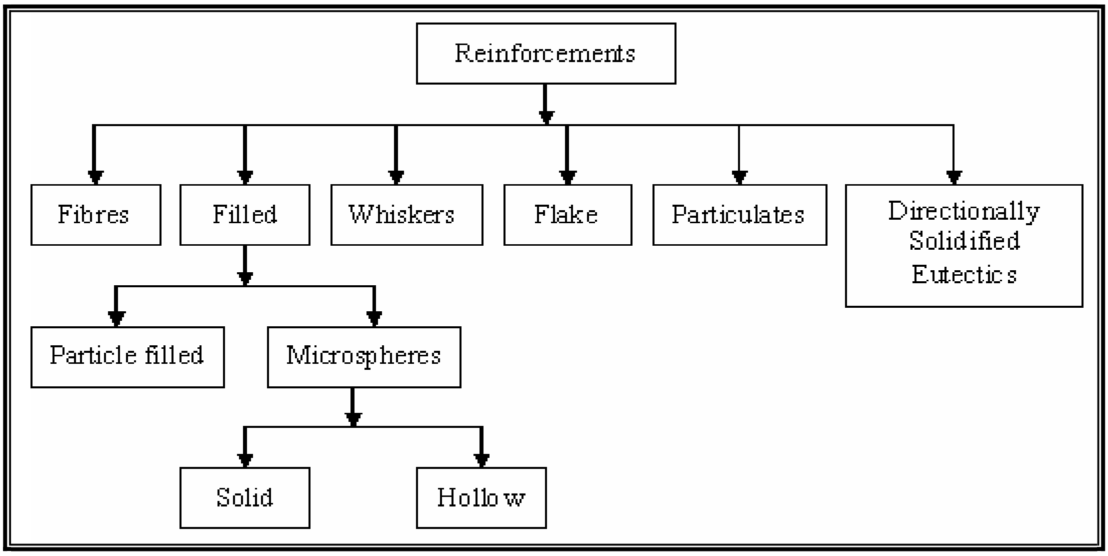


Fig:4.7 Reinforcements

Reinforcing constituents in composites, as the word indicates, provide the strength that makes the composite what it is. But they also serve certain additional purposes of heat resistance or conduction, resistance to corrosion and provide rigidity. Reinforcement can be made to perform all or one of these functions as per the requirements.

A reinforcement that embellishes the matrix strength must be stronger and stiffer than the matrix and capable of changing failure mechanism to the advantage of the composite. This means that the ductility should be minimal or even nil the composite must behave as brittle as possible.

Fiber Reinforced Composites/Fibre Reinforced Polymer (FRP) Composites

Fibers are the important class of reinforcements, as they satisfy the desired conditions and transfer strength to the matrix constituent influencing and enhancing their properties as desired.

Glass fibers are the earliest known fibers used to reinforce materials. Ceramic and metal fibers were subsequently found out and put to extensive use, to render composites stiffer more resistant to heat.

Fibers fall short of ideal performance due to several factors. The performance of a fiber composite is judged by its length, shape, orientation, and composition of the fibers and the mechanical properties of the matrix.

The orientation of the fiber in the matrix is an indication of the strength of the composite and the strength is greatest along the longitudinal directional of fiber. This doesn’t mean the longitudinal fibers can take the same quantum of load irrespective of the direction in which it is applied. Optimum performance from longitudinal fibers can be obtained if the load is applied along its direction. The slightest shift in the angle of loading may drastically reduce the strength of the composite. Unidirectional loading is found in few structures and hence it is prudent to give a mix of orientations for fibers in composites particularly where the load is expected to be the heaviest.

Monolayer tapes consisting of continuous or discontinuous fibers can be oriented unidirectional stacked into plies containing layers of filaments also oriented in the same direction. More complicated orientations are possible too and nowadays, computers are used to make projections of such variations to suit specific needs. In short, in **planar composites**, strength can be changed from unidirectional fiber oriented composites that result in composites with nearly **isotropic properties**.

Properties of **angle-plied composites** which are not **quasi-isotropic** may vary with the number of **plies** and their orientations. Composite variables in such composites are assumed to have a constant ratio and the matrices are considered relatively weaker than the fibers. The strength of the fiber in any one of the three axes would, therefore be one-third the unidirectional fiber composite, assuming that the volume percentage is equal in all three axes.

However, orientation of short fibers by different methods is also possible like random orientations by sprinkling on to given plane or addition of matrix in liquid or solid state before or after the fiber deposition. Even three-dimensional orientations can achieve in this way.

There are several methods of random fiber orientations, which in a two-dimensional one, yield composites with one-third the strength of a unidirectional fiber-stressed composite, in the direction of fibers. In a 3-dimension, it would result in a composite with a comparable ratio, about less than one-fifth. In very strong matrices, moduli and strengths have not been observed. Application of the strength of the composites with such matrices and several orientations is also possible. The longitudinal strength can be calculated on the basis of the assumption that fibers have been reduced to their effective strength on approximation value in composites with strong matrices and non-longitudinally orientated fibers.

It goes without saying that fiber composites may be constructed with either continuous or short fibers. Experience has shown that **continuous fibers** (or filaments) exhibit better orientation, although it does not reflect in their performance. Fibers have a high **aspect ratio**, i.e., their lengths being several times greater than their **effective diameters**. This is the reason why filaments are manufactured using continuous process. This finished filaments.

Mass production of filaments is well known and they match with several matrices in different ways like winding, twisting, weaving and knitting, which exhibit the characteristics of a fabric.

Since they have low densities and high strengths, the fiber lengths in filaments or other fibers yield considerable influence on the mechanical properties as well as the response of composites to processing and procedures. **Shorter fibers** with proper orientation composites that use glass, ceramic or multi-purpose fibers can be endowed with considerably higher strength than those that use continuous fibers. Short fibers are also known to their theoretical strength. The

Continuous fiber constituent of a composite is often joined by the filament winding process in which the matrix impregnated fiber wrapped around a mandrel shaped like the part over which the composite is to be placed, and equitable load distribution and favorable orientation of the fiber is possible in the finished product. However, winding is mostly confined to fabrication of bodies of revolution and the occasional irregular, flat surface.

Short-length fibers incorporated by the **open- or close-mould process** are found to be less efficient, although the input costs are considerably lower than filament winding.

Most fibers in use currently are solids which are easy to produce and handle, having a circular cross-section, although a few non-conventional shaped and hollow fibers show signs of capabilities that can improve the mechanical qualities of the composites.

Given the fact that the vast difference in length and effective diameter of the fiber are assets to a fiber composite, it follows that greater strength in the fiber can be achieved by smaller diameters due to minimization or total elimination of surface of surface defects.

After flat-thin filaments came into vogue, fibers rectangular cross sections have provided new options for applications in high strength structures. Owing to their shapes, these fibers provide perfect packing, while hollow fibers show better **structural efficiency** in composites that are desired for their stiffness and compressive strengths. In hollow fibers, the **transverse compressive strength** is lower than that of a solid fiber composite whenever the hollow portion is more than half the total fiber diameter. However, they are not easy to handle and fabricate.

Laminar Composites

Laminar composites are found in as many combinations as the number of materials. They can be described as materials comprising of layers of materials bonded together. These may be of several layers of two or more metal materials occurring alternately or in a determined order more than once, and in as many numbers as required for a specific purpose.

Clad and sandwich laminates have many areas as it ought to be, although they are known to follow the rule of mixtures from the modulus and strength point of view. Other **intrinsic values** pertaining to metal-matrix, metal-reinforced composites are also fairly well known.

Powder metallurgical processes like roll bonding, hot pressing, diffusion bonding, brazing and so on can be employed for the fabrication of different alloys of sheet, foil, powder or sprayed materials. It is not possible to achieve high strength materials unlike the fiber version. But sheets and foils can be made isotropic in two dimensions more easily than fibers. Foils and sheets are also made to exhibit high percentages of which they are put. For instance, a strong sheet may use over 92% in laminar structure, while it is difficult to make fibers of such compositions. Fiber laminates cannot over 75% strong fibers.

The main functional types of metal-metal laminates that do not posses high strength or stiffness are single layered ones that endow the composites with special properties, apart from being cost- effective. They are usually made by **pre-coating** or **cladding methods**.

Pre-coated metals are formed by forming by forming a layer on a substrate, in the form of a thin continuous film. This is achieved by hot dipping and occasionally by **chemical plating** and **electroplating**. Clad metals are found to be suitable for more intensive environments where denser faces are required.

There are many combinations of sheet and foil which function as adhesives at low temperatures. Such materials, plastics or metals, may be clubbed together with a third constituent. Pre-painted or pre-finished metal whose primary advantage is elimination of final finishing by the user is the best known metal-organic laminate. Several combinations of metal-plastic, vinyl-metal laminates, organic films and metals, account for upto 95% of metal-plastic laminates known. They are made by **adhesive bonding processes**.

Particulate Reinforced Composites (PRC)

Microstructures of metal and ceramics composites, which show particles of one phase strewn in the other, are known as particle reinforced composites. Square, triangular and round shapes of reinforcement are known, but the dimensions of all their sides are observed to be more or less equal. The **size and volume concentration** of the **dispersoid** distinguishes it from dispersion hardened materials.

The dispersed size in particulate composites is of the order of a few microns and volume concentration is greater than 28%. The difference between particulate composite and dispersion strengthened ones is, thus, oblivious. The mechanism used to strengthen each of them is also different. The dispersed in the dispersion-strengthen materials reinforces the matrix alloy by arresting motion of dislocations and needs large forces to fracture the restriction created by dispersion In particulate composites, the particles strengthen the system by the **hydrostatic coercion** of fillers in matrices and by their hardness relative to the matrix.

Three-dimensional reinforcement in composites offers isotropic properties, because of the three systematical **orthogonal planes**. Since it is not **homogeneous**, the material properties acquire sensitivity to the constituent properties, as well as the **interfacial properties** and geometric shapes of the array. The composite’s strength usually depends on the diameter of the particles, the inter-particle spacing, and the volume fraction of the reinforcement. The matrix properties influence the behaviour of particulate composite too.

Classification Based on Reinforcements and Matrices

There are two types of constituent materials: matrix and reinforcement. At least one portion (fraction) of each type is required. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart special physical (mechanical and electrical) properties to enhance the matrix properties.

Classification Based On Matrices

The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal such as aluminum, magnesium, or titanium, and provides a compliant support for the reinforcement. In high temperature applications, cobalt and cobalt-nickel alloy matrices are common. The composite materials are commonly classified based on matrix constituent. The major composite classes include Organic Matrix Composites (OMCs), Metal Matrix Composites (MMCs) and Ceramic Matrix Composites (CMCs). The term organic matrix composite is generally assumed to include two classes of composites, namely Polymer Matrix Composites (PMCs) and carbon matrix composites commonly referred to as carbon-carbon composites. These three types of matrixes produce three common types of composites.

1. **Polymer matrix composites** (PMCs), of which GRP is the best-known example, use ceramic fibers in a plastic matrix.
2. **Metal-matrix composites** (MMCs) typically use silicon carbide fibers embedded in

   a matrix made from an alloy of aluminum and magnesium, but other matrix materials such as titanium, copper, and iron are increasingly being used. Typical applications of MMCs include bicycles, golf clubs, and missile guidance systems; an MMC made from silicon- carbide fibers in a titanium matrix is currently being developed for use as the skin (fuselage material) of the US National Aerospace Plane.

3. **Ceramic-matrix composites** (CMCs) are the third major type and examples include silicon carbide fibers fixed in a matrix made from a borosilicate glass. The ceramic matrix makes them particularly suitable for use in lightweight, high-temperature components, such as parts for airplane jet engines.

Polymer Matrix Composites (PMC)/Carbon Matrix Composites/Carbon-Carbon Composites (CCC)

Polymers make ideal materials as they can be processed easily, possess lightweight, and desirable mechanical properties. It follows, therefore, that high temperature **resins** are extensively used in aeronautical applications.

Two main kinds of polymers are **thermosets** and **thermoplastics**. Thermosets have qualities such as a well-bonded three-dimensional molecular structure after curing. They decompose instead of melting on hardening. Merely changing the basic composition of the resin is enough to alter the conditions suitably for curing and determine its other characteristics. They can be retained in a partially cured condition too over prolonged periods of time, rendering Thermo sets very flexible. Thus, they are most suited as matrix bases for advanced conditions fiber reinforced composites. Thermo sets find wide ranging applications in the **chopped fiber composites** form particularly when a premixed or moulding compound with fibers of specific quality and aspect ratio happens to be starting material as in epoxy, polymer and phenolic polyamide resins.Thermoplastics have one- or two-dimensional molecular structure and they tend to at an elevated temperature and show exaggerated melting point. Another advantage is that the process of softening at elevated temperatures can reversed to regain its properties during cooling, facilitating applications of **conventional compress techniques** to mould the compounds.

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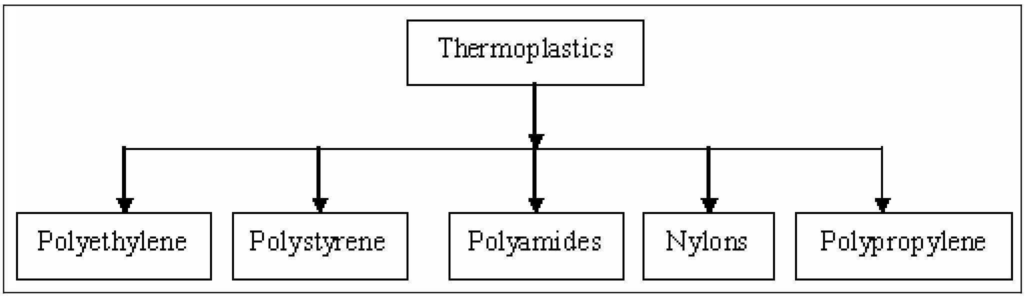

Fig:4.8 Thermoplastics

A small quantum of shrinkage and the tendency of the shape to retain its original form are also to be accounted for. But **reinforcements** can change this condition too. The advantage of thermoplastics systems over thermosets are that there are no chemical reactions involved, which often result in the release of gases or heat. Manufacturing is limited by the time required for heating, shaping and cooling the structures.

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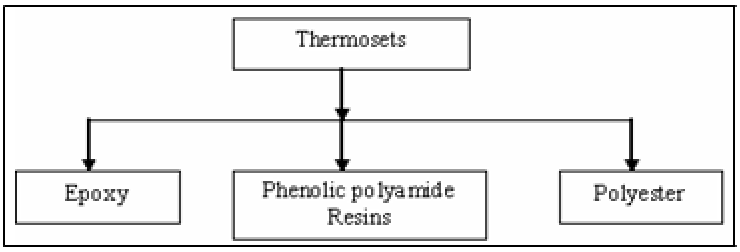

Fig : 4.9 Some Kinds of Thermosets

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Classification Based On Reinforcements

Introduction to Reinforcement

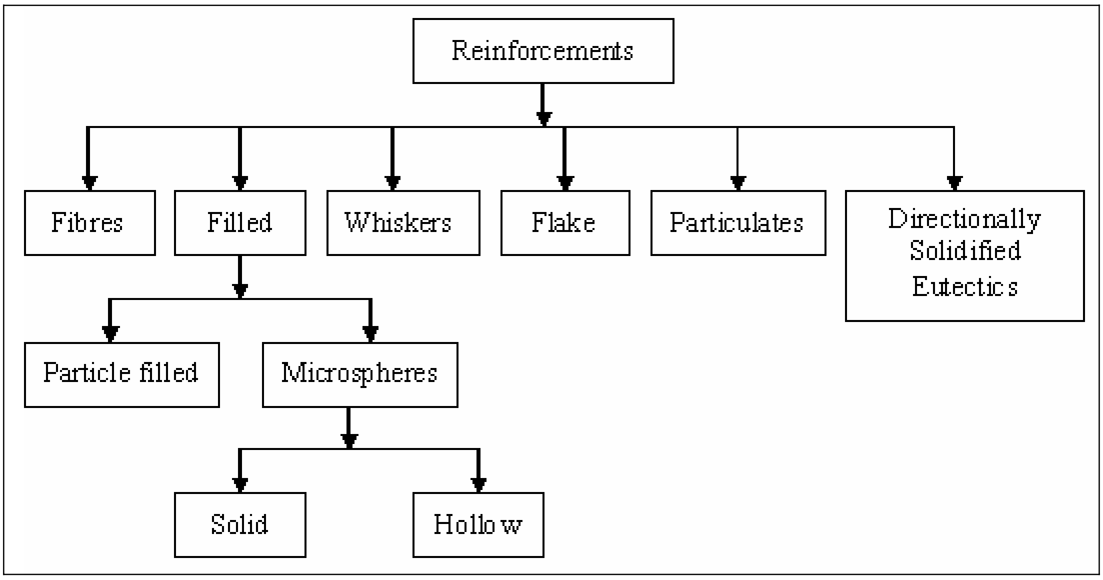
Reinforcements: A strong, inert woven and nonwoven fibrous material incorporated into the matrix to improve its metal glass and physical properties. Typical reinforcements are asbestos, boron, carbon, metal glass and ceramic fibers, flock, graphite, jute, sisal and whiskers, as well as chopped paper, macerated fabrics, and synthetic fibers. The primary difference between reinforcement and filler is the reinforcement markedly improves tensile and flexural strength, whereas filler usually does not. Also to be effective, reinforcement must form a strong adhesive bond with the resin.

The role of the reinforcement in a composite material is fundamentally one of increasing the mechanical properties of the neat resin system. All of the different fibres used incomposites have different properties and so affect the properties of the composite in different ways.

However, individual fibres or fibre bundles can only be used on their own in a few processes such as filament winding. For most other applications, the fibres need to be arranged into some form of sheet, known as a fabric, to make handling possible. Different ways for assembling fibres into sheets and the variety of fibre orientations possible lead to there being many different types of fabrics, each of which has its own characteristics.

Reinforcements for the composites can be fibers, fabrics particles or **whiskers**. Fibers are essentially characterized by one very long axis with other two axes either often circular or near circular. Particles have no preferred orientation and so does their shape. Whiskers have a preferred shape but are small both in diameter and length as compared to fibers. Figure

Shows types of reinforcements in composites.



Reinforcements

Reinforcing constituents in composites, as the word indicates, provide the strength that makes the composite what it is. But they also serve certain additional purposes of heat resistance or conduction, resistance to corrosion and provide rigidity. Reinforcement can be made to perform all or one of these functions as per the requirements.

A reinforcement that embellishes the matrix strength must be stronger and stiffer than the matrix and capable of changing failure mechanism to the advantage of the composite. This means that the ductility should be minimal or even nil the composite must behave as brittle as possible.

Fiber Reinforced Composites/Fibre Reinforced Polymer (FRP) Composites

Fibers are the important class of reinforcements, as they satisfy the desired conditions and transfer strength to the matrix constituent influencing and enhancing their properties as desired. Glass fibers are the earliest known fibers used to reinforce materials. Ceramic and metal fibers were subsequently found out and put to extensive use, to render composites stiffer more resistant to heat.

Fibers fall short of ideal performance due to several factors. The performance of a fiber composite is judged by its length, shape, orientation, and composition of the fibers and the mechanical properties of the matrix.

The orientation of the fiber in the matrix is an indication of the strength of the composite and the strength is greatest along the longitudinal directional of fiber. This doesn’t mean the longitudinal fibers can take the same quantum of load irrespective of the direction in which it is applied. Optimum performance from longitudinal fibers can be obtained if the load is applied along its direction. The slightest shift in the angle of loading may drastically reduce the strength of the composite.

Unidirectional loading is found in few structures and hence it is prudent to give a mix of orientations for fibers in composites particularly where the load is expected to be the heaviest.

Monolayer tapes consisting of continuous or discontinuous fibers can be oriented unidirectional stacked into plies containing layers of filaments also oriented in the same direction. More complicated orientations are possible too and nowadays, computers are used to make projections of such variations to suit specific needs. In short, in **planar composites**, strength can be changed from unidirectional fiber oriented composites that result in composites with nearly **isotropic properties**.

Properties of **angle-plied composites** which are not **quasi-isotropic** may vary with the number of plies and their orientations. Composite variables in such composites are assumed to have a constant ratio and the matrices are considered relatively weaker than the fibers. The strength of the fiber in any one of the three axes would, therefore be one-third the unidirectional fiber composite, assuming that the volume percentage is equal in all three axes.

However, orientation of short fibers by different methods is also possible like random orientations by sprinkling on to given plane or addition of matrix in liquid or solid state before or after the fiber deposition. Even three-dimensional orientations can achieve in this way.

There are several methods of random fiber orientations, which in a two-dimensional one, yield composites with one-third the strength of an unidirectional fiber-stressed composite, in the direction of fibers. In a 3-dimension, it would result in a composite with a comparable ratio, about less than one-fifth.

In very strong matrices, moduli and strengths have not been observed. Application of the strength of the composites with such matrices and several orientations is also possible. The longitudinal strength can be calculated on the basis of the assumption that fibers have been reduced to their effective strength on approximation value in composites with strong matrices and non-longitudinally orientated fibers.

It goes without saying that fiber composites may be constructed with either continuous or short fibers. Experience has shown that **continuous fibers** (or filaments) exhibit better orientation, although it does not reflect in their performance. Fibers have a high **aspect ratio**, i.e., their lengths being several times greater than their **effective diameters**. This is

the reason why filaments are manufactured using continuous process. This finished filaments.

Mass production of filaments is well known and they match with several matrices in different ways like winding, twisting, weaving and knitting, which exhibit the characteristics of a fabric.

Since they have low densities and high strengths, the fiber lengths in filaments or other fibers yield considerable influence on the mechanical properties as well as the response of composites to processing and procedures. Shorter fibers with proper orientation composites that use glass, ceramic or multi-purpose fibers can be endowed with considerably higher strength than those that use continuous fibers. Short fibers are also known to their theoretical strength. The continuous fiber constituent of a composite is often joined by the filament winding process in which the matrix impregnated fiber wrapped around a mandrel shaped like the part over which the composite is to be placed, and equitable load distribution and favorable orientation of the fiber is possible in the finished product. However, winding is mostly confined to fabrication of bodies of revolution and the occasional irregular, flat surface.

Short-length fibers incorporated by the **open- or close-mould process** are found to be less efficient, although the input costs are considerably lower than filament winding.

Most fibers in use currently are solids which are easy to produce and handle, having a circular cross-section, although a few non-conventional shaped and hollow fibers show signs of capabilities that can improve the mechanical qualities of the composites.

Given the fact that the vast difference in length and effective diameter of the fiber are assets to a fiber composite, it follows that greater strength in the fiber can be achieved by smaller diameters due to minimization or total elimination of surface of surface defects.

After flat-thin filaments came into vogue, fibers rectangular cross sections have provided new options for applications in high strength structures. Owing to their shapes, these fibers provide perfect packing, while hollow fibers show better **structural efficiency** in composites that are desired for their stiffness and compressive strengths. In hollow fibers, the **transverse compressive strength** is lower than that of a solid fiber composite whenever the hollow portion is more than half the total fiber diameter. However, they are not easy to handle and fabricate.

Fibre Reinforcements

Organic and inorganic fibers are used to reinforce composite materials. Almost all organic fibers have low density, flexibility, and elasticity. Inorganic fibers are of high modulus, high **thermal stability** and possess greater rigidity than organic fibers and not withstanding the diverse advantages of organic fibers which render the composites in which they are used.

Mainly, the following different types of fibers namely, glass fibers, silicon carbide fibers, high silica and quartz fibers, aluminina fibers, metal fibers and wires, graphite fibers, boron fibers, aramid fibers and multiphase fibers are used. Among the glass fibers, it is again classified into E-glass, A-glass, R-glass etc.

There is a greater marker and higher degree of commercial movement of organic fibers.

The potential of fibers of graphite, silica carbide and boron are also exercising the scientific mind due to their applications in advanced composites.

Whiskers

Single crystals grown with nearly zero defects are termed whiskers. They are usually discontinuous and short fibers of different cross sections made from several materials like graphite, silicon carbide, copper, iron etc. Typical lengths are in 3 to 55 N.M. ranges. Whiskersdiffer from particles in that, whiskers have a definite length to width ratio greater than one. Whiskers can have extraordinary strengths upto 7000 MPa.

Whiskers were grown quite incidentally in laboratories for the first time, while nature has some geological structures that can be described as whiskers. Initially, their usefulness was overlooked as they were dismissed as incidental by-products of other structure. However, study on crystal structures and growth in metals sparked off an interest in them, and also the study of defects that affect the strength of materials, they came to be incorporated in composites using several methods, including **power metallurgy** and **slip- casting techniques**.

Metal-whisker combination, strengthening the system at high temperatures, has been demonstrated at the laboratory level. But whiskers are fine, small sized materials not easy to handle and this comes in the way of incorporating them into engineering materials to come out with a superior quality composite system.

Early research has shown that whisker strength varies inversely with effective diameter. When whiskers were embedded in matrices, whiskers of diameter upto 2 to 10µm yielded fairly good composites.

Ceramic material's whiskers have high moduli, useful strengths and low densities. Specific strength and specific modulus are very high and this makes ceramic whiskers suitable for low weight structure composites. They also resist temperature, mechanical damage and oxidation more responsively than metallic whiskers, which are denser than ceramic whiskers. However, they are not commercially viable because they are damaged while handling.

Laminar Composites/Laminate Reinforced Composites

Laminar composites are found in as many combinations as the number of materials. They can be described as materials comprising of layers of materials bonded together. These may be of several layers of two or more metal materials occurring alternately or in a determined order more than once, and in as many numbers as required for a specific purpose.

Clad and sandwich laminates have many areas as it ought to be, although they are known to follow the rule of mixtures from the modulus and strength point of view. Other **intrinsic values** pertaining to metal-matrix, metal-reinforced composites are also fairly well known.

Powder metallurgical processes like roll bonding, hot pressing, diffusion bonding, brazing and so on can be employed for the fabrication of different alloys of sheet, foil, powder or sprayed materials. It is not possible to achieve high strength materials unlike the fiber version. But sheets and foils can be made isotropic in two dimensions more easily than fibers. Foils and sheets are also made to exhibit high percentages of which they are put. For instance, a strong sheet may use over 92% in laminar structure, while it is difficult to make fibers of such compositions. Fiber laminates cannot over 75% strong fibers.

The main functional types of metal-metal laminates that do not posses high strength or stiffness are single layered ones that endow the composites with special properties, apart from being cost-effective. They are usually made by **pre-coating** or **cladding methods**.

Pre-coated metals are formed by forming by forming a layer on a substrate, in the form of a thin continuous film. This is achieved by hot dipping and occasionally by **chemical plating** and **electroplating**. Clad metals are found to be suitable for more intensive environments where denser faces are required.

There are many combinations of sheet and foil which function as adhesives at low temperatures. Such materials, plastics or metals, may be clubbed together with a third constituent. Pre-painted or pre-finished metal whose primary advantage is elimination of final finishing by the user is the best known metal-organic laminate. Several combinations of metal-plastic, vinyl-metal laminates, organic films and metals, account for upto 95% of metal-plastic laminates known. They are made by **adhesive bonding processes**.

Flake Composites

Flakes are often used in place of fibers as can be densely packed. Metal flakes that are in close contact with each other in polymer matrices can conduct electricity or heat, while mica flakes and glass can resist both. Flakes are not expensive to produce and usually cost less than fibers.

But they fall short of expectations in aspects like control of size, shape and show defects in the end product. Glass flakes tend to have notches or cracks around the edges, which weaken the final product. They are also resistant to be lined up parallel to each other in a matrix, causing uneven strength. They are usually set in matrices, or more simply, held together by a matrix with a glue-type binder. Depending on the end-use of the product, flakes are present in small quantities or occupy the whole composite.

Flakes have various advantages over fibers in structural applications. Parallel flakes filled composites provide uniform mechanical properties in the same plane as the flakes. While angle- plying is difficult in continuous fibers which need to approach isotropic properties, it is not so in flakes. Flake composites have a higher theoretical modulus of elasticity than fiber reinforced composites. They are relatively cheaper to produce and be handled in small quantities.

Particulate Reinforced Composites

Microstructures of metal and ceramics composites, which show particles of one phase strewn in the other, are known as particle reinforced composites. Square, triangular and round shapes of reinforcement are known, but the dimensions of all their sides are observed to be more or less equal. The size and volume concentration of the **dispersoid** distinguishes it from dispersion hardened materials.

The dispersed size in particulate composites is of the order of a few microns and volume concentration is greater than 28%. The difference between particulate composite and dispersion strengthened ones is, thus, oblivious. The mechanism used to strengthen each of them is also different. The dispersed in the dispersion-strengthen materials reinforces the matrix alloy by arresting motion of dislocations and needs large forces to fracture the restriction created by dispersion.

In particulate composites, the particles strengthen the system by the **hydrostatic coercion** of fillers in matrices and by their hardness relative to the matrix.

Three-dimensional reinforcement in composites offers isotropic properties, because of the three systematical **orthogonal planes**. Since it is not **homogeneous**, the material properties acquire sensitivity to the constituent properties, as well as the **interfacial properties** and geometric shapes of the array. The composite's strength usually depends on the diameter of the particles, the inter-particle spacing, and the volume fraction of the reinforcement. The matrix properties influence the behaviour of particulate composite too.

Cermets/Ceramal

The Cermet is an abbreviation for the "'ceramic" and "metal." A CerMet is a composite material composed of ceramic (Cer) and metallic (Met) materials. A Cermet is ideally designed to have the optimal properties of both a ceramic, such as high temperature resistance and hardness, and those of a metal, such as the ability to undergo plastic deformation. The metal is used as a binder for an oxide, boride, carbide, or alumina. Generally, the metallic elements used are nickel, molybdenum, and cobalt. Depending on the physical structure of the material, cermets can also be metal matrix composites, but cermets are usually less than 20% metal by volume.

It is used in the manufacture of resistors (especially potentiometers), capacitors, and other electronic components which may experience high temperatures.

Some types of cermet are also being considered for use as spacecraft shielding as they resist the high velocity impacts of micrometeoroids and orbital debris much more effectively than more traditional spacecraft materials such as aluminum and other metals.

One application of these materials is their use in vacuum tube coatings, which are key to solar hot water systems.

Cermets are also used in dentistry as a material for fillings and prostheses. Also it used in machining on cutting tools.

Cermets are one of the premier groups of particle strengthened composites and usually comprises ceramic grains of borides, carbides or oxides. The grains are dispersed in a refractory ductile metal matrix, which accounts for 20 to 85% of the total volume. The bonding between ceramic and metal constituents is the result of a small measure of mutual solutions.

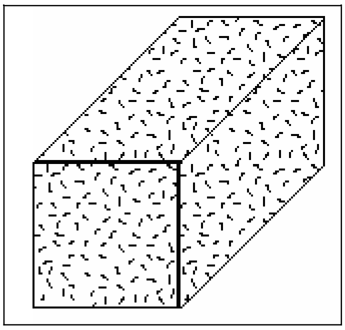
Metal oxide systems show poor bonding and require additional bonding agents. Cermet structures are usually produced using power metallurgy techniques. Their potential properties are several and varied depending on the relative volumes and compositions

and of the metal and ceramic constituents. **Impregnation** of a porous ceramic structure with a metallic matrix binder is another method used to produce cermets. Cermets may be employed as coating in a power form. The power is sprayed through a gas flame and fused to a base material. A wide variety of cermets have been produced on a small scale, but only a few have appreciable value commercially.

Common Categories of Composite Materials based on fibre length:

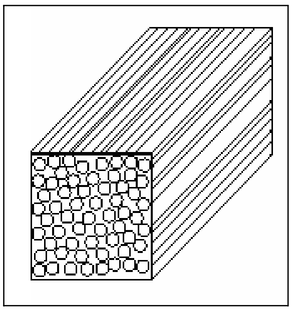
Based on the form of reinforcement, common composite materials can be classified as follows:

1. Fibers as the reinforcement (Fibrous Composites):
    a. Random fiber (short fiber) reinforced composites



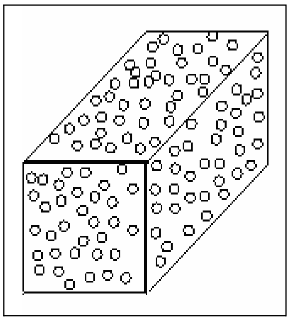
Short-fibre reinforced composites

b. Continuous fiber (long fiber) reinforced composites



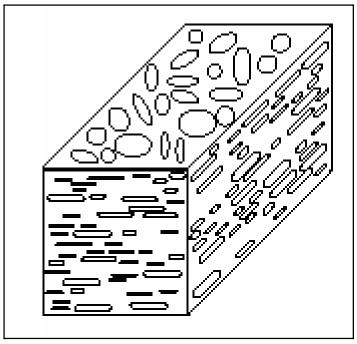
Long- fibre reinforced composites

2. Particles as the reinforcement (Particulate composites):



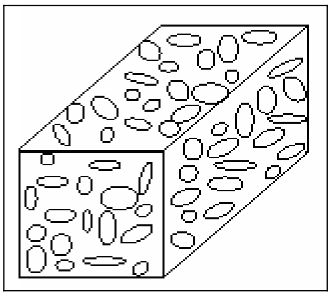
Particulate Composites

3. Flat flakes as the reinforcement (Flake composites):



Flake Composites

4. Fillers as the reinforcement (Filler composites):



Filler Composites

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Examples for composite materials:

- Fibre reinforced plastics:
    - Classified by type of fiber:
        - Wood (**cellulose fibers** in a lignin and hemicellulose matrix)
        - **Carbon-fibre reinforced plastic (CRP)**
        - **Glass-fibre reinforced plastic (GRP)** (informally, "fiberglass")
    - Classified by matrix:
        - **Thermoplastic Composites**
            - short fiber thermoplastics
            - long fiber thermoplastics or long fiber reinforced thermoplastics
            - glass mat thermoplastics
            - continuous fiber reinforced thermoplastics
        - Thermoset Composites
-
- **Reinforced carbon-carbon** (carbon fibre in a graphite matrix)

Metal matrix composites (MMCs):

  - White cast iron
  - Hardmetal (carbide in metal matrix)
  - Metal-intermetallic laminate

- **Ceramic matrix composites**:
  - Bone (hydroxyapatite reinforced with collagen fibers)
  - Cermet (ceramic and metal)
  - Concrete

- **Organic matrix/ceramic aggregate composites**
  - Asphalt concrete
  - Dental composite
  - Syntactic foam
  - Mother of Pearl
-
- **Chobham armour** (see **composite armour**)

  Engineered wood
  - Plywood
  - Oriented strand board
  - Wood plastic composite (recycled wood fiber in polyethylene matrix)
  - Pykrete (sawdust in ice matrix)

- **Plastic-impregnated or laminated paper or textiles**
  - Arborite
  - Formica (plastic)

Role and Selection of fibers

The points to be noted in selecting the reinforcements include **compatibility** with matrix material, **thermal stability**, density, melting temperature etc. The efficiency of discontinuously reinforced composites is dependent on tensile strength and density of reinforcing phases. The compatibility, density, chemical and thermal stability of the reinforcement with matrix material is important for material fabrication as well as end application. The thermal discord strain between the matrix and reinforcement is an important parameter for composites used in thermal cycling application. It is a function of difference between the **coefficients of thermal expansion** of the matrix and reinforcement. The manufacturing process selected and the reinforcement affects the crystal structure.

Also the role of the reinforcement depends upon its type in structural Composites. In particulate and whisker reinforced Composites, the matrix are the major load bearing constituent. The role of the reinforcement is to strengthen and stiffen the composite through prevention of matrix deformation by **mechanical restraint**. This restraint is generally a function of the ratio of inter- particle spacing to particle diameter. In continuous fiber reinforced Composites, the reinforcement is the principal load-bearing constituent. The metallic matrix serves to hold the reinforcing fibers together and transfer as well as distribute the load. Discontinuous fiber reinforced Composites display characteristics between those of continuous fiber and particulate reinforced composites. Typically, the addition of reinforcement increases the strength, stiffness and temperature capability while reducing the thermal expansion coefficient of the resulting MMC. When combined with a metallic matrix of higher density, the reinforcement also serves to reduce the density of the composite, thus enhancing properties such as specific strength.

Matrix Materials

Introduction

Although it is undoubtedly true that the high strength of composites is largely due to the fibre

reinforcement, the importance of matrix material cannot be underestimated as it provides support for the fibres and assists the fibres in carrying the loads. It also provides stability to the composite material. Resin matrix system acts as a binding agent in a structural component in which the fibres are embedded. When too much resin is used, the part is classified as resin rich. On the other hand if there is too little resin, the part is

called resin starved. A resin rich part is more susceptible to cracking due to lack of fibre support, whereas a resin starved part is weaker because of void areas and the fact that fibres are not held together and they are not well supported.

Matrix Selection

Thermodynamically stable dispersoids are essential for the use of metal matrix composites for high temperature applications. This can be done by using an alloy dispersoid system in which **solid state diffusivity**, **interfacial energies** and **elemental solubility** are minimized, in turn reducing coarsening and interfacial reactions. aluminium and magnesium alloys are regarded as widely used matrices due to low density and high thermal conductivity. Composites with low matrix alloying additions result in attractive combinations of ductility, toughness and strength. In discontinuous reinforced metal matrix composites minor alloying elements, used in wrought alloys as grain refiners, are not required. These additions should be avoided since coarse inter- metallic compounds get formed during consolidation, thus, reducing the tensile ductility of the composite.

Advantages and Limitations of Composites Materials

Advantages of Composites

Summary of the advantages exhibited by composite materials, which are of significant use in aerospace industry are as follows:

- High resistance to fatigue and corrosion **degradation**.

- High ‘strength or stiffness to weight’ ratio. As enumerated above, weight savings are significant ranging from 25-45% of the weight of conventional metallic designs.
- Due to greater **reliability**, there are fewer inspections and structural repairs.
- Directional **tailoring capabilities** to meet the design requirements. The fibre pattern can be laid in a manner that will tailor the structure to efficiently sustain the applied loads.
- Fibre to fibre redundant load path.
- Improved dent resistance is normally achieved. Composite panels do not sustain damage as easily as thin gage sheet metals.
- It is easier to achieve smooth **aerodynamic profiles** for drag reduction. Complex double-curvature parts with a smooth surface finish can be made in one manufacturing operation.
- Composites offer improved **torsional stiffness**. This implies high whirling speeds, reduced number of intermediate bearings and supporting structural elements. The overall part count and manufacturing & assembly costs are thus reduced.
- High resistance to impact damage.
- Thermoplastics have rapid process cycles, making them attractive for high volume commercial applications that traditionally have been the domain of sheet metals. Moreover, thermoplastics can also be reformed.
- Like metals, thermoplastics have indefinite shelf life.
- Composites are **dimensionally stable** i.e. they have low thermal conductivity and low coefficient of thermal expansion. Composite materials can be tailored to comply with a broad range of thermal expansion design requirements and

  to minimise thermal stresses.
- Manufacture and assembly are simplified because of part integration (joint/fastener reduction) thereby reducing cost.
- The improved **weatherability** of composites in a marine environment as well as their corrosion resistance and durability reduce the down time for maintenance.
- Close tolerances can be achieved without machining.
- Material is reduced because composite parts and structures are frequently built to shape rather than machined to the required configuration, as is common withmetals.
- Excellent heat sink properties of composites, especially Carbon-Carbon, combined with their lightweight have extended their use for aircraft brakes.
- Improved friction and wear properties.
- The ability to tailor the basic material properties of a Laminate has allowed new approaches to the design of **aeroelastic flight structures**.

The above advantages translate not only into airplane, but also into common implements and equipment such as a graphite racquet that has inherent damping, and causes less fatigue and pain to the user.

Limitations of Composites

Some of the associated disadvantages of advanced composites are as follows:

- High cost of raw materials and fabrication.
- Composites are more brittle than wrought metals and thus are more easily damaged.
- Transverse properties may be weak.
- Matrix is weak, therefore, low toughness.
- Reuse and disposal may be difficult.
- Difficult to attach.
- Repair introduces new problems, for the following reasons:
    - Materials require refrigerated transport and storage and have limited shelf life.
    - Hot curing is necessary in many cases requiring special tooling.
    - Hot or cold curing takes time.
    - Analysis is difficult.
    - Matrix is subject to **environmental degradation**.

However, proper design and material selection can circumvent many of the above disadvantages.

New technology has provided a variety of reinforcing fibres and matrices those can be combined to form composites having a wide range of exceptional properties. Since the advanced composites are capable of providing structural efficiency at lower weights as compared to equivalent metallic structures, they have emerged as the primary materials for future use.

In aircraft application, advanced fibre reinforced composites are now being used in many structural applications, viz. floor beams, engine cowlings, flight control surfaces, landing gear doors, wing-to-body fairings, etc., and also major load carrying structures including the vertical and horizontal stabiliser main torque boxes.

Composites are also being considered for use in improvements to civil infrastructures, viz.,

earthquake proof highway supports, power generating wind mills, long span bridges, etc.

Comparison with Metals

Requirements governing the choice of materials apply to both metals and reinforced plastics. It is, therefore, imperative to briefly compare main characteristics of the two.

- Composites offer significant weight saving over existing metals. Composites can provide structures that are 25-45% lighter than the conventional aluminium structures designed to meet the same functional requirements. This is due to the lower density of the composites.

Depending on material form, composite densities range from 1260 to 1820 kg/in^3 (0.045 to 0.065 lb/in^3) as compared to 2800 kg/in^3 (0.10 lb/in^3) for aluminium. Some applications may require thicker composite sections to meet strength/stiffness requirements, however, weight savings will still result.

- Unidirectional fibre composites have specific tensile strength (ratio of material strength to density) about 4 to 6 times greater than that of steel and aluminium.
- Unidirectional composites have specific -modulus (ratio of the material stiffness to density) about 3 to 5 times greater than that of steel and aluminium.
- **Fatigue endurance limit** of composites may approach 60% of their **ultimate tensile strength**. For steel and aluminium, this value is considerably lower.
- Fibre composites are more versatile than metals, and can be tailored to meet performance needs and complex design requirements such as **aero-elastic loading** on the wings and the vertical & the horizontal stabilisers of aircraft.
- Fibre reinforced composites can be designed with excellent structural **damping features**. As such, they are less noisy and provide lower vibration transmission than metals.
- High corrosion resistance of fibre composites contributes to reduce life- cycle cost.
- Composites offer lower manufacturing cost principally by reducing significantly the number of detailed parts and expensive technical joints required to form large metal structural components. In other words, composite parts can eliminate joints/fasteners thereby providing parts simplification and integrated design.
- Long term service experience of composite material environment and **durability behaviour** is limited in comparison with metals.

Polymers

Introduction:

Plastics belong to the family of organic materials. Organic materials are those materials are derived directly from carbon. They consist of carbon chemically combined with hydrogen, oxygen and other non-metallic substances, and their structures, in most cases, are fairly complex. The large and diverse organic group includes the natural materials: wood, coal, petroleum, natural rubber, animal fibers and food, which have biological origins. Synthesis include the large group of solvents, adhesives, synthetic fibers, rubbers, plastics, explosives, lubricants, dyes, soaps and cutting oils etc. which have no biological origins. Of them plastics and synthetic tubers termed as “Polymers”.

Polymers:

The term “polymer” is derived from the two Greek words: poly, meaning “many”, and meros meaning “parts” or “units”. Thus polymers are composed of a large number of repeating units (small molecules) called monomers. The monomers are joined together end-to-end in a polymerization reaction.

The most common polymers are those made from compounds of carbon, but polymers can also make from inorganic chemicals such as silicates and silicones. The naturally occurring polymers include: protein, cellulose, resins, starch, shellac and lignin. They are commonly found in leather, fur, wool, cotton, silk, rubber, wood and many others. There are also synthetic polymers such as polyethylene, polystyrene, nylon, Terylene, Dacron etc… termed under plastics, fibers and elastomers. Their properties are superior to those of the naturally occurring counterparts. Our concern here is therefore with synthetic polymers, also called plastics or resins.

Polymerization: The process of linking together of monometers, that is, of obtaining macromolecules is called “polymerization”. It can be achieved by one of the two processing techniques i.e., Addition Polymerization and condensation Polymerization.

Polymers can be divided into three broad divisions: plastics, fibers and elastomers. Plastic derive their name from the fact that in a certain phase of their manufacture, they are present in a plastic stage that is acquire plasticity, which makes it possible to impart any desired shape to the product. Plastics fall into a category of known chemically as high polymers.

Engineering Plastics:

The “Plastics” is a term applied to compositions consisting of a mixture of high molecular compounds and fillers, plasticizers, stains, and pigments, lubricating and other substances, some of the plastics can contain nothing but resin.

The word plastics is from the Greek word Plastikos, means which are moulded and shaped. Plastics can be easily machined, formed and joined into required shapes. Hence, plastics find place in engineering materials and domestic applications. Plastics are available in rods, sheets, films and tubes.

Types of Plastics:

Plastics are classified on the broad basis of whether heat causes them to set (thermosetting) causes them to soften and melt (thermoplastic). Plastics are classified as:

(a) Thermo setting plastics
(b) Thermoplastics

(a) **Thermosetting Plastics:** These are formed to shape with heat, with or without pressure, resulting in a product that is permanently hard. The heat first softens the material, but as additional heat or special chemicals are added, the plastic is hardened by chemical change known as “polymerization” and cannot be resoftened. Thermosetting plastics are phenol-formaldehyde. Urea formaldehyde, epoxy resins etc. Products made by thermosetting plastics are T.V cabinets, telephone receivers, camera bodies and automobile parts.

(b) **Thermoplastics:** Thermoplastics under go no chemical change in moulding. They remain soft at elevated temperatures until they are hardened by cooling. These plastics can be reused or recycled by melting and remoulding. Most commonly used thermoplastics are polystyrene, polytene, P.V.V. (polyvinyl chloride) Nylon, Teflon etc… Products made by thermoplastics are photographic films, insulating tapes, hose pipes etc…

Properties of Plastics:

Their great variety of physico chemical and mechanical properties and the ease with which they can be made into various articles have found plastics their wide application in the engineering and the other industries.

1. Their comparatively low density, substantial mechanical strength higher strength – to – weight ratio and high anti friction properties have enabled plastics to be efficiently used as substitute for metals.
2. With certain special properties, plastics can sometimes replace ferrous metals.
3. From the productions point of view, their main advantage is their relatively low melting points and their ability to flow into a mould.
4. Simple processing to obtain machine parts. Generally there is only one production operation required to convert the chemically manufactured plastic in to a finished article.
5. Good damping capacity and good surface finish of the product.
6. The high heat and electric insulation of plastics permits them to be applied in the radio and electrical engineering industries as dielectrics and as substitutes for porcelain, ebonite, shellac, mica, natural rubber etc…
7. Their good chemical stability when subjected to the action of solvents and certain oxidizing agents, water resistance, gas and steam proof properties enable plastics to be used as valuable engineering materials in the automobile and tractor, ship building and other industries.

Comparison between Thermosetting plastics and Thermoplastics:

Thermosetting plastics

1. Once hardened and set, they do not soften with the application of heat.
2. These are stronger and harder.
3. Objects made by these plastics can be used at comparatively high temperatures.
4. These are supplied in monomeric or partially polymerized form in which these are either liquids or semi solids.
5. T.V. Cabinets, Automobile parts are made by these plastics.

Thermoplastics

1. They can be repeatedly softened by heat and hardened by cooling.
2. They are comparatively softer and less strong.
3. Objects made by thermoplastics cannot be used at higher temperatures as these lend to soften under heat.
4. These are usually supplied as granular material.
5. Insulating tapes, photographic films are made by these plastics.

Advantages of Plastics:

1. Light in weight compared to metals.
2. Excellent surface finish.
3. Close dimensional tolerances.
4. Moisture and corrosion resistance.
5. Easy to shape and mould.

Disadvantages of Plastics:

1. Low strength.
2. Low heat resistance.
3. Deteriorate in sunlight.

Applications of Plastics:

Plastics find applications in manufacturing of:

1. Photo films in film industry.
2. Insulating tapes
3. Electrical parts like plugs, switches etc…
4. Radio, T.V. cabinets
5. Furniture like chairs, tubs
6. Telephone receivers
7. Camera bodies
8. Gears and Bearings
9. Toys, bottles, bucket etc…
10. Hose pipes
11. Automobile parts

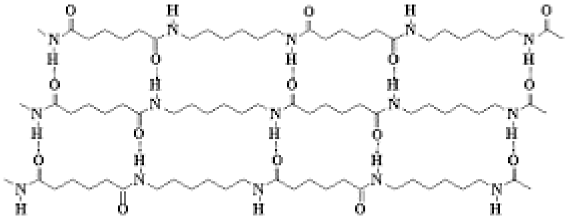
Polymers of Commercial Importance

There are various polymers of commercial importance, which are used in so many different dominions of sciences, industry and technology. Some are listed below:

Nylon

Nylon is a synthetic polymer prepared in labs and produced by industries for its commercial importance. It is commonly used in the textile and fabric industry. Nylon comes under the family of linear polyamides.

Nylon 6 and nylon 6,6 are 2 commonly used types of nylon. In fact, Nylon 6,6 (widely used as fibres) is made from adipic acid and hexamethylene diamine.They have a compact molecular structure exhibiting excellent abrasion resistance. The monomers are joined by hydrogen bonding. Nylon's characteristics which make it such a valuable material can be attributed to its strength, lustre, elasticity and resistance to damage by oil and chemicals.



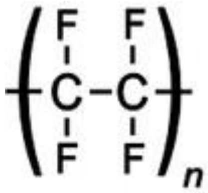
In Nylon6,6, the carbonyl oxygens and amide hydrogens can hydrogen bonded with each other. This allows the chain to line up in an orderly fashion to form fibers

Hydrogen bonding in Nylon 6,6.

Nylon Fiber: Nylon Fibre is used in clothing/apparels in shirts, underwear, raincoats lingeries etc. Industrial uses of Nylon are the production of Conveyer and seat belts, nets and ropes, parachutes and tents.

Polytetrafluoroethylene

It is commonly known as PTFE is a synthetic fluoropolymer of tetrafluoroethylene. It is of high molecular weight and made up of mainly carbon and fluorine.The best-known brand name of PTFE-based formulas is **Teflon** which is extensively used in cook-wares such as non- stick pans.



Structure of PTFE

Bakelite

Bakelite is one of the oldest polymers that was synthesized by man. It is a thermosetting polymer and has high strength and retains its shape after moulding. It is one of the first polymer/plastic created in a laboratory. The polymer is formed by condensation of formaldehyde with phenol. Its chemical formula is **$(C_6H_6O\cdot CH_2O)_n$**.

Bakelite has a high resistance to heat and chemicals and also has a low electrical conductivity due to which it is most commonly used for making electrical switches Bakelite is also used to make the handles of a variety of utensils. It is one of the most important and extensively used polymers for making components and parts of various items. Other uses of this polymer are seen in pipe stems.

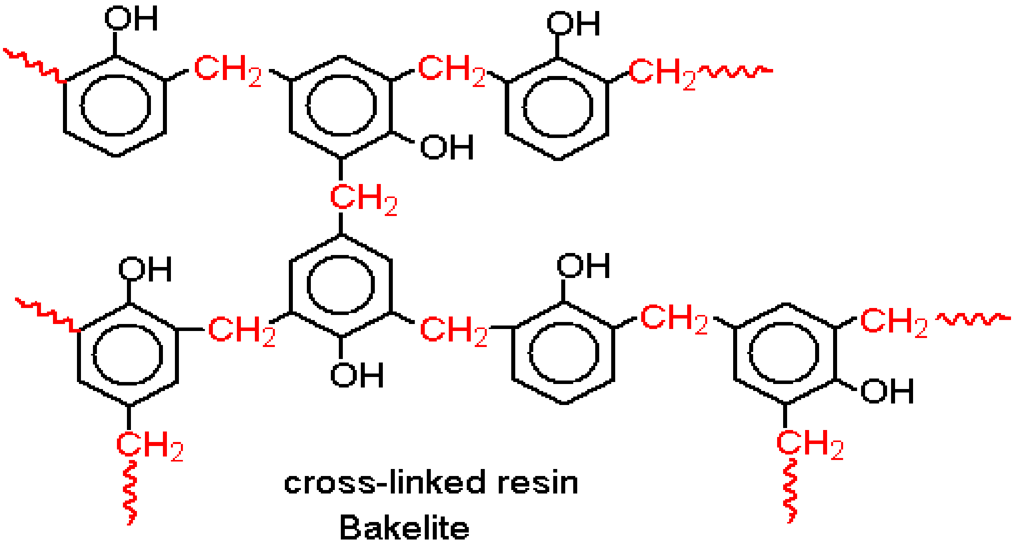


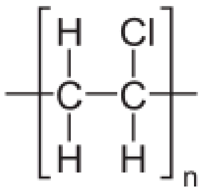
Fig no :4.11

Polyvinyl Chloride (PVC)

When talking about polymers of commercial importance we must discuss PVC. It is one of the most widely used polymers in the world. PVC is used extensively across a broad range of applications (used in building, transport, packaging, electrical etc. products), and this can be attributed to its highly versatile nature.

PVC is a highly durable and long-lasting material. It is thermoplastic in nature.It is formed after polymerization of vinyl chloride monomer. It is a very durable and long-lasting material which can be used in a variety of applications, either rigid or flexible, white black or a range of colours in between.

Some common commercial products which use the polymer PV Care window frames, drainage pipe, medical devices, cable and wire insulation. Credit cards and vinyl records are also made using PVC. Recently PVC has also found a place in the textile industry.



Structure of PVC.

Elastomers:

Elastomers (rubbers) are special polymers that are very elastic. They are lightly cross-linked and amorphous with a glass transition temperature well below room temperature. They can be envisaged as one very large molecule of macroscopic size. The intermolecular forces between the polymer chains are rather weak. The crosslinks completely suppress irreversible flow but the chains are very flexible at temperatures above the glass transition, and a small force leads to a large deformation. Thus, elastomers have a low Young's modulus and very high elongation at break when compared with other polymers. The term

elastomer is often used interchangeably with the term rubber, although the latter is preferred when referring to vulcanized rubbers.

Manufacturing elastomeric parts is achieved in one of three ways: injection molding, transfer molding, or compression molding. The choice of the molding process depends on various factors, including the shape and size of the parts, the required tolerance, as well as the quantity, type of elastomer, and raw material cost.

As with almost any material, selecting the right elastomeric product for the application requires consideration of many factors, including mechanical and physical service requirements, exposure to chemicals, operating temperature, service life, manufacturability of the parts, and raw material and manufacturing cost.

Liquid Crystal Polymers:

Liquid Crystal Polymers (LCPs) make up a family of thermoplastics which have a unique set of properties. They perform very well in harsh environments, including high heat resistance and tolerance, high electrical resistance, and high chemical resistance. Unlike other polymers such as ABS or nylon, LCPs show a high degree of anisotropy in both solid and liquid crystal phases. This means that the strength, stiffness, and thermal expansion will be greater in one direction, not the same in every direction. The three most commonly used LCPs are PET copolyester, copolyamide, and polyester-amide, however others are also possible.

LCPs have a highly crystalline molecular chain in comparison to most common polymers such as ABS and nylon. They exhibit a semi rigid, nearly linear, stacked orientation of molecules which stay highly ordered even in the liquid crystal phase as shown in Fig. 1 (a) below. This is in comparison to the molecular structure of ABS and nylon which have intertwining molecular chains, shown in Fig. 1(b). This special stacked molecular architecture of LCPs creates anisotropic tendencies which introduce many fascinating properties.

The reason for anisotropy is the primary bonds within the molecule, causing a high attractive force within the molecule itself. The molecules are bonded together by less attractive secondary bonds, making them more susceptible to separation. When a force is applied transverse to the molecular orientation the secondary bonds receive the majority of the load resulting in easier separation. Conversely, a load in the longitudinal direction more heavily loads the primary bonds of the molecules resulting in a higher difficulty of separation.

LCPs are most easily injection molded, although it is possible to use other processing techniques to accommodate the material. The melt temperature of LCPs is between 280-330ºC, and mold temperatures should be between 70-130ºC. The molecular chains in the melt are highly oriented along the direction of the resin flow. For this reason, careful attention needs to be given to the gating locations on the mold to achieve the desired resin flow, which will dictate final molecular orientation and anisotropic properties. This has a significant effect on the final part, as anisotropic dependent properties such as tensile strength, thermal expansion, and elastic modulus, can be up to three times greater in the longitudinal versus the transverse direction.

LCPs demonstrate good cycle repeatability due to their high melt flow and low thermal expansion in the direction of molecular orientation. This allows thin walled parts be easily molded without the part warping. LCPs also show a high resistance to heat, burning, weather and UV rays, and very good electrical insulation properties. LCPs are very resistant to hydrolysis, weak acids and bases, alcohols, aromates, chlorinated hydrocarbons, esters, and keytones throughout a wide range of temperatures. They also display good mechanical properties, with high strength, modulus of elasticity, and toughness. Table 1 below illustrates the difference between longitudinal and transverse thermal expansion in LCPs, and also compares it to the thermal expansion of 2 other common polymers. The coefficient of thermal expansion given in Table 1 measures the meters of expansion per degree Celsius per meter.

Conductive Polymers:

An electric current results of the orderly movement of charges in a material as a response of forces that act on them, when a voltage is applied. The positive charges flow in the direction of the electric field applied, whereas the negative charges move in the opposite direction. In the majority of materials, a current is resulted by the flux of electrons, known as electric conduction (see more at [c] of "Links" Section).

The structure of these materials has conjugated chains, that is, an alternating single and double bond between the atoms. The process of doping of conductive polymers becomes easier due to these conjugated bonds. In this process, defects and deformations in the polymeric chain are formed. An electron-deformation pair, or also an electron-phonon cloud pair, is called polarons, which is responsible by the conductivity in polymers. Bipolarons and solitons, other types of quasi-particles, also participates in the conductivity mechanism. The type of soliton, bipolaron, or polaron formed depends on the dopant used. Their meaning and the physics behind that is beyond the scope of this subject.

The charges resulted the doping process in conductive polymers is the reason of their great conductivity. The constant movement of the double bonds to stabilize the charge in the neighbor atoms causes, therefore, the movement of the charge, resulting in the conductivity. This movement of double bonds is called resonance (see more at [d] of "Links" Section) and it describes the delocalized electrons within a molecule. A delocalized electron is an electron, presented in a π bond, which is shared by three or more atoms (see more at

[e] of "Links" Section). Due to this process of the polaron formation, there is a change in the band structure of the conductive polymer. It creates the polaronic conduction bands, allowed bands in the band gap, reducing the band gap energy, making the polymer able to conduct, as shown in figure below.

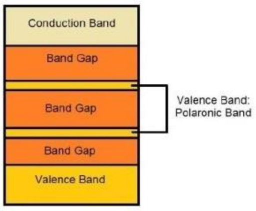


Fig no : 4.12 Band Structure of a Conductive Polymer

Since the conductivity of a conductive polymer is due to the charge formed by the dopant, as the doping level increases, more charges are formed in the polymer and, thus, results in a greater conductivity. The conductivity of a conductive polymer is also temperature dependent, because as the temperature increases the molecules becomes farther from each other. Thus, the doping effect is more effective and, consequently, the amount of charges, which is the doping level of the polymer is greater, increasing the conductivity. Moreover, as the temperature increases, the energy of an electron is related with the temperature by the Boltzmann relationship. Because of that, the greater the temperature, the greater is the energy of the electrons, and, consequently, the easier is to excite the electron to the conduction band. The best-known and most studied conductive polymers are polyacetilene, polyaniline, and polypyrrole due to their wide range of applications.

High Performance Fibers:

There is a new array of fibres which are named as High performance fibres. They are different from conventional fibre, on these are capable to satisfy special technical requirement due to their unique properties.

Some High-performance fibres, such as Kevlar, Nomex, carbon, glass etc. Have more tensile strength, resistance to heat and flame, resistance to the chemical agent than conventional fibres & materials such as steel for example Earlier body of automobile used to be made up with metal but now gain fibre composite used.

It has redeemed the weight and has improved the aerodynamical design. In sport-wear, specially textured nylon fibre is used for better strength and improved breathability to sports wears.

Similarly, Except that two area, high-performance fibres are also used in aerospace, metals, medical Industry except for good tensile property of these are high-performance fibre can be tailored in such a fashion that they can provide versatile, dyeability, adhesion, absorbance, conductivity, flame retardance and a vast range of special surface characteristics.

High performance fibres is the fibre which have their unique properties that require –

1. Exceptional strength and modulus.
2. Stiffness.
3. Heat resistance.
4. Chemical resistance.

For examples – Carbon fibre, glass fibre, aramid fibre, kevlar, nomex, PBO, chlorinated fibre like PVDV etc.

List of High Performance Fiber –

1. Glass Fiber.
2. Carbon Fiber.
3. Aramid Fiber.
4. Spandex Fibre.

Glass Fiber

Glass fiber is one of the most familiar and oldest, high-performance fibres. It has been manufactured since the 1930s. Although early versions had high-strength, they were relatively inflexible and not suitable for several textile applications.

Fig no :4.13

The basic element of glass fibers is silica, SiO_2. In its pure form, it exists as a polymer, $(SiO_2)_n$. It has no true melting point but softens up to 1200 °C.

Today's glass fibers offers much wider range of properties and can be found in many end uses

- Used in making mats.
- The fabric of thermal insulation.
- The fabric of sound insulation.
- Heat and corrosion resistance fabric.

Carbon Fiber

Carbon fiber is mostly used high performance fibres in the material world – it's one of the strongest and most lightweight materials available on the market today. It is one-third its weight and nearly 5 times stronger than steel, carbon fiber is often used in aerospace and aviation, civil engineering, military, car and automobiles and other sports applications. Carbon fiber is alternatively graphite fiber, carbon graphite, is a material consisting of fibers about 5–10 μm in diameter and composed mostly of carbon atoms. Carbon fibre variants differ in flexibility, electrical conductivity, thermal and chemical resistance. Because carbon cannot readily be shaped into fibre form, commercial carbon fibres are made by extrusion of some already made material like rayon, PAN, pitch into filaments, followed by a carbonization process to convert the filaments into carbon.

Applications of Carbon fibre

1. Used in aerospace.
2. Sports Goods.
3. Wind turbine blades.
4. Automotive.

Biomedical applications:

Multiple biological, synthetic and hybrid polymers are used for multiple medical applications. A wide range of different polymers is available, and they have further the advantage to be tunable in physical, chemical and biological properties in a wide range to match the requirements of specific applications. a brief overview about the introduction and developments of polymers in medicine in general, addressing first stable polymers, then polymers with degradability as a first biological function, followed by various other

functional and responsive polymers. It is shown up that biomedical polymers comprise not only bulk materials, but also coatings and pharmaceutical nano-carriers for drugs. There is subsequently an overview of the most frequently used polymer classes.

Biomedical applications of polymers :

a. Containers

Numerous polymer devices are not inside the body, but they are used for packaging of drugs and devices. PVC containing the phthalate plasticizer DEHP is used for many extracorporeal perfusion tubes to provide medicines, or also in blood leading tubes in extracorporeal dialysis or extracorporeal oxygenation. Also blood donations and blood products are typically stored in bags of this polymer. Due to the lipophilic nature of the plasticizer, it transfers from the polymer surface to the lipids and membranes of the red blood cells.

For platelet storage, also alternative polymers like polyolefins are used , and polyethylene and polyurethanes are used for tubings. The tubings of the peristaltic pumps are typically made of silicone.

Vascular catheters

Mechan- ical flexibility along with non-collapsing properties is required. Central venous catheters with longer persistence in the body usually have antimicrobial fitting and properties which prevent the formation and adhesion of bacterial biofilms.

Plasticized PVC was one of the first polymers used for catheters. It is mainly avoided nowadays due to the plasticizers and is used only for short-term applications as peripheral venous catheters. Thermoplastic polyurethanes are the key polymers for catheters as they do not need plasticizers

Urinary catheters and ureteral stents

The catheter & stents must have sufficient strength & sufficiently soft for the tolerance of the patient. The surface must be smooth with a low friction. Coating technologies therefore are generally applied.

Silicone is the best biocompatible material with lowest tendency for encrustation, but low mechanical stiffness and high friction make application difficult. Optimized polyurethane formulationsand PMMA/pHEMA co-polymers have been developed as polymers with improved mechanical properties than silicone. Stents are coated with glycosaminoglycanes (GAGs, heparin or pentosan polysulfate), phosphorylcholine, PVP or hydrogels for reduced bacterial coloninzation, encrustation and enhanced comfort for the patients.

Wound dressings

Wound dressings are a very wide field for polymers in temporary, mainly external contact with the body. They are also more comfortable for the patient than traditional gauze dressings. Mechanical protection and a barrier function are achieved with minimized adherence to the wound avoiding traumatization during movements or removal. The dressing has to provide permeability for oxygen and water vapor for a proper ambient of wound healing without bacterial superinfection.

A wide range of synthetic, biological and hybrid materials are applied in multiple shapes to match different types of wounds PVP or methacrylates as wound dressing are highly flexible, but usually need a mechanical support. As they do not absorb much liquid any more, they are not suitable for heavily exuding wounds, but they rehydrate dry tissue, facilitate autolytic wound debridement and also may be used for drug release.

General surgical implants

Suture materials (a stitch or row of stitches holding together the edges of a wound or surgical incision):Suture materials and staples are a domain of polymers in general surgery.

Tissue adhesives and sealants

Tissue adhesives are an alternative to sutures with lower adhesion strength than sutures, but forming an a priori tight occlusion of the wound. Adhesives find wider application in modern surgical techniques of laparoscopy and robotic surgery or for organs like liver or lung, where the puncture defects of the needle are already problematic. A technological challenge is the adhesion to the wet substrate.

Surgical meshes

Reconstructive meshes in general surgery support organs or tissue to prevent a prolapse or hernia. The main polymers for non-resorbable meshes are expanded PP, ePTFE, PET or PVDF, however, also they show significant signs of degradation at the surface and even fragmentation..

Large pores (o1 mm) generally show less inflammation and bridging scare formation than small pores do.

Orthopedic implants

Joint prostheses

In orthopedic surgery, joint prostheses most frequently have a pairing of metal. . However, inorganic pyrolytic carbon (Pyrocarbon) with graphite-like structure finds increasing attention for small joints or as interposition material because of its inertness, low friction behavior and a Young's modulus close to bone.

Osteosynthesis material

Stabilizing and load transferring applications at bone must be strong enough to withstand the forces, but they also should have elastic properties similar to the bone for a homogeneous load transfer and to prevent stress shielding of the bone, which would lead to bone resorption. bone has a Young‘s modulus of about 20 GPa. Most metals have a higher modulus, but carbon fiber reinforced polymer composites can reach such values and therefore they are applied for some load bearing applications.

Vertebral disc replacement may be necessary in the case of a disrupted or degenerative intervertebral disk.

Bone cements

Bone cements serve for anchorage of a joint prosthesis into the bone and should provide a homogeneous load transfer from the implant to the bone. PMMA is widely predominant for this application. As PMMA does not promote bone adhesion, filling with hydroxyapatite particles has been suggested. The polymerization reaction of PMMA is exothermic and the heat may cause tissue damage. Calcium phosphate cements have excellent biocompatibility, but the mechanical proper- ties do not allow application in load bearing situations; the main applications are in dentistry and cranial surgery

Vascular and cardio-vascular intervention

Vascular stents

Vascular stents in conjunction with balloon angioplasty have revolutionized angiology and cardiology as they maintain blood flow through stenotic vessels. First stents were only metal supports,

Fully degradable stents, which vanish after the blood vessel has sufficiently remodeled are mostly made of the metals magnesium and its alloys or iron . However, there are also polymer stents which can be fully degraded and metabolized.

Vascular grafts

Vascular graft materials are used as vascular prosthesis in aneurysm surgery, for bypass surgery or as hemodialysis access. ePTFE has evolved as the leading material for this application.

Polymeric heart valves

There are two main types of artificial heart valves, either mechanical tilting disk-and-ring constructs of metal or pyrolytic carbon or bioprosthetic valves made of decellularized and cross-linked porcine heart valves or bovine pericardium. The mechan- ical valves have better long-term stability than the bioprosthetic valves, but they require permanent anticoagulation of the patient. Thermoplastic polyurethanes, polycarbonate urethanes and polysiloxane-based polyurethanes provide good flexibility.

Plastic, reconstructive and cosmetic surgery

Tissue augmentation for the correction of contour deficiencies is a specific domain of plastic surgery.

A HDPE with interconnected pores (Medpor) is typically used for craniofacial contour augmentation and reconstruction of nose, orbital rim and floor and also for ear reconstruction. Also ePTFE is used as facial augmentation material.

Ophthalmology

Contact lenses

Contact lenses are the most frequently applied biomaterials on the eye. The introduction of silicon acrylates allowed the formation of rigid gas permeable contact lenses. Siloxane containing hydrogels are used for the formation of soft oxygen permeable contact lenses for up to one month permanent wear

Intraocular lenses

Intraocular lenses (IOLs) after cataract surgery are the most frequently implanted polymer devices in ophthalmology. They traditionally were made of PMMA, and this material still has outstanding biocompatibility for this application; however, due to its stiffness these lenses need large incisions for implantation, and they are less frequently used today. Alternatives are silicone, foldable hydrophobic acrylates, copolymers of acrylate and methacrylate or foldable hydro- philic acrylates.

Other polymer devices in ophthalmology

In the frame of retinal detachment treatment, the vitreous body of the eye is generally removed and needs to be substituted. Silicon oil is the most frequently used polymer for it and it is the first choice for complex retinal detachment, however, it must be removed after healing because of side effects like retina toxicity, cataract progression and glaucoma.

Dentistry

Composites

Dental polymers have high requirements concerning esthetics, toughness, and polymerization mode besides the biocompatibility. Materials must support high load and shear forces, and forces of thermal expansion and shrinkage. The filler is usually inorganic with particle size in nanometer or micrometer range. The resin usually consists of dimethacrylate or monomethacrylate monomers, and different formulations with different viscosity, curing time, improved volume shrinkage and shrinkage stress are the current developments.

Photonic Polymers:

In the last decade, photonics has emerged as a major interdisciplinary field of science and technology with a focus on the transport and manipulation of light. Rapid progress in photonics has been achieved because of continuous advances in nanotechnologies, materials science, optics, physics, and the rapid development of micro fabrication techniques. In particular, interaction of light with materials possessing a periodic modulation in their structure has led to a range of interesting and sometimes unique effects, which have shown promising applications in the production of Bragg mirrors, switches, filters, super prisms, waveguides, and optical resonators.

Polymers play an important role in the development of materials for photonics. Polymers are relatively inexpensive, can be functionalized to achieve required optical, electronic, or mechanical properties, and have demonstrated compatibility with various patterning methods. Polymers can be used as materials for photonic applications in several ways.

Polymers possessing topographic and/or compositional patterns can coherently scatter light. Finally, polymer templates are routinely used for producing photonic materials.

Polymers for Photonic Applications: The microelectronics revolution, which began with the invention of the transistor in 1948 and rapidly accelerated following the invention of the I C in 1960, has had a profound influence on modern society, particularly in the processing and transport of information.

The heart of today's telecommunications network, for example, is the highly sophisticated electronic switching machine, which offers a wide variety of service options that cannot be provided by electromechanical switches. Voice and data are switched over a network that ranges from twisted copper pairs to microwave communication towers. However, two inventions during the 1960s have begun to radically change the way i n which information is transmitted and may, in the future, lead to a totally new switching technology. Those two inventions are the laser and the optical fiber, which together have spawned the photonics revolution upon whose dawn we are now entering.

Simply speaking, photons are to photonics what electrons are to electronics. In electronic transmission, information, encoded in the form of digital or analog electronic signals, is routed along a conductor path such as a copper wire. In an optical transmission system,

UNIT-V

Liquid Crystal Polymers:

Liquid Crystal Polymer (**LCP**) - A relatively unique class of partially crystalline aromatic polyesters based on p-hydroxybenzoic acid and related monomers. Liquid crystals (LCs) are matter in a state which has properties between those of conventional liquids and those of solid crystals. For instance, a liquid crystal may flow like a liquid, but its molecules may be oriented in a crystal-like way.

Liquid crystal polymer (LCP) exhibits a highly ordered structure in both the melt and solid states. LCP can replace such materials as ceramics, metals, composites and other plastics because of its outstanding strength at extreme temperatures and resistance to virtually all chemicals, weathering, radiation and burning.

LCPs are fire resistant at high temperatures and chemically resistant in very thin walled applications. LCPs are typically used for medical applications, including trays and drug delivery systems, and in diagnostics for the automotive and telecommunication industries.

History

1890: Otto Lehmann first identified the liquid crystam phase of matter.

1968: Commercialisation gathered pace when george heilmeier developed the first liquid crystal application prototype

1970 Subsequent global research efforts led to liquid crystal applications replaceing conventional display devices.

Applications:

Coatings, Composites, Additives, Electrical motor components, Electronic applications including sockets, bobbins, switches, connectors, chip carriers and sensors.

Processes

A number of liquid crystal polymers (LCPs) were produced in the 1970s displaying order in the melt (liquid) phase analogous to that exhibited by non-polymeric liquid crystals. However, the commercial introduction of liquid crystal polymer resins did not occur until mid-1980s. This was when these polymers were first processed conventionally at fast speeds, delivering excellent replication of mold details and efficient use of regrind.

Recycling and Recovery

LCPs are recyclable and can be used for energy recovery.

High Performance Fibers

Specialty fibers are engineered for specific uses that require exceptional strength, heat resistance and/or chemical resistance. They are generally niche products, but some are produced in large quantities.

Glass is the oldest, and most familiar, performance fiber. Fibers have been manufactured from glass since the 1930s. Although early versions were strong, they were relatively inflexible and not suitable for many textile applications. Today's glass fibers offer a much wider range of properties and can be found in a wide range of end uses, such as insulation batting, fire resistant fabrics, and reinforcing materials for plastic composites. Items such as bathtub enclosures and boats, often referred to as "fiberglass" are, in reality, plastics (often crosslinked polyesters) with glass fiber reinforcement. And, of course, continuous filaments of optical quality glass have revolutionized the communications industry in recent years.

Carbon fiber may also be engineered for strength. Carbon fiber variants differ in flexibility, electrical conductivity, thermal and chemical resistance. Altering the production method allows carbon fiber to be made with the stiffness and high strength needed for reinforcement of plastic composites, or the softness and flexibility necessary for conversion into textile materials. The primary factors governing the physical properties are degree of carbonization (carbon content, usually greater than 92% by weight) and orientation of the layered carbon planes. Fibers are produced commercially with a wide range of crystalline and amorphous contents.

Because carbon cannot readily be shaped into fiber form, commercial carbon fibers are made by extrusion of some precursor material into filaments, followed by a carbonization process to convert the filaments into carbon. Different precursors and carbonization processes are used, depending on the desired product properties. Precursor fibers can be specially purified rayon (used in fabrication of the space shuttle), pitch (for reinforcement and other applications) or acrylics (for varied end uses). Since carbon fiber may be difficult to process, the precursor fiber may be converted into fabric form, which is then carbonized to produce the end product. The following materials are common precursors for carbon fiber:

Aramids are among the best known of the high-performance, synthetic, organic fibers. Closely related to the nylons, aramids are polyamides derived from aromatic acids and amines. Because of the stability of the aromatic rings and the added strength of the amide linkages, due to conjugation with the aromatic structures, aramids exhibit higher tensile strength and thermal resistance than the aliphatic polyamides (nylons). The para- aramids, based on terephthalic acid and p-phenylene diamine, or p-aminobenzoic acid, exhibit higher strength and thermal resistance than those with the linkages in meta positions on the benzene rings. The greater degree of conjugation and more linear geometry of the para linkages, combined with the greater chain orientation derived from this linearity, are primarily responsible for the increased strength. The high impact resistance of the para-aramids makes them popular for "bullet-proof" body armor. For many less demanding applications, aramids may be blended with other fibers.

PBI (polybenzimidazole) is another fiber that takes advantage of the high stability of conjugated aromatic structures to produce high thermal resistance. The ladder-like structure of the polymer further increases the thermal stability. PBI is noted for its high cost, due both to high raw material costs and a demanding manufacturing process. The high degree of conjugation in the polymer structure imparts an orange color that cannot be removed by bleaching. When converted into fabric, it yields a soft hand with good moisture regain. PBI may be blended with aramid or other fibers to reduce cost and increase fabric strength.

PBO (polyphenylenebenzobisozazole) and **PI** (polyimide) are two other high-temperature fibers based on repeating aromatic structures. Both are recent additions to the market. PBO exhibits very good tensile strength and high modulus, which are useful in reinforcing applications. Polyimide's temperature resistance and irregular cross-section make it a good candidate for hot gas filtration applications.

Sulfar (PPS, polyphenylene sulfide) exhibits moderate thermal stability but excellent chemical and fire resistance. It is used in a variety of filtration and other industrial applications.

Melamine fiber is primarily known for its inherent thermal resistance and outstanding heat blocking capability in direct flame applications. This high stability is due to the crosslinked nature of the polymer and the low thermal conductivity of melamine resin. In comparison to other performance fibers, melamine fiber offers an excellent value for products designed for direct flame contact and elevated temperature exposures. Moreover, the dielectric properties and cross section shape and distribution make it ideal for high temperature filtration applications. It is sometimes blended with aramid or other performance fibers to increase final fabric strength.

Fluoropolymer (PTFE, polytetrafluoroethylene) offers extremely high chemical resistance, coupled with good thermal stability. It also has an extremely low coefficient of friction, which can be either an advantage or disadvantage, depending on the use.

HDPE (high-density polyethylene) can be extruded using special technology to produce very high molecular orientation. The resulting fiber combines high strength, chemical resistance and good wear properties with light weight, making it highly desirable for applications ranging from cut-proof protective gear to marine ropes. Since it is lighter than water, ropes made of HDPE float. Its primary drawback is its low

Bio-Medical Applications:

Glucose sensor:

Earlier times, ultra violet radiation and immobilized probes were used for sensing purpose, but nowadays a fiber based pH meter has been developed in which the cladding material is replaced with polyaniline polymer, a polymer with broad sensitivity to pH. Since only a single broad band is to be measured, the system adapts itself to an IR laser diode system which offers a potential for miniaturization and greater portability. Brown *et al*. modified the sensor by using glucose oxidase immobilised on the polyaniline polymer surface (an enzyme which converts glucose to glucuronic add, resulting in a pH change) to predict glucose concentration.

Laminate cure analysis:

Monitoring reactions in hostile environment becomes much easy with these probes having smaller dimensions and enough durability. Fiber optic probes can be introduced into an autoclave (via the usually standard thermocouple calibration port) and thus can continuously monitor the progress of reactions (e.g. degradation) as a function of the operating conditions. Druy *et al*. utilized this approach to monitor ongoing processes in industries, notably to monitor heal rates of polymer laminates at higher temperature and pressures.

Protein analysis:

FTIR with fiber optic probe is useful for protein analysis since high quality spectra can be obtained from low concentrations of analyte in a variety of environments without any interference. Globular proteins usually exhibit regions of secondary structure including alpha helices, P-sheets, turns and non-ordered regions. Each of these conformational entities contributes to the IR spectrum in the amide I contour region. In addition to the study of protein in its dried state, FTIR coupled with fiber optic probes has been particularly useful for the study of soluble proteins, whose structures had not previously been elucidated using X-ray diffraction or NMR spectroscopy

Dosage form analysis:

Dreassi and co workers have reported the application of an optical fiber probe for quality control in the pharmaceutical industry. The system was used to quantitatively determine the content of a number of pharmaceutical solid dosage forms containing ibuprofen, and powders containing benzydamine an analogue of cetrimide. A team from Burroughs-Wellcome have taken this one step ahead and have performed identification tests on tablets through the plastic wall of the blister packaging] to distinguish between film coated and uncoated tablets and between active and placebo forms. The technique satisfied the requirements of a confirmation of identity test prior to use in a clinical trial.

Fiber optical scanning in TLC for drug identification:

Ahrens *et al*. proposed an organized toxicological analysis procedure using high-performance thin layer chromatography in combination with fibre optical scanning densitometry for recognition of drugs in biological samples. The technique allowed parallel recording of chromatograms by identifying the drugs and comparing their ultra violet spectra with the data obtained from library as a reference spectra.

Determination of DNA oligomers:

Kleinjung and group demonstrated the binding of DNA oligonucleotides to immobilized DNA targets using a fiber optic fluorescence sensor. 13 mer oligonucleotides were attached to the core of a multimode fiber and the complementary sequence was identified by using a fluorescent double stranded specific DNA ligand. The evanescent field was used to differentiate between bound and unbound species. The template DNA oligomer was immobilized either by direct coupling to the activated sensor surface or using the avidin biotin bridge to detect the single base mismatches in the target sequence.

Pesticide detection:

Rajan and group, fabricated and characterized surface plasmon resonance (SPR) based fiber-optic sensor for the detection of organophosphate pesticide. Over the silver coated core of plastic cladded silica (PCS) fiber, the acetylcholine esterase (AChE) enzyme was immobilized to prepare the probe, the detection of which is based on the principle of competitive binding of the pesticide (acting as inhibitor) for the substrate (acetyl thiocholine iodide) to the enzyme AChE. For the fixed concentration of substrate, the SPR wavelength decreases with increase in the concentration of the pesticide, this increase in pesticide amount causes an overall decrease in the sensitivity.

Effluent monitoring:

Krska *et al*. reported the environmental hazard associated with the use of chlorinated hydrocarbons by pharmaceutical manufacturers. Chlorohydrocarbons have their strongest absorption bands and therefore polycrystalline silver halide fibers are of value as light guides. For quantitative measurements, the 10 cm fiber collectors were coupled to the FTIR and samples were monitored. Further study revealed the comparative analysis of tetrachlorethylene and waste water samples showing a good concord with standard gas chromatographic techniques.

Other applications:

Fiber optic probe is not only used for the determination of water by near infrared reflectance spectroscopy[40] but also for determination of penicillamine in pharmaceuticals and human plasma by capillary electrophoresis with in column fiber optics light emitting diode induced fluorescence detection. Fiber lasers are also used for the military applications, biological and biomedical applications and highly sensitive airborne trace gas detection.

Applications that are made possible by the use of filtered fiber optic Raman probes include such things as measuring high levels of organic solvent contaminants in soils and aquifers, chemical process monitoring of petrochemicals and distillation products, monitoring polymer cure reactions in situ and many others.

In spectroscopy, in order to analyse the composition of substance that cannot be placed into the spectrometer itself can be measured by optical bundles by transmitting the light from a spectrometer to a substance. A spectrometer analyzes substances by bouncing light off of and through them. By using fibers, a spectrometer can be used to study objects that are too large to fit inside, or gases, or reactions which occur in pressure vessels.

QUESTION BANK

UNIT-I

1 **a** Define grain and grain boundary? Discuss the effect of grain boundaries on the properties of metal/alloys?

b What is ASTM grain size number? Calculate the number of grains per square millimeter when number of equivalent grains observed at 200x was 62.

c Explain different methods for grain size measurements

2 **a** What is the importance of grain size in steel? How do you determine grain size of the given steel?

b Explain why grains are stronger than grain boundaries at high temperature and grain boundaries are stronger than grain at room temperatures?

3 Explain the characteristic features of the following with examples

a) Metallic bond b) Ionic bond c) Covalent bond

4 What is the effect of heating rate and cooling rate steel on grain growth and properties of steel (consider heating to Austenite zone and cooling from the same zone)?

5 **a** Explain electron cloud. What is role of electron cloud in metallic bond?

b Describe the binding of atoms in metals**.**

6 **a** Write a short note on

a) Metallic bonding

b) Space lattice and unit cell

c) Coordination number and atomic packing factor

d) Crystal structure

7 **a** What are the two kinds of solid materials? Glass is not considering as true solid. Why?

b How is metallic bond similar to both ionic and covalent bond?

c Ionic solids are bad conductors of electricity but an aqueous or fused solution of them conducts electricity. Why?

UNIT-II

1 **a** Explain the governing rules for the formation of substitutional solid solutions.

b Differentiate between intermetallic compounds and intermediate alloy phases.

2 **a** What is the necessity of alloying?

b What is solid solution? Explain about different types of solid solutions with neat sketch

3 **a** Write short notes n the following

a) Intermediate alloy phases?

b) Intermediate compounds?

c) Electron compounds

4 **a** State and explain Hume Rothery rules for the formation of solid solutions.

b What is diferenence between random ordered solid solutions? What is the role of energy of like bonds and unlike bonds in them?

5 **a** An alloy is more useful than a pure metal, discuss?

b What is a master alloy? What are its chief characteristics?

c How are alloys actually made in industry

6 **a** What are intermediate phases? Discuss the various types of intermediate phases.

b List the different experimental methods for construction of a phase diagram and Explain any one of them.

7 **a** What are the invariant reactions in iron- iron carbide equilibrium diagram? Explain them.

b Define, a phase, a component and degree of freedom, invariant reaction

8 **a** What is the role of size factor effect in changing the nature of equilibrium diagram

b What is meant by miscibility gap**?**

9 **a** Differentiate between equilibrium diagram and phase diagram?

b Discuss various methods used for drawing phase diagrams.

10 **a** Draw Cu – Ni phase diagram. Label all points, lines and areas. Explain the cooling behavior of 60 Ni -40 Cu alloy from liquid state to room temperature

b Differentiate between congruent melting compound and interstitial solid solution

11 Write short on the following with neat sketches

a) Eutectoid reaction b) eutectic reaction

12 Draw Fe- C phase diagram and label all the phases. Describe the phase changes during solidification of Fe-0.45% C alloy**.**

UNIT-III

1 **a** What are tool steels? Classify them, and mention their applications

b Discuss the properties and applications of

i) Hadfield Manganese steels ii) White cast iron

2 **a** State and describe various factors effecting the properties of cast iron

b S.G Iron is stronger and tougher than gray iron with same matrix

c N i- hard has high wear resistance.

3 Distinguish between

a) Describe how does the strength of the cast iron vary with the matrix?

b) Describe how does the ductility vary with the shape of the graphite in cast iron?

c) White cast iron and grey cast iron.

4 **a** Explain the malleabilizing treatment given to white cast iron? Sketch the typical microstructure of malleable cast iron. Label the phases in it.

b Write short notes on tool and die steels?

5 Explain the following

a) Hadfield’s manganese steel b) Tool steels c) Grey cast iron

6 **a** Classify steels? Explain the properties of plain carbon steels?

b Write short notes on cast irons?

7 Compare and contrast

a) Age hardening and Tempering. b) Lower bainite and Tempered marten site.

(Tempered at 100^0 C)

8 **a** Define hardening? What are its objectives?

b Steel is made hard by quenching list, at least, three requirements that must be met to justify this statement

9 **a** Explain the mechanism of heat removal during quenching

b Explain the importance of austenitizing temperature and homogeneity Of austenite?

c Explain two different methods of obtaining a spheroid zed cementite structure

10 **a** Explain the important characteristics of the martensite?

b Differentiate between full annealing and process annealing

c Define critical cooling rate. What factors influence the critical cooling rate? Explain?

11 **a** What is the purpose of adding lead to Brass?

b What is the most important property of copper?

c What type of alloys are included under the classification bronzes?

12 **a** What are the characteristics of titanium that makes it attractive for certain engineering applications?

b Which elements are used to alloy with titanium.

c Why are some of the titanium alloys heat – treatable?

13 **a** Discuss the effect on corrosion resistance of copper when increasing the following addition of i) Zinc ii) Tin iii) Nickel

b Why is muntz metal heat treatable? Describe a typical heat treatment and the resulting microstructure.

c What is dezincification? How it is minimized?

14 **a** Differentiate between the terms brass and bronze.

b Why most of the copper-zinc alloys are not age-hard enable?

c What is dezincification? How it is minimized?

15 **a** Explain the outstanding properties of aluminum.

b What is meant by anodizing?

Explain the heat treatment of Al-Cu alloys

16 **a** Explain briefly `AAA' classification of wrought aluminum alloys

b Discuss any two important aluminum alloys, giving its composition, heat Treatment, structure and properties.

UNIT-IV

1 **a** What are ceramic materials? Why are they so important?

b Discuss the mechanical behaviour of ceramic materials

c Discuss briefly classification of ceramic materials

2 **a** What are the attractive package of properties of ceramic materials? Indicate advantages, disadvantages of ceramic matrix composites.

b Discuss any one important ceramic matrix composite.

3 **a** Write explanatory notes on the following:

(a) Piezoelectric *ceramics* and

(b) Ferroelectric ceramics.

b Laminates (Laminated Composite Materials)

4 **a** Discuss in detail about the Micro electromechanical systems (MEMS).

b Write short notes on a) Crystalline Ceramics b) Abrasive Materials c) Nano Materials.

5 **a** What is a cermet? Give the structure, properties and applications of any one cermet.

b Zirconia is one of the most important oxide ceramic. Why?

c Describe briey classes of magnetic ceramics.

6 **a** What is the purpose of reinforcements? Describe different types of reinforcements in composites.

b What are carbon-carbon composites? What are their properties and applications?

7 Suggest an appropriate matrix to be used for the following fiber types with proper justification:

i. SiC, ii. Polyethylene iii. E-glass.

8 **a** What is a nano-composite? Indicate the dificulties of nano-composites

b Write short notes on a) C – C composites b) Nano materials & its Applications

9 Distinguish the three different types of fiber reinforced composites on the basis of fiber length and orientation: comment on the distinctive mechanical characteristics of each type.

UNIT-V

1 Enumerate the characteristics, properties and applications of Polymers.

2 **a** Explain the differences between crystallization of polymers and other solids

b What factors affect the crystallization of polymers?

3 Differentiate between thermoplastic polymers and thermosetting polymers. Give minimum two examples of each type.

4 What is vulcanization of rubber? Why it is done?

5 **a** Explain the differences between crystallization of polymers and other solids

b What factors affect the crystallization of polymers?

Students Projects for Materials Engineering

1. Extraction of activated carbon from used tea and coffee dust.
2. Development of fiber/rubber composites with improved mechanical properties.
3. Non destructive evaluation of quality of adhesive bonds.
4. Effect of carbon and manganese ratio on formability of plain carbon steel.
5. Design and fabrication of rubber based strain sensor for vehicle Tyre.
6. Design and development of cement - fiber (Asbestos free) corrugated sheets for roofing applications
7. Development of a thermal insulator based on phase change materials
8. Identification of the potential of local rice straw as a source of nano cellulose

information is transmitted in digital format as pulses of light along glass fibers specifically designed to confine the light to the interior of the fiber. Lasers and light-emitting diodes are ideal light sources for optical transmission. These solid-state devices can be turned on and off billions of times per second, providing an ideal mechanism for conveying digital information where the presence of light corresponds to a "1 " and its absence signifies a "0".

The driving force behind optical transmission is the enormous capacity, or bandwidth, available. A laser pulsed at 540 megabits per second is equivalent to 24,000 telephone conversations that can be transmitted simultaneously over a single hair-thin optical fiber. Not only does optical transmission offer the potential of essentially unlimited bandwidth, but it is also free from interference effects that plague electronic transmission and offers enormous cost savings in space and materials. As will be shown in the following discussion, polymers play an enormously important role in this rapidly expanding technology.