AEROSPACE COMPOSITES AND MATERIALS (R15A2104)

COURSE FILE

III B. Tech I Semester

(2018-2019)

Prepared By

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Department of Aeronautical Engineering

MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

(Autonomous Institution – UGC, Govt. of India)

Affiliated to JNTU, Hyderabad, Approved by AICTE - Accredited by NBA & NAAC – ‘A’ Grade - ISO 9001:2015 Certified)
Maisammaguda, Dhulapally (Post Via. Kompally), Secunderabad – 500100, Telangana State, India.

MRCET VISION

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

MRCET MISSION

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

MRCET QUALITY POLICY.

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

PROGRAM OUTCOMES
(PO’s)

Engineering Graduates will be able to:

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

DEPARTMENT OF AERONAUTICAL ENGINEERING

VISION

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

MISSION

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

QUALITY POLICY STATEMENT

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

PROGRAM EDUCATIONAL OBJECTIVES – Aeronautical Engineering

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

PROGRAM SPECIFIC OUTCOMES – Aeronautical Engineering

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

MALLA REDDY COLLEGE OF ENGINEERING & TECHNOLOGY

III Year B. Tech, ANE-I Sem

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(R15A2111) AEROSPACE MATERIALS AND COMPOSITES (CORE ELECTIVE – I)

Objectives:

- To study the types of mechanical behavior of materials for aircraft applications.
- To make the student understand the analysis of composite laminates under different loading Conditions and different environmental conditions.
- To impart the knowledge in usage of composite materials in aircraft component design..

UNIT - I

Mechanical behavior of materials Mechanical behavior of engineering materials,
linear and non-linear elastic properties, yielding, strain hardening, fracture Barochinger's effect, notch effect, testing and flow detection of materials including super alloys and P-H. steels. Thermo-Structural behavior of materials for application at elevated temperatures. wrought, cast and forged aluminum alloys, production of semi-fabricated forms for aerospace application

UNIT - II

Introduction to composites and Characterization: Classification characterization, advantages and applications of composite materials – Reinforcements and matrices, composite structures. Single layer symmetric, Anti-symmetric and unsymmetric lay up configurations with cross – ply and angle – ply lay – ups. Introduction to 3D composites, filament wound and Woven composites. Stress strain relations of composites, Otrhotropic behavior of composites, Mechanics of Materials approach to determine Young's modulus, Shear modulus and Poisson's ratio, Stress strain relations in material coordinates, strength concepts, Biaxial strength theories, maximum stress, maximum strain, fracture toughness of composites

UNIT - III

Lamination of CCA models and introduction to micro mechanics. Elasticity based micro-mechanical models, introduction to FEM in composites characterization. Open and closed mould process, filament winding, pull-trusion and online production methods of manufacture of fibers and composites. Manufacture of high performance composite materials applicable in elevated temperature field..

UNIT - IV

Introduction to impact damage of composite life production and damage tolerance studies, fracture toughness of composites. NDT techniques for quality assurance.

UNIT - V

Environmental and Manufacturing considerations in selection of materials for Aircrafts, Rockets. Materials used for Aircraft applications – application of composite materials, super alloys for supersonic vehicles.

Text books:

1. “Analysis and performance of fibre composites “, Agarwal B. D., Broutman. L. J., John Wiley and sons – New york, 1980.
2. Hand Book on “Advanced Plastics and fibre glass “ , Lubin. G, Von. Nostrand, Reinhold Co. New york, 1989.
3. “Advanced Composite Materials” Lalith Gupta, Himalayan book, New Delhi, 1998.
4. “ Mechanics of Composite Materials” Jones R.M. McGrawHill Kogakusha, ltd. Tokyo.

Outcomes:

- Exposure to high temperature materials for space applications
- Understanding the mechanics of composite materials
- Knowledge gained in manufacture of composites

UNIT - I

Mechanical behavior of materials Mechanical behavior of engineering materials

INTRODUCTION

Materials are very important in development of human civilization at various ages. Engineering materials play an important role in the construction and manufacturing of equipment and tools. The knowledge of properties, uses, availability and cost of the material used for the fabrication of an equipment/tool is very important for a design engineer.

Engineering materials subject deals with the manufacturing, properties and uses of materials in applied engineering. The range of engineering materials varies from light weight to heavy materials eg. Alloys and composites for aircrafts, Semi – conductor chips for pc, Energy storage in photo voltaic cells, Semi conductor scanner, etc.,

The major domain of material science is the combination of physics, chemistry, and focus on the relation between the properties of a material and its micro or atomic structure. **Properties** are the way the material responds to the environment. Processing of the materials is the application of heat, mechanical forces etc., to affect their microstructure and thereby its properties.

Classification of Materials

Materials are classified in groups based on their structure, properties, use etc., The atomic structure of the material plays an important role in its application.

In general the materials can be classified as follows:

Metals

Metals account for two thirds of all materials. They have useful properties like strength, ductility, high melting points, thermal and electrical conductivity and toughness. A few of the common metals are as below:

- **Iron/Steel** - Steel alloys are used for strength critical applications
- **Aluminum** - Aluminum and its alloys are used because they are easy to form, readily available, inexpensive, and recyclable.
- **Copper** - Copper and copper alloys have a number of properties that make them useful, including high electrical and thermal conductivity, high ductility, and good corrosion resistance.
- **Titanium** - Titanium alloys are used for strength in higher temperature (~1000° F) application, when component weight is a concern, or when good corrosion resistance is required
- **Nickel** - Nickel alloys are used for still higher temperatures (~1500-2000° F) applications or when good corrosion resistance is required.
- **Refractory materials** are used for the highest temperature (> 2000° F) applications.

The key feature that distinguishes metals from non-metals is their **bonding**. Metallic materials have free electrons that are free to move easily from one atom to the next. The existence of these free electrons has a number of profound consequences for the properties of metallic materials.

For example, metallic materials tend to be good electrical conductors because the free electrons can move around within the metal so freely.

Alloy

An alloy is a mixture of metals. It is obtained by melting two or more elements together, one of them being a metal. An alloy crystallizes into a solid solution, mixture or intermetallic compound. The components of an alloy cannot be separated using physical means. An alloy is homogenous material which retains the property of a metal, even if it includes metalloids or non metals in its composition.

90% of the metals in engineering are used in alloy form. Alloys are mainly used in manufacturing because their physical properties are superior for an application than that of the pure element components. Typical improvements include corrosion resistance, improved wear, special electrical or magnetic properties and heat resistance. They are less expensive when compared to the pure forms.

Ceramics

A ceramic material is an inorganic, non-metallic, often crystalline oxide, nitride or carbide material. Some elements, such as carbon or silicon, may be considered ceramics. Ceramic materials are brittle, hard, and strong in compression, weak in shearing and tension. Si based ceramics are widely used in aero applications due to heat resistance.

They are typically crystalline in nature and are compounds formed between metallic and nonmetallic elements such as aluminum and oxygen (alumina-Al_2O_3), calcium and oxygen (calcia - CaO), and silicon and nitrogen (silicon nitride-Si_3N_4).

USES:

- Ceramics are used in commercial and military aircraft and space shuttles. The low mass of ceramics is highly advantageous for use in aerospace industry.
- Ceramics are used in Structural applications (crystalline inorganic non-metals) as Thermal barrier coatings (TBC's) in the hot part of the engine.
- They are used in composites as a reinforcement or as a ceramic matrix composites (CMC)
- Thermal protection systems in rocket exhaust cones
- Insulating tiles for space shuttle
- Missile nose cones
- SiC ceramics are used in turbine blades

Ceramics have excellent strength and hardness properties and are brittle in nature. Ceramics can also be formed to serve as electrically conductive materials or insulators. Some ceramics, like superconductors, also display magnetic properties. They are also more resistant to high temperatures and harsh environments than metals and polymers. Due to ceramic materials wide range of properties, they are used for a multitude of applications.

The broad categories or segments that make up the ceramic industry can be classified as:

- Structural clay products (brick, sewer pipe, roofing and wall tile, flue linings, etc.)
- White wares (dinnerware, floor and wall tile, electrical porcelain, etc.)
- Refractories (brick and monolithic products used in metal, glass, cements, ceramics, energy conversion, petroleum, and chemicals industries)
- Glasses (flat glass (windows), container glass (bottles), pressed and blown glass (dinnerware), glass fibers (home insulation), and advanced/specialty glass (optical fibers))
- Abrasives (natural (garnet, diamond, etc.) and synthetic (silicon carbide, diamond, fused alumina, etc.) abrasives are used for grinding, cutting, polishing, lapping, or pressure blasting of materials)
- Cements (for roads, bridges, buildings, dams, and etc.)
- Advanced ceramics
  - Structural (wear parts, bioceramics, cutting tools, and engine components)
  - Electrical (capacitors, insulators, substrates, integrated circuit packages, piezoelectrics, magnets and superconductors)
  - Coatings (engine components, cutting tools, and industrial wear parts)
  - Chemical and environmental (filters, membranes, catalysts, and catalyst supports)

The atoms in ceramic materials are held together by a chemical bond which will be discussed a bit later. Briefly though, the two most common chemical bonds for ceramic materials are covalent and ionic. Covalent and ionic bonds are much stronger than in metallic bonds and, generally speaking, this is why ceramics are brittle and metals are ductile.

Polymer

A polymeric solid can be thought of as a material that contains many chemically bonded parts or units which themselves are bonded together to form a solid. The word polymer literally means "many parts." Two industrially important polymeric materials are plastics and elastomers.

Plastics are a large and varied group of synthetic materials which are processed by forming or molding into shape. Just as there are many types of metals such as aluminum and copper, there are many types of plastics, such as polyethylene and nylon.

Elastomers or rubbers can be elastically deformed a large amount when a force is applied to them and can return to their original shape (or almost) when the force is released.

Polymers have many properties that make them attractive to use in certain conditions. Many polymers:

- are less dense than metals or ceramics,
- resist atmospheric and other forms of corrosion,
- offer good compatibility with human tissue, or
- Exhibit excellent resistance to the conduction of electrical current.

The polymer plastics can be divided into two classes, **thermoplastics and thermosetting plastics**, depending on how they are structurally and chemically bonded.

Thermoplastic polymers comprise the four most important commodity materials – polyethylene, polypropylene, polystyrene and polyvinyl chloride.

There are also a number of specialized engineering polymers. The term ‘thermoplastic’ indicates that these materials melt on heating and may be processed by a variety of molding and extrusion techniques.

Thermosetting polymers cannot be melted or re-melted. Thermosetting polymers include alkyds, amino and phenolic resins, epoxies, polyurethanes, and unsaturated polyesters.

Rubber is a natural occurring polymer. However, most polymers are created by engineering the combination of hydrogen and carbon atoms and the arrangement of the chains they form.

The polymer molecule is a long chain of covalent-bonded atoms and secondary bonds then hold groups of polymer chains together to form the polymeric material. Polymers are primarily produced from petroleum or natural gas raw products but the use of organic substances is growing. The super-material known as Kevlar is a man-made polymer. Kevlar is used in bullet-proof vests, strong/lightweight frames, and underwater cables that are 20 times stronger than steel.

Composite Materials

A composite is commonly defined as a combination of two or more distinct materials, each of which retains its own distinctive properties, to create a new material with properties that cannot be achieved by any of the components acting alone. Using this definition, it can be determined that a wide range of engineering materials fall into this category. For example, concrete is a composite because it is a mixture of Portland cement and aggregate. Fiberglass sheet is a composite since it is made of glass fibers imbedded in a polymer.

Composite materials are said to have two phases. The reinforcing phase is the fibers, sheets, or particles that are embedded in the matrix phase. The reinforcing material and the matrix material can be metal, ceramic, or polymer. Typically, reinforcing materials are strong with low densities while the matrix is usually a ductile, or tough, material.

Some of the common classifications of composites are:

- Reinforced plastics
- Metal-matrix composites
- Ceramic-matrix composites
- Sandwich structures
- Concrete

Composite materials can take many forms but they can be separated into three categories based on the strengthening mechanism. These categories are dispersion strengthened, particle reinforced and fiber reinforced. Dispersion strengthened composites have a fine distribution of secondary particles in the matrix of the material. These particles impede the mechanisms that allow a material to deform. (These mechanisms include dislocation movement and slip, which will be discussed later). Many metal-matrix composites would fall into the dispersion strengthened composite category. Particle reinforced composites have a large volume fraction of particle dispersed in the matrix and the load is shared by the particles and the matrix. Most commercial ceramics and many filled polymers are particle-reinforced composites. In fiber-reinforced composites, the fiber is the primary load-bearing component. Fiberglass and carbon fiber composites are examples of fiber-reinforced composites.

If the composite is designed and fabricated correctly, it combines the strength of the reinforcement with the toughness of the matrix to achieve a combination of desirable properties not available in any single conventional material. Some composites also offer the advantage of being tailorable so that properties, such as strength and stiffness, can easily be changed by changing amount or orientation of the reinforcement material. The downside is that such composites are often more expensive than conventional materials.

Advanced Materials

Materials used in "High-Tec" applications, usually designed for maximum performance, and normally expensive. Examples are titanium alloys for supersonic airplanes, magnetic alloys for computer disks, special ceramics for the heat shield of the space shuttle, etc.

Modern Material's Needs

An aircraft must be constructed of materials that are both light and strong.

- 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.

1. LINEAR AND NONLINEAR ELASTIC PROPERTIES OF MATERIALS

1.1 Mechanical Properties of materials

Density: Density is weight of a unit volume of material. It is very important property in estimating the weight of the member and decide which material to be used in the construction of the aircraft.

Hardness: It is the property of resisting penetration or permanent distortion. Hardness can be increased by hammering, rolling or working on it. The hardness of alloys and metals, hardness can be increased by a heat treatment. **Annealing** is a process of heat treatment which softens materials. *Eg: Diamond*

Brittleness: It is a property of resisting a change in relative position of molecules, or tendency to fracture without change of shape. Hard material is more brittle than soft material. Brittle materials fail due to the shock loads applied when used in aircraft. *Eg: glass, ceramics etc.,*

Malleability: The property of the material which allows them to be bent or permanently distorted without rupture. This property permits the manufacture of sheets, bar stocks, forgings and fabrication by bending or hammering. It is opposite to brittleness.

Ductility: It is the property of metals which allows them to be drawn out without breaking. This property is very important in manufacture of wire and tubing by drawing. Ductile material is preferred because of its ease of forming and its resistance to failure under shock loads. In aircraft construction a material is usually referred to as soft or hard or else ductile or brittle. *Eg:copper*

Elasticity: It is the property of returning to original shape when the force causing the change is removed. The structural design of aircraft is based on this property. The point beyond which the material cannot be loaded is called elastic limit of the material. The members are designed such that the maximum applied loads to which it is subjected to will never exceed elastic limit.

Fusibility: Fusibility is the property of being liquefied by heat. Metals are fused in welding.

Conductivity: It is the property of transmitting heat or electricity. During welding, the amount of heat to be used to design a jig depends on the conductivity of the material. In aircraft materials, electrical conductivity is very important in connection with the bonding of atoms to eliminate radio interference.

Contraction and Expansion: They are caused by cooling and heating of metals. These properties effect the design of welding jigs, castings, and tolerances necessary for hot rolled material.

Stiffness: Resistance to undergoing (elastic) deformation in response to the application of a force, the property of being inflexible and hard to distort. A stiff material has a strong supporting structure and does not deform much when a stress is applied. The stiffness of a material is represented by the ratio between stress and strain (called ''Young's modulus of elasticity,'' ''elastic modulus,'' or ''modulus of elasticity''). Stiff materials, by definition, have a high modulus of elasticity (i.e., a considerable stress is need for a minor deformation)

Compliance (Flexibility): Reciprocal of stiffness, representing the tolerance of a material to undergo elastic deformation, the property of being flexible and easy to distort. Compliant (flexible) materials, by definition, have a low elastic modulus, and only minor stress is required for a considerable strain. Highly compliant materials are easily stretched or distended.

Resilience/Proof Resilience: Resilience is the ability of a material to absorb energy when it is deformed elastically, and release that energy upon unloading. Proof resilience is defined as the maximum energy that can be absorbed up to the elastic limit, without creating a permanent distortion.

1.2 Mechanical Terms

Loading: The application of force on an object is called loading. The performance of a material depends on the loading conditions. There are five fundamental loading conditions viz., tension, compression, shear, torsion and bending.

Tension: Either pulled apart or elongated
Compression: Reverse of tensile loading, involves pressing
Shear: applying load parallel to the plane which causes one side of the plane to slide on the other side of the plane.
Torsion: Causes twisting in the material.
Bending: Applying load in a manner that causes the material to curve.

Stress: Stress is the load acting on the certain cross-section material. Internal stresses are the loads present in a material that has been strained by cold working. Stress is a vector quantity. The stress distribution may or may not be uniform, depending on the nature of the loading condition.

Units: N/m^2

Strain: Strain is the response of the system to an applied stress. Engineering strain is defined as the amount of deformation in the direction of the applied force divided by the initial length of the material.

True Stress and True Strain: These measures account for changes in cross-sectional area by using the *instantaneous* values for the area. The engineering stress-strain curve does not give a true indication of the deformation characteristics of a metal because it is based entirely on the original dimensions of the specimen, and these dimensions change continuously during the testing used to generate the data.

Engineering stress and strain data is commonly used because it is easier to generate the data and the tensile properties are adequate for engineering calculations. When considering the stress-strain curves in the next section, however, it should be understood that metals and other materials continues to strain-harden until they fracture and the stress required to produce further deformation also increase.

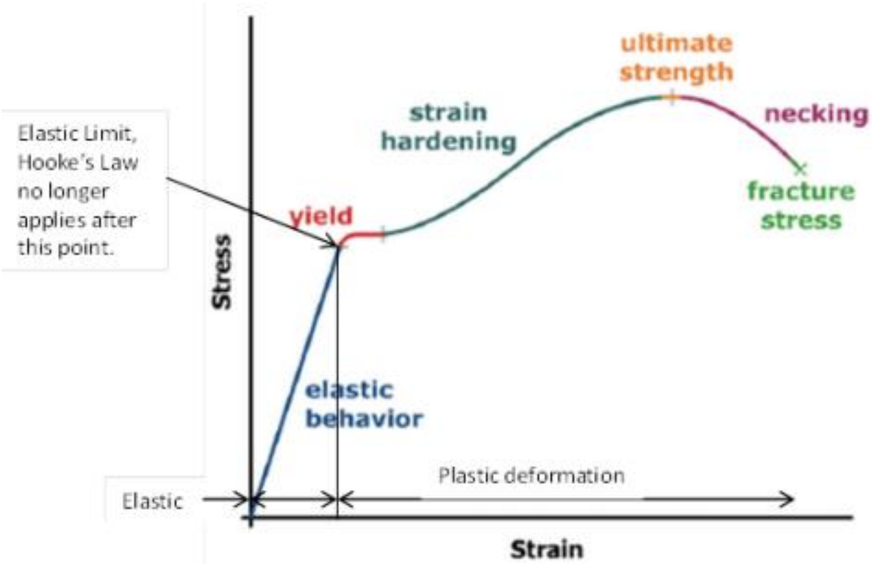
Stress Concentration: When an axial load is applied to a piece of material with a uniform cross-section, the norm al stress will be uniformly distributed over the cross-section. However, if a hole is drilled in the material, the stress distribution will no longer be uniform. Since the material that has been removed from the hole is no longer available to carry any load, the load must be redistributed over the remaining material. It is not redistributed evenly over the entire remaining cross-sectional area but instead will be **redistributed in an uneven pattern** that is **highest at the edges of the hole**. This phenomenon is known as stress concentration.

Poisson's ratio: It is the ratio of transverse contraction strain to longitudinal extension strain in the direction of stretching force. Tensile deformation is considered positive and compressive deformation is considered negative. The definition of Poisson's ratio contains a minus sign so that normal materials have a positive ratio. Poisson's ratio, also called Poisson ratio or the Poisson coefficient, or coefficient de Poisson, is usually represented as a lower case *Greek nu,*

Tensile strength: or Ultimate tensile strength (UTS) is the maximum tensile load per square inch which a material can withstand. It is evaluated by dividing the maximum load obtained in a tensile test by the original cross – sectional area of the test specimen.

Elastic Limit: The elastic limit is the greatest load per square meter of original cross – sectional area which a material can withstand without permanent deformation remaining upon complete release of the load. The aim of aircraft design is to keep the stress on the members under this limit.

Hooke's Law: Within the elastic limit of a material, the stress and strain are directly related.



Proportional Limit: The proportional limit is the load per square meter beyond which the increase in stress is no more proportional to the strain. The elastic limit and proportional limit are nearly equivalent and the later is usually accepted in place of the elastic limit in test work.

Modulus of elasticity: The ratio of stress to strain within elastic limit of the material.

Proof Stress: The proof stress is the load per unit area a material can withstand without resulting in permanent elongation of more than 0.0001 m per m of gage length after complete reease of stress.

Yield Strength: It is the load per square meter at which the material exhibits a specified limiting permanent set or a specified elongation under load.

Yield point: The point is the load per square meter at which there occurs a marked increase in deformation without an increase in load.

Yielding: The component continues to elongate without increase in load at a particular load set.

Necking: The component tends to get fracture point beyond elastic limit.

Fracture: When a material separates into two or more pieces under the action of stress, it is called fracture. When a load is applied on the material beyond its ultimate tensile strength a displacement discontinuity occurs in the surfaces of the solid which causes fracture. The displacement perpendicular to the surface of displacement, then it is called **Tensile crack**, and if it is parallel to the surface of displacement, it is called **shear crack**. **Fracture strength** or **breaking strength** is the stress where the specimen fails or fractures.

2. Stress – Strain Behavior

The relation between stress-strain represented graphically for a particular material is called Stress-strain curve. The curve varies for different materials and different tensile tests conducted on the material give different results depending upon the temperature of the specimen and the speed of loading. The details of the response are important to engineers who must select materials for their structures and machines that behave predictably under expected stresses.

Eg : The stress – strain behavior of ductile and brittle materials vary as explained under

Ductile materials, which includes structural steel and many alloys of other metals, are characterized by their ability to yield at normal temperatures.

Fig: A stress–strain curve typical of structural steel is as shown in fig.

1. Ultimate strength
2. Yield strength (yield point)
3. Rupture
4. Strain hardening region
5. Necking region

A: Apparent stress (F/A_0)
B: Actual stress (F/A)

Brittle materials, which includes cast iron, glass, and stone, are characterized by the fact that rupture occurs without any noticeable prior change in the rate of elongation.

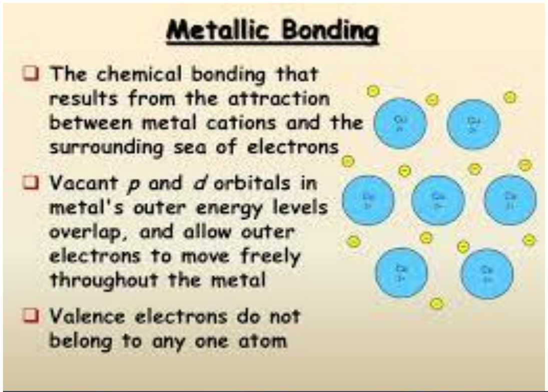
Fig: Stress – Strain curve for Brittle materials

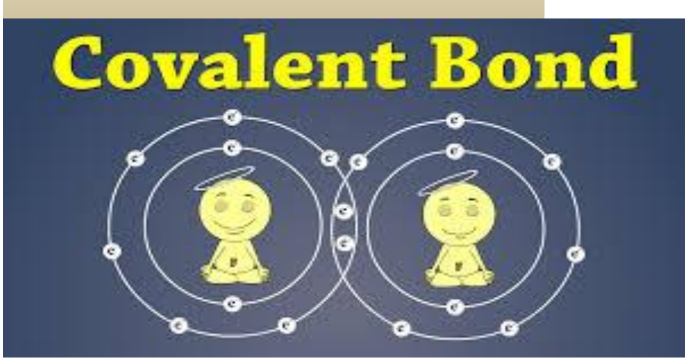
4. Structure of material

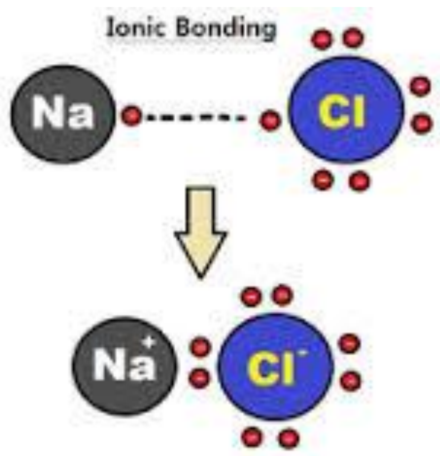
a. Atomic Bonding

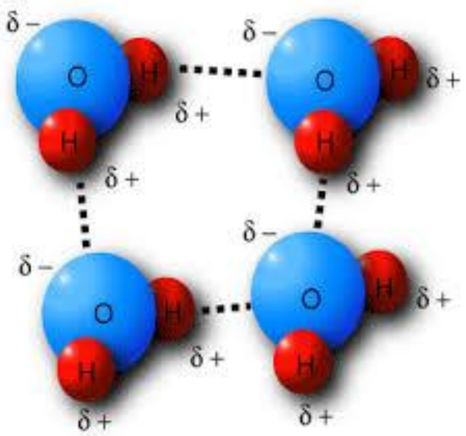
There are four types of bonding. The below figures are self explanatory

Metallic Bonding: Atoms are more stable when they have no partially filled electrons. If an atom has only a few electrons in a shell, it will tend to lose them to empty the shell.









Vanderwaal Bonding

b. Solid state structure

Atoms can be gathered together as an aggregate through a number of different processes like condensation, pressurization, chemical reaction, electro-deposition, and melting. The collection of atoms will take to form of a gas, liquid or solid. The state usually changes as its temperature or pressure is changed. Melting is the process most often used to form an aggregate of atoms. When the temperature of a melt is lowered to a certain point, the liquid will form either a crystalline solid or amorphous solid.

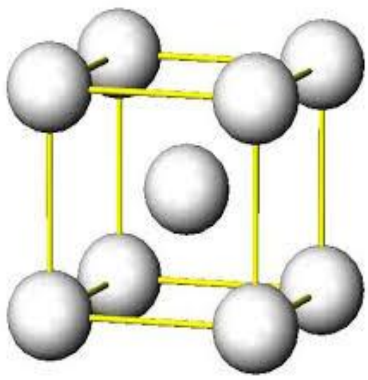
Amorphous Solid: A solid substance with its atoms held apart at equilibrium spacing but with no long – range periodicity in atom location in its structure is called amorphous solid. Eg: Glass and some plastics. They are also called super – cooled liquids because their molecules are arranged in random manner as in liquids. Eg: Formation of glass by melting sand. Amorphous solids are isotropic in nature.

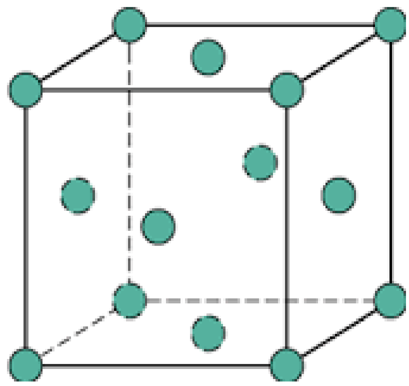
Crystalline Solid: 90% of naturally occurring or artificially made solids are crystalline. A crystal is a regular repeating arrangement of atoms. In crystalline arrangement the particles pack efficiently together to minimize the total intermolecular energy.

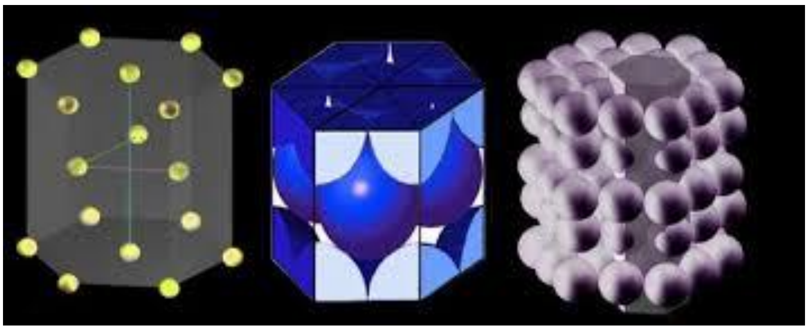
Crystal Structure: Arrangement of atoms within a solid of small representative group of atoms or molecules called unit cell as in adjacent figure.

c. Metallic crystalline structure

Most metals or solids have unit cell structures which can be classified into Body Centered Cubic (BCC), Face Centered Cubic (FCC) & Hexagonal Closely Packed (HCP) as shown in figure. (Detailed dealt in Engineering Physics)



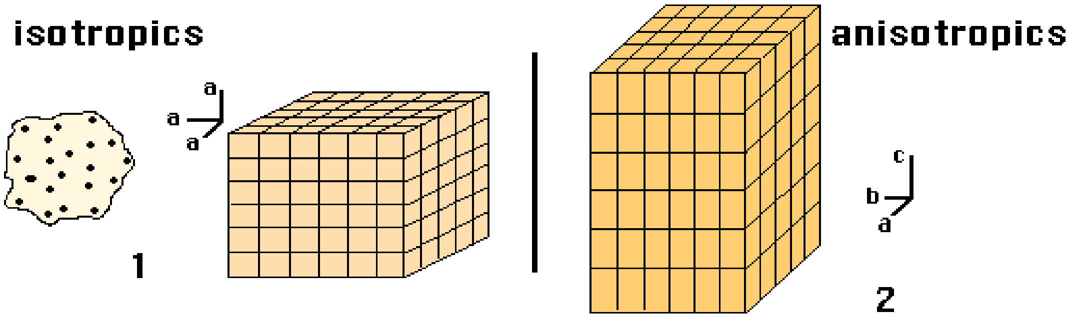




d. Anisotropic and Isotropic

Anisotropic : When the properties of a material vary with different crystallographic orientations, the material is said to be **anisotropic**.

Isotropic: When the properties of a material are the same in all directions, the material is said to be **isotropic.**



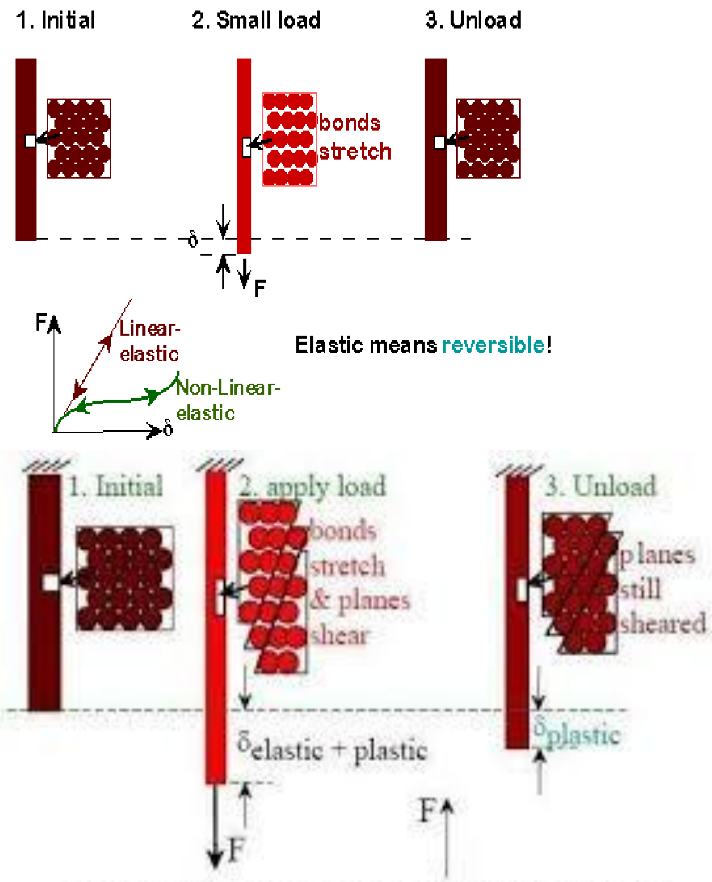
5. Types of Deformation of a material

Force applied on a material causes it to deform. The deformation may be in the form of stretching within the elastic limit or beyond the elastic limit or compression or shear. When a tensile load is applied on the material, the behavior of the material is explained using the stress – strain curve in the above section.

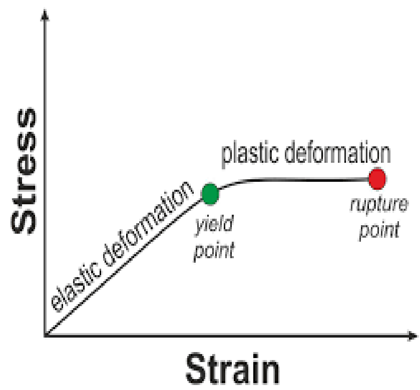
For most materials, the strain experienced when a small stress is applied depends on the tightness of the chemical bonds within the material. **The stiffness of the material is directly related to the chemical structure of the material and the type of chemical bonds present**. The behavior of the material, when the stress is removed depends on how far the atoms have been moved.

There are broadly two types of deformation:

1. ***Elastic deformation***. When the stress is removed the material returns to the dimension it had before the load was applied. The deformation is **reversible, non-permanent**.
2. ***Plastic deformation***. This occurs when a large stress is applied to a material. The stress is so large that when removed, the material does not get back to its previous dimension. There is a **permanent, irreversible deformation.** The minimal value of the stress which produces plastic deformation is known as the ***elastic limit*** (defined in the previous section) for the material.



Schematic Representation of Plastic Deformation



6. **Property Modification process**

Special Treatments like mechanical working, rolling, strain hardening, forging, alloying, heat treatments etc., are made to metals to make them perform better for the intended use.

Strength increases are obtained by adding alloying metals such as manganese, silicon, copper, magnesium and zinc.

Advantages of Mechanical Working (Hot working or Cold Working)

- Products with consistent high quality can be manufactured
- Defects such as porosity and discontinues are minimized
- Inclusions get evenly distributed throughout the product
- Grains are oriented in a particular direction and directional properties are obtained.
- In hot working the grains will be uniform and the properties are also uniform.
- In cold working the properties are enhanced due to strain hardening effect
- Large tonnage can be easily produced.
- The process can be easily mechanized

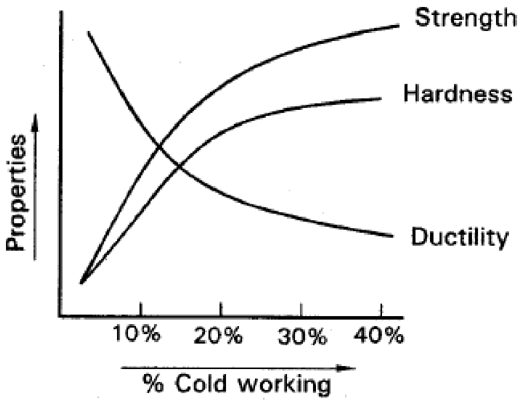
Limitations of Mechanical Working

- The product becomes highly anisotropic in nature
- Final product has to be obtained by machining of the wrought product except in case of structural components
- Needs additional equipment and machinery for metal working process which requires high investments.
- Cost of maintenance is high
- More safety precautions are to be exercised as hot metal and additional equipments are used.

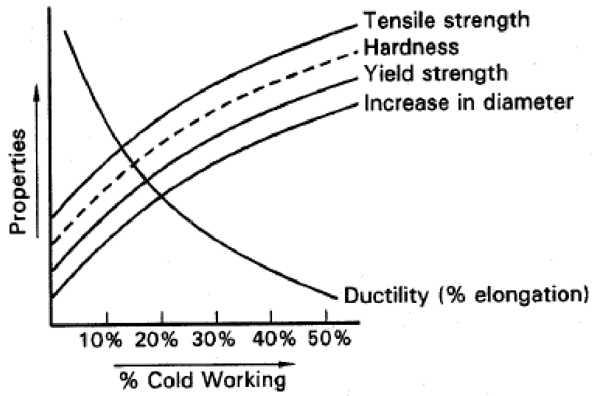
Strain hardening or Work hardening

It is also called as **cold working**. It is the process of strengthening of a metal by plastic deformation. The metal is strengthened by modifying the crystalline structure of the material. Non- brittle materials and polymers can be strengthened in this manner.

The metal is heated at a relatively low temperature after cold-working. During strain hardening the strength of the metal is increased and ductility decreased.



Variation of properties as a function of % cold working



Effect of cold working on properties

Eg: If a low-carbon steel is cold-worked, or strained passed the yield point, then aged for several days at room temperature, it will have a higher yield stress after the aging. This happens because during the aging carbon or nitrogen atoms diffuse to dislocations, resetting them.

Not all materials are strain hardened. Different materials exhibit different behavior after the process.

UNIT-2

2.1. INTRODUCTION TO COMPOSITES AND CHARACTERISATION

Composite material characterisation ensures that advanced composite materials meet application performance requirements for intended use in industry

Composites material characterization is a vital part of the product development and production process. Physical and chemical characterisation helps developers to further their understanding of products and materials, thus ensuring quality control.

Our composite material characterisation services ensure that materials comply with strict industry specifications. This applies to the aerospace, automotive, consumer, medical and defense industries amongst others. With the vast array of lay-ups, prepregs, resin systems, adhesives and reinforcements available, understanding the properties and performance of a material is a key concern to suppliers, manufacturers and developers. This applies across the composite supply chain.

Through our global composite teams, we are a one-source solution provider, specialising in pre-screening of materials, specimen preparation, long-term exposure and extensive mechanical characterization to ASTM, ISO, BS or DIN standards using industry-specific methods.

Formulation, Development and Research Support

Our composite experts support your formulation development ensuring that properties meet the specifications required for their intended application.

Intertek has expertise in composite identification and characterization using a variety of spectroscopic, thermal and rheological methods. These techniques are typically used to study curatives, formulations, resins and filled systems, either during processing or as final products. An area of emphasis is our ability to greatly accelerate the material selection process for thermosetting matrices used in composites, especially when compared to traditionally practiced characterization methods.

Mechanical and Physical Material Characterization

Our physical property testing capabilities include: mechanical, optical, thermal, electrical, exposure, flammability, surface and barrier properties, exposure. We also test for chemical characteristics, including emissions.
Intertek specializes in swift turn of mechanical evaluations using state-of-the-art equipment for mechanical characterization which includes:

- up to 250kN load cell capacity
- data precision through reduced bending effects utilizing Align Pro to meet Nadcap accuracy requirements for tension and Hydraulic Composite Compression Fixture (HCCF) for compression
- high heat extensometers and 8 Channel Strain Gage measurement
- elevated / reduced temperature chamber testing.

Data provided by our scientists assists clients with understanding complex stress/strain graphs, hardness, toughness, impact resistance, corrosion, dielectric strength, density, electrical conductivity, thermal expansion, ultraviolet degradation and more. This data is used to predict how a product reacts to real-world forces, vibration, heat, fluid flow, and other physical effects.

Non-destructive testing (NDT) C-scan of Composite Material

NDT pre-scanning verifies the quality of composite material scanning for damage or material inconsistency prior to verification of mechanical properties.

Specimen Preparation

Specimen preparation is an important step in validating the reliability of materials; helping to ensure consistent, fast manufacturing of composites that are essential in automotive and aerospace applications. Our experienced machinists maintain parallelism required for rectangular specimens necessary for accurate mechanical data generation using state-of-the-art plate saws. Tabbing and strain gages round out extensive capabilities for specimen preparation.

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. Figure M1.1.1 (a): 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). 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, stiff 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 M1.1.1 (f) helps to classify matrices. Figure M1.1 (f): Classification of Matrix Materials M1.2 Basic Definitions and Classifications of Composites M1.2.1 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 carboncarbon 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. M1.2.2 Organic Matrix Composites M1.2.2.1 Polymer Matrix Composites (PMC)/Carbon Matrix Composites or CarbonCarbon 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. Figure M1.2.1: 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. Figure M1.2.2: 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 . M1.2.2.2 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-toweight 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. M1.2.2.3 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. M1.2.3 Classification Based on Reinforcements M1.2.3: 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. Figure M1.2.3: 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. M1.2.3.1 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. M1.2.3.2 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 costeffective. 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. M1.2.3.3 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. Note: In this module text in "Italic" indicates advanced concepts. [Give hyperlink as advanced/reference material] M1.2.4 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. M1.2.4.1 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 siliconcarbide 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. M1.2.4.1.1 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 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 M1.2.4.1 shows kinds of thermoplastics. Figure M1.2.4.1: 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 M1.2.4.2 shows some kinds of thermosets. Figure M1.2.4.2: 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 . M1.2.4.1.2 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-toweight 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. M1.2.4.1.3 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. M1.2.4.2 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 in composites 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 M1.2.4.3 shows types of reinforcements in composites. Figure M1.2.4.3 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. M1.2.4.2.1 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. M1.2.4.2.2 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. M1.2.4.2.3 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. Whiskers differ 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. M1.2.4.2.4 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.

UNIT-3

Introduction

Control and maintenance of a stable environment (relative humidity and temperature) and careful handling practices will significantly prolong the lifespan of a collection. The selection of appropriate archival storage enclosure will also help to increase the life expectancy of the record. This chapter outlines recommended storage environments, storage enclosures and specific handling guidelines for the following media: • Paper – Textual records – Oversized materials – Books – Newspapers • Parchment and vellum • Photographic media – Black and white – negatives and prints – Colour media – Motion picture film – Microfilm • Machine readable records – Phonographic sound recordings – Magnetic media – Digital media • Documentary art One of the more challenging aspects of preservation is that different records/media have different optimal environmental conditions. Ideally, records with different environmental requirements are housed in storage areas with separate, dedicated climate control systems. However, as most small and medium-sized archives lack the space and funds to provide separate relative humidity and temperature zones and as many record series contain a variety of media, compromise is inevitable. In a general collection of mixed archival materials, paper will typically form the bulk of the collection, so the guidelines for paper would therefore set the norm for this kind of collection. Enclosures Enclosures should provide protection from dust, mishandling and pollutants. They should also provide physical support. Most archival enclosures are made from either paper or plastic. The choice of using either paper or plastic will depend on the type of record being enclosed and on the archives environmental conditions. Paper Enclosures Poor quality acidic enclosures may transfer acids to the enclosed record causing embrittlement, discolouration and may increase the rate of deterioration. 52 Canadian Council of Archives All archival paper enclosures should be made from: • Acid-free materials • Fully bleached, alpha cellulose (highly processed wood pulp) or rag (cotton or linen) pulp • Free of lignin and ground wood • Paper with a pH between 7 and 8.5 with an alkaline reserve of 2% calcium carbonate or other suitable alkaline buffer • Paper that is alkaline or neutral sized Paper enclosures selected for photographic enclosures must meet the above recommendations in addition to passing the Photographic Activity Test (ANSI/NAPM IT9.16-1993 /ISO 14523:1997) pH pH (potential Hydrogen) is a measurement which determines acidity or alkalinity. pH is measured on a scale from 0 to 14. pH 7 is neutral; below pH 7 is acidic and above pH 7 is alkaline. The pH scale is logarithmic which means that pH 5 is 10 times more acidic that pH 6 and pH 4 is 100 times more acidic that pH 6. A buffered paper is a paper with a pH above 7. A pH neutral paper has a pH of 7 and an acidic paper has a pH below 7. Molecular Traps Some archival enclosures, in addition to alkaline buffering have molecular traps. Molecular traps, made from either zeolites or activated carbon, are designed to adsorb specific types of gaseous pollutants. It is thought that the molecular trap will trap or adsorb pollutants from the ambient environment or pollutants being off-gassed by the archival record. These types of enclosures could be particularly useful for archives with poor environmental control and/or high indoor pollutant levels. Plastics A wide variety of plastic enclosures are available. Plastic enclosures selected for archival use should not contain plasticizers, slip agents, ultraviolet inhibitors, dyes, coatings or other materials that can break down leading to the deterioration of the enclosed record. Safe plastics include: • Polyester (polyethylene terepthalate) Mylar Type D or Milinex 516 • Polypropylene • Polyethylene – high density • Polystyrene • Polycarbonate Avoid polyvinyl chloride (PVC) plastic. The Beilstein Test (CCI Note N17/1) is simple method to determine if a plastic contains chlorine. It does not specifically identify PVC but if the test is positive, indicating that chlorine is present, the plastic would not be an appropriate archival storage material. Basic Conservation of Archival Materials: Chapter 6 – Collections 53 Paper Records Paper records are found in a myriad of formats in archival collections. Paper forms the base for most textual documents, many types of architectural reproductions, books, photographic prints and even early audio recordings to name a few. The composition of paper plays a key role in its longevity. European paper made prior to the mid 19th century, known as rag paper, was made primarily from cotton and linen fibres. Rag paper tends to be chemically stable with a neutral pH and a life expectancy of several hundred years. Paper made after the mid 19th century is often made from wood pulp fibre and has inherent instability problems from the lignin and hemicellulose left in the semi-processed papers. Newsprint is an example of a minimally processed wood pulp paper. Since the mid 1980s a wide variety of alkaline processed wood pulp papers have been available which meet archival standards in that the lignin, hemicellulose and other undesired byproducts have been removed. In fact, most of the ”archival“ paper enclosures found in conservation supply cat Storage Environment Storage Enclosures Relative Humidity Temperature Paper Records Recommended 18 C

2° Documents – acid-free, buffered file folders 40–45% cooler Fill no more than 1/2" thick if possible Folders – should be stored in archival Acceptable document boxes 30–50% Archival document boxes – acid-free buffered

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3% daily board or Coroplast (polyethylene/polypropylene fluctuation copolymer) Polyester encapsulation Oversize Map folders – acid-free, buffered map folders Records Unbuffered enclosures for blueprints, diazo Fill no more than 1/2" thick Architectural Polyester encapsulation Drawings Maps Books Acid-free drop spine boxes, clam shell boxes, Scrapbooks phase boxes, book wrappers boxes are available commercially although custom made boxes may be required Newspaper Microfilm and maintain microfilm master as outlined on page 62. Buffered drop-front boxes Storage and Handling Enclosures for Unbound Flat Paper Records • Store in acid-free, buffered file folders filled no more than 1/2" thick. • The file folders should be housed in archival document boxes. All file folders should be the same size. The box should be full, with folders fitting snugly within it to prevent sagging, but not so tightly packed that the records are damaged. If the folders do not fill the archival document box, the unused area should be filled with acid free tissue, ethafoam block or other safe archival material. • Boxes should be stored on shelves that support the entire box. • When retrieving a small format record, remove the entire file folder from the document box rather than trying to extract the item from the folder while it is in the box. • Have two people carry large boxes and lift large flat items off shelves or out of map cabinets. Basic Conservation of Archival Materials: Chapter 6 – Collections 55 • Mounting boards can become brittle with age. Support a mounted record adequately to ensure that the board does not break, causing the record to tear or fall to the floor. • Do not roll varnished maps. If they are already rolled and are very brittle, handle them as little as possible. • If a record is folded, unfold it and store it flat if possible. Repeated folding and unfolding will cause breaking or tearing along the folds. Oversize Storage • Oversized records, such as architectural drawings, maps and plans, etc., should be stored horizontally in labeled acid-free map folders. • Acid-free interleaving tissue should be used between coloured records such as architectural presentation drawings and other particularly valuable records. • Blueprints should be stored in unbuffered enclosures as they are alkaline sensitive. • Folders should be selected to fit the size of the drawers. All folders within one drawer should be the same size regardless of the size range of the enclosed records. This minimizes the chance that smaller folders will get pushed to the back of drawer and crushed. • Map cabinets with shallow drawers are best for this type of storage. As a less expensive alternative, use wide, closely spaced shelves of sufficient depth so that stored items do not project beyond the front edge. • Oversized records may have to be rolled. Overall support can be given to an oversized record by rolling it around the outside of an acid-free tube or an ABS (acrylonitrile/butadiene/styrene) plumber's pipe. ABS tube is widely available in hardware stores and generally comes in black. Do not store rolled records inside tubes as it can be difficult to remove them. The rolled record should be covered with either buffered paper or polyester film to protect the record from soiling and abrasion. Newsprint • Most newspapers are produced on acidic paper. As newspapers are valued for their informational content rather than for their artifactual value, photocopying and microfilming are cost-effective preservation options. If you are photocopying newspapers use a "permanent" paper that meets the standards outlined in Permanence of Paper for Publications and Documents in Libraries and Archives ANSI Z39.48-1992 (R1997) or the Canadian standard CGSB-9.70- 2000 Permanence of Paper for Records, Books and Other Documents. • Newspaper clippings and inserts should be removed and photocopied if interspersed with textual documents. The newspaper clipping photocopy should replace the original in the file. 56 Canadian Council of Archives Books • Most books will not require enclosures, however, books which are fragile, damaged or valuable may require enclosures. Phase boxes, book wrappers, drop-front or clam shell boxes can be used to enclose books. Slipcases can cause abrasion and so should be avoided. • Vellum bound books should also be boxed as vellum reacts quickly to changes in relative humidity and temperature which can result in warping of the boards. • Make sure that shelves are of a width and height that will accommodate all the books. Books should not project beyond the edge of a shelf. Designate special areas for oversized books. • Store oversized books on their side on a shelf which is large enough to fully support the book. Do not store more than two or three books on top of one another. • Books are not designed to stand on a shelf without support. Use sturdy, nonslip book ends which are large enough to provide adequate support. • If a book will not fit on the shelf in an upright position, shelve it spine down rather than spine up to avoid placing stress on the hinges. Horizontal storage is a better alternative. • Miniature books should be shelved separately or stored in protective boxes. • To remove a book from its shelf, push in the books on either side, then remove the one you want by grasping it on either side of the cover near the spine. Never remove a book

by pulling the top of the spine with your fingers. • When opening a book, support it with your hands. If the book does not open readily or lie flat when it is opened, don’t force it. • Use a book cradle for research and when placing a book on display. • If a book cover is loose or detached, tie it in place with linen or cotton tape. Place the knot along the fore edge or top of the textblock. Store the book in a box if possible. • Never use elastic bands to hold a book together as they will cut into the book and leave a sticky mess as they deteriorate. • Never use pressure sensitive adhesive tape to reattach covers or repair torn pages. Scrapbooks • Most scrapbooks can be stored following the guidelines outlined for books. • Interleave scrapbook pages where necessary with acid-free buffered tissue. This reduces transfer of acids, staining or other unstable material being transferred from one page to another. Interleaving should be used to separate newspaper clippings from adjacent pages without newspaper clipping, Basic Conservation of Archival Materials: Chapter 6 – Collections 57 photographs from acidic pages etc. Interleaving can cause the textblock to swell which can place excess strain on the spine. If the scrapbook is tightly bound interleave sparingly, if the scrapbook is loosely bound interleave where required. • Every effort should be made to retain the original format of the scrapbook • If the scrapbook is to be taken apart, the original order of the book must be documented by photocopying, photography, or microfilming. Parchment and Vellum Parchment and vellum records are made from animal skins which have been treated with lime, scraped, stretched and burnished. Parchment and vellum are hygroscopic materials which means that they are very susceptible to changes in relative humidity. Fluctuations in relative humidity can result in cockling and other surface deformations. This can make it a challenge to keep the record flat. Movement of the parchment and vellum can cause additional problems as these records often have seals attached to them. Seals are commonly made from wax but can also be made from shellac, applied paper or other materials. Seals do not respond to changes in relative humidity in the same way that the parchment and vellum do resulting in dimensional stress in the areas where the seal is affixed. Storage Environment Storage Enclosures Relative Humidity Temperature Parchment Recommended 18°C
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2° Acid-free buffered board enclosures are Vellum 45–55% cooler if recommend over plastic enclosures as the possible acid-free buffered board provides a better microenvironment as it absorbs moisture whereas the plastic materials do not. Storage and Handling • As parchment and vellum are hygroscopic one of the primary functions of their storage enclosure, in addition to providing safe handling and support, should be to provide a microclimate which buffers against fluctuations in relative humidity. Acid-free buffered board enclosures are recommend over plastic enclosures. The acid-free buffered board provides a better microenvironment as it absorbs moisture whereas the plastic materials do not. • Encapsulation is not recommended for parchment or vellum. Inks and other media do not penetrate the skin but sit on the surface making them more susceptible to lifting due to polyester’s static charge. • Pendant seals must be adequately supported and not allowed to dangle freely from the record. 58 Canadian Council of Archives Photographic Media Photographic archival collections are found in a vast array of media and formats: cased photographs, black and white prints and negatives, motion picture film, colour slides, negatives, prints and transparencies to name just a few. Photographic collections pose a range of preservation challenges ranging from the basics of rehousing collections in archival enclosures, to dealing with the failure of cellulose acetate film base, to providing cold storage for colour media, and deteriorating cellulose acetate and cellulose nitrate negatives. Photographic Negatives Photographic negatives have been made on a range of support media including glass plates and plastic film bases such as cellulose nitrate, cellulose acetate and polyester. Glass Plates Glass plate negatives can be found in archives and date from the mid 1850s through to the early 1920s. Glass plates are fragile and require extra care during handling. Cellulose Nitrate Base Film Cellulose nitrate was introduced commercially in 1889 as a base for negatives and film and was in use until the early 1950s. Cellulose nitrate was the only plastic film base available until the early 1920s when cellulose acetate was introduced. Cellulose nitrate negative deterioration rates are unpredictable. Some negatives show recognizable deterioration while other negatives of the same age show few signs of deterioration. Factors which influence the rate of deterioration include the composition of the cellulose nitrate film, when it was manufactured and the storage temperature and relative humidity. As cellulose nitrate negatives degrade they off-gas a range of deterioration byproducts which in turn increase the rate of deterioration of the off-gassing negatives and surround negatives. The deterioration of cellulose nitrate is characterized by the following five stages: 1. Amber discolouration of the film base. 2. The film becomes sticky. 3. Embrittlement and the formation of gas bubbles on the surface. 4. Film softens and exhibits a viscous frothiness. 5. Films degrades to a brown acrid powder. Cellulose nitrate is a recognized fire hazard. As cellulose nitrate deteriorates its flash point drops dramatically. The reduced flash point in conjunction with a build-up of offgassing byproducts in a film canister can lead to spontaneous combustion of the cellulose nitrate film. However, this does not appear to be a concern for most cellulose nitrate negative collections as the negatives are not generally housed in sealed containers.