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2nd Grade

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Building Materials

1st course

First lecture

Building materials

Introduction:

The engineering structures are composed of materials. These materials are known as the engineering materials or building materials or materials of construction. It is necessary for the civil engineer to become conversant with the properties of such materials. The service conditions of buildings demand a wide range of materials and various properties such as water resistance, strength, durability, temperature resistance, appearance, permeability, etc. are to be properly studied before making final selection of any building material for a particular use. There are different types of building materials used to construct buildings. Some of them have even existed for years, and are still in use.

Building materials are basically divided into **natural and synthetic** materials. The materials made from natural products like clay, twigs, sand, leaves and rocks are natural building materials.

Building materials used in industries, that have gone through human processing is called synthetic building material, like plastics.

Here are the 8 types of building materials:

1. **Rock** is one building material that has been used in building structures for centuries.
2. Another very old building material used today is **thatch**. It is very cheap, is a great insulator and is very easily harvested.
3. **Ice** is another famous building material which was once used only for building igloos. Today, it is also being used in building ice hotels for tourist attractions in cold places.
4. In some places, **earth is still used in creating walls**. These walls are made by tightly packing and compacting mud between planks. This was previously done by hand, but now machines are being used. These houses of rammed earth are warm in winter, and cool in summer. This is because soil and clay help at maintaining temperatures at constant levels.

Cement is a common building material made from rock. Today, cement is used in constructing most buildings mainly because it is long lasting.

6. **Metal** is today popularly used for constructing a building's structural framework. Metals are used mainly because it is long lasting there are

different types of metals you can use for building like steel, which is a metal alloy. Sometimes gold and silver are used for decorative purposes. However not many people can afford it, and moreover, it is not as hard as other metals.

7. **Glass** is a building material used a lot nowadays in building structures because of its class and richness.

This variety of building materials is used for constructing all those beautiful structures found worldwide. The choice of usage is done based on personal preference and the climatic condition of the place.

Responsibilities of Materials Engineer

A material engineer must be familiar with a wide range of materials used in a wide range of structures and is responsible for the following jobs with certain limits of compromises to be made on site.

- **Selection of Materials**
- **Specification of Materials**
- **Quality Control of materials**

Factors Influencing Selection of a Building Materials

A wide range of construction materials is available. The proper selection of materials to be used in a particular construction project depends on the following factors

- Strength
- Availability
- Durability
- Workability
- Ease of Transportation
- Cost
- Aesthetics
- Resistance to Fire
- Ease of Cleaning

High Performance Materials

The increasing scope of civil engineering has brought many researches and advancement in materials and knowledge of molecular structure. These materials have shown better quality with much safety and economy. Such materials are known as High Performance Materials. In addition, improvements have been made to existing materials by changing their molecular structures or including additives to improve quality, economy, and performance.

Advantages of High

Performance Materials

- **High strength concrete can be produced**
- **Elastomeric material are used in joints in highly active earthquake areas**
- **Light weight concrete and aggregate have made cross sections smaller**
- **Polymers have been mixed with asphalt, allowing pavements to last longer under the effect of vehicle loads and environmental conditions.**
- **Fiber-Reinforced Concrete has greater toughness than conventional Portland cement concrete.**

Mortar

Mortar is a mixture of cementations material, aggregate generally with a grain size of less than 4 mm, water and possibly additives and/or admixtures. Mortar can be classified as cement-lime mortar, cement mortar, lime mortar or masonry cement mortar. Mortar is used for the **following functions:**

1- To bind materials together (e. g. masonry mortar and tile adhesive mortar, either non reinforced or reinforced).

2- To serve as a seating and leveling material for the masonry units.

3- To provide aesthetic quality of the structure and a level or smooth finish (e. g. floor screed mortar, internal plastering).

4- To protect against weathering (e. g. external rendering).

5- To improve thermal insulation of walls (e. g. external thermal insulation composite systems, thermal insulation rendering mortar, lightweight masonry mortar)

6- To repair constructions (e. g. concrete repair mortar, dam proofing mortar).

CONCRETE CONSTITUENTS

The constituent materials of concrete should satisfy; **the durability, structural performance and safety requirements, taking into consideration the environment** to which it will be subjected. The common types of **cement used in concreting include**:

- Ordinary Portland cement OPC
- Sulphate-resisting Portland Cement
- Low heat Portland Cement

The exposure conditions of the concrete and whether there are other special requirements, should be considered in the selection of the cement type. For example, concrete made with Portland cement is not recommended for use in acidic conditions.

The various factors affecting the choice of concrete are:

1. Compressive strength of concrete:

It is one of the most important properties of concrete and influences many other describable properties of the hardened concrete. The mean compressive strength required at a specific age, usually 28 days, determines the nominal water-cement ratio of the mix.

2. Workability of concrete:

The degree of workability required depends on three factors. These are the size of the section to be concreted, the amount of reinforcement, and the method of compaction to be used.

3. Durability of concrete:

The durability of concrete is its resistance to the aggressive environmental conditions.

SELECTION OF CONCRETE

REPAIR MATERIALS

Selection of concrete repair materials is based on evaluation of type of damage, types of materials to be used for repair and the local condition. Concrete repairing material must be compatible with the concrete being repaired. Variety of materials is available for repair of concrete structures.

The selection of concrete repair materials should be made based on following properties:

- Bond with concrete
- Strength development of material with concrete(compressive, flexural and tensile)
- Coefficient of thermal expansion of the material
- Coefficient of permeability of the material
- Stress development at interface whether on shrinkage, temperature change, alternative cycles of wetting and drying
- Corrosion resistance property of the material
- appearance of finished surface
- speed of concrete repair

Basically, the concrete repair materials can be grouped into:

i) Cementitious System
ii) Polymer Modified Cementitious System
iii) Polymer Concrete System , composite materials
iv) Reactive Thermosetting Resin System

Green building:

Green building (also known as **green construction** or **sustainable building**) refers to both a structure and the application of processes that are environmentally responsible and resource-efficient throughout a building's life-cycle: from planning to design, construction, operation, maintenance, renovation, and demolition.

The common **objective** of green buildings is to : reduce the overall impact of the built environment on human health and the natural environment by:

- Efficiently using energy, water, and other resources
- Protecting occupant health and improving employee productivity
- Reducing waste, pollution and environmental degradation

Water efficiency

Reducing water consumption and protecting water quality are key objectives in sustainable building. One critical issue of water consumption is that in many areas, the demands on the supplying aquifer exceed its ability to replenish itself.

Materials efficiency

Building materials typically considered to be 'green' include lumber from forests that have been certified to a third-party forest standard, rapidly renewable plant materials like bamboo and straw, dimension stone, recycled stone, recycled metal

Second lecture

Theories of failures

1. Introduction

Machine parts fail when the stresses induced by external forces exceed their strength. The external loads cause internal stresses in the elements and the component size depends on the stresses developed. Stresses developed in a link subjected to uniaxial loading is shown in **figure-1**.

Loading may be due to:
a) The energy transmitted by a machine element.
b) Dead weight.
c) Inertial forces.
d) Thermal loading. e) Frictional forces.

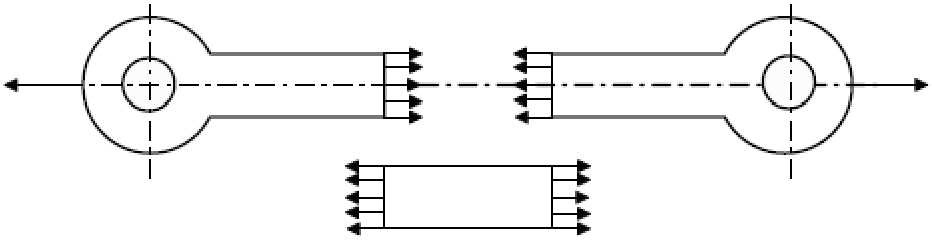
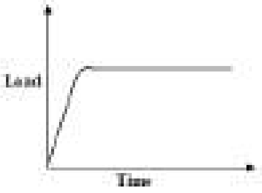
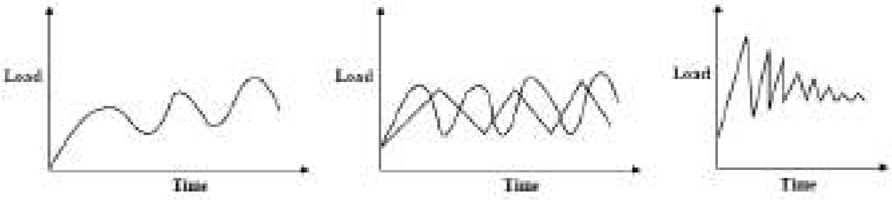


figure-1. - *Stresses developed in a link subjected to uniaxial loading*

In another way, load may be classified as:
a) Static load- Load does not change in magnitude and direction and normally increases gradually to a steady value.
b) Dynamic load- Load may change in magnitude for example, traffic of varying weight passing a bridge. Load may change in direction, for example, load on piston rod of a double acting cylinder.
Vibration and shock are types of dynamic loading. **Figure.2** shows load vs time characteristics for both static and dynamic loading of machine elements.



Static Loading



Dynamic Loading

Figure.2 - *Types of loading on machine elements.*

2. Allowable Stresses: Factor of Safety

Determination of stresses in structural or machine components would be meaningless unless they are compared with the material strength. If the induced stress is less than or equal to the limiting material strength then the designed component may be considered to be safe and an indication about the size of the component is obtained. The strength of various materials for engineering applications is determined in the laboratory with standard specimens. For example, for tension and compression tests a round rod of specified dimension is used in a tensile test machine where load is applied until fracture occurs. The load at which the specimen finally ruptures is known as Ultimate load and the ratio of load to original cross-sectional area is the Ultimate stress.

Similar tests are carried out for bending, shear and torsion and the results for different materials are available in handbooks. For design purpose an allowable stress is used in place of the critical stress to take into account the uncertainties including the following:

1) Uncertainty in loading.
2) In homogeneity of materials.
3) Various material behaviors. e.g. corrosion, plastic flow, creep.
4) Residual stresses due to different manufacturing process.
5) Fluctuating load (fatigue loading): Experimental results and plot- ultimate strength depends on number of cycles.
6) Safety and reliability.

For ductile materials, the yield strength and for brittle materials the ultimate strength are taken as the critical stress.
An allowable stress is set considerably lower than the ultimate strength. The ratio of ultimate to allowable load or stress is known as factor of safety i.e.

$$\frac{\text{Ultimate Stress}}{\text{Allowable Stress}} = \text{F.S.}$$

The ratio must always be greater than unity. It is easier to refer to the ratio of stresses since this applies to material properties

3 .Theories of failure

When a machine element is subjected to a system of complex stress system, it is important to predict the mode of failure so that the design methodology may be based on a particular failure criterion. Theories of failure are essentially a set of failure criteria developed for the ease of design.

In machine design an element is said to have failed if it ceases to perform its function. There are basically two types of mechanical failure:

(a) **Yielding-** This is due to excessive inelastic deformation rendering the machine part unsuitable to perform its function. This mostly occurs in ductile materials.

(b) **Fracture-** in this case the component tears apart in two or more parts. This mostly occurs in brittle materials.
There is no sharp line of demarcation between ductile and brittle materials.
However a rough guideline is that if percentage elongation is less than 5% then the material may be treated as brittle and if it is more than 15% then the material is ductile. However, there are many instances when a ductile material may fail by fracture. This may occur if a material is subjected to:

(a) Cyclic loading.
(b) Long term static loading at elevated temperature.
(c) Impact loading.
(d) Work hardening.
(e) Severe quenching.

Yielding and fracture can be visualized in a typical tensile test .Typical engineering stress-strain relationship from simple tension tests for same engineering materials are shown in **figure- 3**.

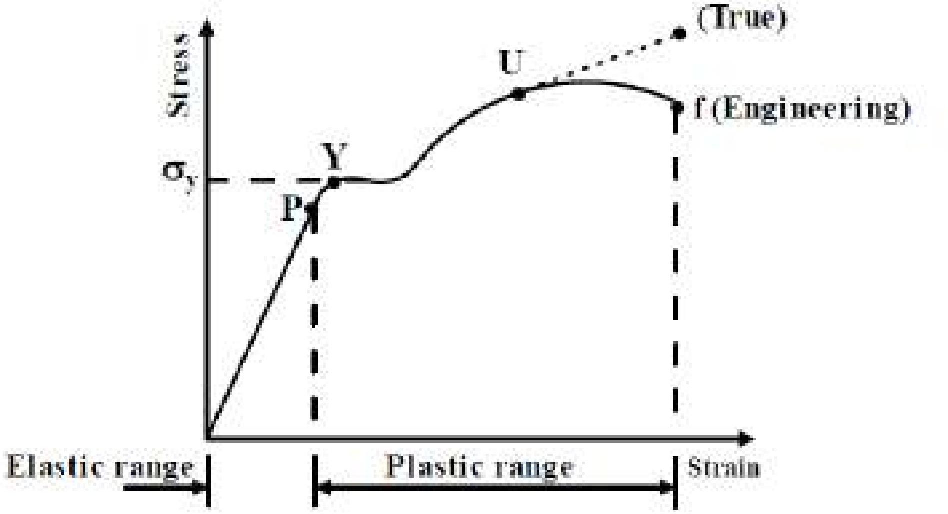
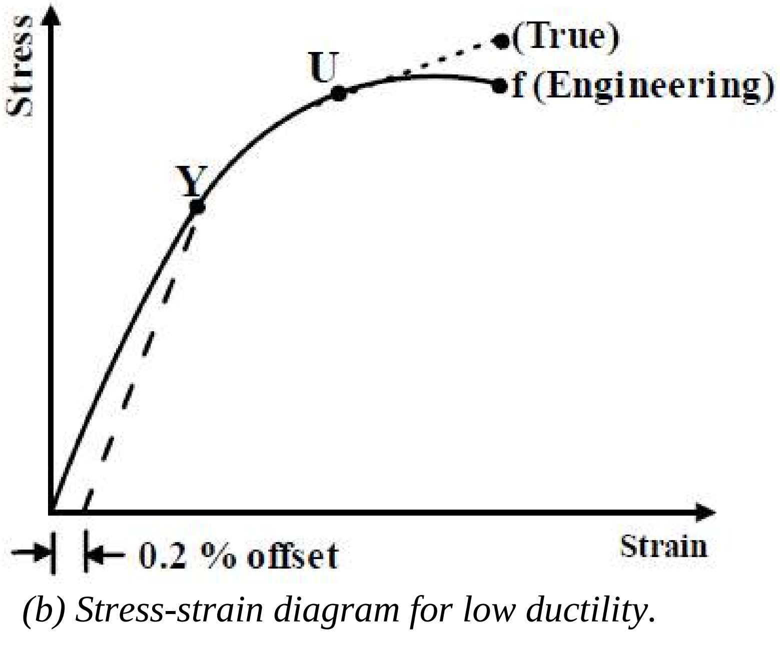
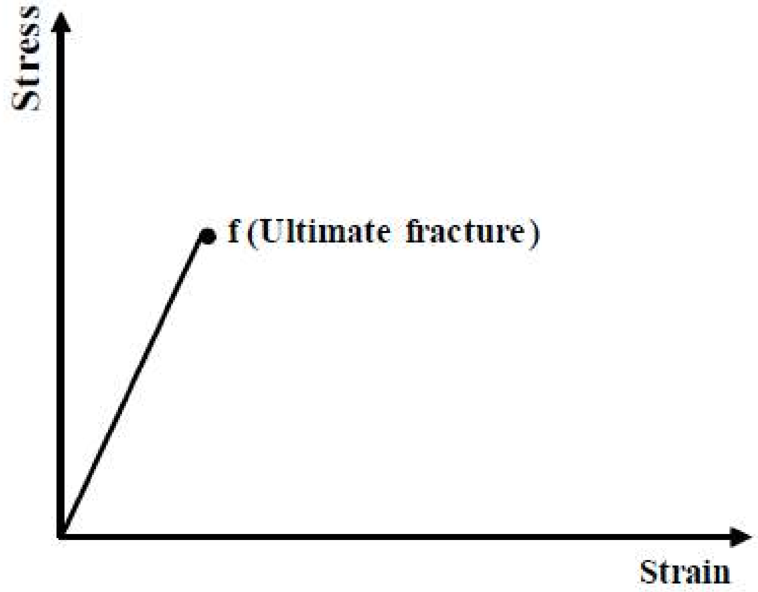


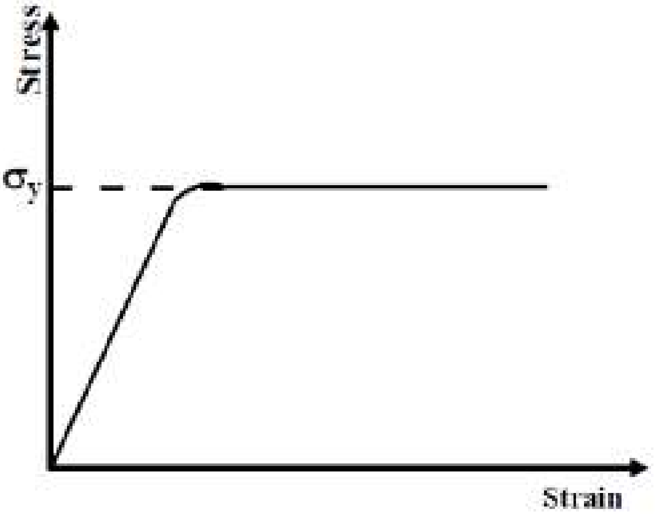
figure- 3. *(a) Stress-strain diagram for a ductile material e.g. low carbon steel.*



(b) Stress-strain diagram for low ductility.



(c) Stress-strain diagram for a brittle material.



(d) Stress-strain diagram for an elastic – perfectly plastic material.

For a typical ductile material as shown in **figure-3 (a)** there is a definite yield point where material begins to yield more rapidly without any change in stress level. Corresponding stress is σy . Close to yield point is the proportional limit which marks the transition from elastic to plastic range. Beyond elastic limit for an

elastic- perfectly plastic material yielding would continue without further rise in stress i.e. stress-strain diagram would be parallel to parallel to strain axis beyond the yield point. However, for most ductile materials, such as, low-carbon steel beyond yield point the stress in the specimens rises up to a peak value known as ultimate tensile stress σo . Beyond this point the specimen starts to neck-down i.e. the reduction in cross-sectional area. However, the stress-strain curve falls till a point where fracture occurs. The drop in stress is apparent since original cross-

sectional area is used to calculate the stress. If instantaneous cross-sectional area is used the curve would rise as shown in **figure- 3 (a)** . For a material
with low ductility there is no definite yield point and usually off-set yield points are defined for convenience. This is shown in **figure-3**.b For a brittle material stress increases linearly with strain till fracture occurs.

4-Yield criteria

There are numerous yield criteria, going as far back as Coulomb (1773). Many of these were originally developed for brittle materials but were later applied to ductile materials. Some of the more common ones will be discussed briefly here.

4.1 Maximum principal stress theory (Rankine theory)

According to this, if one of the principal stresses σ1 (maximum principal stress), σ2 (minimum principal stress) or σ3 exceeds the yield stress, yielding would occur. In a two dimensional loading situation for a ductile material where tensile and compressive yield stress are nearly of same magnitude

$$\sigma_1 = \pm \sigma_y$$

$$\sigma_2 = \pm\sigma_y$$

Using this, a yield surface may be drawn, as shown in **figure- 4.1**
Yielding occurs when the state of stress is at the boundary of the rectangle.
Consider, for example, the state of stress of a thin walled pressure vessel. Here σ1= 2σ2, σ1 being the circumferential or hoop stress and σ2 the axial stress. As the pressure in the vessel increases the stress follows the dotted line. At a point (say) a, the stresses are still within the elastic limit but at b, σ1reaches σy although σ2 is still less than σy. Yielding will then begin at point b.
This theory of yielding has very poor agreement with experiment.
However,the theory has been used σ_2 successfully for brittle materials.

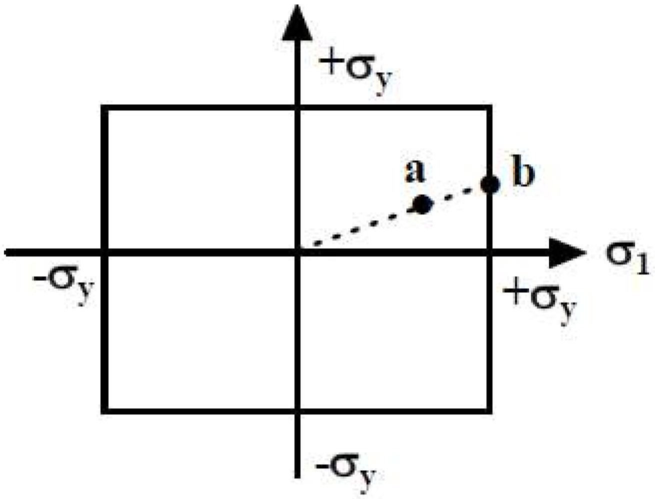


figure- 4.1 *Yield surface corresponding to maximum principal stress theory*

3.1.4.2 Maximum principal strain theory (St. Venant's theory)

According to this theory, yielding will occur when the maximum principal strain just exceeds the strain at the tensile yield point in either simple tension or compression. If ε1 and ε2 are maximum and minimum principal strains corresponding to σ1 and σ2, in the limiting case

$$\varepsilon_1 = \frac{1}{E}(\sigma_1 - \nu\sigma_2) \qquad |\sigma_1| \geq |\sigma_2|$$

$$\varepsilon_2 = \frac{1}{E}(\sigma_2 - \nu\sigma_1) \qquad |\sigma_2| \geq |\sigma_1|$$

$$\text{This gives, } E\varepsilon_1 = \sigma_1 - \nu\sigma_2 = \pm\sigma_0$$

$$E\varepsilon_2 = \sigma_2 - \nu\sigma_1 = \pm\sigma_0$$

The boundary of a yield surface in this case is thus given as shown in **figure-**4-2

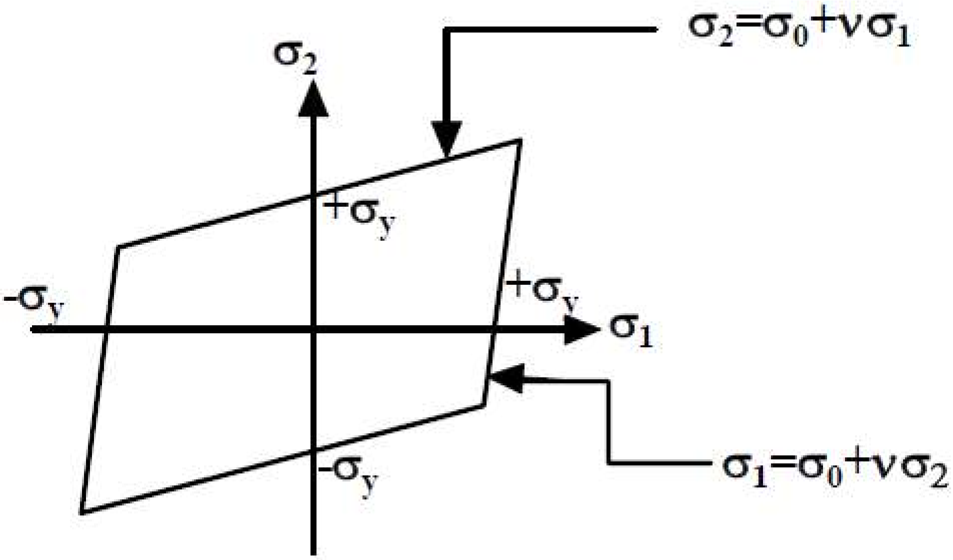


figure-4-2 *Yield surface corresponding to maximum principal strain theory*

3.1.4.3 Maximum shear stress theory (Tresca theory)

According to this theory, yielding would occur when the maximum shear stress just exceeds the shear stress at the tensile yield point. At the tensile yield point σ2= σ3 = 0 and thus maximum shear stress is σy/2. This gives us six conditions for a three-dimensional stress situation:

$$\sigma_1 - \sigma_2 = \pm\sigma_y$$
$$\sigma_2 - \sigma_3 = \pm\sigma_y$$
$$\sigma_3 - \sigma_1 = \pm\sigma_y$$

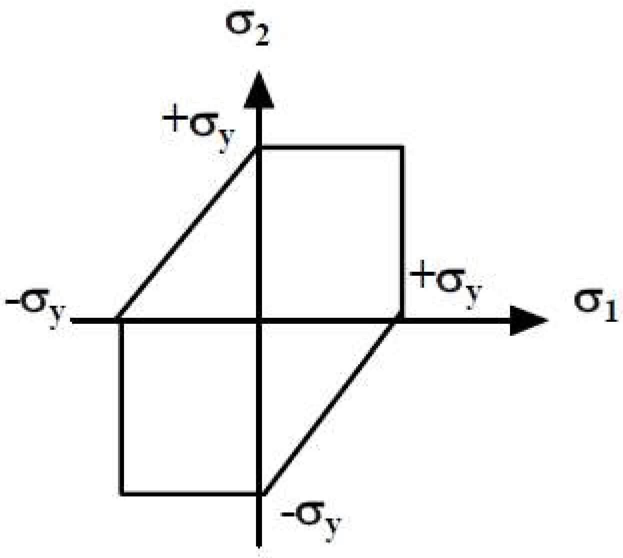


figure-4-3 *Yield surface corresponding to maximum shear stress theory*

In a biaxial stress situation **figure**-4-3 case, σ3 = 0 and this gives

$$\begin{array}{ll}
\sigma_1 - \sigma_2 = \sigma_y & \text{if } \sigma_1 > 0, \sigma_2 < 0 \\
\sigma_1 - \sigma_2 = -\sigma_y & \text{if } \sigma_1 < 0, \sigma_2 > 0 \\
\sigma_2 = \sigma_y & \text{if } \sigma_2 > \sigma_1 > 0 \\
\sigma_1 = -\sigma_y & \text{if } \sigma_1 < \sigma_2 < 0 \\
\sigma_1 = -\sigma_y & \text{if } \sigma_1 > \sigma_2 > 0 \\
\sigma_2 = -\sigma_y & \text{if } \sigma_2 < \sigma_1 < 0
\end{array}$$

This criterion agrees well with experiment.
In the case of pure shear, σ1 = - σ2 = k (say), σ3 = 0
and this gives σ1- σ2 = 2k= σy

This indicates that yield stress in pure shear is half the tensile yield stress and this is also seen in the Mohr's circle (figure- 4.4) for pure shear.

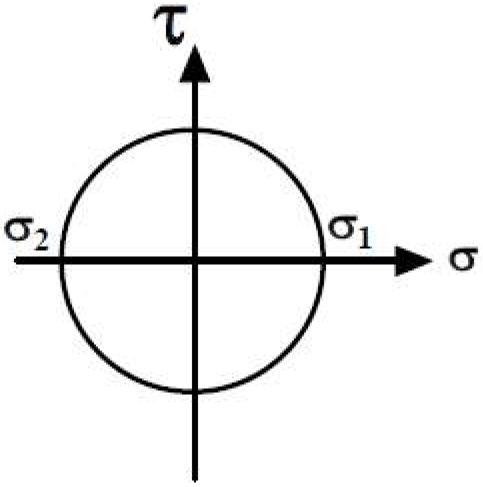


figure- 4.4- *Mohr's circle for pure shear*

Third Lecture

STEEL

According to the World Steel Association, there are over 3,500 different grades of steel, encompassing unique physical, chemical, and environmental properties.

In essence, steel is composed of iron and carbon, although it is the amount of carbon, as well as the level of impurities and additional alloying elements that determine the properties of each steel grade.

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

Different types of steel are produced according to the properties required for their application, and various grading systems are used to distinguish steels based on these properties.

Steel can be broadly categorized into four groups based on their chemical compositions:

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

The table below shows the typical properties of steels at room temperature (25°C). The wide ranges of tensile strength, yield strength, and hardness are largely due to different heat treatment conditions.

Carbon Steels

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

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

Alloy Steels

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

Stainless Steels

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

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

- Martensitic: Martensitic steels contain 11-17% chromium, less than 0.4% nickel, and up to 1.2% carbon. These magnetic and heat-treatable steels are used in knives, cutting tools, as well as dental and surgical equipment.

Tool Steels

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

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

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

What is Stainless Steel?
Stainless steel is a generic term for a family of corrosion resistant alloy steels containing 10.5% or more chromium.

ll stainless steels have a high resistance to corrosion. This resistance to attack is due to the naturally occurring chromium-rich oxide film formed on the surface of the steel. Although extremely thin, this invisible, inert film is tightly adherent to the metal and extremely protective in a wide range of corrosive media. The film is rapidly self repairing in the presence of oxygen, and damage by abrasion, cutting or machining is quickly repaired.

When nickel is added to stainless steel in sufficient amounts the crystal structure changes to "austenite". The basic composition of austenitic stainless steels is 18% chromium and 8% nickel.
Austenitic grades are the most commonly used stainless steels accounting for more than 70% of production (type 304 is the most commonly specified grade by far)

Ferritic
These are nickel-free stainless steels. They have a varying chromium (Cr) content of 12- 18%, but a lower carbon (C) content than the martensitics. (A special heat resistant grade contains 26% Cr.) The common specifications are 430, 409 and weldable 12% Cr steels

Common uses
- *computer floppy disk hubs*
- *automotive trim*

- *automotive exhausts*
- *colliery equipment*
- *hot water tanks*

WHAT IS GREAT ABOUT STAINLESS STEEL?

Corrosion resistance
Wear Resistance
Fire and heat resistance
Hygiene
Aesthetic appearance
Strength-to-weight advantage
Ease of fabrication
Impact resistance
Recyclability
Long term value
Low carbon foot-print

Forth Lecture

ALUMINUM

ADVANTAGES OF ALUMINUM AS A BUILDING MATERIAL

Aluminum made tremendous advances as a structural construction material in the last thirty years. To understand the reasons why, it is necessary to develop an appreciation for the basic fundamentals that make it so well suited for many construction applications.

The following is an item by item review of the reasons:

Non-Rusting: “Rust” is by definition iron oxide formed by oxidation of iron, or steel containing the element, iron (Fe). Since there is no iron in aluminum building products, by definition, they will never “rust”. Aluminum will oxidize forming an Aluminum Oxide film on the surface. Competition, however, tries to draw a parallel between the oxidation of steel (rusting) and the oxidation of aluminum. As a matter of fact, the oxidation action is similar, but the results are totally different. Iron oxide (rust) is very porous, allowing moisture to penetrate the film of rust and thus permitting additional rusting until over time, structural failure results. Aluminum oxide, on the other hand, is a dense, tight film covering that effectively forms a barrier to moisture, resulting in the protection of the metal underneath against further oxidation. Thus, the oxidation rate of aluminum decreases rapidly as the film builds.

An actual bare-aluminum roof installation exposed to salt air with no applied barrier coating or maintenance, had an oxide penetration of only 0.002-inch in 40 years. At this rate, it would require 200 years to penetrate 0.010-inch . . . halfway through a 0.020-inch sheet of aluminum.

Penetration Tests: Results of exposure tests for aluminum by the American Society for Testing Materials, in nine locations (including industrial, sea coast, and rural) indicated an average penetration of only 0.00002-inch per year . . . or 500 years to penetrate midway through an 0.020-inch thick sheet of aluminum.

By contrast, it is not uncommon for rust to completely penetrate 29-gage (0.014-inch) galvanized steel sheet within 8 years after the galvanizing has ceased to provide protection . . . and some new galvanized roofs exhibit the characteristic red-brown tint of rust within a week or two of application.

Surface Marking: Shearing, bundling, shipping, fabrication, and erection of any building products are bound to produce a certain amount of surface marking. It is difficult to erect galvanized roofing without scratching, chipping, breaking, or peeling off some of the galvanizing, exposing the underlying metal to moisture, which causes rust. Fastener holes in particular offer effective starting points for rust, regardless of how careful the application.

Deterioration here is particularly harmful to the roofing, siding, and flashing.

Aluminum, however, being a homogeneous material, has no protective coating to come off. Any scratches that may be produced are quickly protected by the natural protective coating of aluminum oxide. Fastener holes similarly provide their own protection. Thus, holes in aluminum are not weak points for deterioration.

Corrosion of Aluminum: Competition attempts to point out that while aluminum does not “rust”, it does corrode. That is true, but we need to understand the principles of the corrosion.

The corrosion of aluminum is easily controlled and need never be serious. Here are some common occurrences that you may incur in this connection

Watermarking: Pure water allowed to pond on aluminum does not produce a water spotting.

However, it is an unfortunate fact that most water (even moisture condensing from the (atmosphere) contains some chemicals, enough to react with aluminum, and its alloying elements, to form gray or white salts, if the water is allowed to pond on the aluminum for an appreciable length of time. These salts will mark the surface of the aluminum.

It should be emphasized that this attack is superficial, hardly being enough to mark the top layer.

However, these spots or streaks may be unsightly. Such marks are easily removed by mechanically abrading the surface with a power driven wire brush or using some cleanser such as Simonize cleaner, etc. A warm caustic solution or commercial etching compounds also may be used, but acids should not be used.

Watermarking can be prevented by simply not allowing water to pond on the aluminum. Store fabricated aluminum in a place where it is protected from rain. Prevent rapid changes in atmospheric temperature that may cause condensation. If the sheets get wet, stand them on end and separate them so they may dry out. Protection in outside areas include covering sheets with breathable tarps, but not plastics or solid polyethylene

Salt Air Attack: Aluminum will withstand exposure to the salt air encountered near seacoasts, provided an aluminum alloy is used that contains no copper. The high strength alloys such as 2024 used in aircraft

contain copper, so stock of this type gave aluminum a bad name when used
on coastal installations.

Today, most aluminum building products are made from alloys containing no copper, so they are not subject to this corrosion. They can be relied upon to give long life on seacoast installations, as well as elsewhere.

Industrial atmospheres contain comparatively large amounts of chemicals which will increase the tendency to watermark. Aluminum roofs and siding may develop streaks from uneven flow of water over them in such areas. These marks may be removed by suitable cleaners and further marking retarded by correct selection of treating solution. Remember that other roofing materials such as galvanized iron and steel also develop similar markings under these conditions.

Alloy content greatly influences susceptibility of aluminum to attack. Today, most aluminum building products are made from the purer alloys (3004, 3003, etc.) which are most resistant to chemical attack. When an incident of corrosion of aluminum is brought to your attention, inquire as to the alloy involved and point out the deleterious effect of high alloy contents such as those of 2024, etc., especially a high copper content.

Electrolytic Reactions: Competition says, “Care must be taken to protect aluminum against electrolytic action. The use of non-aluminum fasteners or lapping sheets of aluminum and other metals is particularly dangerous.” There are several distortions of fact in this statement.

First, let’s see what we mean by “electrolytic reactions”. Any two dissimilar metals in an electrolyte (conductive solution) sets up an electrolytic cell (electric battery). If the two metals touch each other or immersed in this solution, an electric current will flow, causing one of the metals to go into solution (be dissolved), resulting in pitting and corrosive attack.

For such electrolytic action, the two metals must possess widely differing solution potentials, they must actually contact each other, the contact points must be wet or moist, and these conditions must exist for a sufficient period of time to produce pitting.

Solution Potentials: Therefore, electrolytic action can almost never be serious where aluminum contacts galvanized iron or galvanized steel because the zinc coating has practically the same solution potential as aluminum. Likewise cadmium-plated bolts, screws, and fittings may be used in contact with aluminum, for the same reason.

Industrial and Seacoast vs. Rural Atmospheres: The higher salt content of moisture condensing from industrial and seacoast atmospheres makes such moisture a better electrical conductor, thus promoting electrolytic action.

Mechanical Contact: Since mechanical contact is necessary for electrolytic action, separating the adjoining metals afford an easy method of protection. Thus, where it is necessary for aluminum to contact black sheet iron, cover the iron with aluminum paint, zinc dust paint, or some non-metallic material such as asphalt or bituminous paint, building paper, or asbestos paper.

Immune to Most Chemicals: Aluminum is unaffected by many chemicals and acids that seriously attack galvanized steel and iron. Sulfur fumes that necessitate replacement of ordinary galvanized roofing every few months have no effect whatever on aluminum roofing which has withstood years of use in the same plant.

Alkali Attack: Aluminum is subject to attack by the free alkali in cement, plaster, and mortar where the aluminum contacts are likely to be moist for extended periods, as on wall, roof, and chimney flashing. In such applications, protect the aluminum by coating the contacting areas with asphalt or bituminous paint. No attack will occur if so protected.

From the above, it is evident that the non-rusting characteristic of aluminum is an important feature of real value. The deleterious effect of dissimilar metal contacts, oxidation, and corrosion are all relatively unimportant as they are either easily avoided or do insignificant damage.

No Painting: Competition says, “Aluminum engineers recommend that the same protection be given aluminum as that used for other materials”. That is not true. Aluminum manufacturers advertise, sell, and recommend the use of bare untreated aluminum for all sorts of building products including roofing and siding of many different types. Painting is not necessary to protect aluminum.

Easy to Handle … Lighter Roof Loads: Competition says, “The difference in weight is not considered important in roofing”. While it may not be important to the man selling steel roofing, it is important to the warehouse, applicator, and user of roofing sheet. To say that a reduction of nearly 200 lbs. for every 100 lbs. of aluminum used is unimportant is just plain distortion of fact.

Labor involved in application is a definite and large factor in cost of a roof. The favorable difference in weight of aluminum can be important in reducing the installed cost.

Comparison of Weights: A 10’ sheet of 29-gage galvanized weighs 16-3/4 lbs. A 10’ sheet of aluminum 0.019” thick (35% thicker than the galvanized) weighs only 6-1/4 lbs. A barn roof requiring 30 squares of sheet would weigh 1.25 tons in galvanized, but only 937 lbs. in aluminum. This great weight of galvanized accounts for the sagging roofs readily found in many installations. A sagging roof distorts and leaks. To say that a lighter roof load is unimportant completely disregards the importance of leaks.

Lapping Sheets of aluminum over galvanized sheets can be done without undesired reactions because the zinc coating has approximately the same solution potential as aluminum. However, perfect guarantee against any reaction can be had simply by applying common asphalt roofing paint to one of the contacting surfaces. In average Steel density is 2.9 greater than aluminum density.

Heat Reflectivity … Means Cooler Buildings: Aluminum is much superior to other metals in its ability to reflect the infra-red or heat rays of the sun. And this high reflectivity (up to 95%) is reduced only very slightly as the aluminum weathers and loses its brilliance. Remember that light reflectivity (up to 85% for aluminum) has little relation to heat reflectivity.

On the other hand, galvanized steel rapidly loses its heat reflectivity as it weathers. Here are the figures: Aluminum, 90-95% when bright; 85-94% when weathered. Galvanized steel, 92% when bright; 55-65% when weathered. Carbon steel heat reflectivity 50% new to 20% oxidize
Don’t let anyone tell you that aluminum and galvanized steel have the same reflectivity.

Aluminum is far superior, especially in heat reflectivity, the factor that makes for cooler buildings. Tests have shown an aluminum roof will often reduce inside temperatures by as much as 15° F.

Emissivity: On the other hand, aluminum has lower emissivity than other metals including galvanized steel … but this is good, and here’s why: Emissivity means heat radiating power, the ability to dissipate heat by radiation. If two solid blocks of metal, the same size, one of aluminum, the other of galvanized steel, are both heated to the same temperature and allowed to stand, the aluminum will stay hot longer because it radiates less heat.

But radiation of heat through the roof and sidewalls of a building is not the way to cool any building. It is much better to reflect the heat off the roof and prevent the building from getting hot in the first place. That's what an aluminum roof does, it prevents it from getting hot.

Fire Protection: Competition says, "Steel has an advantage over aluminum; aluminum melts at about 1220º F., steel at about 2700º F. Also, aluminum is more combustible than steel." Both statements are misleading.
Any fire that melts aluminum (1200º F. approx.) will also damage the galvanizing (or painted steel) that the galvanized steel will be worthless because the zinc coating melts at 787º F. The fact that the steel doesn't melt till 2500º F. therefore is of no importance. Once the galvanizing is gone, the steel is of no value as a building material and very little as scrap. On the other hand, damaged aluminum has a high scrap value.

During a fire in a contiguous tank is more likely that the steel roof reaches the melting point first than aluminum. The reasons for that are:
a) Reflectivity: Most of the radiation heat will be reflected by the aluminum (95% to 85%)

b) The heat conductivity for aluminum is in average 3 times larger than steel, therefore when exposed to fire it takes much longer to heat aluminum to its limit temperature than it does steel (the heat is concentrate rapidly in one spot). This property is especially important with respect to the fire safety of the roof structural frame.

c) The specific heat of aluminum is almost twice as great as that of steel. The specific heat is the amount of heat required to raise 1 pound of metal 1 oF. Thus a pound of aluminum will absorb almost twice as much heat as a pound of steel for a given rise of temperature Combustibility of aluminum vs. steel is unimportant because neither will burn unless in finely
divided powder form. Even the thinnest aluminum foil (0.00017" thick) cannot be made to burn, it simply melts.
Strength at high temperature: Aluminum maintains at high degree of

strength at high temperature. If the metal is held at 400 of for one hour its tensile strength will drop approximately 5%. If it is held at 400 of for 16 hours its tensile strength will drop approximately 10%. Niether of these reductions in strength will be critical to the Aluminum dome since the dead weight of the structure (approximately 3 pounds per square foot) is about 17.5 of its live load design capacity (20 pounds per square foot). It is also a fact that aluminum return to almost 100% of its original strength, this fact is not true for steel. This property is also especially important with respect to the fire safety of the roof structural frame.

Less Rigidity: Aluminum is more flexible than steel, having a modulus of elasticity (a measure of its rigidity) about one-third that of steel. However, aluminum sheet can be made as rigid as steel by increasing its thickness approximately 40%. But if the aluminum is embossed it is possible to obtain the same rigidity with the same thickness … offering important additional economies. The embossed pattern greatly strengthens the sheet structurally.

The owner of a building is not so much interested in elasticity figures as he is in maintenance and replacement costs. Remember too, that in cases where the span of the roof sheet or purling spacing is a factor, as in industrial buildings, ample rigidity can easily be obtained by using more deeply corrugated sheet designs which are available. Greatly increased load-carrying ability can be had with only a small amount of added material.

Initial Cost: Many distorted pictures of the cost of aluminum vs. galvanized steel have been presented.
In the first place, equal rigidity may not be required at all. Minimum steel thicknesses are determined by rolling and galvanizing costs. In other words, a thinner steel sheet would not cost less because cost of rolling and galvanizing would more than offset the saving in reduced amount of steel. Since aluminum roofing and siding is homogeneous material, these factors do not enter and it is only necessary to use a sheet of sufficient thickness to give the actual strength required.

Many such cost comparisons disregard the economies possible from use of aluminum, its light weight and ease of application, substantially reducing erection costs; its immunity to rust assuring longer life and less maintenance; the complete elimination of any need for painting or repainting, etc. So watch the initial cost comparisons.

Quiet . . . No Excessive Noise From Wind, Rain, Etc.: Aluminum is acoustically dead material; that is, it tends to deaden sound waves and not transmit them as freely as other metals.

The net result is that a building covered with aluminum roofing and siding is noticeably quieter than one covered with other metallic materials.

Finally, aluminum has been in the building construction market place for many years now. New paint coatings and surfaces have added aesthetics to a substrate that only needed these coatings and surfaces for good looks, not protection from the elements.

Fifth Lecture

Aggregates

- Aggregates generally occupy 65- 80% of a concrete’s volume. Aggregates are inert fillers floating in the cement paste matrix for concretes of low strength. The strength of aggregates do not contribute to the strength of concrete for low strength concrete. The characteristics of aggregates impact performance of fresh and hardened concrete.

Why use aggregate

- Reduce the cost of the concrete – 1/4 - 1/8 of the cement price
- Reduce thermal cracking – 100 kg of OPC produces about 12oC temperature rise
- Reduces shrinkage – 10% reduction in aggregate volume can double shrinkage
- High aggregate : cement ratio (A/C) desirable
- A/C mainly influenced by cement content
- Imparts unit weight to concrete

Aggregate Classification

- Size:- Coarse Aggregates & Fine Aggregates.
- Specific Gravity:- Light Weight, Normal Weight and Heavy Weight Aggregates.
- Availability:- Natural Gravel and Crushed Aggregates.
- Shape:- Round, Cubical, Angular, Elongated and Flaky Aggregates.
- Texture:- Smooth, Granular, Crystalline, honeycombed and Porous.

Aggregate Classification : Size

- Fine Aggregate
  - Sand and/or crushed stone.
  - < 4.75 mm.
  - F.A. content usually 35% to 45% by mass or volume of total aggregate.
- Coarse Aggregate
  - Gravel and crushed stone.

  - >4.75 mm.
  - Typically between 9.5 and 37.5 mm.

Aggregate Classification : Specific Gravity

- Normal-Weight Aggregate
  - Most common aggregates (Ex: Sand, Gravel, Crushed stone)
  - Produce normal-weight concrete 2200 to 2400 kg/m3
- Lightweight Aggregate
  - Expanded (Shale, Clay, Slate, Slag)
  - Produce structural lightweight concrete 1350 to 1850 kg/m3
  - And (Pumice, Scoria, Perlite, Diatomite)
  - Produce lightweight insulating concrete— 250 to 1450 kg/m3

Aggregate Classification : Specific Gravity

- **Heavyweight Aggregate**
  - Barite, Limonite, Magnetite, Hematite, Iron
  - Produce high-density concrete up to 6400 kg/m3
  - Used for Radiation Shielding

Aggregate Classification : Availability

- Natural Gravel
  - River or seashore gravels; desert, seashore and windblown sands
  - Rounded in nature
  - Fully water worn or completely shaped by attrition
- Crushed Aggregates.
  - Crushed rocks of all types; talus; screes
  - Angular in nature

Aggregate Classification : Shape

- The shape of aggregates is an important characteristic since it affects the workability of concrete.

Aggregate Classification : Texture

- Surface texture is the property, the measure of which depends upon the relative degree to which particle surfaces are polished or dull, smooth or rough.
- Surface texture depends on hardness, grain size, pore structure, structure of the rock

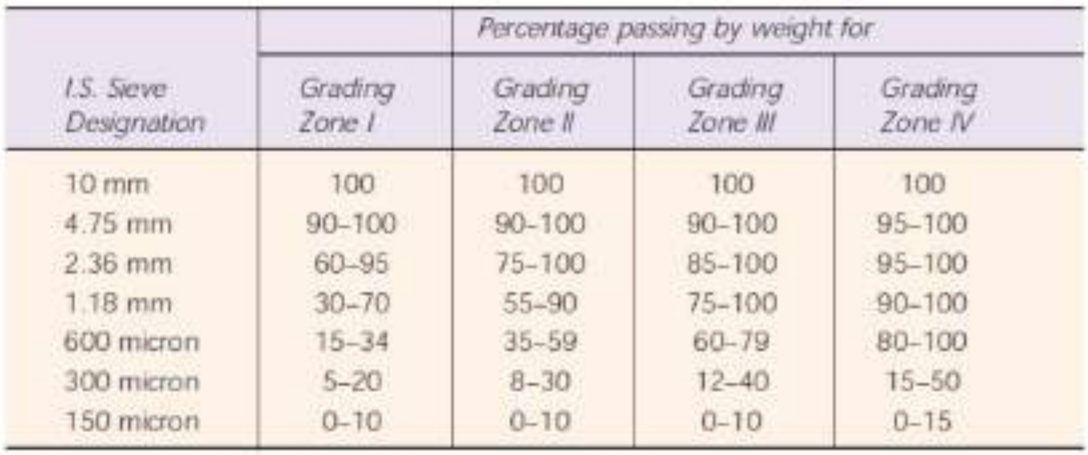
Physical Prosperities of Aggregate : Grading

- Grading is the particle-size distribution of an aggregate as determined by a sieve analysis using wire mesh sieves with square openings.

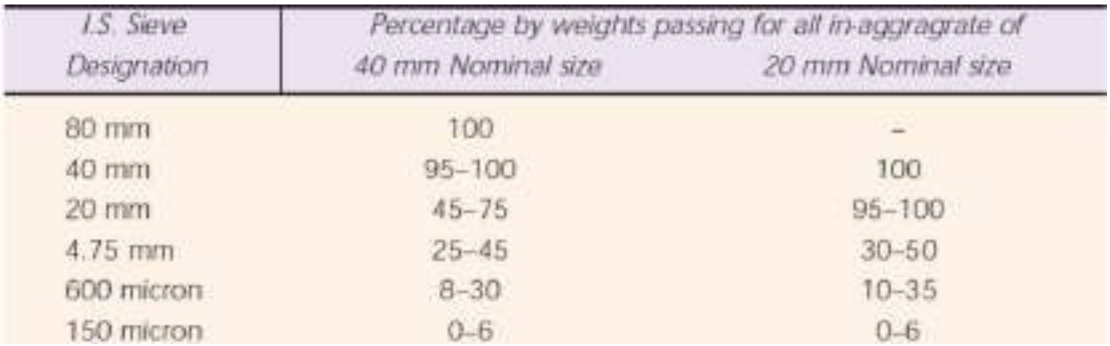
- As per IS:2386(Part-1)
- Fine aggregate : 6 standard sieves with openings from 150 µm to 4.75 mm. (150 µm, 300 µm, 600 µm, 1.18mm, 2.36mm, 4.75mm)
- Coarse aggregate: 5 sieves with openings from 4.75mm to 80 mm. (4.75mm, 10mm, 12.5mm, 20mm, 40mm)

Physical Prosperities of Aggregate : Grading

- Grain size distribution for concrete mixes that will provide a dense strong mixture.
- Ensure that the voids between the larger particles are filled with medium particles. The remaining voids are filled with still smaller particles until the smallest voids are filled with a small amount of fines.



I.S. Sieve Designation	*Percentage passing by weight for*			
	Grading Zone I	*Grading Zone II*	*Grading Zone III*	*Grading Zone IV*
10 mm	100	100	100	100
4.75 mm	90–100	90–100	90–100	95–100
2.36 mm	60–95	75–100	85–100	95–100
1.18 mm	30–70	55–90	75–100	90–100
600 micron	15–34	35–59	60–79	80–100
300 micron	5–20	8–30	12–40	15–50
150 micron	0–10	0–10	0–10	0–15



I.S. Sieve Designation	Percentage by weights passing for all in-aggragrate of 40 mm Nominal size	20 mm Nominal size
80 mm	100	–
40 mm	95–100	100
20 mm	45–75	95–100
4.75 mm	25–45	30–50
600 micron	8–30	10–35
150 micron	0–6	0–6

Fineness Modulus (FM)

- The results of aggregate sieve analysis is expressed by a number called Fineness Modulus. Obtained by adding the sum of the cumulative percentages by mass of a sample aggregate retained on each of a specified series of sieves and dividing the sum by 100.
- The following limits may be taken as guidance:
- Fine sand : Fineness Modulus : 2.2 - 2.6
- Medium sand : F.M. : 2.6 - 2.9
- Coarse sand : F.M. : 2.9 - 3.2
- A sand having a fineness modulus more than 3.2 will be unsuitable for making satisfactory concrete.

$$\text{Finess Modulus, } FM = \left(\frac{\text{Total of Cumulative Percentage of Passing (\%)}}{100} \right)$$

Physical Properties of Aggregate:

Flakiness Index

- The flakiness index of aggregate is the percentage by weight of particles in it whose least dimension (thickness) is less than three-fifths of their mean dimension.
- The test is not applicable to sizes smaller than 6.3 mm.
- The flakiness index is taken as the total weight of the material passing the various thickness gauges expressed as a percentage of the total weight of the sample taken.
- Table 3.18 shows the standard dimensions of thickness and length gauges.

Physical Properties of Aggregate:

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Physical Properties of Aggregate: Flakiness Index

Physical Properties of Aggregate: Elongation Index

- The elongation index on an aggregate is the percentage by weight of particles whose greatest dimension (length) is greater than 1.8 times their mean dimension.
- The elongation index is not applicable to sizes smaller than 6.3 mm.
- The elongation index is the total weight of the material retained on the various length gauges expressed as a percentage of the total weight of the sample gauged. The presence of elongated particles in excess of 10 to 15 per cent is generally considered undesirable, but no recognized limits are laid down.

Six Lecture

Cement

- In the most general sense of the word, a **cement** is a binder, a substance that sets and hardens independently, and can bind other materials together.
- Cement used in construction is characterized as hydraulic or non-hydraulic. Hydraulic cements (e.g., Portland cement) harden because of hydration, chemical reactions that occur independently of the mixture's water content; they can harden even underwater or when constantly exposed to wet weather.

History of the origin of cement

- John Smeaton made an important contribution to the development of cements when he was planning the construction of the third Eddystone Lighthouse (1755–9) in the English Channel. He needed a hydraulic mortar that would set and develop some strength in the twelve hour period between successive high tides.
- In 1824, Joseph Aspdin patented a similar material, which he called Portland cement, because the render made from it was in color similar to the prestigious Portland stone.

History of the origin of cement

- The investigations of L.J.Vicat led him to prepare an artificial hydraulic lime by calcining an intimate mixture of limestone and clay.
- Later in 1845 Isaac Charles Johnson burnt a mixture of clay and chalk till the clinkering stage to make better cement and established factories in 1851.
- The German standard specification for Portland cement was drawn in 1877.

History of the origin of cement

- The British standard specification was first drawn up in 1904. The first ASTM specification was issued in 1904.
- In India, Portland cement was first manufactured in 1904 near Madras, by the South India Industrial Ltd. But this venture failed.
- Between 1912 and 1913, the Indian Cement Co. Ltd., was established at Porbander (Gujarat) and by 1914 this Company was able to deliver about 1000 tons of Portland cement.

Manufacture of Portland Cement

- Cement is made by heating limestone (calcium carbonate) with small quantities of other materials (such as clay) to 1450 °C in a kiln, in a process known as calcinations, whereby a molecule of carbon dioxide is liberated from the calcium carbonate to form calcium oxide, or quicklime, which is then blended with the other materials that have been included in the mix.
- The resulting hard substance, called 'clinker', is then ground with a small amount of gypsum into a powder to make 'Ordinary Portland Cement', the most commonly used type of cement (often referred to as OPC).

Manufacture of Portland Cement

Manufacture of Portland Cement

- Step 1 – Quarrying Limestone and a 'cement rock' such as clay or shale are quarried and brought to the cement works. These rocks contain lime (CaCO3), silica (SiO2), alumina (Al2O3) and ferrous oxide (Fe2O3) - the raw materials of cement manufacture.

product, it is
- Step 2 - Raw material preparation To form a consistent essential that the same mixture of minerals is used every time. For this reason the exact composition of the limestone and clay is determined at this point, and other ingredients added if necessary. The rock is also ground into fine particles to increase the efficiency of the reaction.

Manufacture of Portland Cement

- The dry process :

The quarried clay and limestone are crushed separately until nothing bigger than a tennis ball remains. Samples of both rocks are then sent off to the laboratory for mineral analysis. If necessary, minerals are then added to either the clay or the limestone to ensure that the correct amounts of aluminium, iron etc. are present. The clay and limestone are then fed together into a mill where the rock is ground until more than 85% of the material is less than 90µm in diameter.

Manufacture of Portland Cement

- The wet process :

The clay is mixed to a paste in a wash mill - a tank in which the clay is pulverized in the presence of water. Crushed lime is then added and the whole mixture further ground.

Any material which is too coarse is extracted and reground. The slurry is then tested to ensure that it contains the correct balance of minerals, and any extra ingredients blended in as necessary.

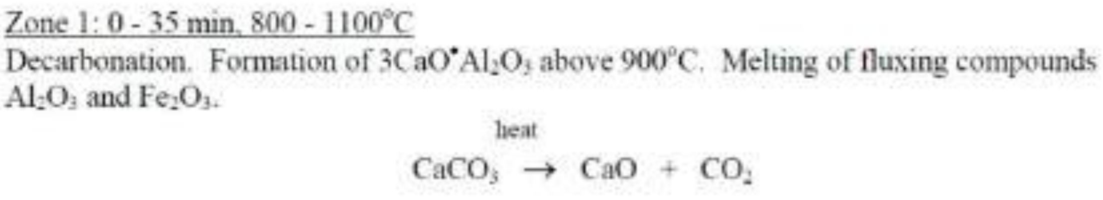
Manufacture of Portland Cement

- Step 3 – Clinkering The raw materials are then dried, heated and fed into a rotating kiln. Here the raw materials react at very high temperatures to form 3CaO • SiO2 (tricalcium silicate), 2CaO • SiO2 (dicalcium silicate), 3CaO • Al2O3 (tricalcium aluminate) and 4CaO • Al2O3 • Fe2O3 (tetracalcium alumino-ferrate).

Manufacture of Portland Cement

- The kiln : The kiln shell is steel, 60m long and inclined at an angle of 1 in 30. The shell is supported on 3 roller trunions and weighs in at over 1100 T. The kiln is heated by injecting pulverized coal dust into the discharge end where it spontaneously ignites due to the very high temperatures. Coal is injected with air into the kiln at a rate of 9 - 12 T/hr.

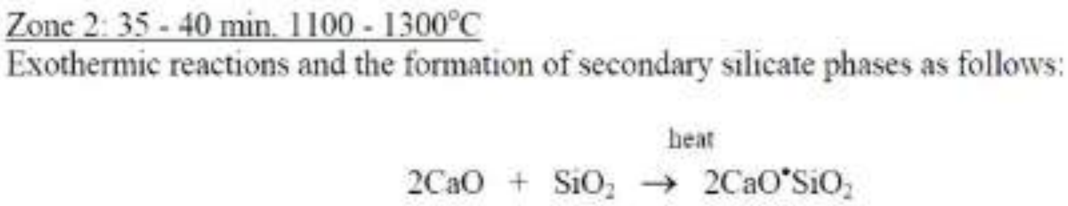
Manufacture of Portland Cement



Zone 1: 0 - 35 min. 800 - 1100°C

Decarbonation. Formation of $3CaO^{\bullet}Al_2O_3$ above 900°C. Melting of fluxing compounds Al_2O_3 and Fe_2O_3.

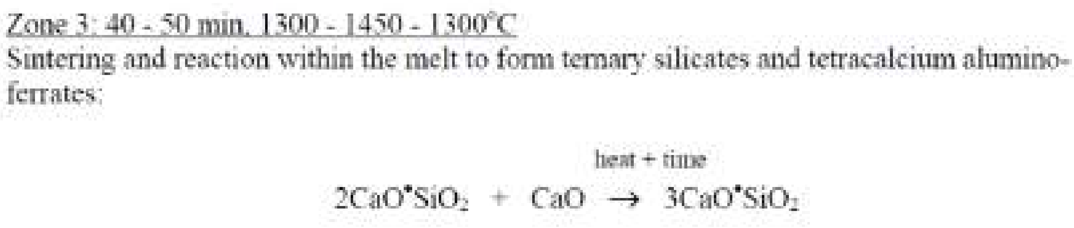
$$CaCO_3 \xrightarrow{\text{heat}} CaO + CO_2$$



Zone 2: 35 - 40 min. 1100 - 1300°C

Exothermic reactions and the formation of secondary silicate phases as follows:

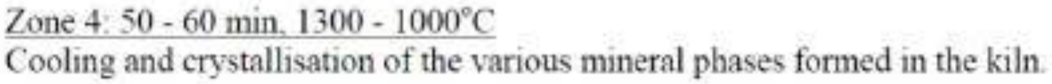
$$2CaO + SiO_2 \xrightarrow{\text{heat}} 2CaO^{\bullet}SiO_2$$



Zone 3: 40 - 50 min. 1300 - 1450 - 1300°C

Sintering and reaction within the melt to form ternary silicates and tetracalcium alumino-ferrates:

$$2CaO^{\bullet}SiO_2 + CaO \xrightarrow{\text{heat + time}} 3CaO^{\bullet}SiO_2$$



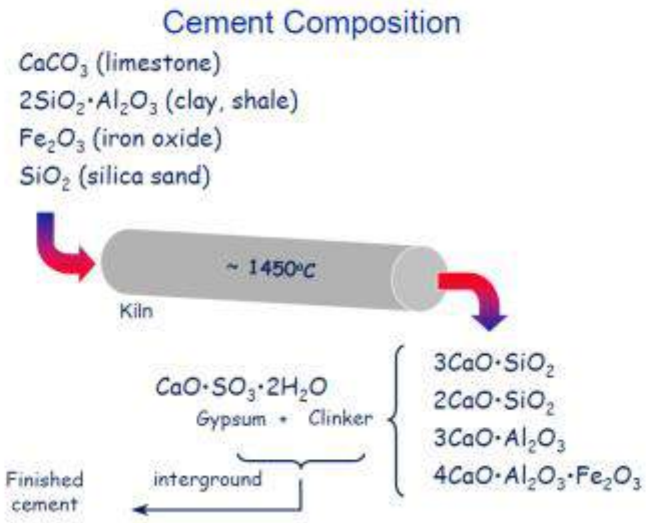
Zone 4: 50 - 60 min, 1300 - 1000°C

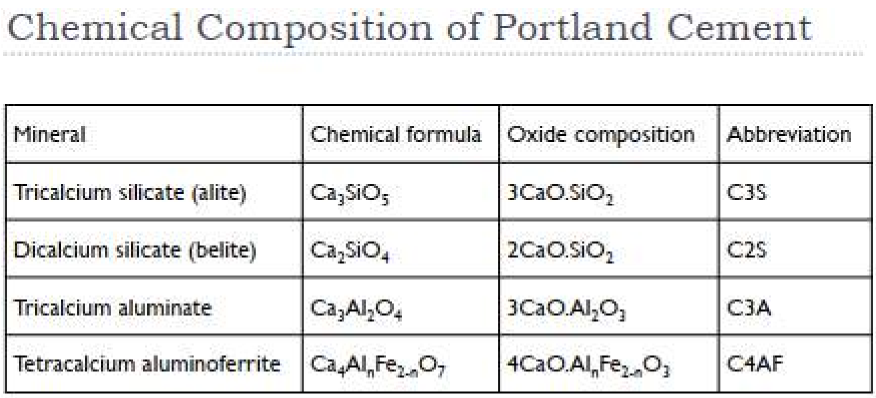
Cooling and crystallisation of the various mineral phases formed in the kiln.

Step 4 - Cement milling The 'clinker' that has now been roduced will behave just like cement, but it is in particles up to 3 cm in diameter. These are ground down to a fine powder to turn the clinker into useful cement.

Chemical Composition of Portland Cement

▸ The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide. These oxides interact with one another in the kiln at high temperature to form more complex compounds. The relative proportions of these oxide compositions are responsible for influencing the various properties of cement; in addition to rate of cooling and fineness of grinding.





Chemical Composition of Portland Cement

Mineral	Chemical formula	Oxide composition	Abbreviation
Tricalcium silicate (alite)	Ca_3SiO_5	$3CaO.SiO_2$	C3S
Dicalcium silicate (belite)	Ca_2SiO_4	$2CaO.SiO_2$	C2S
Tricalcium aluminate	$Ca_3Al_2O_4$	$3CaO.Al_2O_3$	C3A
Tetracalcium aluminoferrite	$Ca_4Al_nFe_{2-n}O_7$	$4CaO.Al_nFe_{2-n}O_3$	C4AF

Hydration of cement

- When Portland cement is mixed with water its chemical compound constituents undergo a series of chemical reactions that cause it to harden. This chemical reaction with water is called "hydration".
- Each one of these reactions occurs at a different time and rate. Together, the results of these reactions determine how Portland cement hardens and gains strength.

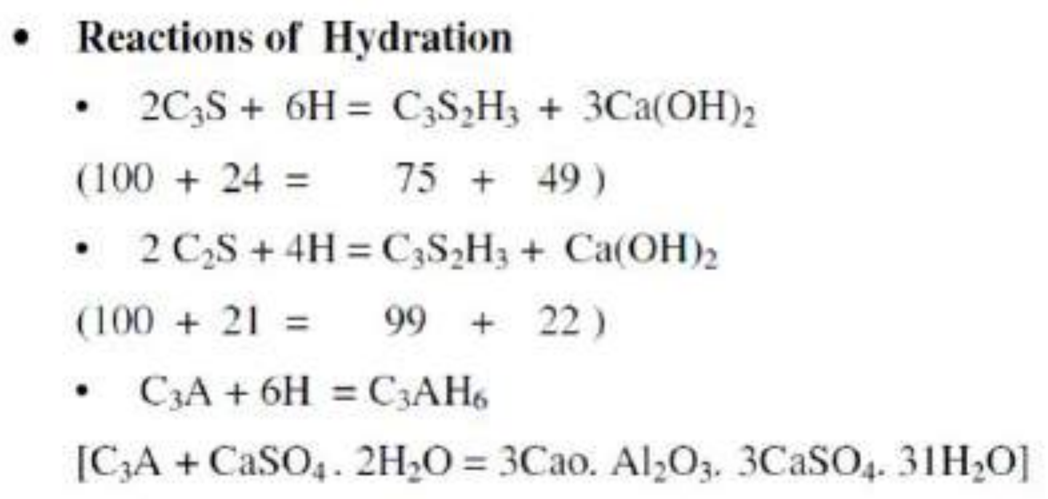
Hydration starts as soon as the cement and water are mixed.

- The rate of hydration and the heat liberated by the reaction of each compound is different.
- Each compound produces different products when it hydrates.
- Tricalcium silicate (C3S). Hydrates and hardens rapidly and is largely responsible for initial set and early strength.

Portland cements with higher percentages of C3S will exhibit higher early strength.

Tricalcium aluminate (C3A). Hydrates and hardens the quickest. Liberates a large amount of heat almost immediately and contributes somewhat to early strength. Gypsum is added to Portland cement to retard C3A hydration.Without gypsum, C3A hydration would cause Portland cement to set almost immediately after adding water.

- Dicalcium silicate (C2S). Hydrates and hardens slowly and is largely responsible for strength increases beyond one week.
- Tetracalcium aluminoferrite (C4AF). Hydrates rapidly but contributes very little to strength. Its use allows lower kiln temperatures in Portland cement manufacturing. Most Portland cement color effects are due to C4AF



- **Reactions of Hydration**
  - $2C_3S + 6H = C_3S_2H_3 + 3Ca(OH)_2$

    $(100 + 24 = 75 + 49)$
  - $2C_2S + 4H = C_3S_2H_3 + Ca(OH)_2$

    $(100 + 21 = 99 + 22)$
  - $C_3A + 6H = C_3AH_6$

    $[C_3A + CaSO_4 . 2H_2O = 3CaO. Al_2O_3. 3CaSO_4. 31H_2O]$

Heat of Hydration

- The reaction of cement with water is exothermic. The reaction liberates a considerable quantity of heat. This liberation of heat is called heat of hydration. This is clearly seen if freshly mixed cement is put in a vacuum flask and the temperature of the mass is read at intervals.
- The study and control of the heat of hydration becomes important in the construction of concrete dams and other mass concrete constructions. It has been observed that the temperature in the interior of large mass concrete is 50°C above the original temperature of the concrete mass at the time of placing and this high temperature is found to persist for a prolonged period.

The heat of hydration is the heat generated when water and Portland cement react. Heat of hydration is most influenced by the proportion of C3S and C3A in the cement, but is also influenced by water-cement ratio, fineness and curing temperature. As each one of these factors is increased, heat of hydration increases.

- For usual range of Portland cements, about one-half of the total heat is liberated between 1 and 3 days, about three-quarters in 7 days, and nearly 90 percent in 6 months.
- The heat of hydration depends on the chemical composition of cement.

Seventh Lecture

Concrete

A composite material that consists essentially of a binding medium, such as a mixture of Portland cement and water, within which are embedded particles or fragments of aggregate, usually a combination of fine and coarse aggregate

. Because the tensile strength of concrete is much lower than its compressive strength, it is typically reinforced with steel bars, in which case it is known as reinforced concrete.

Cement

Cement is the “glue” that binds the concrete ingredients together and is instrumental for the strength of the composite.

The primary product of cement hydration is a complex and poorly crystalline calcium-silicate hydroxide gel (or CSH). A secondary product of hydration is calcium hydroxide, a highly crystalline material. A category of siliceous materials known as pozzolans have little or no cementitious value, but in finely divided form and in the presence of moisture will react chemically with calcium hydroxide to form additional CSH. This secondary hydration process has a generally beneficial effect on the final concrete properties. Examples of pozzolans are fly ash, ground granulated blast-furnace slag, and micro silica or silica fume. The American Society for Testing and Materials (ASTM) defines five types of cement, specifying for each the mineral composition and chemical and physical characteristics such as fineness. The most common cement is Type I. Type III cement is used if more rapid strength envelopment is required. The other types are characterized by either lower heat of hydration or better sulfate resistance than that of Type I cement.

Aggregate

The aggregate is a granular material, such as sand, gravel, crushed stone, or iron-blast furnace slag. It is graded by passing it through a set of sieves with progressively smaller mesh sizes. All material that passes through sieve #4 [0.187 in. (4.75 mm) openings] is conventionally referred to as fine aggregate or sand, while all material that is retained on the #4 sieve is referred to as coarse aggregate, gravel, or stone.

the smaller particles fill the void spaces between the larger particles. Such dense packing minimizes the amount of cement paste needed and generally leads to improved mechanical and durability properties of the concrete.
The aggregate constitutes typically 75% of the concrete volume, or more, and therefore its properties largely determine the properties of the concrete. For the concrete to be of good quality, the aggregate has to be strong and durable and free of silts, organic matter, oils, and sugars. Otherwise, it should be washed prior to use, because any of these impurities may slow or prevent the cement from hydrating or reduce the bond between the cement paste and the aggregate particles.

Admixtures

mineral and chemical admixtures that may be added to the concrete. The four most common admixtures will be discussed.

1. Air-entraining agents

are chemicals that are added to concrete to improve its freeze–thaw resistance. Concrete typically contains a large number of pores of different sizes, which may be partially filled with water. If the concrete is subjected to freezing temperatures, this water expands when forming ice crystals and can easily fracture the cement matrix, causing damage that increases with each freeze–thaw cycle. If the air voids created by the air-entraining agent are of the right size and average spacing, they give the freezing water enough space to expand, thereby avoiding the damaging internal stresses

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2. **Water-reducing admixtures**

superplasticizers, are chemicals that lower the viscosity of concrete in its liquid state, typically by creating electrostatic surface charges on the cement and very fine aggregate particles. This causes the particles to repel each other, thereby increasing the mix flow ability, which allows the use of less water in the mix design and results in increased strength and durability of the concrete

.

3**. Retarding**

delay the setting time, which may be necessary in situations where delays in the placement of concrete can be expected. Accelerators shorten the period needed to initiate cement hydration—for example, in emergency repair situations that call for the very rapid development of strength or rigidity

4. Color pigments in powder or liquid form may be added to the concrete mix to produce colored concrete. These are usually used with white Portland cement to attain their full coloring potential.

Reinforcing steels. Because of concrete's relatively low tensile strength, it is typically reinforced with steel bars Reinforcing steel usually has a nominal yield strength of 60,000 lb/in.2 (414 MPa).

protection The alkalinity of the cement paste generally provides sufficient of the steel against corrosion. However, corrosion protection is often breached, for example, in highway bridge decks with continuous pore structure or traffic-induced cracks that permit the deicing chemicals used in winter to penetrate the protective concrete cover. Additional protective measures may be necessary, such as using epoxy coatings on the bars, noncorrosive steels, or nonmetallic reinforcement.

Cement paste plus fine aggregate is called mortar or concrete matrix. Mortar plus coarse aggregate constitutes concrete. Concrete reinforced

MIX DESIGN

Any excess water creates pores which, together with any air-filled pores, do not contribute to the material strength. The result is a drastic decrease in strength as a function of increasing the w/c ratio. On the other hand, too low w/c ratios cause poor workability of the concrete. For practical reasons, the w/c ratio typically varies between 0.4 and 0.6. The other important mix design variables are the cement-to-aggregate ratio and the fine-to-coarse aggregate ratio. Also, the maximum aggregate size is of importance. And since cement is the most expensive bulk ingredient, the mix design will generally aim at the least amount of cement necessary to achieve the design objectives.

Construction practice

Precast concrete refers to any structure or component that is produced at one site, typically in a precasting plant, and then transported in its hardened state to its final destination.

. if dropped too far, the heavy or big aggregate particles can settle and lighter mix components, such as water, tend to rise.

During placement, large amounts of air are entrapped in the mix, which lowers the strength of the hardened concrete. Much of the air is removed by compaction, which is achieved by either immersing high-frequency vibrators into the fresh concrete or attaching them to the outside faces of the formwork. Care must be taken to avoid excessive vibration; otherwise the heavy aggregate particles settle down and the light mixing water rises to the surface.

For underwater construction, the concrete is placed in a large metal tube, called a tremie, with a hopper at the top and a valve arrangement at the submerged end. For so-called shotcrete applications such as tunnel linings and swimming pools, the concrete mixture is blown under high pressure through a nozzle directly into place to form the desired surface

Curing

For example, in hot or dry weather large exposed surfaces will lose water by evaporation. This can be avoided by covering such surfaces with sheets of plastic or canvas or by periodically spraying them with water. In precast concrete plants, concrete elements are often steam-cured, because the simultaneous application of hot steam and pressure accelerates the hydration process, which permits high turnover rates for the formwork installations.

Properties of fresh concrete.

The most important property of fresh concrete is its workability or flow ability, because this determines the ease with which it can be placed. It is determined using a slump test, in which a standard truncated metal cone form is filled with fresh concrete. The mold is then lifted vertically, and the resulting loss in height of the concrete cone, or the slump value, is indicative of the concrete’s workability.

Properties of hardened concrete.

Most commercially produced concrete has compressive strengths between 3000 and 6000 lb/in.2 (20 and 40 MPa).

During hydration and especially if allowed to dry after hardening, the concrete volume decreases by a small amount because of shrinkage. If this shrinkage is restrained somehow, it can lead to cracking.

A concrete member or structure subjected to external load will undergo deformations which, up to a point, are proportional to the amount of applied load. If these loads remain in place for an appreciable time (months or years), these deformations will increase due to a material property called creep.

Durability. Durability is the ability of a material (or structure) to maintain its various properties throughout its design or service life.

There can be numerous causes for loss of durability or deterioration of concrete structures. The most common one is an excessive amount of cracking or pore structure.

Larger cracks provide easy access for such agents to the steel, thereby promoting corrosion.

The concrete itself may deteriorate or weather, especially if subjected to many cycles of freezing and thawing, during which the pressure created by the freezing water progressively increases the extent of internal cracking. In addition, carbon in the atmosphere can react chemically with the cement hydration products. This process is known as carbonation.
It lowers the pH of the concrete matrix to the point where it can no longer protect the steel against corrosion.

Most types of aggregate used for concrete production are inert; that is, they do not react chemically with the cement or hydration products. However, there are various aggregate types, including those containing amorphous silica such as common glass, which react chemically with the alkali in the cement.
In the presence of moisture, the alkali–aggregate reaction products can swell and cause considerable damage.

Under repeated load applications, structures can experience fatigue failure, as each successive load cycle increases the degree of cracking and material deterioration to the point where the material itself may gradually lose its strength or the increased extent of cracking is the source of loss of durability.
Thermal and other properties. The heavy weight of concrete [its specific gravity is typically 2.4 g/cm3 (145 lb/ft3)] is the source of large thermal mass. concrete structures can moderate extreme temperature cycles and increase the comfort of occupants.

Special concretes and recent developments.

Lightweight concrete

because of the large stresses caused by their own heavy weight, floor slabs are often made lighter by using special lightweight aggregate. To further reduce weight, special chemical admixtures are added, which produce large porosity.
Such high porosity (in either the matrix or the aggregate particles themselves) improves the thermal resistance of the concrete as well as sound insulation, especially for higher frequencies. However, because weight density correlates strongly with strength, ultra lightweight concretes [1.1 g/cm3 (70 lb/ft3) and less] are used only for thermal or sound insulation purposes and are unsuitable for structural applications.

. ***Heavyweight concrete***. When particularly high weight densities are needed, such as for shielding in nuclear reactor facilities

Fiber-reinforced concrete

Fibers may be metallic (primarily steel), synthetic (such as polypropylene, nylon, polyethylene, polyvinyl alcohol, and alkali-resistant glass), or natural (such as sisal, coconut, and rice husk).

fibers give the concrete matrix tensile strength, ductility, and energy absorption capacities that it otherwise would not have.

fiber-reinforced concrete

Whereas in fiber-reinforced concrete the fibers are short [usually no longer than 2 in. (5 cm)]

Ultra-high-strength concrete. Whereas concretes with compressive strengths of 6000 to 12,000 lb/in.2 (40 to 85 MPa) can now be categorized as high-strength

Other characteristics of this material are low water–cement ratios, carefully selected high-strength aggregates, and small steel fibers

. ***“Green” concrete***

the production of 1 ton of portland cement causes the release of 1 ton of carbon dioxide (CO2) into the atmosphere The most significant step is the replacement of portland cement by other cementitious or pozzolanic materials, preferably materials that are byproducts of industrial processes, such as fly ash (the by-product of coal-burning power plants) and granulated blast furnace slag (a by-product of the steel industry)

Eighth Lecture

Mortar

INTRODUCTION

The principal purpose of mortar is to adhesively bind together the individual masonry units. It also provides protection against the penetration of air and water through the joints in a masonry.

Mortar also bonds the non-masonry elements of an assembly such as joint reinforcement and ties. It also compensates for minor dimensional variations in the masonry units, and provides coursing adjustment to meet required dimensions. Finally, mortar joints contribute to the architectural effect of the masonry assembly both through color and shadow.

Mortars are supplied to the job site in three ways:

- Site mixed – the mortar is prepared on site by the worker.
- Pre-mixed wet – the mortar is commercially prepared off-site and shipped in tubs ready to use. A retarder is added to the mixture to ensure the mortar in tubs does not set up before being placed in the wall.
- Pre-mixed dry – the mortar is commercially prepared off-site and supplied in bulk bags or small bags. Water is added to the mix by the mason on site.

The supply of mortar is not typically specified, but rather determined by the mason based on site conditions.

BOND –PROPERTY

Mortar mixes include ingredients that give it strength (i.e. cement) and those that promote workability and good bond with the masonry units. Good workability and water retentively are essential for maximum bond. A mortar that has overly high cement content will be stronger, but may produce less bond. Conversely, a mortar with moderate cement content will not be as strong, but will have better bond strength.

Mortar bonds masonry units together. Good bond strength will significantly contribute to a masonry wall’s integrity and weather resistance.

- The compressive strength of mortar has only a small effect on the strength of the wall, but gives it durability.

A good balance of strength and bond is required. This leads to both good structural performance and weather resistance.

Site inspection of mortar is generally not a significant concern for designers, because the bricklayer and the specifier are both looking for workable, well-proportioned mixes that ensure installation efficiency for the mason, and long-term performance for the designer.

MORTAR COLOR

From 8-22% of the wall area is taken up with mortar (depending on the unit size), therefore the colour of the mortar can significantly alter the appearance of the wall. Natural gray mortar is the most common and generally the best choice for brick and gray block. It sets off the brick colour nicely and is the most economical. In general, if a brick mortar colour is used it matches the brick in a lighter tone. Coloured mortars are usually specified for coloured block to solidify the colour impact and to simplify cleaning after construction.

SPECIFYING MORTAR

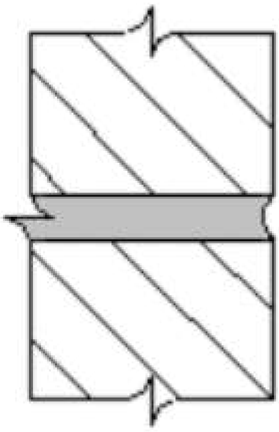
CSA A179-04 Mortar and Grout for Unit Masonry covers raw materials, mortar types, mixing process and mortar specifications. Mortar types within CSA A179-04 are designated by the letters “S” or “N”: Type S is typically used for both structural and veneer masonry, while Type N can also be used for veneer masonry construction. There are also Type O and K mortars that have proportions that are suitable for some restoration projects. Mortar specification can be made either through the Proportion or Property method. The Proportion method is used for site-mixed mortar and is based on the respective volumes of sand and cementitious materials. The Property method is based upon compressive strength tests of mortar cubes, and is typically only used for pre-mixed mortar

JOINT PROFILES

The mortar joint profile has an impact on water resistance. It also has a significant effect on appearance. Ranked by their effectiveness (highest to lowest) to resist penetration of water, common joint types are:

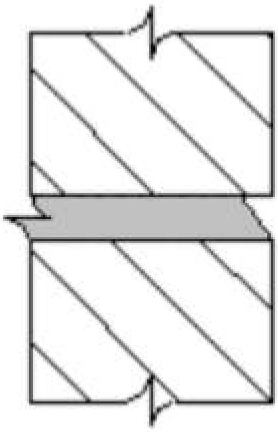
١. Concave Joint

Concave tooling of the mortar joint compacts the mortar properly against the units. A dense, smooth surface is formed that sheds water effectively. This type of joint is very effective in resisting rain penetration and therefore is recommended for use in walls exposed to wind driven rain.



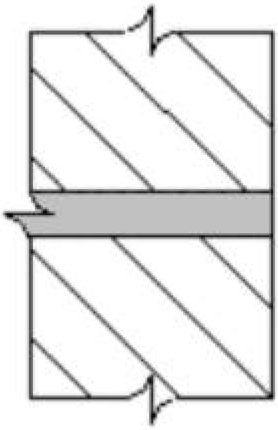
2. Weathered Joint

Although less effective than the concave tooled joint, the weathered or weather joint can be acceptable as a water resistant mortar joint as it is somewhat compacted and sheds the rain.



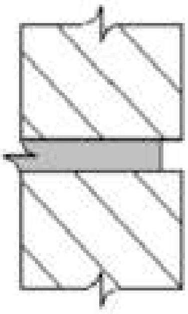
3. Flush Joint

The troweling of a flush joint forms an uncompacted joint with a possible hairline crack where the mortar is pulled away from the unit. Flush joints are not recommended as being rain resistant mortar joints and should only be used on walls that are to receive additional finishes.



4 . Raked Joint

The raked joint may or may not be compacted and it provides a ledge where rain water will settle and possibly enter the wall. It is therefore not recommended as a rain resistant mortar joint and should not be used on walls exposed to weather.
Note: Because raked joints do not weather well, the use of scored block (which require the use of a raked joint) is not recommended for exposed walls)

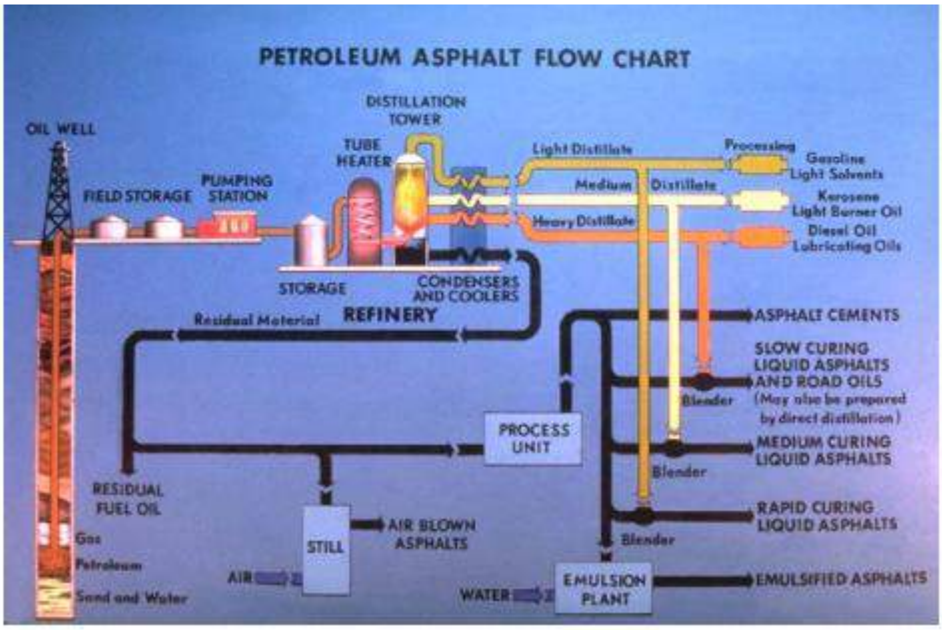


Ninth Lecture

ASPHALT

ASPHALT DEFINED

The black cementing agent known as asphalt has been used for road construction for centuries.
Although there are natural deposits of asphalt, or rock asphalt, most used today is produced
during the refining of crude oil. Asphalt is a constituent of most petroleum's and is isolated
through the refining process



Petroleum Asphalt Flow Chart

Asphalt is called a bituminous material because it contains bitumen, a hydrocarbon material
soluble in carbon disulfate. The tar obtained from the destructive distillation of soft coal also
contains bitumen. Both petroleum asphalt and coal tar are referred to as bituminous materials.

Because their properties differ greatly, petroleum asphalt should not be confused with coal tar. Petroleum asphalt is composed almost entirely of bitumen while the bitumen

content in coal tar is relatively low. The two materials should be treated as separate entities.

One of the characteristics and advantages of asphalt as an engineering construction and maintenance material is its versatility. Although a semi-solid at ordinary temperatures, asphalt may be liquefied by applying heat, dissolving it in solvents, or emulsifying it. Asphalt is a strong cement that is readily adhesive and highly waterproof and durable, making it particularly useful in road building. It is also highly resistant to the actions of most acids, alkalis, and salts.

ASPHALT BINDER

Asphalt is produced in a variety of types and grades ranging from hard-brittle solids to near water thin liquids. The semi-solid form known as asphalt binder is the basic material used in asphalt pavements. Liquid asphalt is produced when asphalt binder is blended or “cut back” with petroleum distillates or emulsified with water and an emulsifying agent. At ambient air temperatures, asphalt binder is a black, sticky, highly viscous material. It is a strong and durable binder with excellent adhesive and waterproofing characteristics. Applying heat, which facilitates mixing with mineral aggregates to produce asphalt pavement, can readily liquefy asphalt binders.

The largest use of asphalt binder is for asphalt pavement. After compacting and cooling to air temperature, asphalt pavement is a very strong paving material with the ability to sustain heavy traffic loads while remaining flexible enough to withstand ambient environmental conditions and stresses. Over 96 percent of the hard-surfaced roads in the United States are paved using asphalt pavement.

EMULSIFIED ASPHALTS

Emulsified asphalts (also known as emulsions) are low-viscosity mixtures of tiny asphalt binder droplets, water and emulsifying agents. The emulsifying agent coats the surfaces of the asphalt droplets and keeps them suspended in the water prior to application. After application, the asphalt emulsion breaks and the water separates and evaporates. Emulsions are brownish in color during application, but after breaking, the asphalt binder returns to its original black color.

Emulsions are used for a Tack Coat between subsequent layers of asphalt pavement to aid in binding the layers together.

CUT-BACK ASPHALTS

Cut-back asphalts are low-viscosity liquid asphalt mixtures manufactured by diluting (cutting back) Asphalt Binders with petroleum solvents (cutter stock or diluent). After application, the petroleum solvent evaporates, leaving the asphalt binder residue.

Cut-Back asphalts may be used as a tack coat between subsequent layers of asphalt pavement, particularly when ambient air temperatures are cool.

ASPHALT BINDER GRADING

Asphalt binders appropriate for pavement construction were previously graded based on resistance to penetration and/or viscosity measures Currently, asphalt binders are graded based on the temperature range over which the binder retains certain desirable characteristics. These desirable characteristics include adequate flexibility to resist cold temperature cracking and sufficient rigidity to resist warm temperature rutting. The current grading system is known as the Performance Grading (PG) system.

PERFORMANCE GRADING

Performance grading specifications were developed as part of the Strategic Highway Research Program (SHRP) and are a major component of SUPERPAVE. Binders are specified on the basis of the climate and pavement temperatures in which the binder is expected to serve.

Performance graded (PG) binders used in Minnesota vary from north to south and with intended use; however, PG 58-28 is the most commonly used grade. The first number (58) represents the average 7-day.

maximum pavement design temperature in degrees Celsius. This maximum temperature establishes the upper temperature limit for the binder to retain adequate rigidity to resist rutting.

The second number (-28) represents the minimum pavement design temperature in degrees

Celsius. The minimum temperature establishes the lower limit for the binder to retain sufficient flexibility to resist thermal cracking.

Physical properties of the binders are measured at various temperatures both before and after laboratory aging. The laboratory aging is conducted to simulate field conditions imposed during the asphalt pavement production process as well as from long-term environmental exposure. Binder physical properties are typically measured using four devices:

- Dynamic Shear Rheometer
- Rotational Viscometer
- Bending Beam Rheometer
- Direct Tension Tester

AGGREGATES

Aggregates (or mineral aggregates) are hard, inert materials such as sand, gravel, crushed rock, slag, or rock dust. Properly selected and graded aggregates are mixed with the asphalt binder to form asphalt pavements. Aggregates are the principal load-supporting components of an asphalt pavement, totaling approximately 95 percent of the mixture by weight.

Classifications

Paving aggregates are classified according to source or means of preparation. A brief description of the classifications follows:

Pit or Bank-Run Aggregates

Gravel and sand are pit or bank-run natural aggregates. They are typically screened to proper size before being used for asphalt paving purposes.

Processed Aggregates

When natural pit or bank-run aggregate has been crushed and screened to make it suitable for asphalt pavements, it is considered a processed aggregate. Crushing typically improves the particle shape by making rounded particles more angular.

Crushed rock is also a processed aggregate. It is created when the fragments of bedrock and large stones are crushed so that all particle faces are fractured. Variation in size of particles is achieved by screening. In the processing of crushed rock, the fines produced are separated from the other crushed aggregate and may be used as manufactured sand in asphalt pavements.

Synthetic Aggregates

Aggregates produced by altering both physical and chemical properties of a parent material are called synthetic or artificial aggregates. Some are produced and processed specifically for use as aggregates; others are the byproduct of manufacturing and a final burning process. Blast furnace slag is an example of a synthetic aggregate.

Desirable Properties of Aggregates

Selection of an aggregate material for use in an asphalt pavement depends on the availability, cost, and quality of the material, as well as the type of construction for which it is intended.

To determine if an aggregate material is suitable for use in asphalt construction, it should be evaluated in terms of the following properties.

1. ***Size and grading.*** The maximum size of an aggregate is the smallest sieve through which 100 percent of the material will pass. The Nominal Maximum size is the next sieve larger than the sieve on which 10 percent of the material is retained. How the asphalt pavement mixture is to be used determines not only the appropriate maximum aggregate size, but also the desired gradation (distribution of sizes smaller than the maximum).
2. ***Cleanliness.*** An excess of foreign or deleterious substances such as shale, oxides, unsound cherts and/or organic material make some materials unsuitable for paving mixtures.
3. ***Toughness.*** Toughness or hardness is the ability of the aggregate to resist crushing or disintegration during mixing, placing, compacting, and other procedures associated with construction or traffic loading.
4. ***Soundness.*** Although similar to toughness, soundness is the aggregate’s ability to resist deterioration caused by the weather; for example, the stresses placed on materials during freezing and thawing.
5. ***Particle shape.*** The shapes of aggregate particles influence the asphalt mixture’s overall strength and workability as well as the density achieved during compaction. When compacted, irregular particles such as crushed rock tend to “lock” together and resist displacement.

6. ***Absorption.*** The porosity of an aggregate permits it to absorb asphalt and form a bond between the particle and the asphalt. A degree of porosity is desired, but aggregates that are highly absorbent are generally not used. Absorption is a significant factor in asphalt pavement mix design.
7. ***Stripping.*** When the asphalt film separates from the aggregate because of the action of water, it is called stripping. Aggregates coated with too much dust also can cause poor bonding, which results in stripping. Aggregates readily susceptible to stripping action usually are not suitable for asphalt paving mixes unless an anti-stripping agent is used.

The attributes mentioned above are quantitatively measured by standard physical tests and limits are included in standard materials specifications.

ASPHALT PAVEMENT

Asphalt pavement is known by many different names: asphalt pavement, asphaltic concrete, plant mix, bituminous mix, bituminous concrete, hot-mix asphalt, warm-mix asphalt and many others.

It is a combination of two primary ingredients - aggregates and asphalt binder. The aggregates total approximately 95 percent of the total mixture by weight. They are mixed with approximately 5 percent asphalt binder to produce asphalt pavement.

The aggregates and asphalt are combined in a manufacturing plant capable of producing specified materials. Plant equipment includes: cold bins for storage and controlled proportioning of graded aggregate; a dryer for drying and heating aggregates to the required mixing temperature; a pug mill or drum for combining the graded, heated aggregate and liquid asphalt cement according to specified mix formulas and tanks for storing the heated liquid asphalt.

Asphalt pavement is transported by truck to the paving site where it is spread to a uniform thickness with a mechanical paving or finishing machine. The material is then compacted to the required degree by heavy, self-propelled rollers, producing a smooth pavement course.

The paving or finishing machine places the asphalt pavement at temperatures between approximately 225° and 300° F., depending on the mixture characteristics, layer thickness and ambient conditions. The material should be compacted before the mix temperature falls below optimum compaction temperature, dependent on ambient conditions, to achieve adequate density.

Covering more than 96 percent of the nation’s paved highways, asphalt pavement is the most widely used paving material in the United States.

For versatility, durability, and ease of construction, it has no equal

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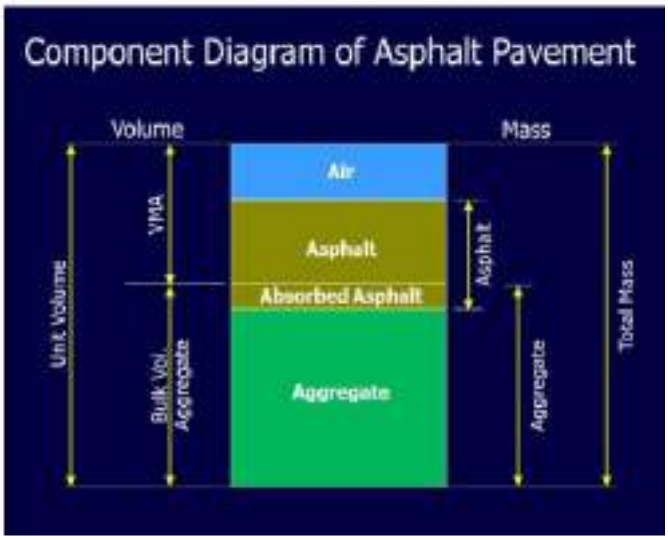

Component Diagram of Asphalt Pavement

Tenth Lecture

WOOD

Wood has been used and adapted by humans since the earliest recognition that they could make use of the materials they found around them. As they used it to meet a varying array of human needs, in peace and in war, in farming and in industry, people gradually came to understand something of the unique nature of wood. Its properties were first understood by experience, more recently by systematic research and refined observation. Wood is still essential to human life, but has evolved over the ages from a simple, readily available natural material to a modern industrial and engineering material, with a unique ability to contribute to human life both as a material for use and as a key element in the natural world of the forest.

The Nature of Wood

Wood is a natural product of the growth of trees. It is primarily composed of hollow, elongate, spindle-shaped cells that are arranged more or less parallel to each other in the direction of the tree trunk. This makes wood basically fibrous in nature and the characteristics of these fibrous cells and their arrangement in the tree strongly affect properties such as strength and stiffness, as well as the grain pattern of the wood.

Structure and Formation of Wood

Trees are divided into two broad classes, usually referred to as hardwoods and softwoods. This can be confusing, because the wood of some softwoods is harder than that of many hardwoods. For example, Scots pine and Douglas-fir are softwoods, but their wood is harder than that of poplar or mahogany, which are classed as hardwoods.

Botanically, the hardwoods are angiosperms, which refers to the fact that the seeds are enclosed in the ovary of the flower. Anatomically, hardwoods are porous in that they contain vessel cells (pores in the transverse section) that form tubes for transporting water or sap in the tree. Typically, hardwoods have broad leaves that, in temperate and semi-tropical regions are shed in winter. Botanically, softwoods are gymnosperms, which refers to the fact that the seeds are naked (not

enclosed in the ovary of the flower). Anatomically, softwoods are nonporous and contain no vessel elements.
Softwoods are usually conifers, cone-bearing plants with needle or scale-like leaves that are retained on the tree for two or more years, though a few of them such as the larches, drop their leaves each year. Softwoods are predominant in many parts of the boreal forest, and mixed with hardwoods in many parts of the temperate forest. Hardwoods are predominant in the tropical and semi-tropical forest.

Most woods grown in temperate regions show a distinct demarcation between cells formed early in the growing season (earlywood) and those formed late in the growing season (latewood) and this is sufficient to produce clear growth rings. The actual time of formation of earlywood and latewood varies with environmental and growth conditions. Earlywood is characterized by cells with thin walls and large cavities, while latewood cells typically have thicker walls and smaller lumens. In some hardwoods, earlywood may be characterized by the growth of large vessels with pores clearly larger and more numerous (see wood cells). Transition from earlywood to latewood may be gradual or abrupt, depending on the species and conditions of growth.
Growth rings, or annual increment, are most readily seen where this transition is abrupt, either due to the thick-walled cells of latewood in softwoods (Figure 2) or the more prominent earlywood vessels of hardwoods (Figure 1). This difference in wood
structure causes noticeable differences in physical properties of the wood and proportion of latewood may be used as a rough indication of differences in properties of lumber or other products made from the wood.

Chemically, wood is composed primarily of carbon, hydrogen, and oxygen. Carbon and oxygen predominate and are usually about 49 and 44 %, respectively, on a weight basis.
The remaining 7% is mostly hydrogen, with small amounts of nitrogen and metallic ions (ash). The organic constituents of wood are cellulose, hemicellulose, lignin, and extractives. Cellulose is formed from glucose by polymerization in long chain polymers that may be as much as 10,000 units long. Other sugars are polymerized into much shorter branched chains called hemicelluloses. These components are laid down in layers

to form the walls of wood cells. Wood cells, the structural elements of woody tissue, are of various sizes and shapes and are quite firmly cemented together. Most cells are considerably elongated, pointed at the ends, and oriented in the direction of the trunk of the tree. They are usually called fibers. The length of fibers is quite variable within a tree and among species of trees. Cellulose, the major component makes up about 50% of wood substance by weight. It is a high-molecular-weight linear polymer consisting of long chains of glucose monomer. These are not individually large structures, however, the largest being about 10 microns (µm) in length and about 0.8 nm in diameter, too small to be seen even with an electron microscope. During growth of the tree, the cellulose molecules are arranged into ordered strands, called fibrils, which in turn are organized into the larger structural elements that make up the cell walls of wood fibers. Hemicelluloses are associated with cellulose and are branched, lowmolecular-weight polymers composed of several different kinds of pentose and hexose sugar monomers. They vary widely among species of wood.

Lignin makes up 23% to 38% of the wood substance in softwoods and 16% to 25% in hardwoods. Lignin is a complex high molecular weight polymer built upon propylphenol units, rather than sugars. Despite being made up of carbon, oxygen, and hydrogen, it is not a carbohydrate, but rather phenolic in nature. Lignin occurs both between the cells, serving to bind them together, and within the cell wall, providing rigidity. Lignin occurs in wood throughout the cell wall, but is concentrated toward the outside of cell walls and between cells. Lignin is a three-dimensional phenylpropanol polymer. A principal objective of chemical pulping is to remove the lignin. Extraneous materials, both organic and inorganic, are not parts of the wood structure. Organic materials, known as extractives, make up 5% to as much as 30% of the wood in a very few species and include such materials as tannins, coloring matter, resins, and others, which can be removed with water or organic solvents. Inorganic materials, such as calcium, potassium, and magnesium, are usually less than 1% of wood substance in the temperate zone.

The xylem of softwoods is relatively simple, usually comprising only three or four kinds of cells, predominantly fibers. Because of this simplicity and uniformity of structure, softwoods tend to be similar in appearance. Most of the wood of softwoods (90-95%) is comprised of

longitudinal tracheids (fibers). These are long, slender cells, about 100 times as long as they are wide, averaging about 3 to 4 mm in length, rectangular in cross section, closed at the ends, with bordered pits primarily on the radial face. A small portion of the wood of softwoods is longitudinal parenchyma, cells shaped like the fibers, but usually divided into short lengths. Some softwoods (*Pinus, Picea, Larix,* and a few others) contain resin canals, which are intercellular spaces in the longitudinal direction surrounded by specialized cells that secrete resin. Radial structures in softwoods are usually wood rays a few cells thick, composed of either ray tracheids or ray parenchyma.

The structure of hardwoods is much more complex and diverse than that of softwoods with at least four major kinds of cells: fibers, vessels, longitudinal parenchyma, and ray parenchyma. Fibers are shaped something like tracheids of softwoods, but are much shorter (<1 mm) and tend to be rounded in cross section. Their function is primarily mechanical support. Vessel elements are specialized conducting tissue, unique to hardwoods, shorter than fibers, and connected end to end. They appear on the transverse face of the wood as pores. In some species, e.g., oak (*Quercus),* these large vessels become blocked with tyloses as the sapwood changes to heartwood. Tyloses may also form as a result of injury or drought. Longitudinal parenchyma are thin walled cells whose function is primarily storage of nutrients. Hardwood rays are made up of from 1 to 30 cell wide bands of parenchyma, storage tissue, running radially in the tree. In some species, such as the oaks and beeches, these are clearly visible to the eye, in others they are scarcely visible. Figure 4 is a three-dimensional representation of a hardwood, showing these types of cells on the transverse, radial, and longitudinal faces.

enclosed in the ovary of the flower). Anatomically, softwoods are nonporous and contain no vessel elements.
Softwoods are usually conifers, cone-bearing plants with needle or scale-like leaves that are retained on the tree for two or more years, though a few of them such as the larches, drop their leaves each year. Softwoods are predominant in many parts of the boreal forest, and mixed with hardwoods in many parts of the temperate forest. Hardwoods are predominant in the tropical and semi-tropical forest.

Most woods grown in temperate regions show a distinct demarcation between cells formed early in the growing season (earlywood) and those formed late in the growing season (latewood) and this is sufficient to produce clear growth rings. The actual time of formation of earlywood and latewood varies with environmental and growth conditions. Earlywood is characterized by cells with thin walls and large cavities, while latewood cells typically have thicker walls and smaller lumens. In some hardwoods, earlywood may be characterized by the growth of large vessels with pores clearly larger and more numerous (see wood cells). Transition from earlywood to latewood may be gradual or abrupt, depending on the species and conditions of growth.
Growth rings, or annual increment, are most readily seen where this transition is abrupt, either due to the thick-walled cells of latewood in softwoods (Figure 2) or the more prominent earlywood vessels of hardwoods (Figure 1). This difference in wood
structure causes noticeable differences in physical properties of the wood and proportion of latewood may be used as a rough indication of differences in properties of lumber or other products made from the wood.

Chemically, wood is composed primarily of carbon, hydrogen, and oxygen. Carbon and oxygen predominate and are usually about 49 and 44 %, respectively, on a weight basis.
The remaining 7% is mostly hydrogen, with small amounts of nitrogen and metallic ions (ash). The organic constituents of wood are cellulose, hemicellulose, lignin, and extractives. Cellulose is formed from glucose by polymerization in long chain polymers that may be as much as 10,000 units long. Other sugars are polymerized into much shorter branched chains called hemicelluloses. These components are laid down in layers

to form the walls of wood cells. Wood cells, the structural elements of woody tissue, are of various sizes and shapes and are quite firmly cemented together. Most cells are considerably elongated, pointed at the ends, and oriented in the direction of the trunk of the tree. They are usually called fibers. The length of fibers is quite variable within a tree and among species of trees. Cellulose, the major component makes up about 50% of wood substance by weight. It is a high-molecular-weight linear polymer consisting of long chains of glucose monomer. These are not individually large structures, however, the largest being about 10 microns (µm) in length and about 0.8 nm in diameter, too small to be seen even with an electron microscope. During growth of the tree, the cellulose molecules are arranged into ordered strands, called fibrils, which in turn are organized into the larger structural elements that make up the cell walls of wood fibers. Hemicelluloses are associated with cellulose and are branched, lowmolecular-weight polymers composed of several different kinds of pentose and hexose sugar monomers. They vary widely among species of wood.

Lignin makes up 23% to 38% of the wood substance in softwoods and 16% to 25% in hardwoods. Lignin is a complex high molecular weight polymer built upon propylphenol units, rather than sugars. Despite being made up of carbon, oxygen, and hydrogen, it is not a carbohydrate, but rather phenolic in nature. Lignin occurs both between the cells, serving to bind them together, and within the cell wall, providing rigidity. Lignin occurs in wood throughout the cell wall, but is concentrated toward the outside of cell walls and between cells. Lignin is a three-dimensional phenylpropanol polymer. A principal objective of chemical pulping is to remove the lignin. Extraneous materials, both organic and inorganic, are not parts of the wood structure. Organic materials, known as extractives, make up 5% to as much as 30% of the wood in a very few species and include such materials as tannins, coloring matter, resins, and others, which can be removed with water or organic solvents. Inorganic materials, such as calcium, potassium, and magnesium, are usually less than 1% of wood substance in the temperate zone.

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Eleventh Lecture

Composite materials

A composite material is made by combining two or more materials – often ones that have very different properties. The two materials work together to give the composite unique properties.

However, within the composite you can easily tell the different materials apart as they do not dissolve or blend into each other.

Natural composites

Natural composites exist in both animals and plants. Wood is a composite – it is made from long cellulose fibres (a polymer) held together by a much weaker substance called lignin. Cellulose is

also found in cotton, but without the lignin to bind it together it is much weaker. The two weak substances – lignin and cellulose – together form a much stronger one.

The bone in your body is also a composite. It is made from a hard but brittle material called hydroxyapatite (which is mainly calcium phosphate) and a soft and flexible material called collagen

(which is a protein). Collagen is also found in hair and finger nails. On its own it would not be much use in the skeleton but it can combine with hydroxyapatite to give bone the properties that are needed to support the body.

Early composites

People have been making composites for many thousands of years. One early example is mud bricks. Mud can be dried out into a brick shape to give a building material. It is strong if you try to squash it (it has good compressive strength) but it breaks quite easily if you try to bend it (it has poor tensile strength). Straw seems very strong if you try to stretch it, but you can crumple it up easily. By mixing mud and straw together it is possible to make bricks that are resistant to both squeezing and tearing and make excellent building blocks.

Another ancient composite is concrete. Concrete is a mix of aggregate (small stones or gravel),cement and sand. It has good compressive strength (it resists squashing). In more recent times it has been found that adding metal rods or wires to the concrete can increase its tensile (bending) strength. Concrete containing such rods or wires is called reinforced concrete.

Making composites

Most composites are made of just two materials. One is the matrix or binder. It surrounds and binds together fibres or fragments of the other material, which is called the reinforcement.

Modern examples

The first modern composite material was fibreglass. It is still widely used today for boat hulls,sports equipment, building panels and many car bodies. The matrix is a plastic and the reinforcement is glass that has been made into fine threads and often woven into a sort of cloth.

On its own the glass is very strong but brittle and it will break if bent sharply. The plastic matrix holds the glass fibres together and also protects them from damage by sharing out the forces acting on them.

Some advanced composites are now made using carbon fibres instead of glass. These materials are lighter and stronger than fibreglass but more expensive to produce. They are used in aircraft structures and expensive sports equipment such as golf clubs.

Carbon nanotubes have also been used successfully to make new composites. These are even lighter and stronger than composites made with ordinary carbon fibres but they are still extremely expensive. They do, however, offer possibilities for making lighter cars and aircraft (which will use less fuel than the heavier vehicles we have now).

The new Airbus A380, the world’s largest passenger airliner, makes use of modern composites in its design. More than 20 % of the A380 is made of composite materials, mainly plastic reinforced with carbon fibres. The design is the first large-scale use of glass-fibre-reinforced aluminium, a new composite that is 25 % stronger than conventional airframe aluminium but 20 % lighter.

Why use composites?

The biggest advantage of modern composite materials is that they are light as well as strong. By choosing an appropriate combination of matrix and reinforcement material, a new material can be made that exactly meets the requirements of a particular application. Composites also provide design flexibility because many of them can be moulded into complex shapes. The downside is often the cost. Although the resulting product is more efficient, the raw materials are often expensive.

DR.ASEEL M. MOHAMMED ALRAWI

2nd Grade

Dams and water resources department

Building Materials

1st course

First lecture

Building materials

Introduction:

The engineering structures are composed of materials. These materials are known as the engineering materials or building materials or materials of construction. It is necessary for the civil engineer to become conversant with the properties of such materials. The service conditions of buildings demand a wide range of materials and various properties such as water resistance, strength, durability, temperature resistance, appearance, permeability, etc. are to be properly studied before making final selection of any building material for a particular use. There are different types of building materials used to construct buildings. Some of them have even existed for years, and are still in use.

Building materials are basically divided into **natural and synthetic** materials. The materials made from natural products like clay, twigs, sand, leaves and rocks are natural building materials.

Building materials used in industries, that have gone through human processing is called synthetic building material, like plastics.

Here are the 8 types of building materials:

1. **Rock** is one building material that has been used in building structures for centuries.
2. Another very old building material used today is **thatch**. It is very cheap, is a great insulator and is very easily harvested.
3. **Ice** is another famous building material which was once used only for building igloos. Today, it is also being used in building ice hotels for tourist attractions in cold places.
4. In some places, **earth is still used in creating walls**. These walls are made by tightly packing and compacting mud between planks. This was previously done by hand, but now machines are being used. These houses of rammed earth are warm in winter, and cool in summer. This is because soil and clay help at maintaining temperatures at constant levels.

Cement is a common building material made from rock. Today, cement is used in constructing most buildings mainly because it is long lasting.

6. **Metal** is today popularly used for constructing a building's structural framework. Metals are used mainly because it is long lasting there are

different types of metals you can use for building like steel, which is a metal alloy. Sometimes gold and silver are used for decorative purposes. However not many people can afford it, and moreover, it is not as hard as other metals.

7. **Glass** is a building material used a lot nowadays in building structures because of its class and richness.

This variety of building materials is used for constructing all those beautiful structures found worldwide. The choice of usage is done based on personal preference and the climatic condition of the place.

Responsibilities of Materials Engineer

A material engineer must be familiar with a wide range of materials used in a wide range of structures and is responsible for the following jobs with certain limits of compromises to be made on site.

- **Selection of Materials**
- **Specification of Materials**
- **Quality Control of materials**

Factors Influencing Selection of a Building Materials

A wide range of construction materials is available. The proper selection of materials to be used in a particular construction project depends on the following factors

- Strength
- Availability
- Durability
- Workability
- Ease of Transportation
- Cost
- Aesthetics
- Resistance to Fire
- Ease of Cleaning

High Performance Materials

The increasing scope of civil engineering has brought many researches and advancement in materials and knowledge of molecular structure. These materials have shown better quality with much safety and economy. Such materials are known as High Performance Materials. In addition, improvements have been made to existing materials by changing their molecular structures or including additives to improve quality, economy, and performance.

Advantages of High

Performance Materials

- **High strength concrete can be produced**
- **Elastomeric material are used in joints in highly active earthquake areas**
- **Light weight concrete and aggregate have made cross sections smaller**
- **Polymers have been mixed with asphalt, allowing pavements to last longer under the effect of vehicle loads and environmental conditions.**
- **Fiber-Reinforced Concrete has greater toughness than conventional Portland cement concrete.**

Mortar

Mortar is a mixture of cementations material, aggregate generally with a grain size of less than 4 mm, water and possibly additives and/or admixtures. Mortar can be classified as cement-lime mortar, cement mortar, lime mortar or masonry cement mortar. Mortar is used for the **following functions:**

1- To bind materials together (e. g. masonry mortar and tile adhesive mortar, either non reinforced or reinforced).

2- To serve as a seating and leveling material for the masonry units.

3- To provide aesthetic quality of the structure and a level or smooth finish (e. g. floor screed mortar, internal plastering).

4- To protect against weathering (e. g. external rendering).

5- To improve thermal insulation of walls (e. g. external thermal insulation composite systems, thermal insulation rendering mortar, lightweight masonry mortar)

6- To repair constructions (e. g. concrete repair mortar, dam proofing mortar).

CONCRETE CONSTITUENTS

The constituent materials of concrete should satisfy; **the durability, structural performance and safety requirements, taking into consideration the environment** to which it will be subjected. The common types of **cement used in concreting include**:

- Ordinary Portland cement OPC
- Sulphate-resisting Portland Cement
- Low heat Portland Cement

The exposure conditions of the concrete and whether there are other special requirements, should be considered in the selection of the cement type. For example, concrete made with Portland cement is not recommended for use in acidic conditions.

The various factors affecting the choice of concrete are:

1. Compressive strength of concrete:

It is one of the most important properties of concrete and influences many other describable properties of the hardened concrete. The mean compressive strength required at a specific age, usually 28 days, determines the nominal water-cement ratio of the mix.

2. Workability of concrete:

The degree of workability required depends on three factors. These are the size of the section to be concreted, the amount of reinforcement, and the method of compaction to be used.

3. Durability of concrete:

The durability of concrete is its resistance to the aggressive environmental conditions.

SELECTION OF CONCRETE

REPAIR MATERIALS

Selection of concrete repair materials is based on evaluation of type of damage, types of materials to be used for repair and the local condition. Concrete repairing material must be compatible with the concrete being repaired. Variety of materials is available for repair of concrete structures.

The selection of concrete repair materials should be made based on following properties:

- Bond with concrete
- Strength development of material with concrete(compressive, flexural and tensile)
- Coefficient of thermal expansion of the material
- Coefficient of permeability of the material
- Stress development at interface whether on shrinkage, temperature change, alternative cycles of wetting and drying
- Corrosion resistance property of the material
- appearance of finished surface
- speed of concrete repair

Basically, the concrete repair materials can be grouped into:

i) Cementitious System
ii) Polymer Modified Cementitious System
iii) Polymer Concrete System , composite materials
iv) Reactive Thermosetting Resin System

Green building:

Green building (also known as **green construction** or **sustainable building**) refers to both a structure and the application of processes that are environmentally responsible and resource-efficient throughout a building's life-cycle: from planning to design, construction, operation, maintenance, renovation, and demolition.

The common **objective** of green buildings is to : reduce the overall impact of the built environment on human health and the natural environment by:

- Efficiently using energy, water, and other resources
- Protecting occupant health and improving employee productivity
- Reducing waste, pollution and environmental degradation

Water efficiency

Reducing water consumption and protecting water quality are key objectives in sustainable building. One critical issue of water consumption is that in many areas, the demands on the supplying aquifer exceed its ability to replenish itself.

Materials efficiency

Building materials typically considered to be 'green' include lumber from forests that have been certified to a third-party forest standard, rapidly renewable plant materials like bamboo and straw, dimension stone, recycled stone, recycled metal

Second lecture

Theories of failures

1. Introduction

Machine parts fail when the stresses induced by external forces exceed their strength. The external loads cause internal stresses in the elements and the component size depends on the stresses developed. Stresses developed in a link subjected to uniaxial loading is shown in **figure-1**.

Loading may be due to:
a) The energy transmitted by a machine element.
b) Dead weight.
c) Inertial forces.
d) Thermal loading. e) Frictional forces.

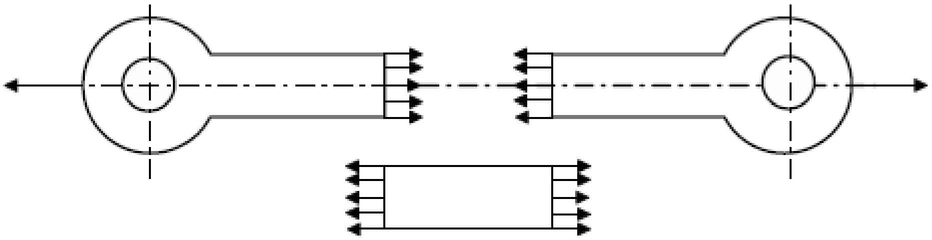
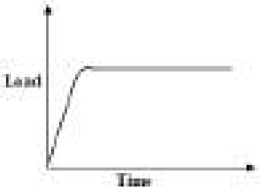
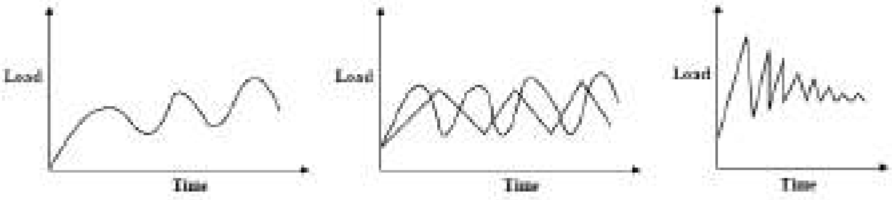


figure-1. - *Stresses developed in a link subjected to uniaxial loading*

In another way, load may be classified as:
a) Static load- Load does not change in magnitude and direction and normally increases gradually to a steady value.
b) Dynamic load- Load may change in magnitude for example, traffic of varying weight passing a bridge. Load may change in direction, for example, load on piston rod of a double acting cylinder.
Vibration and shock are types of dynamic loading. **Figure.2** shows load vs time characteristics for both static and dynamic loading of machine elements.



Static Loading



Dynamic Loading

Figure.2 - *Types of loading on machine elements.*

2. Allowable Stresses: Factor of Safety

Determination of stresses in structural or machine components would be meaningless unless they are compared with the material strength. If the induced stress is less than or equal to the limiting material strength then the designed component may be considered to be safe and an indication about the size of the component is obtained. The strength of various materials for engineering applications is determined in the laboratory with standard specimens. For example, for tension and compression tests a round rod of specified dimension is used in a tensile test machine where load is applied until fracture occurs. The load at which the specimen finally ruptures is known as Ultimate load and the ratio of load to original cross-sectional area is the Ultimate stress.

Similar tests are carried out for bending, shear and torsion and the results for different materials are available in handbooks. For design purpose an allowable stress is used in place of the critical stress to take into account the uncertainties including the following:

1) Uncertainty in loading.
2) In homogeneity of materials.
3) Various material behaviors. e.g. corrosion, plastic flow, creep.
4) Residual stresses due to different manufacturing process.
5) Fluctuating load (fatigue loading): Experimental results and plot-ultimate strength depends on number of cycles.
6) Safety and reliability.

For ductile materials, the yield strength and for brittle materials the ultimate strength are taken as the critical stress.
An allowable stress is set considerably lower than the ultimate strength. The ratio of ultimate to allowable load or stress is known as factor of safety i.e.

$$\frac{\text{Ultimate Stress}}{\text{Allowable Stress}} = \text{F.S.}$$

The ratio must always be greater than unity. It is easier to refer to the ratio of stresses since this applies to material properties

3 .Theories of failure

When a machine element is subjected to a system of complex stress system, it is important to predict the mode of failure so that the design methodology may be based on a particular failure criterion. Theories of failure are essentially a set of failure criteria developed for the ease of design.

In machine design an element is said to have failed if it ceases to perform its function. There are basically two types of mechanical failure:

(a) **Yielding-** This is due to excessive inelastic deformation rendering the machine part unsuitable to perform its function. This mostly occurs in ductile materials.

(b) **Fracture-** in this case the component tears apart in two or more parts. This mostly occurs in brittle materials.
There is no sharp line of demarcation between ductile and brittle materials.
However a rough guideline is that if percentage elongation is less than 5% then the material may be treated as brittle and if it is more than 15% then the material is ductile. However, there are many instances when a ductile material may fail by fracture. This may occur if a material is subjected to:

(a) Cyclic loading.
(b) Long term static loading at elevated temperature.
(c) Impact loading.
(d) Work hardening.
(e) Severe quenching.

Yielding and fracture can be visualized in a typical tensile test .Typical engineering stress-strain relationship from simple tension tests for same engineering materials are shown in **figure- 3**.

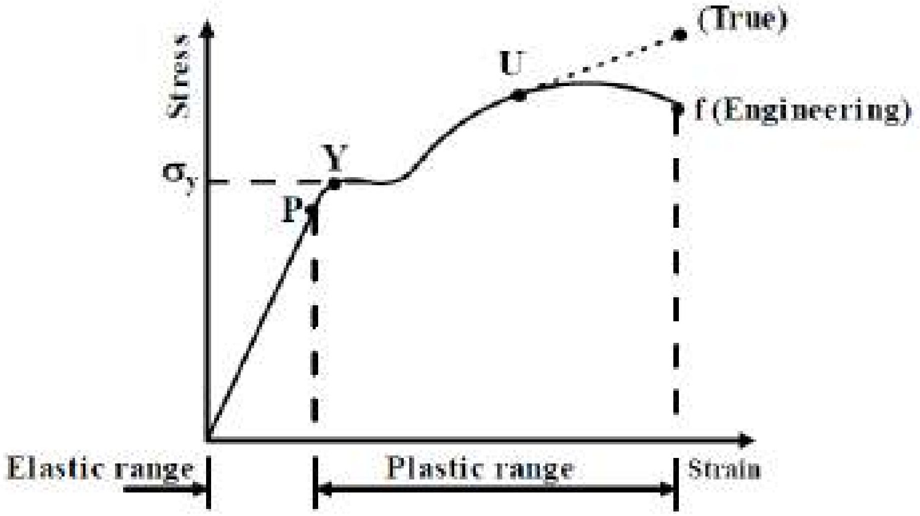
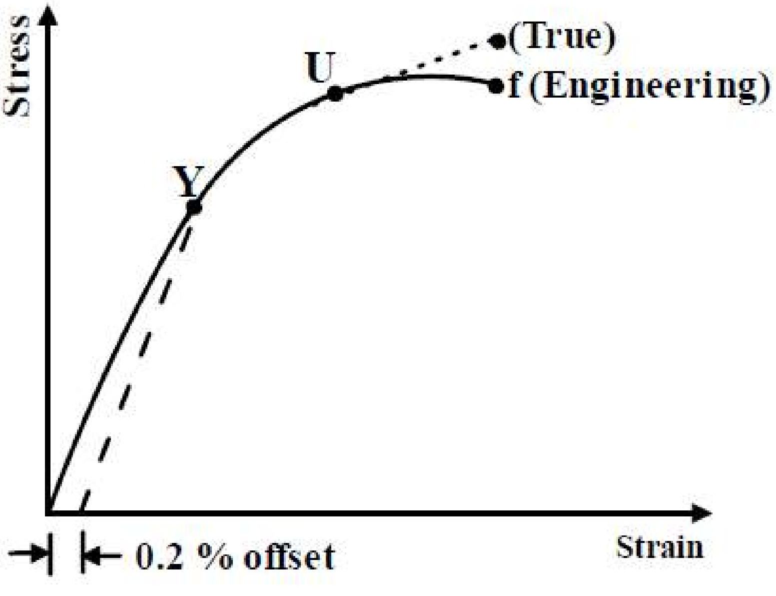
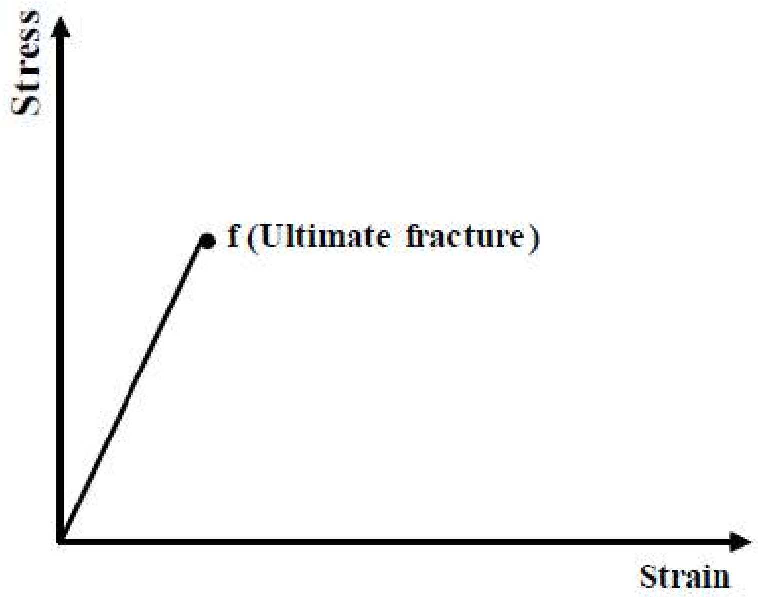


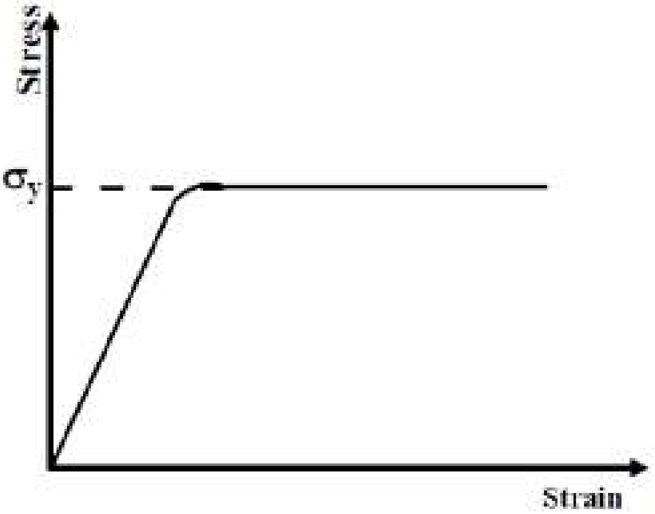
figure- 3. *(a) Stress-strain diagram for a ductile material e.g. low carbon steel.*



(b) Stress-strain diagram for low ductility.



(c) Stress-strain diagram for a brittle material.



(d) Stress-strain diagram for an elastic – perfectly plastic material.

For a typical ductile material as shown in **figure-3 (a)** there is a definite yield point where material begins to yield more rapidly without any change in stress level. Corresponding stress is σy . Close to yield point is the proportional limit which marks the transition from elastic to plastic range. Beyond elastic limit for an
elastic- perfectly plastic material yielding would continue without further rise in stress i.e. stress-strain diagram would be parallel to parallel to strain axis beyond the yield point. However, for most ductile materials, such as, low-carbon steel beyond yield point the stress in the specimens rises up to a peak value known as ultimate tensile stress σo . Beyond this point the specimen starts to neck-down i.e. the reduction in cross-sectional area. However, the stress-strain curve falls till a point where fracture occurs. The drop in stress is apparent since original cross-

sectional area is used to calculate the stress. If instantaneous cross-sectional area is used the curve would rise as shown in **figure- 3 (a)** . For a material
with low ductility there is no definite yield point and usually off-set yield points are defined for convenience. This is shown in **figure-3**.b For a brittle material stress increases linearly with strain till fracture occurs.

4-Yield criteria

There are numerous yield criteria, going as far back as Coulomb (1773). Many of these were originally developed for brittle materials but were later applied to ductile materials. Some of the more common ones will be discussed briefly here.

4.1 Maximum principal stress theory (Rankine theory)

According to this, if one of the principal stresses σ1 (maximum principal stress), σ2 (minimum principal stress) or σ3 exceeds the yield stress, yielding would occur. In a two dimensional loading situation for a ductile material where tensile and compressive yield stress are nearly of same magnitude

$$\sigma_1 = \pm\, \sigma_y$$

$$\sigma_2 = \pm\sigma_y$$

Using this, a yield surface may be drawn, as shown in **figure- 4.1**
Yielding occurs when the state of stress is at the boundary of the rectangle.
Consider, for example, the state of stress of a thin walled pressure vessel. Here σ1= 2σ2, σ1 being the circumferential or hoop stress and σ2 the axial stress. As the pressure in the vessel increases the stress follows the dotted line. At a point (say) a, the stresses are still within the elastic limit but at b, σ1reaches σy although σ2 is still less than σy. Yielding will then begin at point b.
This theory of yielding has very poor agreement with experiment.
However,the theory has been used σ_2 successfully for brittle materials.

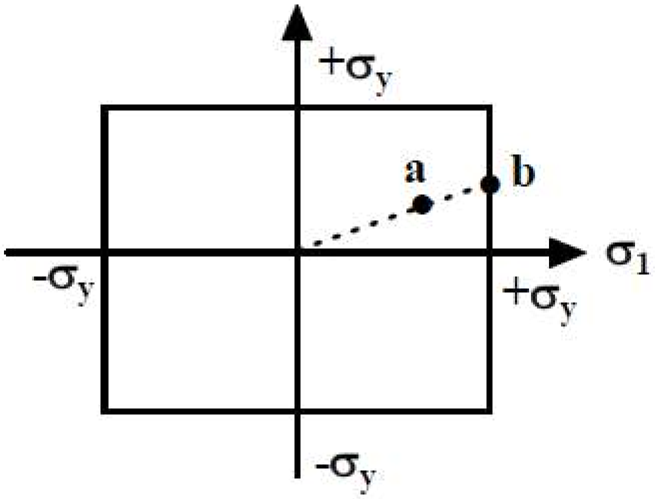


figure- 4.1 *Yield surface corresponding to maximum principal stress theory*

3.1.4.2 Maximum principal strain theory (St. Venant's theory)

According to this theory, yielding will occur when the maximum principal strain just exceeds the strain at the tensile yield point in either simple tension or compression. If ε1 and ε2 are maximum and minimum principal strains corresponding to σ1 and σ2, in the limiting case

$$\varepsilon_1 = \frac{1}{E}(\sigma_1 - \nu\sigma_2) \qquad |\sigma_1| \geq |\sigma_2|$$

$$\varepsilon_2 = \frac{1}{E}(\sigma_2 - \nu\sigma_1) \qquad |\sigma_2| \geq |\sigma_1|$$

$$\text{This gives, } E\varepsilon_1 = \sigma_1 - \nu\sigma_2 = \pm\sigma_0$$

$$E\varepsilon_2 = \sigma_2 - \nu\sigma_1 = \pm\sigma_0$$

The boundary of a yield surface in this case is thus given as shown in **figure-**4-2

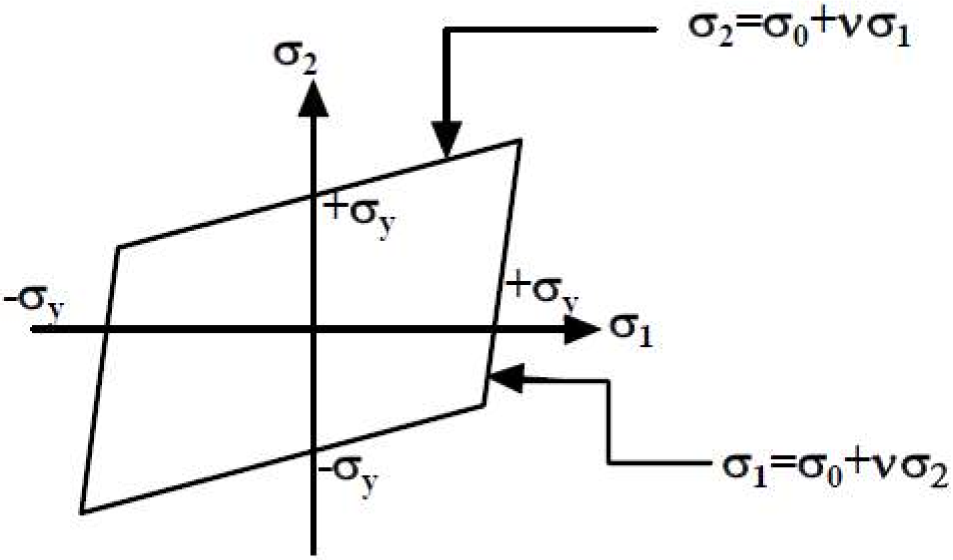


figure-4-2 *Yield surface corresponding to maximum principal strain theory*

3.1.4.3 Maximum shear stress theory (Tresca theory)

According to this theory, yielding would occur when the maximum shear stress just exceeds the shear stress at the tensile yield point. At the tensile yield point σ2= σ3 = 0 and thus maximum shear stress is σy/2. This gives us six conditions for a three-dimensional stress situation:

$$\sigma_1 - \sigma_2 = \pm\sigma_y$$

$$\sigma_2 - \sigma_3 = \pm\sigma_y$$

$$\sigma_3 - \sigma_1 = \pm\sigma_y$$

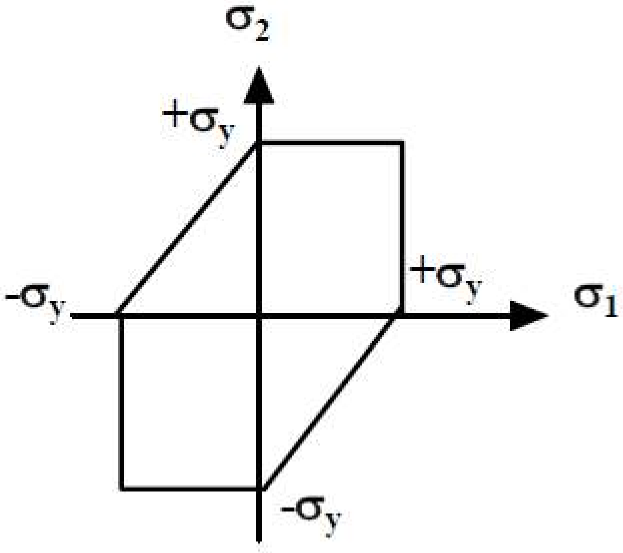


figure-4-3 *Yield surface corresponding to maximum shear stress theory*

In a biaxial stress situation **figure-**4-3 case, σ3 = 0 and this gives

$$\begin{aligned}
&\sigma_1 - \sigma_2 = \sigma_y && \text{if } \sigma_1 > 0, \sigma_2 < 0 \\
&\sigma_1 - \sigma_2 = -\sigma_y && \text{if } \sigma_1 < 0, \sigma_2 > 0 \\
&\sigma_2 = \sigma_y && \text{if } \sigma_2 > \sigma_1 > 0 \\
&\sigma_1 = -\sigma_y && \text{if } \sigma_1 < \sigma_2 < 0 \\
&\sigma_1 = -\sigma_y && \text{if } \sigma_1 > \sigma_2 > 0 \\
&\sigma_2 = -\sigma_y && \text{if } \sigma_2 < \sigma_1 < 0
\end{aligned}$$

This criterion agrees well with experiment.
In the case of pure shear, σ1 = - σ2 = k (say), σ3 = 0
and this gives σ1- σ2 = 2k= σy

This indicates that yield stress in pure shear is half the tensile yield stress and this is also seen in the Mohr's circle (figure- 4.4) for pure shear.

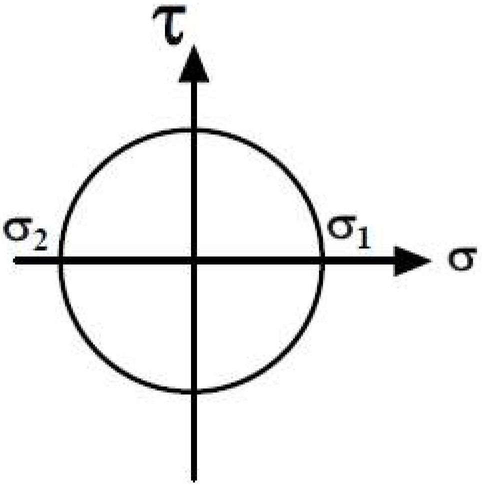


figure- 4.4- *Mohr's circle for pure shear*

Third Lecture

STEEL

According to the World Steel Association, there are over 3,500 different grades of steel, encompassing unique physical, chemical, and environmental properties.

In essence, steel is composed of iron and carbon, although it is the amount of carbon, as well as the level of impurities and additional alloying elements that determine the properties of each steel grade.

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

Different types of steel are produced according to the properties required for their application, and various grading systems are used to distinguish steels based on these properties.

Steel can be broadly categorized into four groups based on their chemical compositions:

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

The table below shows the typical properties of steels at room temperature (25°C). The wide ranges of tensile strength, yield strength, and hardness are largely due to different heat treatment conditions.

Carbon Steels

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

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

Alloy Steels

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

Stainless Steels

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

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

- Martensitic: Martensitic steels contain 11-17% chromium, less than 0.4% nickel, and up to 1.2% carbon. These magnetic and heat-treatable steels are used in knives, cutting tools, as well as dental and surgical equipment.

Tool Steels

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

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

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

What is Stainless Steel?

Stainless steel is a generic term for a family of corrosion resistant alloy steels containing 10.5% or more chromium.

ll stainless steels have a high resistance to corrosion. This resistance to attack is due to the naturally occurring chromium-rich oxide film formed on the surface of the steel. Although extremely thin, this invisible, inert film is tightly adherent to the metal and extremely protective in a wide range of corrosive media. The film is rapidly self repairing in the presence of oxygen, and damage by abrasion, cutting or machining is quickly repaired.

When nickel is added to stainless steel in sufficient amounts the crystal structure changes to "austenite". The basic composition of austenitic stainless steels is 18% chromium and 8% nickel.
Austenitic grades are the most commonly used stainless steels accounting for more than 70% of production (type 304 is the most commonly specified grade by far)

Ferritic

These are nickel-free stainless steels. They have a varying chromium (Cr) content of 12- 18%, but a lower carbon (C) content than the martensitics. (A special heat resistant grade contains 26% Cr.) The common specifications are 430, 409 and weldable 12% Cr steels

Common uses

- *computer floppy disk hubs*
- *automotive trim*

- *automotive exhausts*
- *colliery equipment*
- *hot water tanks*

WHAT IS GREAT ABOUT STAINLESS STEEL?

Corrosion resistance
Wear Resistance
Fire and heat resistance
Hygiene
Aesthetic appearance
Strength-to-weight advantage
Ease of fabrication
Impact resistance
Recyclability
Long term value
Low carbon foot-print

Forth Lecture

ALUMINUM

ADVANTAGES OF ALUMINUM AS A BUILDING MATERIAL

Aluminum made tremendous advances as a structural construction material in the last thirty years. To understand the reasons why, it is necessary to develop an appreciation for the basic fundamentals that make it so well suited for many construction applications.

The following is an item by item review of the reasons:

Non-Rusting: "Rust" is by definition iron oxide formed by oxidation of iron, or steel containing the element, iron (Fe). Since there is no iron in aluminum building products, by definition, they will never "rust". Aluminum will oxidize forming an Aluminum Oxide film on the surface. Competition, however, tries to draw a parallel between the oxidation of steel (rusting) and the oxidation of aluminum. As a matter of fact, the oxidation action is similar, but the results are totally different. Iron oxide (rust) is very porous, allowing moisture to penetrate the film of rust and thus permitting additional rusting until over time, structural failure results. Aluminum oxide, on the other hand, is a dense, tight film covering that effectively forms a barrier to moisture, resulting in the protection of the metal underneath against further oxidation. Thus, the oxidation rate of aluminum decreases rapidly as the film builds.

An actual bare-aluminum roof installation exposed to salt air with no applied barrier coating or maintenance, had an oxide penetration of only 0.002-inch in 40 years. At this rate, it would require 200 years to penetrate 0.010-inch . . . halfway through a 0.020-inch sheet of aluminum.

Penetration Tests: Results of exposure tests for aluminum by the American Society for Testing Materials, in nine locations (including industrial, sea coast, and rural) indicated an average penetration of only 0.00002-inch per year . . . or 500 years to penetrate midway through an 0.020-inch thick sheet of aluminum.

By contrast, it is not uncommon for rust to completely penetrate 29-gage (0.014-inch) galvanized steel sheet within 8 years after the galvanizing has ceased to provide protection . . . and some new galvanized roofs exhibit the characteristic red-brown tint of rust within a week or two of application.

Surface Marking: Shearing, bundling, shipping, fabrication, and erection of any building products are bound to produce a certain amount of surface marking. It is difficult to erect galvanized roofing without scratching, chipping, breaking, or peeling off some of the galvanizing, exposing the underlying metal to moisture, which causes rust. Fastener holes in particular offer effective starting points for rust, regardless of how careful the application.

Deterioration here is particularly harmful to the roofing, siding, and flashing.

Aluminum, however, being a homogeneous material, has no protective coating to come off. Any scratches that may be produced are quickly protected by the natural protective coating of aluminum oxide. Fastener holes similarly provide their own protection. Thus, holes in aluminum are not weak points for deterioration.

Corrosion of Aluminum: Competition attempts to point out that while aluminum does not “rust”, it does corrode. That is true, but we need to understand the principles of the corrosion.

The corrosion of aluminum is easily controlled and need never be serious. Here are some common occurrences that you may incur in this connection

Watermarking: Pure water allowed to pond on aluminum does not produce a water spotting.

However, it is an unfortunate fact that most water (even moisture condensing from the (atmosphere) contains some chemicals, enough to react with aluminum, and its alloying elements, to form gray or white salts, if the water is allowed to pond on the aluminum for an appreciable length of time. These salts will mark the surface of the aluminum.

It should be emphasized that this attack is superficial, hardly being enough to mark the top layer.

However, these spots or streaks may be unsightly. Such marks are easily removed by mechanically abrading the surface with a power driven wire brush or using some cleanser such as Simonize cleaner, etc. A warm caustic solution or commercial etching compounds also may be used, but acids should not be used.

Watermarking can be prevented by simply not allowing water to pond on the aluminum. Store fabricated aluminum in a place where it is protected from rain. Prevent rapid changes in atmospheric temperature that may cause condensation. If the sheets get wet, stand them on end and separate them so they may dry out. Protection in outside areas include covering sheets with breathable tarps, but not plastics or solid polyethylene

Salt Air Attack: Aluminum will withstand exposure to the salt air encountered near seacoasts, provided an aluminum alloy is used that contains no copper. The high strength alloys such as 2024 used in aircraft

contain copper, so stock of this type gave aluminum a bad name when used
on coastal installations.

Today, most aluminum building products are made from alloys containing no copper, so they are not subject to this corrosion. They can be relied upon to give long life on seacoast installations, as well as elsewhere.

Industrial atmospheres contain comparatively large amounts of chemicals which will increase the tendency to watermark. Aluminum roofs and siding may develop streaks from uneven flow of water over them in such areas. These marks may be removed by suitable cleaners and further marking retarded by correct selection of treating solution. Remember that other roofing materials such as galvanized iron and steel also develop similar markings under these conditions.

Alloy content greatly influences susceptibility of aluminum to attack. Today, most aluminum building products are made from the purer alloys (3004, 3003, etc.) which are most resistant to chemical attack. When an incident of corrosion of aluminum is brought to your attention, inquire as to the alloy involved and point out the deleterious effect of high alloy contents such as those of 2024, etc., especially a high copper content.

Electrolytic Reactions: Competition says, “Care must be taken to protect aluminum against electrolytic action. The use of non-aluminum fasteners or lapping sheets of aluminum and other metals is particularly dangerous.” There are several distortions of fact in this statement.

First, let’s see what we mean by “electrolytic reactions”. Any two dissimilar metals in an electrolyte (conductive solution) sets up an electrolytic cell (electric battery). If the two metals touch each other or immersed in this solution, an electric current will flow, causing one of the metals to go into solution (be dissolved), resulting in pitting and corrosive attack.

For such electrolytic action, the two metals must possess widely differing solution potentials, they must actually contact each other, the contact points must be wet or moist, and these conditions must exist for a sufficient period of time to produce pitting.

Solution Potentials: Therefore, electrolytic action can almost never be serious where aluminum contacts galvanized iron or galvanized steel because the zinc coating has practically the same solution potential as aluminum. Likewise cadmium-plated bolts, screws, and fittings may be used in contact with aluminum, for the same reason.

Industrial and Seacoast vs. Rural Atmospheres: The higher salt content of moisture condensing from industrial and seacoast atmospheres makes such moisture a better electrical conductor, thus promoting electrolytic action.

Mechanical Contact: Since mechanical contact is necessary for electrolytic action, separating the adjoining metals afford an easy method of protection. Thus, where it is necessary for aluminum to contact black sheet iron, cover the iron with aluminum paint, zinc dust paint, or some non-metallic material such as asphalt or bituminous paint, building paper, or asbestos paper.

Immune to Most Chemicals: Aluminum is unaffected by many chemicals and acids that seriously attack galvanized steel and iron. Sulfur fumes that necessitate replacement of ordinary galvanized roofing every few months have no effect whatever on aluminum roofing which has withstood years of use in the same plant.

Alkali Attack: Aluminum is subject to attack by the free alkali in cement, plaster, and mortar where the aluminum contacts are likely to be moist for extended periods, as on wall, roof, and chimney flashing. In such applications, protect the aluminum by coating the contacting areas with asphalt or bituminous paint. No attack will occur if so protected.

From the above, it is evident that the non-rusting characteristic of aluminum is an important feature of real value. The deleterious effect of dissimilar metal contacts, oxidation, and corrosion are all relatively unimportant as they are either easily avoided or do insignificant damage.

No Painting: Competition says, “Aluminum engineers recommend that the same protection be given aluminum as that used for other materials”. That is not true. Aluminum manufacturers advertise, sell, and recommend the use of bare untreated aluminum for all sorts of building products including roofing and siding of many different types. Painting is not necessary to protect aluminum.

Easy to Handle … Lighter Roof Loads: Competition says, “The difference in weight is not considered important in roofing”. While it may not be important to the man selling steel roofing, it is important to the warehouse, applicator, and user of roofing sheet. To say that a reduction of nearly 200 lbs. for every 100 lbs. of aluminum used is unimportant is just plain distortion of fact.

Labor involved in application is a definite and large factor in cost of a roof. The favorable difference in weight of aluminum can be important in reducing the installed cost.

Comparison of Weights: A 10’ sheet of 29-gage galvanized weighs 16-3/4 lbs. A 10’ sheet of aluminum 0.019” thick (35% thicker than the galvanized) weighs only 6-1/4 lbs. A barn roof requiring 30 squares of sheet would weigh 1.25 tons in galvanized, but only 937 lbs. in aluminum. This great weight of galvanized accounts for the sagging roofs readily found in many installations. A sagging roof distorts and leaks. To say that a lighter roof load is unimportant completely disregards the importance of leaks.

Lapping Sheets of aluminum over galvanized sheets can be done without undesired reactions because the zinc coating has approximately the same solution potential as aluminum. However, perfect guarantee against any reaction can be had simply by applying common asphalt roofing paint to one of the contacting surfaces. In average Steel density is 2.9 greater than aluminum density.

Heat Reflectivity … Means Cooler Buildings: Aluminum is much superior to other metals in its ability to reflect the infra-red or heat rays of the sun. And this high reflectivity (up to 95%) is reduced only very slightly as the aluminum weathers and loses its brilliance. Remember that light reflectivity (up to 85% for aluminum) has little relation to heat reflectivity.

On the other hand, galvanized steel rapidly loses its heat reflectivity as it weathers. Here are the figures: Aluminum, 90-95% when bright; 85-94% when weathered. Galvanized steel, 92% when bright; 55-65% when weathered. Carbon steel heat reflectivity 50% new to 20% oxidize
Don't let anyone tell you that aluminum and galvanized steel have the same reflectivity.

Aluminum is far superior, especially in heat reflectivity, the factor that makes for cooler buildings. Tests have shown an aluminum roof will often reduce inside temperatures by as much as 15° F.

Emissivity: On the other hand, aluminum has lower emissivity than other metals including galvanized steel … but this is good, and here's why: Emissivity means heat radiating power, the ability to dissipate heat by radiation. If two solid blocks of metal, the same size, one of aluminum, the other of galvanized steel, are both heated to the same temperature and allowed to stand, the aluminum will stay hot longer because it radiates less heat.

But radiation of heat through the roof and sidewalls of a building is not the way to cool any building. It is much better to reflect the heat off the roof and prevent the building from getting hot in the first place. That's what an aluminum roof does, it prevents it from getting hot.

Fire Protection: Competition says, "Steel has an advantage over aluminum; aluminum melts at about 1220º F., steel at about 2700º F. Also, aluminum is more combustible than steel." Both statements are misleading.
Any fire that melts aluminum (1200º F. approx.) will also damage the galvanizing (or painted steel) that the galvanized steel will be worthless because the zinc coating melts at 787º F. The fact that the steel doesn't melt till 2500º F. therefore is of no importance. Once the galvanizing is gone, the steel is of no value as a building material and very little as scrap. On the other hand, damaged aluminum has a high scrap value.

During a fire in a contiguous tank is more likely that the steel roof reaches the melting point first than aluminum. The reasons for that are:
a) Reflectivity: Most of the radiation heat will be reflected by the aluminum (95% to 85%)

b) The heat conductivity for aluminum is in average 3 times larger than steel, therefore when exposed to fire it takes much longer to heat aluminum to its limit temperature than it does steel (the heat is concentrate rapidly in one spot). This property is especially important with respect to the fire safety of the roof structural frame.

c) The specific heat of aluminum is almost twice as great as that of steel. The specific heat is the amount of heat required to raise 1 pound of metal 1 oF. Thus a pound of aluminum will absorb almost twice as much heat as a pound of steel for a given rise of temperature Combustibility of aluminum vs. steel is unimportant because neither will burn unless in finely
divided powder form. Even the thinnest aluminum foil (0.00017" thick) cannot be made to burn, it simply melts.
Strength at high temperature: Aluminum maintains at high degree of

strength at high temperature. If the metal is held at 400 of for one hour its tensile strength will drop approximately 5%. If it is held at 400 of for 16 hours its tensile strength will drop approximately 10%. Niether of these reductions in strength will be critical to the Aluminum dome since the dead weight of the structure (approximately 3 pounds per square foot) is about 17.5 of its live load design capacity (20 pounds per square foot). It is also a fact that aluminum return to almost 100% of its original strength, this fact is not true for steel. This property is also especially important with respect to the fire safety of the roof structural frame.

Less Rigidity: Aluminum is more flexible than steel, having a modulus of elasticity (a measure of its rigidity) about one-third that of steel. However, aluminum sheet can be made as rigid as steel by increasing its thickness approximately 40%. But if the aluminum is embossed it is possible to obtain the same rigidity with the same thickness … offering important additional economies. The embossed pattern greatly strengthens the sheet structurally.

The owner of a building is not so much interested in elasticity figures as he is in maintenance and replacement costs. Remember too, that in cases where the span of the roof sheet or purling spacing is a factor, as in industrial buildings, ample rigidity can easily be obtained by using more deeply corrugated sheet designs which are available. Greatly increased load-carrying ability can be had with only a small amount of added material.

Initial Cost: Many distorted pictures of the cost of aluminum vs. galvanized steel have been presented.

In the first place, equal rigidity may not be required at all. Minimum steel thicknesses are determined by rolling and galvanizing costs. In other words, a thinner steel sheet would not cost less because cost of rolling and galvanizing would more than offset the saving in reduced amount of steel. Since aluminum roofing and siding is homogeneous material, these factors do not enter and it is only necessary to use a sheet of sufficient thickness to give the actual strength required.

Many such cost comparisons disregard the economies possible from use of aluminum, its light weight and ease of application, substantially reducing erection costs; its immunity to rust assuring longer life and less maintenance; the complete elimination of any need for painting or repainting, etc. So watch the initial cost comparisons.

Quiet . . . No Excessive Noise From Wind, Rain, Etc.: Aluminum is acoustically dead material; that is, it tends to deaden sound waves and not transmit them as freely as other metals.

The net result is that a building covered with aluminum roofing and siding is noticeably quieter than one covered with other metallic materials.

Finally, aluminum has been in the building construction market place for many years now. New paint coatings and surfaces have added aesthetics to a substrate that only needed these coatings and surfaces for good looks, not protection from the elements.

Fifth Lecture

Aggregates

- Aggregates generally occupy 65- 80% of a concrete’s volume. Aggregates are inert fillers floating in the cement paste matrix for concretes of low strength. The strength of aggregates do not contribute to the strength of concrete for low strength concrete. The characteristics of aggregates impact performance of fresh and hardened concrete.

Why use aggregate

- Reduce the cost of the concrete – 1/4 - 1/8 of the cement price
- Reduce thermal cracking – 100 kg of OPC produces about 12oC temperature rise
- Reduces shrinkage – 10% reduction in aggregate volume can double shrinkage
- High aggregate : cement ratio (A/C) desirable
- A/C mainly influenced by cement content
- Imparts unit weight to concrete

Aggregate Classification

- Size:- Coarse Aggregates & Fine Aggregates.
- Specific Gravity:- Light Weight, Normal Weight and Heavy Weight Aggregates.
- Availability:- Natural Gravel and Crushed Aggregates.
- Shape:- Round, Cubical, Angular, Elongated and Flaky Aggregates.
- Texture:- Smooth, Granular, Crystalline, honeycombed and Porous.

Aggregate Classification : Size

- Fine Aggregate
  - Sand and/or crushed stone.
  - < 4.75 mm.
  - F.A. content usually 35% to 45% by mass or volume of total aggregate.
- Coarse Aggregate
  - Gravel and crushed stone.

  - >4.75 mm.
  - Typically between 9.5 and 37.5 mm.

Aggregate Classification : Specific Gravity

- Normal-Weight Aggregate
  - Most common aggregates (Ex: Sand, Gravel, Crushed stone)
  - Produce normal-weight concrete 2200 to 2400 kg/m3
- Lightweight Aggregate
  - Expanded (Shale, Clay, Slate, Slag)
  - Produce structural lightweight concrete 1350 to 1850 kg/m3
  - And (Pumice, Scoria, Perlite, Diatomite)
  - Produce lightweight insulating concrete— 250 to 1450 kg/m3

Aggregate Classification : Specific Gravity

- **Heavyweight Aggregate**
  - Barite, Limonite, Magnetite, Hematite, Iron
  - Produce high-density concrete up to 6400 kg/m3
  - Used for Radiation Shielding

Aggregate Classification : Availability

- Natural Gravel
  - River or seashore gravels; desert, seashore and windblown sands
  - Rounded in nature
  - Fully water worn or completely shaped by attrition
- Crushed Aggregates.
  - Crushed rocks of all types; talus; screes
  - Angular in nature

Aggregate Classification : Shape

- The shape of aggregates is an important characteristic since it affects the workability of concrete.

Aggregate Classification : Texture

- Surface texture is the property, the measure of which depends upon the relative degree to which particle surfaces are polished or dull, smooth or rough.
- Surface texture depends on hardness, grain size, pore structure, structure of the rock

Physical Prosperities of Aggregate : Grading

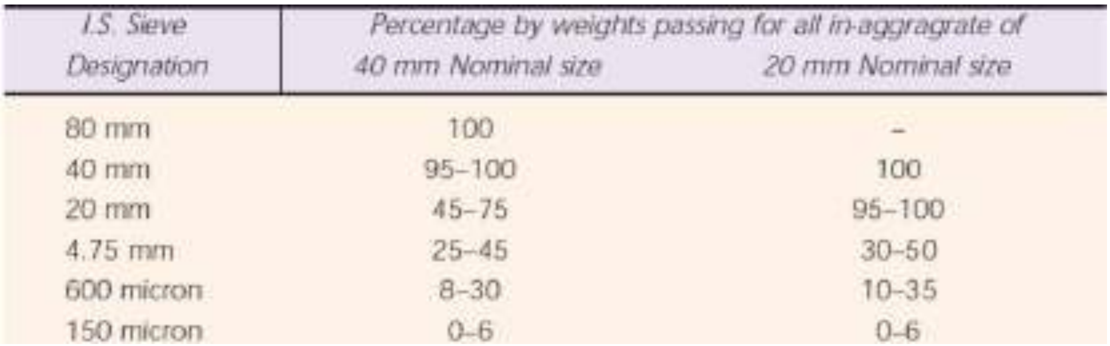
- Grading is the particle-size distribution of an aggregate as determined by a sieve analysis using wire mesh sieves with square openings.

- As per IS:2386(Part-1)
- Fine aggregate : 6 standard sieves with openings from 150 µm to 4.75 mm. (150 µm, 300 µm, 600 µm, 1.18mm, 2.36mm, 4.75mm)
- Coarse aggregate: 5 sieves with openings from 4.75mm to 80 mm. (4.75mm, 10mm, 12.5mm, 20mm, 40mm)

Physical Prosperities of Aggregate : Grading

- Grain size distribution for concrete mixes that will provide a dense strong mixture.
- Ensure that the voids between the larger particles are filled with medium particles. The remaining voids are filled with still smaller particles until the smallest voids are filled with a small amount of fines.

I.S. Sieve Designation	Percentage passing by weight for			
	Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV
10 mm	100	100	100	100
4.75 mm	90–100	90–100	90–100	95–100
2.36 mm	60–95	75–100	85–100	95–100
1.18 mm	30–70	55–90	75–100	90–100
600 micron	15–34	35–59	60–79	80–100
300 micron	5–20	8–30	12–40	15–50
150 micron	0–10	0–10	0–10	0–15



I.S. Sieve Designation	Percentage by weights passing for all in-aggragrate of 40 mm Nominal size	20 mm Nominal size
80 mm	100	–
40 mm	95–100	100
20 mm	45–75	95–100
4.75 mm	25–45	30–50
600 micron	8–30	10–35
150 micron	0–6	0–6

Fineness Modulus (FM)

- The results of aggregate sieve analysis is expressed by a number called Fineness Modulus. Obtained by adding the sum of the cumulative percentages by mass of a sample aggregate retained on each of a specified series of sieves and dividing the sum by 100.
- The following limits may be taken as guidance:
- Fine sand : Fineness Modulus : 2.2 - 2.6
- Medium sand : F.M. : 2.6 - 2.9
- Coarse sand : F.M. : 2.9 - 3.2
- A sand having a fineness modulus more than 3.2 will be unsuitable for making satisfactory concrete.

$$\text{Finess Modulus, } FM = \left(\frac{\text{Total of Cumulative Percentage of Passing (\%)}}{100} \right)$$

Physical Properties of Aggregate:

Flakiness Index

- The flakiness index of aggregate is the percentage by weight of particles in it whose least dimension (thickness) is less than three-fifths of their mean dimension.
- The test is not applicable to sizes smaller than 6.3 mm.
- The flakiness index is taken as the total weight of the material passing the various thickness gauges expressed as a percentage of the total weight of the sample taken.
- Table 3.18 shows the standard dimensions of thickness and length gauges.

Physical Properties of Aggregate:
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Physical Properties of Aggregate: Flakiness Index

Physical Properties of Aggregate: Elongation Index

- The elongation index on an aggregate is the percentage by weight of particles whose greatest dimension (length) is greater than 1.8 times their mean dimension.
- The elongation index is not applicable to sizes smaller than 6.3 mm.
- The elongation index is the total weight of the material retained on the various length gauges expressed as a percentage of the total weight of the sample gauged. The presence of elongated particles in excess of 10 to 15 per cent is generally considered undesirable, but no recognized limits are laid down.

Six Lecture

Cement

- In the most general sense of the word, a **cement** is a binder, a substance that sets and hardens independently, and can bind other materials together.
- Cement used in construction is characterized as hydraulic or non-hydraulic. Hydraulic cements (e.g., Portland cement) harden because of hydration, chemical reactions that occur independently of the mixture's water content; they can harden even underwater or when constantly exposed to wet weather.

History of the origin of cement

- John Smeaton made an important contribution to the development of cements when he was planning the construction of the third Eddystone Lighthouse (1755–9) in the English Channel. He needed a hydraulic mortar that would set and develop some strength in the twelve hour period between successive high tides.
- In 1824, Joseph Aspdin patented a similar material, which he called Portland cement, because the render made from it was in color similar to the prestigious Portland stone.

History of the origin of cement

- The investigations of L.J.Vicat led him to prepare an artificial hydraulic lime by calcining an intimate mixture of limestone and clay.
- Later in 1845 Isaac Charles Johnson burnt a mixture of clay and chalk till the clinkering stage to make better cement and established factories in 1851.
- The German standard specification for Portland cement was drawn in 1877.

History of the origin of cement

- The British standard specification was first drawn up in 1904. The first ASTM specification was issued in 1904.
- In India, Portland cement was first manufactured in 1904 near Madras, by the South India Industrial Ltd. But this venture failed.
- Between 1912 and 1913, the Indian Cement Co. Ltd., was established at Porbander (Gujarat) and by 1914 this Company was able to deliver about 1000 tons of Portland cement.

Manufacture of Portland Cement

- Cement is made by heating limestone (calcium carbonate) with small quantities of other materials (such as clay) to 1450 °C in a kiln, in a process known as calcinations, whereby a molecule of carbon dioxide is liberated from the calcium carbonate to form calcium oxide, or quicklime, which is then blended with the other materials that have been included in the mix.
- The resulting hard substance, called 'clinker', is then ground with a small amount of gypsum into a powder to make 'Ordinary Portland Cement', the most commonly used type of cement (often referred to as OPC).

Manufacture of Portland Cement

Manufacture of Portland Cement

- Step 1 – Quarrying Limestone and a 'cement rock' such as clay or shale are quarried and brought to the cement works. These rocks contain lime (CaCO3), silica (SiO2), alumina (Al2O3) and ferrous oxide (Fe2O3) - the raw materials of cement manufacture.

product, it is ▸ Step 2 - Raw material preparation To form a consistent essential that the same mixture of minerals is used every time. For this reason the exact composition of the limestone and clay is determined at this point, and other ingredients added if necessary. The rock is also ground into fine particles to increase the efficiency of the reaction.

Manufacture of Portland Cement

- The dry process :

The quarried clay and limestone are crushed separately until nothing bigger than a tennis ball remains. Samples of both rocks are then sent off to the laboratory for mineral analysis. If necessary, minerals are then added to either the clay or the limestone to ensure that the correct amounts of aluminium, iron etc. are present. The clay and limestone are then fed together into a mill where the rock is ground until more than 85% of the material is less than 90μm in diameter.

Manufacture of Portland Cement

- The wet process :

The clay is mixed to a paste in a wash mill - a tank in which the clay is pulverized in the presence of water. Crushed lime is then added and the whole mixture further ground.

Any material which is too coarse is extracted and reground. The slurry is then tested to ensure that it contains the correct balance of minerals, and any extra ingredients blended in as necessary.

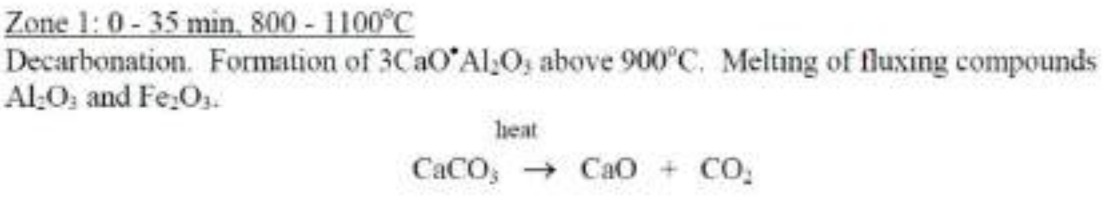
Manufacture of Portland Cement

▸ Step 3 – Clinkering The raw materials are then dried, heated and fed into a rotating kiln. Here the raw materials react at very high temperatures to form 3CaO •
SiO2 (tricalcium silicate), 2CaO • SiO2 (dicalcium silicate), 3CaO • Al2O3 (tricalcium aluminate) and 4CaO • Al2O3 • Fe2O3 (tetracalcium alumino-ferrate).

Manufacture of Portland Cement

▸ The kiln : The kiln shell is steel, 60m long and inclined at
an angle of 1 in 30. The shell is supported on 3 roller trunions and weighs in at over 1100 T. The kiln is heated by injecting pulverized coal dust into the discharge end where it spontaneously ignites due to the very high temperatures. Coal is injected with air into the kiln at a rate of 9 - 12 T/hr.

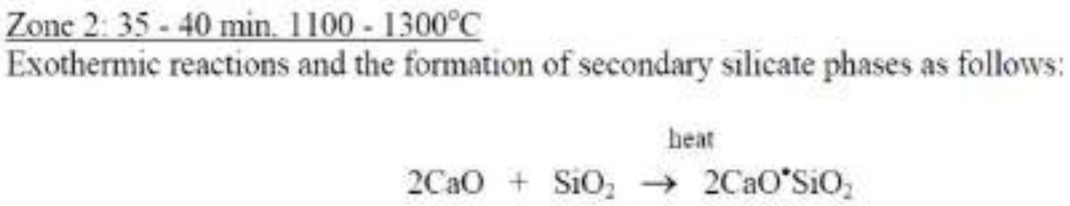
Manufacture of Portland Cement



Zone 1: 0 - 35 min. 800 - 1100°C

Decarbonation. Formation of $3CaO{\cdot}Al_2O_3$ above 900°C. Melting of fluxing compounds Al_2O_3 and Fe_2O_3.

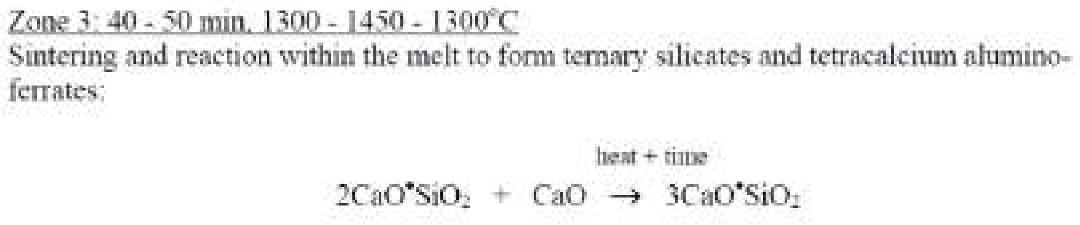
$$CaCO_3 \xrightarrow{\text{heat}} CaO + CO_2$$



Zone 2: 35 - 40 min. 1100 - 1300°C

Exothermic reactions and the formation of secondary silicate phases as follows:

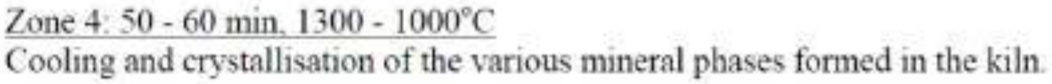
$$2CaO + SiO_2 \xrightarrow{\text{heat}} 2CaO{\cdot}SiO_2$$



Zone 3: 40 - 50 min. 1300 - 1450 - 1300°C

Sintering and reaction within the melt to form ternary silicates and tetracalcium alumino-ferrates:

$$2CaO{\cdot}SiO_2 + CaO \xrightarrow{\text{heat + time}} 3CaO{\cdot}SiO_2$$



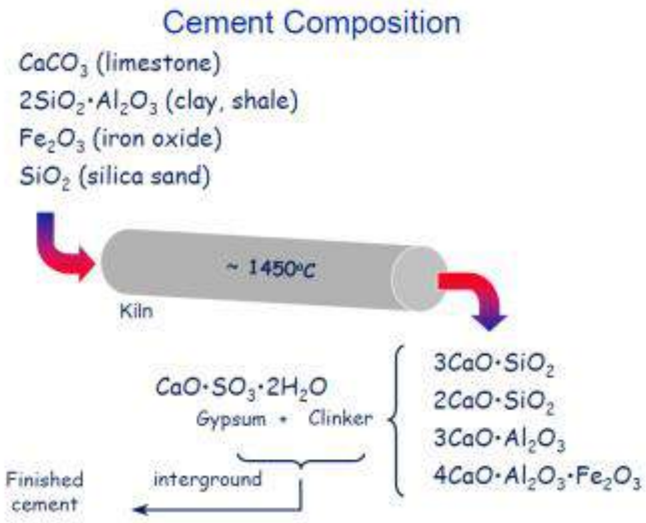
Zone 4: 50 - 60 min, 1300 - 1000°C

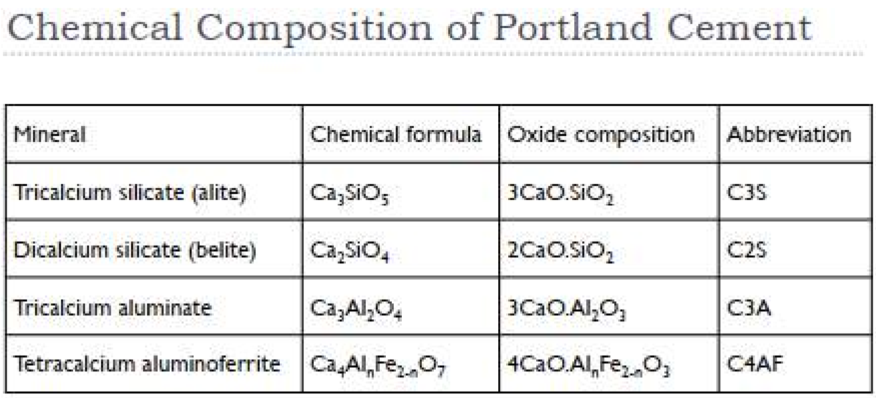
Cooling and crystallisation of the various mineral phases formed in the kiln.

Step 4 - Cement milling The 'clinker' that has now been roduced will behave just like cement, but it is in particles up to 3 cm in diameter. These are ground down to a fine powder to turn the clinker into useful cement.

Chemical Composition of Portland Cement

▸ The raw materials used for the manufacture of cement consist mainly of lime, silica, alumina and iron oxide. These oxides interact with one another in the kiln at high temperature to form more complex compounds. The relative proportions of these oxide compositions are responsible for influencing the various properties of cement; in addition to rate of cooling and fineness of grinding.





Chemical Composition of Portland Cement

Mineral	Chemical formula	Oxide composition	Abbreviation
Tricalcium silicate (alite)	Ca_3SiO_5	$3CaO.SiO_2$	C3S
Dicalcium silicate (belite)	Ca_2SiO_4	$2CaO.SiO_2$	C2S
Tricalcium aluminate	$Ca_3Al_2O_6$	$3CaO.Al_2O_3$	C3A
Tetracalcium aluminoferrite	$Ca_4Al_nFe_{2-n}O_7$	$4CaO.Al_nFe_{2-n}O_3$	C4AF

Hydration of cement

- When Portland cement is mixed with water its chemical compound constituents undergo a series of chemical reactions that cause it to harden. This chemical reaction with water is called "hydration".
- Each one of these reactions occurs at a different time and rate. Together, the results of these reactions determine how Portland cement hardens and gains strength.

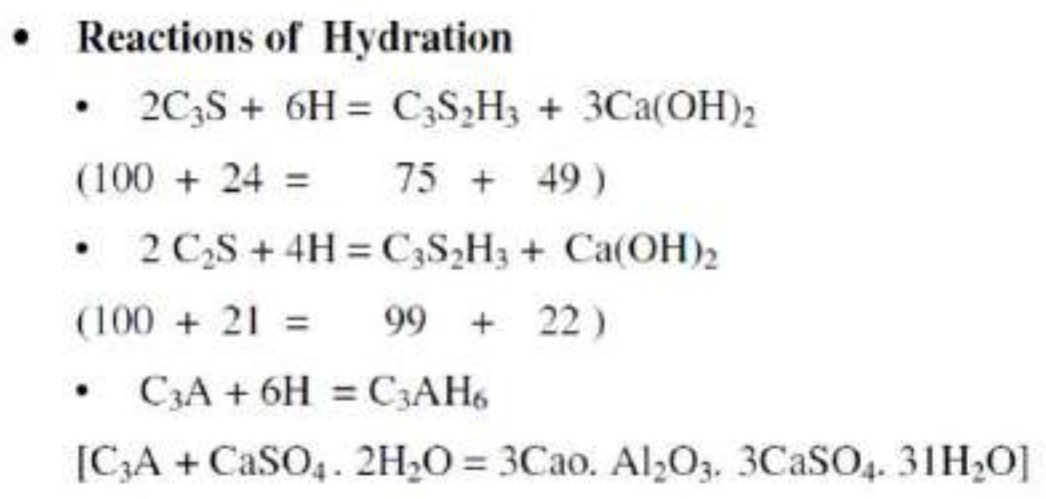
Hydration starts as soon as the cement and water are mixed.

- The rate of hydration and the heat liberated by the reaction of each compound is different.
- Each compound produces different products when it hydrates.
- Tricalcium silicate (C3S). Hydrates and hardens rapidly and is largely responsible for initial set and early strength.

Portland cements with higher percentages of C3S will exhibit higher early strength.

Tricalcium aluminate (C3A). Hydrates and hardens the quickest. Liberates a large amount of heat almost immediately and contributes somewhat to early strength. Gypsum is added to Portland cement to retard C3A hydration.Without gypsum, C3A hydration would cause Portland cement to set almost immediately after adding water.

- Dicalcium silicate (C2S). Hydrates and hardens slowly and is largely responsible for strength increases beyond one week.
- Tetracalcium aluminoferrite (C4AF). Hydrates rapidly but contributes very little to strength. Its use allows lower kiln temperatures in Portland cement manufacturing. Most Portland cement color effects are due to C4AF



- **Reactions of Hydration**
  - $2C_3S + 6H = C_3S_2H_3 + 3Ca(OH)_2$

  $(100 + 24 = 75 + 49)$
  - $2C_2S + 4H = C_3S_2H_3 + Ca(OH)_2$

  $(100 + 21 = 99 + 22)$
  - $C_3A + 6H = C_3AH_6$

  $[C_3A + CaSO_4 . 2H_2O = 3Cao. Al_2O_3. 3CaSO_4. 31H_2O]$

Heat of Hydration

▶□The reaction of cement with water is exothermic. The reaction liberates a considerable quantity of heat. This liberation of heat is called heat of hydration. This is clearly seen if freshly mixed cement is put in a vacuum flask and the temperature of the mass is read at intervals.

▶□The study and control of the heat of hydration becomes important in the construction of concrete dams and other mass concrete constructions. It has been observed that the temperature in the interior of large mass concrete is 50°C above the original temperature of the concrete mass at the time of placing and this high temperature is found to persist for a prolonged period.

The heat of hydration is the heat generated when water and Portland cement react. Heat of hydration is most influenced by the proportion of C3S and C3A in the cement, but is also influenced by water-cement ratio, fineness and curing temperature. As each one of these factors is increased, heat of hydration increases.

▶□For usual range of Portland cements, about one-half of the total heat is liberated between 1 and 3 days, about three-quarters in 7 days, and nearly 90 percent in 6 months.

▶□The heat of hydration depends on the chemical composition of cement.

Seventh Lecture

Concrete

A composite material that consists essentially of a binding medium, such as a mixture of Portland cement and water, within which are embedded particles or fragments of aggregate, usually a combination of fine and coarse aggregate

. Because the tensile strength of concrete is much lower than its compressive strength, it is typically reinforced with steel bars, in which case it is known as reinforced concrete.

Cement

Cement is the "glue" that binds the concrete ingredients together and is instrumental for the strength of the composite.

The primary product of cement hydration is a complex and poorly crystalline calcium-silicate hydroxide gel (or CSH). A secondary product of hydration is calcium hydroxide, a highly crystalline material. A category of siliceous materials known as pozzolans have little or no cementitious value, but in finely divided form and in the presence of moisture will react chemically with calcium hydroxide to form additional CSH. This secondary hydration process has a generally beneficial effect on the final concrete properties. Examples of pozzolans are fly ash, ground granulated blast-furnace slag, and micro silica or silica fume. The American Society for Testing and Materials (ASTM) defines five types of cement, specifying for each the mineral composition and chemical and physical characteristics such as fineness. The most common cement is Type I. Type III cement is used if more rapid strength envelopment is required. The other types are characterized by either lower heat of hydration or better sulfate resistance than that of Type I cement.

Aggregate

The aggregate is a granular material, such as sand, gravel, crushed stone, or iron-blast furnace slag. It is graded by passing it through a set of sieves with progressively smaller mesh sizes. All material that passes through sieve #4 [0.187 in. (4.75 mm) openings] is conventionally referred to as fine aggregate or sand, while all material that is retained on the #4 sieve is referred to as coarse aggregate, gravel, or stone.

the smaller particles fill the void spaces between the larger particles. Such dense packing minimizes the amount of cement paste needed and generally leads to improved mechanical and durability properties of the concrete.
The aggregate constitutes typically 75% of the concrete volume, or more, and therefore its properties largely determine the properties of the concrete. For the concrete to be of good quality, the aggregate has to be strong and durable and free of silts, organic matter, oils, and sugars. Otherwise, it should be washed prior to use, because any of these impurities may slow or prevent the cement from hydrating or reduce the bond between the cement paste and the aggregate particles.

*A**dmixture**s*

mineral and chemical admixtures that may be added to the concrete. The four most common admixtures will be discussed.

1. Air-entraining agents

are chemicals that are added to concrete to improve its freeze–thaw resistance. Concrete typically contains a large number of pores of different sizes, which may be partially filled with water. If the concrete is subjected to freezing temperatures, this water expands when forming ice crystals and can easily fracture the cement matrix, causing damage that increases with each freeze–thaw cycle. If the air voids created by the air-entraining agent are of the right size and average spacing, they give the freezing water enough space to expand, thereby avoiding the damaging internal stresses

.

2. **Water-reducing admixtures**

superplasticizers, are chemicals that lower the viscosity of concrete in its liquid state, typically by creating electrostatic surface charges on the cement and very fine aggregate particles. This causes the particles to repel each other, thereby increasing the mix flow ability, which allows the use of less water in the mix design and results in increased strength and durability of the concrete

.

3**. Retarding**

delay the setting time, which may be necessary in situations where delays in the placement of concrete can be expected. Accelerators shorten the period needed to initiate cement hydration—for example, in emergency repair situations that call for the very rapid development of strength or rigidity

4. Color pigments in powder or liquid form may be added to the concrete mix to produce colored concrete. These are usually used with white Portland cement to attain their full coloring potential.

Reinforcing steels. Because of concrete's relatively low tensile strength, it is typically reinforced with steel bars Reinforcing steel usually has a nominal yield strength of 60,000 lb/in.2 (414 MPa).

protection The alkalinity of the cement paste generally provides sufficient of the steel against corrosion. However, corrosion protection is often breached, for example, in highway bridge decks with continuous pore structure or traffic-induced cracks that permit the deicing chemicals used in winter to penetrate the protective concrete cover. Additional protective measures may be necessary, such as using epoxy coatings on the bars, noncorrosive steels, or nonmetallic reinforcement.

Cement paste plus fine aggregate is called mortar or concrete matrix. Mortar plus coarse aggregate constitutes concrete. Concrete reinforced

MIX DESIGN

Any excess water creates pores which, together with any air-filled pores, do not contribute to the material strength. The result is a drastic decrease in strength as a function of increasing the w/c ratio. On the other hand, too low w/c ratios cause poor workability of the concrete. For practical reasons, the w/c ratio typically varies between 0.4 and 0.6. The other important mix design variables are the cement-to-aggregate ratio and the fine-to-coarse aggregate ratio. Also, the maximum aggregate size is of importance. And since cement is the most expensive bulk ingredient, the mix design will generally aim at the least amount of cement necessary to achieve the design objectives.

Construction practice

Precast concrete refers to any structure or component that is produced at one site, typically in a precasting plant, and then transported in its hardened state to its final destination.

. if dropped too far, the heavy or big aggregate particles can settle and lighter mix components, such as water, tend to rise.

During placement, large amounts of air are entrapped in the mix, which lowers the strength of the hardened concrete. Much of the air is removed by compaction, which is achieved by either immersing high-frequency vibrators into the fresh concrete or attaching them to the outside faces of the formwork. Care must be taken to avoid excessive vibration; otherwise the heavy aggregate particles settle down and the light mixing water rises to the surface.

For underwater construction, the concrete is placed in a large metal tube, called a tremie, with a hopper at the top and a valve arrangement at the submerged end. For so-called shotcrete applications such as tunnel linings and swimming pools, the concrete mixture is blown under high pressure through a nozzle directly into place to form the desired surface

Curing

For example, in hot or dry weather large exposed surfaces will lose water by evaporation. This can be avoided by covering such surfaces with sheets of plastic or canvas or by periodically spraying them with water. In precast concrete plants, concrete elements are often steam-cured, because the simultaneous application of hot steam and pressure accelerates the hydration process, which permits high turnover rates for the formwork installations.

Properties of fresh concrete.

The most important property of fresh concrete is its workability or flow ability, because this determines the ease with which it can be placed. It is determined using a slump test, in which a standard truncated metal cone form is filled with fresh concrete. The mold is then lifted vertically, and the resulting loss in height of the concrete cone, or the slump value, is indicative of the concrete’s workability.

Properties of hardened concrete.

Most commercially produced concrete has compressive strengths between 3000 and 6000 lb/in.2 (20 and 40 MPa).

During hydration and especially if allowed to dry after hardening, the concrete volume decreases by a small amount because of shrinkage. If this shrinkage is restrained somehow, it can lead to cracking.

A concrete member or structure subjected to external load will undergo deformations which, up to a point, are proportional to the amount of applied load. If these loads remain in place for an appreciable time (months or years), these deformations will increase due to a material property called creep.

Durability. Durability is the ability of a material (or structure) to maintain its various properties throughout its design or service life.

There can be numerous causes for loss of durability or deterioration of concrete structures. The most common one is an excessive amount of cracking or pore structure.

Larger cracks provide easy access for such agents to the steel, thereby promoting corrosion.

The concrete itself may deteriorate or weather, especially if subjected to many cycles of freezing and thawing, during which the pressure created by the freezing water progressively increases the extent of internal cracking. In addition, carbon in the atmosphere can react chemically with the cement hydration products. This process is known as carbonation.
It lowers the pH of the concrete matrix to the point where it can no longer protect the steel against corrosion.

Most types of aggregate used for concrete production are inert; that is, they do not react chemically with the cement or hydration products. However, there are various aggregate types, including those containing amorphous silica such as common glass, which react chemically with the alkali in the cement.
In the presence of moisture, the alkali–aggregate reaction products can swell and cause considerable damage.

Under repeated load applications, structures can experience fatigue failure, as each successive load cycle increases the degree of cracking and material deterioration to the point where the material itself may gradually lose its strength or the increased extent of cracking is the source of loss of durability.
Thermal and other properties. The heavy weight of concrete [its specific gravity is typically 2.4 g/cm3 (145 lb/ft3)] is the source of large thermal mass. concrete structures can moderate extreme temperature cycles and increase the comfort of occupants.

Special concretes and recent developments.

Lightweight concrete

because of the large stresses caused by their own heavy weight, floor slabs are often made lighter by using special lightweight aggregate. To further reduce weight, special chemical admixtures are added, which produce large porosity.
Such high porosity (in either the matrix or the aggregate particles themselves) improves the thermal resistance of the concrete as well as sound insulation, especially for higher frequencies. However, because weight density correlates strongly with strength, ultra lightweight concretes [1.1 g/cm3 (70 lb/ft3) and less] are used only for thermal or sound insulation purposes and are unsuitable for structural applications.

. ***Heavyweight concrete***. When particularly high weight densities are needed, such as for shielding in nuclear reactor facilities

Fiber-reinforced concrete

Fibers may be metallic (primarily steel), synthetic (such as polypropylene, nylon, polyethylene, polyvinyl alcohol, and alkali-resistant glass), or natural (such as sisal, coconut, and rice husk).

fibers give the concrete matrix tensile strength, ductility, and energy absorption capacities that it otherwise would not have.

fiber-reinforced concrete

Whereas in fiber-reinforced concrete the fibers are short [usually no longer than 2 in. (5 cm)]

Ultra-high-strength concrete. Whereas concretes with compressive strengths of 6000 to 12,000 lb/in.2 (40 to 85 MPa) can now be categorized as high-strength

Other characteristics of this material are low water–cement ratios, carefully selected high-strength aggregates, and small steel fibers

. *“**Green” concrete***

the production of 1 ton of portland cement causes the release of 1 ton of carbon dioxide (CO2) into the atmosphere The most significant step is the replacement of portland cement by other cementitious or pozzolanic materials, preferably materials that are byproducts of industrial processes, such as fly ash (the by-product of coal-burning power plants) and granulated blast furnace slag (a by-product of the steel industry)

Eighth Lecture

Mortar

INTRODUCTION

The principal purpose of mortar is to adhesively bind together the individual masonry units. It also provides protection against the penetration of air and water through the joints in a masonry.

Mortar also bonds the non-masonry elements of an assembly such as joint reinforcement and ties. It also compensates for minor dimensional variations in the masonry units, and provides coursing adjustment to meet required dimensions. Finally, mortar joints contribute to the architectural effect of the masonry assembly both through color and shadow.

Mortars are supplied to the job site in three ways:
- Site mixed – the mortar is prepared on site by the worker.
- Pre-mixed wet – the mortar is commercially prepared off-site and shipped in tubs ready to use. A retarder is added to the mixture to ensure the mortar in tubs does not set up before being placed in the wall.
- Pre-mixed dry – the mortar is commercially prepared off-site and supplied in bulk bags or small bags. Water is added to the mix by the mason on site.

The supply of mortar is not typically specified, but rather determined by the mason based on site conditions.

BOND –PROPERTY

Mortar mixes include ingredients that give it strength (i.e. cement) and those that promote workability and good bond with the masonry units. Good workability and water retentively are essential for maximum bond. A mortar that has overly high cement content will be stronger, but may produce less bond. Conversely, a mortar with moderate cement content will not be as strong, but will have better bond strength.

Mortar bonds masonry units together. Good bond strength will significantly contribute to a masonry wall’s integrity and weather resistance.

- The compressive strength of mortar has only a small effect on the strength of the wall, but gives it durability.

A good balance of strength and bond is required. This leads to both good structural performance and weather resistance.

Site inspection of mortar is generally not a significant concern for designers, because the bricklayer and the specifier are both looking for workable, well-proportioned mixes that ensure installation efficiency for the mason, and long-term performance for the designer.

MORTAR COLOR

From 8-22% of the wall area is taken up with mortar (depending on the unit size), therefore the colour of the mortar can significantly alter the appearance of the wall. Natural gray mortar is the most common and generally the best choice for brick and gray block. It sets off the brick colour nicely and is the most economical. In general, if a brick mortar colour is used it matches the brick in a lighter tone. Coloured mortars are usually specified for coloured block to solidify the colour impact and to simplify cleaning after construction.

SPECIFYING MORTAR

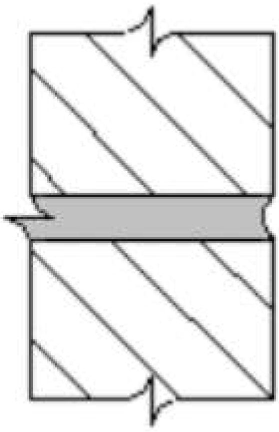
CSA A179-04 Mortar and Grout for Unit Masonry covers raw materials, mortar types, mixing process and mortar specifications. Mortar types within CSA A179-04 are designated by the letters “S” or “N”: Type S is typically used for both structural and veneer masonry, while Type N can also be used for veneer masonry construction. There are also Type O and K mortars that have proportions that are suitable for some restoration projects. Mortar specification can be made either through the Proportion or Property method. The Proportion method is used for site-mixed mortar and is based on the respective volumes of sand and cementitious materials. The Property method is based upon compressive strength tests of mortar cubes, and is typically only used for pre-mixed mortar

JOINT PROFILES

The mortar joint profile has an impact on water resistance. It also has a significant effect on appearance. Ranked by their effectiveness (highest to lowest) to resist penetration of water, common joint types are:

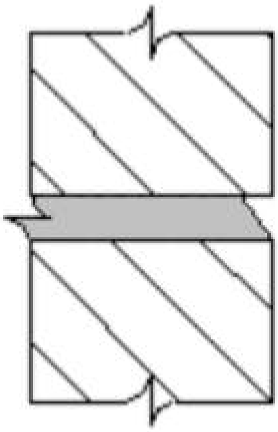
١. Concave Joint

Concave tooling of the mortar joint compacts the mortar properly against the units. A dense, smooth surface is formed that sheds water effectively. This type of joint is very effective in resisting rain penetration and therefore is recommended for use in walls exposed to wind driven rain.



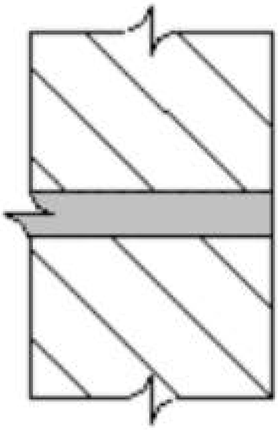
2. Weathered Joint

Although less effective than the concave tooled joint, the weathered or weather joint can be acceptable as a water resistant mortar joint as it is somewhat compacted and sheds the rain.



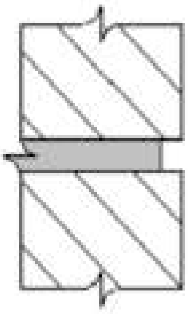
3. Flush Joint

The troweling of a flush joint forms an uncompacted joint with a possible hairline crack where the mortar is pulled away from the unit. Flush joints are not recommended as being rain resistant mortar joints and should only be used on walls that are to receive additional finishes.



4 . Raked Joint

The raked joint may or may not be compacted and it provides a ledge where rain water will settle and possibly enter the wall. It is therefore not recommended as a rain resistant mortar joint and should not be used on walls exposed to weather.
Note: Because raked joints do not weather well, the use of scored block (which require the use of a raked joint) is not recommended for exposed walls)

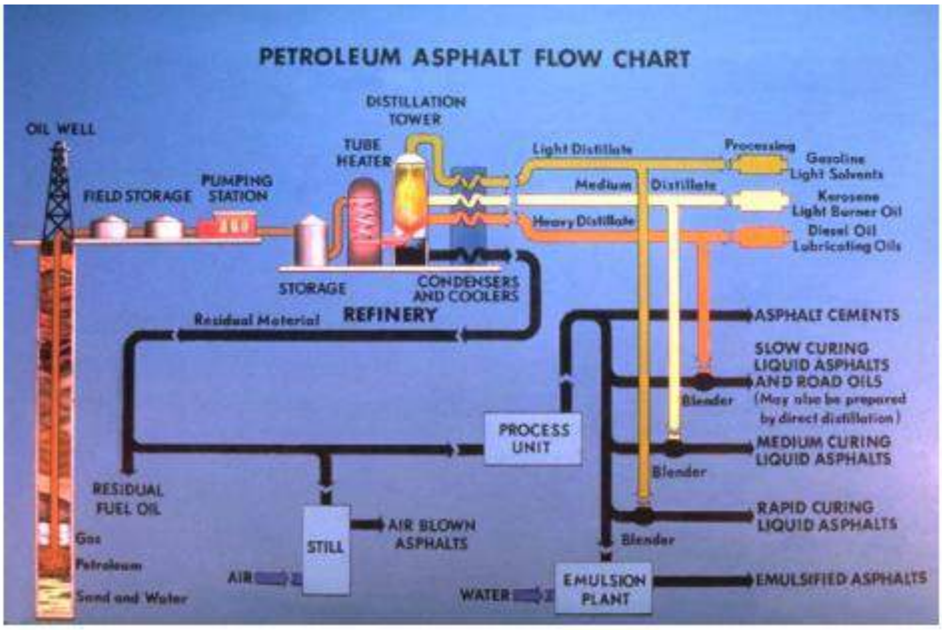


Ninth Lecture

ASPHALT

ASPHALT DEFINED

The black cementing agent known as asphalt has been used for road construction for centuries.
Although there are natural deposits of asphalt, or rock asphalt, most used today is produced
during the refining of crude oil. Asphalt is a constituent of most petroleum's and is isolated
through the refining process



Petroleum Asphalt Flow Chart

Asphalt is called a bituminous material because it contains bitumen, a hydrocarbon material
soluble in carbon disulfate. The tar obtained from the destructive distillation of soft coal also
contains bitumen. Both petroleum asphalt and coal tar are referred to as bituminous materials.
Because their properties differ greatly, petroleum asphalt should not be confused with
coal tar. Petroleum asphalt is composed almost entirely of bitumen while the bitumen

content in coal tar is relatively low. The two materials should be treated as separate entities.

One of the characteristics and advantages of asphalt as an engineering construction and maintenance material is its versatility. Although a semi-solid at ordinary temperatures, asphalt may be liquefied by applying heat, dissolving it in solvents, or emulsifying it. Asphalt is a strong cement that is readily adhesive and highly waterproof and durable, making it particularly useful in road building. It is also highly resistant to the actions of most acids, alkalis, and salts.

ASPHALT BINDER

Asphalt is produced in a variety of types and grades ranging from hard-brittle solids to near water thin liquids. The semi-solid form known as asphalt binder is the basic material used in asphalt pavements. Liquid asphalt is produced when asphalt binder is blended or “cut back” with petroleum distillates or emulsified with water and an emulsifying agent. At ambient air temperatures, asphalt binder is a black, sticky, highly viscous material. It is a strong and durable binder with excellent adhesive and waterproofing characteristics. Applying heat, which facilitates mixing with mineral aggregates to produce asphalt pavement, can readily liquefy asphalt binders.

The largest use of asphalt binder is for asphalt pavement. After compacting and cooling to air temperature, asphalt pavement is a very strong paving material with the ability to sustain heavy traffic loads while remaining flexible enough to withstand ambient environmental conditions and stresses. Over 96 percent of the hard-surfaced roads in the United States are paved using asphalt pavement.

EMULSIFIED ASPHALTS

Emulsified asphalts (also known as emulsions) are low-viscosity mixtures of tiny asphalt binder droplets, water and emulsifying agents. The emulsifying agent coats the surfaces of the asphalt droplets and keeps them suspended in the water prior to application. After application, the asphalt emulsion breaks and the water separates and evaporates. Emulsions are brownish in color during application, but after breaking, the asphalt binder returns to its original black color.

Emulsions are used for a Tack Coat between subsequent layers of asphalt pavement to aid in binding the layers together.

CUT-BACK ASPHALTS

Cut-back asphalts are low-viscosity liquid asphalt mixtures manufactured by diluting (cutting back) Asphalt Binders with petroleum solvents (cutter stock or diluent). After application, the petroleum solvent evaporates, leaving the asphalt binder residue.

Cut-Back asphalts may be used as a tack coat between subsequent layers of asphalt pavement, particularly when ambient air temperatures are cool.

ASPHALT BINDER GRADING

Asphalt binders appropriate for pavement construction were previously graded based on resistance to penetration and/or viscosity measures Currently, asphalt binders are graded based on the temperature range over which the binder retains certain desirable characteristics. These desirable characteristics include adequate flexibility to resist cold temperature cracking and sufficient rigidity to resist warm temperature rutting. The current grading system is known as the Performance Grading (PG) system.

PERFORMANCE GRADING

Performance grading specifications were developed as part of the Strategic Highway Research Program (SHRP) and are a major component of SUPERPAVE. Binders are specified on the basis of the climate and pavement temperatures in which the binder is expected to serve.

Performance graded (PG) binders used in Minnesota vary from north to south and with intended use; however, PG 58-28 is the most commonly used grade. The first number (58) represents the average 7-day.

maximum pavement design temperature in degrees Celsius. This maximum temperature establishes the upper temperature limit for the binder to retain adequate rigidity to resist rutting.

The second number (-28) represents the minimum pavement design temperature in degrees

Celsius. The minimum temperature establishes the lower limit for the binder to retain sufficient flexibility to resist thermal cracking.

Physical properties of the binders are measured at various temperatures both before and after laboratory aging. The laboratory aging is conducted to simulate field conditions imposed during the asphalt pavement production process as well as from long-term environmental exposure. Binder physical properties are typically measured using four devices:

- Dynamic Shear Rheometer
- Rotational Viscometer
- Bending Beam Rheometer
- Direct Tension Tester

AGGREGATES

Aggregates (or mineral aggregates) are hard, inert materials such as sand, gravel, crushed rock, slag, or rock dust. Properly selected and graded aggregates are mixed with the asphalt binder to form asphalt pavements. Aggregates are the principal load-supporting components of an asphalt pavement, totaling approximately 95 percent of the mixture by weight.

Classifications

Paving aggregates are classified according to source or means of preparation. A brief description of the classifications follows:

Pit or Bank-Run Aggregates

Gravel and sand are pit or bank-run natural aggregates. They are typically screened to proper size before being used for asphalt paving purposes.

Processed Aggregates

When natural pit or bank-run aggregate has been crushed and screened to make it suitable for asphalt pavements, it is considered a processed aggregate. Crushing typically improves the particle shape by making rounded particles more angular.

Crushed rock is also a processed aggregate. It is created when the fragments of bedrock and large stones are crushed so that all particle faces are fractured. Variation in size of particles is achieved by screening. In the processing of crushed rock, the fines produced are separated from the other crushed
aggregate and may be used as manufactured sand in asphalt pavements.

Synthetic Aggregates

Aggregates produced by altering both physical and chemical properties of a parent material are called synthetic or artificial aggregates. Some are produced and processed specifically for use as aggregates; others are the byproduct of manufacturing and a final burning process. Blast furnace slag is an example of a synthetic aggregate.

Desirable Properties of Aggregates

Selection of an aggregate material for use in an asphalt pavement depends on the availability, cost, and quality of the material, as well as the type of construction for which it is intended.

To determine if an aggregate material is suitable for use in asphalt construction, it should be evaluated in terms of the following properties.

1. ***Size and grading.*** The maximum size of an aggregate is the smallest sieve through which 100 percent of the material will pass. The Nominal Maximum size is the next sieve larger than the sieve on which 10 percent of the material is retained. How the asphalt pavement mixture is to be used determines not only the appropriate maximum aggregate size, but also the desired gradation (distribution of sizes smaller than the maximum).
2. ***Cleanliness.*** An excess of foreign or deleterious substances such as shale, oxides, unsound cherts and/or organic material make some materials unsuitable for paving mixtures.
3. ***Toughness.*** Toughness or hardness is the ability of the aggregate to resist crushing or disintegration during mixing, placing, compacting, and other procedures associated with construction or traffic loading.
4. ***Soundness.*** Although similar to toughness, soundness is the aggregate's ability to resist deterioration caused by the weather; for example, the stresses placed on materials during freezing and thawing.
5. ***Particle shape.*** The shapes of aggregate particles influence the asphalt mixture's overall strength and workability as well as the density achieved during compaction. When compacted, irregular particles such as crushed rock tend to "lock" together and resist displacement.

6. ***Absorption.*** The porosity of an aggregate permits it to absorb asphalt and form a bond between the particle and the asphalt. A degree of porosity is desired, but aggregates that are highly absorbent are generally not used. Absorption is a significant factor in asphalt pavement mix design.
7. ***Stripping.*** When the asphalt film separates from the aggregate because of the action of water, it is called stripping. Aggregates coated with too much dust also can cause poor bonding, which results in stripping. Aggregates readily susceptible to stripping action usually are not suitable for asphalt paving mixes unless an anti-stripping agent is used.

The attributes mentioned above are quantitatively measured by standard physical tests and limits are included in standard materials specifications.

ASPHALT PAVEMENT

Asphalt pavement is known by many different names: asphalt pavement, asphaltic concrete, plant mix, bituminous mix, bituminous concrete, hot-mix asphalt, warm-mix asphalt and many others.

It is a combination of two primary ingredients - aggregates and asphalt binder. The aggregates total approximately 95 percent of the total mixture by weight. They are mixed with approximately 5 percent asphalt binder to produce asphalt pavement.

The aggregates and asphalt are combined in a manufacturing plant capable of producing specified materials. Plant equipment includes: cold bins for storage and controlled proportioning of graded aggregate; a dryer for drying and heating aggregates to the required mixing temperature; a pug mill or drum for combining the graded, heated aggregate and liquid asphalt cement according to specified mix formulas and tanks for storing the heated liquid asphalt.

Asphalt pavement is transported by truck to the paving site where it is spread to a uniform thickness with a mechanical paving or finishing machine. The material is then compacted to the required degree by heavy, self-propelled rollers, producing a smooth pavement course.

The paving or finishing machine places the asphalt pavement at temperatures between approximately 225° and 300° F., depending on the mixture characteristics, layer thickness and ambient conditions. The material should be compacted before the mix temperature falls below optimum compaction temperature, dependent on ambient conditions, to achieve adequate density.

Covering more than 96 percent of the nation’s paved highways, asphalt pavement is the most widely used paving material in the United States.

For versatility, durability, and ease of construction, it has no equal

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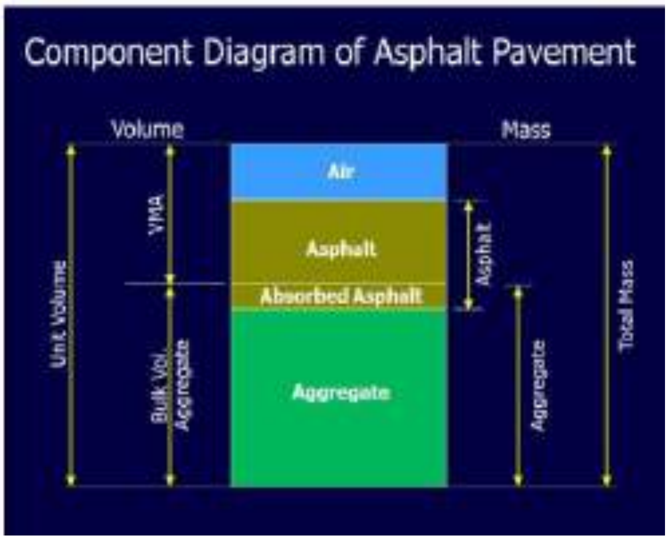

Component Diagram of Asphalt Pavement

Tenth Lecture

WOOD

Wood has been used and adapted by humans since the earliest recognition that they could make use of the materials they found around them. As they used it to meet a varying array of human needs, in peace and in war, in farming and in industry, people gradually came to understand something of the unique nature of wood. Its properties were first understood by experience, more recently by systematic research and refined observation. Wood is still essential to human life, but has evolved over the ages from a simple, readily available natural material to a modern industrial and engineering material, with a unique ability to contribute to human life both as a material for use and as a key element in the natural world of the forest.

The Nature of Wood

Wood is a natural product of the growth of trees. It is primarily composed of hollow, elongate, spindle-shaped cells that are arranged more or less parallel to each other in the direction of the tree trunk. This makes wood basically fibrous in nature and the characteristics of these fibrous cells and their arrangement in the tree strongly affect properties such as strength and stiffness, as well as the grain pattern of the wood.

Structure and Formation of Wood

Trees are divided into two broad classes, usually referred to as hardwoods and softwoods. This can be confusing, because the wood of some softwoods is harder than that of many hardwoods. For example, Scots pine and Douglas-fir are softwoods, but their wood is harder than that of poplar or mahogany, which are classed as hardwoods.

Botanically, the hardwoods are angiosperms, which refers to the fact that the seeds are enclosed in the ovary of the flower. Anatomically, hardwoods are porous in that they contain vessel cells (pores in the transverse section) that form tubes for transporting water or sap in the tree. Typically, hardwoods have broad leaves that, in temperate and semi-tropical regions are shed in winter. Botanically, softwoods are gymnosperms, which refers to the fact that the seeds are naked (not

enclosed in the ovary of the flower). Anatomically, softwoods are nonporous and contain no vessel elements.
Softwoods are usually conifers, cone-bearing plants with needle or scale-like leaves that are retained on the tree for two or more years, though a few of them such as the larches, drop their leaves each year. Softwoods are predominant in many parts of the boreal forest, and mixed with hardwoods in many parts of the temperate forest. Hardwoods are predominant in the tropical and semi-tropical forest.

Most woods grown in temperate regions show a distinct demarcation between cells formed early in the growing season (earlywood) and those formed late in the growing season (latewood) and this is sufficient to produce clear growth rings. The actual time of formation of earlywood and latewood varies with environmental and growth conditions. Earlywood is characterized by cells with thin walls and large cavities, while latewood cells typically have thicker walls and smaller lumens. In some hardwoods, earlywood may be characterized by the growth of large vessels with pores clearly larger and more numerous (see wood cells). Transition from earlywood to latewood may be gradual or abrupt, depending on the species and conditions of growth.
Growth rings, or annual increment, are most readily seen where this transition is abrupt, either due to the thick-walled cells of latewood in softwoods (Figure 2) or the more prominent earlywood vessels of hardwoods (Figure 1). This difference in wood
structure causes noticeable differences in physical properties of the wood and proportion of latewood may be used as a rough indication of differences in properties of lumber or other products made from the wood.

Chemically, wood is composed primarily of carbon, hydrogen, and oxygen. Carbon and oxygen predominate and are usually about 49 and 44 %, respectively, on a weight basis.
The remaining 7% is mostly hydrogen, with small amounts of nitrogen and metallic ions (ash). The organic constituents of wood are cellulose, hemicellulose, lignin, and extractives. Cellulose is formed from glucose by polymerization in long chain polymers that may be as much as 10,000 units long. Other sugars are polymerized into much shorter branched chains called hemicelluloses. These components are laid down in layers

to form the walls of wood cells. Wood cells, the structural elements of woody tissue, are of various sizes and shapes and are quite firmly cemented together. Most cells are considerably elongated, pointed at the ends, and oriented in the direction of the trunk of the tree. They are usually called fibers. The length of fibers is quite variable within a tree and among species of trees. Cellulose, the major component makes up about 50% of wood substance by weight. It is a high-molecular-weight linear polymer consisting of long chains of glucose monomer. These are not individually large structures, however, the largest being about 10 microns (μm) in length and about 0.8 nm in diameter, too small to be seen even with an electron microscope. During growth of the tree, the cellulose molecules are arranged into ordered strands, called fibrils, which in turn are organized into the larger structural elements that make up the cell walls of wood fibers. Hemicelluloses are associated with cellulose and are branched, lowmolecular-weight polymers composed of several different kinds of pentose and hexose sugar monomers. They vary widely among species of wood.

Lignin makes up 23% to 38% of the wood substance in softwoods and 16% to 25% in hardwoods. Lignin is a complex high molecular weight polymer built upon propylphenol units, rather than sugars. Despite being made up of carbon, oxygen, and hydrogen, it is not a carbohydrate, but rather phenolic in nature. Lignin occurs both between the cells, serving to bind them together, and within the cell wall, providing rigidity. Lignin occurs in wood throughout the cell wall, but is concentrated toward the outside of cell walls and between cells. Lignin is a three-dimensional phenylpropanol polymer. A principal objective of chemical pulping is to remove the lignin. Extraneous materials, both organic and inorganic, are not parts of the wood structure. Organic materials, known as extractives, make up 5% to as much as 30% of the wood in a very few species and include such materials as tannins, coloring matter, resins, and others, which can be removed with water or organic solvents. Inorganic materials, such as calcium, potassium, and magnesium, are usually less than 1% of wood substance in the temperate zone.

The xylem of softwoods is relatively simple, usually comprising only three or four kinds of cells, predominantly fibers. Because of this simplicity and uniformity of structure, softwoods tend to be similar in appearance. Most of the wood of softwoods (90-95%) is comprised of

longitudinal tracheids (fibers). These are long, slender cells, about 100 times as long as they are wide, averaging about 3 to 4 mm in length, rectangular in cross section, closed at the ends, with bordered pits primarily on the radial face. A small portion of the wood of softwoods is longitudinal parenchyma, cells shaped like the fibers, but usually divided into short lengths. Some softwoods (*Pinus, Picea, Larix,* and a few others) contain resin canals, which are intercellular spaces in the longitudinal direction surrounded by specialized cells that secrete resin. Radial structures in softwoods are usually wood rays a few cells thick, composed of either ray tracheids or ray parenchyma.

The structure of hardwoods is much more complex and diverse than that of softwoods with at least four major kinds of cells: fibers, vessels, longitudinal parenchyma, and ray parenchyma. Fibers are shaped something like tracheids of softwoods, but are much shorter (<1 mm) and tend to be rounded in cross section. Their function is primarily mechanical support. Vessel elements are specialized conducting tissue, unique to hardwoods, shorter than fibers, and connected end to end. They appear on the transverse face of the wood as pores. In some species, e.g., oak (*Quercus),* these large vessels become blocked with tyloses as the sapwood changes to heartwood. Tyloses may also form as a result of injury or drought. Longitudinal parenchyma are thin walled cells whose function is primarily storage of nutrients. Hardwood rays are made up of from 1 to 30 cell wide bands of parenchyma, storage tissue, running radially in the tree. In some species, such as the oaks and beeches, these are clearly visible to the eye, in others they are scarcely visible. Figure 4 is a three-dimensional representation of a hardwood, showing these types of cells on the transverse, radial, and longitudinal faces.

Eleventh Lecture

Composite materials

A composite material is made by combining two or more materials – often ones that have very different properties. The two materials work together to give the composite unique properties.

However, within the composite you can easily tell the different materials apart as they do not dissolve or blend into each other.

Natural composites

Natural composites exist in both animals and plants. Wood is a composite – it is made from long cellulose fibres (a polymer) held together by a much weaker substance called lignin. Cellulose is also found in cotton, but without the lignin to bind it together it is much weaker. The two weak substances – lignin and cellulose – together form a much stronger one.

The bone in your body is also a composite. It is made from a hard but brittle material called hydroxyapatite (which is mainly calcium phosphate) and a soft and flexible material called collagen (which is a protein). Collagen is also found in hair and finger nails. On its own it would not be much use in the skeleton but it can combine with hydroxyapatite to give bone the properties that are needed to support the body.

Early composites

People have been making composites for many thousands of years. One early example is mud bricks. Mud can be dried out into a brick shape to give a building material. It is strong if you try to squash it (it has good compressive strength) but it breaks quite easily if you try to bend it (it has poor tensile strength). Straw seems very strong if you try to stretch it, but you can crumple it up easily. By mixing mud and straw together it is possible to make bricks that are resistant to both squeezing and tearing and make excellent building blocks.

Another ancient composite is concrete. Concrete is a mix of aggregate (small stones or gravel),cement and sand. It has good compressive strength (it resists squashing). In more recent times it has been found that adding metal rods or wires to the concrete can increase its tensile (bending) strength. Concrete containing such rods or wires is called reinforced concrete.

Making composites

Most composites are made of just two materials. One is the matrix or binder. It surrounds and binds together fibres or fragments of the other material, which is called the reinforcement.

Modern examples

The first modern composite material was fibreglass. It is still widely used today for boat hulls,sports equipment, building panels and many car bodies. The matrix is a plastic and the reinforcement is glass that has been made into fine threads and often woven into a sort of cloth.

On its own the glass is very strong but brittle and it will break if bent sharply. The plastic matrix holds the glass fibres together and also protects them from damage by sharing out the forces acting on them.

Some advanced composites are now made using carbon fibres instead of glass. These materials are lighter and stronger than fibreglass but more expensive to produce. They are used in aircraft structures and expensive sports equipment such as golf clubs.

Carbon nanotubes have also been used successfully to make new composites. These are even lighter and stronger than composites made with ordinary carbon fibres but they are still extremely expensive. They do, however, offer possibilities for making lighter cars and aircraft (which will use less fuel than the heavier vehicles we have now).

The new Airbus A380, the world’s largest passenger airliner, makes use of modern composites in its design. More than 20 % of the A380 is made of composite materials, mainly plastic reinforced with carbon fibres. The design is the first large-scale use of glass-fibre-reinforced aluminium, a new composite that is 25 % stronger than conventional airframe aluminium but 20 % lighter.

Why use composites?

The biggest advantage of modern composite materials is that they are light as well as strong. By choosing an appropriate combination of matrix and reinforcement material, a new material can be made that exactly meets the requirements of a particular application. Composites also provide design flexibility because many of them can be moulded into complex shapes. The downside is often the cost. Although the resulting product is more efficient, the raw materials are often expensive.