University of Missan
College of Engineering
Civil Engineering Department

MATERIALS OF CONSTRUCTION

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1. Masonry

Masonry remains a key component of most buildings. Even steel framed and timber framed buildings often have masonry cladding.

The great majority of masonry walling is produced from performed units, bonded by a mortar. These may be subdivided into

- **Bricks**, which are easily handled with one hand.
- **Blocks**, which are larger units, generally requiring both hands.

The word **Brick** refers to building unit of regular shape which are used in construction. The most widely used dimensions (215x102.5x65mm) according to British Standards BS and (240 mm x 115mm x 75mm) according to Iraqi standard. **Brick dimensions not more specified dimensions (338x225x113mm).**

![Brick Dimensions Diagram](image)

When the dimensions more than this limit is called **Building Block**.

Bricks are making from different materials such as clay, lime, sand or any other material used for reconstructive purposes.
1.1. **Clay Bricks**

It is the most commonly types of bricks in Iraq because of availability of raw materials, low cost of production, appropriate to bear the forces, heat isolation, resistance to fire and atmospheric changes. The clay bricks make from sedimentation clay and silt which contain an amount of other materials because of the pure clay is not fit for the bricks production since other materials help to build a paste don't shrink during drying process likes and which helps to prevent cracks of mud in the cases of drying as well as lime and gypsum, which helps to pride bricks at a moderate temperature without melting. lime or gypsum work as adhesive material for bricks granules.

Physical analysis of the clay used for the brick production in Iraqs:

- 13% pure clay
- 45% Green silt
- 17% of Fine sand
- 8% coarse sand

<table>
<thead>
<tr>
<th>Name</th>
<th>Particle Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>below 0.002 millimeters</td>
</tr>
<tr>
<td>Silt</td>
<td>0.002 to 0.05 millimeters</td>
</tr>
<tr>
<td>Very fine sand</td>
<td>0.05 to 0.10 millimeters</td>
</tr>
<tr>
<td>Fine sand</td>
<td>0.10 to 0.25 millimeters</td>
</tr>
<tr>
<td>Medium sand</td>
<td>0.25 to 0.5 millimeters</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>0.5 to 1.0 millimeters</td>
</tr>
<tr>
<td>Very coarse sand</td>
<td>1.0 to 2.0 millimeters</td>
</tr>
<tr>
<td>Gravel</td>
<td>2.0 to 75.0 millimeters</td>
</tr>
<tr>
<td>Rock</td>
<td>greater than 75.0 millimeters (~2&quot;)</td>
</tr>
</tbody>
</table>

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Table 1. The Size of Sand, Silt and Clay
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**1.1.1. Manufacture**

Clay bricks are made by shaping suitable clay to units of standard size which are then fired to a temperature in the range 900 to 1200 °C. the fired product is a ceramic composed pronominally of

- Silica \( \text{SiO}_2 \) (55-65) %
- Aluminia \( \text{Al}_2\text{O}_3 \) (10-25) %
- Other 25 %

A key property of the clay in relation to brick manufacture is its moisture content at the time of processing.

A very dry clay has the potential to produce a very strong brick since, on firing, any moisture present evaporates leaving voids which in turn cause weakness. however dry clays may have low plasticity and may be difficult to compact; therefore, intense compaction effort would be needed to remove air from the clay during the formation process. The water content may be increased after extraction to assist production but it is much more difficult to reduce the water content of clay prior to moulding. The situation is rather similar to that by which concretes are produced.

**1.1.2. Properties of clay bricks**

**1. Strength**

Since bricks are invariably used in compression, the standard method of test for strength involves crushing the bricks, the direction of loading being the same as that which is to be applied in practice, normally perpendicular to their largest face. The required strength determine according to construction use and so specified brick class.
2. **Bricks porosity**

The higher porosity lead to density and loading capacity reduction and increasing of water absorption and head isolation.

3. **Water absorption**

Water absorption may be an important property of clay bricks, since bricks that have very low absorption are invariably of high durability.

4. **Efflorescence**

The buildup white surface deposits on brickwork when drying after earlier saturation, Figure below. It results from dissolved salts in the brick or other sources and quite commonly spoils the appearance of new brickwork. It will be appreciated that brickwork often reaches high levels of saturation during and immediately after construction for one or more of the following reasons:

1- Bricks may not have been fully protected from rain prior to laying.
2- Mortar loses moisture into the bricks by suction.
3- Brickwork is readily saturated by weather prior to protection.
4- Moisture movement during construction curing.

**Preventing of Efflorescence**
5. **Soluble salt content**

Salts can be harmful in:

1- Causing efflorescence.
2- Leading to problems such as sulphate attack in the mortar.

Bricks are classified as a low soluble salt content if the percentages of the following ions don't exceed the levels stated:

- **Sulphate** 0.5%
- **Calcium** 0.3%
- **Magnesium** 0.03%
- **Potassium** 0.03%
- **Sodium** 0.03%
6. Durability of clay brickwork

The durability of clay brickwork is likely to be more of a problem than its strength. The durability problems are associated with moisture penetration, the mechanisms of the three main modes of deterioration are considered below:

1- Frost damage
2- Crystallization damage
3- Sulphate attack

1.1.3. Quality of good clay bricks

1- The bricks should be well burnt, free from cracks and with sharp and square edges and should be of standard size.
2- The colour should be uniform.
3- The bricks should be given a clear metallic sound when struck with each other.

4- The bricks when broken should show a homogenous and uniform compact structure free from voids.
5- The brick should not absorb water more than standard limits.
6- The bricks should be sufficiently hard. No impression should be left on brick surface, when it is scratched with finger nail.
7- The bricks should not break into pieces when dropped flat on hard ground from a height of about one meter.
8- The bricks should be have low thermal conductivity

1.1.4. Tests for clay bricks

A bricks is generally subjected to the following tests to find out its suitability for the construction work.

1- Shape and size
2- Water absorption
3- Compression strength
4- Efflorescence
5- Hardness
6- Soundness
7- Structure

1.1.5. Colour of clay bricks

The colours of bricks depends on the following factors:

1- Degree of dryness achieved before burning
2- Natural colour of clay and its chemical composition
3- Nature of sand used in moulding operation
4- Quality of fuel used in burning operation
5- Quantity of air admitted to the kiln during burning, and
6- Temperature at which bricks are burnt. The colour of clay bricks producing in Iraq controlled by temperature effect.
Table shows the colours produce by clay with various constituents.

<table>
<thead>
<tr>
<th>No.</th>
<th>Colour</th>
<th>Constituents present in clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Black</td>
<td>Manganese and large proportion of iron</td>
</tr>
<tr>
<td>2.</td>
<td>Bluish green</td>
<td>Alkali (burnt at high temperature)</td>
</tr>
<tr>
<td>3.</td>
<td>Bright red, dark blue or purple</td>
<td>Large amount of iron oxide</td>
</tr>
<tr>
<td>4.</td>
<td>Brown</td>
<td>Lime in excess</td>
</tr>
<tr>
<td>5.</td>
<td>Cream</td>
<td>Iron and little lime</td>
</tr>
<tr>
<td>6.</td>
<td>Red</td>
<td>Iron in excess</td>
</tr>
<tr>
<td>7.</td>
<td>White</td>
<td>Pure clay</td>
</tr>
<tr>
<td>8.</td>
<td>Yellow</td>
<td>Iron and magnesia</td>
</tr>
</tbody>
</table>

The artificial colouring of bricks is achieved by

1- Adding of colouring materials, or
2- Dipping in colouring liquid.
1.1.6. **Classification of clay bricks**

Bricks can be classified as follows:

**1- According to burning temperature**

a- Over burnt clay locally called (musakhrage), this type burnt by extremely high temperature, this type has relatively less porosity, high density and high strength. Use in foundation works for its high strength and high resistance for moisture movement.

b- Yellow bricks

This type manufacture with burning temperature less than first type. Its colour is yellow and it consider relatively brittle.

Use in facing of building for its pure golden colour.

c- White bricks

This type manufacture with acceptable burning temperature. Its colour is white.

Use in internal and external construction.

d- Bricks with various colours.

Bricks burnt by not homogeneous temperature, porosity higher than white bricks.

Use in internal construction.

e- Red bricks

This type doesn't burnt perfectly. Its colour is red

Use in internal construction away from moisture content.

**2 - According to the way of its production**

primitive, a half primitive, half mechanic and mechanical bricks.

**3- According to loading capacity**

a – class A (grade 1 and 2)

This class use in constructions which is design to be loaded and expose to corrosion of external factors.
b- class B (grade 1 and 2)
This class use in constructions which is design to be loaded and doesn't expose to corrosion of external factors.

c- class C (grade 1 and 2)
This class use in constructions which is doesn't carry any loads and doesn't expose to corrosion of external factors.

<table>
<thead>
<tr>
<th>Bricks class</th>
<th>grade</th>
<th>Minimum limits of compression strength Mpa</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>11</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>7</td>
</tr>
</tbody>
</table>

3- **According to voids ratio in bricks**

- **Solid bricks**
No voids, strength higher than all other types so use in foundations and constructions need for high strength and durability.
- **Perforated bricks**
  Voids ratio less than 25%, high strength but the strength less than that of solid type, use in loading constructions and partitions

- **Hollow bricks**
  Voids ratio more than 25%, lower strength and use in partitions and unloaded walls

- **Cellular bricks**
  Voids ratio more than 25% and the voids don't open through brick thickness, use in partitions and unloaded walls
- **Frog bricks**
The frog bricks like solid bricks with frog or two in one surface, high strength and use when the bonding strength is required.

1.1.7. **Indentations and perforations in bricks**

Indentations (frogs) and perforations (cylindrical holes passing through the thickness of the brick) may be provided for one or more of the following reasons:

1. They assist in forming a strong bond between each brick and the wall.
2. They reduce the material cost without serious in situ strength loss.
3. In the case of clay bricks, they reduce the effective thickness of the bricks and hence reduce required power and firing time.

Bricks with single frog should be laid frog up, since this ensures that the frog is filled with mortar

Perforated bricks generally contain less than 25% of voids and behave, in a structural sense, as if they were solid.
1.2. **Concrete masonry unit**
A concrete masonry unit (CMU) – also called concrete block or cement block,– is a large rectangular unit used in construction. Concrete blocks are made from cast concrete, i.e. Portland cement and aggregate, usually sand and fine gravel for high-density blocks. Lower density blocks may use industrial wastes as an aggregate. Lightweight blocks can also be produced using aerated concrete.

Concrete masonry units may be formulated with special aggregates to produce specific colors or textures for finish use. Special textures may be produced by splitting a ribbed unit.

1.2.1. **Structural properties**

- Concrete masonry can be used as a structural element in addition to being used as an architectural element.
- Reinforcement bars can be used both vertically and horizontally inside the CMU to strengthen the wall and results in better structural performance. The cells in which the rebar is placed must be grouted for the bars to bond to the wall. For this reason, high seismic zones typically only allow fully grouted walls in their building codes.
- The compressive strength of concrete masonry units and masonry walls varies from approximately (7 MPa) to (34 MPa) based on:
  1- the type of concrete used to manufacture the unit
  2- stacking orientation,
  3- the type of mortar used to build the wall, and other factors.
2. **Metals**

The metals have special place in the constructional industry because:

- Metals are generally ductile, they exhibit the phenomenon of being able to undergo substantial plastic flow without damage. In this respect they are unique among stronger materials types.
- They have a wide range of properties.
- The stronger metals have higher stiffness and tensile strength than most non metals.
- Metals are easily alloyed, further increasing their versatility.
- Strong bonds can be produced easily by soldering, brazing or welding.

There are some problems associated with metals.

- They are expensive in energy terms to produce.
- They deteriorate by chemical surface action in normal atmospheres (corrosion).
- They have high density, even aluminum, with relative density of 2.7 is denser than concrete (relative density about 2.3)

One of the big advantages of metals is that the metallic bond is a relatively flexible type of bond.

Although the metallic bond is not, in general, as strong as ionic and covalent bonds, the high density of packing of ions in metals **crystals** results in metals being a most important bulk structural materials.
2.1. **Ferrous**

Cast iron, wrought iron and steel are alloys of iron and carbon. Other alloying elements like copper, manganese, nickel, etc may be added to steel to make special steels. Iron is a chemical element, steel is iron containing less than 1.5 % carbon. Wrought iron is different from steel as it contains less than 0.15% carbon.

2.1.1. **Manufacture**

*Iron ore is mined from earth and smelted in blast furnace to produce pig iron which is an impure product, weak in tension.*

*It is convert into cast iron by mixing various other grades of iron so as to form the required composition and melting it down.*

*Pig iron is converted to wrought iron by the puddling process (Method of converting pig iron into wrought iron by subjecting it to heat and frequent stirring in a furnace in the presence of oxidizing substances (oxidation-reduction)).*

*Steel is produced from pig iron by anyone of:*

1- **Bessemer process** (A method for making steel by blasting compressed air through molten iron to burn out excess carbon and impurities).

2- **Siemens Martin process** (a bath of highly-heated pig metal is prepared in the furnace, and three or four times its weight of scrap-iron or steel is gradually added (preferably in a highly-heated condition) and dissolved in the fluid bath)

3- **Electric Furnace process** (using heating generated by electrical current through melt iron to control furnace temperature)

**Carbon content effect**

The approximate percentage of carbon in the three basic forms of iron is as follows.

<table>
<thead>
<tr>
<th>Material</th>
<th>Carbon Content</th>
<th>Specific Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast iron</td>
<td>2 -5 % carbon</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Assistant lecturer: Sajid Kamil
Steel  up to 1.5 % carbon  Specific gravity  7.8
Wrought iron  0.05 – 0.15 % carbon  Specific gravity  7.7

Carbon in excess of 1.5 % does not combine with iron, but will be present as free graphite. Steel become harder and more brittle with higher carbon content. Steel and wrought iron can be distinguished by putting a drop of nitric acid on the materials. Due to higher carbon content than wrought iron, it will produce a grey stain on steel.

2.2. **Wrought Iron**

Wrought iron contains less than 0.15% carbon. It is made from white pig iron by removing most of carbon, manganese, silicon, phosphorous and sulphure by puddling process in a reverberator furnace. Being equally strong in tension and compression, steel has nowadays replaced wrought iron in common use.

A small amount used for making tough articles like spikes, nails, bolts and nut, chains, hard rails, pipe tube, etc.
2.3. **Cast iron**

It is about three to five times stronger in compression than in tension. Its strength in compression is about 560 MPa and its strength in tension is only about 140 MPa. Carbon lowers the melting point of iron, so cast iron melts at lower temperature than steel. It is easier to make castings of cast iron even in small factories. Its melting temperature is about 1200 °C whereas that of wrought iron is above 1500 °C. Cast iron is still used very much in industry where the forces are in compression and the structural parts do not have to withstand shock, bending and tension. Cast iron is cheap as it is capable of manufacture with simple tools in small factories. Unlike steel, cast iron is very resistant to corrosion and so it is extensively used in rainwater pipes.

![Wrought iron hand rail](image1)

![Cast iron productions](image2)
2.3.1. **Corrosion resistance of cast iron**

In the corrosion of grey iron at the surface, say a buried pipes, the graphite present will be left as a residue within the corrosion products which adheres very firmly to the unattached metals substrata. This graphite containing corrosion product provides a barrier against further corrosion attack.

2.4. **Steel**

Steel is the most important ferrous in building construction, is an alloy of iron and carbon, there are many types of steel:

Mild steel (structural steel), high tensile steel and special types are some of them. They differ in their carbon content, ultimate strength, yield point, elongation percentage at ultimate failure, hardness, etc.

The mild steel is very ductile compared to all other types of steel used for engineering purpose. Ductility is a very important for structural steel sections used in steel frame building or steel rods to be used in reinforced concrete design for earthquakes.

2.4.1. **Mechanical Treatment of steel**

One of the very desirable qualities of steel as different from cast iron is that it can be:

- Hot worked into different shapes.
- Cold worked
- Heat treatment

All three operations are important to get desirable properties.

2.4.2. **Hot working of steel**

The steel is heated to the required temperature and the operations involved are the following
1- Rolling
2- Forging
3- Pressing
4- Drawing

Rolling and drawing are the most important operations. Rolling is carried in specially prepared rolling mill. The red hot ingots are passed through different rollers until articles of the desired shapes like I, L or angle are got. In drawing, the metal is drawn through different dies an specially shaped tools. It is with this process that the reinforcement rods are prepared.

2.4.3. **Cold working of steel**
From the stress strain curve of mild steel, we find that if a steel bar is stressed beyond its yield point and unloaded, in the next cycle of loading, it will be found that the yield point has been raised. This is due strain hardening of steel. This higher yield point is lost and the steel restored to normal steel if the steel heated to higher temperature (500-650 °C) after cold working. Cold twisted deformed bars of concrete reinforcement are produced by this principle. The cold working is carried by twisting the bar beyond the yield point. Welding of these bars should be done with great care as otherwise its high strength will be lost due to the heat.

2.4.4. **Heat treatment of steel**
Heat treatment is the process by which the steel is heated and cooled under controlled conditions to change the structural or physical properties of the steel. For example, we can increase the surface hardness of steel by heat treatment.
2.4.5. **Structural applications of steel**

The important forms of structural application of steel in building construction are the following:

1. Steel bars of many shapes and grades (strength). These bars are used for R.C. (Reinforcement concrete) and also for fabrication of grills, gates, etc.
2. High tensile steel for prestressed concrete works.
3. Various shapes of I, channel, angle, plates and other rolled sections.
4. Cold formed light gauge structural steel sections
5. Stainless steel for special uses.

2.4.6. **Types of steel reinforcement**

Steel rods used for reinforcement concrete work should be of specific tensile strength, and they should develop good bond strength with concrete. Steel rods of different diameters are used for R.C. work. In order to identify the sizes easily, only standard sizes should be used in building units.

The following types are commonly available for R.C.:

1. Hot rolled bars, of which there are two types:
   a. Plain round mild steel bars
   b. Deformed steel bars

*Plain (smooth) steel bars*
2- **Hot rolled cold twisted deformed bars** (high strength got by cold twisting)
3- **Thermo mechanically treated bars** (high strength got by controlled cooling)
4- **Cold drawn steel wire fabric** (welded wire fabric)

### 2.4.7. **Standard sizes of steel bars**

Even though bars can rolled into any size, there are nominal standard diameters according to specifications. Theses sizes have the advantage that they can easily be distinguished from each other in the field by visual inspections.
2.4.8. Storing of reinforcements

Steel bars should be stored properly to avoid corrosion and distortion by keeping them off the ground and providing enough support so that they do not bend. If they are to be stored for long periods, some cover should be provided to keep off the rain. Slight rusting of the surface of steel is allowed in steel bars, but bars that have scales of rust must be cleaned off these rust before being used.

It is not a good practice to cement wash steel, as the grout dries quickly and gets scales off powder.

Inspection of reinforcement before using in actual work

All reinforcement for R.C. should be free from paint, oil, grease, loose rust, loose mild scale and any other matter likely to impair the bond strength of the concrete. Oil can be removed by thoroughly washing with petrol. Steel so treated should be left in the open for a few days and then brushed with wire brush before it is used.

The rods when bent into hooks should not crack or split as it will indicated a brittle steel.

The test report should contain data regarding yield strength, ultimate strength as well as percentage elongation at failure load and percentage reduction in cross section area at failure load (necking). Results of the bend test will also be useful.
2.4.9. **Steel for prestressed concrete**

The ultimate strength of these steel will be of order of 1400-1700 MPa. High strength can be produced by alloying steel with carbon, manganese, silicon etc., the more common method of increasing the tensile strength by cold drawing. These high tensile steel usually takes one of the following three forms, bars, wires, and strands made up of wire, for post tension, the small diameter wires are made into cables.

- **Necking**

- **Strands made up of wire**

- **Prestressed bars**
2.4.10. **Structural steel sections**

The two types of structural steel members are the following:

1. Hot rolled steel sections
2. Cold formed steel sections

1. **Hot rolled sections**

Steel used for fabrication of trusses, columns, beams, etc. of building is made by rolling hot steel ingots into various shapes. The section that are popularly available are the following:

1. Angle sections
2. Channel sections
3. I sections
4. T sections
5. Other rolled sections
2- **Cold rolled sections (thin walled)**

Cold formed light gauge sections are structural members, cold formed to desired shapes from carbon or alloy steel. The thickness of the member ranged (0.38-6.35 mm). They have much strengths than hot rolled sections.
The advantage of cold formed over hot formed sections

1- Cold section thinner so that we can get more length of the material from the same length.

2- Effective shapes or configurations of steel sections can be produced by cold forming operations, a more favorable strength to weight ratio can be achieved through cold formed sections.

3- Aesthetically pleasing section get with cold forming operation.

4- Cold formed steel sections have higher strength than hot rolled sections.

5- Cold formed steel sections are extensively used in fabrication of roof trusses.

Selection of structural steel

The selection of a steel for a specific application is determined by several factors:

1- The tensile yield strength required.

2- The toughness, ductility and other properties required.

3- The availability and cost, and

4- Arbitrary local conditions as may be imposed by specifications and codes of practice.
2.4.11. **Stainless steel**

It is possible to manufacture steels with an enhanced resistance to corrosion by making alloying additions of nickel and chromium. After exposure to the weather, an adherent protective oxide film will develop instead of normal flaky rust. Its cost about 20% greater than normal structural steel, but this may be offset by savings in weight, protective treatment and maintenance.

![Stainless steel](image)

**Fire resistance**

Steel loses strength when heated sufficiently. The critical temperature of a steel member is the temperature at which it cannot safely support its load. Building codes and structural engineering standard practice defines different critical temperatures depending on the structural element type, configuration, orientation, and loading characteristics. The critical temperature is often considered the temperature at which its yield stress has been reduced to 60% of the room temperature yield stress.
Temperature effect on steel properties: Steel frame collapsed due to fire effect

2.5. **Aluminum**

Aluminum is the third most common element in the earth’s crust, coming after oxygen and silicon. It makes up 8% of the crust’s total mass and is the most abundant metal. Pure aluminum is not suitable for structural applications because of the low values of its mechanical characteristics. In order for aluminum to be useful as a structural metal, it was essential to develop suitable alloys. However, many alloys are available with a large variety of excellent mechanical and physical qualities. The appropriate alloy depends on the specific application. The 6xxx series alloys are the most useful for structural applications because of their combination of strength, corrosion resistance, and weldability.
2.5.1. **Aluminum Alloys Advantages**

*a.* Low density, of approximately one third of steel.

*b.* Good strength and toughness properties, also at very low temperatures.

*c.* Large variety of possible cross-sectional shapes of profiles and connection elements.

*d.* High corrosion resistance due to a tough oxide-layer.

*e.* Excellent to recycle without a decrease in quality

**The main characteristics of aluminum alloys differ from those of steel as follows:**

*a.* Aluminum alloys offer a wider range of strength than steel. Aluminum is very ductile ($\varepsilon_t \approx 40\%$), but on the other hand its strength is very low for structural application ($f_{0.2} = 20\,\text{MPa}$). In order to increase strength;

- A cold – working process can be used; however, this process does not greatly increase strength ($f_{0.2} = 100\,\text{MPa}$), and ductility is drastically decreased (up to one tenth of the initial value).

<table>
<thead>
<tr>
<th>Series Number</th>
<th>Primary Alloying Element</th>
<th>Relative Corrosion Resistance</th>
<th>Relative Strength</th>
<th>Heat Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1xxx</td>
<td>none</td>
<td>excellent</td>
<td>fair</td>
<td>non-heat-treatable</td>
</tr>
<tr>
<td>2xxx</td>
<td>copper</td>
<td>fair</td>
<td>excellent</td>
<td>heat-treatable</td>
</tr>
<tr>
<td>3xxx</td>
<td>manganese</td>
<td>good</td>
<td>fair</td>
<td>non-heat treatable</td>
</tr>
<tr>
<td>4xxx</td>
<td>silicon</td>
<td>—</td>
<td>—</td>
<td>varies by alloy</td>
</tr>
<tr>
<td>5xxx</td>
<td>magnesium</td>
<td>good</td>
<td>good</td>
<td>non-heat-treatable</td>
</tr>
<tr>
<td>6xxx</td>
<td>magnesium and silicon</td>
<td>good</td>
<td>good</td>
<td>heat-treatable</td>
</tr>
<tr>
<td>7xxx</td>
<td>zinc</td>
<td>fair</td>
<td>excellent</td>
<td>heat-treatable</td>
</tr>
</tbody>
</table>
Another way of increasing the strength of the material is to alloy aluminum with other elements (AlMn, AlMg alloys). After this process, the strength can be higher than 100 MPa, with a ductility equal to $\varepsilon_t \approx 10\%$.

The high strength can be obtained if heat treatment is applied. The strength goes up to $f_{0.2} = 250$ MPa in AlSiMg alloy, and can reach $f_{0.2} = 350-400$ MPa in AlZn and AlCu alloys.

b. Aluminum is lighter than steel, the specific weight is $(2700 \text{ kg.m}^{-3})$ equal to one third that of steel.

A concise comparison can be made if the ratio $(f/\gamma)$ termed the" strength rating" between strength and specific weight is considered.

![Comparison of strength ratio for aluminum alloy and steel](attachment:image.jpg)
c. Young's modulus is one third that of steel, thus giving more frequent problems of deformation and of instability.

d. The coefficient of thermal expansion of aluminum is twice that of steel. This means that the structure is more sensitive to thermal variations, and thus has higher deformation when it is not constrained.

When a structure is constrained against thermal deformation, residual stress will be about 30 percent lower than those in steel structures since they are proportional to the product \( aE \). Aluminum is eminently suitable for cryogenic applications, because it is not prone to brittle fracture at low temperature in the way that steel is prone to fracture. Its mechanical properties steadily improve as the temperature goes down.

e. Most of the alloys can be arc welded as readily as steel, using gas shielded processes. Welding speeds are faster. On other side the alloys sever from heat-affected zone (HAZ) softening at welds which tends to be a serious local drop in strength at welded joints in some alloys.

The use of adhesive bonding is well established as a valid method for making structural joints in aluminum.

f. Extrusion process is the standard way of producing aluminum sections, is vastly more versatile than the rolling procedures in steel.

g. Aluminum components are more prone to failure by fatigue than are steel ones.

h. Aluminum does not rust and can normally be used unpainted.

However, the strongest alloys will corrode in some hostile environments and may need protection.
A Comparison of The Stress – Strain Curves

In a comparison of the stress – strain curves of AlMgSi alloy and Fe360 steel in the figure below.

- It can be observed that aluminum alloys have a strain – hardening portion without a horizontal line corresponding to yielding.
- It is clearly shown that the ultimate elongation is lower than of steel and the \( (f_t/f_{0.2}) \) ratio is lower than that of steel (1.2 against 1.5).
- Both materials behave linear elastically up to the elastic limit, which basically represents the working range of structure.

![Stress-strain curves of AlMgSi alloy and Fe360 steel](image)

2.5.2. Aluminum Applications

The main cases of structural applications belong to the following groups:

a. Long-span roof system with small live loads compared with dead loads.
b. Structures located in inaccessible places far from the fabrication shop
c. Structures situated in corrosive or humid environments.
d. Structures having moving parts.
e. Structures for special purposes.

Installation of an aluminum deck on aluminum beams

3. **Timber**

Timber has been one of the primary materials of engineering construction; it is widely used for structural purpose.

For engineering purposes, trees are classified according to their mode of growth:

a. Endogenous
b. Exogenous
   1. Soft woods
   2. Hard woods

Endogenous trees:
This group is confined largely to tropical semitropical regions. Timber from these trees has very limited engineering applications, examples;

- palms: because of their long, straight stems are sometimes locally used as piles.
- Bamboo: is used structurally to a considerable extent.

Exogenous trees:
These trees increase in bulk growing outer bark and annual rings are formed in the horizontal section of such a tree. This timber can be divided into two groups:

- Soft woods: such as deodar
- Hard woods: such as oak and teak
3.1. **Structure of wood**

Cross section of an exogenous tree

3.2. **Structural axes of wood**

1- Longitudinal axis; parallel to the length of the fibre.

2- Tangential axis: perpendicular to the fibres and tangential growth rings.

3- Radial axis: perpendicular to the fibres and to the growth rings. i.e. parallel to the wood rays that radiate from the centre of a tree as seen in cross section.
3.3. **Conversion to Timber**

The process of cutting and sawing logs into suitable sections of timber is known as conversion.

The types of sawing can be;

a) **Ordinary sawing**
   - The wood sawed normal to its diameter
   - Quickest and cheapest method
   - The wastage of useful timber is the minimum

b) **Quarter sawing**
   - It produces fine timber when the wood has no distinct medullary rays.
   - It produces a timber that has a tendency to get bend in the transverse direction.

c) **Tangential sawing.**
   - It is called plain sawing or flat grained sawing.
   - It produces planks which warp too much as the medullary rays which give strength to the longitudinal fibres are cut.

d) **Radial or rift sawing.**
   - Use for hard wood
   - The production less shrinkage than other
   - Acceptable decoration finish
   - The wastage is the maximum
3.4. **Natural defects in timber**

1. knots; one of the most common defects. They originate in the timber cut from the stem or branches of a tree because of the encasement by the successive annual layers of wood.
   - pin knots, do not exceed 6.5 mm
1. Knots; these are the small knots (6.5-20 mm), Medium knots (20-40) and Large knots (more than 40 mm).

2. Shakes; these are the cracks and splits in the felled long due to many causes. They can be cup shake, heart shake or circumferential shrinkage as shown in fig.

3. Twisted grain or fiber; is caused by wind.

4. Upset or rupture, is due to an injury during growth of the tree.

5. Wane; it is the part of the original outside rounded surface of a tree that remain during conversion.

6. Sloping grain. The cells do not always grow perfectly vertical or straight and parallel to the length of truck.

7. Cracks, fissures, resin pockets. These disruptions affect the strength of timber.

---

a. Knots b. cup shake c. heart shake d. Ring shake e. Star shake f. Twisted fibres g. Upset
3.5. **Mechanical properties of woods**

The intelligent use of wood for any structural purpose requires a general knowledge of the mechanical properties of different woods.

**Loading Direction:**

The strength of timber depends upon loading direction as the tensile strength in the direction parallel to the fibre more than (about 40 times) that in direction normal to the fibres while the compressive strength in the direction parallel to the fibres more than (7 times) that in orient normal to the fibres.

The timber has the ability to observe and dissipate impact loads in the direction normal to fibres; so it is using in structures under impact loads.

**Tensile strength:**

Timber in construction is practically never subjected to pure tensile stresses

**Compressive strength:**

The compressive strength of wood in direction parallel to the grain depends upon the internal structure and the moisture content of the wood and the manner of failure is fixed by these same factors. The individual fibres of wood act as so many hallow columns bound firmly together, and b either buckling or bending of the individual fibres or bundles of elements.

**Flexural strength:**

The flexural strength of timber is determined by the following formula:

\[
S_b = \frac{3}{2} \left( \frac{P L}{bh^2} \right)
\]

- \(P\) applied load
- \(L\) beam length
- \(b\) cross section width
- \(h\) cross section height
The tensile strength of all timber greatly exceeds its compressive strength (about three times as much the average) and the latter will usually be the determining factor in limiting the cross-breaking strength. Compressive strength will always be the determining factor, assuming there exist no defects such as knots or uneven grain on tension side of the beam.

Stiffness:
Stiffness of timber largely upon the same factors as strength. Dense woods are always stiffer than porous woods, and heavy woods are stiffer than light woods.

Moisture and strength
All woods gain in strength and in stiffness when thoroughly air seasoning or kiln dried. The extend of this effect depend upon the size and type of the timbers dried only by air seasoning.

3.6. **Structural Classification of Timber**
1- Hardwood like teak wood for permanent structures
2- Softwood like deodar for permanent structures
3- Hardwood like Sal other than teak for permanent structures
4- Softwood other than deodar used only for temporary structures.
3.7. **Selection of wood for building**

1- Class to which the wood belong. We use teak of superior class or other types of wood of class I for important works

2- Closeness of grain

3- Hardness and durability

4- Pleasing colour

5- Easiness of working

6- The way it can take polish

3.8. **Testing of wood**

1- Determination of moisture content

2- Tensile strength parallel to grains

3- Tensile strength perpendicular to grain

4- Charpy test for brittleness
4. Mortar (masonry)

Mortar is a workable mixture used to bind construction units together and fill the gaps between them.

Mortar becomes hard when it sets, resulting in a rigid aggregate structure. Modern mortars are typically made from a mixture of sand, a binder such as Portland cement or lime, and water. Portland cement (often referred to as OPC, from Ordinary Portland Cement) is the most common type of cement in general use around the world because it is a basic ingredient of concrete, mortar and most non-specialty grout. It usually originates from limestone.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon dioxide (SiO₂)</td>
<td>20.85</td>
</tr>
<tr>
<td>Aluminum oxide (Al₂O₃)</td>
<td>4.78</td>
</tr>
<tr>
<td>Ferric oxide (Fe₂O₃)</td>
<td>3.51</td>
</tr>
<tr>
<td>SiO₂ + Al₂O₃ + Fe₂O₃</td>
<td>29.14</td>
</tr>
<tr>
<td>Calcium oxide (CaO)</td>
<td>63.06</td>
</tr>
<tr>
<td>Magnesium oxide (MgO)</td>
<td>2.22</td>
</tr>
<tr>
<td>Sulfur trioxide (SO₃)</td>
<td>2.48</td>
</tr>
<tr>
<td>Potassium oxide (K₂O)</td>
<td>0.55</td>
</tr>
<tr>
<td>Sodium oxide (Na₂O)</td>
<td>0.24</td>
</tr>
<tr>
<td>Titanium dioxide (TiO₂)</td>
<td>0.25</td>
</tr>
<tr>
<td>Manganese oxide (Mn₃O₄)</td>
<td>0.05</td>
</tr>
<tr>
<td>Loss in ignition (LOI)</td>
<td>1.75</td>
</tr>
</tbody>
</table>

**Lime** is produced from calcium carbonates in the form of limestone, seashells, etc. when they burnt mixed with fuel is given off as gas and the result product is calcium oxide or quicklime.

**Production process by burning:**

\[ CaCO₃ = CaO + CO₂ \]

**Setting process:**

\[ CaO + H₂O = Ca(OH)₂ \]

\[ Ca(OH)₂ + CO₂ = CaCO₃ + H₂O \]
Non-hydraulic and hydraulic lime

Hydraulic limes set under water, and non-hydraulic limes need air to carbonatate and set.
For hydraulic lime mortars, the lime is obtained from lime stone containing impurities.
A non-hydraulic lime is produced from high purity calcium lime stones.

Sand is a naturally occurring granular material (0.15 mm – 4.75 mm) composed of divided rock and mineral particles. The composition of sand is highly variable, depending on the sources and conditions, but the most common constituent of sand is silica (silicon dioxide, or SiO₂), usually in the form of quartz.

The principal tests for sand are:

1- Test for grading
2- Test for organic impurities
3- Test for clay and silt content
Water should be considered as an important material for construction, where it is mainly used with cement for making mortar, concrete, etc. and also for curing of cement work.

**Pozzolans** include volcanic materials, powdered brick, heat treated clay, silica fume, and fly ash. The chemical set imparted ranges from very weak to almost as strong as Portland cement.

4.1. **Portland cement mortar**

Portland cement mortar (often known simply as cement mortar) is created by mixing Ordinary Portland cement (OPC), and aggregate (or sand) with water and other admixtures may be added for desired properties. It is the most common mortar, the main reasons for this were that Portland cement sets hard and quickly, allowing a faster pace of construction, and requires fewer skilled workers. The ratio of cement, and sand included in each mortar type produces different strengths of mortar, the same effect for water / cement ratio (w/c).
Test for mortar

1- Compression strength
2- Tensile strength
3- Test for adhesion to brick
4- Test for brickwork in compression

4.2. Lime mortar

It is a type of mortar composed of lime (hydraulic, or non-hydraulic) and an aggregate such as sand, mixed with water. It is one of the oldest known types of mortar.

With the introduction of ordinary Portland cement (OPC) during the 19th century the use of lime mortar in new constructions gradually declined, largely due to Portland’s ease of use, quick setting and compressive strength.
However the soft, porous properties of lime mortar provide certain advantages when working with softer building materials such as natural stone. For this reason, while OPC continues to be commonly used in brick and concrete construction, in the repair of older, stone-built structures and the restoration of historical buildings the use of OPC has largely been discredited.

Comparison between cement mortar and lime mortar

1- Lime mortar is not as strong in compression as OPC mortar,
2- Both are sufficiently strong for construction of non-high-rise domestic properties.
3- Lime mortar does not adhere as strongly to masonry as OPC.
4- Under cracking conditions, OPC breaks, whereas lime often produces numerous microcracks if the amount of movement is small. These microcracks recrystallize through the action of 'free lime' effectively self-healing the affected area.
5- Historic buildings are frequently constructed with relatively soft masonry units (e.g. soft brick and many types of stone), and minor movement in such buildings is quite common due to the nature of the foundations. This movement breaks the weakest part of the wall, and with OPC mortar this is usually the masonry. When lime mortar is used, the lime is the weaker element, and the mortar cracks in preference to the masonry. This results in much less damage, and is relatively simple to repair.
6- Scrapped lime mortar is simply chalk and sand, which can be returned as normal constituents of soil. Cement mortar on the other hand presents a disposal issue.
7- Lime mortar is more porous than cement mortars, and it wicks any dampness in the wall to the surface where it evaporates.
4.3. **Cement, lime and sand mortar**
Addition of lime to cement mortar makes the mixture thicker and stickier while wet. Addition of cement to lime mortar acts as a pozzolan giving some degree of quick set, but this comes at a price, and is not recommended.

4.4. **Polymer cement mortar**
Polymer cement mortars (PCM) are the materials which are made by partially replacing the cement hydrate binders of conventional cement mortar with polymers. It has low permeability, and it reduces the incidence of drying shrinkage cracking, mainly designed for repairing concrete structures.

4.5. **Pozzolana mortar**
Pozzolana is finely ground and mixed with lime, it acts like Portland cement and makes a strong mortar that will also set under water.

4.6. **Grout**
It is a construction material used to embed rebars in masonry walls, connect sections of pre-cast concrete, fill voids, and seal joints (like those between tiles). Grout is
generally composed of a mixture of water, cement, sand, often color tint, and sometimes fine gravel (if it is being used to fill the cores of cement blocks). It is applied as a thick emulsion and hardens over time, much like its close relative mortar.

Structural grout is used in reinforced masonry to fill voids in masonry housing reinforcing steel, securing the steel in place and bonding it to the masonry.

Non-shrink grout is used beneath metal bearing plates to ensure a consistent bearing surface between the plate and its substrate.

Tiling grout is used to fill the spaces between tiles or mosaics, and is often used to secure tile to its base.
4.7. **Gypsum**

It is a very soft sulfate mineral composed of calcium sulfatedihydrate, with the chemical formula $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. in many forms of plaster and is widely mined.

4.7.1. **Uses of gypsum**

Gypsum is used in a wide variety of applications such as:

- Gypsum board is primarily used as a finish for walls and ceilings, and is known in construction as drywall or plasterboard.
- Arc ceiling by using I-steel section.
- Plaster ingredient and casting moulds

4.8. **Adhesive**

An adhesive is any substance that, when applied to the surfaces of materials, binds the surfaces together and resists separation.

Advantages of adhesive use include:

1- The ability to bind different materials together.
2- The ability to distribute stress more efficiently across the joint.
3- The cost effectiveness of an easily mechanized process.
4- An improvement in aesthetic design, and an increased design flexibility.

Disadvantages of adhesive use include:

1- Decreased stability at high temperatures.
2- Relative weakness in bonding large objects with a small bonding surface area.

Fibre-reinforced Polymer (FRP) (also fibre-reinforced plastic)

It is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass, carbon, etc.

FRP possess the highest specific (divided - by weight) mechanical properties: modulus of elasticity and strength.
**Structural applications of FRP:**

The most structural application are:

1. **Strengthening:** FRP can be applied to strengthen the beams, columns, and slabs of buildings and bridges.
2. **Repairing:** It is possible to increase the strength of structural members even after they have been severely damaged due to loading conditions. In the case of damaged reinforced concrete members, this would first require the repair of the member by removing loose debris and filling in cavities and cracks with mortar or epoxy resin. Once the member is repaired, strengthening can be achieved through impregnating the fibre sheets with epoxy resin then applying them to the cleaned and prepared surfaces of the member.
3. **New construction applications:** especially when weight and size of structural elements are effective parameters in design requirements.

*GFRP Pedestrian Bridge in Spain.*