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Class Project –Advanced Civil Engineering Materials: ENGR 5660

REVIEW OF DIFFERENT CONSTRUCTION AND BUILDING MATERIALS USED BEFORE 21st CENTURY IN AFRICA COMPARED TO THE PRESENT SITUATION AFTER 21st CENTURY

By
Khalafalla, Mohamed
And
Malyuta, Daniel
(MSc in Engineering: Civil)

Class Instructor: Dr. Wu, Weidong.., PhD

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Khalafalla, Mohamed: Signature: .....

Date: .....

Malyuta, Daniel: Signature: .....

Date: .....

……

Dr. Wu, Weidong.., PhD
(Class Instructor)

Date: ……

ABSTRACT

Building materials are any materials which used for a construction purpose. Many of these materials are naturally occurring substances, such as clay, sand, wood and rocks. Also twigs and leaves have been used to construct buildings especially in many African developing countries up to date. Apart from naturally occurring materials, many man-made products are in use, some more and some less synthetic.

The goal of this project is to investigate and to make the review of different materials used in building and construction of different civil engineering infrastructures before 21st Century, specifically in Africa continent. To review their general properties and effectiveness, to compare the previous and present situations on these materials, and to give out the overview of the expected building and construction materials which have to be considered in the future time.

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Daniel Malyuta: Report Editing, Introduction, Nowadays materials and conclusion.

Mohammed Kalafallah: Report Editing, Past materials , potential for future materials , conclusion

DEDICATION

Finally, the authors would like to dedicate this project work to all people who strive for intellectual achievements especially at Civil Engineering.

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1.0 Introduction

1.1 Building materials

Building materials are any materials which used for a construction purpose. Many of these materials are naturally occurring substances, such as clay, sand, wood and rocks. Also twigs and leaves have been used to construct buildings especially in developing countries. Apart from naturally occurring materials, many man-made products are in use, some more and some less synthetic. The manufacture of building materials is an established industry in many countries and the use of these materials is typically segmented into specific specialty trades, such as carpentry, plumbing, roofing and insulation work. They provide the make-up of habitats and structures including homes.

1.2 Objectives

The objectives of this project are:-

(i) To investigate different materials used in building and construction before 21st C, specifically in Africa, their general properties (including mechanical properties) and effectiveness in use, the improvement on these material properties as time goes and technology change, and to compared the previous and present situations on these materials considering different aspects such as material properties.

(ii) To sight out the review on the expected building and construction materials which have to be considered in the future as the worlds technology is advancing every day, in Africa and all over the world.

1.3 Scope

This study project will be limited to learning and reviewing of different building and construction material used in the past centuries, before 21st Century, specifically in Africa. To investigate their general properties (including mechanical properties) and effectiveness in use, the improvement if any, on these material properties as time goes and technology change. The project is based mainly in the literature review at which all the information concerning these reviewed materials are obtained. Finally, the project concluded with the overview discussion and recommendation on different materials and material properties used before, those used now after the technology advancement, and then the general overview of the future materials.

1.4 Methodology

(i) Literature review on:-
- General information about building and construction materials
- Different properties of different material in relation to building and construction
- Different applications of different materials

(ii) Conclusion and recommendations on these materials by sighting the previous situation, the present one and the future situation.

2.0 Materials used in old buildings

There are many types of buildings materials used for centuries in Africa, western and northern Europe as well as the rest of the world. The most common factor between them is that they are all naturally found.

These materials are such as mud, clay, grass and rocks.

2.1 Thatch (Grass & Bamboo):

Thatch is one of the oldest of building materials known, dried grass/straw and bamboo for instance. Grass/straw is a good insulator and easily harvested. Many African tribes have lived in homes made completely of grasses year round. In Europe, thatch roofs on homes were once prevalent but the material fell out of favor as industrialization and improved transport increased the availability of other materials. Today, though, the practice is undergoing a revival.

These materials are still in use to date for many of the African developing countries such as Tanzania, Kenya and Uganda.

2.2 Rocks:

Overview:

Rock structures have existed for as long as history can recall. It is the longest lasting building material available, and is usually readily available. There are many types of rock throughout the world all with differing attributes that make them better or worse for particular uses.

Stone walls have been built for as long as humans have put one stone on top of another. Eventually different forms of mortar were used to hold the stones together, cement being the most commonplace now.

Circular huts were constructed from loose granite rocks throughout the Neolithic and early Bronze Age. Granite continued to be used throughout the medieval period and into modern times. Slate is another stone type, commonly used as roofing material in many parts of the world where it is found.

Mostly stone buildings can be seen in most major cities, some civilizations built entirely with stone such as the Pyramids in Egypt, the Aztec pyramids and the remains of the Inca civilization.

Properties:

Density, Porosity and Water Content:

Rock is a very dense **Brittle** material, so it gives a lot of protection too, its main draw-back as a material is its weight and awkwardness.

Density is a measure of mass per unit of volume. Density of different rock material varies with rock type, and often related to the porosity of the rock. It is sometimes defined by unit weight and specific gravity. Most rocks have density between 2,500 and 2,800 kg/m^3

Porosity describes how densely the material is packed. It is the ratio of the non-solid volume to the total volume of material. Porosity therefore is a fraction between 0 and 1. The value is typically ranging from less than 0.01 for solid granite to up to 0.5 for porous sandstone.

Density is common physical properties. It is influenced by the specific gravity of the composition minerals and the compaction of the minerals. However, most rocks are well compacted and then have specific gravity between 2.5 to 2.8. Density is used to estimate overburden stress.

Density and porosity often related to the strength of rock material. A low density and high porosity rock usually has low strength.

Hardness:

Hardness is the characteristic of a solid material expressing its resistance to permanent deformation. Hardness of rock materials depends on several factors, including mineral composition and density. A typical measure is the Schmidt rebound hardness number.

Abrasivity:

Abrasivity measures the abrasiveness of a rock material against other materials, e.g. steel. It is an important measure for estimate wear of rock drilling and boring equipment. Abrasivity is highly influenced by the amount of quartz mineral in the rock material. The higher quartz content gives higher abrasivity.

Abrasivity measures are given by several tests such as Cerchar

Permeability:

Permeability is a measure of the ability of a material to transmit fluids. Most rocks, including igneous, metamorphic and chemical sedimentary rocks, generally have very low permeability. As discussed earlier, permeability of rock material is governed by porosity. Porous rocks such as sandstones usually have high permeability while granites have low permeability.

Compressive Strength

Compressive strength is the capacity of a material to withstand axially directed compressive forces. The most common measure of compressive strength is the uniaxial compressive strength or unconfined compressive strength. Usually compressive strength of rock is defined by the ultimate stress. It is one of the most important mechanical properties of rock material, used in design, analysis and modelling.

Young's Modulus and Poisson's Ratio:

Young's Modulus is modulus of elasticity measuring of the stiffness of a rock material. It is defined as the ratio, for small strains, of the rate of change of stress with strain. This can be experimentally determined from the slope of a stress-strain curve obtained during compressional or tensile tests conducted on a rock sample.

Similar to strength, Young's Modulus of rock materials varies widely with rock type. For extremely hard and strong rocks, Young's Modulus can be as high as 100 GPa.

Poisson's ratio measures the ratio of lateral strain to axial strain, at linearly-elastic region. For most rocks, the Poisson's ratio is between 0.15 and 0.4

Tensile Strength:

Tensile strength of rock material is normally defined by the ultimate strength in tension, i.e., maximum tensile stress the rock material can withstand

Rock material generally has a low tensile strength. The low tensile strength is due to the existence of microcracks in the rock. The existence of microcracks may also be the cause of rock failing suddenly in tension with a small strain.

Tensile strength of rock materials can be obtained from several types of tensile tests: direct tensile test, Brazilian test and flexure test. Direct test is not commonly performed due to the difficulty in sample preparation. The most common tensile strength determination is by the Brazilian tests.

Correlation between compressive and tensile strengths:

Tensile strength of brittle materials is theoretical 1/8 of the compressive strength. Typically, tensile strength of rock materials is about 1/10 to 1/8 of the compressive strength.

It is important to be aware that compressive strength is significantly greater than tensile strength for rocks. Therefore, rock fails easily under tension. In design, rock should be subjected to minimum tensile stress.

Shear Strength:

Shear strength is used to describe the strength of rock materials, to resist deformation due to shear stress. Rock resists shear stress by two internal mechanisms, cohesion and internal friction.

Cohesion, denoted as C, is a measure of internal bonding of the rock material.

Internal friction is caused by contact between particles, and is defined by the internal friction angle, φ.

Different rocks have different cohesions and different friction angles.

Shear strength of rock material can be determined by direct shear test and by triaxial compression tests.

Rocks are Brittle materials, with good durability and good fire resistance. Mostly have poor Thermal and Electrical Conductivity due to that they are mostly free from metal and carbon elements. They also don't have Corrosion nature.

2.3 Mud, Clay and Fired brick:

Overview:

Mud and clay are the materials that have been used in construction of buildings for many centuries in many African countries up to date. The amount of each material used leads to different styles of buildings. The deciding factor is usually connected with the quality of the soil being used. Larger amounts of clay usually mean using the *cob/adobe* style, while low clay soil is usually associated with *sod* building. The other main ingredients include more or less sand/gravel. *Rammed earth* is both an old and newer take on creating walls, once made by compacting clay soils between planks by hand. Now forms and mechanical pneumatic compressors are used are sometimes used.

Properties:

Soil and especially clay is good thermal mass; it is very good at keeping temperatures at a constant level. Homes built with earth tend to be naturally cool in the summer heat and warm in cold weather. Clay holds heat or cold, releasing it over a period of time like stone. Earthen walls change temperature slowly, so artificially rising or lowering the temperature can use more resources than in say a wood built house, but the heat/coolness stays longer.

Peoples building with mostly dirt and clay, such as cob, sod, and adobe, resulted in homes that have been built for centuries in Africa, western and northern Europe as well as the rest of the world, and continue to be built, though on a smaller scale. Some of these buildings have remained habitable for hundreds of years.

Mud used as building materials has high plasticity index. Actually the Hardness of the wall or any structure constructed from mud is very low with low compressive and tensile

strengths as well as low durability, and very sensitive to weather especially wet weather conditions. Mud is good fire resistance with poor thermal and electrical conductivity. They don't have Corrosion nature.

Applications of Mud, Grass and Rocks:

Regular Huts:

These types of buildings are the most common used from 15th century until now in approximately all African countries. The huts are generally composed of two main elements:

i. Walls: That can be made of animals waste and mud or using rocks as shown in figures below. The bond between the rocks usually is made by mud. The use of each type depends on the topographic nature of the area. For example if the house is on mountains area the people will use rock bricks.
ii. The roof: is generally from grass which is readily available and cheap. They use many types of roof grass depend on what available like Elephant Grass, Tahiti thatch and Thatch Reed Panels.



Figure 1: pictures shows rock and mud huts in africa

Advantages and Limitations:

They are easy to implement, Cheap, Cool at the hot weather (well isolated) and the materials are readily available.

But the roof is a good environment for insects and the materials are not safe against natural dangers like floods and tornados.

Mud brick in applications:

The introduction of this type of building is relatively new compared to regular huts in Africa. The general idea is that they use mud bricks for walls and wood structure for roofing.

A mud brick is a fire free brick, made of a mixture of clay, mud, sand, and water mixed with a binding material such as rice husks or straw. They use a stiff mixture and let them dry in the sun for some days, for instance 20 days or more .

In warm regions with very little timber available to fuel a kiln, bricks were generally sun dried. This had the result that their useful lifespan is reduced to around thirty years. Once a building collapsed, new bricks would have to be made and the new structure rebuilt on top of the rubble of the decayed old brick. This phenomenon is the primary factor behind the mounds or tells on which many ancient cities stand. In some cases they extended the

life of mud bricks by putting kiln dried bricks on top or covering them with stucco. Mud bricks can be recycled.

Mud bricks in use with their Advantages and Limitations:
They are stronger than regular grass huts, does not create an environment to insects, well isolated, Materials are readily available.
But they need skilled labor and more time to implement



Figure 2: pictures shows mud bricks fabrication and installation in sudan



Figure 3: pictures shows mud bricks finished structures in africa

3.0 Materials used in nowadays buildings

With the evolution in construction industry Africa also followed that trend. The trend nowadays in Africa is to use heavy materials like steel and concrete in all kind of buildings even the small residential buildings. Materials used now days are such as:
Concrete, Metal/Steel, Grass, Red Bricks, Cement bricks, Wood and Some types of composites

3.1 Cement:

Overview:
In the most general sense of the word, **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. The chemical reaction that results when the anhydrous cement powder is mixed with water produces hydrates that are not water-soluble. Non-hydraulic cements (*e.g.,* lime and gypsum plaster) must be kept dry in order to retain their strength

Cement is made by heating limestone (calcium carbonate) with small quantities of other materials (such as clay) to about 1450 °C in a kiln, in a process known as calcination, 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).

Strength and its uses:

Ordinary Portland cement is largely used for residential, commercial, and other building construction purposes. It has a compressive strength of > 560 kg per square cm. Also Ordinary Portland Cement is known for its rich quality and is highly durable. Hence it is used for constructing bigger structures like building foundations, bridges, tall buildings, and structures designed to withstand heavy pressure

Portland cement is a basic ingredient of concrete, mortar and most non-speciality grout. The most important use of cement/Portland cement is the production of mortar and concrete; the bonding of natural or artificial aggregates to form a strong building material that is durable in the face of normal environmental effects

Concrete should not be confused with cement, because the term *cement* refers to the material used to bind the aggregate materials of concrete. Concrete is a combination (composite) of a cement and aggregate

3.2 Concrete:

Overview:

Concrete is a composite material composed of coarse granular material (the aggregate or filler) embedded in a hard matrix of material (such as cement or any other binder) that fills the space between the aggregate particles and glues them together. We can also consider concrete as a composite material that consists essentially of a binding medium within which are embedded particles or fragments of aggregates. The simplest representation of concrete is: Concrete = Filler + Binder.

According to the type of binder used, there are many different kinds of concrete. For instance, Portland cement concrete, asphalt concrete, and epoxy concrete. In concrete construction, the Portland cement concrete is utilized the most.

3.2.1 Portland Cement Concrete:

This type of concrete consists of gravel (aggregates), sand, Portland cement and water. After mixing, the cement hydrates and eventually hardens into a stone-like material. For a concrete construction of any size, as concrete has a rather low tensile strength, it is generally strengthened using steel rods or bars. This strengthened concrete is then referred to as reinforced concrete. In order to minimize any air bubbles that would

weaken the structure, a vibrator is used to eliminate any air that has been entrained when the liquid concrete mix is poured around the ironwork. Concrete has been the predominant building material in this modern age due to its longevity, formability, and ease of transport. Recent advancements, such as Insulating concrete forms, combine the concrete forming and other construction steps. All materials must be taken in required proportions as described in standards.

Here we should indicate that admixtures are almost always used in modern practice and thus become an essential component of modern concrete. Admixtures are defined as materials other than aggregate (fine and coarse), water, fibre and cement, which are added into concrete batch immediately before or during mixing. The widespread use of admixture is mainly due to the many benefits made possible by their application. For instance, chemical admixtures can modify the setting and hardening characteristic of cement paste by influencing the rate of cement hydration. Water-reducing admixture can plasticize fresh concrete mixtures by reducing surface tension of water, air-entraining admixtures can improve the durability of concrete, and mineral admixtures such as pozzolans (materials containing reactive silica) can reduce thermal cracking.

Advantages and limitations:

Concrete is the most widely used construction material in the world. It is used in many different structures such as dam, pavement, building frame or bridge. Also, it is the most widely used material in the world, far exceeding other materials. Its worldwide production exceeds that of steel by a factor of 10 in tonnage and by more than a factor of 30 in volume. The present consumption of concrete is over 10 billion tons a year, that is, each person on earth consumes more than 1.7 ton of concrete per year. It is more than 10 times of the consumption by weight of steel. Concrete is neither as strong nor as tough as steel, so why is concrete so popular?

Advantages:

(i) Economical: Concrete is the most inexpensive and the most readily available material. The cost of production of concrete is low compared with other engineered construction materials. Three major components: water, aggregate and cement. Comparing with steel, plastic and polymer, they are the most inexpensive materials and available in every corner of the world. This enables concrete to be locally produced anywhere in the world, thus avoiding the transportation costs necessary for most other materials.

(ii) Ambient temperature hardened material:
Because cement is a low temperature bonded inorganic material and its reaction occurs at room temperature, concrete can gain its strength at ambient temperature.

(iii) Ability to be cast:
It can be formed into different desired shape and sizes right at the construction site.

(iv) Energy efficiency:
Low energy consumption for production, compare with steel especially. The energy content of plain concrete is 450-750 kWh / ton and that of reinforced concrete is 800-3200 kWh/ton, compared with 8000 kWh/ton for structural steel.

(v) Excellent resistance to water.
Unlike wood and steel, concrete can harden in water and can withstand the action of water without serious deterioration. This makes concrete an ideal material for building structures to control, store, and transport water.

(vi) High temperature resistance:
Concrete conducts heat slowly and is able to store considerable quantities of heat from the environment (can stand 6-8 hours in fire) and thus can be used as protective coating for steel structure.

(vii) Ability to consume waste:
Many industrial wastes can be recycled as a substitute for cement or aggregate. Examples are fly ash, ground tire and slag.

(viii) Ability to work with reinforcing steel:
Concrete and steel possess similar coefficient of thermal expansion (steel 1.2 x 10^{-5}; concrete 1.0-1.5 x 10^{-5}).
Concrete also provides good protection to steel due to existing of CH (this is for normal condition). Therefore, while steel bars provide the necessary tensile strength, concrete provides a perfect environment for the steel, acting as a physical barrier to the ingress of aggressive species and preventing steel corrosion by providing a highly alkaline environment with pH about 13.5 to passivate the steel.

Limitations:

(i) Quasi-brittle failure mode: Concrete is a type of quasi brittle material. (Solution: Reinforced concrete)

(ii) Low tensile strength: About 1/10 of its compressive strength. (Improvements: Fiber reinforced concrete; polymer concrete)

(iii) Low toughness: The ability to absorb energy is low. (Improvements: Fiber reinforced concrete)

(iv) Low strength/BSG ratio (specific strength):
Steel (300-600)/7.8. Normal concrete (35-60)/2.3. Limited to middle-rise buildings. (Improvements: Lightweight concrete; high strength concrete)

(v) Formwork is needed: Formwork fabrication is labour intensive and time consuming, hence costly (Improvement: Precast concrete)

(vi) Long curing time: Full strength development needs a month. (Improvements: Steam curing)

(vii) Working with cracks: Most reinforced concrete structures have cracks under service load. (Improvements: Pre stressed concrete).

Classification of concrete:

Based on unit weight:

Ultra light concrete <1,200 kg/m^3
Lightweight concrete 1200- 1,800 kg/m^3
Normal-weight concrete ~ 2,400 kg/m^3
Heavyweight concrete > 3,200 kg/m^3

Based on strength (of cylindrical sample)

Low-strength concrete < 20 MPa compressive strength
Moderate-strength concrete 20 -50 MPa compressive strength
High-strength concrete 50 - 200 MPa compressive strength
Ultra high-strength concrete > 200 MPa compressive strength

Based on additives:

Normal concrete

Fiber reinforced concrete
Shrinkage-compensating concrete
Polymer concrete

Concrete in Applications in the present situation:



Figure 4: Under construction building of Sudapet Oil & Gas Co. Ltd, Khartoum, Sudan



Figure 5: Building of Sudapet Oil & Gas Co. Ltd, Khartoum, Sudan



Figure 6: National Tower of communication, Khartoum, Sudan

3.2.2 Asphalt:

The modern use of asphalt for road and street construction began in the late 1800s and grew rapidly with the emerging automobile industry. Since that time, asphalt technology has made giant strides so that today the equipment and techniques used to build asphalt pavement structures are highly sophisticated. One rule that has remained constant throughout asphalt's long history in construction is this: A pavement is only as good as the materials and workmanship that go into it. No amount of sophisticated equipment can make up for use of poor materials or poor construction practices.

Asphalt concrete is composed of two components, aggregates and asphalt. Aggregates are generally classified into two groups, fine and coarse, and normally constitute from 90 to 95 percent by weight of the total mixture. The asphalt is composed of a Performance Graded (PG) binder or some variation of PG binder, and ordinarily constitutes 5 to 10 percent by weight of the mixture

Properties of PG Binder (Asphalt):

Consistency:

Binders (Asphalts) are characterized by their properties at different temperatures and stages of life simulated by laboratory aging. Consistency is the term used to describe the degree of fluidity or plasticity of binders at any particular temperature. The consistency

of binder varies with temperature. Binders are graded based on ranges of consistency at a standard temperature. When the Binder is exposed to air in thin films and is subjected to prolonged heating, i.e. during mixing with aggregates, the binder tends to harden.
This means that the consistency (viscosity) of the binder has increased for any given temperature. A limited increase is allowable. However, careless temperature and mixing control can cause more damage to the binder, through hardening, than many years of service on the finished roadway.

Purity:
Binder (Asphalt) is composed almost entirely of bitumen, which by definition is soluble in carbon disulfide. Refined binders are almost pure bitumen and are usually more than 99.5 percent soluble in carbon disulfide. Impurities, if they are present, are inert. Normally, the binder is free of water or moisture as it leaves the refinery. However, tank transports loading binder may have some moisture present in their tanks. If any water is inadvertently present in the binder, it may cause the binder to foam when it is heated above 212°F (100°C).

Safety:
Binder (Asphalt) foaming can be a safety hazard. Specifications usually require that asphalt not foam at temperatures up to 350°F (177°C). Binders, if heated to a high enough temperature, will flash in the presence of a spark or open flame. The temperature at which this occurs is well above the temperatures normally used in paving operations. However, to be sure there is an adequate margin of safety, the flash point of the binder should be known.

Durability:
Durability is the measure of how well a binder retains its original characteristics when exposed to normal weathering and aging processes. The performance grading of current binders include laboratory tests that simulate the weathering and aging processes and establishes pass/fail limits on the test results. The pavement performance is still greatly affected by mix design, aggregate characteristics, workmanship and other variables.

Adhesion and Cohesion:
Adhesion is the binder's ability to stick to the aggregate in the paving mixture. Cohesion is the binder's ability to hold the aggregate particles in place in the finished pavement

Temperature Susceptibility:
All binders are thermoplastic; that is, they become harder (more viscous) as their temperature decreases and softer (less viscous) as their temperature increases. This characteristic is known as temperature susceptibility, and is one of a binder's most valuable assets.
Knowing the temperature susceptibility of the binder being used in a paving mixture is important because it indicates the proper temperature at which to mix the binder with aggregate, and the proper temperature at which to compact the mixture on the roadbed. It should be understood that it is vitally important for a binder to be temperature susceptible.

It must be fluid enough at elevated temperatures to permit it to coat the aggregate particles during mixing and to allow these particles to move past each other during compaction.
It must then become viscous enough at normal air temperatures to hold the aggregate particles in place in the pavement. Also remember that temperature susceptibility varies among binders from different petroleum sources, even if the binders are of identical grade.

Aging and Hardening:

Binders (Asphalts) harden in the paving mixture during construction and in the pavement itself. The hardening is caused primarily by oxidation (binder combining with oxygen), a process that occurs most readily at higher temperatures (such as construction temperature) and in thin binder films (such as the film coating aggregate particles). During mixing, binder is both at a high temperature and in thin films as it coats the aggregate particles. This makes mixing the stage at which the most severe oxidation and hardening usually occurs. Figure 1-3 shows the increase in viscosity caused by heating a thin film of a binder. The viscosity range of the original material before the Rolling Thin Film Oven (RTFO) test is significantly lower than after the test.
Not all binders harden at the same rate when heated in thin films. Therefore, each binder used should be tested to determine its aging characteristics so that construction techniques can be adjusted to minimize hardening. Such adjustments usually involve mixing the binder with the aggregate at the lowest possible temperature for the shortest practical time.
The hardening of a binder continues in the pavement after construction. Again, oxidation and polymerization are the main causes. These processes can be retarded by keeping the number of connected voids (air spaces) in the final pavement low, and the binder coating on the aggregate particles thick

Asphalt in Applications



Figure 7: picture shows asphalt in roads, South Africa

3.2.3 Pre stressed Concrete:

The technique of pre stressing consists of subjecting precast concrete parts to compressive stresses prior to its commissioning. It is achieved through steel cables that are tensioned and anchored to the concrete.

The aim in the use of pre stressed concrete is to increase the tensile strength of concrete by introducing an internal compressive stress, counteracting in part the tensile stresses caused by these loads on the structural element.

Usually, when applying this technique, high strength concrete and high tensile steels are used, given the magnitude of the stresses induced. Shortly, Prestressed concrete is a method for overcoming concrete's natural weakness in tension.

It can be used to produce beams, floors or bridges with a longer span than is practical with ordinary reinforced concrete.

Prestressing tendons (generally of high tensile steel cable or rods) are used to provide a clamping load which produces a compressive stress that balances the tensile stress that the concrete compression member would otherwise experience due to a bending load. The idea of prestressing was, apparently, familiar to the ancient Rome architects; the tall attic wall of the Colosseum works as a stabilizing device for the wall piers beneath.

Today, the concept of prestressed structure is widely employed in design of buildings, underground structures, TV towers, power stations, floating storage and offshore facilities, nuclear reactor vessels, and numerous kinds of bridge systems.

Advantages and disadvantages of pre-stressed concrete construction:

The following advantages of prestressed concrete are often put forward when compared to reinforced concrete.

1. Prestressed concrete requires smaller quantities of material (smaller dead load) than reinforced concrete. This means that prestressed concrete members are lighter and more slender than their reinforced concrete counterparts.
2. The fact that members are lighter and more slender if prestressed concrete rather than reinforced concrete is used, leads to other advantages: Savings can be realized in the reduced cost of lighter supporting structures and, in the case of precast elements, in the reduced handling and transportation costs. Aesthetically pleasing structures are more readily provided. Longer spans are possible because of the reduced self weight (Facilitates construction of long span members)
3. Prestressed concrete generally provides better corrosion protection to the reinforcement than does reinforced concrete. This advantage is significant for structures subjected to aggressive environments and for fluid-retaining structures.
4. Improved deflection control is possible with prestressed concrete. Prestressing offers a means of controlling deflections. A prestress force eccentric to the centroid of a member will cause a vertical deflection, usually in the opposite direction to that caused by the applied load. By suitable choice of prestress force, the deflections under applied load can be reduced or eliminated entirely.

5. Prestressed concrete members will require less shear reinforcement than reinforced concrete members. This follows from the fact that the shear capacity of a prestressed member is increased.
6. Prestressing the structure can be rendered crack-free, which has important implications for durability (important durability consideration), especially for liquid-retaining structures.

Limitations

Against the advantages listed above, there must be listed some limitations of using prestressed concrete.

The fact that most, if not all, of the concrete cross-section is in compression under all load conditions means that any inherent problems due to long term creep and relaxation movements are increased.

From the point of view of construction, a high level of quality control is required, both for material production and for locating the tendons within the structure.

The technology required for prestressing concrete may not be available in many African developing countries, and, if specified, may prove to be uneconomical since all equipment and personnel would have to be imported. Hence expensive for these countries

The essential items needed in prestressed concrete technique are:-

Tendon: is the prestressed reinforcement used to apply the prestress to the concrete. This steel reinforcement may either be high-strength wires, bars or strand.

Cable conduits

Hydraulic jack for tensioning cables

Pulling anchors for post-tensioning cables

Prestressing methods can be classified either as being a **pre tensioning** method or as being a **post-tensioning** method, depending on whether the concrete has not been placed or whether it has been placed at the time of tensioning of the reinforcement.

Prestress concrete in applications:

Mainly used in Bridges and some building slabs



Figure 8: Aldamr Bridge, Aldamr City, Sudan

3.3 Metal (specifically Steel):

Metal Overview:

Metal is used as structural framework for larger buildings such as skyscrapers, or as an external surface covering. There are many types of metals used for building. Steel is a metal alloy whose major component is iron, and is the usual choice for metal structural building materials. It is strong, flexible, and if refined well and/or treated, it lasts a long time. Corrosion is metal's prime enemy when it comes to longevity. The lower density and better corrosion resistance of aluminum alloys and tin sometimes overcome their greater cost. Brass was more common in the past, but is usually restricted to specific uses or specialty items today.

Metal figures quite prominently in prefabricated structures such as the semi cylindrical hut, and can be seen used in most cosmopolitan cities. It requires a great deal of human labor to produce metal, especially in the large amounts needed for the building industries.

Other metals used include titanium, chrome, gold and silver. Titanium can be used for structural purposes, but it is much more expensive than steel. Chrome, gold, and silver are used as decoration, because these materials are expensive and lack structural qualities such as tensile strength and hardness

3.3.1 Steel:

This part presents and discusses the properties of structural steels that are of importance in design and construction Steels for structural uses may be classified by chemical composition, tensile properties, and method of manufacture as carbon steels, high-strength low-alloy (HSLA) steels, heat-treated carbon steels, and heat-treated constructional alloy steels.

Carbon Steels:

Steel may be classified as a carbon steel if:

(1) The maximum content specified for alloying elements does not exceed the following: manganese 1.65%, silicon 0.60%, copper 0.60%

(2) The specified minimum for copper does not exceed 0.40%

(3) No minimum content is specified for other elements added to obtain a desired alloying effect.

High-Strength Low-Alloy Steels:

Those steels which have specified minimum yield points greater than 40 ksi and achieve that strength in the hot-rolled condition, rather than by heat treatment, are known as HSLA steels. Because these steels offer increased strength at moderate increases in price over carbon steels, they are economical for a variety of applications.

Heat-Treated Carbon and HSLA Steels:

Both carbon and HSLA steels can be heat treated to provide yield points in the range of 50 to 75 ksi. This provides an intermediate strength level between the as-rolled HSLA steels and the heat-treated constructional alloy steels.

Heat-Treated Constructional Alloy Steels:

Steels that contain alloying elements in excess of the limits for carbon steel and are heat treated to obtain a combination of high strength and toughness are termed constructional alloy steels.

Having yield strength of 100 ksi, these are the strongest steels in general structural use.

Tensile Properties:

The tensile properties of steel are generally determined from tension tests on small specimens or coupons in accordance with standard ASTM procedures. The behavior of steels in these tests is closely related to the behavior of structural-steel members under static loads. Because, for structural steels, the yield points and moduli of elasticity determined in tension and compression are nearly the same, compression tests are seldom necessary.

Yield Point, Yield Strength, and Tensile Strength:

Carbon and HSLA steels usually show an upper and lower yield point. The upper yield point is the value usually recorded in tension tests and thus is simply termed the yield point.

The heat-treated steels, however, do not show a definite yield point in a tension test. For these steels it is necessary to define yield *strength*, the stress corresponding to a specified deviation from perfectly elastic behavior. Yield strength is usually specified in either of two ways: For steels with a specified value not exceeding 80 ksi, yield strength is considered as the stress at which the test specimen reaches a 0.5% extension under load (0.5% EUL) and may still be referred to as the yield point. For higher-strength steels, the yield strength is the stress at which the specimen reaches a strain 0.2% greater than that for perfectly elastic behavior.

Since the amount of inelastic strain that occurs before the yield strength is reached is quite small, yield strength has essentially the same significance in design as yield point. These two terms are referred to collectively as yield stress.

The maximum stress reached in a tension test is the tensile strength of the steel. After this stress is reached, increasing strains are accompanied by decreasing stresses. Fracture eventually occurs.

Proportional Limit:

The proportional limit is the stress corresponding to the first visible departure from linear-elastic behavior. This value is determined graphically from the stress-strain curve. Since the departure from elastic action is gradual, the proportional limit depends greatly on individual judgment and on the accuracy and sensitivity of the strain-measuring devices used. The proportional limit has little practical significance and is not usually recorded in a tension test.

Ductility:

Ductility is an important property of structural steels. It allows redistribution of stresses in continuous members and at points of high local stresses, such as those at holes or other discontinuities.

In a tension test, ductility is measured by percent elongation over a given gage length or percent reduction of cross-sectional area. The percent elongation is determined by fitting

the specimen together after fracture, noting the change in gage length and dividing the increase by the original gage length. Similarly, the percent reduction of area is determined from cross-sectional measurements made on the specimen before and after testing.

Both types of ductility measurements are an index of the ability of a material to deform in the inelastic range. There is, however, no generally accepted criterion of minimum ductility for various structures. Note that ductility is inhibited under plane strain conditions where restraint is present.

Poisson's Ratio:

The ratio of transverse to longitudinal strain under load is known as Poisson's ratio, *v*. This ratio is about the same for all structural steels—0.30 in the elastic range and 0.50 in the plastic range.

True-Stress–True-Strain Curves:

In the stress-strain curves shown previously, stress values were based on original cross-sectional area and the strains were based on the original gage length. Such curves are sometimes referred to as engineering-type stress-strain curves. However, since the original dimensions change significantly after the initiation of yielding, curves based on instantaneous values of area and gage length are often thought to be of more fundamental significance. Such curves are known as true-stress–true-strain curves.

Properties in Shear:

The ratio of shear stress to shear strain during initial elastic behavior is the shear modulus, G. According to the theory of elasticity, this quantity is related to the modulus of elasticity, E, and Poisson's ratio, *v*, by:

Thus a minimum value of G for structural steels is about $11x10^3$ ksi. The yield stress in shear is about 0.57 times the yield stress in tension. The shear strength, or shear stress at failure in pure shear, varies from two-thirds to three-fourths of the tensile strength for the various steels. Because of the generally consistent relationship of shear properties to tensile properties for the structural steels, and because of the difficulty of making accurate shear tests, shear tests are seldom performed.

Other Properties:

Steel has a corrosion nature when exposed to air, with good thermal and electricity conductivity properties. It is a malleable material at which it can be shaped in different shapes.

3.4 Wood:

Overview:

Wood is a hard and fibrous substance which forms a major part of the trunk and branches of a tree. It can also be defined as a natural polymeric material which practically does not age. Wood as a building material falls in two major classes; natural and man-made. With the advances in science and technology, wood in its natural form as timber, lumber, etc. is being rapidly replaced by composite wood materials in which natural wood is just a basic ingredient of a matrix or a laminate. The latter are found to be more useful and adaptable as they may be treated chemically, thermally or otherwise as per requirements. Some examples are plywood, fiberboards, chipboards, compressed wood, impregnated wood, etc.

Wood has many advantages due to which it is preferred over many other building materials. It is easily available (may be this won't be true after some years) and easy to

transport and handle, has more thermal insulation, sound absorption and electrical resistance as compared to steel and concrete. It is the ideal material to be used in sea water. Wood is a good absorber of shocks and so is suitable for construction work in hilly areas which are more prone to earthquakes. Finally, since wood can be easily worked, repairs and alterations to wood work can also be done easily. Owing to the above mentioned advantages, presently wood is very widely used in buildings as doors, windows, frames, temporary partition walls, etc. and in roof trusses and ceilings apart from formwork.

Mechanical properties of wood:

(i) Wood are an anisotropic material: this means that are directionally dependent
(ii) Wood is an orthotropic material: that is, have the different materials properties or strength in different orthogonal directions.
(iii) Wood is considered to be the lighter material compared to many construction materials such as steel, stone and concrete (Dry density of wood = usually 20-45 lb/ft^3, (300-700 kg/m^3) **)**
(iv) Thermal conductivity: This is the rate that heat flows through (inverse of thermal resistance R value), Good R value (R = 1 / conductivity). Wood has poor thermal conductivity and reduces loss of heat and cold.
(v) Thermal Diffusivity: This is the rate that material absorbs heat from surroundings. Wood has lower thermal diffusivity than most other building materials such as steel
(vi) Electrical Properties: Wood is good electrical insulator which decreases with moisture content; more water is a better electrical conductor. But generally, wood is good insulator.
(vii) Wood does not corrode, though water will degrade wood.

Wood is anisotropic material; properties change with direction. Consider the following diagram:-

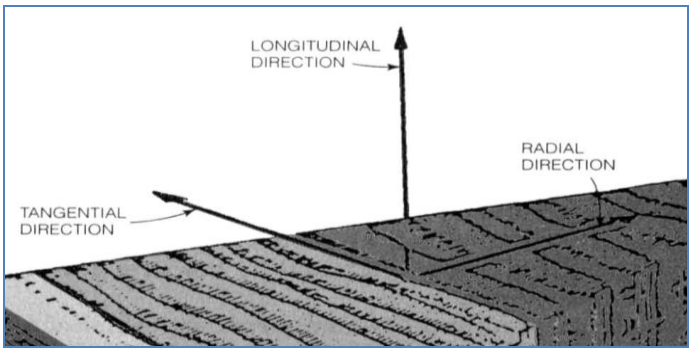


Figure 9: figure shows the grains of tree

- ✓ Longitudinal: Parallel to the long axis (grain). Strongest and least shrinkage
- ✓ Radial: Perpendicular to the growth rings (out from center)
- ✓ Tangential: Tangent to the growth rings. Weakest and most shrinkage

Directions influence strength, modulus, thermal expansion, conductivity, shrinkage, etc**.**

Modulus of Elasticity and Strength:

Modulus of elasticity ranges from 1 to 2 x 10^6 psi for compression parallel to the grain

Modulus of Elasticity depends on species variation, moisture content, specific gravity, direction of grain
Strength Properties vary widely because of anisotropy and other factors such as moisture content, defects, etc.
Tensile strength is greater than compressive strength. Tensile strength parallel to grain is 20 times greater than that perpendicular to grains

Wood in application:



Figure 10: Wood pedestrian bridge



Figure 11: real wood houses, South Africa

3.5 Plastic and Foam:

Overview:

The term plastics cover a range of synthetic or semi-synthetic organic condensation or polymerization products that can be molded or extruded into objects or films or fibers.

Their name is derived from the fact that in their semi-liquid state they are malleable, or have the property of plasticity.
Plastic pipes penetrating a concrete floor, roofs and walls of a building for electrical wiring, water and sewerage purposes.
Plastics vary immensely in heat tolerance, hardness, and resiliency. Combined with this adaptability, the general uniformity of composition and lightness of plastics ensures their use in almost all industrial applications today.
Foamed plastic sheets are used as backing for fire-stop mortar. More recently synthetic polystyrene or polyurethane foam has been used in combination with structural materials, such as concrete. It is light weight, easily shaped and an excellent insulator. It is usually used as part of a structural insulated panel where the foam is sandwiched between wood and cement or insulated concrete forms where concrete is sandwiched between two layers of foam

3.6 Glass:
Overview and Properties:
Glassmaking is considered an art form as well as an industrial process or material. Clear windows have been used since the invention of glass to cover small openings in a building. They provided humans with the ability to both let light into rooms while at the same time keeping inclement weather outside. Glass is generally made from mixtures of sand and silicates, in a very hot fire stove called a *kiln*. Glass is very brittle material. Very often additives are added to the mixture when making to produce glass with shades of colors or various characteristics (such as bulletproof glass, or light emittance)
The use of glass in architectural buildings has become very popular in the modern culture. Glass "curtain walls" can be used to cover the entire facade of a building, or it can be used to span over a wide roof structure in a "space frame". These uses though require some sort of frame to hold sections of glass together, as glass by itself is too brittle and would require an overly large kiln to be used to span such large areas by it.
Most glasses have strong covalent bonds, Si-O bonds, 435 kJ/mole
Yields theoretical strength of 17 GPa, Practical strength is much less. Manufactured glass has nominal strength of 70 MPa [10 KPsi]. Design stresses often 7 MPa or less for high reliability structures. Low surface area structures [e.g. fibers] have higher strengths. Ordinary bulk glass has a nominal strength of 70 MPa. Bulk synthetic glass [SiCl4-derived] has a strength of 500 MPa [7 x increase] due to fewer impurity defects. Drawing fibers from synthetic glass reduces the surface area under test and increases strength to 4 GPa for 10 cm gage length. Bending fibers to test strength reduces gage length to a few microns. Strength increases to 8 GPa. Perform bending test in liquid nitrogen [77 K] to zero chemical effects. Strength is statistically the same as theoretical strength

Glass in Use:



Figure 12: proposed design of glass covered building, South Africa

3.8 Immerging of other green materials and modern construction technology such as Curtain walls

Curtain walls are the lightweight wall systems installed outside of building structure. Often they are not the design of the Structural Engineer. They are designed to resist wind and rain. Must also accommodate building drift and seismic movements without distress



Figure 13: green building design, South Africa

4.0 Potential Materials to be used in future:

Because of the rich nature of Africa, most of the people nowadays do not care much about the scarcity of materials they will face in future. We can optimize our use of materials by using different materials like composites.

Composite materials and Nano Composites:

Composite materials are made of two or more distinct materials or phases. This is done in order to obtain the best properties of each and reduce the effect of the weak properties between the materials. There are four types of composite materials:

- Fibrous composites (fibers in a matrix) Continuous fibers, woven fibers, chopped fibers
- Laminated composites (layers of various materials)
- Particulate composites
- Combinations of some or all of the above

By making the composite materials the mechanical and other properties are improved such as strength, stiffness, fracture resistance, corrosion resistance, attractiveness, temperature susceptibility, thermal properties, and many other properties.

Composite materials have been used throughout history for building and construction industry: for example straw fibers in mud bricks, plain concrete, reinforced concrete, structural shapes replacing steel and aluminum, Fiber-reinforced polymer rebars, strengthen and wrap partially damaged columns and bridge supports, fiber-reinforced concrete and also entrained air in concrete.

Many of these materials which used for several years have the following properties:

They are very heterogeneous, very anisotropic, cheaper and lighter, do not yield, fatigue resistant, age subject to humidity and heat, do not corrode, not sensitive to common chemicals, medium to low level impact resistance and excellent fire resistance

Sometimes, composites materials are difficult to inspect with conventional ultrasonic, eddy current and visual NDI methods such as radiography.

Nanocomposites are the multiphase solid material where one of the phases has one, two or three dimensions of less than 100 nanometers (nm), or structures having nano-scale repeat distances between the different phases that make up the material.

Some composite applications:

Composite materials have been used in aerospace, automobile, and marine applications. Recently, composite materials have been increasingly considered in civil engineering structures. The latter applications include seismic retrofit of bridge columns, replacements of deteriorated bridge decks and new bridge structures.



Figure 14: a complete composites material building design, South Africa

5.0 Conclusion and Recommendation

The materials used in building and construction for several centuries in Africa were stone, mud, brick, wood/timber, grass/straw. There after concrete and metals. Of these, some are naturally obtained and others are manmade. They differ in several factors as reviewed in this document.

Because of the rich nature of Africa, most of the people nowadays do not care much about the scarcity of materials they will face in future. We can optimize our use of materials by using different materials like composites.

It can be observed as the time goes, technology is advancing in such a way that the material properties are being enhanced over time and African countries must follow that so as to optimize the use of the materials by using the green material, e.g. Recyclable materials.

Also the African countries have to adopt the modern construction technologies that results to the construction

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