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Geo-polymer Modified Cellulosic Fibre Reinforced Concrete

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Abstract: **Normal concrete is characterised by high compressive strength but low tensile strength and with little elasticity causing it to fracture and crack due to its brittle nature. Reinforced concrete was discovered in a quest to produce a material with improved compressive and tensile strengths but it is faced with a disadvantage of long post crack formations due to strain softening. Normal reinforced concrete is faced by durability challenges due to ingression of deleterious substances such as chloride and carbonation ion attacks that result in corrosion of steel leading to complete structural deterioration. Concrete as a material is also itself susceptible to attack from the aggressive environment. The need for discovering sustainable and energy efficient construction materials have pushed researchers and academics to search for better and effective construction materials. Concrete is the most used construction material worldwide due to its outstanding properties, these include its versatility, durability and reliability in terms of availability of materials required in its production. Ordinary Portland cement is a crucial element required in concrete production. According to studies done by scientists, cement-producing industries are the second contributors to the rise in greenhouse gases. On the other hand, steel production is an expensive process requiring high consumption of energy and it generated from non-renewable mined ores. This study aims to produce a geo-polymer modified natural fibres reinforced concrete with improved resistance to impact loads, higher durability and low porosity. Fly ash is proposed to partially replace cement to form the geo-polymer modified concrete. Natural fibres made from sisal will be added in reasonable proportions based on past research to the geo-polymer modified concrete. To determine the strength and durability of the produced concrete compressive strength, tensile strength, flexural strength and chloride permeability tests will be performed to achieve the set objectives.**

Keywords: **geo-polymer, Reinforced concrete, natural fibres, tensile strength, flexural strength.**

1. INTRODUCTION

Background Study

Engineers and academics with goals to come up with sustainable and energy efficient building materials have done broad research in the past. Low construction costs have been achieved through structural design optimisation and application of sustainable construction. Geopolymer concrete and fibre reinforced concrete are some of the construction materials that have gained attention from researchers due to their many advantages.

Industries manufacturing ordinary Portland cement (OPC) are responsible for 0.8 to 1 tonnes of Carbon IV Oxide release to the atmosphere for every 1 tonne of cement manufactured. This is equivalent to 5-10% global Carbon IV Oxide release. Calcining of Calcium Carbonate in the production of OPC is the major source of Carbon IV Oxide. Replacement of OPC with geo-polymer binder can reduce Carbon IV Oxide emissions for each cubic meter of OPC concrete replaced by 90%. Advantages of using geo-polymer cement include inherent protection of steel reinforcement due to low chloride diffusion and high residual pH, low thermal conductivity and low shrinkage, resistance to alkali-aggregate reactions, high resistance level to different salts and acids and improved fire resistance. These properties result in improved strength and concrete durability. Performance of geo-polymer concrete under impact loads can be improved by incorporation of fibre reinforcements into the concrete.

With the rapidly increasing need for superior structural properties in concrete, cement concretes containing randomly distributed steel fibres is gaining importance. These composite structural materials portray durability, high energy absorption, high toughness, low drying shrinkage, high compressive and tensile strengths due to the effect of the steel fibres in minimising micro cracks in cement matrix by deflecting or containing those micro cracks considering the great compatibility between the fibres and the cement matrix (Li, et al., 2010). Previous studies have shown that the combination of mechanical interlocking, friction and adhesion enhance the interfacial bond between the matrix and the fibres. Further studies have shown that the bond can be improved further by the use of long steel fibres, polymers, silane coupling agents and silica fume.

Properties of polymer-modified concrete include good ductility, high tensile strength and because of formation of the three-dimensional polymer network in hardened cement composites, the concrete possesses high impact capability (Li, et al., 2010). In polymer-modified concrete, pore radius is refined and porosity decreases because of the void filling of this three-dimensional polymer network and bridging across microcracks. Moreover, the addition polymer improves the transition zone.

Although concrete has a good compressive strength, its tensile strength is relatively low because of weak adhesion among others. Concrete porosity because of pores in the cement matrix and microcracks makes it susceptible to chemical and physical deterioration. On the other hand, polymers show good adhesion and high tensile capacities but are weaker in compression and they show better resistance to chemical and physical attacks (Kardon, 1997). Thus, concrete composites with improved durability and strength properties can be made by combining these materials.

Aim

This study aims to investigate the properties of geo-polymer modified cellulosic fibre reinforced concrete.

Objectives

a) To investigate the workability properties of freshly mixed geo-polymer modified cellulosic fibre reinforced concrete.

b) To investigate the strength and durability properties of hardened geo-polymer modified cellulosic fibre reinforced concrete.

c) To investigate the combined effect of fly ash and jute fibres on setting time of cement.

2. LITERATURE REVIEW

Introduction

This chapter covers existing literature and research on fibre reinforced concrete and polymer modified Portland cement concrete. The influence of these materials in concrete is discussed below. Their properties and limitations of use in concrete are discussed as well. This chapter considers previous studies on vegetable fibres and fly-ash use in concrete.

Cement-polymer Composites

Polymer-modified Concrete

Polymer-modified concrete (PMC) is also referred to as polymer Portland cement concrete (PPCC). This is ordinary Portland cement concrete with polymer added as an admixture. This is done to improve the concrete properties by combining cement hydration products and the polymer to form two interpenetrating matrices that work together.

Polymer Concrete

This is construction material made of polymer binder and aggregates. Portland cement is not used in polymer concrete. Unlike Portland cement concretes, the polymer matrix binds aggregate well without transition zones. Polymer concrete is made with evenly graded aggregates to ensure particles are closely packed and to minimise the spaces between aggregates to contain the polymer since the material is more expensive as compared to Portland cement and can generate heat and experience shrinkage during curing. Polymer concrete is usually used in overlays for concrete repairs, precast polymer concrete (PC) elements and making cast-in-situ (polymer concrete) PC connections in precast constructions. Use of PC comes with the disadvantage that PC is sensitive to cyclical temperature changes and high temperatures. An example of polymer concrete is using recycled polyethylene terephthalate (PET). One of the major causes of environmental pollution is plastics; this is because they are non-biodegradable thus they remain in the environment for a long time in the oceans killing sea creatures and on land creating space for growth of pathogens and causing visual intrusion among other adverse effects. Use of plastics in construction can greatly reduce garbage portion thus providing significant environmental benefits.

Polymer-impregnated Concrete

Polymers are combined with concrete in several ways including meshes and fibres. By infusing a monomer into concrete voids and cracks, polymer-impregnated concrete (PIC) is made from hardened concrete. Through the application of heat and action of chemical hardener, the monomers polymerise after they get into the cracks and voids. The polymer binds with concrete contents and fills the void. The applied pressure, polymer setup time, volatility and viscosity of monomer and concrete porosity determines the impregnation depth. Polymer impregnated concrete has been applied in precast panels and repair and maintenance of highway surfaces due to limited impregnation depth and difficulties in the practical application of the material on other surfaces rather than the top of horizontal surfaces.

Fibre Reinforced Concrete

Growth in world population is expected to increase by 2000 million by 2030 and thus this is an indicator more concrete structures will be built to serve the growing population. With an increase in concrete structures, more deterioration of these structures is expected if mitigation measures are not considered in the design. Location and environmental conditions greatly influence the durability of concrete structures. The environmental impact on concrete can be greatly decreased if the concrete life is increased.

Natural Fibre Properties and Characteristics

Natural fibres are acquiring from natural plants with cell structures, different layers are composed of different proportions of lignin, hemicellulose and cellulose. Lignin is a heterogeneous and amorphous mixture of phenylpropane monomers and aromatic polymers, hemicellulose is a polymer composed of various polysaccharides and cellulose is a polymer composed of glucose parts. Natural fibres have a low modulus of elasticity and high tensile strength making them a better substitute for other fibres but their high variation in their properties can lead to unpredictable concrete properties. Natural fibres require pre-treatment before use in concrete to improve their durability and compatibility with concrete. Pulping is done by mechanical or chemical means improves resistance to alkaline attack and adhesion between cement paste and fibres. Mechanical pulping is preferred over chemical method because it is cheaper and no effluent treatment is required.

Table 0.1: Properties of Cellulosic Fibres

Properties	Specific gravity [Kg/m^3]	Water absorption [%]	Tensile strength [MPa]	Modulus of elasticity [GPa]
Sisal	1370	110	347-378	15,2
Coconut	1177	93,8	95-118	2,8
Bamboo	1158	145	73-505	10-40
Hemp	1500	85-105	900	34
Caesarweed	1409	182	300-500	10-40
Banana	1031	407	384	20-51
Piassava palm	1054	34-108	143	5,6
Date palm [7]	1300-1450	60-84	70-170	2,5-4

Effect on Cement Matrix

Based on previous studies some natural fibres release acid compounds that reduce cement paste setting time. Presence of lignin, hemicellulose and sugar components in large quantities can prevent hydration cement. In some instance, the presence of pectin in fibre can fix calcium thus hindering the formation of CSH structures and therefore delaying cement paste hydration for a while. The interfacial transition zone between natural fibres and concrete is rich in calcium hydroxide, cracked and porous, based on previous research (Savastano Jr & Agopyan, 1999), fibres imprints were seen in concrete thus indicating weak adhesion between cement paste and natural fibres. Other researchers applied high pressure and vacuum dewatering on the concrete, which resulted in dense interfacial transition zones. Addition of water reducing agents also resulted in better bonds between concrete and vegetable fibres. Other ways of improving vegetable fibres – concrete bonds include alkaline treatment of fibres and mechanical treatment of natural fibres.

Effect of Natural Fibres on Concrete Properties

Addition of 25 mm sisal fibres by 0.2% by volume of concrete led to plastic shrinkage reduction in concrete. The combined use of sisal short fibres and coconut fibres controlled the development of cracks during plastic shrinkage at early ages (Al-Oraimi & Seibi, 1995). Impact resistance of concrete and its mechanical properties were improved by adding a low percentage of natural fibres and the performance compared to the use of synthetic fibres. Mechanical performance of fibre concrete is dependent on the type of natural fibre used; sugar cane bagasse and coconut fibres have shown an increase in fracture toughness but banana pseudostem fibres do not. Researchers have reported a 3 to 10 times increase in impact resistance in fibre reinforced concrete. Coconut fibres have recorded better flexural strength as compared to carbon and glass synthetic fibres. Sisal fibres resulted in a reduction in compressive strength of concrete as compared to control concrete because of reduction in workability of concrete with the addition of sisal fibres.

The durability of Natural Fibres Reinforced Concrete

Reinforced concrete durability relates to its ability to resist adverse external conditions exposed to concrete such as chloride and sulphate attack, changes in moisture content and temperature variations among others; and internal changes such as volumetric changes, and compatibility between concrete and natural fibres. High alkalinity in concrete threatens the life of natural fibres added to the concrete by dissolving hemicellulose and lignin, therefore, weakening fibre structure. The durability of coir fibre and sisal was studied by exposing them to alkaline solutions and later measuring their tensile strengths (Silva & Rodrigues, 2007). Calcium ions had a deleterious effect on fibre causing degradation. Fibres preserved their flexibility and strength in parts of concrete with a pH less than 9. Filho, et al., 2000, did an investigation on the durability of coconut fibres and sisal fibres when conditioned in sodium hydroxide. Coconut and sisal fibres retained 60.9% and 72.7% of their initial strength respectively after 420 days. The durability of natural fibres can also be affected by their ability of these factors to absorb water. Water absorption can cause volume changes that can result in concrete cracks. This study employs a matrix modification method to improve the durability of natural fibre reinforced concrete. Addition of fly ash is expected to portland cement is expected to lower alkalinity in concrete. Sisal fibres will be impregnated with magnesium sulphate, sodium sulphite or sodium silicate to avoid absorption of free alkalis and water by the fibres. Silane coating is also considered as an effective way of improving vegetable fibre reinforced concrete durability.

3. MATERIALS AND METHODS

Introduction

Materials and methods proposed in this research are stated in this section. To achieve the set objectives a series of experimental tests will be done on the produced concrete in its fresh and hardened states.

Materials

Vegetable Fibres

Pre-treated sisal fibres.

Fly Ash

Low calcium (class F) fly ash acquired from local markets.

Cement

A product of Lafarge Cement Blue Circle Cement (CEM II) acquired from local markets.

Fine Aggregates

River sand with low silt level and free from any deleterious materials. Particles should be hard, strong clean, free from absorbed chemicals and coatings of clay that could negatively affect concrete properties. Fine aggregates shall be able to pass through the BS 410 5.0 mm sieve and shall not contain any coarser material.

Coarse Aggregates

Crushed stone with 20 mm maximum size and free from any deleterious substances. The aggregates should be free from any coatings of clay or other harmful materials. If necessary aggregates will be cleaned to remove contaminants. Aggregates should be retained in a BS 410 5.0 mm sieve and no finer materials shall be allowed. Coarse aggregates should meet the requirements of BS 882: 1992.

Experimental Methods

Setting Time

Tests on cement will be done in accordance with BS EN 196-3:2005+A1:2008 Methods of testing cement. Determination of setting times and soundness. Initial cement paste setting time is the time after which the cement paste starts to harden while final cement paste setting time is the time after which a 5 mm needle does not mark the cement paste while the 1 mm needle makes an impression when testing using the Vicat apparatus.

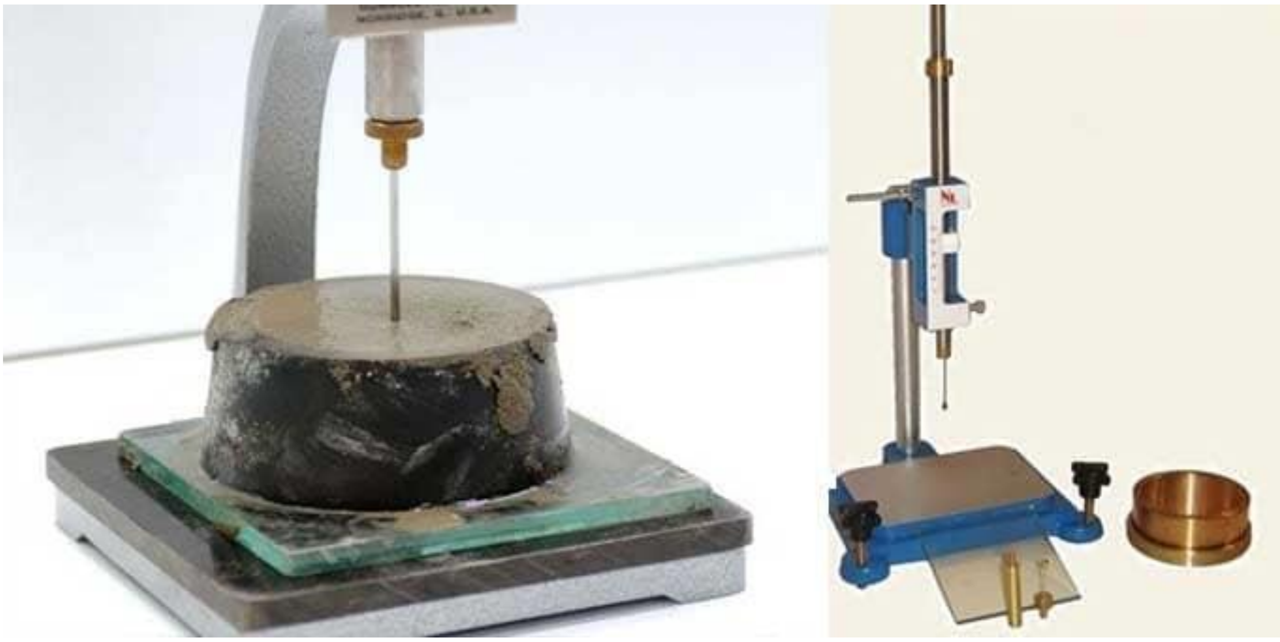

Figure 0.1: Setting time test

Apparatus

- Trowel.
- Enamel tray.
- Glass plate.
- Stopwatch.
- Measuring cylinder.
- Balance.
- Vicat's apparatus.

Consistency Test Procedure

a) This is done to determine the amount of water required to produce a paste with normal consistency (P).

b) Prepare a neat cement paste with 400g of cement and 0.85(P) of water by cement weight.

c) Measure time from the instant water is added to the cement.

d) Rest the Vicat mould on a glass plate and fill with cement paste, strike the top to smooth the surface at the level of the mould.

e) Use the Vicat apparatus to test for consistency by lowering the plunger to contact with the surface of cement paste and releasing it into the mould.

f) Note scale reading after 30 seconds.

Workability Test

To determine concrete workability, slump tests will be done in accordance with BS EN 12350-2: 2009 Testing Fresh Concrete part 2: slump test.

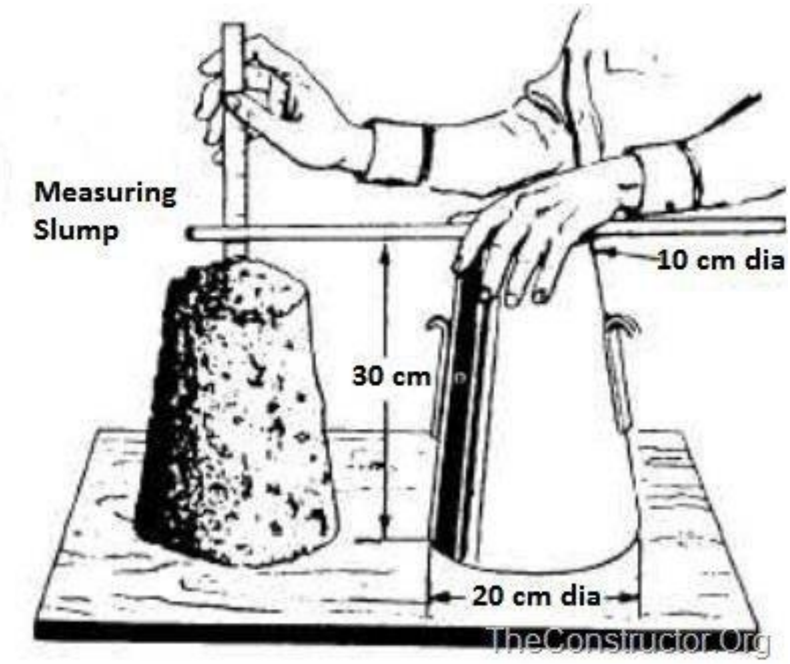

Figure 0.2: Slump test

Apparatus

- Timer
- Scoop.
- Moist cloth.
- Shovel.
- Remixing container.
- Base plate.
- Rule.
- Funnel.
- Compacting rod.
- Mould.

Procedure

a) Dampen base plate and mould. Hold the mould firmly against the base plate and fill with concrete in three layers each approximately 1/3 of the height.

b) Compact each layer by 25 uniformly distributed strokes using the tamping rod while ensuring the strokes penetrate through the layers. For the top layer add excess concrete to exceed the top of the mould.

c) After compacting the top layer, strike the surface of the mould using the compacting rod and remove concrete spilt on the base plate.

d) Raise the mould carefully and vertically from concrete.

e) Measure and record the slump.

Compressive Strength Test

Compressive strength tests will be done in accordance with BS EN 12390-3: 2009 + C1 2011 using a testing machine satisfying the requirements of BS EN 12390-4: 2000.

Figure 0.3: Compressive strength test

Apparatus

Testing machine satisfying requirements of EN 12390-4.

Procedure

a) Prepare the specimens by wiping water on surfaces and remove any extraneous material on their surfaces.

b) Place the concrete cube specimen on the machine in a way to ensure loading is applied perpendicularly to the direction of casting. Centre the specimen on the loading area.

c) Apply load on the specimen ensuring a continuous constant loading rate without shock loading.

Tensile Strength Test

Concrete tensile strength will be determined using tensile splitting strength test of concrete specimens in accordance with BS EN 12390-6: 2009.

Figure 0.4: Split tensile test

Apparatus

- Packing Strips.
- Jig.
- Testing machine conforming to requirements of EN 12390-4.

Procedure

a) Prepare the specimen by wiping excess water on the surface before placing on the testing machine. Wipe extraneous material from surfaces of platens, loading pieces, packing strips and jig.

b) Ensure the specimen is placed centrally on the testing machine, that packing strips are carefully positioned along the bottom and top of loading plane and ensuring the lower platen and upper platen is parallel before and during loading.

c) Ensure the specimen remains centred during load application.

Flexural Strength Test

Flexural strength test of hardened concrete will be performed in accordance with BS EN 12390-5: 2009.

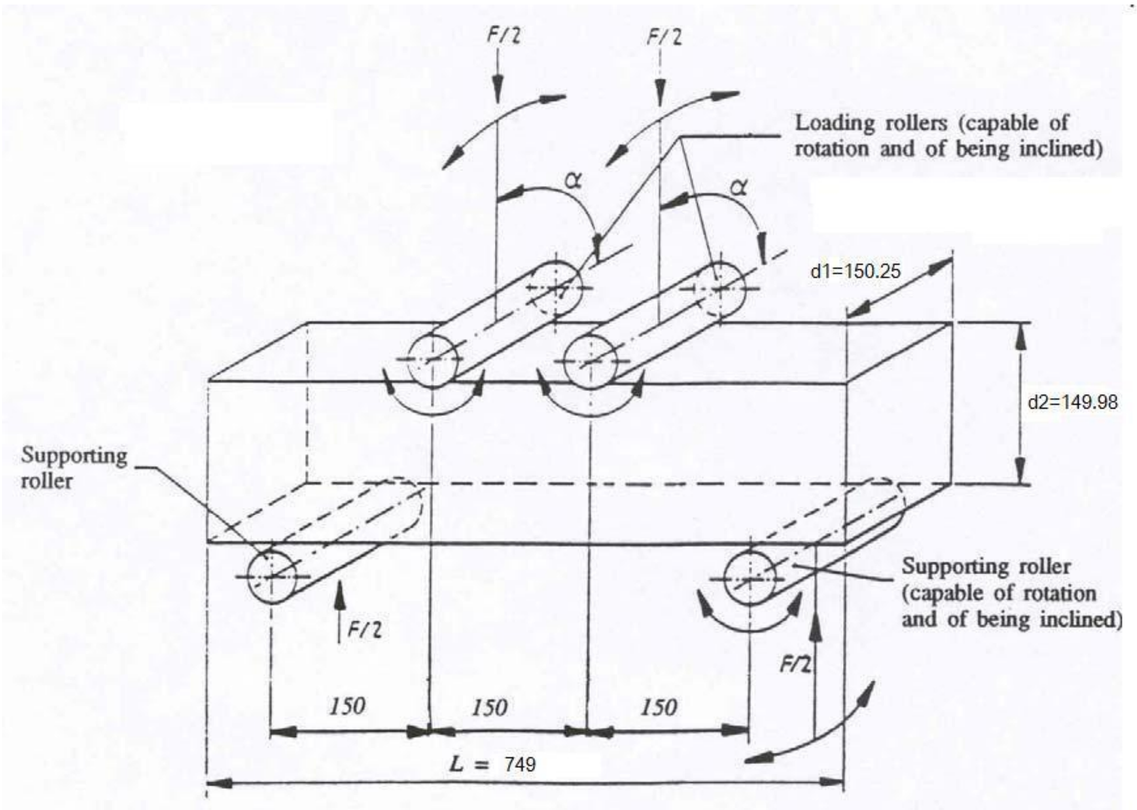

Figure 0.5: Two point loading specimen arrangement in flexural test

Apparatus

- Force application as discussed in BS EN 12390-5: 2009.
- Testing machine conforming to requirements of EN 12390-4.

Procedure

a) Prepare and position the specimen on the machine. Clean machine bearing surfaces to remove dirt and loose grit. Wipe water from surfaces of the specimen before placing on the machine. Ensure the specimen is correctly centred with specimen longitudinal axis at right angle to the upper and lower rollers' longitudinal axis before load application.

b) Before load application ensure all supporting and loading rollers are evenly resting on the specimen. Select a constant stress rate at 0.05 MPa/s. Apply initial load on the specimen without exceeding 20% of the failure load. Load the specimen further increasing continuously at a constant rate ± 10% without shock until the specimen cannot sustain any greater load.

Chloride Permeability Test

Chloride permeability test will be executed in accordance with BS EN 12390-11: 2015 Determination of chloride resistance of concrete, unidirectional diffusion.

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