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EFFECTS OF COCONUT HUSK FIBRE AND POLYPROPYLENE FIBRE ON FIRE RESISTANCE OF CONCRETE

Anthony Nkem Ede (PhD) and Adebodun Oluwaseyi Aina
* Department of Civil Engineering, College of Engineering, Covenant University, Canaan Land, KM 10, Idiroko Road, P.M.B. 1023 Ota, Ogun State, Nigeria

ABSTRACT

Fire disasters have become a common occurrence in Lagos metropolis and in Nigeria as a whole, resulting in the loss of lives and property. The performance of every structure against event of a fire is supposed to be considered during the preliminary phase of material selection and design. Concrete and structural steel are primary construction material in the World. Concrete is known to have good thermal resistive property when compared to steel. If concrete is subject to elevated temperatures, the separation of concrete masses occur, giving rise to a phenomenon known as "Spalling". This research investigates the effects of fire on coconut husk fibre and polypropylene fibre reinforced concrete. Several samples of fibre reinforced concrete cubes were casted using 0.5% of coconut and polypropylene fibres and exposed to temperatures of 200ºC, 400ºC, 600ºC, 800ºC and 1000ºC after 7, 14, 21, and 28 days of curing. Compressive tests on concrete cube samples were conducted according to standards. The percentage increases in compressive strength of the test specimen show that the coconut fibres produced a higher strength increase over polypropylene fibres and that the fire resistance of coconut fibre is greater than that of polypropylene fibre for the increasing rates of temperature exposure.

Keywords: Fibre Reinforced Concrete, Coconut Husk Fibre, Polypropylene Fibre, Compressive Strength, Fire Resistance.

INTRODUCTION

The frequent cases of fire occurrences in buildings have always been of great concern to the society for the risks it poses to both human lives and property. Fires can occur at any time in a building and the safety of occupants and the ability of structures to maintain its integrity are very important to the people. Building codes and regulations specify detailed measures for the safety of structural members in the event of a fire. They categorises construction materials with particular emphasis on their fire resistance and recommends fire suppression systems required for various building types. Hence, the objective of fire safety is to protect life and property. The fire safety requirements of materials are based on the ability of structural elements built with the materials to maintain its load-bearing capability at various fire conditions. In other words, the fire resistance rating of a structural member can be said to be proportional to the period of time it can resist in terms of structural integrity and stability to standard fire conditions.

The risk of uncontrollable fires and the desire to avoid their consequences is as old as human civilization. Though the causes and nature of fire incidence have changed considerably over the years, the risk have always remained there and for this, the desire to minimize these risks have always remained high virtually in every society as fire is a destroyer of human lives and properties. The quest to reduce the risk of fire in constructed facility has taken various forms and the most proactive has been the search for methods and means whereby the negative aspects of fire on structures are mitigated or prevented altogether. This desire can be expressed in a simple equation stating that Fire Resistance must be greater or equal to Fire Severity (NIST, 2004). To achieve this result requires a robust basis upon which both sides of the inequality can be evaluated.

Selection of construction material for any structure is a very important task that must be resolved at the preliminary phase of any construction project for its overbearing influence on safety, durability, constructability, aesthetics, total cost of construction and of maintenance. The risk of fire occurrence must be one of the principle factors affect the choice of building materials. Statistics gotten from the Lagos State Fire Service Department reveals that there has been a huge increase in the number of fire occurrences per year in Lagos State alone.

Testing for the fire resistance of materials is done in laboratories by exposing elements to fire conditions and supervising their performance. Numerical and analytical methods of determining fire performance were developed based on these fire tests as an economical substitute to laboratory testing as it is highly dangerous and risky to perform fire tests on buildings. Over the past years there has been a widespread use of finite element programs to determine structural performance in both standard and natural fire conditions. The use of these programs requires a strong background in fire protection engineering which most structural engineers do not have (Adam, 2006).

Concrete and structural steel are primary construction material in the World. Concrete is known to have good thermal resistive property when compared to steel. If concrete is subject to elevated temperatures, the separation of concrete masses occur, giving rise to a phenomenon known as “Spalling”. Spalling of concrete leads to a weakening of the cross section area of the concrete member thereby decreasing the resistances to loads as well as the exposure of steel reinforcement bars directly to elevated temperatures which softens it and renders it completely useless in terms of strength. Over the years, many researches have been going on how to improve concrete strength through the use of fibres. Fibre reinforced concrete can be defined as a composite material made with Portland cement, aggregates, water and admixtures such discrete discontinuous fibres (Chanh, 2001, Ede et al 2015). Unlike normal concrete which is brittle and possess low tensile strength and low resistance to impact, fibre reinforced concrete possesses some post cracking ductility which will allows the concrete to carry significant stresses over a relatively large strain at the post-cracking stage (Chanh, 2001). The mechanical properties of the fibres play significant role when cracks occur. Some fibres such as polypropylene fibres have been known to reduce the effect of spalling which is a commonest failure mode of concrete exposed to high temperatures (Fletcher et al, 2007).

This research aims at evaluating the fire resistance normal Portland cement concrete reinforced with Coconut fibre and Polypropylene fibres. Several samples of fibre reinforced concrete cubes where casted using coconut and polypropylene fibres and exposed to temperatures of 200ºC, 400ºC, 600ºC, 800ºC and 1000ºC after 7, 14, 21, and 28 days of curing. Various samples exposed to fire were tested and compare with the control sample as to ascertain the strength degradation and fire resistance after exposure to fire.

LITERATURE REVIEW

Fire and buildings

Fire incident in building structures is a recurring problem in Nigeria and many parts of the World. Fire outbreaks have a great impact on the society: on human lives, on the economy and the environment. For that, fire protection is an important decision that should be carefully considered at an early design stage. To a larger extent, issues bordering on reduction of fire incidents on structures and approaches to reduce the impacts of fire on structures continue to attract the attention of researchers and policy makers worldwide. The idea of precautions against the effects of fire in buildings is not new. Some of the approaches have been in existence for many years and as knowledge increased over the years and the new structures become more complex, so must the precautions against fires improve. Structural elements are required by building regulations to have a certain degree of fire resistance to prevent the immediate collapse of the structure in the event of a fire. The British buildings regulation states that “ a building shall be so constructed that in the event of fire, its stability will be maintained for a reasonable period of time’’.

Structures

According to the Merriam-Webster dictionary (2012), “A structure is the arrangement of part of elements as dominated by the general character of the whole’’. A structure could also be said to be a complex entity, constructed from the arrangements of several parts. In engineering and architecture, a structure is a body or assembly of the body elements to form a system capable of resisting loads. The effects of loads on physical structures are determined through structural analysis. Structures can also be categorised by the type of material used for its construction. Structural engineering depends on the knowledge of materials and their properties, in order to understand how different materials support and resist loads. The choice of what material to use for construction depends on some factors: material properties (strength and durability), cost (acquisition, technology, maintenance, sustainability), aesthetics/taste and constructability. Common structural materials are concrete, steel, bricks, timber, fibre reinforced plastic (FRP) composites. Each of these materials resist fire differently and scientist are working tirelessly to improve their fire rating. Fire resistance can be defined as the ability of structural elements to withstand fire or to give protection from it (IBC, 2006). This includes the ability to confine a fire or for a structure to continue to perform its structural functions after fire incidence or both. Fire Resistance Rating (or fire rating), is defined as the duration of time that an assembly (roof, floor, beam, wall, or column) can endure a “standard fire” as defined in ASTM E 119 (ASTM, 2000).

Ideally in the early stage of planning a building project, the entire design team made up of architect, structural engineer and the services engineers should join hands to decide on a form and correct materials for the structure that would satisfy the safety, economic, functionality, aesthetics and serviceability requirements. It is at this preliminary stage that the choice of material comes into consideration and in the choice of material, the fire rating must be considered as fire affects every aspect of a building on whether it will be on its foot to serve the purpose for which it is built.

Fire

Fire is rapid process of combustion of inflammable material with the evolution of heat and usually accompanied by flame. The high probability of extreme fire situations occurring, causing damages in structures has made fire design / protection to be among the primary considerations in the design process of structures. For a fire to start, three elements must be present simultaneously: oxygen (21 % volume in air), combustible materials and a heat source. These make up what is convenient to call the fire triangle. The first two elements combust when the inflammation temperature is reached. The combustion of carbon produces carbon dioxide (CO_2) and, if there is a lack of oxygen, it leads to the well-known toxic gas, carbon monoxide or carbonous oxide with the molecular formula of CO which is highly dangerous to man, (Adam, 2006).

Fire protection and fire engineering

Fire safety must be regarded as a major priority at the earliest stage of a building project as it can have a major impact on the design of a building and its structural form. Nevertheless, it should not stifle aesthetic or functional freedom; fire engineering techniques are now available which permit a more rational treatment of fire development and fire protection in buildings. The strength of all materials reduces as their temperature increases. It is essential that the structure should not weaken in fire to the extent that collapse occurs prematurely, while the occupants are seeking to make their way to safety. For this reason it is necessary to provide a minimum degree of fire resistance to the building structure. There are two basic ways to provide fire resistance: first, to design the structure using the ordinary temperature properties of the material and then to insulate the members so that the temperature of the structure remains sufficiently low, or secondly, to take into account the high-temperature properties of the material, in which case no insulation may be necessary (Steel Designers' Manual, 2003). Three issues involved in fire protection include life safety, protection of the structure, and fire suppression. The need to protect a structure is a matter of compliance with the building codes that specify the number of hours of fire exposure that a building structure must withstand, within specific temperature limits. This is determined by such factors as the building use, occupancy, number of stories, building height, total floor area, area of each floor, and building separation. Both the building codes and the insurance underwriters determine fire suppression requirements. For example, the building codes specify that high-rise buildings, large shopping malls and large industrial storage buildings be equipped with sprinkler systems (AISC, 2002).

It is important to understand what the performance criteria are intended to be when selecting a particular material or method, including exposure to fire, duration, aesthetics, cost, maintenance, blast/impact resistance, etc. As there are numerous stakeholders (architects, owners, insurers, manufacturers, etc.) involved in a project, each with their own desires for performance criteria, (which may often compete with each other), these criteria should be discussed during selection of appropriate materials (Michael, 2004).

Having discussed various aspects of fire and established that there is a great link between fire resistance of a structure and the material used for construction, the attention will be focus on concrete and the efforts to make it more fire resistant.

Concrete

Concrete is the most common construction material used in Nigeria and most of structural problems experienced in Nigeria like building collapse (Ede, 2011) affect concrete structures. Concrete is non-combustible and has a low thermal conductivity. Besides, the cement paste in concrete undergoes an endothermic reaction when heated which assists in the reduction of temperature rises in concrete elements. When those factors are combined with concrete's large member sizes, the result is that concrete structures perform relatively well in fire conditions in comparison with other construction types (Adam, 2006). Concrete is a composite material per excellence (Ede et al, 2015) for which many factors could affect its performance especially at elevated temperatures. During a fire incidence, heat is absorbed by concrete leading to an increase in its temperature. The resultant strength and deformations of concrete elements and structure as a whole when exposed to temperatures of high degrees are highly dependent on its thermal and mechanical properties. These properties determine the temperature rise in concrete, so knowing and understanding their function is critical in determining the behaviour of concrete elements in fire conditions. Certain properties of concrete influence these thermal and mechanical properties and determine the rate of temperature increase and strength variation. These properties include density, moisture content, thermal conductivity and specific heat. The density of concrete depends primarily upon the type of aggregate (heavy, normal or light weight). When concrete is heated, free moisture is driven away once the temperature in the section exceeds 100ºC. Losses of moisture reduce the density of concrete and will affect the strength. Thermal conductivity of concrete is the rate of heat is transferred through a unit thickness of the material per unit temperature difference. It is dependent upon the type of aggregate, porosity of the concrete, and the moisture content. Also, thermal conductivity values for concrete elements are dependent on the temperature of the concrete (Lie 1992). Specific heat is the heat required to raise the temperature of a unit mass of material by one degree.

Fibre Reinforced Concrete

A fibre is a structure composed of filaments of natural or synthetic material (Webster's dictionary, 2012). It is a small piece of reinforcing material that possesses some characteristic properties such as strength, toughness, flexibility, rigidity, resilience, elasticity and even fire resistance amongst others. Over the years, fibres have gained relevance in construction industry due to their effects on concrete which include control of plastic and shrinkage cracking, prevention of concrete spalling, greater impact and abrasion resistance, reduction in the permeability, increased toughness, delay of crack formation and propagation. This research will be focusing on polypropylene and coconut fibres.

Polypropylene fibre is one of the most commonly used fibres in concrete mixtures. They have low modulus of elasticity, varying between 3 and 5 Giga Pascal (Rossi, 2011). Available polypropylene fibres are typically short in length and have small diameter. It has the ability to mitigate the explosive tendency of concrete during fire as it melts and relieve volatile steam pressure in concrete. According to Ahmed et al (2006), the addition of polypropylene fibres to concrete has an appreciable impact on the properties of the concrete such as slight increase in compressive, flexural and tensile strengths and shrinkage crack reduction.

Coconut fibre is extracted from the outer shell of a coconut. Its common name is coir and scientific name is Cocos Nucifera. These fibres are extracted from the husk of a matured coconut and they are brown in colour. The fibrous husk is soaked in water to soften it. The soften fibres can be extracted by beating. The extracted fibres are then combed to remove the dirt particles and to loosen them. The properties of coconut fibres include excellent insulation against temperature and sound, unaffected by moisture and dampness, toughness, durability and durability (Ali et al, 2011, Aziz et al., 1984, Asasutjarit et al., 2005, Okere, 2013, Paramasivam et al., 1984 and Munawar et al., 2007).

Concrete responds to high temperatures produced by fire through cracking and spalling of concrete. Certain factors affect the occurrence and intensity of fire in a structure such as; the quantity and nature of combustible materials present, the possibility and extent of ventilation, the extent of fire protection and suppression system such as sprinklers, and the geometric and thermal properties of the structural members. To be able to resist fire, we must understand the concept of fire, the causes and possible ways of terminating a fire

Concrete is a composite material produced from aggregate, cement, and water. Therefore, the type and properties of aggregate also play an important role on the properties of concrete exposed to elevated temperatures. For a reinforced concrete exposed to heating, increasing temperature leads to the deterioration of concrete member (Khaled, 2011). One common behavioural reaction of concrete to high temperatures or fire is the phenomenon of spalling. Spalling may manifest itself at relatively low temperatures, before any other negative effects of heating on the strength of concrete have taken place (Fletcher et al, 2007). Spalling may significantly reduce or even eliminate the layer of concrete cover to the reinforcement bars, thereby exposing the reinforcement to high temperatures, leading to a reduction of strength of the steel and hence a deterioration of the mechanical properties of the structure as a whole. One well-known method of reducing spalling is the addition of polypropylene fibres to the concrete mix. This approach works on the basis that, as the concrete is heated by fire, the Polypropylene fibres melt at about 160 Cº - 170 Cº thus creating channels for vapour to escape and thereby release pore pressures. Khaled (2011) tested short reinforced concrete columns with 0.5 kg/m³ and 0.75 kg/m³ of polypropylene fibres, at ambient temperature, 400 C°, 600 C° and 800 C° at 0, 2, 4 and 6 hours of exposure, respectively. He concluded that Polypropylene fibres have a positive impact on axial load capacity of unheated concrete columns. Shihada, (2011) investigated the effect of Polypropylene fibres on fire resistance of concrete with 0 %, 0.5 % and 1%, by volume of fibre at 200 C°, 400 C° and 600 C°, for 2, 4 and 6 hours for each of the three temperatures, and tested for compressive strength. He concluded that Polypropylene fibres improved the fire resistance of concrete.

MATERIAL AND METHOD

Material Selection and Mix Design

Concrete is a composite material per excellence (Ede, 2015) since it is made up of several different materials such as aggregate, sand, water, cement and admixture. For the purpose of this experiment, ordinary Portland cement concrete was used. Sharp sand is the material used as fine aggregate while gravel was adopted as coarse aggregates. Drinkable water was used in all concrete mixtures and in the curing of all the test samples. For the purpose of assessing the performance of fibre reinforced concrete, 2 types of fibres, namely Coconut Fibre and Polypropylene Fibres were adopted.

Coconut fibre was drawn from coconut husk after removing short fibres and dust by a manual process. The fibre has high lignin content and thus low cellulose content which makes it resilient, strong and highly durable. Polypropylene is a synthetic/plastic polymer fibre.

For the mix design, the following values were adopted: 0.56 water/cement ratio, cement content of 360 kg/m³, 0.5% replacement by weight of fine aggregate for polypropylene fibres and for coconut fibres. Exposure to heat were in the ranges of 0 C°, 200 C°, 400 C°, 600 C°, 800 C° and 1000 C° lasted for 2 hours for each of the sample tested. The fresh concrete was cast into steel moulds (150 mm x 150 mm x 1500 mm) already prepared by cleaning and greasing of the mould. The mould was filled with three equal layers and with each layer tempered to avoid segregation of concrete elements using the 1:2:4 mix ratio. Sample 1 consisted of normal concrete without fibres to serve duo purposes: one as control specimen and the other to undergo temperature tests. Sample 2 consist of cubes with partial weight replacement of fine aggregate by 0.5% of Coconut husk fibres and sample 3 made with a partial weight replacement of fine aggregate by 0.5% of polypropylene fibres.

A day after the fresh concrete is casted, the de-molded samples were submerged completely in water for the duration of their curing period and brought out a day before burning to dry by air.

Testing Procedures

The experimental program consisted of fire endurance tests and compressive tests to assess the performance of Coconut fibre and Polypropylene fibre reinforced concrete. After finishing the curing process for the samples, the heating process were executed for the samples in an electrical oven, for temperatures of 200 Cº, 400 Cº, 600 Cº, 800 Cº, 1000 Cº. After all the concrete samples were exposed to temperatures of various degrees, the samples are tested for their compressive strength capacity. 2 samples of the each concrete cube type were prepared and tested it in order to obtain averaged value and then the results are taken, analysed and compared to the results of the un-burnt cubes. The research procedure is as indicated in figure 1.

The heating tests took place in the Mechanical Engineering Department Laboratory while all the other tests took place in the Civil Engineering Department Laboratories of Covenant University.

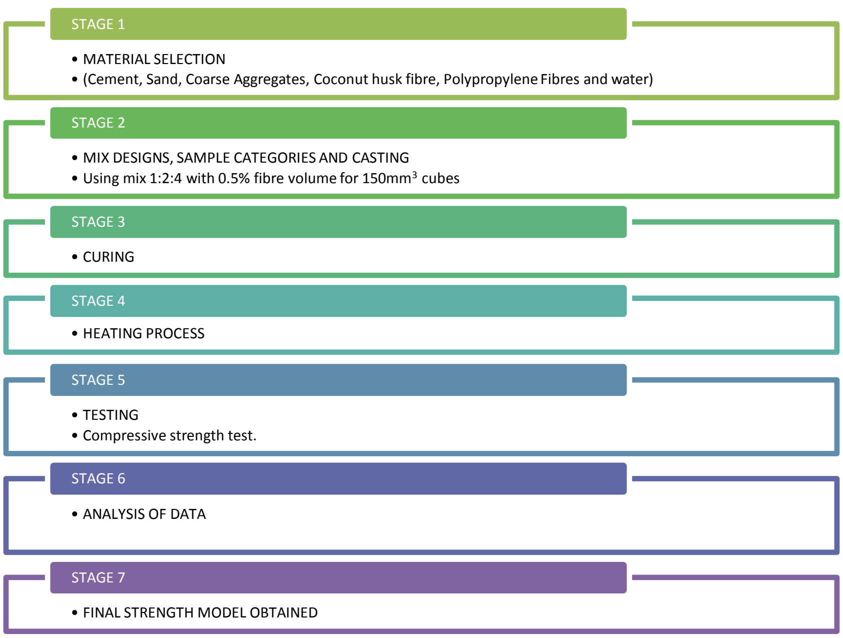

Figure 1. Schematic Diagram Showing the Sequence Used In Facilitation of the Experiment.

RESULTS AND DISCUSSION

Here, the results gotten from the test performed on normal concrete, coconut fibre reinforced concrete and polypropylene fibre reinforced concrete cube samples are discussed. The compressive tests on concrete cube samples were conducted according to standards. Control samples of 150mm x 150mm x 150mm dimension were cured and tested to determine their 7, 14, 21, and 28 days compressive strength using a digital compression testing machine. The other samples of normal concrete, coconut fibre reinforced concrete and polypropylene fibre reinforced concrete were heated at various temperatures of 200ºC**,** 400ºC, 600ºC, 800ºC, and 1000ºC on their 7, 14, 21, and 28 days of curing and tested to determine their compressive strength. Figure 2 shows the variation of Compressive Strength as Temperature increases for 7 days old concrete.

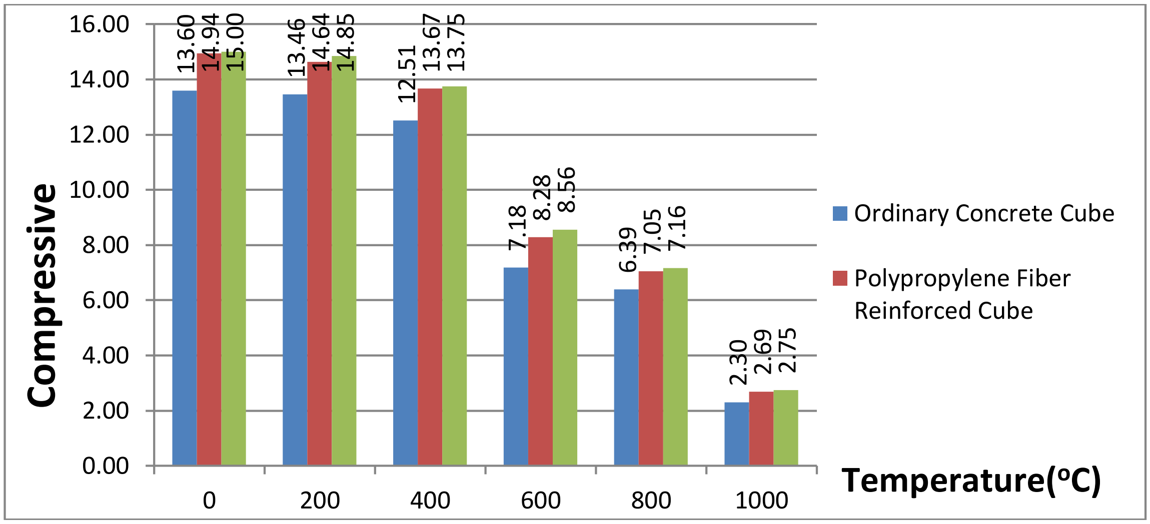

Figure 2: Bar Chart shows the variation of Compressive Strength as Temperature increased for 7 days old concrete.

Figure 2 shows the behaviour of the samples for 7 days of age. From these results it can be easily deduced that at 7 days, coconut fibre reinforced concrete has a higher compressive strength and higher fire resistance having as much as 10.29% of strength gain at the ambient temperature and 19.57% residual strength after exposure at 1000°C. The polypropylene reinforced concrete had a strength gain of 9.83% at the ambient temperature and 16.98% at 1000°C.
Figure 3 shows the behaviour of the samples for 14 days of age. From these results it can be easily deduced that at 14 days, coconut fibre reinforced concrete has a higher compressive strength and higher fire resistance having as much as 14.28% of strength gain at ambient temperature and 9.46% residual strength after exposure at 1000°C. The polypropylene reinforced concrete had a strength gain of 12.72% at the ambient temperature and 5.68% at 1000°C.

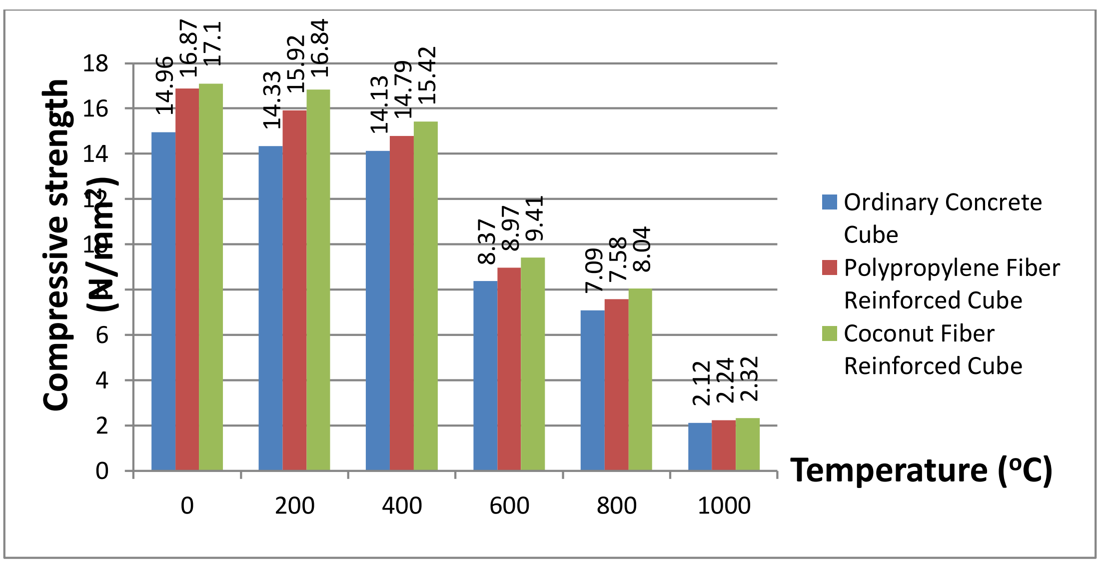

Figure 3: Bar Chart shows the variation of Compressive Strength as Temperature increases for 14 days old concrete.

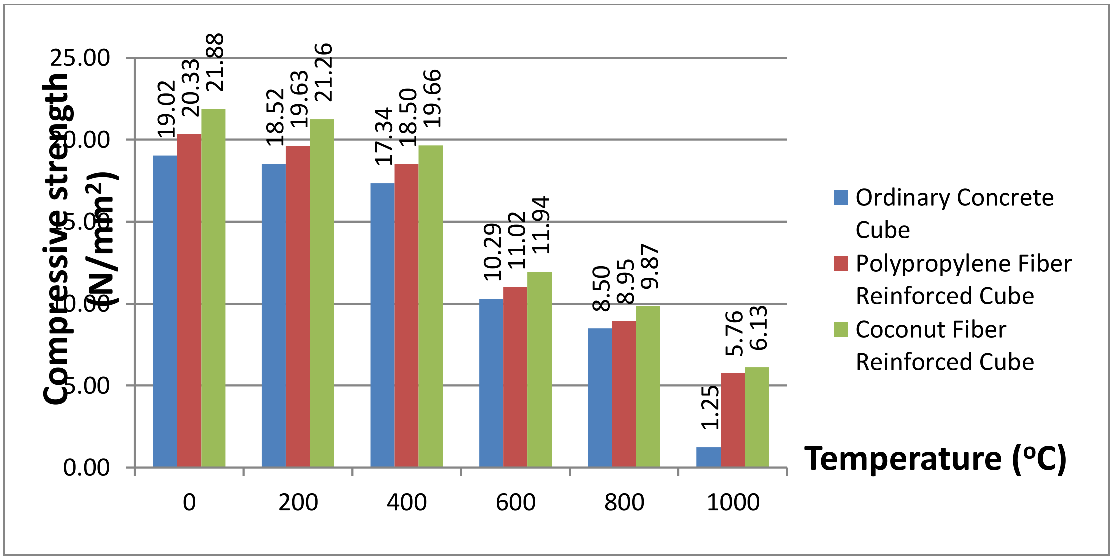

Figure 4: Bar Chart shows the variation of Compressive Strength as Temperature increases for 21 days old concrete.

Figure 4 shows the behaviour of the samples for 21 days of age. From these results it can be easily deduced that at 21 days, coconut fibre reinforced concrete has a higher compressive strength and higher fire resistance having as much as 15.03% of strength gain at ambient temperature and 389.09% residual strength after exposure at 1000ºC. The polypropylene reinforced concrete had a strength gain of 6.9% at the ambient temperature and 359.14% at 1000ºC.

Figure 5 shows the behaviour of the samples for 28 days of age. From these results it can be easily deduced that at 28 days, coconut fibre reinforced concrete has a higher compressive strength and higher fire resistance having as much as 19.03% of strength gain at ambient temperature and 10.74% residual strength after exposure at 1000ºC. The polypropylene reinforced concrete had a strength gain of 13.03% at the ambient temperature and 4.64% at 1000ºC.

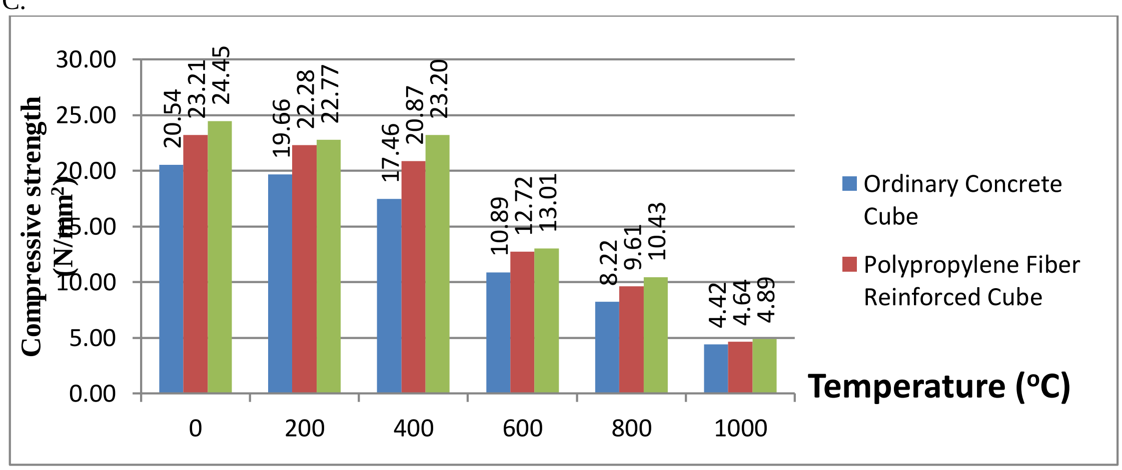

Figure 5: Bar Chart shows the variation of Compressive Strength as Temperature increases for 28 days old concrete.

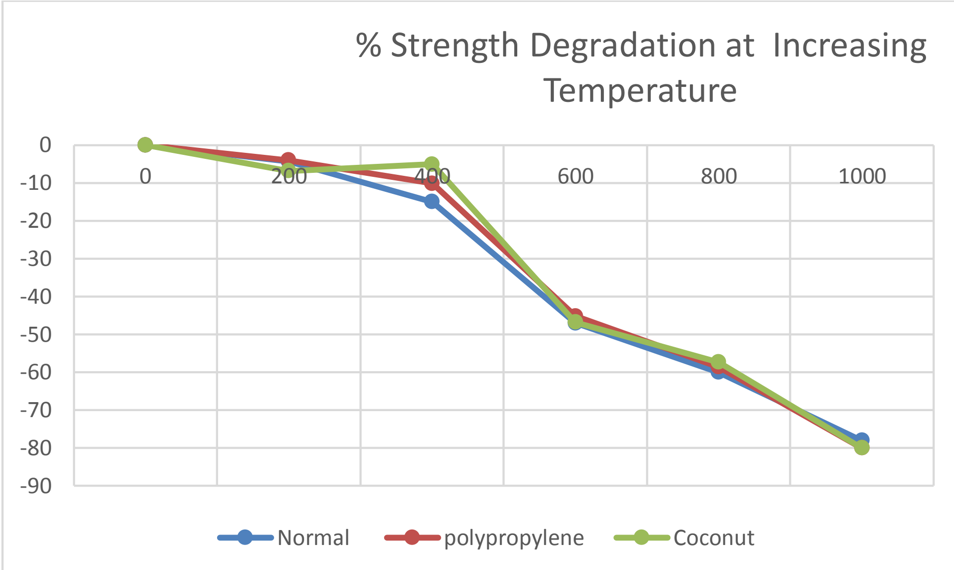

Figure 6: shows the strength degradation Temperature increases for 28 days old concrete.

Figure 6 shows the strength degradation for 28 days concrete cubes as temperature increased. It is noticed that for temperatures below 400ºC, the degradation of strength was very moderate with 15% for Normal concrete, 10.12% for polypropylene fibre reinforced concrete and 5.10% for coconut fibre reinforced concrete, respectively. For temperatures of 600ºC and above, the strength degradation was very pronounced with the minimum of 45% for polypropylene fibre sample at 600ºC and maximum of 80% strength degradation for both polypropylene fibre sample and coconut sample at of 1000ºC.

It is important to notice some changes in colour after the exposure for temperatures. Between 300ºC and 600ºC, the colour was be light pink, for temperatures between 600ºC and 900ºC the colour was light grey, and for temperatures over 900ºC the colour was dark Beige "Creamy". This confirms previous findings in the literature.

It is to be noted that the fibres conferred greater compaction on the concrete samples. The fibre reinforced samples remained very compact form after failure taking the behaviour of the samples away from the usual fragile mode of failure. This would be advantageous for preservation and evacuation of lives and properties in the case the concrete sudden fail as often verified in building collapse.

CONCLUSION

This research tried to provide an understanding of the effect of coconut and polypropylene fibre on the fire resistance property of concrete. Based on laboratory test results obtained, it can be easily concluded that the presences of either of the two types of fibres increases the compressive strength of concrete especially at the lower temperatures up to 400^0C, with greater increase in the coconut fibre samples than polypropylene sample. The percentage increase in the compressive strength of the concrete samples show that the coconut fibres produce a higher strength increase over the polypropylene fibres. The addition of both fibres did not just increase the compressive strength, but test results have proven that they also increase the fire resistance property of the concrete. Coconut fibres can therefore not only improve strength for concrete but also improve the fire resistance of concrete more than polypropylene fibres. The presence of coconut fibre confers greater ductility on concrete as it prevents fragile collapse. In light of the results obtained, these fibres are recommended because of their good influence in improving the compressive strength of concrete even at elevated temperatures. More research are needed for improved fire resistance properties of fibre reinforced concrete because of the importance and seriousness of protecting lives and properties.

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