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Thermo-Physical Properties of Concrete Containing Sisal Fibre after High Temperature Effect

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ABSTRACT
The behavior of concrete structures under thermal stresses is of significant importance to energy consumption of buildings. This study aims to investigate the thermal properties of concrete made from 0.64 water/cement ratio, 0%, 0.5%, 1.5% and 3% by weight of cement replacement with Sisal fibre (SF) and then subjected to elevated temperatures so as to establish a correlation between thermal conductivity and thermal diffusivity with thermal comfort of Sisal fibre (SF) made concrete. The results show that at 900°C, SF-1.5 and SF-3.0 had the lowest thermal diffusivity value of 0.24mm/s among all series. It is concluded that the incorporation of Sisal Fibre improves the thermo-physical properties of concrete at high temperature. Sisal fibre can be used to delay heat transmission in concrete elements in case of fire, since it has the ability to increase specific heat as well as reducing thermal conductivity and thermal diffusivity in concrete

INTRODUCTION
Assessing and controlling the thermo-physical properties of concrete such as thermal conductivity, thermal diffusivity and heat capacity is required in delivering comfort to building occupants. The accurate assessment of the thermal conductivity of concrete is an important part of building design in terms of thermal efficiency and thermal performance of materials at various temperatures Yun (2014). Also, Buildings are responsible for a third of the total energy consumption and emit 30% of greenhouse gases (GHGs) in the atmosphere (Zhang et al, 2004). The energy needed for heating and cooling of structure or to provide thermal tranquility almost depend on the thermal properties of the materials used in constructing a building De-Giuli, (2012). The thermo-physical properties of construction material play a significant role in achieving the energy required for heating and cooling. By understanding mode of heat transfer in concrete, various methods can be employed to regulate heat in buildings. Conduction heat transfer in concrete occurs through vibrations

of the molecules and energy transport by free electrons (Bhattacharjee and Krishnamoorthy, 2004). Thermal conductivity values indicates how much heat energy transfer a material permits while Thermal diffusivity indicates the speed of heat transfer through concrete in transient heat transfer conditions.

Concrete is a widely used construction material around the world, so much so that annual production is about 5.0 billion cubic yards; the concrete used amount is almost double of all other construction industrial materials. The main detail mix proportions of concrete with the water-cement ratio plays an important factor that have an effect on the strength of concrete (Talebi et al, 2020). Concrete is a mix of cement, water, coarse aggregate, fine aggregate and admixture in some cases. Changes in each component will change the thermal properties of concrete, around 60% of the concrete volume consists of aggregate (Chan, 2014). Asadi et al. (2018) reported that the thermal conductivity for different types of concrete was between 2.24 to 3.85 (W/m.K). Using lightweight aggregates as a replacement for normal weight aggregates of concrete reduce the thermal conductivity significantly. By introducing surrogate aggregate Yun et al (2014) were able to achieve a thermal conductivity value of 1.25W/m.K. Howlader et al (2012) reported that specific heat capacity of concrete containing burnt clay brick-chips as aggregate is 13% greater than the concrete having stone-chips, furthermore, the achieved results show that the thermal diffusivity of concrete with burnt clay brick-chips was 19% lower than stone-chips concrete. Utilizing cementitious material as cement replacement can also change the thermal properties of concrete. Wongkeo et al (2012) reported that replacement cement by bottom ash (BA) up to 30% can increase the k-value of autoclaved concrete around 5%. The concrete with thermal properties such as low thermal conductivity, low thermal diffusivity, and high specific heat capacity is desirable for use as insulation in buildings construction

Sisal Fibre

Sisal fibre is fairly coarse and flexible. It is valued for use because of its better strength properties, durability, ability to stretch, affinity for certain dyestuffs, resistance to deterioration in saltwater, easy availability, light weight, high toughness, non-corrosive nature, low density, low cost, good thermal properties, reduced tool wear, less dermal and respiratory irritation, less abrasion to processing equipment and renewability. Sisal is being used in composites instead of fibreglass to reinforce components in the automotive and aircraft industry. Sisal is also being used in the construction industry as cement reinforcement for low cost housing, as plaster reinforcement and for roofing materials, as well as insulation due to its low thermal conductivity coefficient (0.07 W/mK) and would provide a decrease in concrete's thermal conductivity in case of fire. Despite the availability of literature on SF used as thermal insulation and as cladding material, there is no information on the performance of SF made concrete subjected to high temperatures. This study aims at assessing the thermal conductivity and Diffusivity of SF made concrete at elevated temperatures with the goal of providing information for low cost solutions to thermal comfort in buildings. Therefore the objectives of this study will focus on determining the heat capacity, thermal conductivity coefficients and thermal diffusivity of all specimens. These objectives will be carried out at a temperature range of 25°C-900°C.

MATERIAL AND METHODS

Materials

All the materials used in this study are conventionally available in Jos, Plateau State, Nigeria.

Sisal Fibre

The vegetable sisal fibres were obtained, in the form of bundles and were cut into 25mm length to be dispersed randomly in the concrete. The fibres were washed to remove dust from their Surfaces. Table 1 shows the properties of sisal fibre.

TABLE 1: Properties of Sisal Fibre.

Density	Aspect	Porosity	Moisture Absorption	Length	Melting
g/cm^3	%	%	%	mm	°C
1.42	100	17	100	25	180-200

Cement

Ordinary Portland cement (42.5R grade, 3X) manufactured by Dangote Cement Company Plc was used in all mixes throughout this investigation. The use of ordinary Portland cement was in compliance with the limits of the British Standard BS 12:1996.

Aggregates

The coarse and fine aggregates used were of crushed granite and Natural River sand of zone C grading, complying with BS 882:1992. Their sieve analysis plots are shown in Fig. 1.

Design of Experiment

A total of four NSC mixes were prepared with Ordinary Portland Cement, two types of aggregates (coarse aggregates and fine aggregates) were used and sisal fibres varied at mixing ratios of 0%, 0.5%, 1.5% and 3.0% by weight of cement was incorporated. The mix proportion of the concrete was designed to satisfy compressive strength of 20N/mm at water/cement ratio of 64%. For each mixture, 150mm cubic and Φ100/200mm cylindrical specimens were cast, immersed in water for 28 days and air-dried for 35 days before the high temperature effect at the age of 63 days. The concrete specimens were tested in the furnaces of the Refractory Laboratory, National Metallurgical Development Centre Jos, For 600 °C and 900 °C for two hours at the target temperatures. The concrete cubes of 150mm were used to determine the mass (density) loss and the specific heat and thermal conductivity determined using concrete cylinders of ø100/40mm obtained from the Φ100/200mm cylindrical specimens. The experimental details of this study are shown in Table 2.

Table 2: Experimental Details

Parameters			Properties Measured	
W/C	Sisal Fibre (% by wt of Cement)	Concrete Codes	Fresh Concrete	Hardened Concrete
0.64	0	N	*Slump	* Fire resistance test
	0.5	SF-0.5		* Mass Loss
	1.5	SF-1.5		* Specific Heat
	3.0	SF-3.0		* Thermal Conductivity
				*Thermal Diffusivity

Concrete Mix Proportioning

A total of four concrete mixtures were prepared. The Normal Strength Concrete (NSC) specimens mix is designed in accordance with D.O.E method (Design of Environment) to have a 28 day compressive strength of 20N/mm. The other mixtures are made with addition of sisal fibres at 0.5%, 1.5% and 3.0% by weight of cement and concrete series coded according to the additives and their amount in concrete as follows; (a) plain concrete, i.e. 0% sisal fibre coded as N, (b) concrete with 0.5% SF coded as SF-0.5, (c) concrete with 1.5% SF coded as SF-1.5, (d) concrete with 3.0% SF coded as SF-3.0. The amount of water was adjusted in SF mixes in order to maintain a slump value of 30+5mm and this was accomplished by taking the water absorption of SF into account. The concrete mix proportions and their relative slump values are presented in Table 3.

Table 3: Concrete Mix Proportions and Their Related Slump Values

Mixture code	Cement ($Kg/^3$)	Water ($Kg/^3$)	FA ($Kg/^3$)	CA ($Kg/^3$)	SF ($Kg/^3$)	SLUMP (mm)
N	330	210	865	935	-	30
SF-0.5	330	210	865	935	1.65	35
SF-1.5	330	210	865	935	4.95	35
SF-3.0	330	210	865	935	9.90	33

Preparation and Casting of Specimens

The preparation of the concrete specimens was in accordance with B.S 1881: Part 116 (1983). The materials for all specimens were hand mixed. For the control specimen (N), the aggregates were first mixed in the dry state followed by the addition of the mixing water. In the case of SF mixes, fibres were added to the aggregates in the dry state and mixed thoroughly followed by gradual addition of mixing water. The freshly mixed concrete was tested for slump prior to casting of specimens. The fresh concrete was then transferred with a scoop and compacted with a steel tamping rod in three layers into clean and properly oiled 150mm cube and Φ100/200mm cylinder moulds. After the top layer had been compacted, they were leveled to the top of the mould with steel float. The specimens were allowed to remain in the mould for the first 24 hrs at ambient conditions, then they were demoulded and cured by immersion in a water tank kept at 24 ± 2°C for a duration of 28 days. After 28 days curing, the specimens were brought out of water and allowed to air-dry in the laboratory for 35 days before exposing to high temperature effects.

Testing Instrumentation, Methods and Procedures

Workability Retention (Slump)

Standard slump test equipment was used and included a slump cone, a steel rod, a measuring meter and a steel platform (see Plate 1, Appendix I). The slump test was carried out in accordance with BS 1881: part 102: 1983. During the workability retention study, the slump of fresh concrete for each series was measured and the values are presented in Table 3.

Heating and Cooling Regime

The fire resistance test was performed using a Gas-fired Furnace at the National Metallurgical Development Centre (NMDC), Jos, Plateau State, Nigeria. The furnace is built with thermal clay bricks on the inside and the outside covered with aluminum sheeting. It has a vent in the roof and an aperture in the side where a pyrometer can be inserted to read the temperature on the thermocouple. The furnace has the capacity to attain maximum temperatures of 1500°C. At the end of curing and air-drying days, the specimens were heated to a range of elevated temperatures of 300, 600 and 900°C in the furnace at the age of 63 days. The heating rate was 7.5°C/min. All specimens were kept for 2 hours at the target temperature to achieve a thermally steady state and then allowed to cool naturally to room temperature in the furnace. Variation in mass of concrete specimens as a funvtion of Temperature is given in Fig. 1.

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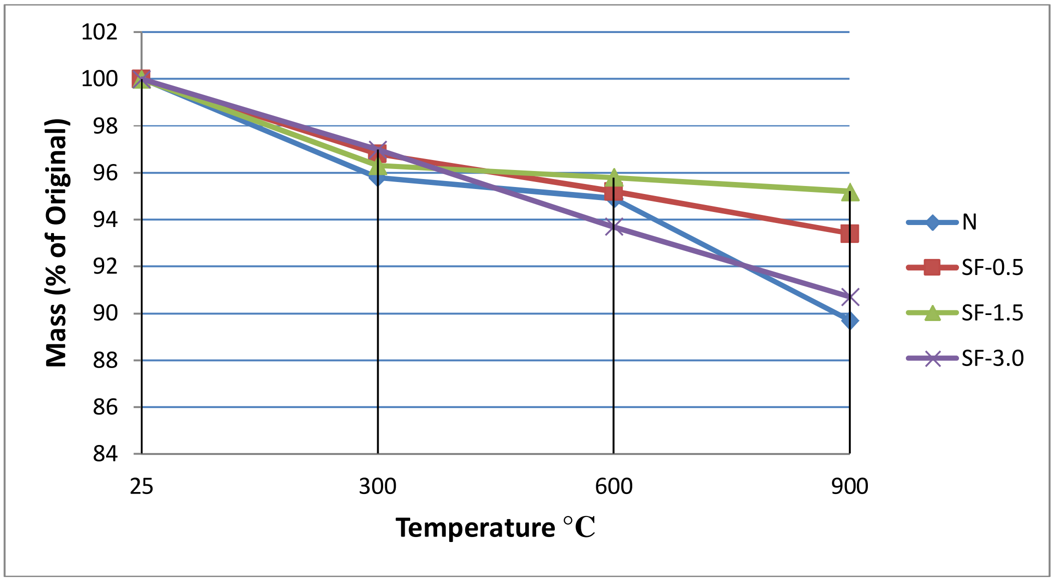

FIG. 1: Variation in Mass of Concrete Specimens as a Function of Temperature

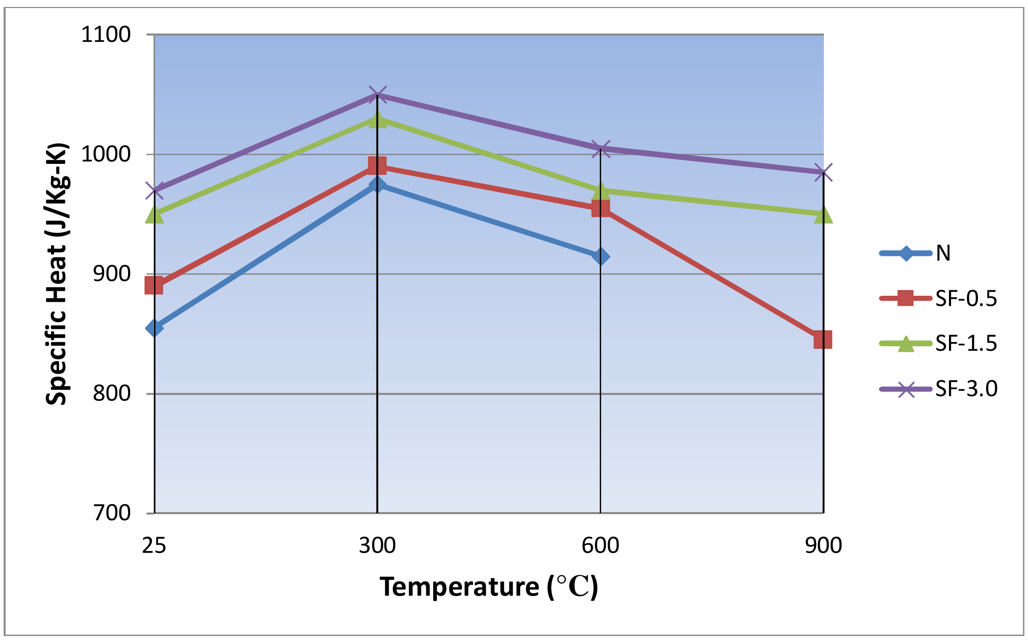

FIG. 2: Effect of Temperature on Specific Heat of NSC with SF

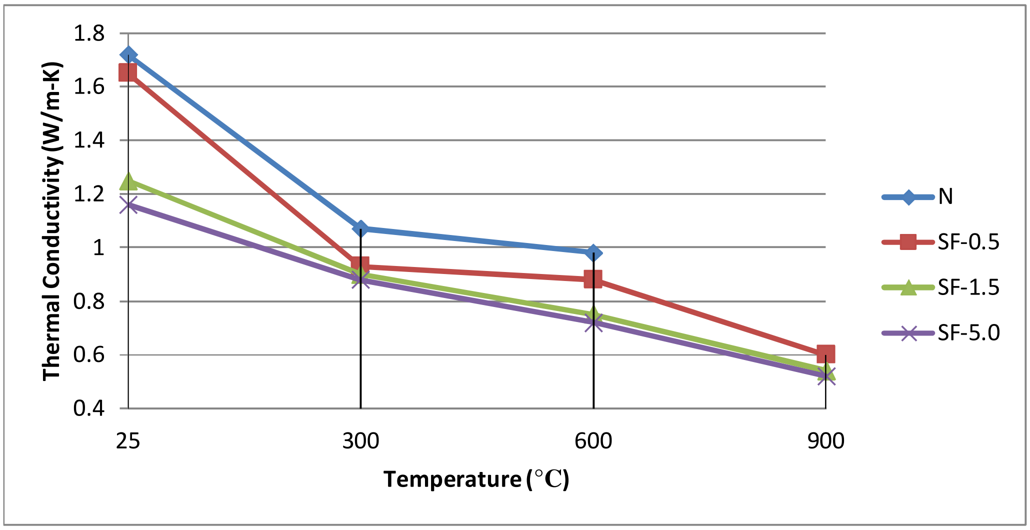

FIG. 3: Effect of Temperature on Thermal Conductivity of NSC with SF

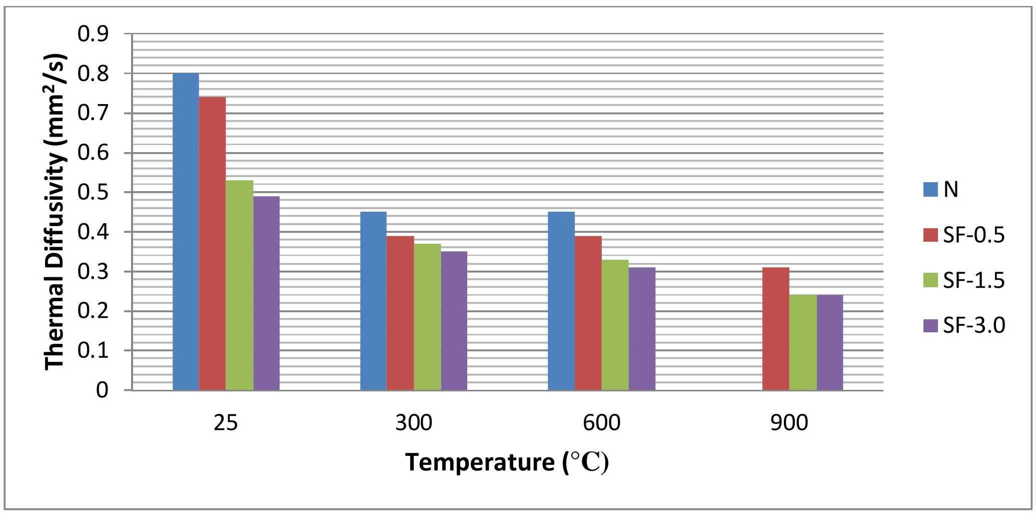

FIG. 4: Effect of Temperature on Thermal Diffusivity of NSC with SF

Specific Heat (Volumetric Heat) Testing

The specific heat was determined by method of mixtures in accordance with ASTM, C 351-92b (1999). The experimental set-up consist of an electric oven, a pyrometer, a lagged copper calorimeter with an insulated cover in which are openings for thermometer and stirrer, thermometer, stop clock and a balance. The materials of which the specific heat was to be determined were crushed into test specimens of $25cm^3$ ($\pm 5cm^3$) in volume due to limitation in size of the calorimeter. To determine the specific heat, a specimen of measured mass was kept in an oven, having an internal temperature of 200 ± 5°C, for 30 mins to absorb heat. The heated specimen was quickly transferred into measured water mass contained in a lagged calorimeter at low temperature and stirred continuously until maximum temperature is attained by water and calorimeter. The specific heat was then calculated from equation (1) below;

$$\boldsymbol{Cs} = \frac{(\boldsymbol{MwCw} + \boldsymbol{McCc})(\boldsymbol{\theta s} - \boldsymbol{\theta w})}{\boldsymbol{Ms}(\boldsymbol{\theta h} - \boldsymbol{\theta s})} \qquad (\mathbf{1})$$

Where: Cs is the specific heat of specimen; Mw and Mc is the mass of water and copper calorimeter respectively; Ms is the measured mass of specimen; Cw is the specific hcat ol water, Cc is the specilie heat of copper calorimeter: θh is the temperature of the oven; θs is the maximum temperature of specimen; and θw is the temperature of water and lagged calorimeter. Results of specific heat are shown in Fig. 2.

Thermal Conductivity Testing

The thermal conductivity was measured by means of steady state method according to standard ASTM E1530, (2011). In this test, ø100/200mm cylindrical specimens were cut in the Section Laboratory of the Department of Geology and Mining, University of Jos, using a rock cutting machine in order to obtain Φ100/40mm cylindrical specimens for the test. The thermal conductivity test was carried out using the Lee's Disc method consisting of a steam chest and a brass slab suspended by means of strings. The experimental set-up involves a steam flask from which steam is generated. The test specimen was placed between the steam chest and brass slab. The steam chest was heated by steam passed into it and this heat was transferred to the bottom brass slab through the test specimen by mode of conduction. The temperatures of the top (θ_1) and bottom (θ_2) slabs were obtained, when steady state had been reached, with thermometers inserted into the holes drilled in the slabs. The test duration for all series was 30 minutes. Thereafter, the rate of cooling was determined by removing the steam chest leaving the specimen on the bottom brass slab and warming the bottom surface of the bottom slab to about 10°C above θ_2. The thermal conductivity was then determined according to equation (2);

$$\lambda = \frac{\boldsymbol{MCd}}{\boldsymbol{A\Delta\theta}} . \left(\frac{\boldsymbol{\delta\theta}}{\boldsymbol{\delta t}}\right)\boldsymbol{\theta_2} \qquad (2)$$

where λ Is thermal conductivity. M is mass of the specimen, C is the specific heat of the specimen. A is the specimen area, Δθ is the temperature change between θ_1 and θ_2 and $(\frac{\delta\theta}{\delta t})$ is the rate of cooling determined at θ_2. Results of thermal conductivity of specimens are shown on Fig. 3.

Thermal Diffusivity Testing

The thermal diffusivity of a material is defined as the ratio of thermal conductivity to the volumetric specific heat of the material. It measures the rate of heat transfer from an exposed surface of a material to inner layers. Thermal diffusivity was determined using the relation in (3).

$$\alpha = \frac{\lambda}{pC} \qquad (3)$$

Where: α is the thermal diffusivity, λ is the thermal conductivity, p is the density, and C is the specific heat of the specimen.
Results of thermal diffusivity are shown on Fig. 4.

RESULTS AND DISCUSSION

Specific Heat Test

The specific heat of concrete at room temperature varies in the range of 840 J/Kg.K and 1800 J/kg.K for different aggregate types (V.R. Kodur, 2014). The specific heat property is sensitive to various physical and chemical transformations that take place in concrete at elevated temperatures. This includes the vaporization of free water at about 100°C, the dissociation of Ca(OH) into CaO and H2o between 400-500°C, and the quartz transformation of some aggregates above 600°C. The measured specific heat of all series of test specimen is shown in Fig. 2 as a function or temperature. Specific heat of all the series, at room temperature, ranged between 855 and 970J/Kg-K. It can be seen from the figure that concrete series containing SF possessed higher values than the reference concrete (N). This may be due to high specific heat of the cellulose fibre (SF). At 300°C, the specific heat of the N series and SF series increased by about 14% and 8% respectively, with respect to their initial values at room temperature, as the temperature increased in concrete at high temperatures.

Thermal Conductivity Test

The measured thermal conductivity of all series is shown in Fig. 3 as a function of temperature of the result showed that thermal conductivity values for all series at room temperatures ranged between 1.72 and 1.16W/m-K. As shown in Fig. 3, the thermal conductivity of all series decreased with increase in temperature. Concrete series containing SF had lower values due to the very low thermal conductivity value (0.07W/m-K) of SF. The thermal conductivity of N, SF-0.5, SF-1.5 and SF-3.0 decreased by 38%, 44%, 28% and 24% respectively, as the temperature increased to 300°C. At 600°C, there was a slight decrease in thermal conductivity of N series and an insignificant change in SF-0.5 series. There were no significant difference between the values of SF-l.5 and SF-3.0. As the temperature reached 900°C, SF-3.0 had the lowest value with 0.52W/m-K and 0.54W/m-K for SF-1.5. This decreasing trend in thermal conductivity can be attributed to variation of moisture content, insulating property of sisal fibre and permeability since fibres generate micro pores in the concrete with increase in temperature.

Thermal Diffusivity Test

Fig. 4 shows the effect of sisal fibre (SF) on thermal diffusivity of conventional NSC at room temperature. The result showed that concrete containing SF had lower thermal diffusively. As the weight fraction of SF increased, the thermal diffusivity of concrete series decreased. The thermal diffusivity of all concrete series at elevated temperature is presented in Fig. 4. As the temperature reached 300°C, the decrease in thermal diffusivity ranged between 47% and 24% in all series considering their initial thermal diffusivity. Until 600°C, there was no significant change in thermal diffusivity of N and SF-0.5 series, while a further decrease of 11% was recorded for SF-1.5 and SF-3.0. At 900°C, SF-1.5 and SF-3.0 had the lowest value with 0.24mm/s among all series.

CONCLUSION

The aim of this study was to investigate the thermal properties of concrete made from 0.64 water/cement ratio, 0%, 0.5%, 1.5% and 3% by weight of cement replacement with Sisal fibre (SF) and then subjected to elevated temperatures so as to establish a correlation between specific heat, thermal conductivity and thermal diffusivity with thermal comfort of Sisal fibre (SF) made concrete. Based on findings of the experimental studies of the applicability of sisal fibre in normal strength concrete, the following conclusions were made.

Specific Heat

1) Concrete series containing Sisal fibre possesses higher specific heat capacity than the reference concrete at room temperature. This may be due to high specific heat of cellulose fibre (sisal).
2) As the temperature reaches 300°C, the specific heat increases by 14% in the reference concrete and 8% ın the concrete containing sisal fibre.
3) The specific heat starts dropping as the heating temperature reaches 600°C and decreases further as the temperature reaches 900°C.
4) At 900'C, the specific heat in concrete containing sisal fibre ranged between 845J/Kg-K and 985J/Kg-K in the order of increasing fraction of sisal fibre in the concrete.

Thermal Conductivity

1) Increase in fraction of sisal fibre in concrete leads to a corresponding decrease in thermal conductivity of concrete. This is due' to lower thermal conductivity of sisal fibre (0.07W/m-K). The thermal conductivity decreased from 1.72W/m-K to 1.16W/m-K.
2) Thermal conductivity of all specimens decreases with increasing temperature. At 900°C, concrete specimen SF-3.0 had the lowest value of 0.52W/m-K. The decrease in thermal conductivity can be attributed to variation of moisture content, insulating property of sisal fibre and permeability since fibre generate micro pores in the concrete with increase in temperature.

Thermal Diffusivity

1) Thermal diffusivity of concrete decreases with increasing weight fraction of sisal fibre.
2) Also, thermal diffusivity decreases with increasing exposure temperature.
3) In the research, concrete containing sisal fibre and fired at 900°Cgives the lowest value of 0.24mm/s.

Therefore all series containing sisal fibre showed higher values of specific heat at all exposure temperatures compared to the plain concrete, since Sisal fibre has high specific heat capacity. Due to low thermal conductivity of sisal fibre, all series containing Sisal fibre showed lower thermal conductivity values at all temperatures. Also Sisal fibre decreases the thermal diffusivity of concrete at all temperatures as concrete series containing sisal fibre showed lower values. In conclusion, the incorporation of Sisal Fibre improves the thermo-physical properties of concrete, thus, increasing thermal comfort as well as fire resistance property due to its ability to decrease thermal conductivity and thermal diffusivity. It is the recommendation of this study that Sisal fibre can be used to delay heat transmission in concrete elements in case of high temperatures, since it has the ability to increase specific heat as well as reducing thermal conductivity and thermal diffusivity in concrete. Therefore, the concrete can be used in wall, slabs and staircase (means of escape). It can also be used as an insulating material in underground structures such as tunnels and basements, thus helping to reduce casualties.

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