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PHYSICAL AND THERMAL PROPERTIES OF RICE HUSK ASH BLENDED HIGH STRENGTH CONCRETE AT ELEVATED TEMPERATURE

Professor Olorunmeye Fredrick Job[1], Miriam Pam[2] and Amma Awari Ishaya[3]

[1,3] Department of Building, University of Jos, Nigeria.

[2]Graduate Student,Department of Building, University of Jos, Nigeria.

Abstract— High temperature is one of the most detrimental effects that cause important changes in concrete's physical, thermal and mechanical properties. Despite numerous advantages accrued to High Strength Concrete (HSC), it may experience damages such as cracks and spallings as in the case of Normal Strength Concrete (NSC). The addition of pozzolan such as Rice Husk Ash (RHA) as partial replacement of cement in concrete is a well known method for improving the strength and durability of NSCs because of the interface reinforcement. In this study, RHA as a partial replacement material in HSC at high temperature to prevent spallings and improve thermal and physical properties were investigated. The Ordinary Portland cement (OPC) was partially replaced by 0%, 5%, 10%, 15%, and 20% to produce grade 50N/mm^2 concrete cube and disc samples. Concrete was first made without supplementary cementitious material, which served as the control, concrete. The cubes and disc were cured for 28, 56 and 90 days and the hardened concrete was thermally treated at 25^{0}C (control), 200^{0}C, 400^{0}C, 600^{0}C and 1000^{0}C for 2hours. The physical properties, such as cracks/ spalling, weight, and thermal properties such as thermal conductivity, specific heat and thermal diffusivity and mass loss were conducted on the hardened samples and compared with the control. The results showed that the addition of 5% RHA in OPC led to improvement in physical and thermal properties of the concrete when exposed to elevated temperature up to 400^{0}C.

Keywords— High strength concrete, pozzolan, elevated temperature, diffusivity, rice husk ash

I. INTRODUCTION

The soaring cost of building materials and indeed concrete in Nigeria has led to an urgent and necessary need to develop alternative and cheaper options to the ordinary concrete. Concrete is a material often used for the construction of many different structures such as dams, pavements, bridges, high rise buildings and in case of unexpected fire, the concrete properties changes after fire. It is therefore necessary to understand the changes in the properties of concrete due to extreme temperature exposures.

High temperature is one of the most harmful effects that cause durability problems in constructions. This effect can cause permanent damages in constructions, reduce the service life and may cause causalities, thus affecting the construction's sustainability [1]. Concrete is well known for its capacity to endure high temperatures and fires owing to its low thermal conductivity and high specific heat [2]. However, it does mean that the fire as well as the high temperatures does not affect the concrete. High strength concrete may exhibit damages such as cracks and spallings when exposed to high temperatures [3].

During exposure to high temperatures such as fire, important changes may occur in its mechanical, physical and thermal properties according to [4]. These suggest that failure of the elements could be multidimensional as observed by [4]. In addition, elevated temperature reduces the strength of concretes and the degree of strength-loss is dependent on the temperature reached and the exposure duration [5] and [6]. Other factors that influence the strength loss according to [7] are aggregate types and the strength of the concrete at room temperature

High Strength Concrete (HSC) according to Kodur [8] provides a high level of structural performance, especially in strength and durability, as compared to Normal Strength Concrete (NSC).

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As such, Bui [9] defined high strength concrete as that concrete designed to give optimized performance characteristics for a given set of load, usage, and exposure conditions consistent with the requirement cost, service life and durability.

Concrete containing mineral admixtures is used extensively throughout the world for their good performance and for ecological and economic reason. Some of the common cementitious materials that are used as concrete constituents, besides Portland cement are silica fume, fly ash, ground granulated blast furnace slag and rice husk ash. They save energy, conserve resources and have many technical benefits [2]. Rice husk ash is a recent addition in the list of pozzolanic materials.

Ramezanianpour, Mahdi & Ahmadibeni [10] opined that one of the most suitable sources of pozzolanic material among agricultural waste components is rice husk, as it is available in large quantities and contains a relatively large amount of silica. Chukwudebelu, Igwe & Madukasi [11] indicated that rice is an increasing important crop in Nigeria and relatively easy to produce and grown for sale and for home consumption. . Rice husk is an agricultural remainder derived from the external covering of rice grains during milling procedure. It comprises 20% of the 500 million tons of paddy generated in the world [12]. When rice husk is burnt, about 20% by weight of the husk is recovered as ash in which more than 75% by weight is silica. Unlike natural pozzolan, the ash is an annually renewable source of silica.

Rice husk ash is one of the promising pozzolanic materials that can be blended with Portland cement for the production of durable concrete and at the same time a value added product. Binary blending of Portland cement with rice husk ash does not only improve the early strength of concrete, but also forms a calcium silicate hydrate (CSH) gel around the cement particles which is highly dense and less porous, and may increase the strength of concrete against cracking [13]. Also, addition of rice husk ash (RHA) speeds up setting time, although compared to OPC the water requirement is higher, it has improved compressive strength due to its higher percentage of silica and improved resistance to acid attack compared to OPC which is said to be due to the silica present in the RHA which combines with the calcium hydroxide and reduces the amount susceptible to acid attack [14]. RHA can also replace silica fume in high strength concrete as further described by [14] and silica fume or micro silica is the most commonly used mineral admixture in high strength concrete although the major characteristics of RHA are its high water demand and coarseness compared with condensed silica fume.

Koksal, Gencel, Brostow & Hagg [15] used four different composite mixtures with varying amount of expanded vermiculite exposed to high temperatures of 300, 600, 900 and 1100^{o}C for 6hrs, the physical and mechanical properties including unit weight, porosity, water absorption, residual compressive strength, residual splitting tensile strength and also ultrasonic pulse velocity were determined after air cooling, micro-structures were investigated by scanning through electron microscopy and disclosed that light-weight concrete with vermiculite shows a good performance at elevated temperatures.

Thermal conductivity is the property of a material to conduct heat. Concrete contains moisture in different forms, and the type and the amount of moisture have a significant influence on thermal conductivity [16]. Thermal conductivity is usually measured by means of steady state or transient test methods. The thermal conductivity of a material is not always constant and the main factors that affect the thermal conductivity are the density of material, moisture of material and ambient temperature. With increasing density, moisture and temperature the thermal conductivity increases too [16]. A study by Nimlat & Datok [17] indicated that thermal conductivity of the 0% OPC replacement is 1.77 W/m^{o}C while the thermal conductivity for the 10% saw dust ash (SDA)/OPC replacement is 1.68W/m^{o}C which shows that the thermal conductivity of the blended cement concrete is a little lower than that for the control concrete. The saw dust ash (SDA) in the concrete reduced its conductivity thereby making it a lesser conductor of heat than the concrete made from 100% ordinary Portland cement (OPC). Saw dust ash (SDA) content, therefore, had only a slight influence on thermal conductivity of the concrete [17].

Extensive studies have been carried out and have indicated that the RHA can be beneficially utilized; however, the contribution of this material at high temperatures for higher strength grades of concrete is limited. This study is therefore premised on determining the physical and thermal properties of high strength rice husk ash blended concrete at elevated temperatures.

II. MATERIALS AND METHODS

2.1 Materials

The materials used for the concrete production include; Nigerian brand of Ordinary Portland Limestone Cement (CEM 1 42.5R) which was produced from Obajana cement plant in Kogi State, Nigeria. This brand of cement conforms to [18]. The Rice Husk used was sourced from Lafiya, Nasarawa State and burnt into ashes at a temperature of 650^{o}C using a kiln at the ceramic firing section, Department of Industrial design, School of Environmental Technology Abubakar Tafawa Balewa University Bauchi, Laboratory tests such as sieve and chemical analysis were carried out at the National Metallurgical Development Centre (NMDC) Jos, Plateau State to ascertain the general specifications of the ash. The super-plasticizer was BETOCRETE-FN which was based on a blend of synthetic polymer, organic substances and other additives to improve its performance. Two types of aggregates, coarse aggregates with maximum size of 20mm, and natural river sand with maximum size of 5mm as well as water were all sourced and used in accordance with the relevant specifications.

The physical properties of aggregates and rice husk ash used are presented in Tables 1 and 2. The chemical composition of the pozzolan and cement are also given in Tables 3 and 4 respectively.

2.2 Methods

2.2.1 Concrete Mix Proportions and Curing

Batching by weight was adopted due to relative closeness in specific gravities of the aggregates. HSC of 50N/mm^2 grade of was designed. Concrete mix proportions were determined for 1m^3 according to [19] while mix proportions are presented in Table 5. The proportions of RHA were 0% (Control), 5%, 10%, 15%, and 20% by weight of cement. The adopted replacement levels were based on previous similar works carried out by [20]. Cubes were cast in 100 x 100 x100 mm while the discs were cast in 100mm diameter x 25mm thick moulds and were vibrated for 5 seconds on a vibrating table. All cubes and discs were de-moulded after 24 hours and then cured in water for a period of 28, 56 and 90 days. Hardened samples were then exposed to high temperatures of 23^{o}C, 400^{o}C, 600^{o}C, 800^{o}C and 1000^{o}C for two to four hours to achieve a steady thermal state. Physical properties such as weight, density, and colour change as well as thermal conductivity and the water absorption rate of the sampled concrete cubes and discs were determined.

2.2.2 Consistency and Setting Time Tests

The consistency and setting times (initial and final) of cement paste for this research were measured using the vicat apparatus in accordance with [21] for all the samples. The results are presented in Table 6.

2.2.3 Workability Test

Slump test is an empirical test that measures the workability of fresh concrete. The test was conducted in accordance to [22] on the fresh concrete and the results presented in Table 7.

2.2.4 Spalling, Cracks and Colour Change Observations

The changes in colour, spalling and cracks on the samples were observed for both heated and unheated samples. At each temperature scale the colour of the samples were observed and recorded accordingly and results presented in Table 8.

2.2.5 Mass Loss

Mass loss of the samples was measured by subtracting the final weight from the initial weight of the samples. This was done in accordance to [23]. The results of the 0% and 5% RHA replacement are presented in Figs. 1-2. Mass loss was measured in kg and calculated using the formula

$$Mass\ Loss = Initial\ weight\ (w_1) - Final\ weight\ (w_2)$$

2.2.6 Thermal Conductivity Test

Thermal conductivity (K) measures the ability of the material to conduct heat. The samples were prepared for thermal conductivity test in accordance with the provisions of [24]. Thermal equilibrium was reached when temperature and voltage readings were steady. Thermal conductivity was determined using [24] equation.

$$Q = K * A * \frac{\Delta T}{d}$$

Where: Q is the quantity of heat required, K is the thermal conductivity coefficient of the material; A is the area of the material, ΔT is the increase in temperature and d is the thickness of the material. The results are presented in Figs 3-4.

2.2.7 Specific Heat Capacity

The specific heat capacity (C) of the heated sample concrete was determined in accordance to [23]. Specific heat capacity (C) was measured in J/Kg^{o}C using the formula:

$$C = \frac{Q}{M\Delta T}$$

Where C is specific heat capacity, Q is the quantity of heat required, M is the mass of the sample and ΔT is the temperature change in the sample. The results are presented in Figures 5 and 6.

2.2.8 Thermal Diffusivity

Thermal diffusivity (δ) of the concrete sample discs was determined in accordance to [23] and the results shown in Figs 7 and 8. The ratio of thermal conductivity to density and specific heat as denoted by was used for the computation.

$$\delta = \frac{K}{C\gamma}$$

Where δ is the thermal diffusivity, K is thermal conductivity, C is the specific heat of the material and γ is the density of concrete. Thermal diffusivity is measured in m^2/s.

III. RESULTS AND DISCUSSION

3.1 Physical and Chemical Properties of RHA

From Table 2, the RHA has a specific gravity of 2.13 and high fineness with about 86.5% passing through 75µm sieve. Khan, *et al* [25] stated that the high fineness of RHA, contributes to the hardened properties of concrete or mortar by filling or densification of the microstructure.

The chemical properties obtained differ from other researches. This confirmed the assertion of [26]. Chemical properties of rice husk ash vary from one region to another due to the condition under which rice is grown such as; climate, soil, paddy (rice) variety and use of fertilizers. The RHA used contains high silica compound of 80.30%. The total percentage of major oxide ($SiO_2 + Al_2O_3 + Fe_2O_3$) was observed to be 81.353%, which exceeds 70%, specified in [27] for class F pozzolan. The lower loss on ignition values of RHA indicates less amount of carbon content. Therefore, the presence of mainly reactive silica compound, large specific surface area and higher fineness of RHA makes it suitable for use as partial replacement of cement as indicated by [25].

3.2 Consistency and Setting Time Tests

Standard consistency increased with increase in partial replacement of RHA. This implies that more water is required as RHA increased, which further indicates that RHA has no adverse effect on OPC. The consistency for partial replacement were between 28 – 29.5% which are less than 30-35% as stipulated in [28] and [29].

Similarly, the setting time increased with increase in RHA content. The initial setting times were all greater than 30 minutes and the final setting time where not more than 305 minutes. This is in agreement with findings of [30]. This implies that partial replacement up to 20% of RHA in concrete was satisfactory. ASTM C191 [31] limits of not less than 45 minutes initial setting time and not more than 10 hours final setting time for OPC were achieved.

3.3 Workability Test

Table 7 gives the result of the slump as well as the compacting factor of the concrete used. The higher the replacement of cement by ash, the water demand increases and therefore for given water cement ratio and cement content, the workability reduces as justified by [32]. From this study it was found that the silica-lime reaction requires more water in addition to water required during hydration of cement as opined by [33] and as such, for every increase in replacement of cement by the ash, the water content was also increased to increase the workability.

3.4 Spalling/Cracks and Colour Change

At 400^{o}C – 600^{o}C, samples with 0% - 15% OPC replacement showed visible cracks on the surface but between 800^{o}C – 1000^{o}C, the cracks were deeper thereby resulting into aggregate and surface spalling. For samples with up to 15% – 20% OPC replacement, a form of sloughing-off spalling occurred as shown in Table 8. This indicates that a given concrete's propensity for spalling depends not only on its material parameters (e.g. concrete mix composition, the nature of the mix constituents and their specific material properties), but also on the compactness of the concrete, the rate of heating, the moisture content, and the degree of temperature at which it was exposed to as described by [34].

At 400^{o}C, all the samples retained their grey colour and at 600^{o}C the colour was observed to change slightly to dust colour (brownish grey) but at 800^{o}C – 1000^{o}C the colour changed to whitish brown for control concrete while the samples with higher content of RHA, the colour changed to brown. Increasing temperatures causes a vapour pressure build up within the concrete. In high strength concrete, spalling is a major problem due to its very low porosity [35]. These colour changes of heated concrete samples results principally from the gradual water removal and dehydration of the cement paste, but also transformations occurring within the aggregate. The most intense colour change was observed for the siliceous oxides present in the RHA thereby agreeing with [36].

3.5 Mass Loss

The mass loss from all concrete mixes increased with the increase in the maximum exposed temperatures and the increase in durations of exposures due to reduction in moisture content and water cement ratio thereby causing accelerated drying. Up to the temperature of 1000°C, concrete cubes lost between 4% and 10% due to the increased density of the concrete grade agreeing with [37] that mass loss varies depending on the density of the concrete and decreases with increasing temperature due to loss of moisture. Also, an increase in the percentage replacement of OPC with RHA results in an increase in the mass loss of the concrete. This was mainly due to the low specific gravity of RHA compared to OPC. The longer the age of concrete, the less weight is lost due to an increase in density gained as the concrete ages and the increased moisture content.

3.6 Thermal Conductivity

For concrete samples with 5% OPC replacement, the thermal conductivity was lower with a value of 1.7 W/Kg^{o}C at 28days and 1.5 W/Kg^{o}C at 56day curing age. This is as a result of the low specific gravity of the RHA compared to OPC and the presence of silica oxides, which decreases the heat of hydration, and reactivity as indicated by [38]. When subjected to various high temperatures such as 400°C, 600°C, 800°C and 1000°C, thermal conductivity increased by 24% - 200% due to the decrease in moisture content, disintegration of the aggregates from the cement paste and presence of cracks and spalling as the temperature increased.

3.7 Specific Heat Capacity

From Figs 5-6, the concrete disc samples showed lesser specific heat capacity at 56day age of curing than 28days due to an increase in density and moisture content. Specific heat capacity is therefore highly dependent on moisture content and considerably increases with higher water to cement ratio as indicated by [37]. Concrete disc samples with 5% OPC replacement also showed a lower specific heat capacity than the control samples due to the low density.

When subjected to high temperatures of 400°C, 600°C, 800°C and 1000°C, the specific heat capacity of concrete disc samples increased as the temperature increases, this is due to a decrease in the moisture content of the concrete and the decrease in density of the concrete when subjected to high temperatures which agrees with [39] that specific heat capacity increases with increase in temperature and decrease in the density of the concrete.

3.8 Thermal Diffusivity

Thermal diffusivity measures the ability of the material to conduct thermal energy relative to its ability to store thermal energy and the rate of transfer of heat from the hot side of the sample to the cold side of the sample. For the concrete disc samples tested, there was a steady increase in thermal diffusivity with increase in temperature. From Figs 7 - 8 the thermal diffusivity ranges between 1.92×10^{-6} m^2/s to 3.95×10^{-6} m^2/s when subjected to 25°C, 400°C, 600°C, 800°C and 1000°C for the control but has values ranging between 1.43×10^{-6} m^2/s to 3.23×10^{-6} m^2/s for 5% OPC replacement at 28 days. This indicates that thermal diffusivity is affected by the moisture content of the concrete, which depends on the original water content of the mix, degree of hydration of cement, and exposure to drying when heated as stated by [39].

This proves that thermal diffusivity reduces with an increase in density and a decrease in specific heat capacity as the curing age increases.

IV. CONCLUSION

This study revealed that the appropriate amount of RHA required to improve the performance of high strength concrete exposed to high temperatures is 5% of the total weight of cement. Standard consistency of the concrete increases with an increase in RHA content thereby reducing workability and increasing the water cement ratio required due to the presence of silica lime reaction.

Physical observation shows an increased level of cracks/spalling as the temperature increases and as the percentage replacement of OPC with RHA content increases, the rate of cracks/spalling also increases but as the age of concrete increases, the rate of cracks/spalling reduces. High strength concrete produced with RHA when used at definite ratios, can prevent spalling, improves the physical property of the concrete subjected to high temperatures in terms of colour and density than the control. High strength concrete blended with RHA reduces specific heat capacity, thermal conductivity, thermal diffusivity and the rate of mass loss of the concrete thereby improving the thermal properties of the concrete at high temperatures. It may be concluded that HSC blended with 5% RHA can be used in construction of structural members to improve the concrete's thermal property against fire outbreaks and consequently increase the durability of the concrete.

Table 1: Physical Properties of Aggregates (Fine and Coarse)

Physical Properties	Fine Aggregate	Coarse Aggregate
Maximum Sieve Size (mm)	4.75	20
Specific Gravity	2.60	2.70
Bulk Density (kg/m^3)	1610	2535
Free Moisture Content (%)	0.18	1.18
Water Absorption (%)	0.29	18.79
Aggregate Impact Value (AIV)	-	14.65
Aggregate Crushing Value (ACV)	-	24.84

Table2: Physical Properties of RHA

Physical properties	**RHA**
Specific gravity	2.15
Fineness passing through 75µm sieve (%)	86.5
Physical state	Solid, non-hazardous
Colour	Grey
Odour	Odourless
Appearance	Very fine powder

Table 3: Chemical Properties of RHA

Composition	**Value (%)**
Sodium Oxide (Na_2O)	1.003
Magnesium Oxide (MgO)	2.01
Silica Oxide (SiO_2)	80.30
Phosphorus Oxides (P_2O_5)	4.76
Sulphur Oxide (SO_3)	0.02
Potassium Oxide (K_2O)	2.03
Calcium Oxide (CaO)	1.04
Titanium Oxide (TiO_2)	0.05
Vanadium Oxide (ViO_5)	0.01
Chromium Oxide (Cr_2O_3)	0.007
Manganese Oxide (MnO)	0.26
Iron Oxide (Fe_2O_3)	1.05
Nickel Oxide (NiO)	0.005
Copper Oxide (CuO)	0.02
Zinc Oxide (ZnO)	0.08
Aluminium Oxide (Al_2O_3)	0.003
Rubidium Oxide (Rb_2O)	0.02
Strontium Oxide (SrO)	0.006
Ziconium Oxide (ZrO_2)	0.01
Bsrium Oxide (BaO)	0.03
Lead Oxide (PbO)	0.02
Loss on Ignation (LOI)	0.15

Table 4: Chemical and Physical Composition of Cement

Composition	**Value (%)**
SiO_2	19.43
Al_2O_3	5.60
CaO	63.01
MgO	2.51
SO_3	2.90
Na_2O	-
K_2O	1.00
Insoluble Material	3.29
Loss of Ignition	3.30
Specific Gravity	3.00
Specific Surface/m^2kg^{-1}	394

Table 5: Summary of Materials needed per m^3 of Concrete

Percentage replacement (%)	**Cement Content (Kg)**	**RHA Content (Kg)**	**Fine Aggregate (Kg)**	**Coarse Aggregate (Kg)**	**Water Content (Kg)**	**Super-Plasticizer (Kg)**
0	0.64	0.00	0.41	1.24	0.25	0.000
5	0.61	0.03	0.41	1.24	0.25	0.003
10	0.58	0.06	0.41	1.24	0.28	0.004
15	0.54	0.54	0.41	1.24	0.30	0.005
20	0.51	0.51	0.41	1.24	0.33	0.006

Table 6: Standard Consistency of OPC and RHA Pastes

Parameter Measured	Percentage replacement of PSA									
	0%		5%		10%		15%		20%	
	OPC	RHA	OPC	RHA	OPC	RHA	OPC	RHA	OPC	RHA
Mass of sample (g)	400	0	380	20	460	40	340	60	320	80
Initial Setting Time (Hrs+ Minutes)	0 + 40		0 + 50		1 + 20		1 + 45		2 + 10	
Final Setting Time (Hrs + Minutes)	2 + 10		2 + 50		3 + 30		4 + 10		5 + 05	
Mass of water (g)	105		112		115		117		118	
Plunger Reading from base (mm)	6		7		7		6		5	
Standard/ Consistency (%)	26.25		28.00		28.75		29.25		29.50	

Table 7: Workability of Concrete

S/N	RHA content (%)	Slump (mm)	Compacting factor	Actual water/cement material ratio	Amount of water over control (%)
1	0	0	0.88	0.25	-
2	5	0	0.86	0.25	-
3	10	10	0.84	0.28	10.00
4	15	15	0.82	0.30	20.00
5	20	15	0.84	0.33	30.00

Table 8: Colour change and Spalling/Cracks of Concrete Cube Samples

Temp. (^{o}C)	Description of Colour Change and Spalling/Cracks				
	0%	5%	10%	15%	20%
25	- Grey - No Cracks	- Grey - No Cracks	- Grey - No Cracks	- Grey - No Cracks	- Grey - No Cracks
400	- Grey -Linear Cracks	- Grey -Linear Cracks	- Grey -Linear Cracks	- Grey -Linear Cracks	- Grey -Linear Cracks
600	-Grey -Multiple cracks	-Grey -Multiple cracks	-Grey -Multiple cracks	-Brownish grey Multiple cracks	-Brownish grey -Multiple cracks
800	-Whitish grey -Surface spalling	-Brownish grey -Surface spalling	-Brownish grey -Surface/aggregate spalling	-Brown -Surface/ aggregate spalling	-Brown -Sloughing-off spalling
1000	-Whitish grey -Surface/aggregate spalling	-Brownish grey -Surface/ aggregate spalling	-Brown -Surface/aggregate spalling	-Brown -Sloughing-off spalling	-Brown -Sloughing-off spalling

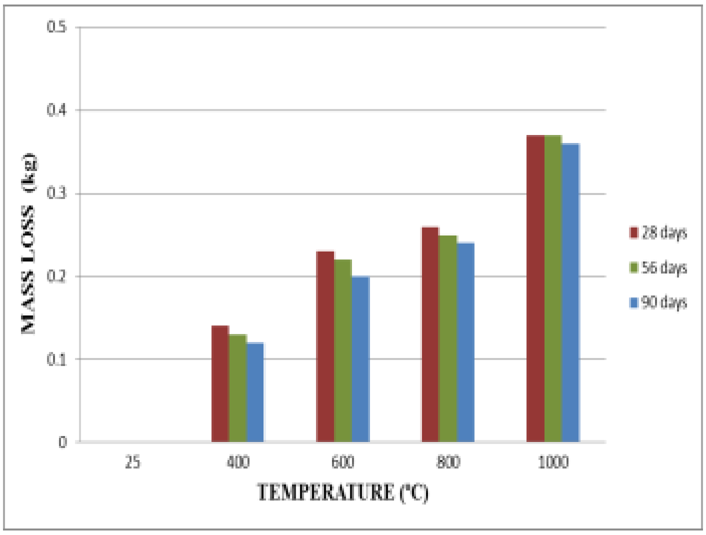

Figure 1: Mass Loss at 0% OPC Replacement

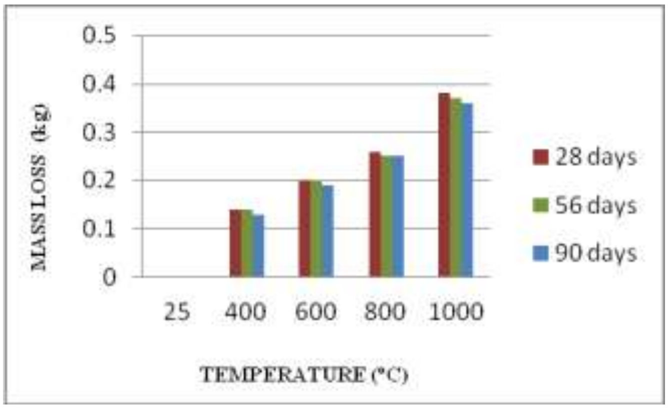

Figure 2: Mass Loss at 5% OPC Replacement

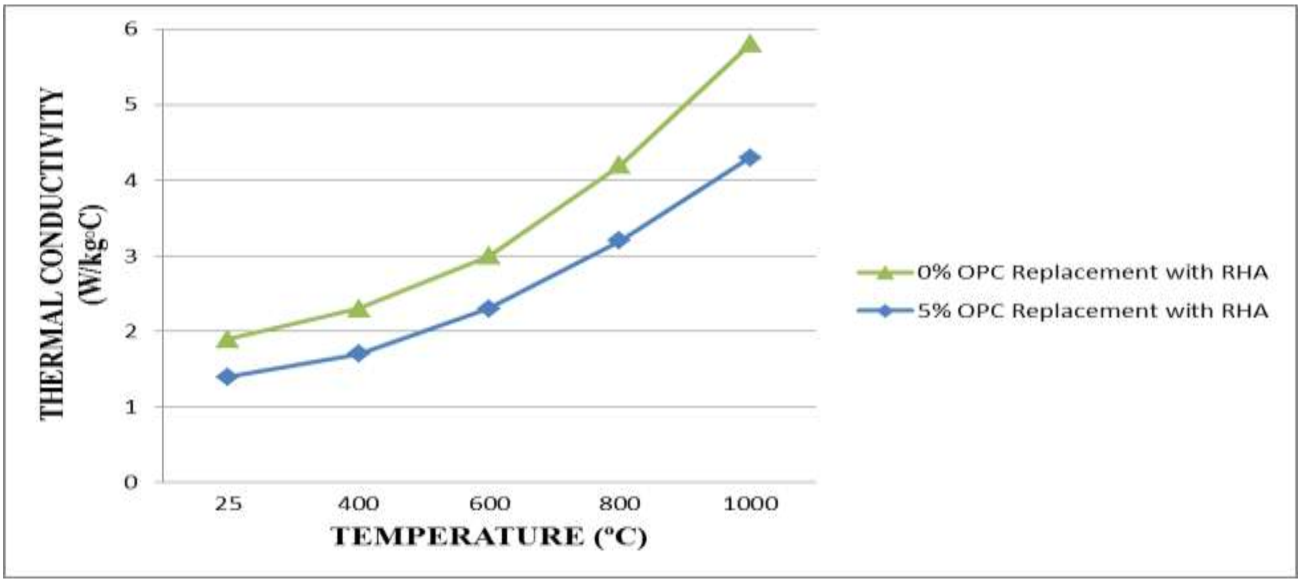

Figure 3: Thermal Conductivity at 28days.

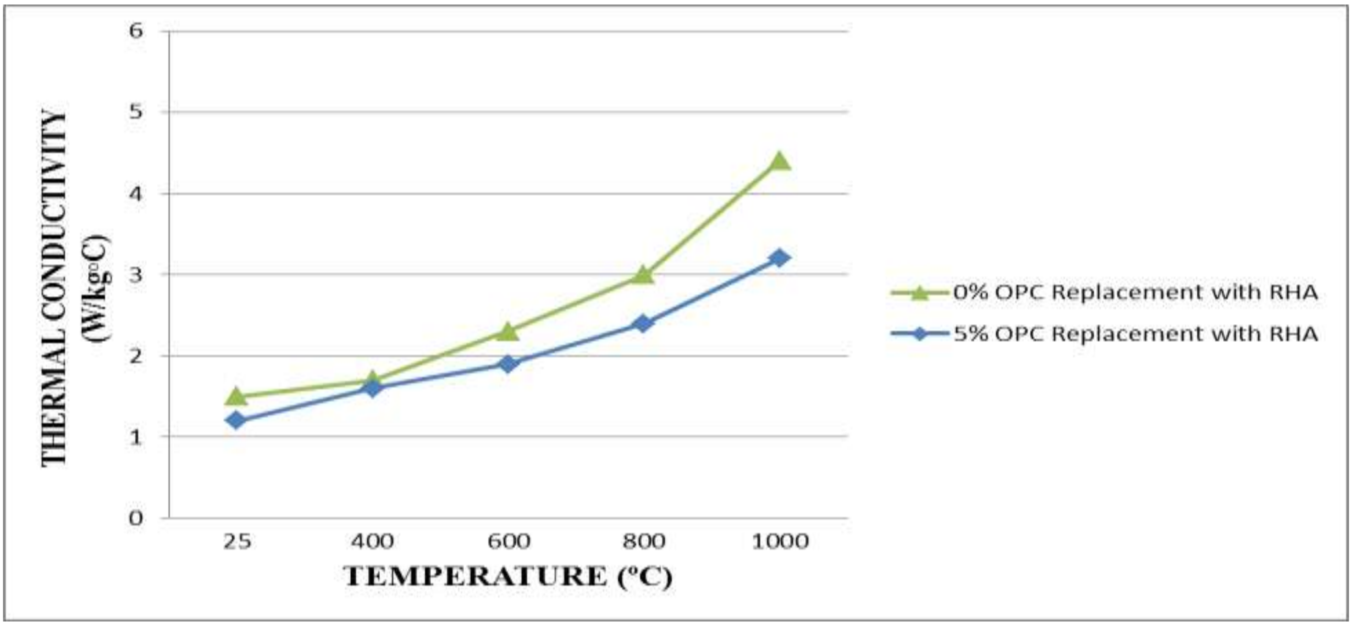

Figure 4: Thermal Conductivity at 56days.

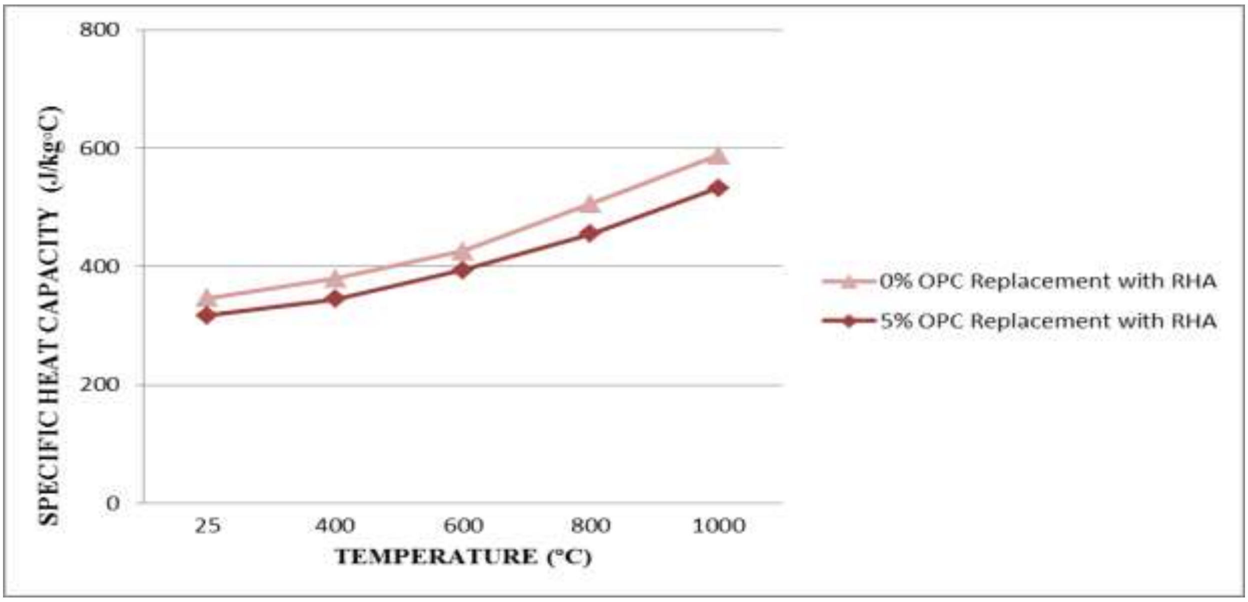

Figure 5: Specific Heat Capacity at 28days.

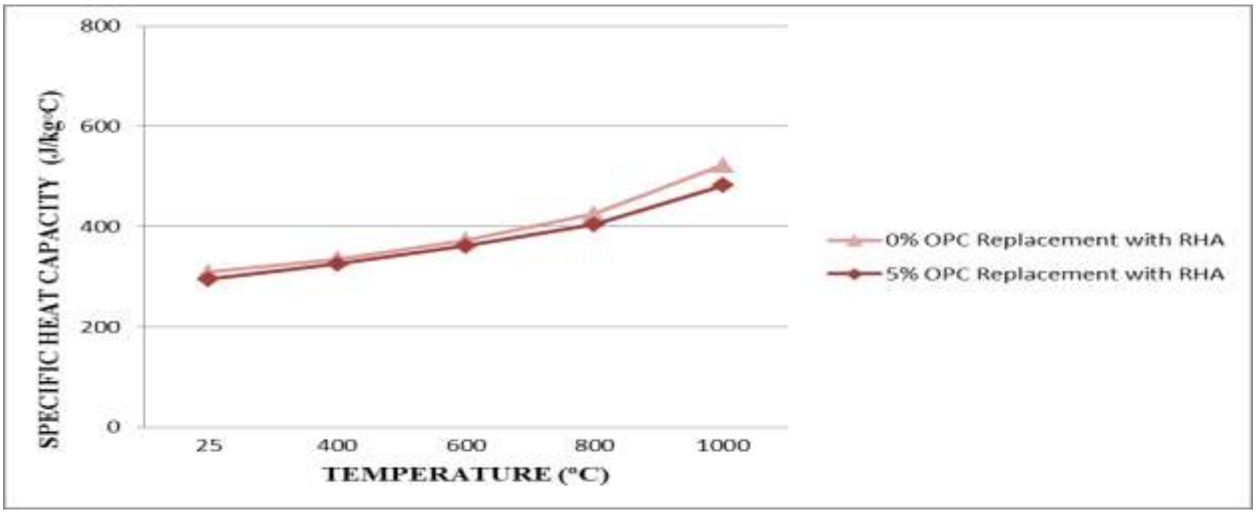

Figure 6: Specific Heat Capacity at 56days

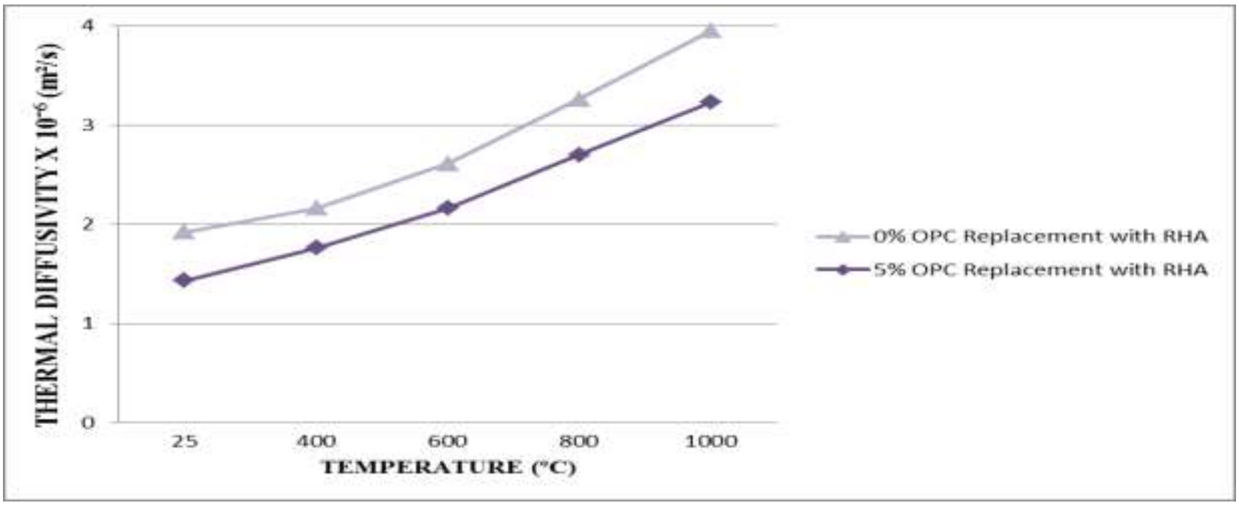

Figure 7: Thermal Diffusivity of Grade 50N/mm^2 at 28day

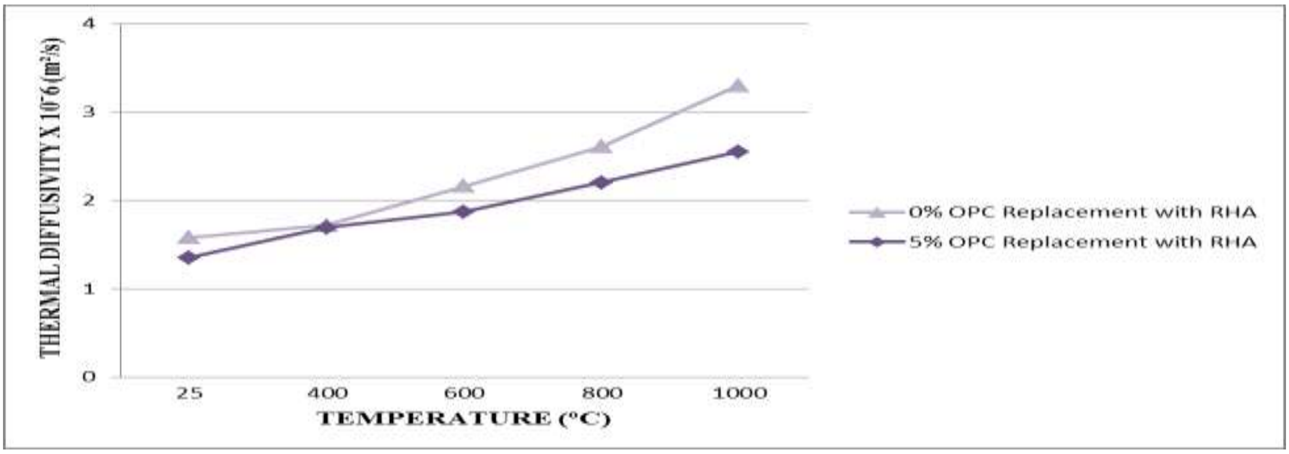

Figure 8: Thermal Diffusivity of Grade 50N/mm^2 at 56days

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