Effect of Elevated Temperatures on the Mechanical Properties of High Strength Concrete Blended with Rice Husk Ash (RHA)

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Abstract*—Durability of concrete is affected by many factors, amongst which is exposure to extreme temperatures such as in the case of fire outbreak. When concrete is exposed to abrupt temperature changes, the mechanical properties of the concrete such as strength, elastic modulus and volumetric stability are significantly reduced. However, pozzolanas such as rice husk ash (RHA) in High Strength Concrete (HSC) have been observed to be beneficial in terms of strength and durability at room temperature. The use of high strength blended concrete could reduce this menace in concrete exposed to elevated temperatures. This study thus determined how mechanical properties of HSC concrete blended with RHA are affected under high temperatures and ascertained the extent to which durability is effective. Ordinary Portland cement (OPC) was partially replaced with RHA at 0%, 5%, 10%, 15% and 20% respectively. Grade 40N/mm^2 and 50N/mm^2 blended concrete were produced using DOE mix design method. 450 concrete cubes and discs were cast and cured by immersion in water for 28, 56 and 90 days. The samples were subjected to temperature scale of 25^{o}C, 400^{o}C, 600^{o}C, 800^{o}C and 1000^{o}C after the curing and hibernation period respectively. The findings showed that for all concrete mix design, strength increases with age but generally reduced with increase in temperatures for all the percentage replacements. However, concrete sample blended with 5% RHA subjected to 400^{o}C had a compressive strength of 41N/mm^2 and 52N/mm^2 with elastic modulus of 20008.8N/mm^2 and 20011.0N/mm^2 for both 40N/mm^2 and 50N/mm^2 grades of concretes. But at 600^{o}C, the concrete loses 70% of its initial strengths. The longer the age of curing of all concrete samples, the better the general performance of the concrete samples when subjected to high temperatures thus durability of the concrete is greatly improved at a later age of curing. This implies that the use of HSC blended with RHA for construction will be beneficial in reducing the treat of fire on its.

Keywords—Concrete; strength; temperature; density; rice husk ash; elastic modulus.

I. INTRODUCTION

Different concrete require different degrees of durability requirement depending on the exposure environment and properties desired as well as the concrete ingredients, their proportioning, interactions between them, placing and curing practices and the service environment determine the ultimate durability and life of concrete [1]. Thus, durability of concrete is affected by many factors, amongst which is exposure to extreme temperatures such as in the case of fire outbreak. When a building structure is exposed to extreme temperature, the structural elements such as columns, beams, slabs and walls, suffer structural failure drastically as such the performance assessments of these elements when exposed to extreme temperatures and an understanding of the properties is paramount as indicated by [2]. During exposure to high temperatures such as during fire event, the mechanical properties of the concrete such as strength, elastic modulus and volumetric stability according to [3] are significantly reduced. These suggest that failure of the elements could be multidimensional as observed by [3]. In addition, elevated temperature reduces the strength in both high strength concrete (HSC) and normal strength concrete (NSC) and the degree of strength-loss are dependent on the temperature reached and the exposure duration [4]. Other factors which influence the strength loss are the aggregate types and the strength of the concrete at room temperature [5].

Reference[6] described rice husk ash as one of the promising pozzolanic material that can be blended with Portland cement for the production of durable concrete and at the same time a value added product. Also, addition of rice husk ash (RHA) speeds up setting time, although compared to Ordinary Portland Cement(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 [7]. RHA can also replace silica fume in high strength concrete as further indicated by [7] and silica fume or micro silica as 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.

Reference[8] discovered that the compressive strength for grade M20 of RHA concrete subjected to high temperatures increases at initial temperatures of 100-150ºC but reduces thereafter and 10% replacement of rice husk ash concrete cured at 7,14, and 28 days respectively, showed better compressive strength than normal concrete. Reference[9] used four different composite mixtures with varying amount of expanded vermiculite exposed to high temperatures of 300ºC, 600ºC, 900ºC and 1100ºC 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.

Despite numerous advantages accrued to HSC, when the concrete is exposed to elevated temperatures, the mechanical properties such as compressive strength, tensile strength and elastic modulus of HSC undergoes a significant reduction compared with the reductions observed in normal strength concrete. These differences are most pronounced in the temperature range between 100ºC and 400ºC where HSC's mechanical properties could be reduced by close to 40% of the original values and a reduction of approximately 20% to 30% lower than normal strength concrete when exposed to the same temperature range [10]. When concretes are exposed to high temperatures, changes such as nonlinearities in material properties, variation of mechanical and physical properties with temperature, tensile cracking, and creep effects affect the build-up of thermal forces, the load-carrying capacity, and the deformation capability that is, ductility of the structural members occurs as indicated by [11]. Concrete is a heterogeneous multiphase material with relatively inert aggregates that is held together by the hydrated Portland cement paste. The addition of pozzolanas to OPC in concrete, therefore, has a way of improving the strength and durability of concrete, because of the interface reinforcement [12]. The use of mineral pozzolanas such as RHA could be a remedy to this problem, and as such development in materials and application of HSC as well as the understanding of its mechanical behaviour when subjected to fire (high temperatures) is needed to guarantee its safe application hence this research is adopted.

II. MATERIALS AND METHOD

A. Materials

The materials used for the concrete production include cement, aggregates, plasticizer, rice husk ash and water.

Nigerian brand of Ordinary Portland Cement (CEM 1 42.5R) produced at Obajana cement plant in Kogi State, Nigeria and conforms to [13] with its properties shown in table 1 was used.

TABLE I. 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

The Rice Husk used was sourced from Lafia, Nasarawa State and burnt into ashes at 650ºC using a kiln at the ceramic firing section, Department of Industrial design, School of Environmental Technology Abubakar Tafawa Balewa University Bauchi, Sieve and chemical analysis were carried out on the resulting RHA at the National Metallurgical Development Centre (NMDC) Jos, Plateau State to ascertain the general specifications of the ash with results shown in table 2 & 3.

Two types of aggregates, coarse aggregates with a nominal size of 12.0mm and fine aggregates (natural river sand) with sieve size of 4.75mm was used conforming to [14] for high strength concrete were used and properties shown in table 4.

Water used for the production of the concrete was portable water fit for drinking and conforms to the requirements of [15]. Due to the low water-cement ratio (W/CM) in which a HSC mix generally requires, a high range water reducing admixture (super-plasticizer) was used.

TABLE II. PHYSICAL PROPERTIES OF RHA USED

Physical Property	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 III. CHEMICAL PROPERTIES OF RHA USED

Chemical Property	RHA (%)
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
Zirconium Oxide (ZrO_2)	0.01
Barium Oxide (BaO)	0.03
Lead Oxide (PbO)	0.02
Loss on Ignition (LOI)	0.15

TABLE IV. PHYSICAL PROPERTIES OF AGGREGATES (FINE AND COARSE)

Physical Properties	Fine Aggregates	Coarse Aggregates
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

The super-plasticizer used was BETOCRETE-FN which was based on a blend of synthetic polymer, organic substances and other additives to improve its performance. The super-plasticizer, BETOCRETE-FN is very suitable for use in the case of mineral admixtures for concrete such as silica fume and complies with all the requirements of [16], [17] and [18]. The general properties and specifications are indicated in table 5.

TABLE V. TECHNICAL PROPERTIES OF BETOCRETE-FN

PROPERTY	DESCRIPTION
Appearance	Brown liquid
Specific Gravity	1.18 at 23°C
Air entrainment	1% additional air (maximum)
Chloride Content	Nil
Permeability	Waterproofing properties will be improved. Resistance to water & water-borne salts will be improved.
Water-reduction	Up to 20% of mixing water can be reduced. The durability will be also increased.
Compatibility	Compatible with all types of Portland cements
Cohesion	The cohesion of the matrix will be increased.
Mechanical Properties	All the mechanical properties (such as compressive, flexural and tensile strengths) will be improved.
Dosage	0.50 – 3.00 % by weight of cement (usually influenced by the mix design including pozzolanic materials and W/ C Ratio).

[a] (Schomburg Technical data sheet, Art-No. 406658).

B. METHODS

For the purpose of this research, HSC with 40N/mm^2 and 50N/mm^2 grades of concrete were used. The mix design was done based on [19] DOE method of concrete mix design. Batching by weight was adopted due to relative closeness in specific gravities of the aggregates. Concrete mix proportions were determined for 1m^3 mould according to [20]. The proportions of RHA were 0% (Control), 5%, 10%, 15% and 20% by weight of cement.

TABLE VI. SUMMARY OF MATERIALS NEEDED PER M^3 OF CONCRETE IN KG FOR M40

Percentage replacement (%)	Cement Content (Kg)	RHA Content (Kg)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)	Water Content (Kg)	Super-Plasticizer (Kg)
0	0.60	0.00	0.51	1.18	0.24	0.000
5	0.57	0.03	0.51	1.18	0.24	0.003
10	0.54	0.06	0.51	1.18	0.26	0.004
15	0.51	0.09	0.51	1.18	0.28	0.005
20	0.48	0.12	0.51	1.18	0.31	0.006

Also, the content of BETOCRETE-FN used was measured according to increase in the percentage replacement of RHA starting from 5% by weight of cement that is for every percentage increase of RHA, 0.2% increase of BETOCRETE-FN by weight of cement with mix proportions presented in Table 6 & Table 7 respectively.

The consistency and setting times (initial and final) of cement paste were measured using the Vicat apparatus in accordance with [21] for all the samples and the results presented in Table 8.

TABLE VII. SUMMARY OF MATERIALS NEEDED PER M^3 OF CONCRETE IN KG FOR M50

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

Workability test (slump test) was carried out on the fresh concrete in accordance to [22] on the fresh concrete and the results presented in Table 9.

Cubes were cast in 100mm^3 moulds and were vibrated for 5 seconds on a vibrating table, then cured for 28, 56 and 90 days and allowed to hibernate for a period of 21 days in accordance with [23]. These samples were then exposed to different temperature conditions ranging from 25ºC (control), 400ºC, 600ºC, 800ºC and 1000ºC in a local kiln and burnt for 2-4 hours to achieve thermal steady state before allowing it to cool by air drying. Tests were then conducted on the samples in accordance with [24] to ascertain their performance.

These tests include compressive strength test where the crushing or failure loads were observed and recorded accordingly with the compressive strength computed using

TABLE VIII. STANDARD CONSISTENCY OF OPC AND RHA PASTE

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 IX. WORKABILITY OF CONCRETE

Parameter	RHA content (%)	Slump (mm)	Compacting Factor	Actual water/cement material ratio	Amount of water over Control (%)
A	0	0	0.86	0.24	-
B			0.88	0.25	
A	5	0	0.87	0.24	-
B			0.86	0.25	
A	10	10	0.84	0.26	10.00
B			0.84	0.28	
A	15	15	0.83	0.28	20.00
B			0.82	0.30	
A	20	15	0.83	0.31	30.00
B			0.84	0.33	

the formula shown in equation (1);

$F_c=F/A_c$ - - - - - - - - - (1)

Where F_c = compressive strength (N/mm^2), F = Maximum load at failure (N) and A_c = Cross sectional area of concrete on which compressive force acts (mm^2).

Density of heated and unheated samples which is usually expressed as the degree of its consistency and determined by the ratio of its mass and volume as shown in equation (2)

Density (γ)=Weight(mass)/Volume(m^3) (Kg/m^3) - - - -- (2)

Modulus of elasticity of both grades of concrete was determined using the formula in equation (3) below;

$E_c=20000+0.2f_c$ - - - - - - (3)

Where: E_c = elastic modulus, f_c = compressive strength.

III. RESULTS AND DISCUSSIONS

A. FRESH CONCRETE

1) Consistency and Setting Time Test : The consistency for partial replacement were between 28 – 29.5% which are less than 30-35% as stipulated in [25] and [26]. The standard consistency increased for every increase in partial replacement of RHA which indicates an increase in water requirement as RHA is added. It also shows RHA has no adverse effect on OPC. Also, setting time of the concrete samples increased with increase in RHA content. The initial setting times were all greater than 30 minutes and the final setting time not more than 305 minutes. This implies that partial replacement up to 20% of RHA in concrete is satisfactory to setting time standard requirement. Table 8 shows the results of the standard consistency of various percentages of partial replacement of RHA

2) Workability Test: From Table 9, both grades of concrete ($40N/mm^2$ and $50N/mm^2$) workability reduced due to higher replacement of cement by ash with an increase in the water demand and therefore for the given water cement ratio and cement content, the workability reduced as justified by unpublished[27]. Also, silica-lime reaction requires more water in addition to water required during hydration of cement as confirmed by unpublished[28].

B. HARDENED CONCRETE

1) Densities of Heated and Unheated Cubes: Concretes with density greater than $2600kg/m^3$ are classified as heavyweight concrete [29][30]. From the results obtained, as shown in Figures 1-10, an analysis can be drawn that the concrete cubes produced are all within the range of heavy weight concrete (High strength concrete) as

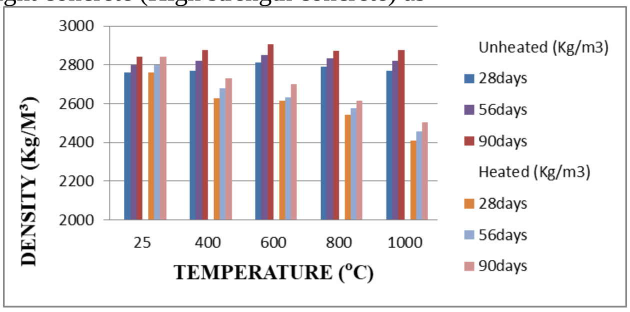

Fig. 1. Densities of Unheated and Heated Cubes for 0% OPC replacement with RHA for $40N/mm^2$

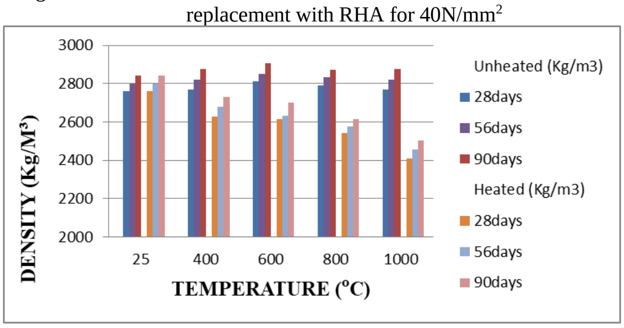

Fig. 2. Densities of Unheated and Heated Cubes for 0% OPC replacement with RHA for $50N/mm^2$

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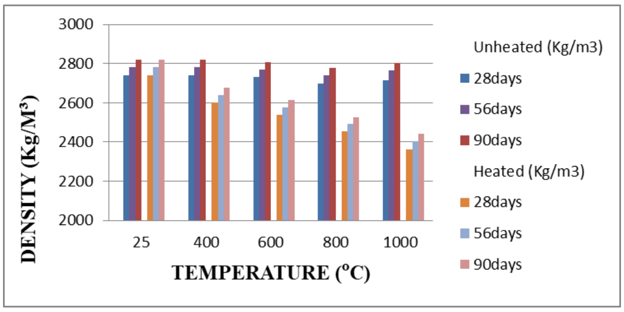

Fig. 3. Densities of Unheated and Heated Cubes for 5% OPC replacement with RHA for 40N/mm^2

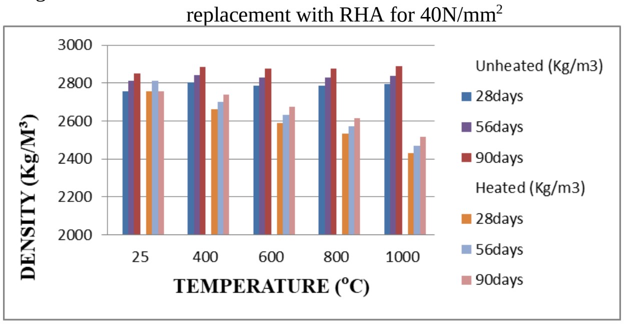

Fig. 4. Densities of Unheated and Heated Cubes for 5% OPC replacement with RHA for 50N/mm^2

values obtained from both grades 40N/mm^2 and 50N/mm^2 exceeded the 2600 kg/m^3 after 28days curing for a heavy weight concrete. However the cubes exhibited increase in their densities at 28days by an average of 3%, at 56days by an average of 4.5% and an average of 6.5% after 90days of curing for both grade 40N/mm^2 and 50N/mm^2 concrete due to an increase in the moisture content and water absorption by the

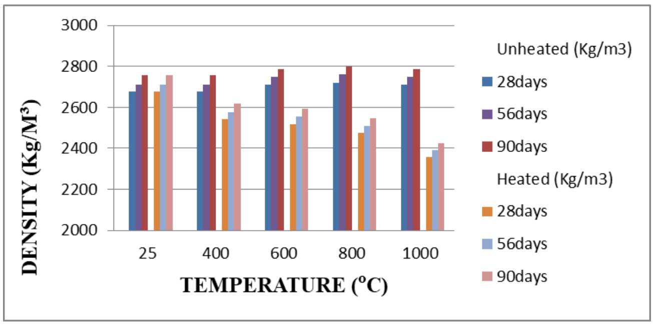

Fig. 5. Densities of Unheated and Heated Cubes for 10% OPC replacement with RHA for 40N/mm^2

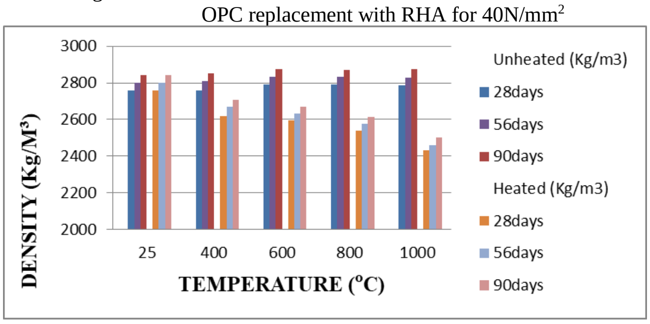

Fig. 6. Densities of Unheated and Heated Cubes for 10% OPC replacement with RHA for 50N/mm^2

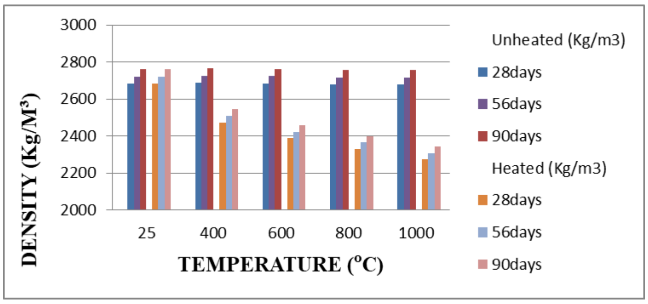

Fig. 7. Densities of Unheated and Heated Cubes for 15% OPC replacement with RHA for 40N/mm^2

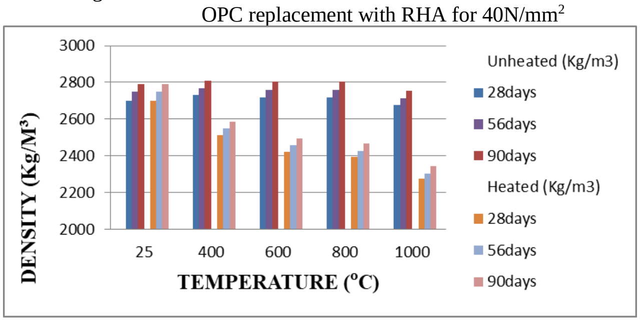

Fig. 8. Densities of Unheated and Heated Cubes for 15% OPC replacement with RHA for 50N/mm^2

concrete. The cubes also exhibited a decrease in densities when subjected to various elevated temperatures. At room temperature of 25°C, the densities remained the same but decreased to an average of 5% to13% for 0% OPC replacement

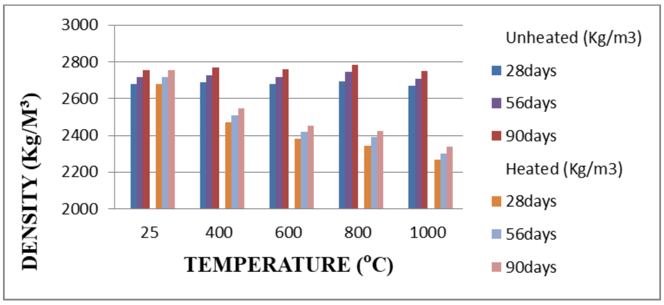

Fig. 9. Densities of Unheated and Heated Cubes for 20% OPC replacement with RHA for 40N/mm^2

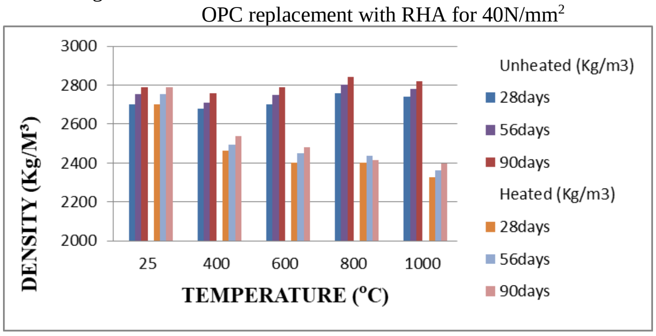

Fig. 10. Densities of Unheated and Heated Cubes for 20% OPC replacement with RHA for 50N/mm^2

with RHA when subjected to 400°C, 600°C, 800°C and 1000°C respectively but an average of 4.5%, 6%, 8.4% and 12% decreased when subjected to 400°C, 600°C, 800°C and 1000°C respectively for, 5%, and 10% OPC replacement with RHA. It further decreased to 8%, 11% to 15% respectively for 15% and 20% OPC replacement with RHA when subjected to the same temperatures which conforms to [7] who noted that

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increase in replacement of OPC with RHA results in reduction of concrete's density. Reference[31] also confirmed and concluded that concrete loses its density after exposure to elevated temperature.

2) Compressive Strength: Table 10 and 11 illustrates the compressive strength for concrete cubes with 0%, 5%, 10%, 15% and 20% of OPC replacement with RHA subjected to a temperature range of 25ºC, 400ºC, 600ºC, 800ºC and 1000ºC after 28, 56 and 90 days of curing for both grades 40N/mm^2 and 50N/mm^2. These results show that the longer the age of curing, the higher the compressive strength which conforms to [32] who stated that the properties of concrete increases at a later age of curing. The results also show that when subjected to various elevated temperatures, the compressive strength decreases for both grades of concrete in line with [3] who established that during exposure to high temperatures such as during fire event, the strength significantly reduced. But the strength reduction for 5% and 10% OPC replacement with RHA was lesser compared to 0% OPC replacement. The ability of the blended cement concrete with 5% and 10% RHA contents to have improved fire resistance compared to 0% OPC replacement is as a result of the reduction in $Ca(OH)_2$ content, by the action of SiO_2 and Al_2O_3 which are elements present in the RHA as opined by [33]. The addition of RHA to concrete shows an

TABLE X. COMPRESSIVE STRENGTH OF GRADE 40N/MM^2 CONCRETE SAMPLES

Days of curing	Temperature	Ave. Compressive strength (N/mm^2)				
		0% RHA	5% RHA	10% RHA	15% RHA	20% RHA
28	25	42	44	41	3	3
					8	3
	400	37	42	36	3	2
					1	0
	600	12	13	10	6	6
	800	6	7	5	3	3
	1000	4	5	4	2	0
56	25	48	48	46	3	3
					9	4
	400	43	47	44	3	2
					2	9
	600	15	16	12	9	8
	800	8	8	5	4	3
	1000	3	4	4	2	2
90	25	54	56	51	4	3
					5	5
	400	48	52	46	3	3
					6	0
	600	18	18	13	1	1
					1	0
	800	9	10	7	6	5
	1000	5	5	5	2	3

TABLE XI. COMPRESSIVE STRENGTH OF GRADE 50N/MM^2 CONCRETE SAMPLES

Days of curing	Temperature	Ave. Compressive strength (N/mm^2)				
		0% RHA	5% RHA	10% RHA	15% RHA	20% RHA
28	25	52	5	51	48	40
			7			
	400	46	5	45	29	20
			1			
	600	20	2	13	11	4
			1			
	800	8	9	6	5	3
	1000	4	5	4	3	0
56	25	60	6	57	49	43
			3			
	400	53	5	52	31	22
			5			
	600	23	2	15	12	7
			1			
	800	10	1	11	5	3
			0			
	1000	6	7	4	3	2
90	25	68	7	60	54	50
			6			
	400	61	6	54	42	31
			8			
	600	26	2	18	14	9
			3			
	800	10	1	7	5	4
			2			
	1000	6	6	5	3	2

increase in compressive strength of the concrete and decrease in water permeability of concrete under the ambient condition as confirmed by [34].

3) Elastic Modulus: The modulus of elasticity (E) for both grades of concrete cube samples (40N/mm^2 and 50N/mm^2) varied slightly and decreased rapidly with an increase in temperature. As shown in figures 11-16. The presence of SiO_2 and Al_2O_3 contained in the RHA increased the elastic modulus for concrete samples at 5% OPC replacement with RHA compared with the concrete samples with 0% OPC replacement but decreases rapidly with high content of RHA (at 15% and 20% OPC replacement). This shows that the elastic modulus for all the concrete types increased with an increase in compressive strength, in line with [35] and decreases with an increase in RHA replacement due to the low specific gravity of RHA compared to OPC, in conformity with [36]. However, the modulus of elasticity for both grades of concrete cubes blended and unblended increases with the age of curing and the trend of loss in elastic modulus

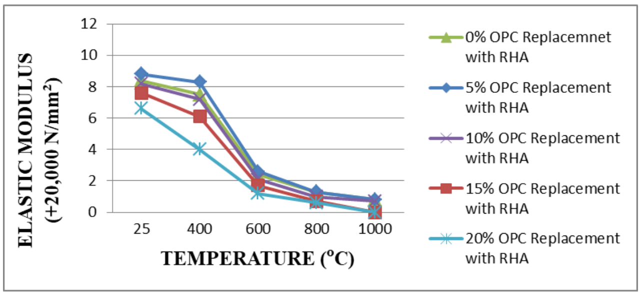

Fig. 11. Elastic Modulus of Grade 40N/mm^2 at 28days

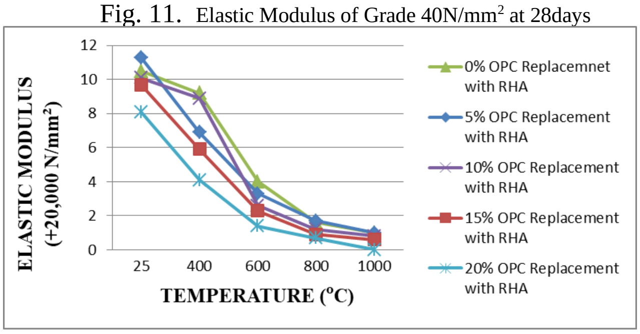

Fig. 12. Elastic Modulus of Grade 50N/mm^2 at 28days

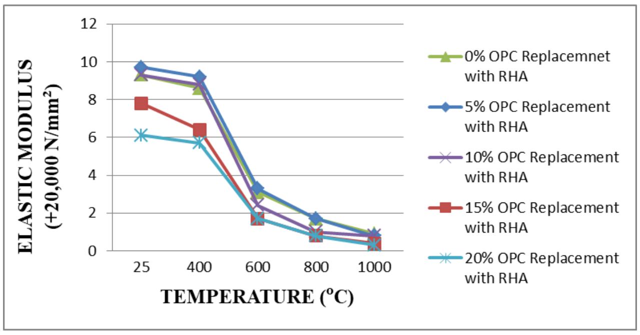

Fig. 13. Elastic Modulus of Grade 40N/mm² at 56days

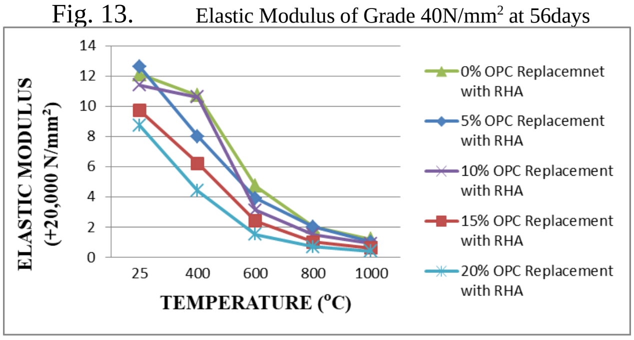

Fig. 14. Elastic Modulus of Grade 50N/mm² at 56days

for both grades of concretes (40N/mm² and 50N/mm²) blended and unblended with different percentage of RHA (0%, 5%, 10%, 15% and 20%) exposed to different elevated temperatures (25°C, 400°C, 600°C, 800°C and 1000°C) is similar and the fractional decline does not depend

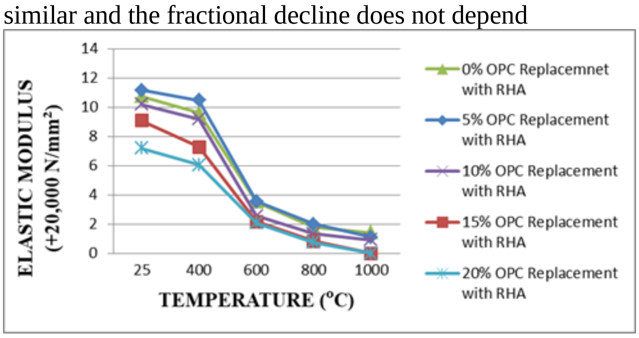

Fig. 15. Elastic Modulus of Grade 40N/mm² at 90days

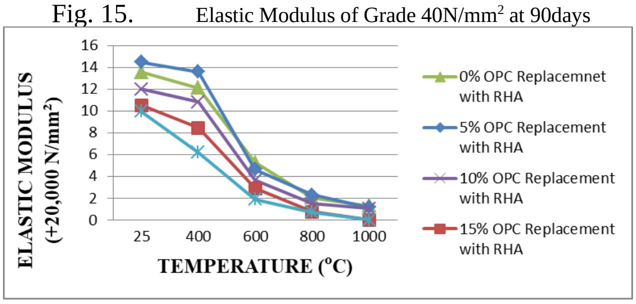

Fig. 16. Elastic Modulus of Grade 50N/mm² at 90days

significantly on the type of aggregate used which conforms to [37] who stated that elastic modulus of concrete decreases with the rise of temperature and is dependent mainly on the water-cement ratio in the mixture, the age of concrete as well as the method of conditioning.

IV. CONCLUSION

Elevated temperatures has adverse effect on strength and durability properties of concrete, as such, the appropriate amount of RHA required to improve the performance of HSC exposed to such ambient conditions is 5% of the total cement content. The compressive strength and elastic modulus of HSC concrete blended with RHA content improves greatly thus increasing the mechanical property of the concrete subjected to different high temperatures compared to HSC with 100% OPC and at 600°C, the concrete loses 70% of its strength. The longer the age of curing of all concrete samples, the better the general performance of HSC blended with RHA when subjected to high temperatures thus durability of the concrete is greatly improved at a later age of curing.

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