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Influence of Rice Husk Ash Admixture on Key Perfomance Indicators of High Stregth and High Performance Concrete

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Abstract

The demand of tall structures, large span bridges and dams, and development of concrete technology such as pre-stressed concrete construction demanded high strength concrete. In line with strength, method of mixing and placing need a concrete with high performance in fresh and hardened state. These drive the need of 'High Stregth, High Performance Concret' in industries. This research explores the influence of 'Rice Husk Ash' on the key performance indicators of high stregth, high performance concret. The research investigated the key performance properties of high stregth, high performance concret. High stregth, high performance concret of 40 MPa incorporating 0%, 5%, 10% and 15% rice husk ash. Workability of high stregth, high performance concret was found to decrease as the amount of rice husk ash was increasing. The desired workability was from 30 to 60 mm, but the actual values achieved were 58mm for the control mix which decreased to 48 mm on addition of 10 % rice husk ash admixture. The compression and flexural strength obtained for the control concrete were 36.3 and 4.6 MPa respectively at 7 day curing period. The 28 day compressive strength of control concrete was 53.5 MPa but for the high strength, high performance concret was 57.9 MPa achieved at an addition of 10 % rice husk ash admixture. The 7 and 28 day curing periods, the compressive and flexural strengths of concrete containing 10 % of rice husk ash admixture were better compared to the control concrete that incorporate 5% and 15% of rice husk ash. The compressive strength of 48.6 and 57.9 MPa achieved at 7 and 28 days respectively proved the potential of rice husk ash as admixture in the production of high stregth, high performance concret. Also rice husk ash attested the forth coming contribution to the sustainable development and economic success to the construction and agricultural industries.

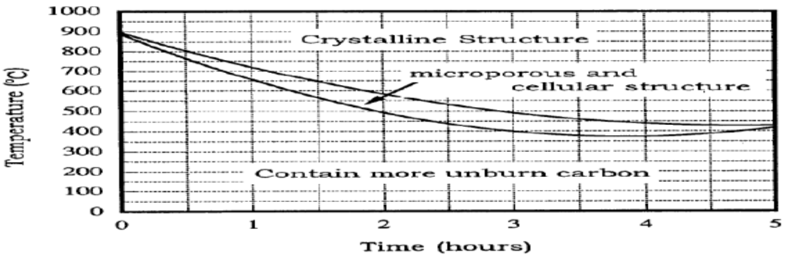
Keywords: High strength, high performance concrete; rice husk ash; compressive strength

1.0. Introduction

Concrete is a building material comprised of binding medium and aggregates (and sometimes with other additives or admixtures) that can be moulded into different shapes and sizes. It is adaptable and most popular construction material in the world (Güneyisi et al., 2008; ACT 116R-00, 2005). Normally, concrete is classified by types of material used, strength, performance, application and method of construction (Ermichev et al., 2006; Neville & Brooks, 2010). New types of structures and new technologies in building created more difficult requirements for conventional concrete, so improvements with addition of mineral admixtures is necessary for producing sustainable high strength high-performance concrete (Güneyisi et al., 2008; Mohammed, 2013). Common mineral admixtures used are Silica Fume (SF), Meta Kaolin (MK), Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBFS) (Kiliç et al., 2003; Güneyisi et al., 2008 & Mohammed, 2013; Juenger & Siddique, 2015). Other residue materials such as Rice Husk Ash (RHA), Sugar Cane Bagasse Ash (SCBA), and Oil Palm Shell Ash (OPSA) burnt under controlled condition have reactive silica required for pozzolanic material.

The RHA, which is agricultural by product, possesses about 95% silica when burnt at 600 °C to 700 °C (Della et al., 2002; Mboya et al., 2017). Also researcher have found out that, burning of rice husks between 500 - 800 °C results into amorphous ash but at higher temperature above 800 °C form crystalline silica (Mboya et al., 2017). It has been confirmed that rice husk ash burnt between 500 to 700 °C for more than 12 hours produced high reactive ash with no significant crystalline silica (Nair et al., 2008). The optimum burning temperature versus time curve has been developed by (Hwang & Chandra, 1997) (Figure 1). The rice husk ash burnt under such conditions is highly amorphous and has quite high specific surface area necessary for pozzolanic reactions.

Figure 1
Optimum Burning Condition Curve



Source: Nair et al. (2008).

Amorphous rice husk ash react earlier than other pozzolanic materials such as scoria, pumice and meta kaolin, (Shakhmenko et al., 2001; Mboya et al., 2017). Potential benefits of RHA in concrete include reduced amount of Portland cement, reduced alkali silica reaction, reduced chloride-associated corrosion and sulfate attack, reduced permeability, increased strength and durability, reduced CO_2 emission and energy consumption in cement manufacturing (Della et al., 2002; Mehdipour & Khayat, 2016). On the other hand, if rice husk is left unutilized it can result into a great threat to environmental pollution. The need of high strength high performance concrete (HSHPC) in conjunction with environmental pollution, cost of additives for improving concrete properties and energy intake, prompt investigation on beneficial applications of RHA is necessary.

HSHPC has captured many advantages over normal and other types of concrete. The most important being: reduced member size and savings cost of concrete; reduced self-weight hence reduced foundation area; enable longer spans and fewer beams for the same magnitude of loading; increased service performance under static, dynamic and fatigue loading; higher resistance to freezing and thawing, chemical attack, and significantly improved long-term durability.

Rice husk ash is an agricultural waste material containing high amount of silica obtained by burning rice husk in a controlled conditions (Table 1). Proper burning of rice husk produces ash with high reactive silica content used as an admixture or supplementary cementing materials in mortar and concrete. When burnt at ordinary condition rice husks produce ash with high carbon content. When rice husk is burnt between 500 °C - 800 °C results into RHA with high amorphous silica, which reacts with calcium hydroxide from hydration reaction (Mboya et al., 2017; Kilic et al., 2003; Naveen & Antil, 2015; Kumar, 2012). If rice husk is burned at higher temperature above 800 °C, it results into crystalline silica that is not reactive (Güneyisi et al., 2008).

Table 1

Chemical Compostion of Rice Husk Ash

Reference	Constituent								Loss on ignition (LoI)
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	
Mboya et al., (2017)	94.25	0.33	0.26	0.63	0.28	0.25	0.00	2.51	0.56
Ephraim et al., (2012)	88.32	0.46	0.67	0.6	0.44	-	0.12	2.91	1.73

Alireza et al., (2017)	86.73	0.04	0.61	0.08	1.32	9.76	0.01	0.54	-
Christopher et al., 2017	89.47	0.18	0.003	1.10	0.44	0.11	0.062	1.32	4.06
Antiohos et al., (2014)	93.15	0.13	0.002	0.89	0.4	0.10	0.02	1.63	5.61
Bansal & Yogender, (2015)	87.20	0.15	0.16	0.55	0.35	0.24	-	-	5.44
Physical properties		Specific gravity (g/cm^3)			Specific surface area			Fineness: passing 45 µm (%)	
Mboya et al., (2017)		2.14			462			85	
Ephraim et al., (2012)		2.16						96.6	
Alireza et al., (2017)		-							
Antiohos et al., (2014)		-			382			81.7	
Antiohos et al., (2014)		-			393			91.7	
Bansal & Yogender, (2015)		-			-			96	

2.0. Materials and Methods

2.1. Materials

Portland limestone cement from Dangote (PLC), CEM II/A-L class 42.5 N conforming to BS EN: 197-1, (2011), with specific gravity of 3.15 was used. Coarse and fine aggregate used conformed to BS 882. The coarse aggregate from crushed rock has a maximum nominal size 19 mm. The fine aggregate was from Mbarali River passing 4.75 mm standard sieve and retain on 75 microns standard sieve. RHA burnt using muffle furnace for two hours and ground to a fine powder was also used. For the purpose of this research de-ionized water was used.

2.2. Methods

Cement conformity evaluation was done at Mbeya University of Science and Technology (MUST) – Soil and materials testing laboratory and Mbeya cement laboratories: the test performed were the standard consistency, initial and final setting times, soundness and strength (SS-EN 196-3:2005+A1:2008 (E), 2015; SS-EN 196-1, 2005). Sampling and testing of fine and coarse aggregate was performed according to (BS, 1990 & ACI Bulletin, 2007). Since the aim of this research was to investigate the influence of RHA to the key performance properties of HSHPC, testing of chemical and physical properties of RHA was necessary. Rice husk was collected from Wella rice factory and burned to a temperature of 600 °C and left to soak for 1 hr. Milling was then performed using the same procedure devised by the author (Mboya et al., 2017). Thereafter, the chemical composition of RHA was determined at Mbeya Cement Company laboratories and fineness (that is, proportion passing 45μm) at MUST laboratory.

Concrete mix design, production and testing were conducted at MUST laboratory. Mix design embracing the process of selecting suitable ingredients of concrete and determining their relative proportions ingredient of concrete was also done. The concrete mix design was performed according to BRE procedure targeting to a characteristic strength of 40 MPa. The standard deviation of 8 MPa and the confidence factor *K* equals 1.64 were adopted leading to a target mean strength of 53.12 MPa. Water cement ratio of 0.48 and slump of 30 - 60 mm were considered (BRE, 1997). RHA was added as mineral admixture at a dosage of 0, 5, 10 and 15 % of cement by mass. The mix design proportions for maximum nominal aggregate size of 20 mm are shown in Table 2. Four mixes were prepared, one with 0 % RHA (control mix) and the other three with addition of 5, 10 and 15 % of RHA admixture. The water to cement ratio was kept constant. Likewise the absorption characteristics of both fine and coarse aggregates together with absorption of RHA were taken into account. The proportions of fine and coarse aggregates decreased with addition of RHA but the overall density of fresh concrete increased as the fine particles was increased. Batching, mixing casting, curing and testing of fresh and hardened concrete was performed according to British Standard procedures (BS EN 12350-1, 2009; BS-EN 1350-7, 2009; BS EN 12390-2:2000, 2003).

Table 2

Concrete Mix Proportions of HSHPC

	Control	**Proportions of Ingredients**		
Percent of RHA added	**0**	**5**	**10**	**15**
Water cement ratio	0.46	0.46	0.46	0.46
Cement content (kg/m^3)	457	457	457	457
RHA (kg/m^3)	0	22.9	45.7	68.6
Water (kg/m^3)	233	235	237	239
Fine aggregate (kg/m^3)	586	578	570	561
Coarse aggregate (kg/m^3)	1088	1073	1058	1043
Wet density (kg/m^3)	2364	2367	2368	2369

3.0. Results and Discussion

3.1. Properties of Aggregates

Figure 2 and **Error! Reference source not found.** show the properties of fine and coarse aggregates determined according to (BS EN 12620, 2002). The test results show that fine aggregate was composed of about 100 % particles less than 4.75 mm (

Figure 2). The grading modulus (GM) was 50.5 % and Fineness Modulus (FM) was 2.51. **Error! Reference source not found.** suggests that the fine aggregate is fine sand which is good for cohesive concrete production. Correspondingly, most particles in coarse aggregate lie between 4.75 mm, and 19 mm diameters. The coarse aggregates was found to have a FM of 6.7 which is within the range of 6.0 – 6.9 for maximum particle size of 19 mm which is suitable for HSHPC. Observation from **Error! Reference source not found.** reveals that, the absorption of 0.74 % and 1.74 % for both fine and coarse aggregates respectively. The observed low absorption was associated with aggregates of low porosity which are good for the mitigation of alkali silica reaction. Also, it is the evident that no interconnected pores suggesting impermeable, strong and durable aggregates suitable for durable concrete. The specific gravity of 2.6 and 2.63 respectively were obtained for both fine and coarse aggregates corresponded to normal weight aggregate suitable for general concrete. Moreover, with regard to soundness and loss on ignition test, no significant organic content found in fine aggregates addressing a clean and suitable sand for concrete production. Such sand has no adverse reaction with the hydrating cement therefore it is suitable in all important cement concrete.

Figure 2
Particle Size Distribution of Aggregates

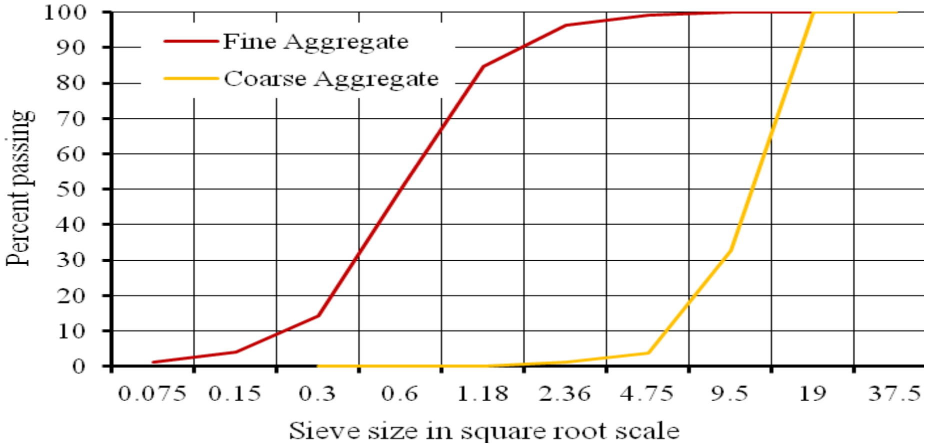


Table 3
Properties of Aggregates

Property	**Fine Aggregate**	**Coarse Aggregate**
Grading modulus (GM) (%)	50.5	-
Fineness modulus (FM)	2.51	6.7
Specific gravity (SG)	2.6	2.63
Water absorption (%)	0.74	1.74
Loss on ignition (%)	2.1	-
Soundness	sound	-

3.2. Properties of Rice Husk Ash and its Influence to the High Stregth, High Performance Concrete

The physical and chemical properties of RHA determined are presented in Table 3. The RHA was found to contain silica of about 93.04 % which agreed to other researchers' findings. This revealed that, the burning process, milling and testing procedures correlated. The high silica content and high fineness exposed a large proportion of the reactive silica. Such reactive part could influence the pozzolanic reaction and increased the calcium silicate hydrate (C-S-H) and calcium aluminosilicate hydrate (C-A-H) gel which contributed to strength. The products, C-S-H and C-A-H, contributed to increased bond strength in the aggregate-paste interface which increased the overall strength of concrete. Furthermore, the finer particles of the ash fill the micro pores in the microstructure and hence improved the parking density. These lead to a low permeability and increased strength and durability of concrete. No aggressive alkali reaction could be expected since the sodium equivalent ($Na_2O_{eq} = Na_2O + 0.658*K_2O$) in the percent of RHA added has no significant effect to the gross alkali content in the concrete microstructure.

Table 3

Chemical and Physical Properties of RHA

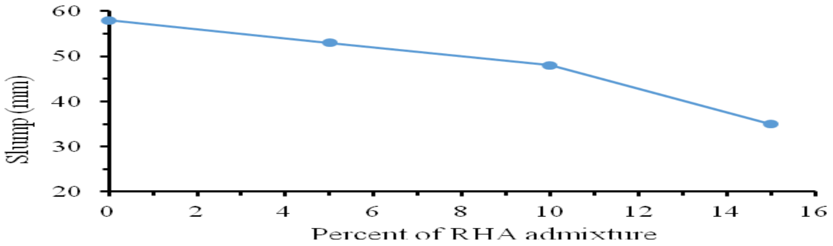
Constituent	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LoI
RHA	93.04	0.23	0.21	0.42	0.14	0.20	0.01	2.61	1.02

Physical properties	Specific gravity (g/cm^3)	Specific surface area (m^2/kg)	Fineness - passing 45 µm (%)
	-	-	81

3.3. Effects of Rice Husk Ash to the Properties of Fresh High Stregth, High Performance Concrete

Workability of the fresh concrete decreased with additions of RHA, **(** Figure **3**). There was solely linear decrease of slump from 58 mm for control mix to 48 mm for a mix containing 10 % of RHA. This indicated that the increased amount of finer materials in the microstructure resulted into increased water demand and cohesion thus decreasing particle lubrication. Also absorption characteristics of RHA contributed to reduced slump observed on Figure **3**. The slump reduced further at higher rate from 48 mm for a concrete mix with 10 % of RHA to 35 mm for a concrete mix containing 15 % RHA. The indicated further absorption as well as early hydration and pozzolanic reactions. Figure **3** also shows that, the amount of RHA in the mix exceeding 10 % destroyed the properties of fresh concrete and later the properties of hardened concrete. Therefore, addition of up to 10 % of RHA admixture can be decided as the optimum dose to achieve a desired workability as well as optimum hydration and pozzolanic reactions.

Figure 3
Influence of RHA on Concrete Workability



3.4. Effect of Rice Husk Ash on compressive Strength of High Stregth, High Performance Concrete

Figure 4 shows the strength development of HSHPC made without admixture and those made with a varying amount of RHA admixture. The 3 day strength decreased linearly with addition of RHA admixture from 22.0 MPa for the control concrete to 20.0 MPa for a concrete with 10 % of RHA admixture. Then drop to 16.8 MPa for a concrete containing 15 % of RHA admixture. The reduced strength was ascribed to the increased of non-hydraulic materials in the microstructure and low concentration of calcium hydroxide (CH) needed for pozzolanic reactions. Addition of 15 % RHA diluted the hydration products and resulted into slow strength development.

The 7 day strength increased from 36.3 MPa for control concrete to 48.6 MPa for a concrete containing 10 % of RHA admixture (

Figure 4); then reduced to 34.4 MPa for concrete containing 15 % of RHA admixture. It was revealed that, at 7 day curing period, the concentration of CH from hydration of cement has increased to a level that balanced the pozzolanic reaction with RHA silica. This leads to additional C-S-H gel which increased the overall strength of concrete. The fundamental cause of the reduced strength at 15% of RHA admixture was the excessive non-hydraulic materials in the microstructure and exhaustion of CH.

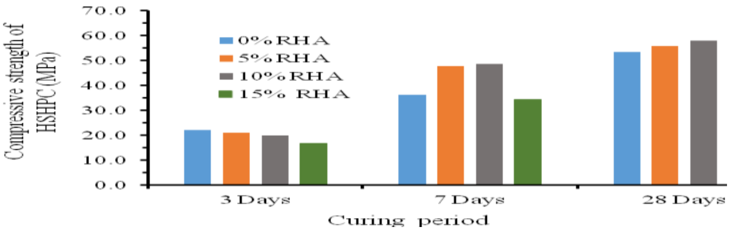
The 28 day strength increased linearly from 53.5 MPa for control concrete to 57.9 MPa for the concrete mix with 10 % of RHA admixture (

Figure 4). This unveiled the balance between CH and silica from RHA which continue to stabilize the pozzolanic reaction. The reaction produced additional C-S-H gel which fill the micro pores in the microstructure and increased the overall compressive strength of concrete. At 15 % of RHA admixture, the 28 day strength reduced to 54 MPa due to extra non-reactive RHA admixture more than the available CH. Further observation indicated that, compressive and flexural strength of concrete at all curing age reduced on addition of 15 % of RHA admixture. The reasons being the excess RHA in the microstructure, which increased the interfacial distance between the hydrated cement gel and aggregate which culminate to low strength. Therefore, 10 % could be decided as the optimum amount of RHA admixture to enhance minimum porosity, maximum parking density and compressive strength of HSHPC. It was also realized that, all concrete mixes containing RHA admixture showed superior performance in terms of strength over the control mix at 28 day curingage, (

Figure 4).

Figure 4

Compressive Strength versus Curing Period



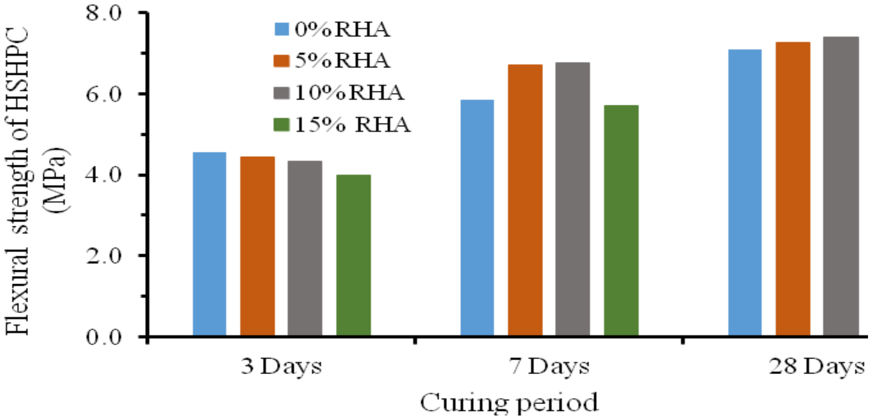
3.5. Effect of Rice Husk Ash on Flexural Strength of High Stregth, High Performance Concrete

Figure 5 shows the flexural strength of HSHPC concrete made of Portland cement and RHA admixture. The 3 day flexural strength of concrete was found to be 4.6 MPa for the control concrete which reduced to 4.0 MPa for the concrete mix containing 15 % of RHA admixture. The flexural strength reduced due to extra non-hydraulic materials in the microstructure and low CH concentration which was needed in the pozzolanic reaction. At 7 day curing period the flexural strength of HSHPC increased significantly for the mixes with 5 and 10 % RHA, (

Figure 5). The values of 6.7 and 6.8 MPa was found for 5 and 10 % of RHA admixture respectively. In contrast, 5.9 and 5.7 MPa were obtained for the control concrete and that containing 15 % of RHA admixture. The addition of 5 and 10 % RHA admixture indicated improved performance of HSHPC. The strength growth at 10% RHA was ascribed to a balanced CH - silica reactions which produced additional C-S-H gel.

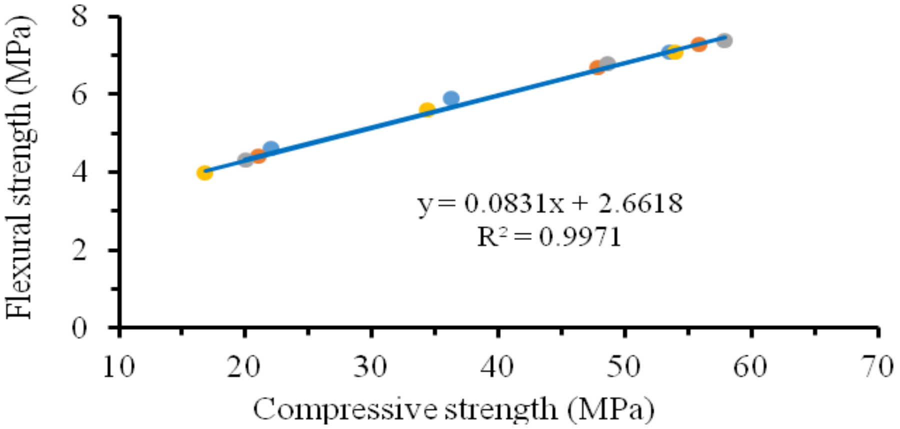
The 28 day flexural strength increased marginally from 7.1 MPa for the control concrete to 7.4 MPa for a concrete containing 10 % of RHA admixture. However, it drops to 7.1 MPa for a concrete with 15 % of RHA admixture. Observation attributed the slow rate of flexural strength growth to the brittleness which increased as the non-hydraulic RHA admixture increased in the microstructure. It was also observed that, further addition of RHA admixture to 15 % reduced the flexural strength of concrete at all curing ages. This was stirred by the increased the aggregate-paste interfacial distances that created microcracks initiation cites.

Figure 5
Flexural Strength versus Curing Period



shows the relationoship between flexural strength and compressive strength of HSHPC. Observation revealed linear relationship between compressive strength and flexural strength of HSHPC. The relationship can then be represented by exponential, linear or logarithimic equation giving approximatelly the same coefficient, $R^2 = 0.997$. The variable y representing the flexural strength and the variable x representing the compressive strength. The equation $y = 0.0831x + 2.6618$ can then be used accuratelly to estimate the flexural strength of HSHPC containg up to 15 % of RHA amixture and compressive strength above 40 MPa.

Figure 6
Flexural Strength - Compressive Strength Relationship



3.6. The influence of Rice Husk Ash on the Density of High Stregth, High Performance Concrete

Density of concrete increased with curing time and strength, (

Figure 6). At 7 and 28 day curing period, the density increased with increasing RHA admixture up to 10 %, but beyond 10 % of the RHA admixture, the density decreased (

Figure 7). The highest densities afforded at 7 and 28 day curing period were 2410 and 2492 kg/m^3 respectively (

Figure 6) achieved at 10 % of RHA admixture. The RHA admixture reduced the pores in the microstructure and improved the particle parking density leading to increased density and strength of HSHPC. This was attributed to formation of more hydration products after 3 day curing period occurring as pozzolanic reactions become steady. These steady reactions could be associated with balanced concentration of CH and the RHA silica in the microstructure. It could also be ascribed that, as the density were increasing the micro-fissures in the microstructure were continually closed. In this instance the particle parking densities increased while reducing the porosity and lowering permeability. The impermeable concrete is resistant to alkali silica reaction and has better durability. These also lead to increased resistance to transverse tension which improved compressive strength of HSHPC. From

Figure 4,

Figure 6 and

Figure 7, the 10 % of the RHA admixture could be the optimum amount for the utmost performance of HSHPC.

Figure 6
Density of HSHPC against Curing Period

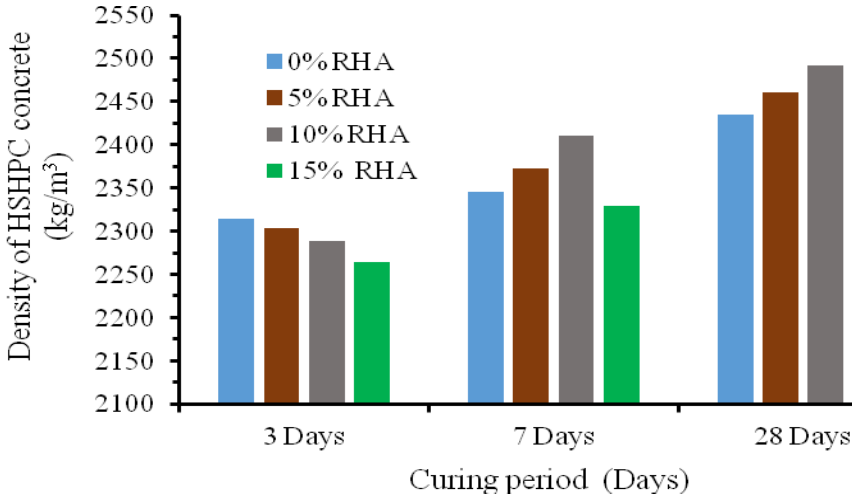
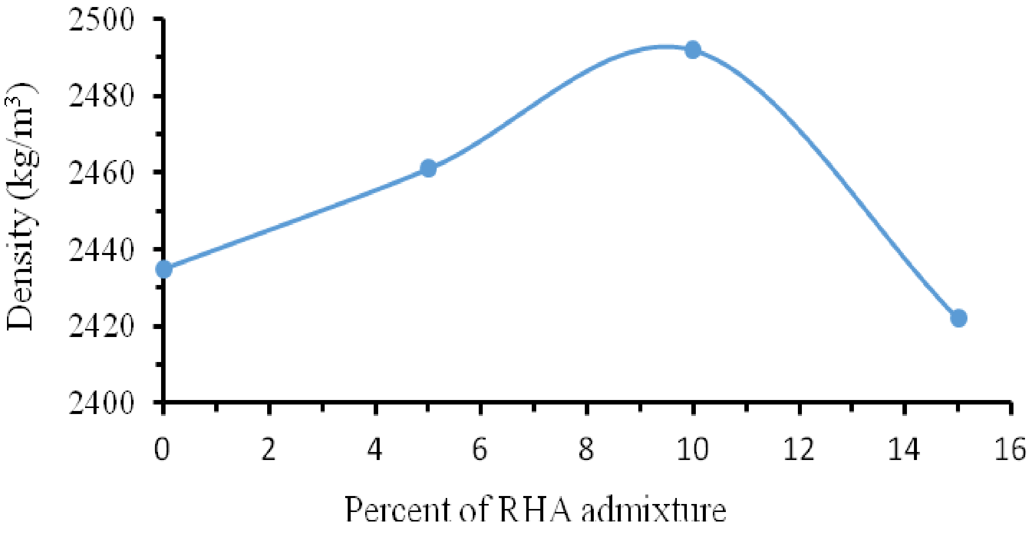


Figure 7

Density versus Percent of RHA Admixture



4.0. Conclusion and Recommendations

The fresh and hardened properties of HSHPC are highly influenced by the constituent materials. Therefore, materials selected for HSHPC production should conform to the specified physical and chemical requirements for optimum performance. Rice husk burnt at 600 °C and soaked for 1 hour produced rice husk ash with silica (SiO_2) content 93.04 %. This was the maximum percentage of silica produced as compared to other temperature of above 700 °C and below 600 °C. The properties of fresh concrete increased with increasing dose of RHA admixture up to 10 %. The maximum compressive strength attained for a concrete containing 10 % of RHA admixture was 57.9 MPa at 28 day curing period. The flexural strength afforded at 28 day curing period was 7.4 MPa at 10 % of RHA admixture but beyond this both compressive and flexural strength decreased. The maximum density of concrete afforded at 28 day curing period was 2492 kg/m^3 for a concrete containing 10 % of RHA admixture. Therefore, 10 % of RHA admixture can be added to concrete to improve durability since it is also the optimum for optimum parking density and minimum permeability. The same amount reduces the pore size and pore size distribution in HSHPC microstructure. Therefore RHA admixture is suitable for the mitigation of alkali silica reaction in concrete. Thus, 10 % of RHA admixture can be concluded as the optimum amount for the best performance of HSHPC. In this regards, 10 % of RHA admixture is recommended as the optimum amount for the production of HSHPC of class 40 and above for large structural concrete such as tall structures, large span reinforced and pre-stressed concrete bridges and dams. More research is recommended on the other pozzolanic materials to establish their potential for the production of HSHPC.

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