RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND MODULUS OF ELASTICITY OF SELF CONSOLIDATING HIGH PERFORMANCE CONCRETES (SCHPCS) INCORPORATING GSA AS SCM

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Abstract: This experimental work evaluates the relationship between compressive strength and modulus of Elasticity of self-consolidating High performance concrete (SCHPC) containing high volume of Groundnut Shell Ash (GSA) up to 40% substitution as SCM. A total of 210 specimens of the GSA blended SCHPCs comprising 105 cubes (100 x100 mm) and 105 cylinders (150x300 mm) were cured in water for 7,14,28 ,56, 92,120 and 180 days hydration periods and the compressive strength and Modulus of elasticity determined. The linear relationships were studied with regression analysis. The findings revealed that all the mixes met the Modulus of Elasticity values requirement of 18,000N/mm^2 to 42,000N/mm^2 and the compressive results show that three substitution levels of 0%, 10% and 20% attained the proposed design strength (40-130 Mpa) and also satisfied the requirement for self-consolidating and high strength concretes. In conclusion, 0%-20% GSA substitutions (SCHPCA0-SCHPCA20) indicated a strong linear relationship with regressions values obtained varies between 0.842 and 0.954 for the two variables. Addition of GSA as SCM has improved the mechanical properties of SCHPC and creates a strong relationship between the compressive strength and Modulus of Elasticity.

Keywords: *Compressive strength, GSA, Modulus of elasticity, Regression analysis and SCHPC.*

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1. Introduction

The global trend field of engineering materials development in the last few decades is a modification of ordinary concrete properties with the development of self-consolidating high performance concrete (SCHPC) by exploiting the benefits of high-range water reducer (HRWR) and supplementary cementing material for producing sustainable, durable, and environmentally friendly construction materials. In this research, the residual strength performance and Modulus of Elasticity of a groundnut Shell ash blended Self-consolidating high strength concrete was investigated. Groundnut shell ash (GSA) as supplementary cementing materials in SCHPC is a new trend in research area of development of new construction and engineering materials [1, 2]. The use of SCC/HPC in engineering and construction projects globally in recent time is because of its inherited advantages of ease of workability, self-compatibility, high strength and durability over ordinary concrete [2]. Apart from CO_2 emissions in cement production, the use of GSA has benefits such as less cement use, reduction in concrete production costs; reduces environmental pollution and improvement of the durability properties of the concrete. Many Researches have proven that GSA blended concretes are of better strength with better elasticity and minimal water absorption's [3,4, 5]. The use of GSA as SCM in SCHPC can greatly enhance the workability, durability and aesthetic appeal of the concrete. For this reasons, this work examined the strength performance and elasticity behaviour of SCHPC developed by incorporating GSA as SCM with precautionary measures in the design and production to prevent it vulnerability like convectional concrete of known deterioration inheritance. In this study, percentages of GSA substitutions were kept at (0%, 10%,20%, 30%, 40%) to produce SCHPC and characteristics performance were measured after curing in water at 7,14,28, 56,92,120 and 180 days hydration periods by determining its Compressive strength and Modulus of elasticity of the hardened concretes. The Design variables and percentage substitutions level of GSA (SCM) used for this research were based on specification guidelines in [6, 7,8] and similar researches carried out by[1,2,9,10, 11].

2. Materials and Method

Materials employed in this research work were; OPC/GSA as binder: river sand of 4.5 mm as fine aggregate: crushed stones of 12.5 mm as coarse aggregate, a super-plasticizers and clean water for mixing and curing medium. Groundnut shell ash (GSA) used for this research was obtained through controlled burning in an electrical furnace at temperature of 650 °C for 3hours. An amorphous class C ash was obtained as classified by [12, 13]. Consequently, the physical (sieve analysis, moisture content, specific gravity) and chemical (SEM, XRF and XRD) analysis were carried out on GSA at the Soil Mechanics Laboratory of the Department of Civil Engineering, Physic Electronics laboratory of Science laboratory Department, Federal Polytechnic, Ede Osun State and Department of Civil Engineering, University of Ibadan, Oyo state, respectively. The results of physical and chemical properties of all materials used are presented in tables 1and 2 and Figures 1.0 respectively. All aggregates used were of control moisture contents to prevent increase in the water content in the concrete mix. Cement used as the main binder is of Dangote brand that conforms to type1 cement as specified by [14].

Table 1.0: Physical properties of materials used

Property	CA	FA	OPC	GSA	Conplast SP430MS
size (mm)	10.5	4.5	-	-	-
Water absorption (%)	0.36	1.12	-	-	-
Specific gravity	2.63	2.18	3.08	1.87	
Fineness modulus	6.2	2.18			
Colour			Grey	Grey	Brown
Passed on a 45-µm (No. 325) sieve (%)			97	100	-
Relative Density (at 20oC):					1.190
pH (concentrate)					8.5

Source: Laboratory Analysis and Company Manual, 2018

2.1 Mix Proportions

A designed mix to obtain the target strength of 40 Mpa at 28 days hydration was used for the production of SCHPC cubes at water / cement ratio of 0.36. The target strength was opined based on similar research in development of high strength concrete with use of fly ash as SCM with 100Mpa at 28days [15].cement contents were replaced by mass of total binder at 0%, 10%, 20%, 30% and 40% with An amorphous groundnut shell ash.[1, 7, 11] recommends between 10% to 50% replacement levels for suitable SCHPC. The mix proportions and variables of all the mixes are presented in Table 2.0 and table 3.0 below. All the designed mixes had the same binder content of 510 kg/m^3, the coarse aggregate at 960 kg/m^3 and fine aggregate at 730 kg/m^3 for all the mixes. Super plasticizer (HRWR) was kept at 1.8% to total binder to achieve the required fresh properties of SCHPC. The samples were designed and labeled as SCMAO-SCMA4 which contains 0%, 10%, 20%, 30% and 40% GSA replacements.

Table 2.0: design Mix of SCHPC

Samples	Cement (kg/m^3)	Water (kg/m^3)	W/C Ratio	GSA (kg/m^3)	GSA (%)	F.A (kg/m^3)	C.A. (kg/m^3)	(S.P) (%B)
SCMA 0	510	185	0.36	0	0	730	960	1.8
SCMA 1	459	185	0.36	51	10	730	960	1.8
SCMA 2	408	185	0.36	102	20	730	960	1.8
SCMA 3	357	185	0.36	153	30	730	960	1.8
SCMA 4	308	185	0.36	204	40	730	960	1.8

Source: laboratory analysis and product manual, 2019

Table 3.0 Variables for concrete mixtures

Variables	by weight
W/B ratios	0.36 by weight
Binder content	510 kg/m^3
GSA	10%, 20%, 30%, 40% of binder by weight
Total air content	3%
HRWR dosage	1.8% of binder by weight
Net mixing time	7 to 13 minutes
Segregation ration	15% maximum

Figure1.0: SEM images (at 2500×), physical appearance of GSA resembling Portland cement and its XRD

The mineralogical and Morphological analysis of GSA were studied by using X-ray diffraction and SEM image as shown in figure 1.0 above. The SEM image revealed irregular surface with visible pores. The distinctly visible pores would enhance the pore structures formation of the concrete produced with this ash by improving the binding capacity of the component materials.

3.0 Results Analysis and Discussions

3.1Compressive Strength

Previous researches have proved that admixtures enhance the strength and durability properties of SCHPC at later stages [16, 17]. Incorporating GSA in this research with necessary precautions has proved the importance of this admixture with increase in compressive strength of the mixes as curing age increased up to 20% replacement and this is in accordance with [2]. Generally, strength development of the mixes increased and target strength obtained at 20% substitution level compared with control. These results are similar with those obtained by [18, 19, 20], with use of fly ash, GSA and several admixtures within the values specified by[21]for high strength concrete.

Table 4.0: Compressive Strengths of SCHPCs in Water

Samples	Mix	Compressive Strength In (N/mm^2)						
		7	14	28	56	92	120	180
SCMA0	OPC only	14.39	28.46	42.38	55.11	76.19	84.87	109.23
SCMA1	OPC+10% GSA	18.60	34.26	48.60	53.74	72.18	81.43	118.27
SCMA2	OPC +20% GSA	14.11	17.14	39.83	59.43	77.92	85.96	113.92
SCMA3	OPC +30% GSA	10.39	14.79	36.44	55.16	78.60	88.57	124.00
SCMA4	OPC +40% GSA	9.8	14.00	33.39	54.00	83.10	89.75	118.20

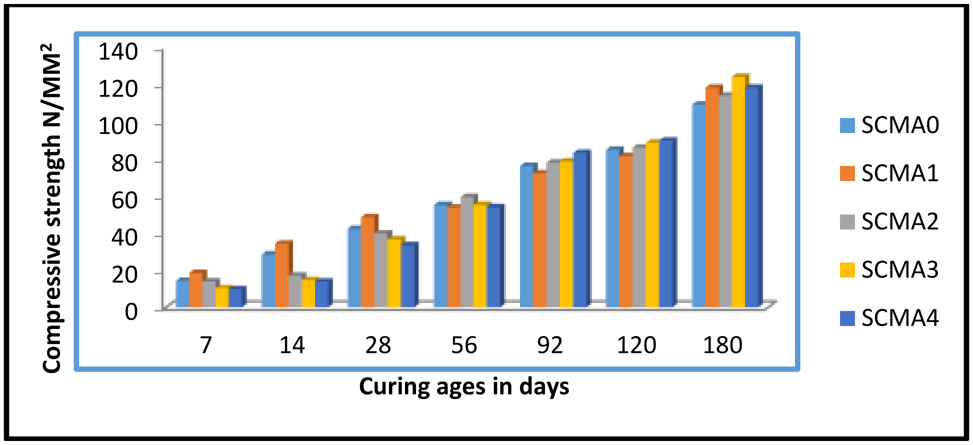


Figure 2.0: Compressive strengths of SCHPC's in water at different curing ages

Table 4.0 and figure 2.0 above presents an average compressive strength of SCHPC for various hydration periods of 7, 14, 28, 90, 120 and 180 days with percentage substitution level of cement with GSA (0%, 10%, 20%, 30% and 40%) and its strength developments variations at these curing ages of the study. The obtained results revealed gradual increase in compressive strength. At early curing age and up to 20% substitution with values of 14.39 N/mm^2, 18.60 N/mm^2, 14.11 N/mm^2, 10.39 N/mm^2 and 9.80 N/mm^2 for 0%, 10%, 20%, 30% and 40%GSA substitution levels respectively. The observed results was lower than values obtained by [19] with 26.13 N/mm^2 ,36.34 N/mm^2 , 30.37 N/mm^2 and 25.43 N/mm^{2}for 0%, 5%, 10% and 15%GSA substitution levels respectively. The behavioural pattern may be associated to the effect of GSA in reducing the reacting power of cement in the early strength development of SCHPC. However, at 28, 56, 90, 120 and 180 days, there were faster strength improvements in all GSA blended SCHPC than those control specimens (0%). The results as shown in Table 4.0 revealed that three substitution levels of 0%, 10% and 20% attained the proposed design strength (40-130 Mpa) in this SCHPC designed. The obtained values satisfied the requirement for self-consolidating and high strength concretes, strength development as obtained in similar researches by [9, 10, 22] with compressive strengths of 31.54 N/mm^2, 36.74 N/mm^2 and 41.52 N/mm^2 respectively. The flow value, V-funnel values and U-box values of these researchers was within the stipulated values of [7].However, the rate of strength development from 7days hydration periods and 28days hydration periods was higher than 30-75% increment obtained [9] with use of POFA and FLY ASH as their SCMs. These obtained compressive strength values reveals the suitability of GSA as SCM in developing SCHPC. In conclusion, the strength progression shows the superiority of SCHPC containing GSA over control specimen and values obtained are similar to that of [22] which recorded values of 31.22 N/mm^2, 29.00 N/mm^2, 27.60 N/mm^2, 25.70N/mm^2 and 21.80 N/mm^2 for 0%, 10%, 20%, 30% and 40% recycled coarse aggregate content at 28 days in producing a self-compacting concrete and that of [19] which recorded values of 32.90 N/mm^2, 37.21 N/mm^2, 34.07 N/mm^2 and 33.57 N/mm^2 for 0%, 5%, 10% and 15% GSA content respectively at 28days curing age.

3.2 Modulus of Elasticity

The static modulus of elasticity of concrete usually affected with the use of pozzolans (GSA) as SCM.[23], reported the effects of Pozzolans and similarities of values of modulus of elasticity of convectional and Self compacting concretes. Table 5.0 below indicated that control specimen

(0%GSA), has a greater values of the static modulus of Elasticity at early curing ages than those of the blended SCHPC. At 7 days, the values were 24451 N/mm^2, 24210 N/mm^2, 23568 N/mm^2, 23310 N/mm^2 and 20144 N/mm^2 for 0%, 10%, 20%, 30% and 40% GSA replacement of cement respectively. At 28 days, all the mixes met the requirement of 18,000 N/mm^2 to 30,000 N/mm^2 stipulated by [6] and that of 14,000 N/mm^2 to 42,000 N/mm^2 reported by [23]. For instance, the values were observed to increase at 9.89%, 4.75%, 10.30%, 9.40% and 4.60% for 0, 10, 20, 30 and 40%GSA substitution levels respectively. At 120 and 180 days, there was no significant difference between the values obtained for the control specimen and that of 10% and 20% GSA replacement with maximum strength increment of 4.24% attained at 20% GSA replacement in 120days hydration period. The increased in the value with curing age, particularly with 0 – 20%GSA content, indicated the fact that there is a continuous hydration and pozzolanic reactions. The reduction in elasticity with increase in GSA content could be attributed to higher carbon content (expressed as loss on ignition) and low quantity of cement in the mixes as a result of its replacement. This finding is in line with the result observed by [25] that static modulus of elasticity in compression of concrete mixed with different proportions of rice husk ash and tested at 28 and 90 days period revealed that after 90 days, mixtures containing 15% RHA showed 7% increase in static modulus of elasticity compared to the control concrete. They concluded that generally, concrete containing RHA had higher values when compared to the control concrete. On the other hand, [26] reported that the replacement of Portland cement by slag in concrete seems to decrease the modulus of elasticity for a compressive strength below about 55 N/mm^2 and to increase it slightly, by about 10%, for compressive strength greater than about 60 N/mm^2. Modulus of elasticity is reported to be low at early ages and high at later ages for fly ash-blended cement concrete [27].

Table 5.0: Summary of static modulus of elasticity of GSA blended SCHPC at different curing ages

SAMPLES	Static Modulus of Elasticity (N/mm^2)						
	7 days	14 days	28 days	56days	92 days	120 days	180 days
SCMA0	24451	27148	28537	28730	29034	30813	31556
SCMA1	24210	25431	26790	27862	31875	32043	32189
SCMA2	23568	23957	26417	28892	31154	32119	29460
SCMA3	23310	23359	25556	26986	28981	30482	23387
SCMA4	20144	22038	23059	25797	25863	21678	21183

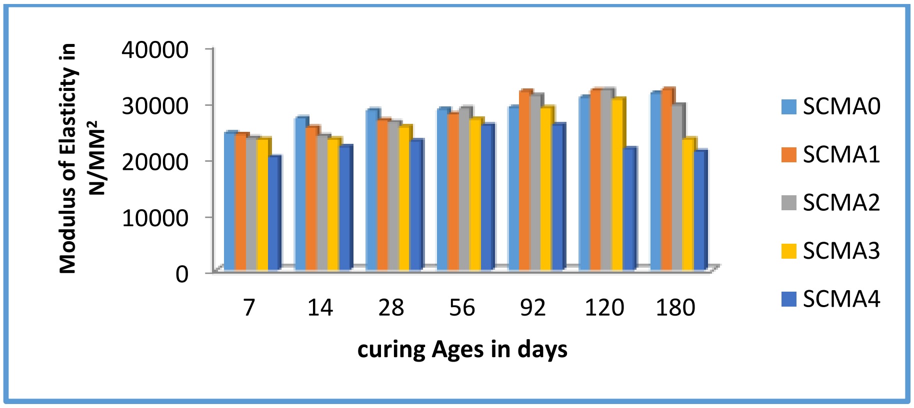


Fig.3.0: Effect of curing age on static modulus of elasticity of GSA blended SCHPC

3.3 Relationship between Compressive Strength and Static Modulus of Elasticity

An empirical relationship was established through mathematical regression analysis between the compressive strength and static modulus of elasticity of SCHPC incorporating different percentages of groundnut shell ash as SCM at various hydration periods (7, 14, 28, 56, 92, 120 and 180). The summary of detailed analysis is presented in Table 6.0 with cube root of the Compressive strengths obtained at various substitutions levels, Elastic Modulus values and Compressive strengths inclusive in the table. The results revealed a higher rate of increase in Modulus of elasticity as compressive strength of samples (SCHPCA0- SCHPCA40) increases. The observed results are similar to similar researches carried out by [28, 24, 29] in both self-compacting and ordinary concretes with strength relations attributed to the beneficial effect of improvement in the density of the interfacial transition zone, as a result of slow chemical interaction between the alkaline cement paste and aggregate, which is more pronounced for the stress – strain relationship than for the compressive strength of concrete. However, there are contradictory researches as regard modulus of Elasticity of an SCC with [30, 31] concluded that Modulus of Elasticity of SCC is lower than that of convectional concrete. [32] Associated contradictory of modulus of elasticity values between convectional concretes and SCC to the variations in materials components and rheological behaviour of SCC.

Table 6.0: Summary of relationship between compressive strengths and static modulus of elasticity of SCHPC incorporating GSA

GSA Content (%)	Curing Age (Days)	Static Modulus of Elasticity (Gpa)	Compressive Strength (N/mm^2)	Cube Root of Compressive Strength (N/mm^2)
0	7	24.451	14.39	2.43
10		24.210	18.60	2.65
20		23.568	14.11	2.42
30		23.310	10.39	2.18
40		20.144	9.80	2.14
0	14	27.148	28.46	3.05

10 20 30 40		25.431 23.957 23.359 22.038	34.26 17.14 14.79 14.00	3.25 2.58 2.45 2.41
0 10 20 30 40	28	28.537 26.790 26.417 25.556 23.059	42.38 48.60 39.83 36.44 33.39	3.49 3.65 3.42 3.32 3.22
0 10 20 30 40	56	28.730 27.862 28.892 26.986 25.797	55.11 53.74 59.43 55.16 54.00	3.81 3.77 3.90 3.81 3.78
0 10 20 30 40	92	29.034 31.875 31.154 28.981 25.863	76.19 72.18 77.92 78.60 83.10	4.24 4.16 4.27 4.28 4.36
0 10 20 30 40	120	30.813 32.043 32.119 30.482 21.678	84.87 81.43 85.96 88.57 89.57	4.39 4.33 4.41 4.46 4.47
0 10 20 30 40	180	31.556 32.189 29.460 23.387 21.183	109.23 118.27 113.92 124.00 118.20	4.78 4.91 4.85 4.99 4.91

The Modulus of elasticity of SCHPC is calculated based on materials components used in its productions. There are no specific approach meant for SCHPC and The expression, $E = 9.1F_{cu}^{0.33}$ proposed by [1] was applied for determination of Modulus of elasticity of SCHPC produced for this research. The results are presented in Figures 4.0 to 6.0 with regression analysis showing the various linear relationship. The regression equations below were generated for various SCHPCS produced:

SCHPCA0: $E_s = 2.7883F_{cu}^{0.33} + 18.177$; ($R^2 = 0.9409$)
(1)

SCHPCA10: $E_s = 4.2777F_{cu}^{0.33} + 12.300$; ($R^2 = 0.8774$)
(2)

SCHPCA20: $E_s = 3.3359F_{cu}^{0.33} + 15.619$; ($R^2 = 0.841$)
(3)

SCHPCA30: $E_s = 1.4332F_{cu}^{0.33} + 20.79$; ($R^2 = 0.2642$)
(4)

SCHPCA40: $E_s = 0.658F_{cu}^{0.33} + 20.446$ ($R^2 = 0.098$)
(5)

The regression equations above revealed that Elasticity of the SCHPC produced was decreasing with the increase in the percentage substitution of groundnut shell ash. There is no significant difference between generated expressions and that of [1] for normal-weight concrete. The linear regressions values of SCHPCs obtained varies between 0.842 and 0.954 for 0%-20% GSA substitutions (SCHPCA0-SCHPCA20), indicating a strong linear relationship between the two variables at these levels. A static modulus of elasticity of SCHPCs at any age up to 20% substitution level can be predicted by the model given by [1] for normal weight concrete.

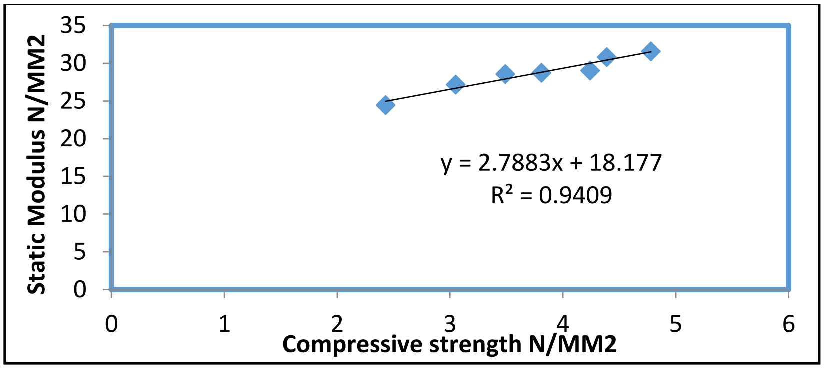
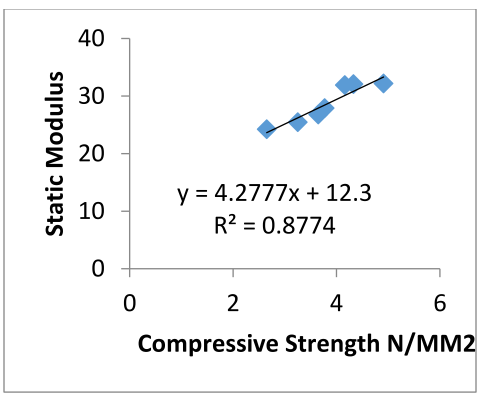


Figure 4.0: Relationship between static modulus of elasticity and compressive strength of SCHPC at 0%GSA content



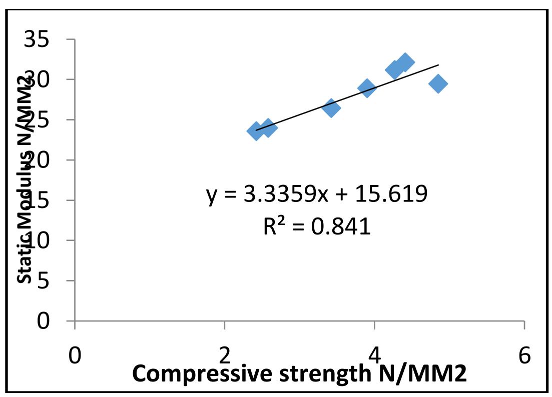


Figure 5.0: Relationship between static modulus of elasticity and compressive strength of SCHPC at 10% and 20%GSA contents respectively

4.0 Conclusions

This research work has revealed the importance of admixtures (GSA) on the properties of SCHPC as both compressive strength and modulus of elasticity properties greatly depend on characteristics of cement, cementitious material, aggregates and curing ages.

The compressive strength of GSA blended SCHPC is higher than the control with a continuous strength development comparable with that of the control. The optimum level of GSA replacement from structural load view point is 10% at curing age of 28days (having attained 122.50% of the design strength).

The relationship between compressive strength and static modulus of elasticity of GSA blended SCHPC up to 180 days fitted into the model given by BS 8110-2:1985 for normal-weight concrete. Static modulus of elasticity of SCHPC has been affected by the amount of GSA substitutions in the mix and the hydration periods of the specimen.

The characteristics strength and static modulus of elasticity values of the developed SCHPC at up to 20% replacement level performed better and is suitable for production of SCHPC in an environment where high strength, durability and ease of work are required.

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