Mechanical Properties of High-Performance Concrete with Guinea Corn Husk Ash as Additive

¹*Odeyemi, S.O., ²Anifowose, M.A., ¹Abdulwahab, R. and ³Oduoye, W.O.

¹Department of Civil and Environmental Engineering, Kwara State University, Malete, Nigeria

²Department of Civil Engineering, The Federal Polytechnic Offa, Offa, Nigeria.

³Department of Civil Engineering, Osun State University, Osogbo, Nigeria

*Corresponding author E-mail: samson.odeyemi@kwasu.edu.ng; +2348054147596

Abstract

Consideration on High Performance Concrete (HPC) has risen drastically because of the requirement for application of concrete volume with high strengths for construction work. In this study, the mechanical properties of HPC with Guinea Corn Husk Ash (GCHA) as supplement of cement was investigated. The proportioning of Ordinary Portland Cement (OPC) with GCHA is from 0 - 20%. Design of the concrete mix was done to achieve a characteristic strength of 50 N/mm². The chemical composition of the GCHA was determined using X-ray Fluorescence (XRF). Slump and compacting factor of fresh HPC were determined. Concrete cubes (for compressive strength), beams (for flexural strength) and cylinder (for split tensile strength) samples were cast and cured in water for 7 - 56 days. Density, compressive, flexural, and split tensile strengths were determined on the hardened HPC and were further examined using SEM analysis. Compressive strength at 56 days showed that control and inclusion of 5% GCHA gave strength 56.85 N/mm² and 57.76 N/mm², respectively above the designed target strength of 56.56 N/mm² while inclusion of 10% GCHA met characteristics strength of 50 N/mm². However, 5% GCHA-concrete had the highest flexural and split tensile strengths at 56 days of curing. Integration of 10% GCHA as replacement of OPC would produce concrete of higher strengths compared to conventional HPC at longer curing age. Based on the SEM results, uniform distribution of filler was obtained at 10% GCHA inclusion. At higher percentage of GCHA, resulting composite presents multiple and distinct grains with possible weak interfaces.

Keywords: Compressive strength, Flexural strength, Guinea Corn Husk Ash, High Performance Concrete, Split tensile strength

Introduction

High performance concrete (HPC) are in high demand because of its high strength, good workability, and better durability. The common strategy in increasing the strength of high-performance concrete is by lowering the water-cement ratio and increasing the cement content (Mahmud *et al.*, 2016). HPC is a type of concrete that fulfils distinct performance and uniformity requirements which would not be accomplished by adopting conservative materials and standard mixing, placing, and curing practices (Rana *et al.*, 2016). The focus on HPC has drastically risen because of the utilization of large volume of concrete, resulting to the growth in infrastructure such as Highways, Bridges, Buildings, Hydraulic Structures, and Industrial Structures (Choudhary *et al.*, 2014). HPC possesses high durability, fluidity, workability, density, modulus of elasticity, dimensional stability, and compressive strength, self-compacting, easy mixing, low permeability, higher flexural strength, resistance to chemical attack, cost effectiveness, and environmental friendliness (Mondal and Banerjee (2017).

HPC concrete is usually produced with materials such as Ground Blast Furnace Slag, Fly Ash or Silica fume in addition to cement to achieve its requirement. The materials are mixed with

Portland cement in varying proportions depending on the desired requirement (Choudhary *et al.*, 2014).

This research was aimed at using Guinea Corn Husk Ash (GCHA) as fractional replacement of cement in HPC to improve the strength of the concrete. GCHA is obtained from the combustion of Guinea Corn Husk (GCH) either in a furnace (controlled temperature) or open burning (uncontrolled temperature). Akinloye *et al.*, (2014) described GCHA as agricultural waste which is derived from the processing of guinea corn. Close to ten (10) million tonnes of guinea corn husk are produced yearly in the world. About two (2) million tonnes of Guinea corn are harvested per annum in Nigeria (Akinloye *et al.*, 2014). GCH are regarded as wastes by farmers and large quantities of the husks are burnt in preparation for another farming season (Adebayo *et al.*, 2017). However, commercial use of guinea corn husk (with its ash) is the alternative solution to disposal and environmental problems caused by farmers through these wastes.

Ndububa and Nurudeen (2015) examined the influence of GCHA as fractional replacement for cement in concrete. The findings showed that GCHA meets the requirement of a pozzolan in accordance with standards and it was concluded that GCHA is a good pozzolan for normal concrete while the optimum replacement levels is between 5% - 10%. However, it was observed that much work have not been done on utilization of GCHA for production of concrete especially in Nigeria where large deposit of GCH can be found. Nonetheless, the study did not examine consistency and setting time of GCHA; flexural and split tensile strengths; Scanning Electron Microscopy (SEM) of hardened concrete; 56 days curing age and mechanical properties of HPC.

Subbulakshmi *et al.*, (2014) studied the strength behaviour of HPC using silica fume, fibres and fly ash. The study revealed that 20% fly ash plus 10% silica fume possess better flexural, compressive and split tensile strengths than the control mix. Farzadnia *et al.*, (2011) reviewed the combination of inorganic admixtures in binary, ternary and quaternary blended mortars in concrete. It was concluded that metakaolin, rice husk ash, silica fume, blast furnace slag, fly ash and palm oil fuel ash can improve the dry shrinkage, compressive, creep and tensile strength of concrete. Ismeik (2009) studied the influence of inorganic admixtures on the mechanical properties of HPC made from local materials. The findings showed that the optimum compressive and flexural strengths was observed at a replacement level of 10% for silica fume content and at 15% replacement of fly ash content.

A study by Kannan (2017) on HPC using silica fume and fly ash at 0 - 10% replacement of silica fume and 10% unchanging replacement of fly ash to investigate its mechanical properties at 7 and 28 days. The findings showed that the HPC containing 7.5% of silica fume produced compressive, split tensile and flexural strengths of 61.33 N/mm², 5.83 N/mm² and 5.96 N/mm², respectively at 28 days when compared with conventional concrete. While HPC containing 7.5% of silica fume blended 10% fly ash produced compressive, split tensile and flexural strengths of 57.33 N/mm², 5.19 N/mm² and 5.36 N/mm², respectively. Hence, it was evident that concrete containing silica fume alone attains higher strength than those containing silica fume with fly ash.

Magudeaswaran and Eswaramoorthi (2013) examined the mechanical properties on micro silica (silica fume) and fly ash as partial cement replacement. The study showed that 5% silica fume blended 10% fly ash gave maximum compressive strengths of 61.33 N/mm² at 28 days compared to 54 N/mm² for the control mix. The optimum replacement for the split tensile and flexural strengths were obtained at 15% silica fume blended 7.5% fly ash (3.60 N/mm²) and 5% silica fume blended 2.5% fly ash (9.91 N/mm²), respectively. Thus, HPC containing silica fume blended fly ash attained enough strength for structural use.

Basavaraja *et al.*, (2018) studied strength properties of HPC by means of ultra-fine fly ash and nano silica. Optimum compressive, split tensile and flexural strengths of 82.36 N/mm², 5.51 N/mm² and 82.36 N/mm², respectively was achieved at 10% of ultrafine fly ash blended 4.5% Nano-silica admixtures. This generated a higher strength when compared to conventional concrete. Banjare and Jaiswal (2017) determined the performance of Supplementary Cementitious Materials (SCM) on high strength concrete mixes with Fly ash, Metakaolin, Silica Fume and combinations of the ashes. The fulfilment of the compressive strength of the fly ash combined silica fume performed better than the control mix.

Hunchate *et al.*, (2014) studied HPC incorporated with silica fume and superplasticizer. It was observed that the compressive strength increased as the proportion of the silica fume rises to 15%. Likewise, as the proportion of cement replacement with silica fume rose, the workability of the HPC declined. Dembovska *et al.*, (2017) studied the influence of pozzolanic additives on the strength development of HPC. In the study, silica fume (10% by weight of cement) led to increase in bending and compressive strengths (108MPa) of the HPC at 56 days.

Sata *et al.*, (2007) studied the influence of pozzolan obtained from waste materials on mechanical properties of high-strength concrete. Pulverized coal combustion fly ash (FA), Fluidized bed combustion fly ash (FB), Rice husk–bark ash (RHBA), and Palm oil fuel ash (POFA) were utilized in partly replacing Portland cement Type I to produce high-strength concrete. Their findings recommend that FA, FB, RHBA and POFA are suitable as substitutes to cement in the manufacture of high-strength concrete without altering the mechanical configuration of concrete.

Based on the previous research, it was observed that much work have not been done on utilization of GCHA for production of concrete and no study was found on utilization of GCHA in HPC (as of the time of completing this study in 2019). However, the study of Ndububa and Nurudeen (2015) on GCHA was limited to normal strength concrete of mix ratio 1:2:4 (water cement ratio of 0.65) with maximum strength of 26.27 N/mm² and maximum curing age of 28 days. This study examined the oxide compositions of GCHA; consistency and setting time of GCHA; fresh properties (slump and compacting factor) of HPC produced with GCHA; compressive, flexural and split tensile strengths of HPC produced with GCHA, and Scanning Electron Microscopy (SEM) of HPC produced with GCHA.

Materials and Methods

Materials used in this study are Dangote cement brand of OPC (Grade 42.5R) with specific gravity of 3.13; clean water; natural sand passing through sieve 4.75 mm and crushed stone of maximum diameter 12.5 mm both meeting the standard specified in BS 882 (1992); Paracel Superplasticizer which conformed to ASTM C494 (1999) was used and guinea corn husk ash (GCHA) with specific gravity of 2.80. The GCH were sourced from a milling store at Ijagbo, Oyun Local Government of Kwara State. The husks were burnt to ashes at a temperature of 650 °C by Thermolyne Furnace at Foundry and Forging Workshop, Mechanical Engineering Department, The Federal Polytechnic Offa. The ashes were further ground to finer particles with a milling machine and allowed to pass through sieve 90 µm (micron). The GCH and GCHA are presented in Figures 1 and 2 while Table 1 shows the physical properties of the materials.

Figure 1: Guinea corn husks

Figure 2: Guinea corn husks ash

The Fineness of OPC and GCHA were determined by sieving method, using sieve No. 9 (90 microns). The empty pan was weighed, and the weight was recorded. One hundred (100) grams of the cement sample was added to the weighing pan with the help of spatula. The new reading was taken as weight of empty pan plus 100 grams of cement. The cement was placed in the sieve and continuously sieved through circular and vertical motion for a period of 15 minutes. The residue left on the sieve was weighed and the weight was recorded (this weight shall not exceed 10% by weight of 100g of cement used for OPC). The fineness was obtained using equation 1.

$$\text{Fineness} = \text{Percentage of Sample Retained on Sieve} \quad (1)$$

The fineness modulus was conducted in accordance with BS EN 933-1 (2012). The test sample was oven dried at temperature of $110 \pm 5^\circ \text{C}$ and weighed. The sample was sieved with a set of BS sieves and electric sieve shaker. On completion of sieving, the materials on each sieve were weighed. Cumulative weight passing through each sieve was calculated as a percentage of the total sample weight. Fineness modulus was obtained (using equation 2) by adding cumulative percentage of aggregates retained on each sieve and dividing the sum by 100.

$$\text{Fineness Modulus} = \frac{\text{Total Cumulative \% Retained}}{100} \quad (2)$$

Specific gravity of the materials was done in accordance with BS 1377:2 (1990). The samples were screened on BS sieve thoroughly to remove unwanted particles and other deleterious materials. The weight of empty bottle was recorded as W_1 . The sample were filled into the bottle and weighed; the weight was recorded as W_2 (weight of bottle + dry sample). The bottle was filled gradually with distilled water to gauge mark, soon after the end of soaking, air entrapped and bubbles on the surface of the sample was removed by shaking the bottle and the weight was recorded as W_3 (weight of bottle + dry sample + distilled water), after which the bottle was emptied and oven dry. The bottle was then filled with distilled water to the gauge mark and weighed as W_4 (weight of bottle + distilled water). The specific gravity was obtained using equation 3.

$$\text{Specific Gravity} = \frac{w_2 - w_1}{(w_4 - w_1) - (w_3 - w_2)} \quad (3)$$

Table 1: Physical properties of materials

Test	Materials			
	OPC	GCHA	Fine Aggregate	Coarse Aggregate
Fineness (%)	2.5	7		
Fineness Modulus (%)			2.8	4.0
Specific Gravity	3.13	2.80	2.67	2.69

The replacement proportioning of OPC with GCHA were 0, 5, 10, 15 and 20%. This range of replacements was in conformity to a previous study by Ndububa and Nurudeen (2015). Consistency and setting time of GCHA were determined in accordance with BS EN 196-3 2005+A1:2008 (2009) using the Vicat Apparatus. Slump and compacting factor were conducted on the fresh properties of HPC. Both tests conform to BS EN 12350-2 (2009) and BS EN 12350-4 (2009), respectively. One (1) percent of superplasticizer (SP) by mass of cement was added to the mix to improve the strength of the concrete thereby reducing the water cement ratio. Concrete mix design was adopted in accordance with COREN Mix Design Manual (2017) with a characteristic strength of 50 N/mm² and designed target mean strength of 56.56 N/mm². Forty-five (45) concrete cubes were produced (9 cubes for the control mix and 36 cubes for concrete with GCHA), Thirty (30) rectangular concrete beams (6 beams for the control mix and 24 beams specimen with GCHA) and a total number of 45 cylindrical concrete samples (9 cylindrical specimens for the control mix and 36 cylindrical specimens for concrete with GCHA) were formed. The concrete specimens were immersed in water for a period of 7, 28 and 56 days. At the end of each curing ages, density of the concrete cubes was conducted in conformity to BS EN 12390-7 (2009). While compressive, flexural and split tensile strengths of the concrete cubes, beams and cylindrical samples were carried out in accordance to BS EN 12390-3 (2009), BS EN 12390-5 (2009) and BS EN 12390-6 (2000), respectively using Haida Universal Testing Machine (UTM) of 2000 kN capacity at the Materials and Structures Laboratory, Department of Civil Engineering, Osun State University, Osogbo, Nigeria. The oxide composition of the GCHA was carried out at the National Agency for Science and Engineering Infrastructure (NASENI), Centre of Excellence, Nanotechnology and Advanced Material, Akure, Nigeria with the aid of Skyray EDX 3600B Energy Dispersive X-ray Fluorescence (XRF) Spectrometer. Scanning Electron Microscopy (SEM) was conducted on GCHA hardened concrete specimens. The SEM images were conducted at Kwara State University, Malete and measured on a Scanning Electron Microscope (ASPEX 3020) at 16.0 kV accelerating voltage. The samples were coated with gold using Balzer's sputtering device before observing them in the microscope.

The mix proportions used are presented in Tables 2 to 4.

Table 2: Mix proportions for concrete cube

W/C Ratio	Cement (kg)	GCHA (%)	GCHA (kg)	SP (g)	Aggregates	
					Fine (kg)	Coarse (kg)
0.31	24.60	0	0	246	19.35	35.85
0.31	23.37	5	1.23	246	19.35	35.85
0.31	22.14	10	2.46	246	19.35	35.85
0.31	20.91	15	3.69	246	19.35	35.85
0.31	19.68	20	4.92	246	19.35	35.85

Table 3: Mix proportions for concrete beam sample

W/C Ratio	Cement (kg)	GCHA (%)	GCHA (kg)	SP (g)	Aggregates	
					Fine (kg)	Coarse (kg)
0.31	24.60	0	0	246	19.08	35.40
0.31	23.37	5	1.23	246	19.08	35.40
0.31	22.14	10	2.46	246	19.08	35.40
0.31	20.91	15	3.69	246	19.08	35.40
0.31	19.68	20	4.92	246	19.08	35.40

Table 4: Mix proportions for concrete cylindrical sample

W/C Ratio	Cement (kg)	GCHA (%)	GCHA (kg)	SP (g)	Aggregates	
					Fine (kg)	Coarse (kg)
0.31	38.70	0	0	387	30.33	56.25
0.31	36.76	5	1.94	387	30.33	56.25
0.31	34.83	10	3.87	387	30.33	56.25
0.31	32.89	15	5.81	387	30.33	56.25
0.31	30.96	20	7.74	387	30.33	56.25

Results and Discussion

Oxides composition of GCHA

The oxide composition of the GCHA is presented in Table 5.

Table 5: Oxides composition of GCHA

Content	Percentage (%)
SiO ₂	66.06
Al ₂ O ₃	4.44
Fe ₂ O ₃	4.36
CaO	2.90
MgO	0.00
K ₂ O	10.79
Na ₂ O	0.00
SO ₃	1.74
Mn	0.05
Zn	0.42

The summation of the oxides - SiO₂, Al₂O₃, and Fe₂O₃, of GCHA used in this research, is 74.86 % with silicon dioxide (SiO₂) possessing the maximum percentage of oxide composition. This fulfils the condition for a supplementary cementing material given in BS EN 197-1 (2011). In addition, the sum of the oxides - SiO₂, Al₂O₃, and Fe₂O₃ of the GCHA, which is above 70% agrees with the previous finding by Ndububa and Nurudeen (2015).

Consistency and setting time of OPC-GCHA

The consistency and setting time results of the OPC-GCHA are presented in Figures 3 and 4 respectively.

Figure 3: Consistency of OPC-GCHA HPC

Figure 4: Setting time of OPC-GCHA HPC

The results from Figure 3 shows that 20% GCHA by weight of OPC have the highest consistency while 0% have the lowest consistency. However, as the ratio of replacement of OPC increased, the consistency also increased. It should be noted that the specific gravity of GCHA is lower than that of OPC, resulting in larger volume of GCHA compared with the OPC, since the OPC was replaced by mass. This led to addition of more water to form a paste for consistency for the different percentages of GCHA in the blended OPC (Adesanya and Raheem, 2009). ASTM

C150/C150M (2012) recommends 45 minutes as the least for initial setting time and 375 minutes as the extreme for final setting time while BS EN 197-1 (2000) recommends 60 minutes as the least for initial setting time for 42.5R OPC. The outcome of the setting time (Figure 4) reveals that all percentage replacement (OPC/GCHA) conformed to the least initial time and highest final time specified by ASTM C150/C150M (2012). The behaviour of the consistency and setting correlates with the earlier study by Ige *et al.*, (2017) and Anifowose *et al.*, (2018).

Workability of fresh concrete

The results for the workability (slump and compacting factor) of fresh HPC are presented in Figures 5 and 6.

Figure 5: Slump of OPC-GCHA HPC

Figure 6: Compacting factor of OPC-GCHA HPC

From Figure 5, the slump height values reduced as the proportion of GCHA by weight of OPC surges. This shows that the concrete became stiff as the proportion of GCHA by weight of OPC increases. This agrees with the submission by Ige *et al.*, (2018) that SCM absorb more water in concrete which makes it become less workable. The high demand for water as the GCHA content increases is as a result of the increased amount of silica in the mixture (Obilade, 2014). Nonetheless, the compacting factor value (Figure 6) reduced at 10% replacement and afterwards increased at 15 and 20%. Compacting factor is suitable for concrete of low workability (Shetty, 2000). The compacting factor values in Figure 6 fell within the minimum value of 0.70 and maximum value of 0.98 specified by BS EN 12350-4 (2009).

Density of fresh concrete

The mean density of the GCHA-HPC cubes conducted is as presented in Table 6.

Table 6: Density of Concrete Cubes

Replacement of GCHA (%)	Mean Density (Kg/m ³)		
	7 Days	28 Days	56 Days
0	2489	2607	2610
5	2489	2578	2615
10	2459	2419	2582
15	2350	2359	2480
20	2300	2330	2476

The densities of all the concrete cubes formed is within the boundary of 2300 kg/m³ - 2615 kg/m³ for structural concrete as specified in BS EN 12390-7 (2009). The density of the concrete declined as the proportion of GCHA increased and this corresponds to the study by Magudeaswaran and Eswaramoorthi (2013) on HPC. However, the density of the cubes increased with increase in curing age, which leads to improvement in unit weight due to prolongation of curing (rate of hydration). The maximum unit weight of 2615 kg/m³ recorded at 5% GCHA signified the peak compressive strength obtained at 56 days curing.

Compressive strength

The compressive strength results of the GCHA-HPC at 7, 28 and 56 days are presented in Figure 7.

Figure 7: Compressive strength of OPC-GCHA HPC

The compressive strength results at 7 days curing shows that the control and 5% GCHA met the least required compressive strength of 36 N/mm² for concrete grade 50 as contained in BS 8110-2 (1985) while the strength of 10% GCHA, 15% GCHA and 20% GCHA are below the required strength. Likewise, at 28 days of curing, the compressive strength of 0% GCHA and 5% GCHA met the least required compressive strength of 50 N/mm² for concrete grade 50 as contained in BS 8110-2 (1985) while the strength of 10% GCHA, 15% GCHA and 20% GCHA falls below the required strength. At 56 days curing age, the compressive strength of the control and 5% GCHA is above the designed target mean strength of 56.56 N/mm² while the compressive strength of 10% GCHA met the characteristics strength of 50 N/mm² but that of 15% GCHA and 20% GCHA falls below the designed target mean strength and characteristics strength. Nonetheless, the findings reveal that the compressive strength of concrete rises with increase in curing age and 5% GCHA-concrete had the highest strength of 57.76 N/mm². This is followed by the control (56.85 N/mm²), 10% GCHA (50.87 N/mm²), 15% GCHA (45.82 N/mm²), and 20% GCHA (43.83 N/mm²).

Since SCM in concrete tends to gain strength at a longer curing age, the optimum GCHA that conforms to the characteristic compressive strength of 50 N/mm² is 5% and 10% GCHA replacement. The highest compressive strength (57.76 N/mm²) obtained at 5% GCHA agrees and corresponds to the optimum replacement of GCHA reported by Ndububa and Nurudeen (2015) for use in concrete production. However, the study of Ndububa and Nurudeen (2015) was limited to normal concrete with maximum strength of 26.27 N/mm² (obtained at 5% GCHA), compressive strength and maximum curing age of 28 days.

Flexural strength

Results of the flexural strength of GCHA-HPC at 7, 28- and 56-days curing are presented in Figure 8.

Figure 8: Flexural Strength of OPC-GCHA HPC

The outcome reveal that the flexural strength improved as the curing age increased. It was further observed that 5% GCHA have the peak flexural strength at 56 days of curing unlike 28th day and 7 days where the conventional concrete has the peak strength. Nonetheless, 7 days flexural strength of 20% GCHA-Concrete was higher than that of 28th day curing. This is an indication of a drop in strength at 28th day which later improved at 56 days of curing age. At 56 days, 5% GCHA provides the highest flexural strengths which negates the optimum replacement reported by Ismeik (2009) and Subbulakshmi *et al.*, (2014). This is due to the difference in the SCM used in this research as compared to the one used by the Authors.

Split tensile strength

The split tensile strength result on GCHA-HPC at 7, 28- and 56-days curing are presented in Figure 9.

Figure 9: Split Tensile Strength of OPC-GCHA HPC

Just as observed in the flexural strength, the results shown in Figure 9 reveal that the split tensile strength increased as the curing age increased. It was also observed that 5% GCHA replacement gave the highest splitting strength at 56 days of curing unlike 28th day and 7th day results where the conventional concrete had the highest strength. However, GCHA did not perform better in terms of optimum replacement of cement in HPC when compared with fly ash plus silica fume, silicafume and flyash, silicafume blended flyash, and micro silica (silica fume) blended fly ash used by Subbulakshmi *et al.*, (2014), Ismeik (2009), Kannan (2017) and Magudeaswaran and Eswaramoorthi (2013), respectively.

Microstructure of HPC

The SEM images were measured and presented in Figures 10a-e.

(a) 0% GCHA Inclusion

(b) 5% GCHA Inclusion

(c) 10% GCHA Inclusion

(d) 15% GCHA Inclusion

(e) 20% GCHA Inclusion

Figure 10: SEM Images of OPC-GCHA HPC

From the SEM micrographs in Figure 10, best uniform distribution of filler was obtained at 10% GCHA inclusion. At higher percentage of GCHA, resulting composite presents multiple and distinct grains with possible weak interfaces. These weak interfaces can provide weakness to the overall mechanical properties of the composite. On the other hand, the GCHA inclusion is expected to influence the mechanical properties of the composite with optimum values expected at 10% GCHA after 56 days curing. These improved properties can be because of crack deflection/impediment by the GCHA filler at the appropriate content.

The SEM results thus corroborates the results obtained from the compressive, flexural, and split tensile strength tests which reveals that OPC-GCHA HPC will perform optimally when GCHA is used as a replacement for OPC up to 10%.

Conclusion

The following inferences were made from the study:

- i. Guinea Corn Husk Ash meets the requirement for pozzolanic materials.
- ii. All proportions of replacement of OPC with GCHA considered in the study meets the requirement for minimum initial and maximum final setting time for OPC.
- iii. Concrete becomes stiff (less workable) as percentage of GCHA increases.
- iv. Up to 5% GCHA and 10% GCHA replacement can be used for production of concrete grade 50 provided the minimum curing days is 56 days.

- v. 10% GCHA is recommended as the optimum replacement since it meets the 50 N/mm² characteristics strength at 56 days curing age.

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