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ORIGINAL RESEARCH ARTICLE

EVALUATION OF THE INFLUENCE OF GROUND WASTES GLASS ON MECHANICAL PROPERTIES OF HIGH PERFORMANCE CONCRETE

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ABSTRACT

The construction industry is largely reliant on the use of cement-based products. Every tonne of ordinary Portland cement (OPC) emits equivalent amount of CO_2 into the atmosphere, contributing to increased raw material consumptions and environmental concerns. In this regard, the use of waste materials that can be blended with OPC as partial or full replacement to reduce the environmental impacts is strongly desirable. This research was experimentally carried out to evaluate the influence of ground waste glass (GWG) as a partial replacement of cement in high performance concrete (HPC). A grade 50 HPC was designed based on ACI 211.1-91. Various experiments were carried out to determine the mechanical properties of the HPC. Tests include specific gravity of constituent materials, sieve analysis of GWG and aggregates, slump flow of fresh HPC, compressive, splitting tensile and flexural strengths of hardened HPC were carried out. The chemical composition analysis of GWG was conducted using X-Ray Fluorescence (XRF) analytical method. HPC cubes, cylinders and beams were cast, cured and tested at curing ages of 3, 7, 28, 56 and 90 days using 0, 5, 10 15, 20 and 25 percentage replacement levels. The optimum compressive strength of 57.44 N/mm^2 was obtained at 10% cement replacement after 28 days of curing age. The slump test result shows that the workability of the HPC decreased as the GWG content increases. Generally, the strengths of HPC reduced as the percentage of GWG replacement increased beyond 10% but increases with curing age. Therefore, 10% is the optimum replacement level of GWG for cement in HPC.

1.0 Introduction

Concrete is the most used construction material due to its satisfying performance in strength requirements and its ability to be moulded into a variety of shapes and sizes. Nowadays, the higher demand for housing and infrastructure, accompanied by recent developments in civil engineering facilities, such as high-rise structures, offshore platforms, tunnels, highway pavement, hydropower structures and long-span bridges associated with long term poor performance and poor consolidation of conventional concrete (CC) especially in congested reinforcement led to accelerated research for the development of concrete which would score on all the aspects of strength, workability, durability, affordability. Thus, to overcome the aforementioned shortcomings associated with CC, high performance concrete (HPC) was introduced due to its technical and economic advantages of high strength, high early strength, high modulus of elasticity, high durability and long life in severe environments, resistance to chemical attack, toughness and impact resistance, ease of placement, compaction without segregation (Mehta and Aitcin, 1990; Aitcin and Neville, 1993; Bickley and Mitchell, 2001).

The constituent materials used for the production of HPC are the same as those for CC except that HPC has higher cement content about 450-550kg/m^3, silica fume or any other supplementary cementitious materials and always a superplasticizer (Neville and Brooks, 2010). The higher cement content could produce substantial heat of hydration in the concrete due to reaction between cement and water, lead to cracking. Furthermore, the higher cement content will necessitate the production of more cement, which will led to global warming and climate change due to the emissions of green-house gases like CO_2 to the atmosphere. The International Energy Agency (IEA) in the year 2020 reports that the cement industry emits 2.4 billion tons of CO_2 corresponding to 7% of total global emissions. The practice of incorporating the industrial waste materials has gained tremendous attention in research to develop greener and sustainable building materials. In Nigeria, 4% of the solid wastes generated are glass Micheal *et al., (*2014) which is disposed in the form of glass bottles from beverage factories and glass sheets from ceramics industries. Glass disposal in landfill could have significant negative effects on the environment because it is non-biodegradable. Therefore, recycling the waste glass as supplementary cement materials into concrete production could be a viable solution not only to the pollution problem, but also to the problem of the high cost of building materials.

The American Concrete Institute (ACI Committee 363, (1998)) defines HPC as concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely when using conventional constituents and normal mixing, placing and curing practices. HPC enhances the service life of the structure and suffers less damage which would reduce overall costs. HPC consist of all ingredients of CC with chemical and mineral admixtures. Chemical admixtures, usually a superplasticiser which reduces the water content, thereby reducing the porosity within the hydrated cement paste (Bharatkumar *et al.,* 2001) and supplementary cementitious materials generally called mineral admixtures and or pozzolana. The pozzolana was introduced to reduce the cost, overcome the adverse effects of OPC and utilize wastes. Also, the use of pozzolana improves/modifies fresh and hardens properties of concrete as well as microstructure of the concrete matrix resulting in stronger and durable concrete. This is due to the reaction between the amorphous silica of the pozzolana and calcium hydroxide during the cement hydration.

Glass is a non-crystalline amorphous solid that is often transparent and has widespread practical, technological and decorative usage. Glass is an immensely versatile material used every day in numerous applications. It is produced in many forms such as container glass, flat glass, and bulb glass. Glass is an inert material that could be recycled and used many times without changing its chemical property (Shayan and Xu, 2004). It is an amorphous material with high silica content, so it is reasonable to expect fine glass powder to be used as pozzolana and/or partial replacement of cement in concrete. This is also a higher value choice than the use of glass as aggregate, not only because it makes full use of its physical and chemical properties, but also because cement is more expensive than aggregate, thus offering more economic and environmental advantages. Several researches show that, at a higher age, GWG with 15% to 20% of cement replacement provides compressive strengths exceeding those of control concrete (Lalitha et al., 2017, kumarappan, 2013, Nassar and Soroushian, 2011). However, a study by Rashed (2014) showed that previous studies with glass addition were not conclusive considering workability and strength. In this research, we tried to evaluate the influence of GWG as partial replacement OPC in the production of HPC.

2. Materials and Methods

2.1 Materials

Grade 42.5 OPC, manufactured in Nigeria by BUA Group, was used it was obtained from a major dealer along Gwarzo Road, Kano State, Nigeria. The coarse aggregate is a crushed granite rock of nominal size of 20 mm obtained from monkey rock quarry, Kano-Nigeria. The fine aggregates used is naturally occurring clean river sand obtained from Challawa river, Kano. Potable tap water at Civil Engineering laboratory of Bayero University, Kano was used for mixing and curing of specimens. Conplast SP 342 MS, which is a chloride free super-plasticising admixture based on selected sulfonated naphthalene polymer was also used. GWG was prepared from transparent soda-lime glass waste. Broken waste glasses were collected from disposal sites at Kofar-ruwa market, Kano-Nigeria. The samples were cleaned, given time to dry and crushed into smaller pieces using a mortar and pestle. The crushed waste glasses were ground to a fine powder using a model 2A corn milling machine manufactured by Nildeep Talavia, India, then sieved through a 75µm BS sieve. The X-Ray Fluorescence (XRF) analysis of OPC and GWG was conducted using a model FTIR-8400S manufactured by Shimadzu, Japan, at Spectral Laboratory Services, Kaduna-Nigeria.

2.2 Methods

To achieve the objectives of this study, HPC grade 50 was designed based on ACI 211.1 (1991). Six (6) mixes as shown in Table 1 were used, G-00 is the control mix and G-05, G-10, G-15, G-20 and G-25 are mixes containing GWG at replacement levels of OPC by weight at 5, 10, 15, 20, and 25%, respectively. The mixes were used for the determination of the slump flow in accordance with BS EN 12350-2 (2000). The test for compressive, splitting tensile and flexural strengths of GWG-HPC was carried out in accordance with BS EN 12390-2 (2009), BS EN 12390-6 (2009) and BS EN 12390-5 (2009) respectively. The specimens were prepared and cured for 3, 7, 28, 56 and 90 days, all tests were conducted for three replicates and averages were evaluated.

Table 1. Grade 50 HPC mix proportions per cu.m.

Mix Mark	Cement (kg/m^3)	GWG (kg/m^3)	Fine Aggr. (kg/m^3)	Coarse Aggr. (kg/m^3)	Water (kg/m^3)	Super-plasticizer (kg/m^3)
G-00	539.5	0	631.16	979.34	205	6.5
G-05	512.525	26.975	631.16	979.34	205	6.5
G-10	485.55	53.95	631.16	979.34	205	6.5
G-15	458.575	80.925	631.16	979.34	205	6.5
G-20	431.6	107.9	631.16	979.34	205	6.5
G-25	404.625	134.875	631.16	979.34	205	6.5

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3. Results and Discussion

3.1 Physical and Chemical Analysis of the Constituents Materials

The specific gravities and fineness moduli of constituent materials a presented in Table 2, while the oxides composition of the OPC and GWG are presented in Table 3. The particle size distribution of GWG, fine and coarse aggregates are presented in Figure 1.

Table 2. Specific Gravities of constituents Materials

Sample	OPC	GWG	FA	CA	SP
Specific Gravity	3.16	2.58	2.63	2.70	1.19
Fineness Modulus			2.8	6.62	

Table 3. Chemical Composition of OPC (BUA brand) and GWG

Oxides	OPC Composition (%)	BS EN 197-1 (2000)	GWG Composition (%)	ASTM C618 (2008)
SiO_2	10.773	The sum of	72.697	The sum of
Al_2O_3	1.702	reactive CaO and	1.257	reactive SiO_2,
Fe_2O_3	2.877	SiO_2 shall be at	0.352	Al_2O_3 and Fe_2O_3
CaO	60.773	least 50%.	4.696	shall be at least
MgO	0	The ratio of CaO	1.890	70%.
ZnO	0.004	to that of SiO_2	0.001	The reactive
MnO	0.04	shall be at least	0.110	SiO_2 shall not be
SO_3	0	2%.	0.000	less than 25%
TiO_2	0.066	MgO ≤ 5%.	0.041	The CaO shall
Cr_2O_3	0.012	Cl ≤ 0.1 %.	0.011	be less than
Cl	0	SO_3 ≤ 4.0%.	0.000	10%.
LoI	6.424	LoI ≤ 5%.	3.221	SO_3 ≤ 4%
				LoI ≤ 10%.

The result indicates that the OPC has a combined CaO and SiO_2 of 71.546% Which is above the minimum recommended value of 50%. The individual oxides of SO_3 and MgO are all within the limits recommended in BS EN 197-1 (2000) for OPC. Thus, the OPC used can be said to be of sound quality in terms of chemical composition and satisfied the standard requirements.

The chemical composition of GWG indicates a combined SiO_2, Al_2O_3 and Fe_2O_3 content of 74.306%, which is slightly above the minimum value of 70% recommended in ASTM C618 (2008) for a good pozzolana and would therefore be a reactive pozzolana. The magnesium oxide content was 0.0% which satisfied the required maximum value of 4%. Calcium oxides content of 4.696% which satisfied the required value of not more than 10%, loss on ignition (LoI) value of 3.221% which is within the acceptable value of 10% and SO_3 content of 0% which is also within the maximum content of 4%.

This shows that GWG is a good pozzolanic material which satisfied the recommended limit given in BS EN 197-1 (2000) and ASTM C618 (2008). The result is consistent with the findings of Shao *et al.* (2000); Shi and Wu (2005); Chen *et al.* (2006) and Taha and Nounu, (2008) on conventional concrete made with GWG.

The particle size distribution of GWG, fine and coarse aggregates were presented in Figure 1. As indicated, the fine aggregate falls in grading zone 2 based on BS 882 (1992) grading limits for fine aggregates. This shows that there is more medium sand than fine and coarse sand. It is cohesive and well-graded, which is desirable for making HPC. Also, in Figure 1, the curve indicates that coarse aggregates have dominant particle sizes of 14 mm and 10 mm. This shows that the aggregate size is within the specified limits of a maximum of 20 mm as suggested by Shetty (2012) for use in HPC. GWG has grain sizes ranging from 1.75 to 75µm. This implies that the GWG could be used as pozzolana in concrete based on BS EN 206-1 (2000).

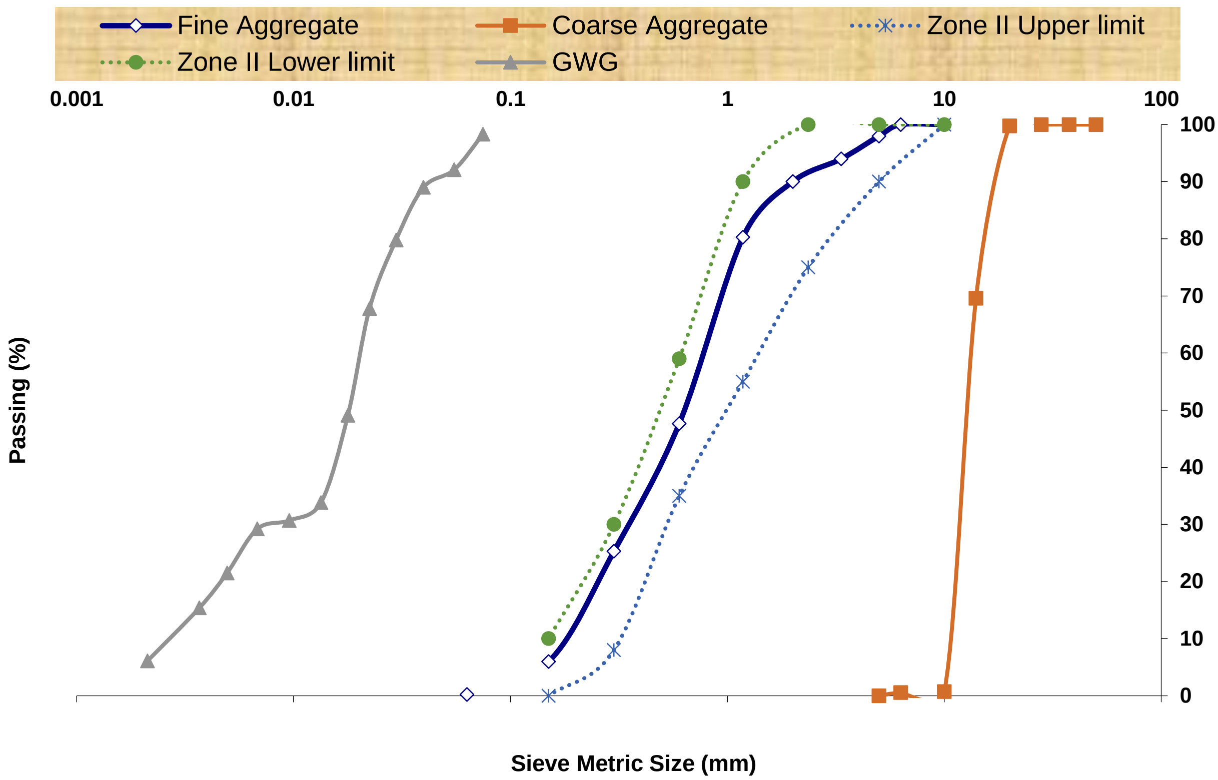

Figure 1. Particle size distribution chart of GWG, fine and coarse aggregates

3.2 Slump Flow of GWG-HPC

The slump flow result is presented in Figure 2; it can be seen that the slump flow value gradually reduces with increasing levels of GWG. The reduction in workability could be due to the high reactivity and higher surface area of GWG when compared to OPC. It may also be due to the increase in water demand due to increase in GWG content leading to the increase in surface area of glass particles and the number of angular shaped glass particles in the mix resulting in lesser fluidity Consistent with the findings of Ferraris *et al.* (2001) and Shekhawat and Aggarwal (2014).

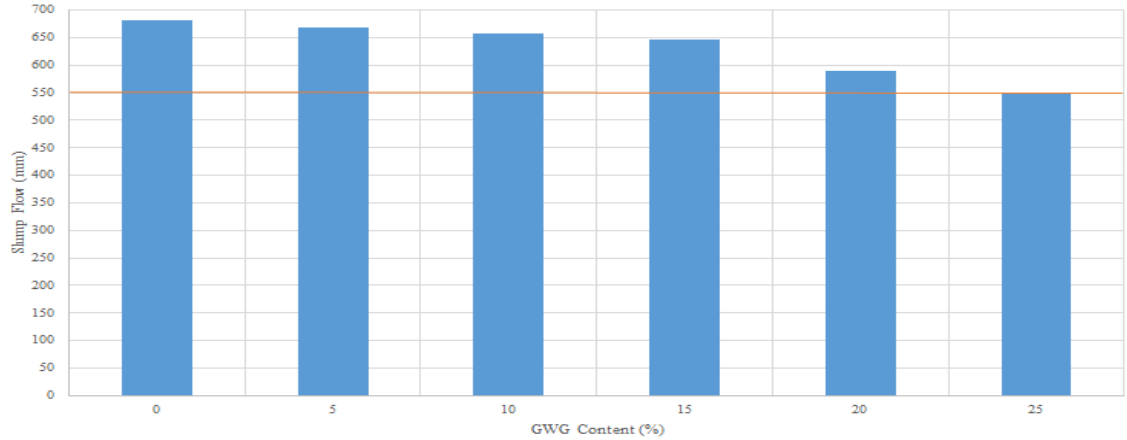

Figure 2. Slump flow GWG-HPC

Similar trends in the slump flow values were reported by Metwally (2007); Vandhiyan *et al.* (2013); and Afif *et al.* (2017). All the samples examined satisfied the requirement of BS EN 206-9 (2010) for slump flow value of 550-850mm.

3.3 Effects of GWG on Strength of HPC

The compressive strength of GWG-HPC is shown in Figure 3. The result shows an improvement in compressive strength with increase in GWG at 5% and 10% and starts to reduce gradually at 15%, 20% and 25% OPC replacement level. The reason behind the improvement is due to the pozzolanic reaction of GWG. Ground waste glass being highly reactive, it reacts with calcium hydroxide ($Ca(OH)_2$) (a by-product of cement hydration) in the presence of water to produce calcium silicate hydrates (C-S-H). The decrease in compressive strength beyond 10% GWG content. In this case, the amount of silica available in the hydrated cement matrix is probably too high and the amount of produced C-S-H is most likely insufficient to reacts with all the available silica and as result of that, the dilution effect of OPC and weaker formation of C-S-H gel due the pozzolanic reaction takes over and the strength starts to decrease. The observation is consistent with earlier works by Ogork and Auwal (2016).

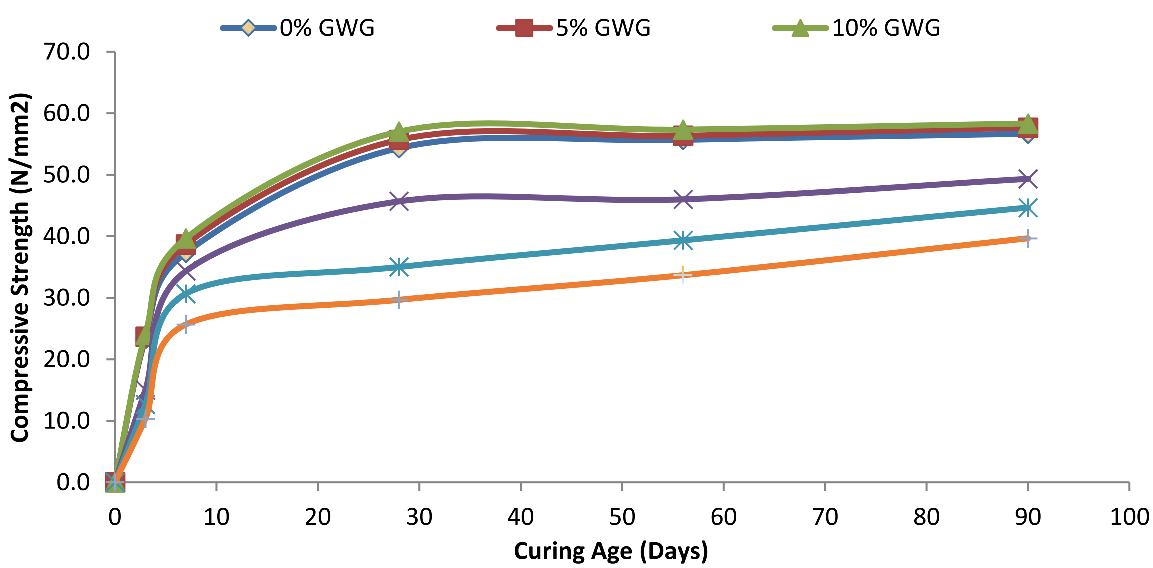

Figure 3. Compressive Strength of GWG-HPC.

The results also, shows an improvement in compressive strength with increase in curing period at all replacement levels. The improvement in compressive strength with increase in curing age could be due to micro filling ability and pozzolanic activity of GWG. The smaller particle size of GWG can fill the micro voids within the OPC particles. This observation is in agreement with earlier studies of Ogork and Uche (2014) and Lalitha *et al.* (2017) who worked on groundnut husk ash (GHA), corn cob ash (CCA) and GWG respectively. Thus, it can be concluded that 10% is the optimum level for replacement of cement with GWG. The optimum dosage is in agreement with Kumarappan (2013) and Lalitha *et al.* (2017) who worked with glass powder as partial replacement of OPC. Thus, it can be concluded that 10% is the optimum level for replacement of cement with GWG.

The splitting tensile and flexural strengths of GWG-HPC follow a similar pattern to compressive strength, as shown in Figures 4 and 5.

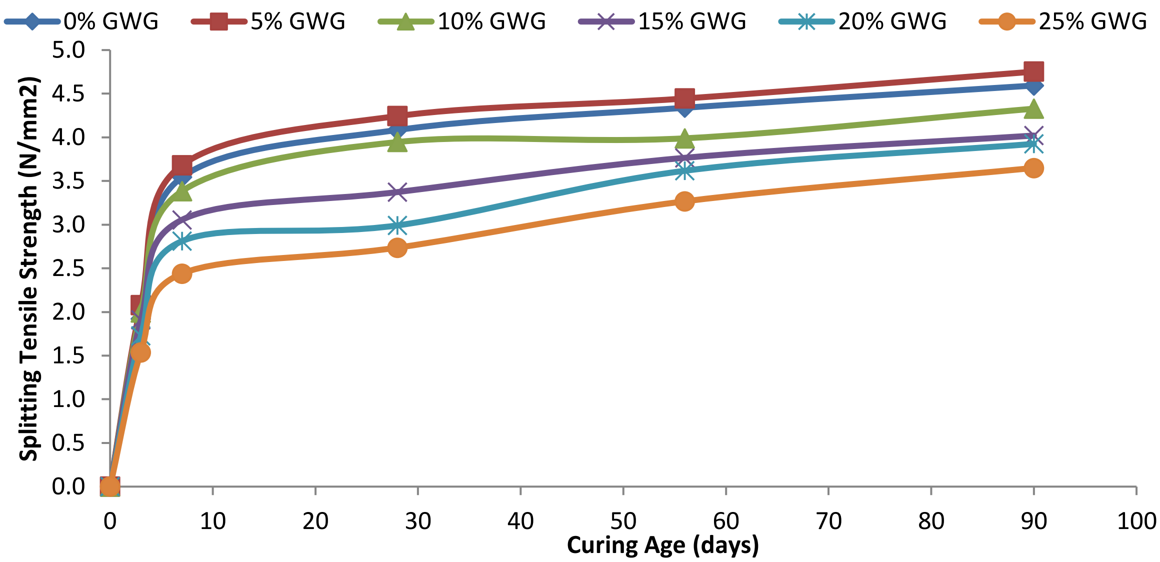

Figure 4. Splitting Tensile Strength Development of GWG-HPC

The result reveals a gain in splitting tensile and flexural strengths with increases in GWG at 5% and 10%, then gradually drops at 15%, 20%, and 25% OPC replacement levels. There was also an improvement in splitting tensile and flexural strengths as the curing age increases. The improvement could be due to micro filling ability and pozzolanic activity of GWG. The smaller particle size of GWG can fill the micro voids within the OPC particles. This observation is consistent with the findings of Ogork and Auwal (2016) using corn cob ash as supplementary cementitious material (SCM).

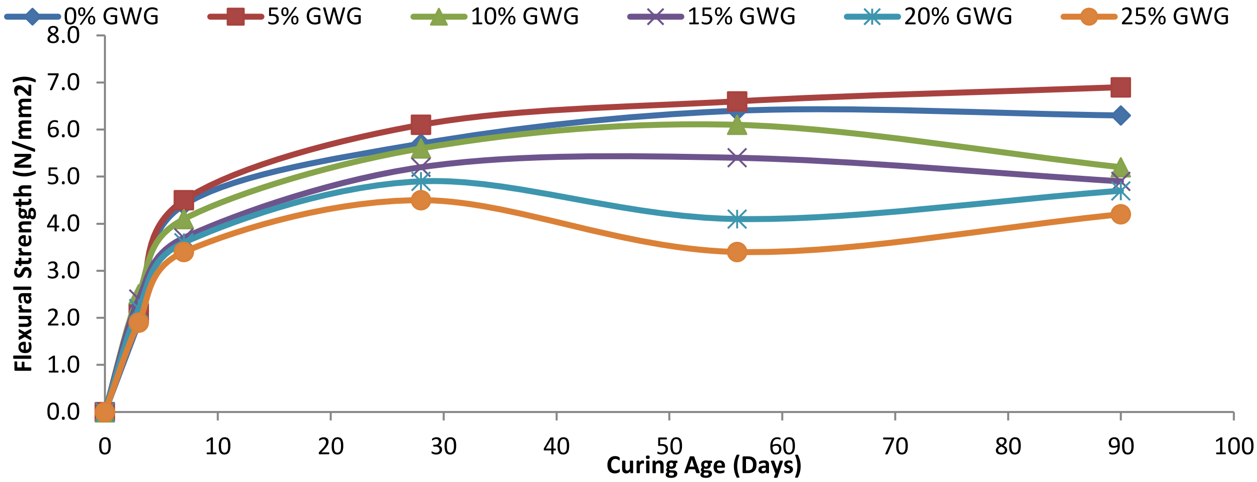

Figure 5. Flexural Strength of GWG-HPC

4. Conclusion

The following conclusions are drawn from the study:

i. The soda-lime GWG is suitable material for use as a pozzolana since it satisfied the requirement for such material by having a combined ($SiO2$ + $Al2O_3$ + Fe_2O_3) of more than 70%.
ii. The workability of HPC reduces as percentage of GWG increases. Therefore, more water is required to make the mixes more workable.
iii. The strengths of concrete can be improved by the replacement of cement with GWG of adequate replacement level.
iv. The optimum replacement level of GWG for cement in HPC is 10%.

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