

Effect of nano silica on the properties of slag concrete

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Abstract. As a sustainable approach to reduce greenhouse gases emission during cement production and waste generation from steel manufacturing industry, ground granulated blast furnace slag (GGBFS) has been widely used as a cement replacement material for concrete production. However, due to its low pozzolanic activity, GGBFS causes delay in early strength development leading to prolonged curing of concrete. In this study, the influence of nanosilica (Ns), a highly reactive pozzolan on the properties of GGBFS concrete was examined. Different concrete samples containing intermixed GGBFS (0- 30%) and Ns (0- 3%) by weight were produced. The workability, setting time, compressive strength, tensile strength, water absorption and sorptivity of the samples were tested. The results show that the addition of nanosilica improves compressive strength and tensile strength of the GGBFS concrete. Therefore, the combination of GGBFS and Ns can be used for the production of good quality

1. Introduction

Concrete is the most used construction material in the globe due to its versatile and economic benefits. However, concrete is known to have environmental sustainability issue mainly due to one of its key ingredients, cement. Cement contributes to CO₂ emission during its production. Cement industry is responsible for 5-8% of the anthropogenic CO₂ emission [1]. As a way to curb the emission, to reduce waste generation from industries, and to improve the performance of concrete, mineral admixtures such as ground granulate blast furnace slag (GGBFS), fly ash and silica fume are utilized to produce concrete.

GGBFS is a by-product from iron producing industry, obtained by rapidly quenching blast furnace slag in water and then ground into a powder. It possesses a latent hydraulic characteristic that requires activation. The activation of GGBFS can be achieved through pozzolanic reaction with lime liberated during Portland cement hydration to produce secondary hydrates that enhance strength and durability properties of concrete [2]. However, slag was established to delay early strength development of concrete due to its slow reactive characteristic [3]. Interestingly, blending slag with other highly reactive admixtures such as, nano silica and nano metakaolin may improve the low strength development of slag concrete.



Nano silica (Ns) is a siliceous material with particle size of between 1nm and 100nm. Due to its size and large content of silica, Ns in small quantity (1-5%) can improve strength and durability properties of concrete [4]. In this study, the effect of Ns on the properties of slag concrete was investigated. The properties studied include, setting times, workability, strength properties and durability properties in the form of sorptivity and water absorption.

2. Materials and methods

2.1. Materials

The binders used for this study include, ground granulated blast furnace slag (GGBFS), colloidal Nano silica (Cembinder 8) supplied by AkzoNobel Germany, and Portland limestone cement. The GGBFS was obtained from Katsina steel rolling mill located in northern Nigeria. Prior to use, GGBFS was oven-dried at 105°C to remove surface moisture, sieved using 150 µm sieve to remove larger particles, and then ground to increase its fineness. The physical properties and chemical compositions of the binders are shown in Table 1. River sand with a maximum size of 5mm, fineness modulus of 2.43, and 1% absorption was used as fine aggregate. Single size crushed granite stone of 20mm size and 1% absorption was also used as coarse aggregate. A superplasticizer, CONPLAST SP 561, to achieve the desired workability at constant water binder ratio was used.

Table 1. Chemical composition and physical properties of binders.

Binder	Chemical composition (%)									Physical properties		
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O	K ₂ O	LOI	Specific gravity	Mean particle size	Surface area (m ² /g)
OPC	20.1	4.90	2.5	65.0	3.1	2.85	0.20	0.4	1.90	3.15	17µm	6.5
GGBFS	39.0	13.1	1.8	39.0	3.6	0.2	-	-	1.6	2.4	33µm	3.7
Nanosilica*	99.8	-	-	-	-	-	0.2	-	0.50	1.4	35nm	80

*properties as provided by the manufacturer

2.2 Sample preparation and methods

Concrete sample (control) of grade 30 with cement as the only binder was designed using the Department of Environment (DOE) method. Other sample types with 10-30% GGBFS and 1-3% Ns replacing cement either separately to form binary blends or combined to form ternary blends were also produced. After mixing, the fresh concrete was cast into 100mm cube moulds and then vibrated to achieve proper consolidation. The cubes were demoulded after 24 hours of casting and then cured in water for 28 days.

At fresh state, workability of concrete was determined using slump test in accordance with ASTM C143/143M-15a [5]. Setting times test on the samples (binder paste) using Vicat apparatus was also conducted following the procedure outlined in ASTM C191-13 [6]. At hardened state, compressive strength and tensile strength tests on the samples were carried out based on BS EN 12390-3:09 [7] and ASTM C494/C494M [8] respectively. Furthermore, sorptivity test using ASTM C 1585-04 [9] and water absorption test based on ASTM C642-06 [10] were also conducted on the entire samples. Cube samples of 100mm size were used for the water absorption, sorptivity and compressive strength tests, while cylinders of 100 mm diameter and 200 mm height were used for tensile strength test.

3. Results and discussion

3.1. Setting Times

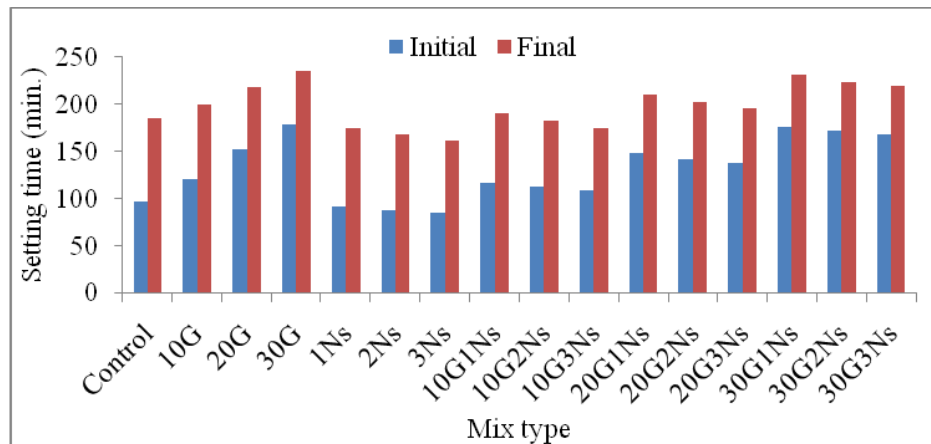


Figure 1. Setting times of the specimens

The initial and final setting times of the various mix types are shown in Figure 1. It can be seen that, compared to the control, slag retards setting times while nano silica accelerates setting times. The retarding and accelerating effects of slag and nano silica respectively on the samples increased with their increasing content. However, the samples with intermixed nano silica and slag at all replacement levels exhibited moderation in the setting times such that the retarding effect of slag was reduced. For instance, the initial setting times of 30G specimen (179 min.) was reduced by 10min when 3% Ns was added to it. The reduction effect of Ns on the setting time is due to its nano-sized particle that accelerate hydration [4]. However, the decelerating effect of GGBFS can be attributed to its slow hydration characteristic and dilution especially with increasing replacement level [11].

3.2. Workability

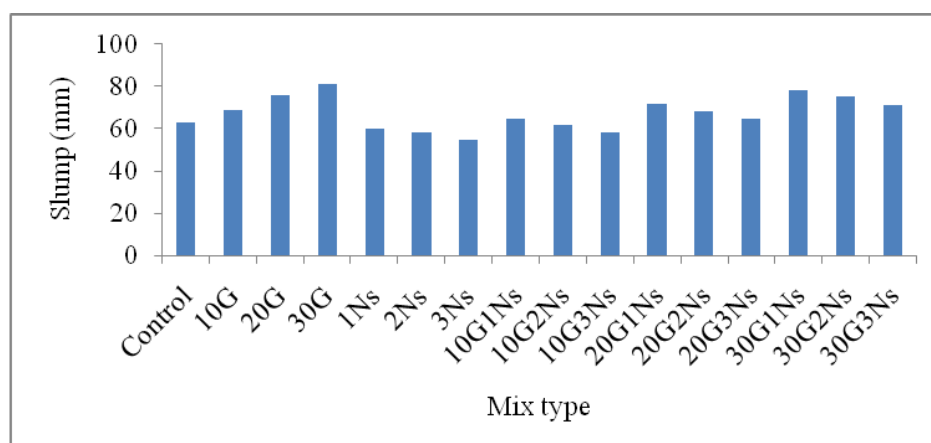


Figure 2. Slump of concretes

The workability of concrete mixtures expressed in terms of slump is depicted in Figure 2. It can be seen that slag improved workability while Nano silica (Ns) decreased workability of concrete. However,

the addition of Ns to slag concrete led to the reduction of workability. The reduction effect increased with the increasing Ns content. The slump for 20G sample (76mm) was reduced by 4mm, 8mm and 11mm when 1%, 2% and 3% Ns was added, respectively. The change in slump may be attributed to the high surface area of Ns leading to high water demand for adequate consistency. Similar behavior was observed when Nano silica was introduced into palm oil fuel ash concrete [4].

3.3. Compressive strength

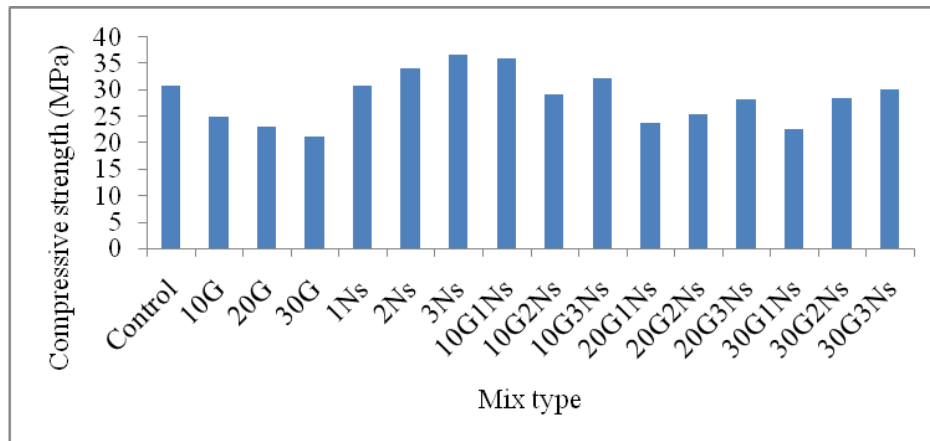


Figure 3. Compressive strength of different concrete mixes

Figure 3 shows the compressive strengths of concrete containing binary blends of slag, binary blends of Ns and ternary blends of slag and Ns. Generally, Ns improved the compressive strength of slag concrete. In fact, strength comparable to that of control was achieved when 1-3% Ns was added to 10G specimens, and when 2-3% Ns was added to 30G specimens. The improvement can be associated to the high pozzolanic and filling effects of Ns that refine the microstructure of concrete. Improvement in strength of fly ash concrete with the introduction of nano-silica was also reported by [12].

3.4. Tensile strength

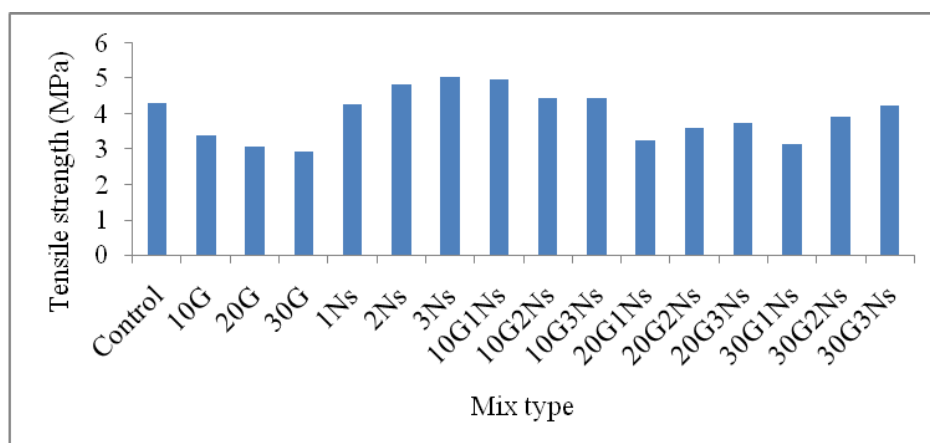


Figure 4: Tensile strength of concretes

The tensile strengths of concrete mixes are shown in Figure 4. In a similar pattern to the compressive strength results, nano silica was found to improve the tensile strength of slag concrete. In fact, a linear relationship with a high correlation coefficient ($R^2=0.97$) between compressive strength and tensile strength was established as shown in Figure 5. Therefore, nano silica was useful for enhancing the strength properties of slag concrete by filling micro pores and making a dense concrete through pozzolanic effect [13].

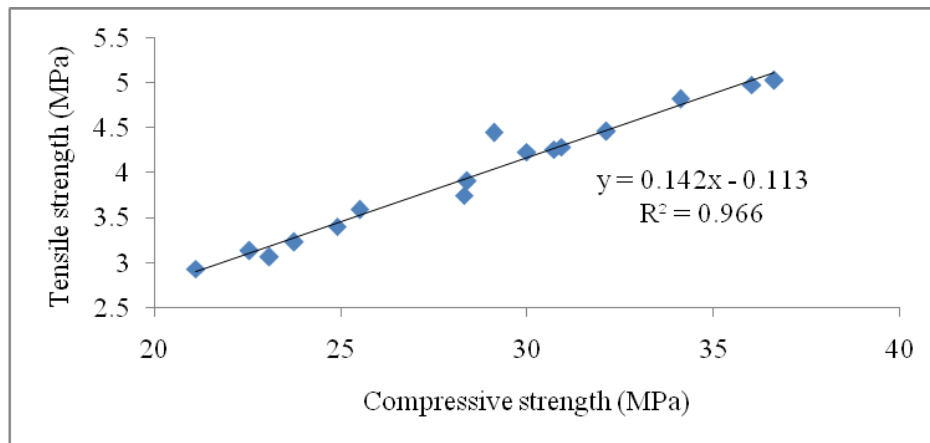


Figure 5. Relationship between compressive strength and tensile strength

3.5. Water Absorption

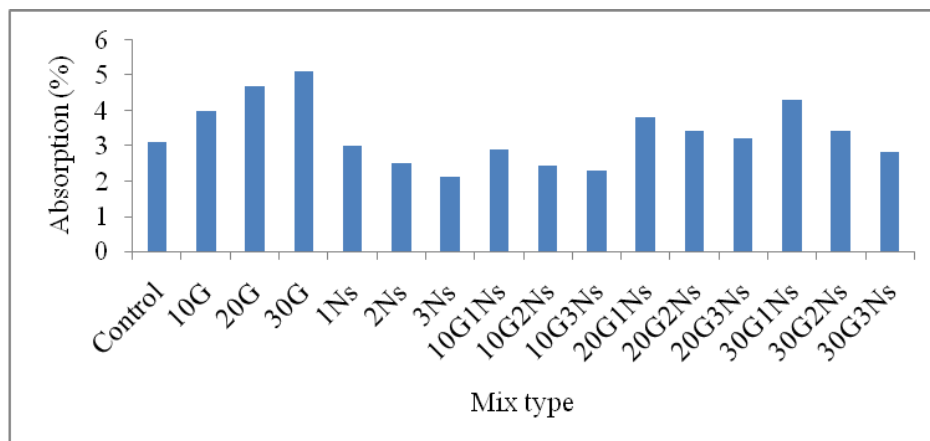


Figure 6. Water absorption of concretes

Figure 6 shows the water absorption of the various concrete samples. It can be observed that slag at all replacement levels increased water absorption of concrete. However, Ns decreased water absorption at all replacement levels. Similarly, reduction in absorption was observed in all the specimens blended with both Ns and slag compared to those with slag alone. The modification of pore structure due to pozzolanic and filling effects of Ns may be responsible for the reduction [13].

3.6. Sorptivity

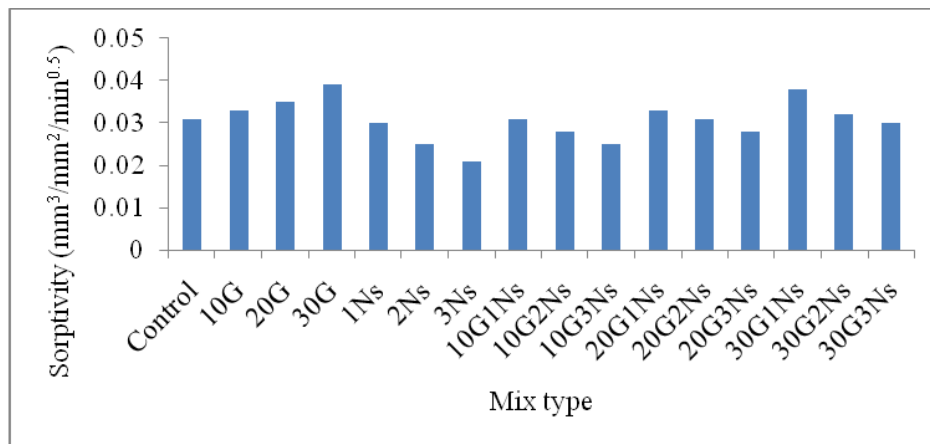


Figure 7. Sorptivities of concretes

The sorptivities of the specimens are shown in Figure 7. Sorptivity measures the extent of water uptake by the specimen through capillary action. It is considered as one of the parameters for assessing durability of concrete. It is observed that sorptivity increased with slag but decreased with Ns. Interestingly, the increasing effect of slag on sorptivity was reduced with the use of Ns. Hence, Ns can be beneficial in improving durability properties of slag concrete. Impliedly, Ns can improve the durability of slag concrete. The ability of Ns to refine the pore structure of concrete via filling, nucleation and pozzolanic effects is responsible for the reduction of sorptivity exhibited by the concrete containing Ns [13].

4. Conclusion

Based on the study, the following conclusions are drawn:

1. Nano silica reduced the retarding effect and workability of fresh slag concrete
2. Compressive strength and flexural strength of slag concrete containing 10-30% slag improved with the addition of 1-3% Ns
3. Nano silica reduced the water absorption and sorptivity of slag concrete, thus, improved the durability of slag concrete.

5. Acknowledgement

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