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PERFORMANCE OF CONCRETE MODIFIED WITH DISCARDED GLASS AT ELEVATED TEMPERATURES FOR SUSTAINABLE CONSTRUCTION

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This study examines the residual strength of concrete produced with crushed discarded soda-lime glass as aggregates after exposure to elevated heating. The natural aggregates, which comprise both the coarse and fine aggregates were partially and completely replaced by 0, 25, 50, 75 and 100% of the discarded glass. The control and samples containing crushed discarded glass aggregates were prepared at constant water-cement ratio (w/c) of 0.50 and the cube samples were exposed to temperatures of 60, 150, 300 and 500°C after curing in water for 90 days. The heating was increased at a constant heating rate of 10°C/min. The strength of the concrete samples was measured before and after exposure to heating after air-cooling of the heated samples. Moreover, scanning electron microscope (SEM) examination was carried out on selected samples to investigate the extent of change in the concrete bonding, especially at higher heating. Test results depict reduction trend in the characteristic strength of the tested samples as the level of heating increases, while the SEM micrographs reveal clear decomposition in the concrete interfaces. However, it was noticed from the results that concrete containing crushed discarded glass show better performance in terms of strength compared to the reference concrete at certain temperature exposure indicating a modified concrete with improved post-fire resistance.

Keywords: Modified concrete, Waste recycling, Waste glass, Compressive strength, Post fire performance, Sustainable materials.

1 INTRODUCTION

Concrete is one of the most commonly used materials for construction in both developed and developing nations of the world (Bamigboye *et al*. 2016). This is because among the properties of concrete includes; good strength, durability and noncombustible nature. Moreso, it can be easily fabricated into any preferred shapes and sizes (Siddique *et al*. 2018). The growing demand for concrete has significantly placed an increasing need for more exploration of raw materials used for producing concrete thereby resulting in the depletion of these natural resources (Olofinnade *et al*. 2018). A study reported that dependent by the construction industry on nonrenewable materials for construction might result in a possible environmental degradation. Hence, the need for the industry to embrace sustainability, such that new innovative and non-traditional cost-effective materials can be employed as an alternative to compensate and possibly enhance the properties of concrete composite used for structures under a loading condition

(Siddique *et al*. 2018, Olofinnade *et al*. 2019). Besides, there are also the global challenges of waste management and reduction, whereby some solid waste materials are reported to be a growing menace to the environment and society (Heriyanto and Veena 2018). One of such solid wastes is discarded glass, which is a non-biodegradable material and not suitable to be disposed of in landfill (Heriyanto 2018, Olofinnade *et al.* 2018, Ngene *et al*. 2019). However, studies have shown that recycling and reusing of glass wastes as concrete and mortar constituent will help to preserve the natural resources, while also save energy and valuable spaces that could have been used as a landfill sites (Siddique 2008, Ling *et al.* 2013, Jani and Hogland 2014, Olofinnade *et al*. 2018). Past studies have reported on the suitability of reusing discarded glass as natural aggregate replacement material in concrete, asphalt and mortar production (Siddique 2008, Ling *et al.* 2013, Rashad 2014, Olofinnade *et al.* 2018). For instance, a study by Olofinnade *et al.* (2018) showed that crushed glass has physical attributes almost similar to sand, but with a lower water absorption rate. Studies have also shown that discarded glass in finely ground form can be deployed as a pozzolan to partially substitute cement or as filler material in concrete and mortar (Jani and Hogland 2014, Olofinnade *et al.* 2017b). However, reports by Taha and Nounu (2008) and Olofinnade *et al*. (2017a, 2018) mentioned that factors limiting the use of discarded glass in cement-based concrete and mortar are a reduction in strength and cracking caused by alkali-silica reaction (ASR). Furthermore, concrete structures are exposed to increased temperature conditions, therefore heat or fire resistance properties of concrete structures are always considered at the design stages. Naturally, concrete is considered to have a good fire resistance attributes (Siddique *et al.* 2018), however, studies have shown that exposing concrete to elevated heating would cause a loss of strength and stiffness due to aggregates decomposition, water evaporating from pores and dehydration of the binding paste (Nassif 2006, Olofinnade *et al*. 2017b). However, Siddique *et al.* (2018) stated that the fire-resistant properties of concrete can be possibly improved by employing materials like waste tempered glass to enhance the behavior of concrete under elevated temperatures. A study by Poutos *et al.* (2008) noted that glass aggregates exhibit better temperature stability due to its lower specific heat compared to sand. Therefore, this current study is aimed at examining the influence of elevated temperatures on the properties of concrete modified with discarded glass. The discarded glasses were crushed to aggregate sizes similar to both natural fine and coarse aggregate particle sizes and used to partially and completely replace the aggregates.

2 EXPERIMENTAL PROGRAM

The materials used in this research for the production of concrete include; cement of grade 42.5 conforming to NIS 444 (2003) with a specific gravity of 3.15. River sands of 0.075 - 4.75 mm sizes with a specific gravity of 2.62, and gravel having a maximum size of 20 mm with a specific gravity of 2.70. The discarded glasses used in the concrete mixes were sourced as container bottles from waste disposal locations within Ota town, Nigeria. Before crushing, the waste bottles were properly washed with clean water and allowed to dry to remove impurities. Then, the discarded glasses were crushed to particle sizes similar to the particle sizes of sand and gravel. The chemical compositions of the used discarded glasses are depicted in Table 1. The natural aggregates, which comprise both the coarse and fine aggregates were partially and completely replaced by 0, 25, 50, 75 and 100% of the discarded glasses. The control and samples containing crushed glass particles were prepared at constant water-cement ratio (w/c) of 0.50 with a target strength of 20 MPa and the cube samples were exposed to a temperature of 60, 150, 300 and 500°C after curing in water by total immersion for 90 days at 20 - 22°C. The types of concrete mixes and batching proportions used in this study are shown in Table 2 and 3. Selected reading was taken as the average of 3 test results. The samples were heated using a thermostat regulated muffle furnace that can reach temperatures beyond 1000°C at a constant rate of heating, 10 °C/min in the furnace. After heating to reach desired temperatures, the concrete samples were left in the furnace for 3 hours to have a uniform temperature distribution around the concrete samples as adopted in the study of Olofinnade *et al.* (2017b). To prevent uneven building up of thermal stresses, the samples were passed through a slow cooling process by allowing the samples to cool in the furnace and open-air before testing for their residual strength using a compressive machine at a loading rate equal to 3 kN/s. The scanning electron microscope (SEM) using the Phenom ProX type SEM was used to analyses the control and concrete samples containing the discarded glass aggregate at ambient and elevated temperature.

Table 1. Chemical compositions of the used discarded glass.

	%Weight
Silica (SiO_2)	60-64
Sodium oxide (Na_2O)	11-13
Magnesium oxide (MgO)	0.6-1
Aluminum oxide (Al_2O_3)	19-20
Calcium oxide (CaO)	10-11
Potassium oxide (K_2O)	0.7-1

Table 2. Concrete mix type.

Concrete mixes	
Mix I	Concrete mix produced with natural aggregates
Mix II	FWG-concrete mix produced by replacing sand with 25, 50, 75 and 100% of the crushed glass.
Mix III	CWG-concrete mix produced by replacing gravel with 25, 50, 75 and 100% of the crushed glass.

Table 3. Concrete batching.

Mixes		Cement (kg/m^3)	Aggregates (kg/m^3)				Water (kg/m^3)	w/c
			Sand	Gravel	FWG	CWG		
Control	0%	275	550	1100	-	-	138	0.5
Glass sand	25%FWG	275	412.5	1100	137.5	-	138	0.5
	50%FWG	275	275	1100	275	-	138	0.5
	75%FWG	275	137.5	1100	412.5	-	138	0.5
	100%FWG	275	-	1100	550	-	138	0.5
Glass coarse	25%CWG	275	550	825	-	275	138	0.5
	50%CWG	275	550	550	-	550	138	0.5
	75%CWG	275	550	275	-	825	138	0.5
	100%CWG	275	550	-	-	1100	138	0.5

3 RESULTS AND DISCUSSION

Table 1 clearly indicated that the composition of the oxides of the discarded glass material used for this study is within the range of soda-lime glass sheets and container bottles. However, the aluminum oxide (Al_2O_3) compound was noticed to be above the limits for soda-lime glass. Figures 1 and 2 depict the strength performance of control concrete samples and concrete samples with glass aggregates (FWG and CWG) used as a partial and complete substitute for sand and gravel stones in dosage proportions shown in Table 3. The presented results indicated an obvious reduction trend in the residual strength of the concrete samples as the temperatures increased. However, it was observed that at a specific percentage substitution of the traditional aggregates with glass aggregates, the residual strength of the hardened concrete was found to show considerable improve post-fire performance in terms of strength compared to the control concrete. For instance, Figure 1 depicts the residual strength results of concrete produced with 50% fine glass sand (FWG) used as a replacement for sand. It was noticed that concrete produced with 50% FWG as sand replacement performed better compared to the control at elevated heating conditions. The results display a higher recorded residual strength at lower temperature exposure up to the heating level of 500°C compared to the control samples up to the same heating level. In a similar pattern, it was also observed in Figure 2 that concrete samples made by replacing the gravels with CWG at 25% replacement level depicted a higher residual strength but only at a lesser heating exposure compare to the control. After which a significant reduction trend in the residual strength was observed as the heating progressed to 500°C and beyond.

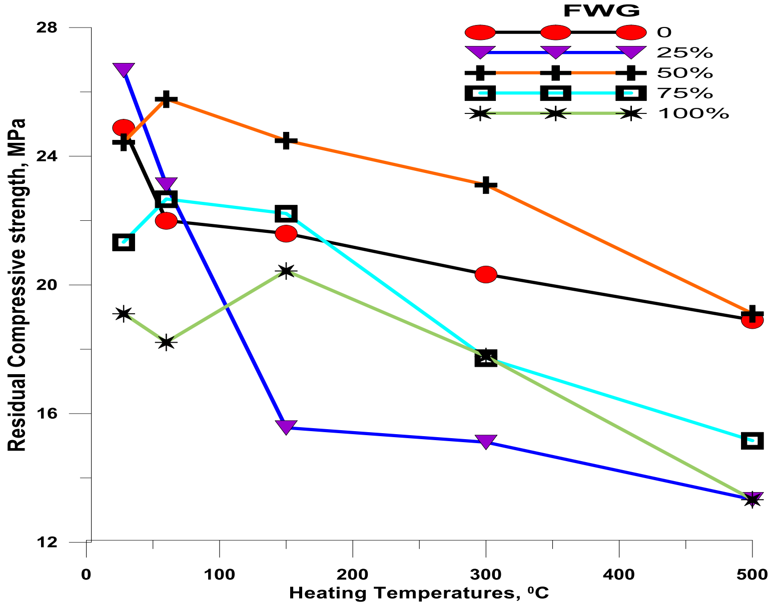


Figure 1. Strength variations with temperature for control and fine glass sand (FWG) concrete.

The results on the SEM examinations carried out on selected fractured concrete surfaces are shown in Figures 3 and 4. The SEM examined the interfacial transition zone (ITZ) between the binder paste and aggregate before and after exposing the samples to elevated heating. SEM micrographs in Figures 3(a-c) show the conditions of control and concrete produced with discarded glass aggregates at normal temperature, while in Figures 4(a-b), the SEM micrographs show plainly the states of the concrete samples after exposure to elevated heating indicating a total change and decomposition of the binding paste and destruction of the interfacial bond between the aggregates and paste. Moreso, Figure 4(b) shows the glazing effect of the molten glass on the heated concrete samples after cooling compare to Figure 4(a).

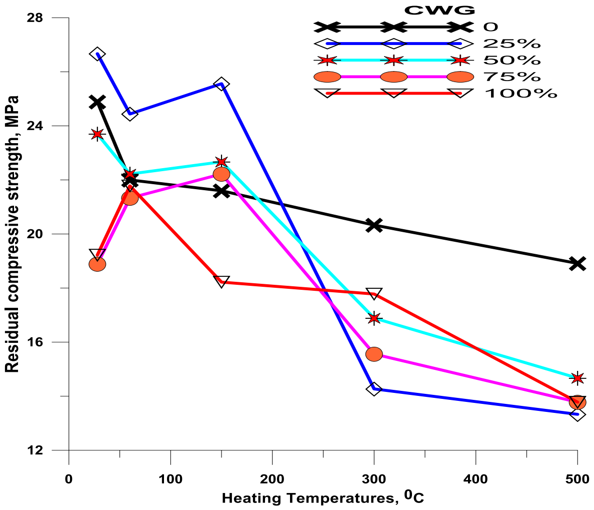
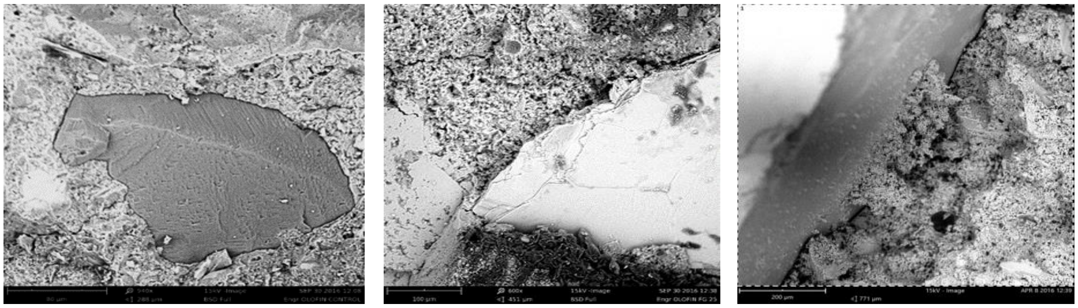
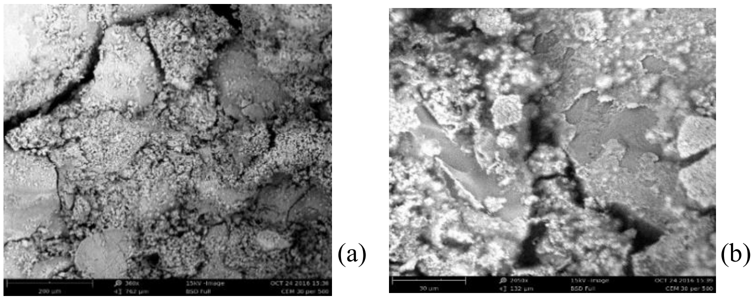


Figure 2. Strength variations with temperature for control and glass coarse (CWG) concrete.



(a) (b) (c)

Figure 3 (a – c). SEM images on control and concrete with glass aggregates at ambient temperature.



(a) (b)

Figure 4 (a – b). SEM images on concrete showing altered bonding and surfaces after heating.

4 CONCLUSIONS

This study shows a reduction trend in compressive strength of concrete produced with and without discarded glass aggregates as the heating temperatures increase, however, concretes produced with 50% glass sand (FWG) and 25% glass coarse (CWG) aggregates exhibited an improved performance in strength at ambient and elevated temperatures, not beyond 200°C compare to the control concrete. Meanwhile, the SEM analyses on the concrete samples show a clear decomposition of the concrete surfaces and bonding the aggregates and paste. Consequently, using discarded soda-lime glass aggregates can be used to modify the properties of normal strength concrete to enhance its post-fire resistance for sustainable construction.

Acknowledgments

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