Relative Strength Performance Evaluation of Self-Compacting and High Strength Concrete Beams containing Polyethylene Terephthalate

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ORIGINAL RESEARCH

Abstract- This research compares the flexural resistance of self-compacting concrete (SCC) and High Strength Concrete (HSC) beams with embedded polyethylene terephthalate (PET) plastic bottle below the neutral axis using concrete grade of C70. Mix design for both SCC and HSC were performed in line with relevant specification. Experimental programme was achieved on both beam specimens. Workability, compressive and flexural strength tests were performed in the laboratory. The workability test revealed a more flowable concrete with the SCC mix than that of the HSC. The compressive strength for the SCC design mix yields a higher value (about 21.5% higher) than that of the HSC. The flexural resistance of each beam specimens (SCC beams and HSC beams) increases with increase in curing days of the beams but higher strength was achieved with SCC beams at 28 days curing. The stress-strain behaviour is within the specified acceptable limit (0.002-0.0035) for concrete with grade less than or equal to C50/C60. It is concluded that the replacement of concrete with PET plastic bottles beneath the neutral axis will lead to reduction in volume of materials, reduction in environmental waste, price of removal of the garbage and eco-friendly environs.

Keywords- Modulus of Rupture, Millet husk ash, Polyethylene Terephthalate, Self-compacting concrete, Workability.

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1 INTRODUCTION

Concrete is the most popularly used construction material around the globe. It is a dense material obtained from the mixture of cement, fine aggregate (sand), coarse aggregates (gravel or granite) and water (Narendra et al., 2017). With increase in population and high demand for housing, access road and other civil/structural infrastructure (high rise building and long span bridges), numerous types of concrete have been developed over the years to improve on the compressive strength and the durability of a harden concrete. Ordinarily, concrete requires vibration and compaction to eliminate gas and voids in order to prevent poor resistance to load. (Dey et al., 2021). However, vibration and compaction are strenuous and cumbersome and can lead to undetected problems later if done inadequately. Also, some complex forms of concrete cannot be easily vibrated. It is in view of the aforementioned that high flowable concrete is designed. Self-compacting concrete is designed to avoid these problems because it does not require compaction or vibration which therefore reduces labour, time and all possible sources of technical and quality control issues (Caijun et al., 2015).

Self-compacting concrete (SCC) is a kind of concrete mix with high fluidity and workability, it flows like honey, which spreads into every corner of a framework, around reinforcement without blocking or segregating under the action of its own weight and get compacted without any mechanical vibration and has nearly a horizontal concrete level after placing (Wasiu et al., 2019).

About 30 years ago, SCC was developed in Japan when the Japanese drastically reduced the number of their skilled workers at the construction sites (Nan et al., 2001). SCC ultimately required less skilled worker for the mixing, placement, vibration and compaction. The properties of SCC and high strength concrete (HSC) are similar except in consistency. In the mixing of self-compacting concrete, the workability of concrete is increased by using plasticizers (Apoorva et al., 2016,) to enhance the uniformity of constituents and greater mobility of mix.

Plasticizers are the kind of additives when added to concrete mixture help to plasticize (make it flow-able) the concrete mixture and reduce the liquid limit while the workability is retained. The resultant effect of reducing liquid limit in the design is to increase strength and durability in the concrete (Wasiu and Fashina 2020). To allow the coarse aggregates float in the mortar without segregation, the SCC must have the desired flow ability which can be achieved by the use of particles finer than 150μm (520 to 560 kg/m3). (Nitereka, and Neale, 1999). In order to eliminate voids in the concrete mix, fillers are added to change the rheological properties. (Da-Silva and De-Brito 2015). In this research, millet husk ash (MHA) has been used. Beams are capable of resisting applied load primarily through bending.

Concrete beams are commonly used as roof supports for industrial and residential buildings and also in bridges. It is an effective and commonly used structural system. Bending forces transferred into beam system due to loads, span reactions and self-weight is termed bending moment. Wasiu and Adedeji (2018) reported that high quality and optimized beams can significantly improve safety and longevity of structures. Oyenuga (2011) also reported that the design of concrete member in flexure neglects the tensile resistance of the concrete beneath the neutral axis. Hence, such concrete is theoretically ineffective. This theory enables the engineers to remove

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such concrete portion while still keeping the structure intact. To this effect, voided concrete came about as a viable option for beam lightening (Sivaneshan and Harishhanker, 2017).

However, the demerits of voided slabs have led to the use of PET bottles in concrete beams. (Roberto, 2020). Akinyele *et al* stated that engineers have resorted to the alternative use of PET in concrete mix due to unrestrained dumping on land. This work attempts to check the viability of PET in concrete, reduction of PET waste and prevention of environmental strains caused by them.

2 MATERIALS AND METHODS

2.1 MATERIALS

Ordinary Portland Cement (OPC) of grade 42.5R (Dangote brand), millet husk ash (MHA), coarse aggregates of 20mm size, 10mm diameter bars and 8mm diameter links, river sand devoid of any organic impurities were all obtained from Ado-Ekiti. Obtained from Purechem is the Superplasticizer (SP 430) mainly made of sulphonated naphthalene polymers and is a brown liquid solution which disperses instantly in water. The properties are shown in Table 1. The water used for mixing and curing of concrete specimen was a potable borehole water. It was ensured that the water was free from any impurities.

Table 1. Physical Properties of SP430

Appearance:	Brown Liquid
Specific Gravity:	1.18 @ 25^{0}C
Chloride Content:	Nil to BS 5075/BS: EN934
Air Entrainment:	Less than 2%

2.2 EXPERIMENTAL PROCEDURE

The mix design for the self-compacting concrete (SCC) and that of the High Strength Concrete (HSC) was carried out using the Nan et al., (2001) method. The mix design is presented in Table 2. Two categories of tests were carried out.

2.2.1 Workability Tests

Workability tests which include V-funnel and L-box apparatus tests were carried out according to the specifications of BS EN 12350-9 and BS EN 12350-10 respectively. The results are validated using Table 3. V-Funnel Test: This test was carried out to evaluate the stability of SCC mixtures, the flow time was determined by observing the total time a completely filled funnel with fresh concrete become empty after opening the orifice. A flow time less than 6 seconds is recommended for a concrete to qualify for a SCC (Wasiu *et al.*, 2019). The degree to which the concrete is prevented from flowing by the reinforcement is determined by the L-Box test.

2.2.2 Strength Tests

Strength tests such as compressive strength and flexural strength tests for both Self-Compacting Concrete beam (SCCB) and High Strength Concrete beam (HSCB) were carried out with maximum aggregate sizes of 20mm. The grade of concrete considered for this study was C70.

Compressive strength test: The compressive strength to be obtained is the maximum strength that the concrete can hold prior to failure. The compressive strength is obtained by dividing the failure load by the area of the material whose compressive strength is to be obtained.

$$Compressive\ strength = \frac{Force\ (N)}{Area\ (N/mm^2)} \quad (1)$$

Figure 1 shows the 2000kN compression testing machine used in this research. The $100 \times 100 \times 100\,mm$ cubes were tested in line with BS EN 12390-3. Figure 2 shows the demoulding operation before testing.

Flexural strength test: flexural strength is also referred to as modulus of rupture (MoR). It is the stress upon a material before if yields in flexure. It is computed from equation

$$\text{Flexural strength, } f_m = \frac{3FL}{2bd^2} \quad (2)$$

Where, F = load applied in kN, L = length between supports, b = width and d = depth of beam. A total of 32 beams were cast with PET embedded below the neutral axis as shown in Figure 3. The test was performed in accordance with ASTM C293 / C293M-16 using the centre-point loading system. All samples were tested using a 100kN electronically operated universal testing machine. The beams (SCCB and HSCB) were cured under normal room temperature before testing. Tests were performed at 7-, 14-, 21- and 28-days curing. Figure 4 shows the beam specimen under test using UTM. A dial gauge was used to measure the mid-span deflection. As the specimen is loaded, the value of load and the corresponding value of deflection are displayed.

Table 3. Acceptance Criteria for SCC

Test	Unit	Typical range of values	
		Minimum	Maximum
Slump	mm	650	800
V-funnel test	Sec	6	12
V-funnel at T_5	Sec	6	15
L-box test	H_2/H_1	0.8	1.0

(EFNARC, 2002)

Table 2. Mix design proportion for High Strength Concrete

	Cement (kg)	MHA (kg)	Fine Aggregates (kg/m^3)	Coarse Aggregates (kg/m^3)	SP430 (kg)	Water (kg)
Quantity (Kg/m^3)	603	64.1	857	754.25	10.92	182.59
Mix Ratio	1	0.106	1.41	1.24	0.02	0.302

Fig. 1: Compression Testing Machine in action

Fig. 2: Demoulding of concrete cubes

Fig. 3: PET bottles arranged in the beam meld

Fig. 4: Flexural test using the ASTM 293 C

3 RESULTS AND DISCUSSION

3.1 RESULTS OF WORKABILITY TESTS

The results of workability tests using the V-Funnel and L-Box apparatus is presented in Tables 4. The rate of flow using the V-funnel apparatus was 9 seconds and the ratio:$\frac{H_2}{H_1}$ was 0.954. These results are in consonance with the requirements of EFNARC. The SCC exhibited a higher flow ability than HSC. Generally, the results of the workability tests revealed a highly workable concrete for SCC (>84 mm) and poor flow ability for HSC (<63 mm).

Table 4. V-Funnel and L-Box workability test

Type of Test	SCC	HSC	Code Range	
			Minimum	Maximum
V-funnel	9 secs	Nil	6 secs	12 secs
L-box T:$\frac{H_2}{H_1}$	$\frac{12.4}{13.0}$=0.954	Nil	0.8	1.0

3.2 RESULTS OF STRENGTH TESTS

3.2.1 Results of Compressive Strength

The results of the cube test are presented in Figure 5. The compressive strength for both the high strength concrete (HSC) and self-compacting concrete (SCC) increases with increase in curing days but higher strength was recorded with the SCC due to the presence mineral additives (Millet husk ash) and chemical additive (super plasticizer) SP 430. Both helps in the improvement of strength and workability properties of the concrete. The strength recorded for SCC and HSC is 86.9 N/mm2 and 71.5 N/mm2 at 28 days curing. This is 21.5% increase in strength compared to the high strength concrete (HSC).

3.2.2 Results of Flexural Strength

The Modulus of Rupture (MoR) for the SCC and the HSC increases with days of curing. The SCC beam with embedded PET below the neutral axis tends to withstand more load than that of the HSC as shown in Figure 6. The MoR for the SCC beams is 20.5% higher than that of HSC. For both samples, the MoR increases with increase in curing days. The range of their MoR is 18.6-27.48 N/mm^2 and 17.4-22.8 N/mm^2 respectively for SCC and HSC. The maximum Load-Deflection curve for SCC indicates similar trend with that of HSC. The deflection is generally higher with SCC due to the presence of both mineral and chemical additives. Although all are within the allowable limit of span/effective depth ratio. Figure 7 shows the deflection curve for both beam samples (SCC beams and HSC beams). The stress-strain behaviour is presented in Figure 8. The strain for the HSC beams ranges between 0.0019-0.00235 while that of the SCC beams ranges from 0.0019-0.0028. This is within the specified acceptable limit (0.002-0.0035) for concrete with grade less than or equal to C50/C60 (Mosley *et al.*, 2013).

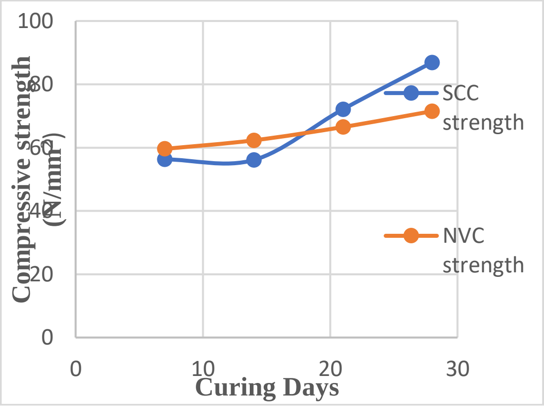

Fig. 5: Compressive strength against days of curing

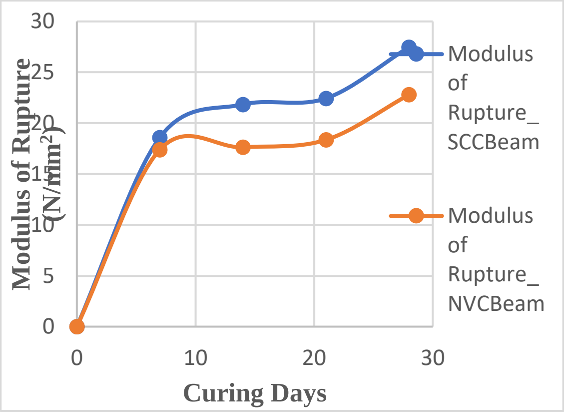

Fig. 6: MoR against curing days

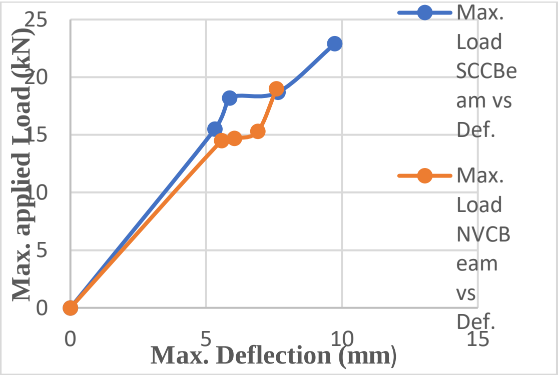

Fig. 7: Load-deflection curve

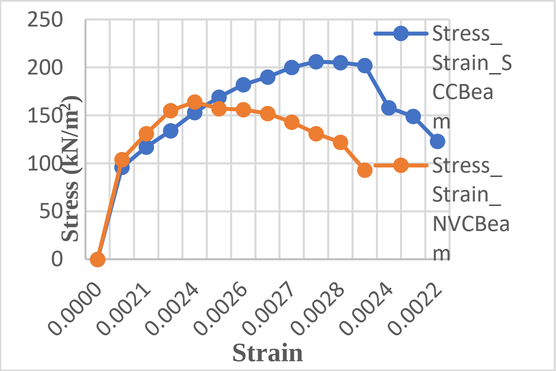

Fig. 8: Stress-Strain Curve

4 CONCLUSIONS

The results of this research work are summarized as follows:

a) The presence of mineral constituents such as silica, alumina and ferrite oxides in MHA showed a promising potentials as mineral additives in SCC.

b) Workability tests using the L-Box test and V-Funnel for the SCC, revealed a flow that can easily be filled in a meld and self-consolidated while the HSC revealed a true slump but not self-consolidated as in the case of SCC.

c) The compressive strengths of SCC are considerably higher than that of HSC of the same grade of M70. The increment is about 21.5%.

d) The MoR for the SCC beams with embedded PET bottles revealed a higher strength value than that of HSC beams. This also indicate a good quality control. The force–deflection curve revealed a higher deflection value under load for SCC beams than that of HSC beams. But both specimens do not exceed the limiting deflection ($\frac{span}{effective\ depth}$) as specified by BS 8110 (1997).

e) The stress-strain behaviour of both SCC beams and HSC beams with embedded PET bottles are within the specified limit, though it is slightly higher with SCC beams with embedded PET bottles.

f) Generally, the SCC beams with embedded PET bottles below the neutral axis have shown better resistance to loads than those of HSC beams. Therefore, concrete below the neutral axis is theoretically ineffective and replacing with PET bottles will help to reduce environmental waste, cost of disposal of such waste, concrete volume reduction and additional strength.

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