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Self-compacting concrete in pavement construction: Strength grouping of some selected brands of cements

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Abstract

This paper investigates strength properties of some selected cement brands for self-compacting concrete application in pavement construction. Three brands each of Portland limestone cement grades, CEM II/A-L 42.5 (Brand A), CEM II/B-L 32.5 (Brand B) and CEM II/B-L 32.5 (Brand C), were used. Rheological test was carried out using the L-Box, V-Funnel and slump cone while compressive and flexural strength tests were carried out, on the hardened concrete, at 3, 7, 14, 21 and 28 days. Brand A exhibited the highest compressive strength right from 3rd day test and maintained this performance through maturity (the 28th day test). Also Brand A had the highest flexural strength of 4.54 MPa, as against 4.5 MPa specified for road construction, at 28 days, while Brand B and Brand C exhibited strengths that were lower. Although Brand C showed good rheological properties, it exhibited the lowest strength properties among the cement grades. These findings engender implication that cement grade lower than 42.5 should be discouraged in pavement construction.

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Keywords: Self-compacting concrete, cement brand, cement grade, rigid pavement, strength grouping, mechanical strength

1. Introduction

Concrete is one of the most utilized construction materials [1-4]. There are several types and applications of concrete in the construction industry. Self-compacting concrete (SCC) is a special type of high strength and high performance concrete used for construction purpose that requires no mechanical vibration, for even without this mechanical vibration, SCC is flowable as well as deformable [3,5], and by these, it has revolutionized concrete

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placement [6]. The use of SCC in civil engineering applications has been on the rise since more than 20 years ago, especially, through its adoption in the construction of bridges, tunnel and structures [7]. However, recent trend is now geared towards its application in road construction, the industry for which SCC has been indicated to hold positive future prospects due to its enormous advantages [8].

The uses of SCC in the construction of rigid pavements (such as traffic lanes and bridges, high-ways and airports runways) are now evidence in major areas [7]. However, problems arise from the consideration that most of the SCC pavements are found to be susceptible to different forms of cracking and other structural defect [8]. This challenge is connected to the fact that strength is one of the most important attribute of concrete pavement and concrete structures and this same attribute applies to SCC, largely because the strength of concrete depends on the quality and quantity of cement, the strength giver in concrete. The cement in concrete binds the fine aggregate (usually sand) and coarse aggregate (gravel, crushed granites etc) together to form a rigid/solid mass that is capable of sustaining loads [9]. Among others, the most important quality of cement that affects the strength of concrete is the compressive strength inherent by the concrete from the cement usage. The strength of concrete structures largely depends on the grade or the strength class of cement since the strength of concrete largely determines the safety, strength and structural integrity of concrete structures [9]. This cement grade or cement strength class corresponds to the minimum 28th days compressive strength of cement. Generally, there are three cement grades: grade 33, grade 43, and grade 53 which are also referred to as cement strength classes 32.5MPa, 42.5MPa and 52.5MPa respectively [10]. In Nigeria, the branded class of cement is the Portland Limestone Cement instead of OPC that is usually employed by many as the branded grade [10].

Although, several works has been done on cement brands (OPC and Portland Limestone Cement) on the strength properties of steel-reinforced concrete applications [11-18] and of normal concrete for structures, there is dearth of study on the strength grouping of Portland limestone cement in SCC production for pavement construction. This study, therefore, investigated the strength properties of some selected grades and brands of Portland limestone cement for SCC in pavement construction.

Nomenclature

SCC	Self-compacting concrete
Brand A	CEM II/A-L 42.5 (High early strength) grade of Portland-limestone cement
Brand B	CEM II/B-L 32.5 (High early strength) grade of Portland-limestone cement
Brand C	CEM II/B-L 32.5 (Normal early strength) grade of Portland-limestone cement

2. Methodology

2.1. Experimental material

The research experiment was designed for M30 grade of concrete. Locally available aggregates of size 25 mm and 4.75 mm for both coarse and fine aggregate were used in the experimental work. Portable water free from toxins and deleterious materials was used all through the research [11]. Mix ingredients, and proportions were according to [17]. The selected cement for this study were tagged Brand A, Brand B and Brand C, which are different brands of Portland-limestone cement, CEM, but of the group belonging to the type of common cement called Portland-composite cement designated as CEM II. This cement brand is different from the Ordinary Portland Cement (OPC) because of the single secondary major constituent, which is limestone, as well as in terms of setting time and quantities required to achieve the same strength [9]. As available in Nigeria open market and which are used for this study, Brand A is grade 42.5 of CEM II/A-L 42.5 (High early strength) while Brand B is CEM II/B-L 32.5 (High early strength) and Brand C is CEM II/B-L 32.5 (Normal early strength).

2.2. Experimental method

The composition of oxides in each selected brand/grade of cement was studied by Atomic Absorption Spectroscopy (AAS) techniques using the AAS - Analyst 200 Perkin Elmer® instrument. Each of the cement brands was employed in the development of plain SCC mixture that was designed at a w/c ratio of 0.41 with fine and coarse aggregate and prepared according to rational mix design method detailed in [18]. The rheology of the concrete was assessed using the slump cone, V-funnel and the L-box according to the specifications prescribed in [19, 21]. In a bid to attain the desired workability using the approach detailed in [20], several trials were made via varying the water cement ratio and super-plasticizer dosage while the mass of fine and coarse aggregate were kept constant. CONPLAST super-plasticizer according to specification in [22] was used in improving the workability. 150 mm × 150 mm × 150 mm and 100mm x 400mm x 100mm mould were used for both compressive and flexural test respectively with oil smeared on the inside of the mould for avoiding sticking after obtaining a uniform and consistent mixture.

3. Methodology

3.1. Chemical composition of cement brands

Results of the composition of oxides in the selected brands and grades of cement are presented in Table 1. This table shows that Brand A had higher calcium oxide than the remaining two brands, which, as suggested in [23], may have implication on the strength and setting time of the cement. Also having strength implication includes the composition of silicon and aluminum oxide also has strength implication. By this, therefore, that it was indicated in Table 1 that Brand C exhibited the lowest composition of the alkaline oxides implies that this will have impact on the strength properties for this brand of cement, according to the details in [23].

Table 1. Chemical composition of the cement brands.

Chemical	Brand A	Brand B	Brand C
Potassium Oxide	0.34	0.32	0.37
Silicon Oxide	19.07	21.3	20.05
Sodium Oxide	0.42	0.54	0.6
Calcium Oxide	64.52	64.22	63.84
Iron Oxide	0.72	0.85	0.63
Magnesium Oxide	2.2	2.1	1.98
Manganese Oxide	0.08	0.07	0.02

Statistical analyses carried out on the chemical composition of these cement brands, the results of which are presented in Table 2, showed that calcium oxide had the highest percentages in the three cement brands considered. From this table also, the skewness of the compositional distribution, which indicates character of the variability of the oxides, showed a positive skewness for calcium oxide and iron oxide, i.e. indicative of a symmetrical distribution of the distribution of these compositions of oxides.

Table 1. Statistical analyses of the compositions of oxides in the cement brands.

Statistical Parameter	CaO	FeO	SiO ₂	Al ₂ O ₃	MgO	K ₂ O
Mean	63.9500	0.7633	20.2167	4.8333	2.1267	0.3333
Std. Error of Mean	0.13577	0.09207	0.64452	0.13170	0.07333	0.00667
Median	63.8400	0.7200	20.2800	4.9600	2.1267	0.3333
Mode	63.79	0.63	19.07	4.57	2.20	0.34

Statistical Parameter	CaO	FeO	SiO ₂	Al ₂ O ₃	MgO	K ₂ O
Std. Deviation	0.23516	0.15948	1.11635	0.22811	0.12702	0.01155
Variance	0.055	0.025	1.246	0.052	0.016	0.000
Skewness	1.644	1.132	-0.254	-1.728	-1.732	-1.732
Std. Error of Skewness	1.225	1.225	1.225	1.225	1.225	1.225
Range	0.43	0.31	2.23	0.40	0.22	0.02
Minimum	63.79	0.63	19.07	4.57	1.98	0.32
Maximum	64.22	0.94	21.30	4.97	2.20	0.34

3.2. Rheological properties of the cement brands

Results of the rheological property tests of the cement brands for this study are presented in Fig. 1 and, in the figure, the unit of T-50 and V-funnel tests are in second (sec) while the unit of L-box is dimensionless [19]. Also, from this figure, the slump flow, which is an indication of the flowability of the SCC mix, finds interpretation as per [19] for the acceptable criteria for the rheological properties of SCC.

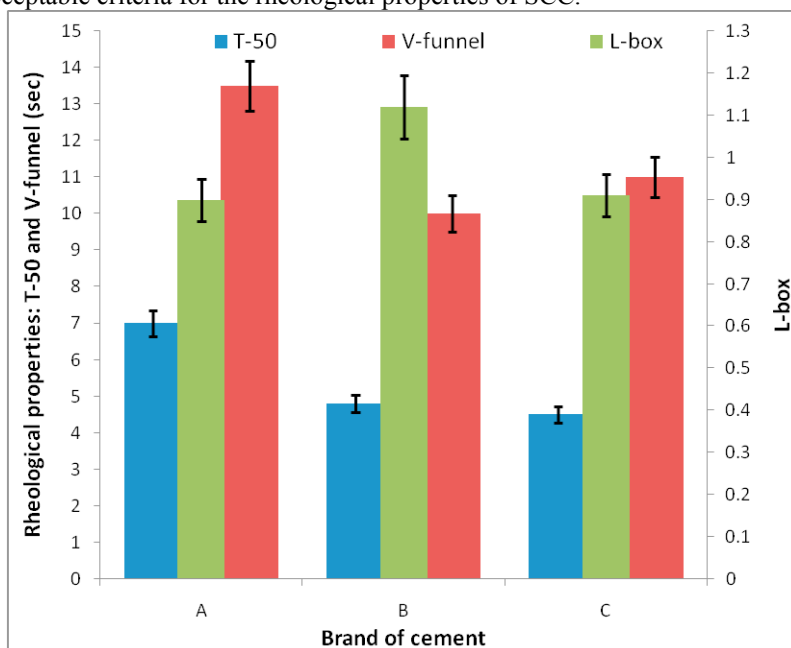


Fig. 1. Rheological properties of the selected brand of cement.

Thus, Brand A's slump flow (T50) was not within the specified range of (2 to 5 secs) while the other two brands were within this limit set in [19]. For the three cement brands, V-funnel result were satisfactory (within the range of 6-12 secs) according to the specifications in [19]. This showed that the viscosity and filling ability are satisfactory for these tested brands. Results of L-box testing, useful for assessing the passing and filling ability of the concrete mix, revealed that Brand A and Brand C was between the standard specifications (0.8 to 1) while the L-box result for Brand B was higher, at 1.12, than the specified range in [19]. Ultimately, workability properties showed that only Brand C had good rheological properties having satisfied the specification for viscosity (T50), segregation and passing ability using the standard prescribed from [19]. Explanation for these trends of result followed from the chemical composition of the cement brands. For instance, the calcium oxide contents in Brand A and in B are

higher than in Brand C and interpreting this based on details in [23], high calcium oxide increases the setting time and hence reduces the workability which may account for the variation in the tested rheological properties. However, it worth noting that both Brand B and Brand C are of the 32.5 cement grade unlike Brand A, which is of 42.5 grade of cement. This is hinting at the fact that cement of lower than 42.5 grade of cement may not be suitable for designing pavement construction.

3.3. Compressive strength of the SCC mixes

Results of the compressive strength obtained from SCC mixes of the different brands of cement for the study are presented in Fig. 2. Also indicated in the figure is the linear plot of 27.5 MPa, the compressive strength at maturity recommended for concrete meant for pavement construction in [24]. Thus, the results of the compressive strength testing showed that cement Brand A acquired the suitable strength required for pavement construction at 28 days of curing. This indicated that it is good for rigid pavement construction. In contrast, the compressive strength for each of the other brands of cement employed in the study falls short of the requisite standard at 28 days. The major reason for this could be both due to the grade of the cement and the chemical composition of the cement brand. Brand A and Brand B had higher composition of calcium oxide, aluminum oxide and silica oxide which may invariably affect the percentage of clinker and gypsum, which are known to be the strength giver [23], in the cement brand. Brand A and Brand C showed a high early compressive strength, in the 7th and 14th days, while Brand B exhibited the lowest strength for these early days but, at maturity, Brand C exhibited the lowest compressive strength.

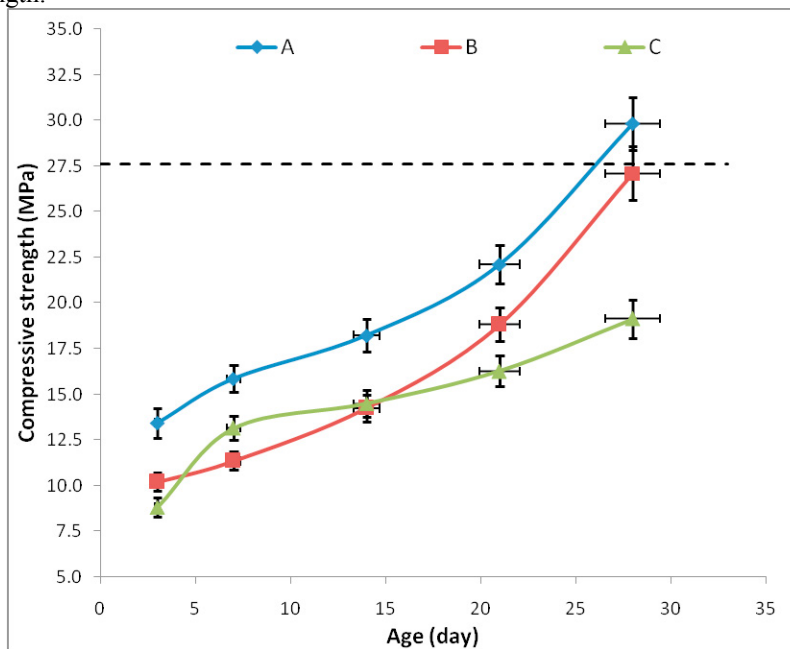


Fig. 2. Compressive strength of the selected brand from early age to maturity.

By these results, it could be inferred that only Brand A exhibited the suitable compressive strength, at maturity, for pavement construction.

3.4. Flexural strength of the SCC mixes.

The results of the flexural strength of the selected brands of cement are presented in Fig. 3 along with the linear plot of 4.5 MPa, the standard flexural strength of concrete for rigid pavement detailed in [24-25]. This figure also showed that Brand A exhibited the highest flexural strength among the tested brands even as this brand of cement, unlike the other two brands in the study, additionally satisfies the required standard specification of flexural strength

for rigid pavement in [24-25]. Implication from this finding include the consideration that Brand A cement can find suitability for constructing concrete pavement that will carry load as simple plain non reinforced concrete beam [26]. Rigid concrete pavements constructed using the brand of cement sharing the composition and properties exhibited by Brand A can therefore possess the requisite degree of beam strength that will allow the constructed pavement to span [24] and exhibit degree of deflection that will be within acceptable range in the designed concrete pavement structure.

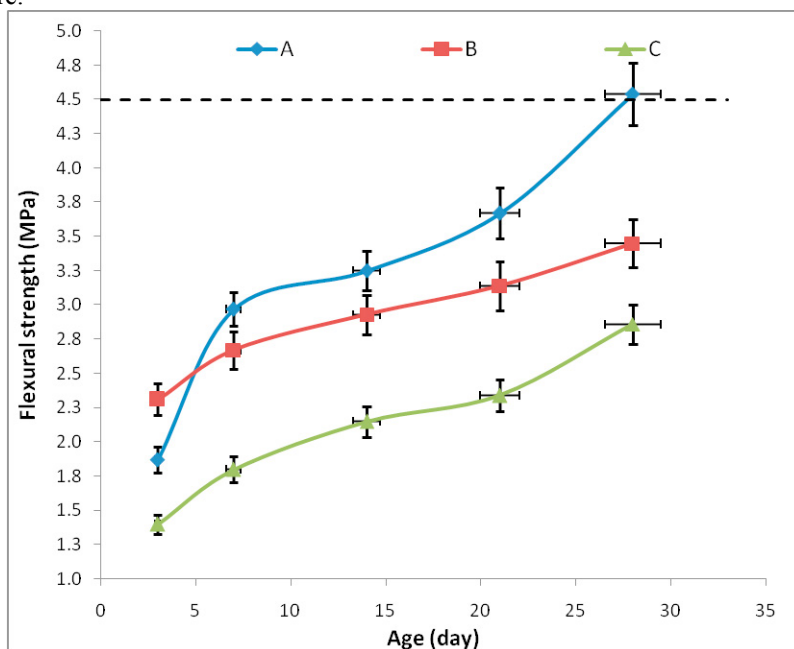


Fig. 3. Flexural strength of the selected brand from early age to maturity.

4. Conclusion

In this work, rheological and strength properties of some selected brands of cements for utilization in self-compacting concrete in pavement construction has been studied. Results from the study showed that Brand C possesses the best rheological properties in the study but the compressive and flexural strength exhibited by this brand at maturity is low, which support the conclusion that the brand may be suitable for construction work requiring good rheological properties. However, the compressive and flexural strength values exhibited by Brand B and Brand C, which fall short of required value from standard and the literature, engender the conclusion that Brand B and C may not be suitable for pavement construction. In contrast, the compressive and flexural strength results exhibited by Brand A showed that these strength values at maturity satisfy requisite standard specified for pavement construction. From the consideration that strength is one of the most important attribute of pavement, findings from this study therefore support the usage of cement brand sharing the composition and properties with Brand A for self-compacting concrete applications in pavement design and construction. That the Brand A cement is of 42.5 grade of cement and that both Brand B and Brand C are both of 32.5 grade of cement also engender the suggestion that cement grade lower than the 42.5 may not be suitable in self-compacting concrete for pavement construction.

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