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# Characterization of Superplasticized Microsilica Concrete

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## ABSTRACT

*Deplorable highway conditions due to poor concrete proportioning has led to the search for possible acceptable mixes for construction. Two groups of mixes, each one consisting of a normal concrete (NC) and three different types of superplasticized microsilica concretes (SMC) were investigated. The SMC process involved six concrete mixtures having partial replacement of cement with microsilica and addition of equal amount water of superplasticizer independently to the mixing water. SMC had superplasticizer content of 2% while microsilica varied from 1% to 3% of cement amount. The two groups of concretes were of aggregates-cement ratio of 3:1 as Group A and 4:1 as Group B. NC of Group A had water cement ratio of 0.45 while SMC had water cementitious material ratio of 0.325. NC Group B had water cement ratio of 0.5 while SMC had water cementitious material ratio of 0.35. I-pavers, Z-pavers, rectangular pavers and 150 mm cubes were used as experimental specimens. Hardened concretes specimens produced were examined for compressive strength at moist curing scheduled for 7, 28, 56 and 90 days. The results showed that the higher the partial replacement of cement with microsilica the higher the slump value for Group A experiment whereas Group B gave reverse of same. Z-paver had the highest compressive strength of the three types of paving blocks but lower than that of 150 mm cube. However, the cube compressive strength could not satisfactorily be the representation of pavers for flexible pavements design.*

## 1. INTRODUCTION

The use of concrete in the production of paving blocks for the construction of flexible pavement is growing rapidly in recent times. Water, superplasticizer, Portland cement, microsilica, fine and coarse aggregates form constituents of superplasticized microsilica concretes (SMC). Increasing the workability of concrete could be achieved using superplasticizer (Akiije, 2018). Zareiyan and Khoshnevis (2018) reported that superplasticizer reduces the amount of water needed for a specific slump and increases the compressive strength of the concrete. Using high dosages of superplasticizer should be avoided for it could reduce the compressive and flexural strength of the concrete. According to Mardani-Aghabaglou et al. (2013) consequential influence of the superplasticizer upon superplasticized concrete is oftentimes obvious at the early ages of the concrete while considering its compressive strength.

Görhan and Kürklü (2014), Kumar and Kisku (2016) as well as Najif and El-Hassan (2018) claimed that in concrete production, fly ash, silica fumes, ground granulated blast furnace slag etc., are potential supplementary cementitious material (SCM). Partial replacement of cement using microsilica (also known as silica fume) in concrete production should be given consideration as part of its disposal as a waste and for enhancing concrete strength development and durability. Microsilica is a by-product of the silicon and ferrosilicon alloy production and a useful mineral admixture in the concrete mix which has significant effects on the properties of the resulting material (Panjehpour et al., 2011). The workability of concrete containing microsilica decreases with the increase in its percentage and with enhanced strength characteristics of the hardened concrete (Salim and Prasad, 2018). SCM possess benefits such as ability to replace certain amount of cement in concrete production whilst displaying cementitious property. This reduces the cost of using portland cement. Imam et al. (2018) emphasized that microsilica is being used in concrete production because of the fine particles, large surface area, high silicon dioxide ($SiO_2$) content and of a high reactive pozzolanic property.

Fine aggregate is a concrete mineral constituent that passes the 9.5 mm sieve and almost entirely passing the 4.76 mm sieve and predominantly retained on the 76-micron sieve (ASTM C125, 2019). Coarse aggregate nominal maximum size for concrete production varies from 4.75 mm to 90 mm of which the commonly used of same varied from 9.5 mm to 25 mm (ASTM D448, 2015). Coarse aggregate generally takes approximately 60-75% of the total volume of the structural concrete while coarse and fine aggregates typically make up to 70% to 90% of same (Buertey et al., 2018).

The aim of this study is the investigation of the potential of normal concretes (NC) and superplasticized microsilica concretes (SMC) which could satisfy standard strength requirements for highway flexible and rigid pavements.

## 2. MATERIALS AND METHODS

### 2.1. Constituents of Concrete

Water, superplasticizer (SP), Portland cement, microsilica, river sand and 12.5 mm maximum size gradation granite were the materials employed in this study. They were appropriately used in the production of both normal concrete (NC) and superplasticized microsilica concretes (SMC). Clean and clear water running out from a pipeline inside the laboratory of the Department of Civil and Environmental Engineering, Faculty of Engineering, University of Lagos was used for each concrete mix. Grade 42.5 R Ordinary Portland Cement (OPC) brand was employed for the concrete mixture and which was bought from nearby market. Physical properties, chemical and compound composition properties of the OPC used were determined through laboratory tests for its level of conformity for concrete production in accordance to AASHTO M 85 (2018). The cement initial and final setting time as well as its consistency values were determined using Vicat apparatus in accordance with ASTM C 191 (2013). Also, the fineness of the cement used was measured by determining the percent passing the 0.045 mm sieve in accordance with ASTM C 430 (2017) procedure. The relative density of cement used was determined as its weight per unit volume in the laboratory according to ASTM C 188 (2015) while its bulk density was determined in accordance with ASTM D6023 (2016).

Sand from Majidun river bed in Lagos State was air dried in the laboratory for the production of the concrete specimens whilst its gradation, coefficient of uniformity and curvature were determined in accordance with

AASHTO T 27 (2014). The moisture content, relative density, dry density and absorption of the fine aggregate used were determined in accordance with AASHTO T 85 (2018) specification. Also, the bulk density of the fine aggregates used was determined in accordance with AASHTO T 19 (2014) specifications.

Granite of 12.5 mm nominal size gradation was used as coarse aggregate in the production of the concretes. The granite was subjected to sieve analysis, coefficient of uniformity and curvature tests in accordance with AASHTO T 27 (2014). The bulk density of the coarse aggregate used was determined in accordance with AASHTO T 19 (2014) specifications. In accordance with AASHTO T 84 (2013) specification, the moisture content, specific gravity, dry density and absorption of the granite used were determined.

## 2.2. Fresh Concrete Production and Testing

Concrete mix proportioning in relationship to the identification number and the proportion of concrete constituents employed for the production of fresh concrete in this study are shown in Table 1 based on two groups A and B. Each group experiment has production of a normal concrete (NC) and three types of superplasticized microsilica concretes (SMC) of the mixture of cement (C), fine aggregate (FA) and coarse aggregate (CA). Also, in Table 1 the relationship among the concrete constituents by water cementitious materials ratio, percent of superplasticizer (SP) and percentage of microsilica (SF) by weight of cement. Table 2 describes the concrete mix proportioning (kg/m$^3$) of concrete of each concrete mixture in each group.

Fresh concrete production involved using 50 kg of cement for a batch by means of tilting mobile rotating drum type mixer inside the laboratory. In the process, small amount of water was introduced into the rotating drum mixer to make the internal condition saturated dry surface and then the ingredients were thoroughly mixed dry. In the case of concrete mix for each of Type NC0A and NC0B concrete mixtures, 80% of the required water was added to the constituents in the rotating drum and after fresh concrete was poured on a saturated surface dry platform. The balance of 20% of the required water was poured inside the rotating drum again to drain out the remaining concrete and later thoroughly mixed manually on the platform. Similar mixing operation was carried out for types SMC1A, SMC2A, SMC3A, SMC1B, SMC2B and SMC3A using the required superplasticized water.

For each fresh concrete batch produced, casting of concrete specimens was carried out as programmed in Table 3. The degree of workability involving slump and compacting factor tests were also carried out. Four types of specimen paver moulds used are shown in Figure 1. In Figure 1, the paver moulds and the paver types are arranged as of I-shape, Rectangular shape, Z-shape and cube. The slump test was carried out upon the fresh concrete produced in accordance with AASHTO T 119 (2013). Also, the compacting factor test upon the fresh concrete was carried out in accordance with BS 1881 (2011).

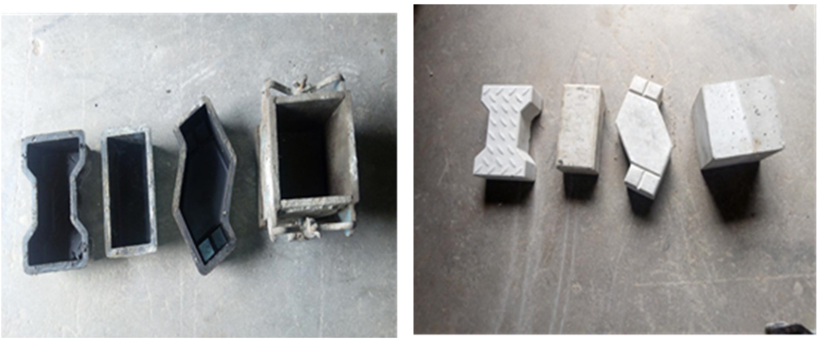

Figure 1: Pavers and cube moulds as well as concrete pavers plus cube

Table 1: Concrete mix proportions

| | Concrete mix type | Water cementitious material ratio by weight of cement (water/superplasticizer) | SP percent by wt. of cement | SF percent by wt. of cement proportion | C | F A | CA |
|---|---|---|---|---|---|---|---|
| Group A | NC0A | 0.45(0.45/0) | 0 | 0 | 1 | 1.5 | 1.5 |
| | SMC1A | 0.325(0.305/0.02) | 2 | 1 | 1 | 1.5 | 1.5 |
| | SMC2A | 0.325(0.305/0.02) | 2 | 2 | 1 | 1.5 | 1.5 |
| | SMC3A | 0.325(0.305/0.02) | 2 | 3 | 1 | 1.5 | 1.5 |
| Group B | NC0B | 0.5 (0.5/0) | 0 | 0 | 1 | 2.0 | 2.0 |
| | SMC1B | 0.35(0.48/0.02) | 2 | 1 | 1 | 2.0 | 2.0 |
| | SMC2B | 0.35(0.48/0.02) | 2 | 2 | 1 | 2.0 | 2.0 |
| | SMC3B | 0.35(0.48/0.02) | 2 | 3 | 1 | 2.0 | 2.0 |

Table 2: Batch quantities per m³ of concrete

| | Concrete Mix Identification | Water cementitious material ratio by weight of cement (water/superplasticizer) | Water content (kg/m³) | SP content (kg/m³) | SF content (kg/m³) | Cement content (kg/m³) | Fine Agg. (kg/m³) | Coarse Agg. (kg/m³) |
|---|---|---|---|---|---|---|---|---|
| Group A | NC0A | 0.45(0.45/0) | 237 | 0 | 0 | 527 | 792 | 792 |
| | SMC1A | 0.325(0.305/0.02) | 180 | 11 | 5.5 | 559 | 848 | 848 |
| | SMC2A | 0.325(0.305/0.02) | 180 | 11 | 11 | 559 | 848 | 848 |
| | SMC3A | 0.325(0.305/0.02) | 180 | 11 | 16.5 | 559 | 848 | 848 |
| Group B | NC0B | 0.5 (0.5/0) | 215 | 0 | 0 | 430 | 861 | 861 |
| | SMC1B | 0.35(0.48/0.02) | 158 | 9 | 4.6 | 456 | 921 | 921 |
| | SMC2B | 0.35(0.48/0.02) | 158 | 9 | 9.2 | 456 | 921 | 921 |
| | SMC3B | 0.35(0.48/0.02) | 158 | 9 | 13.8 | 456 | 921 | 921 |

Table 3: Concrete specimens casting modules

| | Concrete mix identification | I-Shape paving blocks (220 x 110 x 80) (mm) | Rectangular paving blocks (200 x 100 x 80) (mm) | Z-Shape paving blocks (240 x 100 x 80) (mm) | Cube (150 x 150 x150) (mm) |
|---|---|---|---|---|---|
| Group A | NC0A | 12 | 12 | 12 | 12 |
| | SMC1A | 12 | 12 | 12 | 12 |
| | SMC2A | 12 | 12 | 12 | 12 |
| | SMC3A | 12 | 12 | 12 | 12 |
| | Total | 48 | 48 | 48 | 48 |
| Group B | NC0B | 12 | 12 | 12 | 12 |
| | SMC1B | 12 | 12 | 12 | 12 |
| | SMC2B | 12 | 12 | 12 | 12 |
| | SMC3B | 12 | 12 | 12 | 12 |
| | Total | 48 | 48 | 48 | 48 |

## 2.3. Hardened Concrete Strength Tests

Hardened concrete compressive strength tests were carried out on each of the four types of specimens after they had been cured in water respectively as programmed for 7, 28, 56, 90 and 120 days. The specimens were tested individually using a 1500 kN capacity hydraulic compression testing machine powered with electricity in accordance with BS EN 12390 (2009). During testing, I-shape pavers, rectangular pavers, Z-shape pavers and cube were tested by 3 specimens per each shape of samples respectively. The average result of the three specimens was considered individually for the compressive strengths of I-shape paver, Z-shape paver, rectangular paver and cube.

## 3. RESULTS AND DISCUSSION

The results of all the tests on concrete material constituents, fresh concretes produced and moist cured hardened concrete pavers and cubes cast are discussed as follows.

## 3.1. Cement Properties

Table 4, Table 5 and Table 6 show the results of the physical properties, chemical and compound compositions of the Portland cement grade 42.5 R respectively. Considering the results of the cement used by the physical properties, chemical composition and of its compound composition they conformed favourably to the specification requirements in accordance with AASHTO M 85 (2018). Also, as seen in Table 4, the cement values of bulk density and specific gravity were suitable for concrete mix proportioning by weight and absolute method. Considering the results as stated, it could obviously be said that the cement used was satisfactorily suitable for concrete production.

Table 4: The cement physical properties

| Compound Composition | Portland cement 42.5 R | Specification requirements content | Remarks |
|---|---|---|---|
| Specific gravity $\gamma_G$ | 3.15 | 3.13-3.15 | Conformed |
| Bulk density, $\gamma_b$ (kg/m³) | 1160 | 1000-1300 | Conformed |
| Fineness, % retained on 45 (μm) | 2 | 10 | Conformed |
| Loss of ignition, LOI, (%) | 0.006 | 0.04-0.05 | Not Conformed |
| Insoluble residue, IR, (%) | 99.96 | 99.95-99.97 | Conformed |

Table 5: The cement chemical composition

| Chemical Composition | Portland cement 42.5 R (%) | Specification requirements content (%) | Remarks |
|---|---|---|---|
| Silicon dioxide ($SiO_2$) | 21.23 | 18.7 – 22.0 | Conformed |
| Aluminum oxide ($Al_2O_3$) | 5.11 | 4.7 – 6.3 | Conformed |
| Iron oxide ($Fe_2O_3$) | 0.95 | 1.6 – 4.4 | Not Conformed |
| Calcium oxide (CaO) | 63.74 | 60.6 -66.3 | Conformed |
| Magnesium oxide (MgO) | 2.10 | 0.7 – 4.2 | Conformed |
| Sulphur trioxide ($SO_3$) | 1.02 | 1.8 – 4.6 | Not Conformed |
| Sodium oxide ($Na_2O$) | 0.64 | 0.11 -1.2 | Conformed |

Table 6: The cement compound composition

| Compound Composition | Portland cement 42.5 R (%) | Specification requirements content (%) | Remarks |
|---|---|---|---|
| Tricalcium Silicate, $C_3S$ | 21.23 | 18.7 – 22.0 | Conformed |
| Dicalcium Silicate, $C_2S$ | 5.11 | 4.7 – 6.3 | Conformed |
| Tricalcium Aluminate, $C_3A$ | 0.95 | 1.6 – 4.4 | Not Conformed |
| Tetracalcium Aluminate, $C_4AF$ | 63.74 | 60.6 -66.3 | Conformed |

### 3.2. Fine and Coarse Aggregates Properties

The results of the physical properties of fine and coarse aggregates are shown in Table 7. The value obtained for each property indicated that the materials were quite satisfactory for concrete production based upon American Society for Testing and Materials (ASTM) standard. The fine aggregate used in this study was a well-graded river sand material based upon the gradation test and as seen in Figure 1. The fine aggregate gradation satisfied the ASTM C 33 (2018) standard requirements specification and could be classified as grading No. 1. The coarse aggregate used in this study was a uniformly graded granite material as shown in Figure 2.

Table 7: The physical properties of fine and coarse aggregates

| S/No | Physical properties | Fine agg. river Sand | Coarse aggregate 12.5 mm granite |
|---|---|---|---|
| 1 | Percent of particles retained on the 4.75 mm sieve, (%) | 1 | 97 |
| 2 | Percent of particles passing the 4.75 mm sieve, (%) | 99 | 3 |
| 3 | Percent of particles passing the 0.075 mm sieve, (%) | 2.8 | 0 |
| 4 | Fineness modulus | 2.74 | 2.69 |
| 5 | Coefficient of uniformity, (Cu) | 2 | 1.96 |
| 6 | Coefficient of curvature, (Cc) | 1 | 0.9 |
| 7 | Bulk density, (kg/m$^3$) | 1655 | 1650 |
| 8 | Specific gravity | 2.67 | 2.7 |
| 9 | Moisture (water) absorption (%) | 1.12 | 0.43 |
| 10 | Aggregate crushing value (%) | - | 18 |
| 11 | Aggregate impact value (%) | - | 13 |
| 12 | Los Angeles Abrasion Value (%) | - | 19 |

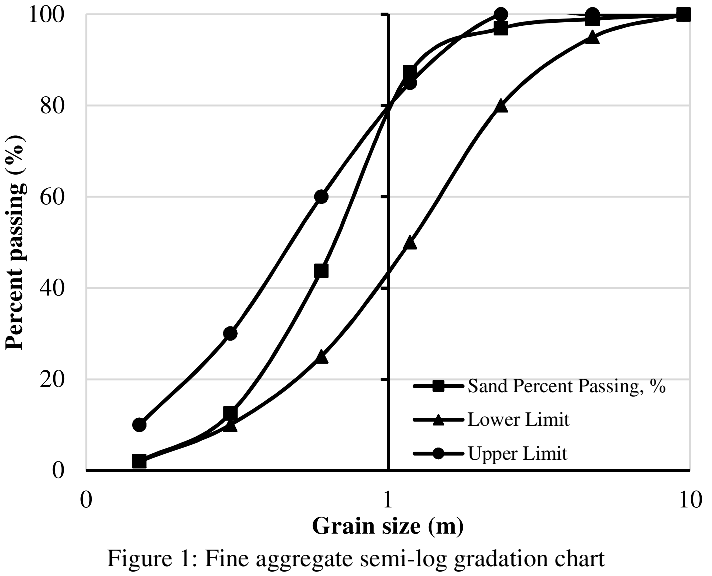

Figure 1: Fine aggregate semi-log gradation chart

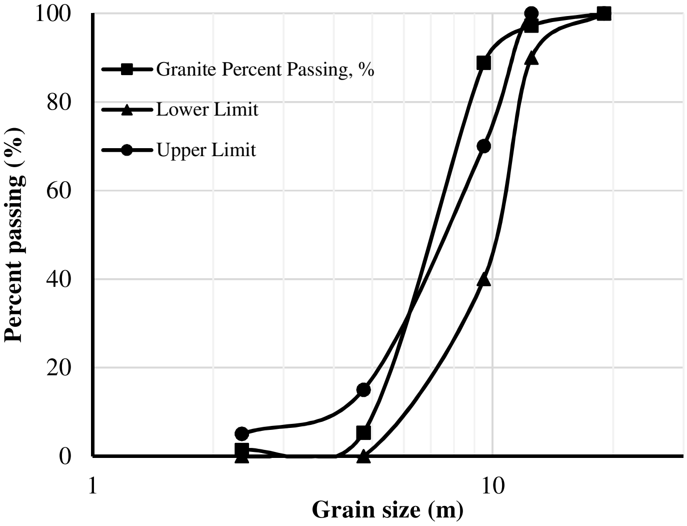

Figure 2: Coarse aggregate semi-log gradation chart

### 3.3. Fresh Concrete Properties

The results of the workability characteristics trend of the fresh concretes with the following individual identification NC0A, SMC1A, SMC2A, SMC3A, NC0B, SMC1B, SMC2B and SMC3B are presented in Table 8. Group A experiments with 1:1.5:1.5 mix concrete has aggregates-cement ratio of 3 whereas Group B experiments with 1:2:2 mix concrete has aggregates-cement ratio of 4. It could be seen in Table 8 that Group A experiments with aggregates-cement ratio of 3 proffered mixes of which the higher the microsilica the higher the slump. Whereas, Group B experiments with aggregates-cement ratio of 4 as shown in Table 8 proffered mixes of which the higher the microsilica the lower the slump. There were similarities as exhibited by slump tests for compaction factor tests as shown in Table 8 by the superplasticized concretes. Marotta (2005) claimed that workability is a relative term because concrete which satisfied its requirements under one set of conditions may not satisfy its requirements under different conditions.

Table 8: Workability tests results

| | Concrete Mix Identification | Super plasticizer dosage in % of cement content | Microsilica amount in % of cement content | Slump Values (mm) | Degree of work ability | Comp action factor | Degree of work ability |
|---|---|---|---|---|---|---|---|
| Group A 1:1.5:1.5 mix | NC0A | 0 | 0 | 28 | Low | 0.93 | Medium |
| | SMC1A | 2 | 1 | 86 | High | 0.84 | Very Low |
| | SMC2A | 2 | 2 | 110 | High | 0.86 | Low |
| | SMC3A | 2 | 3 | 135 | High | 0.95 | High |
| Group B 1:2:2 mix | NC0B | 0 | 0 | 20 | Low | 0.95 | High |
| | SMC1B | 2 | 1 | 25 | Low | 0.96 | High |
| | SMC2B | 2 | 2 | 21 | Low | 0.94 | High |
| | SMC3B | 2 | 3 | 15 | Low | 0.87 | Low |

### 3.4. Hardened Concrete Strength Properties

Figures 3 through 13 show the values of the result of compressive strengths of the moist cured pavers and cubes for NC and SMC. In Figure 3 through Figure 6, it was observed that the higher the percentage of microsilica the higher the value of compressive strength with decreased rate of development. This is in conformity with Mamlouk and Zaniewski (2006) claiming that microsilica is a very reactive pozzolan of which concrete containing it could have very high strength and be very durable. Figures 3 and 4 with concrete mix of 1:1.5:1.5 showed higher values of compressive strength than those of concrete mix of 1:2:2 of Figures 5 and 6. In Figures 3 and 5 specimens' compressive strength indicated high differences in values between 7- and 28-days moist curing as shown for Group A and Group B experiments. However, very small differences in compressive strength values were noticed in Figures 4 and 6 for both 28-and 90-days moist curing for Group A and Group B experiments. Figures 3 and 5 also showed that the differences in compressive strengths between 7-and 28-days moist curing are high while comparing same with 28-and 90-days moist curing of Figures 4 and 6 that were small. Pertinently, the highest compressive strength value obtained per group was obtained from the application of SF at 3% of cement content. Also, it was observed that the lower the aggregates cement ratio the higher the compressive strength.

In Figure 7 through Figure 12, it was observed that the value of compressive strength was increasing with increase in curing days for each specimen. Figure 7 and Figure 10 gave the comparison of compressive strength as exhibited by specimens whilst considering aggregates cement ratio 3 and 4 respectively. It was between rectangular paver and Z-paver with different percentages of SF at constant value of SP upon moist curing in days for Group A and Group B respectively. The results showed that Z-paver was of higher value of compressive strength than the rectangular paver in both cases. Figures 8 and 11 also showed that rectangular paver had higher compressive strength than I-paver. Correspondingly, considering Figure 9 and Figure 12, the results showed that 150 mm cube had higher value of compressive strength than the Z-paver. Also, Figure 13 showed the extent of the differences in compressive strengths between the Z-paver and 150 mm cube. This is an indication that using 150 mm cube compressive strength meant for rigid pavement could not be a useful representation to be employed for concrete pavers of flexible pavement as exhibited in this study.

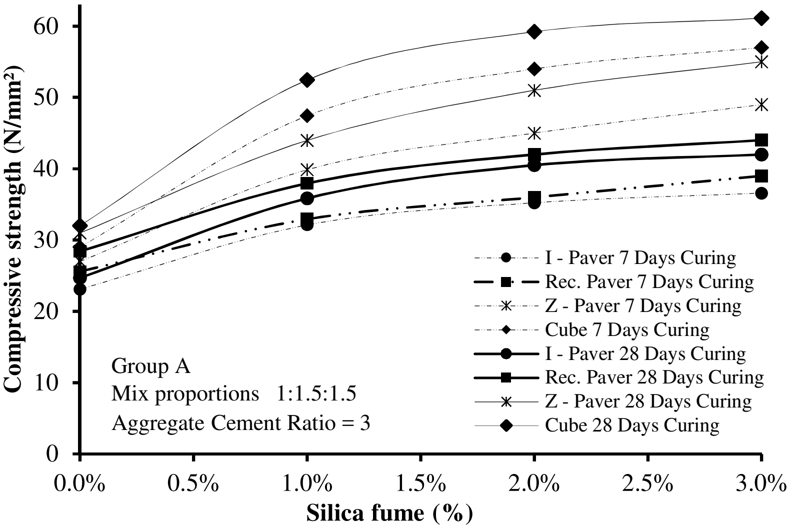

Figure 3: Compressive strength for Group A for 7- and 28-days moist curing

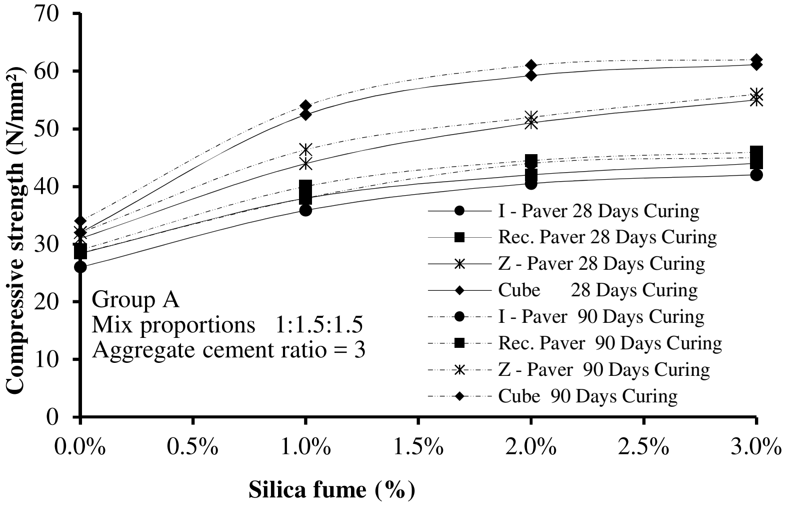

Figure 4: Compressive strength for Group A for 28- and 90-days moist curing

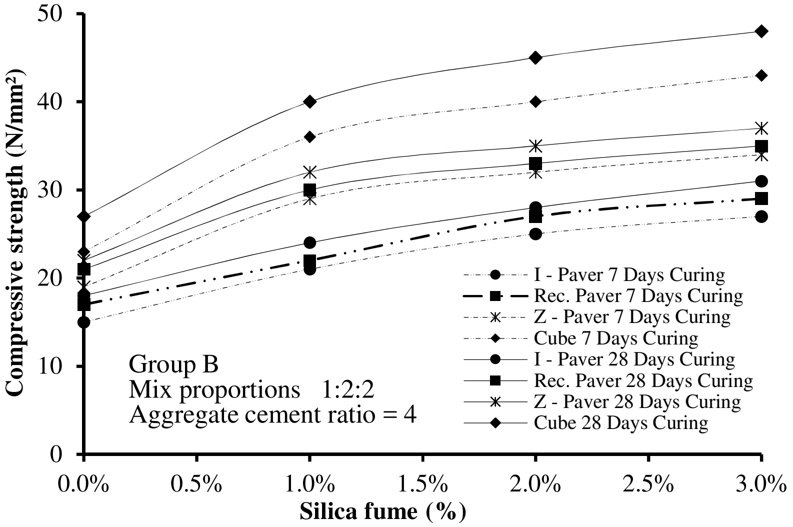

Figure 5: Compressive strength for Group B for 7- and 28-days moist curing

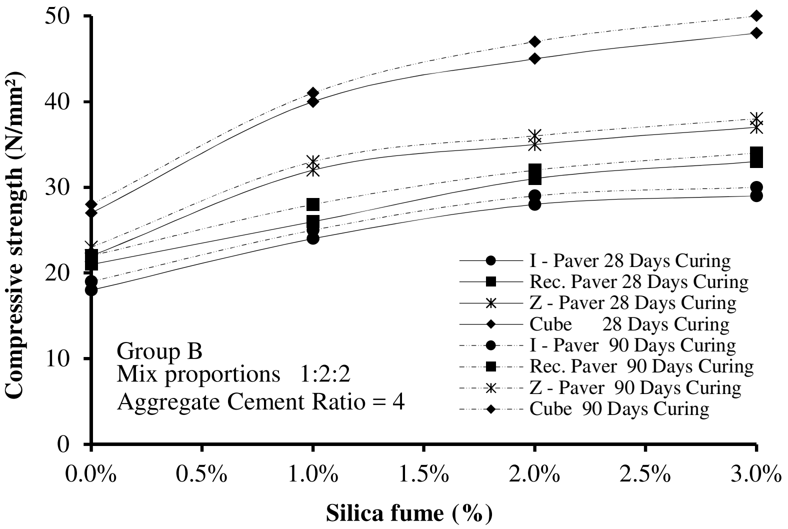

Figure 6: Compressive strength for Group B for 28- and 90-days moist curing

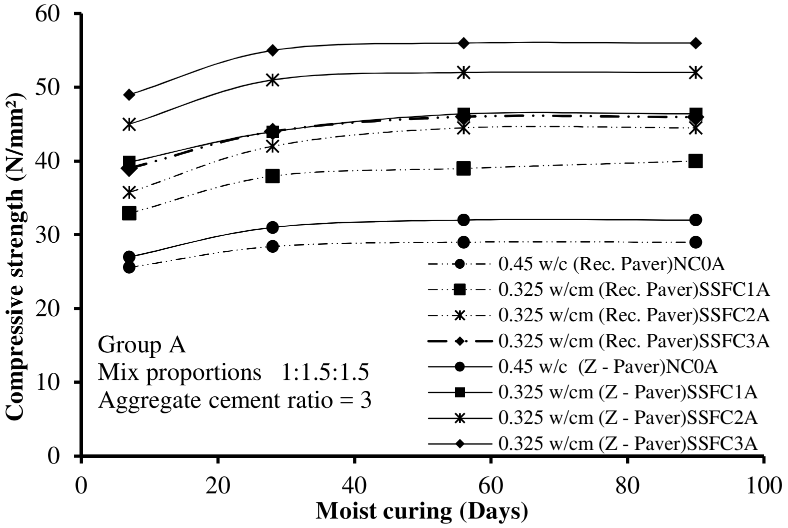

Figure 7: Comparison of compressive strength of Z-pavers and rectangular pavers

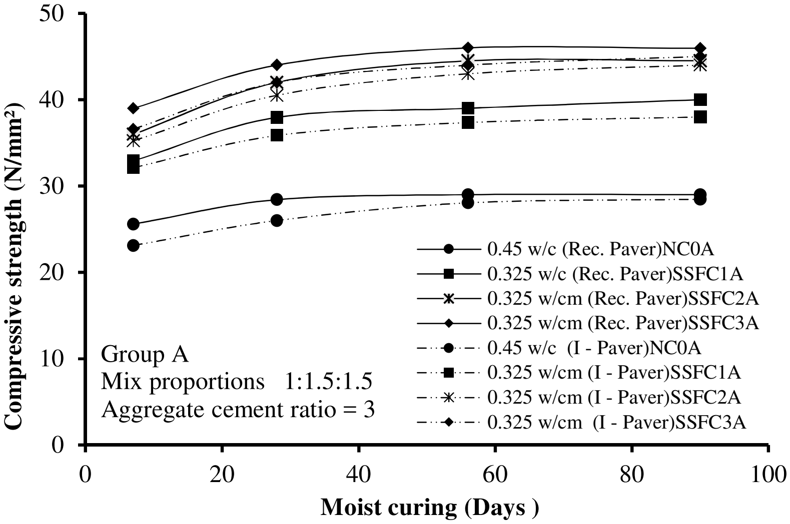

Figure 8: Comparison of compressive strength of rectangular pavers and I-pavers

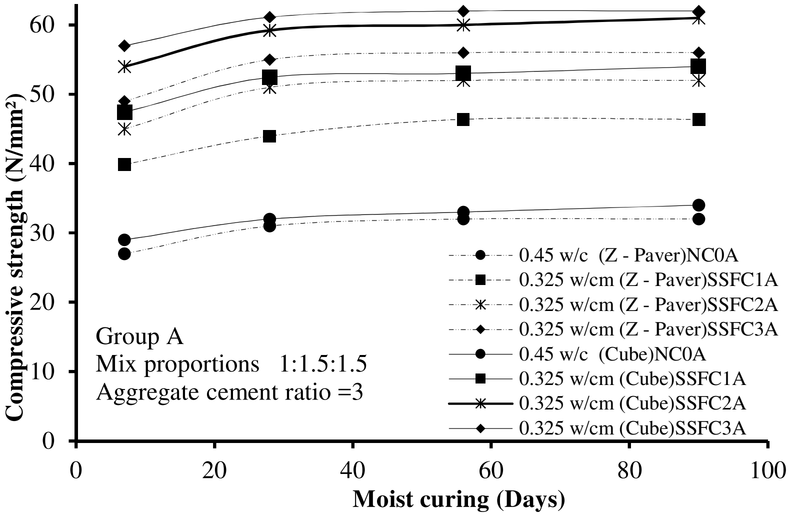

Figure 9: Comparison of compressive strength of 150 mm cube and Z-pavers

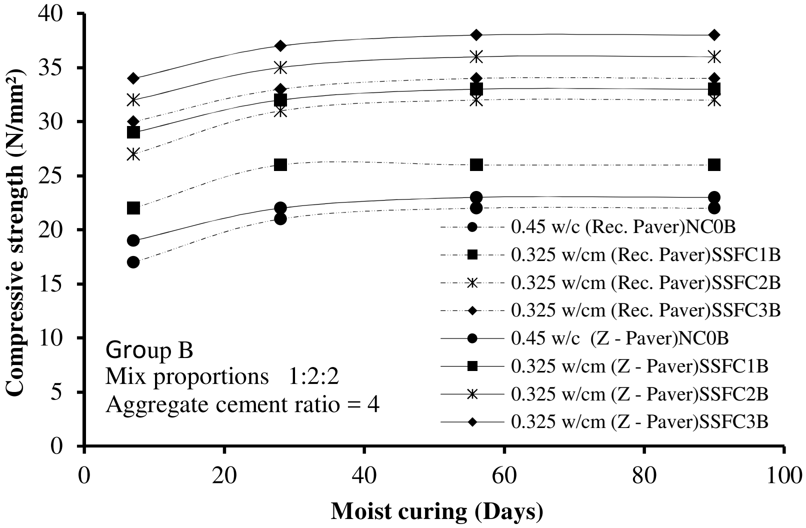

Figure 10: Comparison of compressive strength of Z-pavers and rectangular pavers

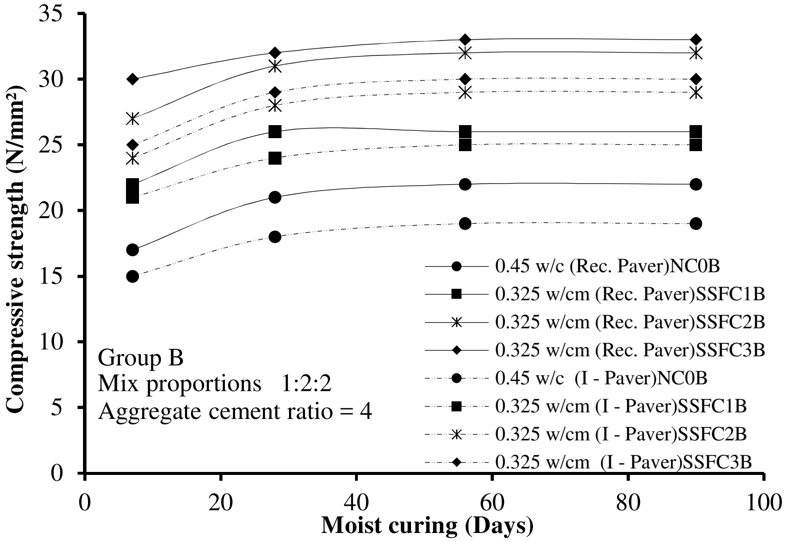

Figure 11: Comparison of compressive strength of rectangular pavers and I-pavers

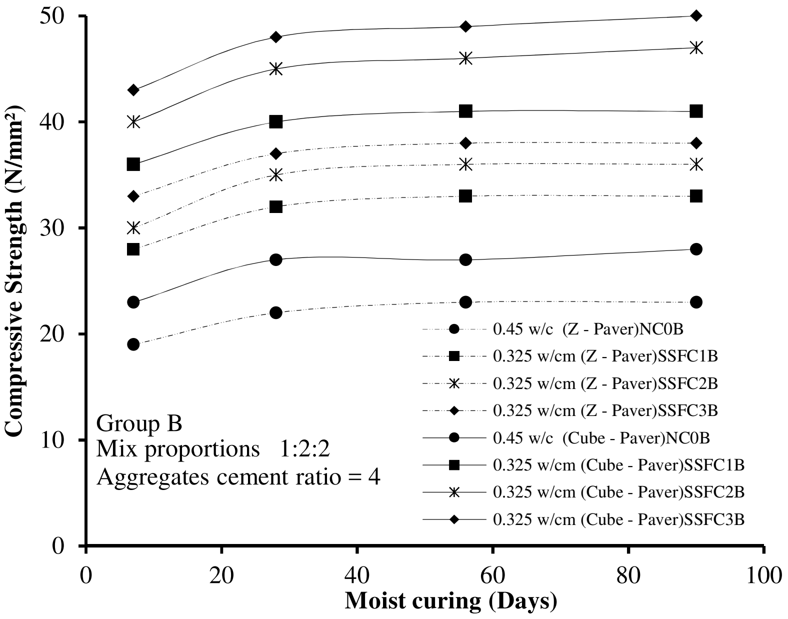

Figure 12: Comparison of compressive strength of 150 mm cube and Z-pavers

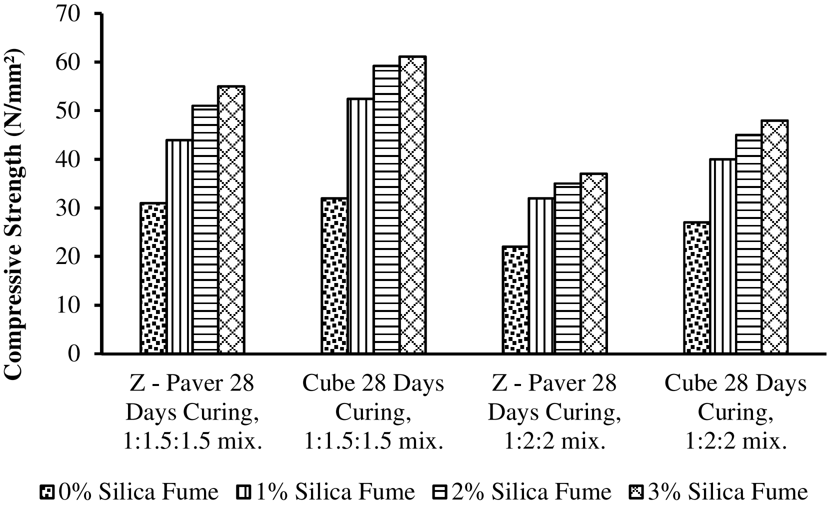

Figure 13: Comparison of compressive strength of 150 mm cube and Z-pavers

## 4. CONCLUSIONS

The following conclusions are deduced based upon the result of this study.

1. The higher the percentage of SF the higher the values of concrete compressive strength for both normal and superplasticized microsilica concretes.
2. The highest value of both NC and SMC compressive strength of Group A of 1:1.5:1.5 mix is higher than those of same in Group B of 1:2:2 mixture.

3. At 28 days moist curing tests, the Z-pavers for both NC and SMC have highest values of compressive strengths of all while those of the rectangular pavers have higher values than those of the I-pavers for both Groups A and B mixtures.
4. The cube compressive strengths at 28 days proffered higher values of compressive strengths than those of Z-pavers for both Groups A and B mixtures.
5. Concrete compressive strengths of 150 mm cube obtained from Group A using fixed 2% SP and SF at varying 1%, 2% and 3% of cement content only satisfied required 50 N/mm² for rigid pavement but Group B of same did not.
6. Only Z-paver concrete compressive strength value obtained from Group A using fixed 2% SP and SF at 3% of cement content only satisfied the required 55 N/mm² for flexible pavement but Group B of same did not.
7. Concrete compressive strength made as of Group B of aggregates-cement ratio of 4:1 could not satisfy highway rigid pavement requirement as does 3:1 of Group A.

## 5. ACKNOWLEDGMENT

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- Elkem Silicon Materials
- Purechem Manufacturing Limited – Fosroc Construction Chemical.

## 6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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