Journal of Engineering Science and Technology
Vol. 14, No. 5 (2019) 2746 - 2760

INFLUENCE OF GRANITE-GRAVEL COMBINATION ON THE STRENGTH OF SELF-COMPACTING CONCRETE: TOWARDS A SUSTAINABLE CONSTRUCTION MATERIAL

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Abstract

This study focusses on the influence of granite-gravel (washed and unwashed) combination as coarse aggregate on hardened properties of Self-Compacting Concrete (SCC). Granite-gravel combination in varying percentages was used as coarse aggregates to produce SCC while other concrete constituents were kept constant. The experiments executed on hardened SCC were compressive and split tensile strength. Concrete were made using 150 mm cubes and 100 mm × 200 mm cylinders. Data obtained were analysed using graphical illustrations while Minitab was used to model values for the mix proportions. The compressive strength of SCC produced reliable results with a minimum strength of 30.96 N/mm² for 50% washed gravel at 28 days of which, the strength also increases as curing age increased. The split tensile strength of SCC increases as the curing day increased but decreased as gravel content increased with 50/50 threshold limit. The Surface plots analysis shows that the percentage increase of granite-washed gravel combination as coarse aggregate and curing ages in SCC has significant impact on compressive strength. It can be concluded that granite/gravel combination as coarse aggregates in SCC production is feasible and reliable provided the threshold limits of 50% washed gravel and 30% unwashed gravel are not exceeded.

Keywords: Aggregates, Cement, Compressive strength, Concrete, Granite and gravel, Self-compacting concrete.

1. Introduction

EFRNARC [1] reported that self-compacting concrete (SCC) is a non-segregating and flowable concrete that can spread into place and fill the form work without internal and external vibration. The ease of flow, reduction in the time of casting, placement, flexibility in the architectural and structural design are some of the importance of studying self-compacting concrete. Topcu and Uygunoglu [2] reported that the upward movement of coarse aggregates as a result of plain concrete vibration, may lead to segregation of fresh concrete during transporting and placing of concrete. The introduction of self-compacting concrete provides lasting solution for upward movement of coarse aggregates due to easy flow of aggregates without vibration. The hardened properties of concrete as well as construction productivity and job site safety can be increased using SCC [3]. However, to achieve workable and durable SCC greater technical expertise and quality control measures are required. SCC produced better results with respect to higher cement content, higher paste volume, lower water-cementitious materials, fine and coarse aggregates content [4].

Different factors such as properties of aggregates, mix proportions, type of admixtures, temperature, cement characteristics, mixing condition and time can affect the rheology of concrete [5]. Aggregate properties are the utmost factor among the factors mentioned because it occupies 70-80% of the entire volume of conventional concrete [6]. However, aggregates mostly constitute approximately 60% by volume of self-compacting concrete. It plays major roles on the characteristic properties of SCC, due to the large volume fraction it occupies and can be expected to have significant effect on other properties as well [2]. To achieve economical SCC, the constituent materials of SCC and mixture proportions should be properly selected. There are two categories of aggregate used in concrete production namely; fine aggregates and coarse aggregates. Fine aggregates are those that pass through a 4.75 mm square mesh sieve [7-9]. Coarse aggregates used for this study were made up of gravel and granite with particles mostly greater than 5 mm and usually between 9.5 mm and 12.5 mm

Gravel and granite were studied as coarse aggregates in this current work. Granite and gravel are coarse aggregates used in concrete production. In most part of Nigeria gravel is readily available and is acquired at cheaper price than granite. The availability and cost of aggregates play vita role when selecting aggregates for civil engineering applications because of the quantities required for concrete production [10, 11]. Frequently, one of the primary challenges facing the materials engineer on a project is how to use the locally available material in the most cost-effective manner for both conventional and self-compacting concrete [12, 13]. Hence, any backing for totally new or combined (composite) materials must be examined structurally and mechanically, to establish their short-time and long-time behaviours. This will definitely be of assistance to create a well-defined boundary for concrete constituents selection.

Topcu and Uygunoglu [2] reported that due to the large volume fraction aggregate occupies in SCC, it is expected to have significant influence on the characteristic proportions of the mix and other properties as well. Kim et al. [14] studied self-compacting concrete produced with lightweight aggregates and found that decrease in density of lightweight aggregates improves the flowability with an increase in resistance to segregation. Bamigboye et al. [15] studied the influence of aggregate properties on strength of concrete and reported that the flakiness of coarse aggregates adversely affected the workability and mobility of concrete as well as the strength, which decreased with the increasing flakiness. Yang and Huang [16] and Ede et al., [17] reported that the behaviour of composite materials such as self-compacting concrete are determine by the physical and chemical properties of constituents materials. Bouzoubea and Lanchemi [18] studied SCC combining high-volume fly class F ash with cement and found that as fly ash and water cement ratio percentage decreases the concrete strength increases.

This current study focusses on influence of granite-gravel (both washed and unwashed) combination as coarse aggregate on compressive and split tensile strengths of self-compacting concrete towards a sustainable construction material. The sustainability of SCC using granite and gravel combination as coarse aggregates can be judged based on availability and affordability of gravel. Gravel is readily available and cheaper than granite in most part of Nigeria [19]. The utilization of gravel allows the efficient use and conservation of locally available resources.

2. Materials and Methods

The materials, which were used in this study are washed gravel, unwashed gravel and granite as coarse aggregates in line with ASTM C136 [20], natural river sand as fine aggregates in line with ASTM C33 [21]. Ordinary Portland cement (CEM 42.5N), which conforms to the standard specified in ASTM C150 [22], was used throughout the experiment. Coarse aggregates used were granite and gravel with 12. 5 mm maximum for all the mix. Tap water was used for mixing the concrete in accordance with ASTM C31 [23]. Aggregates grading into various sizes was determined by sieve analysis in line ASTM C136 [20].

The specific gravity of fine and coarse aggregates (granite and gravel) were determined using buoyancy apparatus in line with ASTM C127-15 [24] for fine and ASTM C128-15 [25] for coarse aggregates. Also, the water absorption of the aggregates used was determined in accordance with ASTM C1585-13 [26]. The bulk specific gravity (SG), bulk saturated surface dry (SSD) specific gravity, apparent specific gravity and water absorption of the samples were determined. Batching of concrete was done by weight [27]. Table 1 provides details of batching and mixing for both washed and unwashed gravel where SCC1 represent 100% granite, which is the control while SCC2, SCC3, SCC4, SCC5 and SCC6 represent 10%, 20%, 30%, 40%, 50% granite replacement with gravel in line with EFNARC [1].

Granite-gravel combination in varying percentages was used as coarse aggregates while other concrete constituents were kept constant. The compressive strength of concrete produced was determined in agreement with ASTM C39 [28] standard using 150 mm concrete cubes. The split tensile strength was determined according to ASTM C496 [29] standard using 100 × 200 mm for concrete specimens produced from SCC. The specimens (fresh concrete) were cast in 150 × 150 × 150 mm and 100 mm × 200 mm molds without shaking and tamping for SCC specimens. For split tensile the cylindrical specimens were crushed along two diametrically opposed generators to avert multiple cracking and crushing at the point of loading. Fig. 1. showing the compression machine use for both compressive and split tensile strength tests. The data obtained were analysed using graphical illustrations while Minitab 17 was used to model strength values.

Table 1. Mix proportions of self-compacting concrete samples [3].

S/N	Mix samples	Mix proportion (%)	Cement (g)	Fine aggregate (g)	Coarse aggregate (g)		Water (g)	Super-plasticizer (%)
					Granite	Gravel		
1	**SCC1**	100	561	977	620	-	168.8	1.14
2	**SCC2**	90/10	561	977	558	62	168.8	1.14
3	**SCC3**	80/20	561	977	496	124	168.8	1.14
4	**SCC4**	70/30	561	977	434	186	168.8	1.14
5	**SCC5**	60/40	561	977	372	248	168.8	1.14
6	**SCC6**	50/50	561	977	310	310	168.8	1.14

Fig. 1. Compression machine use for both compressive and split tensile strength tests with cube under load.

3. Results and Discussion

3.1. Particle size distribution for aggregates

The grading curves of sand, gravel and granite for sieve analysis are as shown in Figs. 2 and 3. Particle size graphs formed S-shape curves, and it was concluded that the fine and coarse aggregates used for this study are well graded and are therefore suitable for concrete production [20, 30, 31].

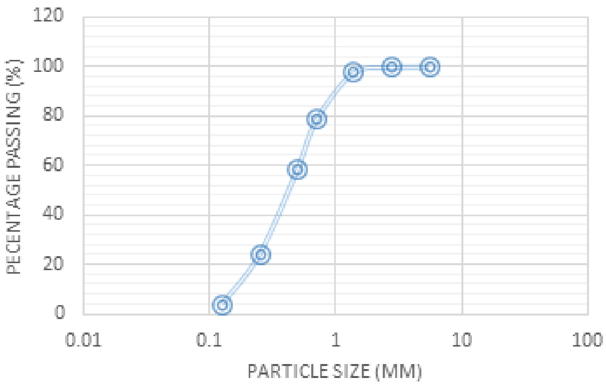

Fig. 2. Sharp sand grading curve.

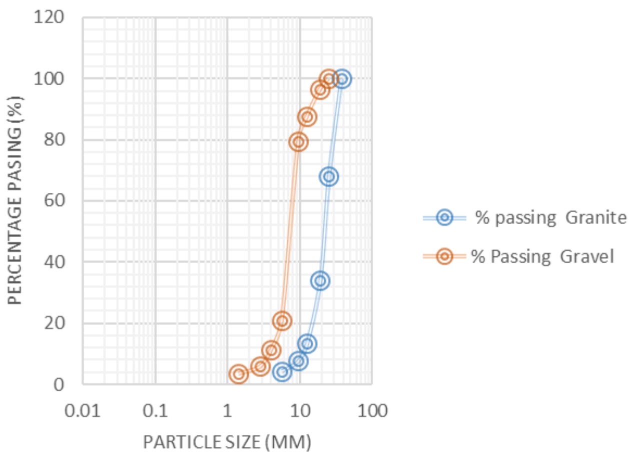

Fig. 3. Grading curves for granite and gravel.

3.2. Specific gravity and water absorption

The specific gravity and water absorption of the aggregates used for this study were determined to indirectly measure the aggregates strength for durable concrete production and also to know the pores and voidage in the aggregates. The specific gravity obtained for fine aggregate used in this study was 2.64, which is line with ASTM C33 [21] standard, while bulk specific gravity, bulk SSD specific gravity and apparent specific gravity obtained for granite were 2.59, 2.60 and 2.61 respectively. Also, the bulk specific gravity, bulk SSD specific gravity and apparent specific gravity obtained for gravel were 2.67, 2.68 and 2.69 respectively. The specific gravity results obtained from this study were as expected because the relation bulk specific gravity<SSD<apparent hold as specified by ASTM C33 [21]. According to ASTM C33 [21], specific gravity for normal weight aggregates ranges between 2.40-3.00. Kosmatka et al. [32] recommended that the natural aggregates relative density should fall in between 2.4 and 2.9. It should be noted that the higher the specific gravity, the denser the rock is and stronger is the aggregates

The concrete quality is control by amount of water absorption by the aggregates. The water absorption values obtained from all the samples (sand, granite and gravel) tested in this study are below 2% recommended by ASTM C33 [21]. The water absorption obtained for fine sand was 0.7% while that of granite and gravel were 0.26% and 0.21% respectively. The result shows that gravel with 0.21% water absorption is the soundest and has the least amount of pore spaces and sand with 0.7% has the highest amount of pore spaces. The more the water absorption, the higher the voidage because water absorption depends on the pores and voidage in rock. Neville [33] reported that in concrete mix proportioning, additional water and cement will be needed by aggregates with considerable absorption to make workable fresh concrete and to meet the water-cement ratio requirement.

3.3. SCC fresh properties for washed and unwashed gravel

Tables 2 and 3 show the workability results for SCC concrete with washed and unwashed gravel aggregates. From Table 2 the results obtained for SCCI –SCC3 fell into SCC class 2 with slum flow ranging from 600-750mm and T500≥ $2s$. Also, SCC4-SCC6 were classified as class 1 with slump flow ranging between 550-650 mm and T500 ≤ 2 s. Hence, From Table 2 it was discovered that SCC1, SCC2 and SCC6 were classified as class 2 while SCC3, SCC4 and SCC5 were classified as class 1. V-funnel results for washed and unwashed show that the mix were satisfactory. L-box results for washed and unwashed gravel show good passing ability. For both washed and unwashed gravel SCC4 has the highest segregation resistance. All the results obtained from the study are in line with EFNARC [1] standard.

Table 2. Fresh properties of SCC with varying proportions of washed gravel [4].

Mix samples	Slump (mm)	T_{500} (s) (2-5 s)	V-funnel (s)	L-box (mm) (0.8-1.0)	Segregation resistance (%)
SCC1	600	2.89	6.21	0.9	4.3
SCC2	653	2.08	3.69	0.8	4.2
SCC3	624	2.21	3.43	0.82	4.0
SCC4	560	1.98	6.75	1.0	1.5
SCC5	522	1.70	4.68	0.75	3.3
SCC6	555	2.0	3.98	0.87	3.7

Table 3. Fresh properties of self-compacting concrete made with varying proportions of unwashed gravel [3].

Mix samples	Slump (mm)	T_{500} (s) (2-5 s)	V-Funnel (s)	L-Box (mm) (0.8-1.0)	Segregation resistance (%)
SCC1	600	2.89	6.21	0.9	4.3
SCC2	636	2.45	4.34	0.8	6.9
SCC3	585	2.11	4.84	0.6	2.2
SCC4	563	2.11	4.56	0.75	2.1
SCC5	552	2.38	4.72	0.67	5.7
SCC6	635	2.01	3.91	0.87	3.9

3.4. Compressive strength for granite-gravel (washed and unwashed) combination

The behaviour of concrete under compressive load and the strength of concrete produce with granite-gravel (washed and unwashed) as coarse aggregates in SCC were determined to know the extent of such materials to resist axially directed pushing forces. The relationship between compressive strength of concrete and periods of immersion (water curing) in days was presented in Figs. 4 and 5 respectively. The percentage variations of washed and unwashed gravel with granite as coarse aggregate in SCC specimens were tested at 7, 14, 21, 28, 56 and 90 days of curing. From the test results obtained from experimental study, it was detected that, compressive strength increases with increase in curing ages and as the percentage of washed gravel content increases the strength decreases.

Neville [34] reported that the compressive strength of concrete can be significantly influenced by the following factors cement type, aggregates content, water-cement ratio, water curing period and exposure conditions. The formation of calcium-silicate-hydrate (CSH) gel during the hydration reaction increases the compressive strength of which, the hydration reaction is a never-ending process [35]. Curing ages play major roles in strength development and durability of concrete. Concrete compressive strength is greatly influenced by curing since the hydration of cement is greatly influenced by it. A proper curing maintaining a suitably warm and moist environment of hydration products and thus, reduces the porosity in hydrated cement paste, which leads to increases in the density of microstructure in concrete [36].

Johnson et al. [37] found that increase in curing age increase the compressive strength of concrete while decrease in porosity leads to increase in compressive strength for the stipulated curing ages. The increase in strength was prominent starting from 7 days up to 90 days strength for washed gravel with 100% granite which is the control producing the highest strength followed by 90%, 80%, 70%, 60% and 50% respectively. The 21.78 N/mm² strength produced at 7 days by 50% granite/washed gravel contents as coarse aggregate in SCC, which satisfied the minimum 28 days characteristic or specified strength of 21 N/mm^2 for reinforced concrete as specified by BS 8110 and EC 2 [38, 39] is a prove that SCC using granite–gravel combination as coarse aggregates produced high strength concrete compared to conventional concrete. The range of strength produced by SCC for 100 percent granite to 50/50 percentage proportion of granite/gravel combination varied from 21.78 N/mm2 to 30.02 N/mm^2 at 7 days, from 28.14 N/mm^2 to 34.71 N/mm^2 at 14 days, from 29.04 N/mm^2 to 36.44 N/mm^2 at 21 days, from 30.96 N/mm^2 to 38.67 N/mm^2 at 28 days, from 35.56 N/mm^2 to 42.80 N/mm^2 at 56 days and from 37.11 N/mm^2 to 45.56 N/mm^2 at 90 days.

From Fig. 5 at 50% unwashed gravel aggregate combination with granite the low in strength was discovered in compressive strength and it was due to the presence of silty materials in the unwashed gravel aggregate, which lead to decrease in the aggregate-cement paste bound. The significant decrease in strength, as the percentage of unwashed gravel increases, was as a result of increase silty materials present in the unwashed gravel compared with 100% granite [40]. The outcomes from this study shows that the inter connectivity of pores, (which is one of concrete permeability factors) in concrete containing granite-washed gravel combination as coarse aggregate is more than that of concrete containing granite-unwashed gravel combination as coarse aggregate [41-44].

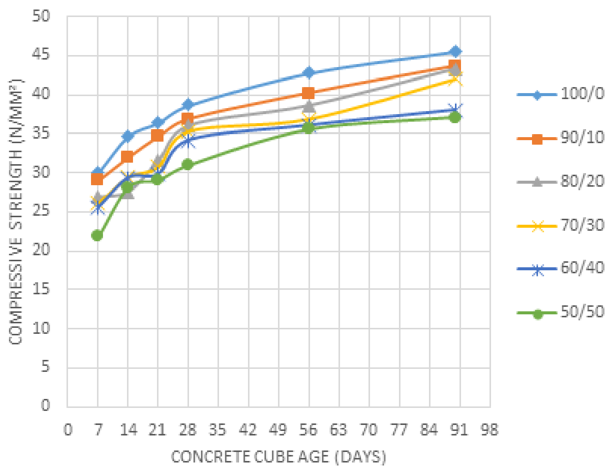

Fig. 4. Interaction between compressive strength of SCC of varying granite/washed gravel and periods of immersion in days.

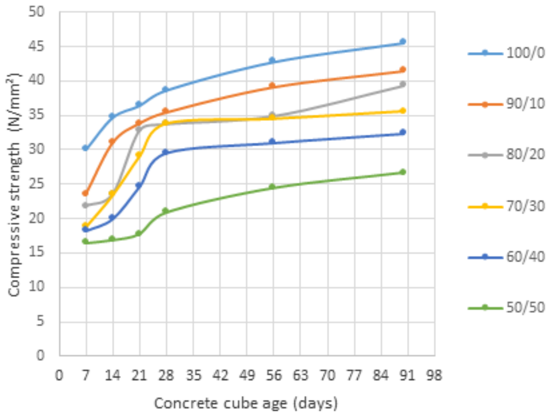

Fig. 5. Interaction between compressive strength of SCC of varying granite/unwashed gravel and periods of immersion in days.

3.5. Split tensile strength of granite-gravel combination

The granite-gravel combination as coarse aggregate in SCC effect on split tensile was considered for washed and unwashed gravel in varying percentages. The results are presented in Figs. 6 and 7. The split tensile strength increases as the curing days increases and decrease as the percentage of gravel content decreases. Split tensile strength of self-compacting concrete produced from granite-washed gravel combination for 100 percent granite, which serve as control to 50/50 granite-washed gravel combination ranges from 4.14 N/mm^2 to 2.84 N/mm^2 at 28 days, 4.62 N/mm^2 to 3.07 N/mm^2 at 56 days and 5.09 N/mm^2 to 3.47 N/mm^2 at 90 days. However, the following were obtained for unwashed gravel 4.14 N/mm^2 to 2.42 N/mm^2 at 28 days, 4.62 N/mm^2 to 2.61 N/mm^2 at 56 days, 5.09 N/mm^2 to 3.21 N/mm^2. Despite the low strength generated in early ages of SCC, they later produced satisfactory strength. The SCC specimen's failure for split tensile occurred at the weak interfacial zone between normal aggregate and cement paste, this is as a result of aggregate strength greater than the bond strength [31, 41, 42].

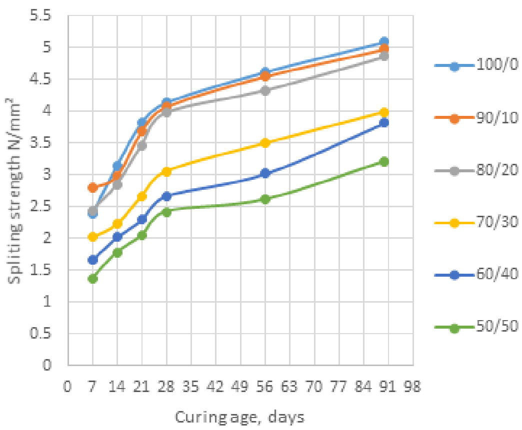

Fig. 6. Interaction between split tensile strength of SCC of varying granite/washed gravel and periods of immersion in days.

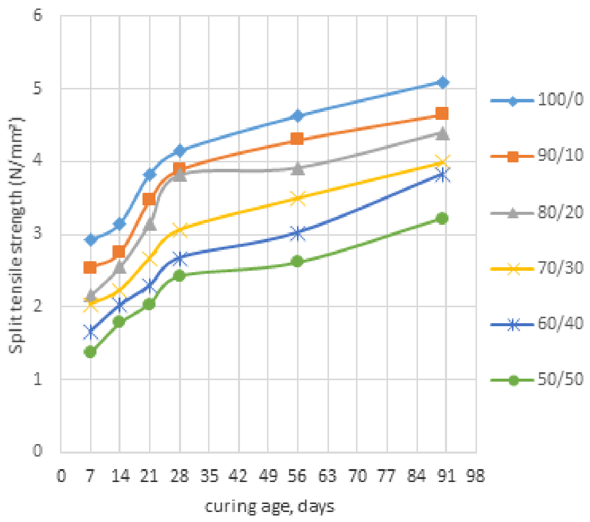

Fig. 7. Interaction between split tensile strength of SCC of varying granite/unwashed gravel and periods of immersion in days.

3.6. Surface plots of SCC granite/washed gravel combination as coarse aggregates using MINITAB

Minitab 17 was used to predict the compressive strength of concrete at any age with varying granite-gravel combination as coarse aggregate while other constituents remain constant. Strength prediction in concrete plays vital role in reducing construction cost and ensuring safety in construction ASTM C1074-19 [45]. Many factors such as cement, aggregates types, water/cement ratio and water curing medium influence the compressive strength of concrete [46]. This model helps in predicting compressive strength for a specified SCC mix at varying granite-gravel as coarse aggregate and curing ages while others concrete constituents such as fine aggregates, cement, water, superplasticizer remain constant. The three-dimensional (3D) response surface plots of compressive strength versus granite aggregates, compressive strength versus gravel aggregates and compressive strength versus curing days were plotted. These plots show the predicted effect of variables granite, gravel and curing days on compressive strength as the response.

3.6.1. Surface plots of compressive strength versus percentage of granite and percentage proportion of washed gravel

Surface plot of compressive strength versus percentage proportion of granite, percentage proportion of washed gravel as shown in Fig. 8 shows the influence of granite-gravel mixture on compressive strength of SCC. The lowest condition in washed gravel case produced the highest compressive strength. As the proportion of washed gravel content increases, compressive strength decreases. At the highest washed gravel proportion, the compressive strength has reduced to less than 30 Nmm^2. The highest percentage proportion of granite and the lowest percentage proportion of gravel gave the highest compressive strength of about 45.56 Nmm^2.

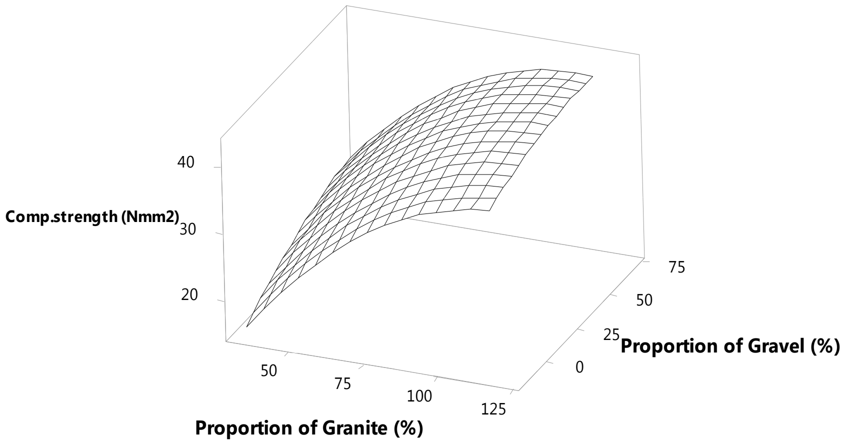

Fig. 8. Response surface plot of proportions of granite and gravel against compressive strength.

3.6.2. Plot of strength versus curing days and proportion of granite

The effect of percentage proportion of granite and curing days on compressive strength of self-compacting concrete are shown in Fig. 9. Compressive strength increases as the curing day's increases with increase in percentage proportion of granite. The highest curing day and percentage proportion of granite produced the highest compressive strength of 56 Nmm².

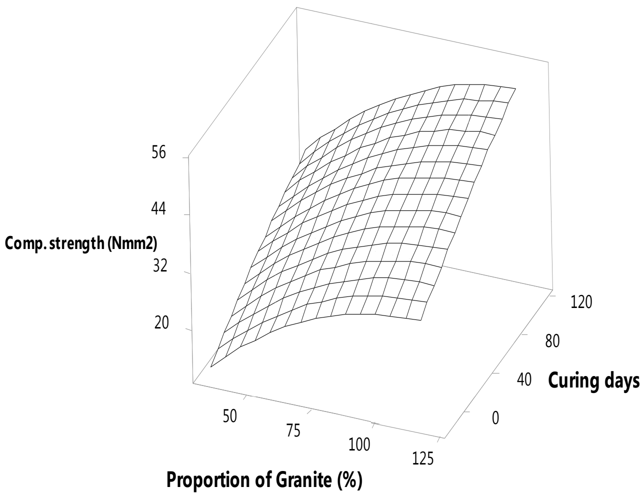

Fig. 9. Response surface plot of proportions of granite and curing days against compressive strength.

3.6.3. Surface plot of compressive versus curing days and proportion of gravel

Figure 10 shows the interaction of percentage proportion of washed gravel and curing days and their effect on the compressive strength of SCC. Compressive strength increases as the curing day's increases with increase in percentage proportion of washed gravel. The highest curing day and percentage proportion of gravel produced the highest compressive strength of 50 Nmm².

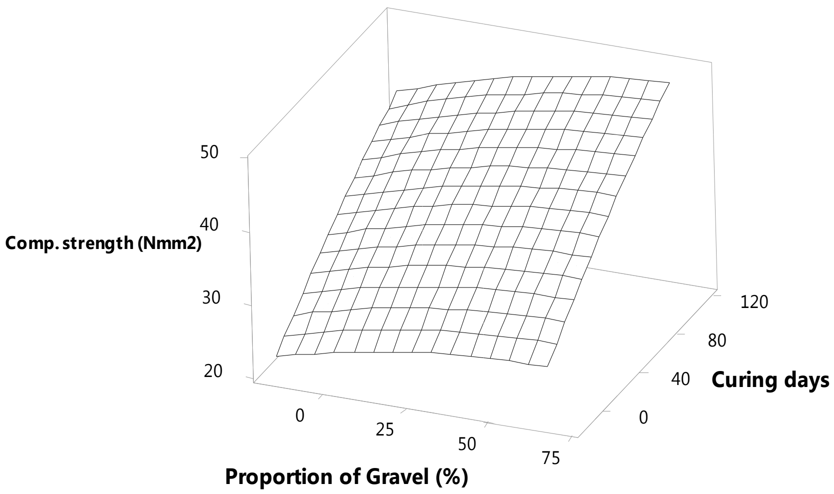

Fig. 10. Response surface plot of proportions of washed gravel and curing days against compressive strength.

4. Conclusions

From the study the following conclusions were drawn

- The results obtained from the study, which fell in between 2.4-2.9 and less than 2% for specific gravity and water absorption respectively, shows that aggregates (sand, gravel and granite) used for the study are durable and at the same time possess good strength for concrete production.
- From the test results obtained from experimental study of hardened SCC, the compressive and split tensile strength increases with increase in curing ages and decreased with increase in percentages of gravel content for both washed and unwashed content.
- The compressive strength of SCC, made of 50% washed gravel and 30% unwashed gravel as partial replacement of granite aggregates, was reliable for structural applications for reinforced concrete.
- For split tensile strength of SCC produced 30% washed gravel as partial replacement for granite was reliable for structural applications, the reliable percentages of granite/gravel content satisfying the minimum strength requirements.
- The models could be used for process behaviors and strength prediction for the performance measure of granite-gravel combination as coarse aggregates in SCC while other parameters such as fine aggregates, water, cement and superplasticizers are kept constant.
- Curing of SCC concrete in deicers environment for a period of 365 days to determine its impact on long time cured concrete need further study

- Varying of Sodium Chloride (NaCl) and Sodium Carbonate (Na_2CO_3) concentrations to determine the behaviour of SCC under different concentrations should be investigated;
- Therefore, the results of this work should be used as the basis for further studies on investigation of granite-gravel combination as coarse aggregate in SCC.

Acknowledgments

The authors wish to thank the chancellor and the management of Covenant University for the platform made available for this research and for sponsoring the publication of this work.

Abbreviations

3D	Three Dimensional
ASTM	American Society of Testing Materials
BS	British Standard
C	Concrete System
CSH	Calcium Silicate Hydrate
EC	Eurocode
EFNAR	European Federation for Specialist Construction Chemical and
SCC	Self-Compacting Concrete
SG	Specific Gravity
SSD	Saturated Surface Dry

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