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Research Article

# Properties of self-compacting concrete containing granite dust particles

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**ABSTRACT**

In the course of production in the Granite Industry, a lot of quarry dust wastes is generated which is either heaped at sites causing environmental and health hazards or dumped in landfills causing ecological problems. It is imperative to evolve a viable option for disposal so to rid the environment of this menace. This study investigated the use of quarry dust particles (QDP) generated from the granite industry as a cement replacement in self-compacting concrete (SCC). The experimental program was carried out in two phases: the first phase optimized the amount of QDP as replacement of Portland cement (PC) with acceptable flow-ability. The second phase evaluated the fresh and hardened properties of SCC which include tests on slump flow, J-ring and L-box to determine filling, passing abilities of SCC while compression and splitting tensile tests were conducted to determine the compressive and splitting tensile strengths, respectively. Test results show that at 20% replacement of cement with QDP, the SCC-QDP mixes has a slump ranged from 642 to 730 mm compared with 578 mm for SCC mix, a compressive strength of 37 N/mm$^2$ compared with 30 N/mm$^2$ for SCC. This was enhanced by QDP which filled the voids between the coarse grains of cement and water molecules which facilitated the flow ability of the mixes and then at later ages reacted with liberated calcium hydroxide from cement hydration to enhance the strength of the mixes. The results then indicated that QDP can be used to replace PC up to 20% by mass of PC in the production of SCC without adverse effect on both fresh and hardened properties. This results also show that QDP, a suitable material for partial replacement of PC in SCC production, can be used to reduce demand for cement thus reducing carbon dioxide emission and also solve other environmental problems.

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## 1. Introduction

Among the most widely manufactured and used materials, concrete is second to none. Because of this fact, it has to fulfill a wide range of requirements in both fresh and hardened state. Since in most cases, the fresh properties affect the quality of the hardened state and by extension the durability, it is imperative to attain a correct mix proportion so as to remain homogeneous during placing and after compaction in order to avoid bleeding and segregation. Self-compacting concrete (SCC) is concrete cast and compacted without any vibrational means which flows under its own weight. SCC mixes increase productivity, reduce noise pollution and improve construction quality. Furthermore, it has both filling, passing ability and high resistance to segregation during transportation and placing. To achieve this the concrete requires high slump with the aid of super-plasticizer (SP) added to the concrete mixture and its mix proportioning. The use of SP is imperative for the production of a high fluid concrete mix with high powdery content materials (viscosity modifying agents) is required to enhance sufficient stability/cohesion of the mixture hence reducing bleeding and segregation and settlement (Wenzhong and Gibbs, 2005).

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The work of Ouchi et al. (2003) has shown that it is beneficial to use SCC because of its improvement in homogeneity of concrete production and its excellent surface quality without honey combs. The mix proportioning is achieved by a suitable selection and proportioning of raw materials, reduction of water/powder ratio, increasing paste volume, controlling the total volume of coarse aggregates and its maximum particle size (EFNARC, 2005) and other constituents to achieve the required level of material performance both in the fresh and hardened state. Consequently, the powdery materials content is high, resulting in high volume content of cement which in turn leads to a higher temperature rise, increase in heat of hydration, creep, shrinkage and increase in cost which can be off-set with the use of mineral admixtures. Industrial by products such as ground granulated blast furnace slag, Limestone powder and fly ash are commonly used mineral admixtures (Poon and Ho, 2004), similarly, other industrial by product such as granite dust particles, if its use in SCC is proven to be appropriate can serve as a solution to its disposal problem confronting the granite industry.

Granite dust particles is obtained when rocks of granite origin are crushed to produce aggregates on quarry sites. Granite particles is fine aggregates less than 4.75 mm in diameter. It is also obtained from granite cutting and polishing industry which yields fine granite particles which is disposed in nearby areas without any treatment. Granite dust particles as an admixture when used in SCC can sufficiently improve workability of SCC (Sahmarain et al., 2006; Uysal et al., 2011) and also reduce the amount of SP necessary to achieve a given property as obtained by Sonebietaal, (2000). Hafez et al. (2014) has pointed out in their study that the effect of mineral admixture on admixture requirements is significantly dependent on their particle size distribution, shape and surface characteristics. This shows that a cost effective SCC design is obtained upon the incorporation of reasonable amounts of mineral admixtures such as limestone powders (LP), Ballast powder, (BP) and marble powder (MP) as indicated by the work of Uysal et al. (2011). Hafez et al. (2014) further established that the addition of MP is the best among the aforementioned mineral admixtures which improved SCC fresh properties such as slump-flow, $T_{50}$ time, L-box ratio and J-ring.

Results of studies conducted on the effects of mineral admixtures as filler materials on the properties of SCC improved the workability with reduced cement content, which in turn led to the reduction of hydration, thermal and shrinkage cracking as seen in the works of Ye et al., 2007; and Poppe and Schutter (2005). The work of Belaidi et al. (2012) shows that at a constant water / binder ratio and SP content, cement substitution by the use of natural pozzolan and MP has no negative effects on workability of SCC. Stone dust and other industrial by –products have been used as filler materials in SCC (Suhmarain et al. , 2006).The incorporation of quarry dust (QD) in SCC improves its workability, increase in strength and durability against chemical attack (Manjul and Premalatha, 2006). Manju et al. (2014) studied the effect of partially reducing quantities of cementitious materials with MP on the compressive, tensile as well as flexural strength of mortar and concrete. The compressive strength of sample cubes increased with increase in waste content of MP up to 12.5% and then decreased with further increase in MP. This confirms the earlier work of Baboo et al. (2011) on the influence of MP in concrete.

The work of Vijayalakshimi et al. (2013) on durability properties of concrete shows that QD can replace sand up to 15% without any adverse effect on the durability properties of n concrete. The work of Suma (2016) also show that QD as a filler is a suitable material for the production of SCC. Gowda et al (2000)'s work also show that fresh and hardened properties of SCC improved when QD was used to replace sand at varying proportions. For normal concrete, Allam et al. (2016) studied the effect of partial replacement of cement with granite waste on the mechanical properties of concrete. Test results showed that with 5% granite replacement of cement, splitting tensile strength was 20% higher, flexural strength was 19% lower with bond strength also slightly lower by 1% when compared with control values. Working along the same line of thought, Kumar et al. (2013) increased QD replacement of cement proportions of 10, 20, 25, 30, 35 and 40% respectively. From experimental results, they reported that 25% partial replacement of cement with QD showed improved hardened properties of normal concrete. It is worthy to note that granite waste particles used in these studies were sieved through sieve size 300 μm and through sieve size 4.75 mm and the concrete is normal concrete.

When granite fines as supplied is compared with Limestone powder, the work of Ho et al. (2002) on both paste and concrete confirmed that granite fines incorporated in SCC required a higher dosage of SP for similar yield stresses and other rheological properties. But one must take cognizance of the fact that granite fines being a waste material, its properties will vary over time and also dependent on parent rock and mode of generation such as crushing, cutting or sawing. Dehwah (2012) has also reported that the mechanical properties of SCC incorporated with QDP is better than those of SCC with silica fume (SF) with QDP or only Fly ash (FA). He further pointed out that it is more economical to use QD alone especially in regions where SF and FA are not readily available locally and has to be imported.

From the works of researchers reviewed so far, it shows that the flow properties of SCC depend on powder particle size, shape, surface morphology and internal porosity in addition to other factors such as mixing regimes, sequence of admixtures addition, and water / SP content (Rizwan and Bier, 2013). It is also clear that the focus of most studies was on the utilization of marble and granite powder as fillers in concrete and also as a sand replacement material. However, this study will focus on the application of QDP as a replacement of cement in the production of SCC. This is because mixes containing MP and QD required the use of SP otherwise more quantity of water will be required for similar workability, which consequently reduces strength. On the other hand, the high fines of QD may be beneficial for providing good cohesion to SCC, if it is used as mineral additive (Uysal and Sumer, 2011). However, more studies are required to evaluate the behavior of SCC containing QDP of high fineness. It is hypothesized that the finer particle sizes of QDP would further increased the pozzolanic reactivity between cement and the former during secondary hydration process. Therefore, this paper evaluated the effect of partial replacement of cement with QDP on the fresh and mechanical properties of SCC. The fresh and hardened properties of SCC was investigated and compared with those of control mix produced with plain Portland cement.

## 2. Materials and Method

### *2.1. Materials*

Concrete mixes were prepared with Portland cement CEM 1 42.5 N conforming to BS EN 196-6 (1997). Fine aggregates used was natural siliceous sand with a fineness modulus of 3.0 and specific gravity of 2.39. Blended crushed granite aggregates of 19 mm and 10 mm nominal sizes with specific gravities of 2.69 and 2.60 were used. QDP was used as a partial replacement of cement. It was obtained from a local quarry site in Minna, Niger state Nigeria. The sieve analysis test for the sample (as supplied) is shown in Table 2. The sample used for the study was sieved and the particle size distribution (PSD) is shown in Fig. 4. Portland cement classified as CEM 1 42.5 N was used for the study. The physical and chemical composition of the materials are shown in Tables 1 and 4.

**Table 1.** Properties of cement and quarry dust particles (QDP).

| Property | Cement | QDP |
|---|---|---|
| Colour | Gray | Off-white |
| Specific gravity | 3.15 | 2.19 |
| Specific surface area ($cm^2/g$) | 3000 | 4580 |
| Soundness (mm) | 4.8 | |
| Setting time (mins) | | |
| Initial | 161 | 170 |
| Final | 202 | 261 |

**Table 2.** Sieve analysis test result on QDP.

| Sieve Size | % Passing |
|---|---|
| 4.75 mm | 100 |
| 2.36 mm | 97.65 |
| 1.18 mm | 81.15 |
| 600 µm | 64.15 |
| 300 µm | 46.75 |
| 150 µm | 29.75 |
| 75 µm | 69.68 |
| Pan | 5.72 |

### *2.2. Mix proportion*

A fixed water/binder ratio of 0.40 was used while the dosage of the SP was slightly altered to obtain the desired slump-flow for the SCC; maintaining consistency with QDP replacement of cement. By reducing contents of the blended coarse aggregates (19 mm and 10 mm based on packing density approach) with corresponding fine aggregates and conducting trial tests on fresh properties of SCC, a constant coarse / fine aggregate ratio of 0.87 was used for all the mixtures for the study (Table 3). An SP (Master Glenium ACE 456), a high range water reducing admixture based on a newly developed poly carboxylate ether polymer was used for the study so as to enhance flow ability of SCC. It is a whitish to light brownish liquid with a specific gravity of 1.06, PH value of 4–7 at 23°C with a chloride content of less than 0.01%; and alkali content ($Na_2O$ equivalent %) less than 3%. It conforms to EN 934–2 and ASTM C494, Type A, E, and F. A cement content of 400 kg/m$^3$ was used for the study and percentage replacement of cement with QDP material was 0, 10, 20, 30 and 40% respectively. In all five concrete mixes were cast as shown in Table 3.

**Table 3.** Mix proportion of SCC (kg/m$^3$).

| Mix ID | Cement (kg/m$^3$) | QDP (kg/m$^3$) | Fine Agg. (kg/m$^3$) | Coarse Agg. (kg/m$^3$) | Water (kg/m$^3$) | SP (kg/m$^3$) | W/B lt/100kg |
|---|---|---|---|---|---|---|---|
| SCC | 400 | - | 848 | 741 | 160 | 2.00 | 0.40 |
| SCC-$QD_{10}$ | 360 | 40 | 848 | 741 | 160 | 2.00 | 0.40 |
| SCC-$QD_{20}$ | 320 | 80 | 848 | 741 | 160 | 2.00 | 0.40 |
| SCC-$QD_{30}$ | 280 | 120 | 848 | 741 | 160 | 2.00 | 0.40 |
| SCC-$QD_{40}$ | 240 | 160 | 848 | 741 | 160 | 2.00 | 0.40 |

**Table 4.** Chemical composition of PC and QDP.

| Material | Chemical Composition | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ | MnO | $SO_2$ | LOI |
| PC | 19.92 | 4.72 | 3.58 | 1.84 | 65.72 | 0.93 | 0.52 | 0.054 | 0.46 | 8.97 | 1.86 |
| QDP | 72.7 | 13.28 | 2.19 | 0.78 | 1.44 | 2.45 | 5.70 | 0.12 | 0.17 | 0.13 | 2.07 |

### 2.3. Method

The study was conducted in two phases. Phase one was the optimization of the amount of QDP as a replacement to cement content at which the optimum paste content was attained with acceptable flow ability of SCC, J–ring and L–box test values which measured the passing abilities of the SCC. The second phase was the evaluation of the hardened properties of SCC in terms of compressive and splitting tensile strength tests. These tests were conducted in accordance with EFNARC (2005), BS EN 12350–8 (2010), ASTM C642 (2013) and BS 1881: Part 3, respectively.

The slump flow test measures the filling ability of the fresh SCC. It is used to assess the horizontal free flow of SCC in the absence of obstructions, its ability to fill Formworks of structural elements with ease. The required SCC constituents (Table 3) was dry-mixed, then 70% of required water was gradually added and mixed thoroughly for 3 minutes and finally, remaining 30% of water was mixed with the required SP content, added to the concrete and mixed again for 2 minutes. The mix was then scoped into the inverted slump cone without any compaction or vibration and flushed with a straight edge. The cone was vertically lifted and SCC flows horizontally on the mixing pad until it stops flowing. The average diameter of the concrete circle was used as a measure of the filling ability (Fig. 1). The test was also used to measure the resistance to segregation in the SCC mixes tested, which can be detected by virtual inspection of periphery of the mix after it stopped flowing. Segregation is indicated by the occurrence of a 'halo' of paste or uneven distribution of aggregates in the mix which was absent in any of the mix.

**Fig. 1.** Slump flow test measurement.

The passing ability of SCC was determined using the J–ring and L–box tests. Either of the tests measured the ability of the SCC mixes to flow through obstructions like reinforcement bars in form work of structural elements. The J–ring was placed on the mixing pad and the inverted slump cone was placed inside the cone and slump cone test carried out as aforementioned (Fig. 2a). The slump was measured after the concrete stopped flowing through the ring which indicated the passing ability of the mix. Similarly, for the L–box test, the vertical section was filled with 12 Litres of fresh concrete for each SCC mix, allowed to stand for 30 seconds and the gate lifted for the concrete to flow into the horizontal section of the L–box. The height of the concrete at the end of the horizontal section is expressed as a ratio to that remaining at the vertical section ($H_2/H_1$) after the concrete stopped flowing. This indicated the passing ability for each of the SCC mix cast and tested (Fig. 2b).

(a) J–ring flow test

(b) L–box flow test

**Fig. 2.** Flow test measurement of passing ability.

The J–ring test also measures the passing ability of SCC cast through reinforcement bars spaced evenly. The slump flow cone placed in the J–ring was filled with SCC cast and lifted vertically above mixing pad to allow concrete flow horizontally through the J–ring. The diameter of the concrete circle which flowed through the ring was measured which indicated the passing ability of the mix tested. The J–ring flow spread and the unrestricted slump flow were compared for each mix. The difference between spread diameters, ($D_{flow}$–$D_{ring}$) were measured for the SCC mixes. On completion of fresh property tests, the SCC specimens were cast in steel moulds (100 mm x 100 mm x 100 mm) cubes and of cylindrical diameter

150 mm x 150 mm in height without compaction, covered with plastic sheets and kept in laboratory conditions for 24 hrs. The specimens were de-moulded and cured in a water tank for varying curing ages. The cube specimens were then tested for compressive strength with a compression testing machine with a capacity of 2000 kN taking into account that each reading is the average of three specimens. Splitting tensile strength was determined in accordance with the provisions in ASTM C496/C496M (2004).

## 3. Test Results and Discussions

The constituent properties of the SCC, its fresh properties in terms of filling and passing abilities, and the hardened properties in terms of compressive and splitting tensile strengths and that due to replacement of PC with QDP in the concrete is discussed as follows:

### *3.1. Properties of QDP*

Chemical composition of QDP and PC used for the study (Table 4) shows that the three main oxides ($SiO_2$, $Al_2O_3$ and $Fe_2O_3$) for QDP which amounted to 88.17% met the requirements of ASTM C618 (2003) for pozzolanic materials. Furthermore, it implies that with the high content of $SiO_2$ (72.70%) in QDP, it readily reacted with calcium hydroxide ($Ca(OH)_2$) from the hydration of cement to form additional calcium silicate hydrate (C-S-H) that further enhanced high and early strength gains.

Also, from Table 1, the specific gravity of QDP is less than that of PC and the specific surface area for QDP is higher than that of PC. These properties enhanced high early strength gains as aforementioned. The Loss on ignition (LOI) for QDP and PC conforms to ASTM C 618:2003 provisions.

The particle size distribution (PSD) was carried out on the QDP sample as supplied (Fig. 3) and sieved. (Fig. 4).

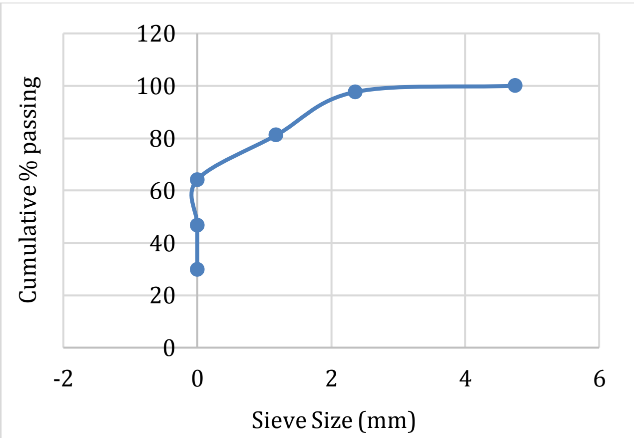


**Fig. 3.** PSD of QDP (as supplied).

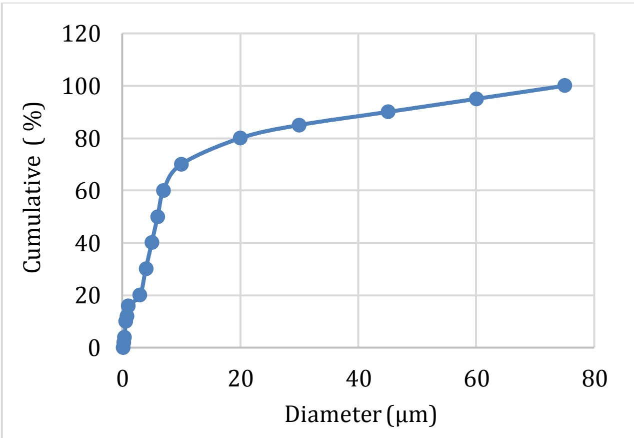


**Fig. 4.** PSD of sieved QDP.

### *3.2. Fresh properties of SCC and SCC-QDP*

The results of the slump flow, J–ring flow values and blocking ability which measured the filling and passing abilities for all the mixes (SCC, SCC-$QD_{10}$, SCC-$QD_{20}$, SCC-$QD_{30}$ and SCC-$QD_{40}$) used for the study are shown in Figs 1, 2a&b, and Table 5, respectively. From Fig. 2a and Table 5, slump flow values ranged from 578 mm to 730 mm while the J–ring flow values ranged from 525 mm to 726 mm. The slump flow value and that of the J–ring can be used in combination to assess the passing ability of SCC (ASTM C1621/C1621M, 2008). If the difference between spread diameters ($D_{flow}$–$D_{ring}$) of the two values is less than 25 mm then there is no visible blockage. If it is between 25 and 50 mm then, there is minimal to noticeable blockage. In comparison for both values, the difference is 15 mm, 9 mm and 4 mm for control mix (SCC), SCC-$QD_{10}$, and SCC-$QD_{20}$ signifying that these mixes had no visible blocking while for mix SCC-$QD_{30}$ with a difference of 27 mm flow value exhibited minimal blocking, while for mix SCC-QD40 with a difference of 53 mm flow value exhibited a noticeable blocking (EFNARC, 2005; ASTM C1621/C1621M, 2008) as shown in Table 5. For all the mixes, no "halo" was observed. Table 5 shows increase in slump flow values for varying concrete mixes while Fig. 5 also show increase in flow values with the replacement of PC with QDP dosage up to 20% when it decreased. This is same for the J–ring flow values. This was enhanced by the high fineness of QDP particles compared with cement particles, which is able to fill the voids between the coarse grains of cement and water molecules which facilitated the flow ability of the mixes. However, beyond 20% replacement of PC with QDP dosage led to excess compared with the quantity required to fill the voids between cement particles and water molecules. These excess particles affected the plastic viscosity of the mix (Rebaye, 2017) which in turn led to a reduction in the slump flow values. The plastic viscosity is a measure of the resistance of SCC to flow due to internal friction. Even though the excess particles caused a reduction in the mix flow ability, it increased resistance to segregation as it helps to thicken the paste, increase in viscosity and density and thus the thickened paste enables the aggregate particles to be uniformly suspended within the SCC paste.

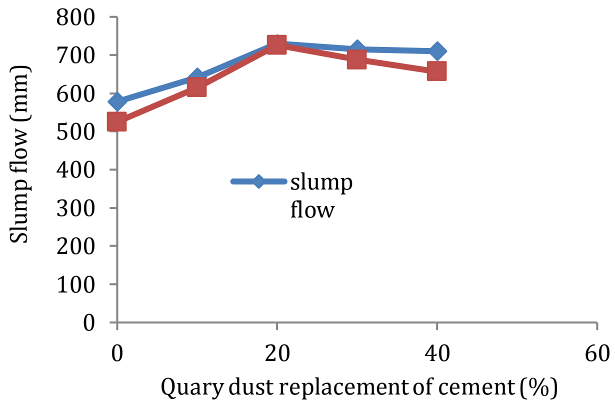


**Fig. 5.** Slump and J–ring flow values compared.

This shows that all the mixes have good ability, free deformability and the filling and passing abilities met EFNARC-2000 and ASTM C1621/1621M (2006) specifications but for mix SCC-QDP$_{40}$ that exhibited noticeable blocking. This is not a connected with the fact that SCC-QDP$_{40}$ has high QDP content leading to high water demand and since water–binder ratio and SP dosage remains constant, led to increase in viscosity. It is interesting to note that with increase in replacement level of PC with QDP content up to 30% slump values were still within Code specifications.

**Table 5.** Difference between slump flow and J–ring spread diameter.

| Mix ID | $D_{flow}$ (mm) | $D_{J\text{-ring}}$ (mm) | $D_{flow} - D_{J\text{-ring}}$ (mm) |
|---|---|---|---|
| SCC | 578 | 563 | 15 |
| SCC-QD$_{10}$ | 642 | 633 | 9 |
| SCC-QD$_{20}$ | 730 | 726 | 4 |
| SCC-QD$_{30}$ | 715 | 688 | 27 |
| SCC-QD$_{40}$ | 710 | 657 | 53 |

The results of the blocking ratio ($H_2/H_1$) shown in Table 6 was to assess the passing ability of the SCC investigated. Nehdi and Landchuk (2003), and Bartos (2005) opined that this blocking ratio is from 0.70 to 0.90 while that of EFNARC, 2005 is from 0.80 to 1.0. Test results showed that all mixes excluding SCC-QD$_{40}$ met Code specifications. Table 6 shows test results of mixes as regards blocking ratios. The Table shows that SCC-QDP$_{10}$ and SCC-QDP$_{20}$ falls under SCC class F1 and F2 for the filling ability in accordance with EFNARC specifications. For the passing ability, the results (Table 6) showed that the aforementioned mixes are in class PA 1 and PA 2, respectively. This means that the mixes exhibited blockage ratio of more than 0.80 which reflects good filling and passing ability; therefore, from the flow and passing ability perspective, all thee mixes except SCC-QDP$_{40}$ met the required criteria for viscosity class 1 to qualify them as SCC in accordance with BS-EN 206-9 (2010).

**Table 6.** L–box test results.

| S/No | Mix ID | $H_1$ (mm) | $H_2$ (mm) | $H_2/H_1$ (mm) |
|---|---|---|---|---|
| 1 | SCC | 72.80 | 55.80 | 0.766 |
| 2 | SCC-QD$_{10}$ | 72 | 58.50 | 0.813 |
| 3 | SCC-QD$_{20}$ | 71 | 62.00 | 0.873 |
| 4 | SCC-QD$_{30}$ | 73 | 59.00 | 0.783 |
| 5 | SCC-QD$_{40}$ | 79 | 52.00 | 0.658 |

### *3.3. Hardened Properties*

#### *3.3.1. Compressive strength*

Fig. 6 shows the compressive strength at varying mixes and also at varying curing ages for the mixes. In figure 8, the compressive strength of concrete for control mix (SCC) compared with that of SCC-QDP$_{10}$, SCC-QDP$_{20}$, SCC-QDP$_{30}$ and SCC-QDP$_{40}$ at 7 and 14 days are higher because most of the reactions at this stage are attributed mainly to hydration of the PC. Furthermore, in the mixes other than the control, quantity of PC is less which accounts for lower hydration and lower strength. But most importantly, the substitution of PC with pozzolanic materials reduces the initial rate of strength development at early ages due to slow rate of the pozzolanic reaction (Massazza, 1993). At this point in time, the pozzolana (QDP) acts as a filler thus diluting the PC which reduces the strength of the pozzolanic cement compared with that of the control. At later ages the reverse is the case and the pozzolanic cements attains the same or even higher compressive strength than the corresponding control PC. This is because, as the hydration ages, apart from the traditional hydration products from control cement, the QDP reacts with the calcium hydroxide ($Ca(OH)_2$), a by- product from the Pc hydration to form more cementitious materials such as Calcium silicate hydrate (C-S-H) and Calcium –alumina- silicate hydrate (C-A-S-H), leading to an increase in compressive strength of hardened cement pastes and concrete (ACI 232.1R, 1994; Taha et al., 1981). This can be seen in Fig. 6.

The compressive strength of all the mixes increases with curing age as well as with replacement of PC with QDP. As the curing ages, hydration continued and more hydration products are formed especially after 28 days when hydration products or cementitious materials which came from PC and the reaction between $Ca(OH)_2$ and QDP which accounts for the increase in strength. This is not unconnected with the fact that the hydration product possessed a large specific volume than the unhydrated cement particle leading to the accumulation and compaction of these hydrated products which gave rise to higher strength. The compressive strength values of the mixes increased with age and varying replacement of PC with QDP up to 20% then decreased. The increase in compressive strength is due to the pozzolanic reaction between $Ca(OH)_2$ and the silica content of QDP as aforementioned as well as hydration of the silica content of QDP (Yu et al., 1999). The decrease in compressive strength beyond 20% replacement of PC with QDP may be due to the fact that the quantity of QDP present in the mix is higher than the amount required to react with the liberated $Ca(OH)_2$ during the hydration process leading to presence of excess silica leaching out and causing a deficiency in strength as evident in the work of Al-Khalaf and Yousif (1984). Furthermore, the depletion of $Ca(OH)_2$ in the mix solution probably lowered the PH of the pore water in the mix solution thereby leading to decrease in strength (Maragu et al., 2018). This can also be attributed to the fact that the W/B ratio remains constant and with increase in silica content requires more water and $Ca(OH)_2$ for more reaction to produce more C-S-H and C-A-S=H but are not available, because subsequence reactions has stabilized these ions. This dis-stabilizes the system leading to decrease in strength. It is of interest to note that QDP has high specific surface area that requires more water, hence 20% content of QDP can be considered as optimum limit for the replacement of PC.

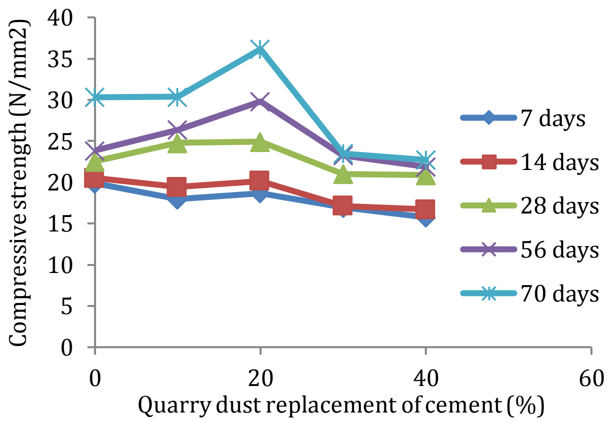


**Fig. 6.** Compressive strength for varying mixes at varying ages.

### 3.3.2. Splitting tensile strength

Fig. 8 shows the results of splitting tensile test (Fig. 7) conducted on cylindrical concrete specimens. For control and pozzolanic cement mixes, strength increases with curing ages as expected. This is because splitting tensile strength is related to compressive strength. For the control specimens, there is an increase of 5.52 in 28 days from 7 days and 9.68% in 70 days. Maximum strength increase of about 22.41% was obtained for mix SCC-$QDP_{20}$ at 70 days from 7 days and a minimum increase in strength of 16.89% for mix SCC-$QDP_{40}$ for the same period. This shows that split tensile strength of SCC is influenced by the replacement of PC with QDP content.

## 4. Conclusions

To gain a compressive understanding of the influence of QDP replacement of cement in SCC, performance in terms of optimum use of QDP as a replacement of cement, fresh and mechanical properties of five mixtures of SCC containing QDP at varying levels (0, 10, 20, 30, and 40) of cement replacement were evaluated. From the results, discussion and findings from the study, thee following conclusion can be drawn:

**Fig. 7.** Splitting tensile testing.

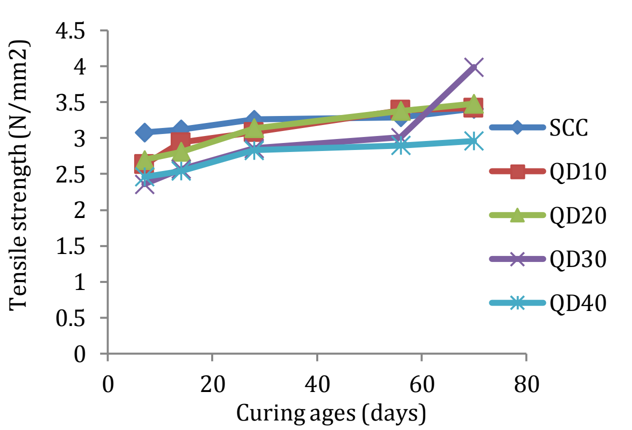


**Fig. 8.** Splitting tensile test results.

- Substitution of PC with QDP in SCC mixes positively improves its fresh properties as evident in slump/J–ring flow values, filling and passing ability values which meets EFNARC, 2005 specifications.
- Quarry dust particles can be used to replace PC in SCC up to 20% optimum without any adverse effect on its properties.
- The replacement of PC with QDP higher than 20% by mass of PC led to reduction in both physical and mechanical properties.
- In the production of SCC mixtures the use of QDP extend its technical and environmental benefit since it reduces air pollution and health hazards resulting from its production at sites and disposal. However, its use beyond 20% replacement of PC in SCC has adverse effects on both physical and mechanical properties and requires higher dosage of Super plasticizer to achieve similar properties which is an addition to cost of production.

The research mainly evaluated the fresh and mechanical properties of SCC containing QDP at a fixed W/B and SP content. Further comprehensive studies are required to investigate the hydration behavior, micro structure and durability properties of SCC containing QDP at more than 20 % content, varying W/B and super plasticizer contents.

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