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Effect of Quarry Dust content on the Properties of Self-compacting concrete

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Abstract

Self-compacting concrete (SCC) is a highly flow able and stable concrete that can easily fill its Formwork under its own weight without any compaction and any significant segregation. It has gained wide application in the construction Industry as its use eliminates noise due to compaction among other things on site. Since its Paste requires high viscosity and deformability, its stability and flow ability is achieved by increasing the cement content with some mineral admixtures such as quarry Dust since this is more economical and to avoid problems associated with the use of high content of Portland cement (PC) in SCC. Though quarry Dust has been used to replace PC in normal concrete and SCC, the effect(s) of its content on the properties of SCC is yet to be fully investigated. Quarry Dust (QD) sample, slightly pozzolanic or has low reactivity, obtained from a granite quarry site was tested for the optimum percentage mass replacement of PC by, 0, 10, 20, 30 and 40 % respectively in the study. The mixes containing aforementioned quantity of QD were obtained using a constant w/b ratio of 0.50 and a Super plasticizer (SP) of 2.0 – 2.35 kg/m3 to account for the constant water binder ratio. Also, effect of QD content on the fresh and hardened properties of SCC in terms of setting times, Slump flow ability, passing ability, Water demand of QD, compressive and tensile strengths were studied. The aforementioned parameters were determined by tests conducted on fresh and hardened samples of SCC. Results indicates that QD content in SCC increase the initial and final setting times, at 10 – 20 % QD content its flow-ability was okay and also show strong sensitivity to water demand but at 30 % replacement of PC in SCC, its passing ability is susceptible. A maximum compressive strength of 34 N/mm2 was obtained at 56 days curing age for an optimum partial replacement of 20 % QD content. The test results have shown that QD content has positive effect(s) on fresh and hardened properties of SCC and can optimally replace PC partially at 20 % without any adverse effect on SCC.

Keywords: quarry dust, blended cement, water demand, deformability coefficient, compressive strength, setting times;

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1. Introduction

Quarry Dust (QD), a by-product of Granite quarrying. In other words, fines obtained during crushing of granite rocks to obtain aggregate for concrete production is referred to as quarry Dust. About 1 % of total aggregate obtained during production is QD. Because of its fineness (less than 75πm), incorporating it in mortar or concrete will increase its demand for application, will also increase its demand for water which in turn will affect the properties of Mortar and concrete such as work ability and strength. However, this fines produced at quarry sites presently constitute health hazards because heaps of the material can be seen visibly at many quarry sites with no visible use or application. They are easily blown about and when inhaled could constitute health hazards such as Lung or respiratory diseases. Hence it is imperative if it finds application in the production of self- compacting concrete (SCC). In recent years, the use of SCC in construction industry came into limelight because of its ability to overcome compaction and placement of fresh concrete.in confined spaces and in structural elements with congested reinforcements. This is achieved by using high content of fines ensuring its self-compatibility and stability so as to avoid segregation and bleeding. The use of high content PC in SCC is not economical since it is expensive, hence the dire need for alternatives.

Previous studies have shown that QD can be used as a supplementary cementitious Material (SCM) in the partial replacement of PC in Mortar or concrete and as well as improve the various properties of concrete in terms of fresh and hardened properties and also contribute to economy in construction costs. The work of [1] shows that Techno-genic materials can be used as fillers in SCC, thus solving environmental problems rationally. The work of [2] on the use of granite Dust as partial replacement of PC in concrete shows that the fresh properties of PC (control) mixtures and the character of the strength increase, slightly differs from that of mixtures of PC blended with QD. Along the same line of thought, the work of [3] on properties of SCC containing QD evaluated the fresh and hardened properties of SCC and obtained an optimum 20 % replacement level of PC with QD. The work of [4] shows that the rheological properties of cement Mortars and concrete are positively influenced by the addition of Marble Dust and Limestone powder. It has also been established that the compressive strength of cement Mortars and concrete increases with the addition of granite and basalt powder. The dispersion component fills the space between sand and cement grains and creates a rigid structure improving the density and other fresh properties of SCC. The work of [5] shows that.an increase in the solid phase of SCC (Aggregate content) which in turn results to low Liquid phase (cement phase) leads to high internal friction which increase the tendency of blocking (poor passing ability) and thus reduce flow ability. This implies that the solid content of SCC must be determined in such a way as to avoid adverse effect on the Mix. However, from studies so far [6,7], various types of waste materials including QD has been used both as partial replacement of PC and as a filler, but the effect(s) of its content on the fresh and hardened properties of SCC is yet to be considered and this is the focus of the study. As such, the study aimed at evaluating the optimum content of QD that will replace PC without adverse effect on the properties of SCC as well as evaluate the effect of QD content in SCC on its setting times, flow ability, passing ability, water demand and deformability coefficient as well as the compressive and tensile strengths of SCC.

2. Materials and method

2.1 Materials

Portland cement which conforms to [8] with specific gravity of 3.15g/cm^3 and Blaine fineness of 3280 cm^2/g was used for the study. Natural river sand (NRS) with a specific gravity of 2.63g/cm^3, a nominal size of 4.75 mm, was used in conformity with [9] specifications. Coarse aggregate of 19 mm diameter and bulk density of 1500kg/m^3 was used for the study. QD with specific gravity of 2.60g/cm^3 and specific surface a/cm3rea (Blaine) of 3550 cm^2/g was used to replace PC details of the properties of the materials used for the study are in Table

2.2 **Mix Proportion**

For the mix proportions, absolute volume method was adopted; Pc and water contents were fixed so as to achieve self compatibility by varying QD, Coarse and fine Aggregate contents. Sixteen concrete specimen mixes were prepared based on replacement level of PC with QD at 0, 10, 20, 30 and 40 % by mass respectively. A water – binder (w/b) ratio of 0.50 was kept constant and the amount of SP was slightly adjusted to ensure consistency of the Mixes when PC was partially replaced with QD.

2.3 **Method**

2.3.1 Consistency and Setting Times

To determine the standard consistency of the mixes, Vicat apparatus was used. A Paste of control mix and mixes blended with QD were prepared and the consistency for each mix was determined using the Vicat apparatus. This was achieved by adding water at each different percentage levels until the pastes had a given resistance to penetration of the vicat needle. Consistency was recorded when the plunger of the Vicat apparatus penetrated into the paste 5 mm – 7mm above the bottom of the Mold. The Value of consistency was taken as a mean of three Tests values. The initial and final setting times then determined. For the initial setting time (IS), a Needle of 1 mm diameter head of the Vicat apparatus was used to penetrate the paste at every 10 minutes intervals till the index scale reads 5 + 0.5 mm from the bottom of the Mold. A Needle with an annular attachment of the Vicat apparatus was used to determine the final setting time for the pastes. The depth of penetration of the Needle in the paste was observed every 30 Minutes until it made no impression on the surface of the paste. The time elapsed for the needle not to make any impression was recorded as the final setting time. An average of three test values was recorded for each paste tested.

2.3.2 Flow ability

Flow ability of a Mix is the ability of the Mix to fill a Form completely without any bleeding or segregation. Flow ability of the Mixes were measured using the Slump Cone Test. A Slump Cone was filled with a fresh Mix to the brim and excess mix flushed in accordance with [9] and [10]. After 60 seconds, the Cone was lifted vertically and the SCC flows horizontally on a flat surface until it stops flowing. The diameter of the SCC flow was measured twice at right- angles. The mean value was recorded as the slump of the Mix. This was repeated for all the Mixes tested.

2.3.3 Passing Ability

The passing ability of an SCC Mix is its ability to pass through obstacles like congested reinforcement Bars in a concrete structural element or through confined space. The L- Box was used to assess the passing ability of the Mixes. A six Litre volume of freshly mixed SCC was poured into the vertical portion of the L- Box and after 30 to 60 seconds was allowed to flow through a slit modeled as a confined area into the horizontal portion until it stopped. The height of the concrete at the horizontal portion, H_1 and that at the vertical portion, H_2 were measured. The ratio H_1/H_2, called the blocking ratio is a measure of the passing ability of the Mix. The test was repeated for all the Mixes and the average of three tests values was recorded as the passing ability for the Mix.

2.3.4 Water Demand / retained water ratio of PC and QD powders

The water demand or Water retained ratio of a powder is the maximum amount of water the powder particles can retain, beyond which slump of the Mix containing the Powder particles occur [11]. To assess the water demand of PC and QD and the deformability coefficient of these Powders, the Hangermann Cone (figure3.0) was used to conduct spread flow tests. Sample test specimens based on the required flow ability were prepared. The spread flow tests were conducted and their slumps, d measured accordingly. A relative slump, Tp was calculated using equation (1 and 2):

$$d = (d1+d2)/2 \quad \text{----------} \quad (1)$$

$$Fp = (d/d0)^2 - 1 \quad \text{----------} \quad (2)$$

Where d = average slump, d1, d2 are slump values, d0 = diameter of Hangermann Cone (100 mm), Fp = relative slump. The water / Powder ratio for each corresponding relative slump, Fp was also calculated. A graph of ratio of age of volume of water to that of Powder was plotted against corresponding relative slump, FT and then regressed to obtain equation (4), used to determine water demand and deformability coefficient of the Powders.

$$Vw/Vp = \epsilon p\, \Gamma p + ßp \quad \text{.............} \quad (3)$$

Where, Vw/Vp = Volume ratio of water to powder, ϵp = deformability coefficient of powder, ßp = water demand of powder, Γp = relative slump of Mix. Graphs for PC and PC-QD were plotted for 10, 20 and 30 % contents and their water demand and deformability coefficient were determined.

2.4 Compressive and Tensile strengths of PC and PC blended Mixes

Each fresh Mix prepared was cast in cubes (100 mm X 100 mm X 100 mm) Moulds , kept in the laboratory for 24 hours at room temperature and relative humidity of about 96 %. It was then de-moulded and immersed in a curing Tank for 3, 7, 14, 28 and 56 days. Compressive strength (fc) of SCC cubes were then determined in accordance with [13] by means of a 3000 kN capacity testing Machine. An average of three test values was recorded at each tested age. The splitting tensile strength test was conducted on Ө150 mm X 300 mm cylindrical test specimens at aforementioned ages in accordance with [14].The average of three results are reported herein.

Table 1. Physical and chemical Properties of constituent Materials

Physical Property	**PC**	**QD**	**FA (Sand)**
Specific gravity	3.15 g/cm^3	2.60	2.63
Fineness modulus		2.68	
Specific surface Area (Blaine)	3050 cm^2/g	3280 cm^2/g	
Chemical Property			
SiO_2	20.25	71.43	
Al_2O_3	5.72	13.11	
F_2O_3	3.52	5.62	
CaO	66.84	1.55	
MgO	2.00	1.05	
K2O	0.36	7.75	
Na2O	0.08	2.17	
SO_3	2.72	0.13	
TiO2	0.12	0.18	
P_2O_5	0.06	0.20	
MnO	0.06	0.10	
Loi	1.86	1.57	

3.0 Results and Discussion

The properties of QD were compared with that of PC to determine to what extent QD can replace PC. The properties of the SCC Mixes were discussed in terms of consistency, setting times, flow ability(filling and passing), water demand and deformability as well as compressive and tensile strengths. Also, the effects of QD contents on the aforementioned parameters were discussed.

3.1 Properties of QD

The physical and chemical properties of PC and QD are shown in Table 1.0. The specific gravity and fineness modulus of QD is less than that for PC, which means that more quantity of QD will be required to replace PC which helps to mitigate or check the adverse effect of production of QD in the atmosphere. Also, QD being smaller in size than PC can easily fill the voids between the grains of PC and between PC particles and sand particles thereby increasing the compaction of the Mix. From Table 1.0, the chemical properties of QD and PC are complementary. The Silica (SiO_2) content for PC is 20.25 % while for the QD, it is 71.43 %. The Calcium oxide (CaO) content of QD is 1.55 % while that for PC is 66.84 %. This shows that where QD is deficient in a property, PC will complement or make it up and vice-versa. Their combination enhanced the chemical reactions of the SCC. The sample QD meets [15] provisions for pozzolanic Materials.

3.2 Fresh Properties

3.2.1. Standard consistency

Table 2.0 shows the water consistency and the setting times of the control (PC) and the blended pastes containing varying contents of QD. The standard consistency of the control paste is about 29.20 % and slightly reduced to 27 % with PC replaced at 0, 10, 20 30 and 40 % respectively. The reduction may be due to decrease in PC content which contain Tri- calcium silicate (C_3S) and Di-calcium silicate (C_2S) ions responsible for rate of hydration.

3.2.2 Setting Times

Setting times (both initial and final) increase with increase in QD content when compared with control value. For a 10 – 40 % QD replacement of PC, resulted to an increase in initial setting times of 24, 42, 48 and 50 % occurred respectively. Also with the final setting times which increased by 8, 10, 27 and 33 % respectively for the same percentage replacement of PC with QD. This can be attributed to the reduction of C_3S and C_2S in PC which accounts for rate of hydration of PC and other elements.

Table 2. Standard consistency and setting Times of PC and PC blended with QD Mixes

Mix ID	standard Consistency (%)	Initial setting time (Mins)	Final setting time (Mins)
SCC	29.20	116	231
SCC-QD10	28.30	153	252
SCC-QD20	27.65	203	289
SCC-QD30	27.25	226	316
SCC-QD40	27.00	234	346

3.2.3 Flow ability

Table 3.0 show the slump flow and the L-Box test results conducted to evaluate the filling and passing ability of SCC under its own weight. From the Table, the slump flow for control Mix is 634 mm. For the SCC mix containing 10 % QD, an improved 2.16 % was obtained, 5.09 % for 20 % QD Mix, but decreased for 30, 40 % QD Mixes when compared with control value. It has been established that waste powders has high specific surface area hence their particles act as micro-fillers filling capillary pores and as transition zone leading to effective packing and better dispersion of cement grains thus ensuring flow able concrete with greater cohesiveness and denser microstructure [16,17]. This is responsible for the improvement in flow- ability for 10 and 20 % QD content Mix. However, for the 30 % or more QD Mix, the decrease in flow ability could be attributed to excess QD which fills the voids between cement and sand particles resulting in particles pushing each other apart, leading to a reduction in packing density which in turn reduce flow ability [18]. The work of [19] has shown that use of mineral additives in SCC increases paste volume which reduce the friction at the aggregate paste interface and consequently increase the fluidity of concrete. This may be true for QD, but due to its morphology and rough surface texture, [20], its water requirement increases consequently decreasing its flow ability.

Table 3. Slump Flow and blocking ratio Test results

Mix ID	Slump Flow (mm)	Blocking ratio	H_1	H_2
SCC	634	0.70	110	77
SCC-QD10	648	0.81	106	86
SCC-QD20	668	0.86	102	89.44
SCC-QD30	592	0.79	112	88.42
SCC-QD40	580	0.76	106	82.08

3.2.4 Passing ability

To evaluate the passing ability (free movement of SCC through restrictions) of SCC, the L-box test was conducted for all the Mixes used for the study. It was determined by measuring the blocking ratio values for each of the Mixes as shown in Table 3. For the control Mix, the blocking ratio was 0.70 and increased to 0.81 (13.58 %) of control value, and to 0.86 (18.6 %) for 20 % QD mix. but reduced to 0.79 for 30 % and 0.76 for 40 % QD Mixes. The recommended blocking Limits [21] is 0.80 – 1.0. From the results, up to 20 % QD content, SCC remains self-compacting and has good passing ability but at 30 % QD content and more, it becomes denser leading to the loss of passing ability. That is to say, there is less flow from the vertical portion of the L- box through the slit which is modeled as the confined space to the horizontal portion of the L-box resulting to a low blocking ratio. From the test results, it can be observed that while the control Mix has a flow ability of 643 mm its passing ability is 0.70 which makes it susceptible to passing through confined spaces. To overcome this draw back, a dosage of SP Will be required.

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3.2.4 Water demand of PC and QD

The water demand of PC and QD and their coefficient of deformability were determined using the Hangermann's Cone. Spread flow tests were conducted for the Mixes. For each Mix, the volume of water to Powder ratio and the relative slump was calculated. These values were regressed to obtain equation (3), from which both the water demand and the deformability coefficient values were determined as shown in figures 1 – 3. From the Figures, the ordinate is the water demand for the powder while its slope is the coefficient of deformability which is a measure of the sensitivity on the water need for a specific flow ability. Hence, for flow ability, minimum water requirement for the control Mix has to be greater than 0.93 of volume of PC Mix; for 10 % QD mix, it has to be greater than 0.83 of volume of its Mix, for 20 % QD MIX, it has to be greater than 0.73 of volume of its Mix and for 30 % QD Mix, it is 0.80 of the volume of the Mix. Similarly, the deformability coefficient for the control Mix is 0.062 and for the blended Mixes, it is 0.0323, 0.018 and 0.058 for 10 % QD, 20 % QD and 30 % QD Mixes respectively. The water demand for 10 % QD Mix is about 11 % less compared with control value, and its deformability coefficient is about 48 % less than control value. For 20 % QD Mix, its water demand is 21.5 % less than control value while its deformability coefficient is also 71 % less than control value. However, for 30 % QD Mix, its water demand is just 4 % less than control value while its deformability coefficient is 6.45 % less than control value. These results indicates that the water demand and deformability coefficient decreases for a given flow ability. The results further show that for the blended Mixes (10 % QD and 20 % QD) with its low corresponding deformability coefficients, respond with higher change in deformability to a certain change in water dosage compared with control Mix. In other words, these Mixes show strong sensitivity to water changes. Any Mix with such behaviour will enhance the identification of materials having high tendency to bleeding and segregation. The results also indicate that QD content in Mortar and concrete influence the water demand and sensitivity on the water need for a specified flow ability.

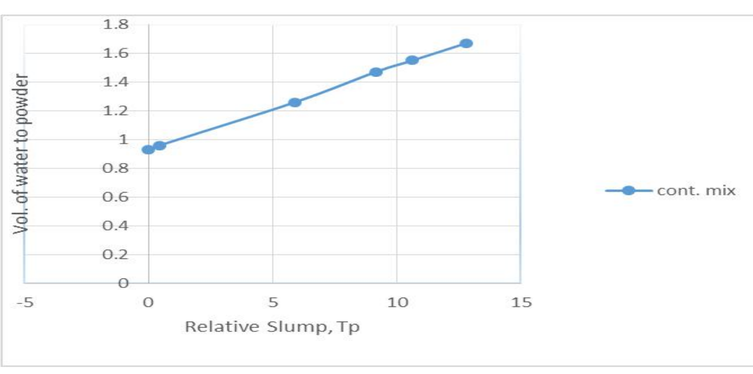

Figure 1.0 Volume of water to Powder ratio versus Relative Slump for PC Mix

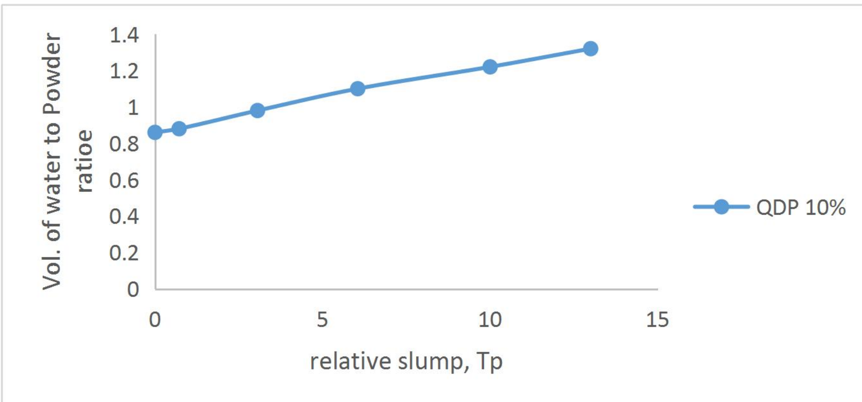

Figure 2.0 Volume of water to Powder ratio versus Relative Slump for 10 % QD Mix

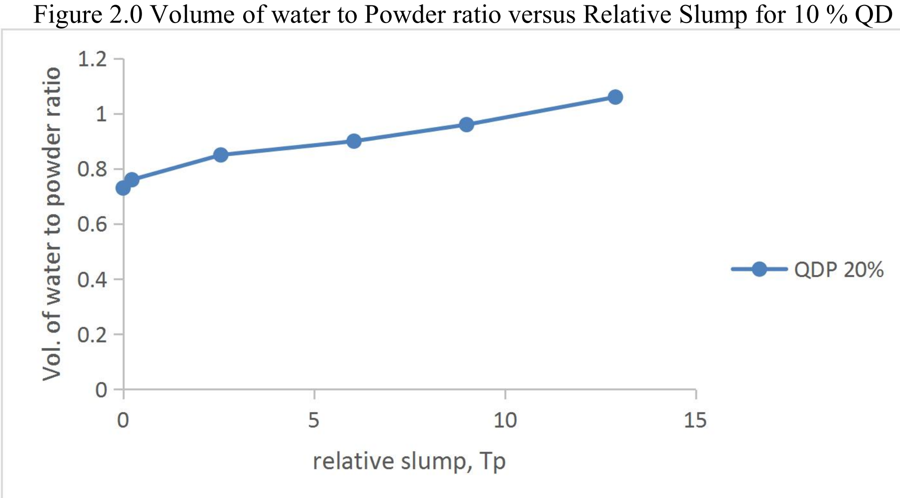

Figure 3.0 Volume of water to Powder ratio versus Relative Slump for 20 % QD Mix

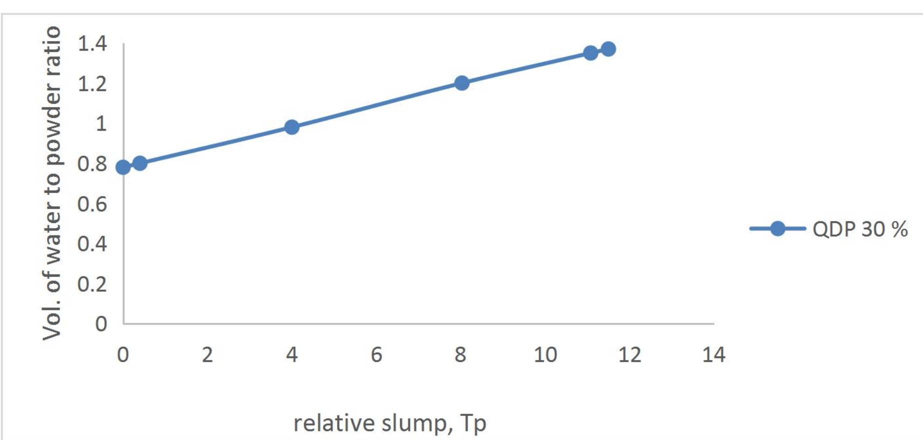

Figure 4.0 Volume of water to Powder ratio versus Relative Slump for 30 % QD Mix

3.3 Hardened Properties

3.3.1 Compressive strength

The compressive strength, (fc), of the Mixes cast in cubes and cured at the aforementioned ages were tested in accordance with [22] provisions by means of a 3000 kN capacity compressive testing Machine. The test was conducted on three (100 x 100 x 100 mm) cubes for each Mix and the average value reported herein.
The splitting tensile strength for the SCC was determined for each Mix on three ϴ150 X 300 mm cylindrical specimens and the average value reported herein. The results of the compressive and tensile strengths values are as shown on Table 4a and 4b respectively

Table 4a. Compressive strength of PC and PC blended with QD Mixes.

Mix ID	Compressive strength (N/mm^2)				
Age (Days)	3	7	14	28	56
SCC	12	14.75	21.15	26.85	30.5
SCC-QD10	11.5	12.92	18.25	28.50	33
SCC-QD20	11.8	13.42	19.00	29.22	34.8
SCC-QD30	10.42	11.15	17.88	27.35	30.3
SCC-QD40	9.25	10.12	16.32	24.25	29

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The results show that control values are higher than that for blended Mixes at early ages. This is due to reduction in PC content (that contains C_3S ions responsible for accelerating hydration) in the blended Mixes. Also, QD particles in the blended Mixes has to wait for the production of Ca $(OH)_2$, a by- product of PC hydration which then reacts with the QD to produce C-S-H responsible for strength development in concrete. However, at 28 days and more days of age, compressive strength of blended Mixes equalled and even surpassed control Mix values. This is because, in addition to hydration of PC, pozzolanic reaction between QD and Ca $(OH)_2$ reacts to produce more C-S-H which accounts for the increase in C-S-H responsible for strength development at later ages. 10 % QD mix has a 6 % increase in strength and 9 % at 56 days while 20 % QD Mix has an improved value of 8 and 25 % at 28 and 56 days when compared with control values. For 30 % QD Mix and more, strength values decreased even at aforementioned ages due to dilution effect. These results also indicates the influence of QD content on the properties of SCC Mixes.

3.3.2 Splitting tensile strength.

Tensile strength has a direct relation with compressive strength of concrete. The results of the tensile strength tests are also shown in Table 5.0. The values are apparently of the same trend with that for compressive strength.

Table 4b. Splitting Tensile strength of PC and PC blended with QD Mixes.

Mix ID	Tensile strength (N/mm^2)					
	Age (Days)	3	7	14	28	56
SCC		2.15	2.40	2.91	3.22	3.56
SCC-QD10		2.10	2.23	2.68	3.31	3.66
SCC-QD20		2.13	2.27	2.71	3.35	3.78
SCC-QD30		2.00	2.08	2.62	3.24	3.45
SCC-QD40		1.91	1.98	2.52	3.06	3.25

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4.0 Conclusions

The study sets out to evaluate the effects of QD content on the properties of SCC with a view to determine the optimum content of QD in SCC with no adverse effect on its properties. Experimental Tests were conducted and based on the results, analysis, discussions and findings it is concluded that:

(i) QD can be used to replace PC in SCC up to an optimum content of 20 % by mass of PC with no adverse effect on its properties.

(ii) The inclusion of QD in SCC increase the setting times but does not significantly affect its standard consistency.

(iii) The flow ability of SCC blended with QD meets EFNARC, 2005 Provisions and are classified as SF2 and PA2 respectively.

(iv) The water demand and deformability coefficient of SCC containing QD are low and has strong sensitivity to water changes for a given flow ability.

(v) SCC containing QD influence its hardened Properties

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