EFFECT OF GRANITE DUST PARTICLES ON FRESH AND HARDENED PROPERTIES OF SELF-COMPACTING CONCRETE

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MTech/SET/2018/8147

DEPARTMENT OF BUILDING

FEDERAL UNIVERSITY OF TECHNOLOGY

MINNA

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD

OF THE DEGREE OF

MASTER OF TECHNOLOGY IN CONSTRUCTION TECHNOLOGY.

OCTOBER, 2023

DECLARATION

I hereby declare that this thesis titled **"Effect of Granite Dust Particles on Fresh and Hardened Properties of Self-Compacting Concrete**" is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) and their contributions has been duly acknowledged**.**

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CERTIFICATION

The thesis titled "**Effect of Granite Dust Particles on Fresh and Hardened Properties of Self-Compacting Concrete" by Michael, Jacob (MTECH/SET/2018/8147)** meets the regulations governing the award of the degree of Masters of Technology (MTech) of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

This work is dedicated to THE ALMIGHTY GOD, the maker of Heaven and the Earth, the only merciful and gracious One. He gave me the grace to complete this project. May His name be praised forever.

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God bless you all.

ABSTRACT

To partially replace Cement in Concrete, different Cementitious materials can be used to mitigate the effect of environmental pollution with serious health issues during Cement production. In this light, it is imperative to use locally available pozzolanic materials as partial replacement of cement in concrete since they are less expensive and more environmentally friendly and without compromising quality of concrete. Quarry Dust particles (QDP) obtained from a granite quarry site was tested for the optimum percentage mass replacement of Portland cement (PC) by, 0, 10, 20, 30 and 40 % respectively in the Study. Also, effect of QDP content on the fresh and hardened properties of Self – compacting concrete (SCC) in terms of setting times, slump flow ability, passing ability, water demand of QDP, compressive and tensile strengths were studied. The aforementioned parameters were determined by tests conducted on fresh and hardened samples of SCC. Results indicates that QDP content in SCC increase the initial and final setting times, 10 – 20 % QDP content in SCC enhanced its flow-ability, but at 30 % replacement level of PC in SCC, its passing ability is susceptible. At 10 – 20 %QDP content in SCC, it shows strong sensitivity to water demand. A maximum compressive strength of 34 N/mm^2 was obtained at 56 days curing age for an optimum partial replacement of 20 %. The test results have shown that QDP 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.

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LIST OF ABBREVIATIONS

FA	Fly Ash
GDP	Granite Dust Particles
GGBFS	Ground Granulated Blast Furnace Slag
ITZ	Interfacial Transition Zone
LP	Limestone Powder
MK	Metakaolin
PC	Portland Cement
SCC	Self Compacting Concrete
SCMs	Supplementary Cementitious Materials
VMA	Viscosity Modifying Admixture

CHAPTER ONE

1.0 INTRODUCTION

1.1. Background to the study

The latest development in concrete Technology in the world today is self-compacting concrete (SCC). It is a concrete made with the same materials as in conventional concrete, though in some cases, viscosity modifying admixture (VMA) is used to counteract segregation, which improve the cohesion of the concrete mixture components and control powder content (Gołaszewski, 2009 and Domone, 2006). The American Concrete Institute (ACI, 2007) defines SCC as a highly flowable, non-segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation. Self-compacting concrete differs from normal concrete as it is at a higher end in workability and the issues of segregation and bleeding are encountered in these types of concrete (Duval & Kadri, 1998) reviewed by Vyas & Shekhawat (2023). The workability of SCC is mainly assessed in terms of its flow-ability, passing ability and resistance to segregation.

To attain self-compatibility and required strength, its constituents and the ratio of cement paste or mortar is carefully selected (Koura *et al*., 2019). Due to the high deformability of SCC mixes and sensitivity to changes in ingredients, the fresh properties require special quality control. The work of Koura *et al.* (2019) show that an increase in the solid phase (aggregate content) leads to low liquid phase (cement paste) results to high internal friction which increase the tendency of blockage (poor passing ability) and thus reduce flow- ability. However, there is a decrease in powder content, the mechanical properties of SCC are affected negatively and this also leads to segregation. To reduce cement content so as to lower cost of production and other environmental impacts, supplementary cementitious materials (SCMs) have been used such as metakaolin (MK), Fly ash (FA), Limestone powder (LP), Granite Dust Particles (GDP) as well as VMA.

GDP is one of the most widely used materials in SCC mixes due to its low cost and availability. For most researchers concerned with SCC studies, the most paramount issue is to provide stability and segregation resistance of fresh mix without loss of uniformity. Ever since its inception in the construction industry, the work of Gesoğlu and Özbay (2007) and Guneyisi (2010) have shown that extensive studies have been undertaken on the properties of SCC. In SCC, to provide high fluidity, overcome segregation and bleeding issues during transportation and placing, it is imperative that high amounts of materials such as Portland cement (PC), Fillers and the use of VMA have been specified by researchers (Lachemi *et al.*, 2004 and Ferraris *et al.*, 2000). It has been established that for finer materials less than 0.1 mm diameter, PC content of 500 – 600 Kg/m^3 is critical to achieving self- compatibility. This is not only uneconomical but also an issue in terms of high heat of hydration and high cost due to high cement content. It becomes imperative to seek for alternative to use of PC in SCC such as GDP. The use of such material not only reduce cost but also provide additional performance to SCC (Bouzoubaâ and Lachemi, 2001). Studies further show that the reaction mechanism of GDP is generally influenced by its particle size and amount. However, like other materials used in SCC, the effect of GDP on SCC is likely to be in terms of its filler and nucleation, dilution and chemical interactions. It is imperative to evaluate these effects on the fresh and hardened properties of SCC so as to ascertain a better behavior of SCC incorporating GDP. The application of GDP in SCC will also help reduce environmental impacts of GDP during its production, especially as it is currently being dumped in Landfills occupying agricultural Land spaces.

1.2 Statement of the Research Problem

To characterize concrete as self-compacting entails the assessment of its workability in terms of its flow ability (ability to completely fill all areas and corners of formwork), passing ability (being able to flow through congested reinforcement without separation of its constituents or blockage) and segregation resistance (being able to retain the coarse component of the mix in suspension in order to maintain a homogenous Material. When these properties are attained in accordance with EFNARC (2006) and ACI-237 (2007) provisions, then, the concrete can be regarded as an SCC.

Presently, workability tests for SCC are conducted using either the ABRAMS' Cone or the slump cone Mould. The concern here is that, with the incorporation of GDP in SCC, will its workability values still meet EFNARC and ACI-237 (2007) provisions? This is yet to be ascertained. The workability of a Mix like SCC determines to a large extent the behavior of the Mix. Hence, it is imperative to determine the workability of SCC-GDP and then compare with reference values so as to ascertain suitability in accordance with relevant code provisions.

Since SCC is a high powder content material, and to avoid the high content of PC so as to reduce cost, supplementary cementitious materials (SCMs) are used to replace PC partially. Adding a quantity of finer material like GDP can eliminate the segregation risk by enhancing the cohesion and results in good dispersion between powder phase and aggregates in SCC. Moreover, to ensure high filling ability and flow without blockage, it should have a less coarse aggregate content and therefore a higher binder content. Replacing PC with a finer SCM could be a better solution as it will make the Mix more cohesive and reduce the high PC demand and hence, minimizes materials cost as well as reduction of heat of hydration of the Mix.

GDP is a by-product of granite quarry in large quantities stored as dumps on quarry sites. It is a fine material with a specific surface area of 4580 cm^2/gm (Apeh, 2019). Apart from being a filler material, can be also react with Calcium hydroxide to form binder that increase the strength of concrete. It is important to study its inclusion in SCC and how its percentage content affect(s) the fresh and hardened properties of SCC. Essentially, freshly- mixed SCC is a concentrated suspension of coarse aggregates in mortar; while mortar too is a concentrated suspension of fine aggregates in cement grout which is a two-phase material (composed of cementitious grains and water). Hence, mortar behavior is dominated by that of cement grout and the properties of fine aggregates, but the behavior of SCC is dominated by that of mortar and the properties of coarse aggregates. Therefore, change in cement paste behavior (grout and mortar) would affect the flow properties of SCC. Studying the fresh properties of SCC paste with and without GDP and to what extent the content would assist in predicting the flow ability, passing ability and segregation of SCC is the objective of this study.

1.3 Aim and Objectives of the Research Study

1.3.1 Aim

The aim of the study is to evaluate the fresh and hardened properties of SCC incorporating GDP and determining its suitability in SCC production.

1.3.2 Objectives of the study

The following objectives of the study are to:

1 Evaluated the physical and chemical properties of the constituent materials

2 Evaluate the fresh and mechanical (compressive & splitting tensile) property of SCC incorporating varying percentages of GDP.

3 Determine the optimum content of the GDP in SCC.

4 Examine the durability properties of SCC.

5 Develop a model for predicting the strength of SCC containing GDP.

1.4 Significance of Study

In achieving higher sustainability in the construction industry, it is imperative to utilize materials for filling and mineral admixtures as substituting additives in concrete. Such materials can readily be utilized to mitigate issues such as costs, recycling the industrial waste, rehabilitation, durability and mechanical performance of concrete. The study highlighted the effect(s) of GDP content as a replacement of PC on the fresh and hardened properties of SCC. From mixtures obtained from the Mix proportions, PC was replaced by GDP at 10, 20 and 30 % by Mass. Fresh properties of SCC mixes were tested for Flow ability, passing ability, segregation, setting times while compressive strength was determined as one of its mechanical properties. The study is significant as it highlighted the effects of GDP content replacement of PC on the fresh and hardened properties of SCC-GDP such as reduction in Flow ability, increase in setting times, decease in resistance to segregation when the paste volume of SCC-GDP concrete increased. These results could serve as a basis for modelling of SCC-GDP concrete.

1.5 Scope of the Study

The study focused on the evaluation of physical and chemical properties of the constituent materials used for the study, as well as the fresh and hardened properties of SCC in--corporating GDP as a partial replacement of PC. The research also determined the effect(s).

1.6 Justification of the study

In achieving higher sustainability in the construction industry, it is imperative to utilize filling materials, mineral admixtures as substituting additives in concrete. Such material can readily be utilized to mitigate issues such as cost, recycling the industrial waste, rehabilitation, durability and mechanical performance of concrete. The outcome of the study indicates that inclusion of QD in SCC increase the setting times but does not significantly affect the consistency of SCC. The water demand and deformability coefficient of SCC containing QD are low and has strong sensitivity to water changes for a given flow-ability. This implies that for a known flowability of SCC, the water demand for the mix can be estimated with the aid of the deformability coefficient. The significance of the study in this regard is that the water demand of an SCC containing QD can be estimated for a given flow-ability. In other words, figure 4.5 – 4.7 can be used to estimate the water demand of SCC containing 10% QD, 20% QD and 30% QD respectively for each given flow-ability using the mini slump cone. This is in agreement with the work of Dadsetan (2017) who used 30% GBFS in SCC and obtained an increase in compressive strength of 30% after 28days of curing.

The study also revealed that an optimum content of 20% QD can be used to replace PC in SCC production without any adverse effect on the properties of SCC. The significance of the study can also be seen from the relationship between compressive strength versus slump flow values at 28 days. The strength increased up to 20% PC replacement with QD and then decreased above 20% PC replacement with QD.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Properties of SCC

The latest development in concrete Technology in the world today is SCC. It has very important features such as minimum noise during production, elimination of vibration and Smooth surface finishing (Apeh, 2019). it is a concrete made with the same materials as that of normal Concrete, though in some cases, with viscosity modifying admixture (VMA) to attain the homogeneity of mixes and control powder content. It is referred to as self-compacting because it has the ability to fill and be placed in a formwork without expending any energy for compaction. The workability of SCC is mainly assessed in terms of its flow-ability, passing ability, resistance to segregation. To attain self-compatibility and required strength, its constituents and the ratio of cement paste /mortar is carefully selected (Koura et al, 2019). Due to the high deformability of SCC mixes and sensitivity to changes in the fresh properties, requires special quality control ingredient properties.

The work of koura *et al.* (2019) shows that an increase in the solid phase (aggregate content) results in low liquid phase (cement paste content) which in turn leads to high internal friction which increased the tendency of blockade (poor passing ability) and thus reduce flow ability. However, when there is a decrease in Powder content, the mechanical properties of SCC are affected and which also leads to segregation. To reduce cement content so as to lower cost of production, supplementary cementitious materials (SCMs) have been used such as Metakaolin (MK), Fly ash (FA) and Granite Dust Powder (GDP) as well as viscosity modifying admixtures (VMA). GDP is one of the most widely used materials in SCC mixes due to its wide and cheap availability. Research has shown that the energy required to grind

GDP to required size for application in SCC is much less compared to the energy expended to produce Clinker for the same particle size. This has attracted its recommendation for use SCC by Standards such as EN 197-1 and others. Studies have shown that the reaction EN 197-1 mechanism of GDP is generally influenced by its particle size and amount. However, like other materials used in SCC, the effect of GDP on SCC is likely to be in terms of its filler, nucleation, dilution and chemical interactions. it is imperative to evaluate these effects on the properties of SCC incorporating GDP.

2.2 SCC Design Mixture

A major characteristic is the rate of bleeding, its fluidity, resistance to segregation and bleeding when pouring. This is essential during the movement of the cement paste within the congested reinforcement bars. Therefore, a decrease in the fluidity is achieved when there is increase in the coarse aggregate incorporated. Consequently, in the mixture design of SCC, care should be taken to ensure that proportion of coarse aggregate content to the volume of SCC is within the Code specifications for both EFNARC and ACI 257R-07. These codes stipulate that the draw back can be overcome by the addition of powder cement and Plasticizer. The design of SCC in accordance with stipulated codes shows that it contains higher powder content compared with normal vibrational concrete (EN 197-1 2011). The work of Domone (2006) showed that more 95 % of SCC has powder content more than 400 Kg/m^3 which indicates that SCMs such as GDP can be added to SCC.

2.2.1 Mix constituents and Mix proportions

SCC is a complex composite with different constituents of various types and contents. Generally, these constituent materials can be classified into three major components:

(l) Fine Powder materials

(ii) Water content and Super-plasticizer

(iii) fine and coarse aggregates.

The fine Powder part of the SCC mix is made up of PC and Fillers (inert or reactive). powder materials consist of particles of PC or Fillers with sizes less than 125 μm. Inert fillers such as limestone are traditionally used to increase the powder content of SCC mixes. More recently, mineral admixtures have also been considered (Ho *et al. 2002)*

Super-plasticizers, also known as high range water reducers, are chemical admixtures used where well-dispersed particle suspension is required. These polymers are used as dispersants to avoid particle segregation (coarse and fine aggregates) and to improve the flow characteristics of suspensions such as in concrete applications. Their addition to concrete or mortar allows the reduction of the water to cement ratio and enables the production of self-compacting concrete and high-performance concrete (Alyhya, 2016)

2.3 Material Characteristics

Different types of waste materials are used for SCC. Their suitability solely depends on the Chemical composition. The chemical composition of the materials differ and even between the same materials because of the differences in the procedures employed during the manufacturing and discharge process. Depending on the nature of the chemical composition of the material to be used in SCC, for example, Fly Ash (FA) which is a spherical particle can play a very crucial function in SCC at its fresh state, while for Silica Fume (SF) with very small size particles when used in SCC resulted in to water demand increment of the cement paste at its fresh state. Hence, others pozzolans (such as GGBFS and LP) due to their irregular, as well as angular shapes, if used, can contribute to better binding of the matrix paste.

Thomas and Harilal (2015) also incorporated QD in the coarse aggregate (artificial) production using cold bonding different proportions of PC having specific gravity in the range of 1.9 to 2.5. The work of Shakir *et al.* (2013) explored the utilization of QD in producing bricks. Also, the use of QD has found application in Ultrasonic pulse velocity (UPV) test results. The past studies also affirmed and confirmed that the incorporation of QD in producing bricks is feasible and viable to the threshold's relevant requirements. The work of Appukutty and Murugesan (2009) shows that QD as a coarse aggregate can be used in the preparation of mortar as an alternative to sand in the production of brick masonry by employing different mix proportions such as 1:4, 1:5 and 1:8 in comparism with bricks having basic compressive strengths above 3.5N/mm^2 and 7.5N/mm^2. They further found that QD in coarse form can be used to completely Natural River Sand (NRS) in masonry construction with higher strength and cheaper cost.

2.3.1 Shape and grading of Aggregates

Normally, aggregate shape requirements for both normal concrete and SCC are the same. An aggregate is considered elongated if the ratio of length to its maximum thickness is greater than 3.0. Elongated aggregates cause increase in internal friction, Voids and Pipe blockages at times. Such blockages are also caused by bleeding, high coarse/fine aggregate ratio and using pipes with different wear (Kaplan *et al.*, 2005).

Furthermore, a high elongated aggregate content also, needs a higher paste volume for SCC conveyance because paste is the vehicle for the aggregate. Aggregates, in addition to their use as economical fillers, can enhance concrete dimensional stability and wear resistance (Neville and Brooks, 2010).

2.3.2 Fine and coarse aggregates

2.3.2.1 *Volumetric ratio of fine aggregate (Vs/Vm)*

In SCC, the phase that provides lubrication between the coarse aggregate particles and the overall stability to concrete is the Mortar. The required properties are similar to those of concrete itself. Low yield stress to ensure the flow under its self -weight and a plastic viscosity is sufficient to ensure that the concrete does not segregate during flow. However, in practice, the high viscosity could be a problem because of its slow flow ability. The work of Domone et al. (1999) suggests as suitable the yield stress values between 20 Pa - 50 Pa and plasticity viscosity between 6 Pa - 12 Pa for Mortar. To attain stable concrete mix with desired flow ability, volume of paste phase plays an important role. This is because SCC usually has lower coarse aggregate mixes. The powder used should be as low as possible, the required solid phase is maintained by its volume fraction of the aggregate. Furthermore, the proportion of fine particles (less than 125μm) in the fine aggregate has a more obvious influence on SCC than normal vibrated concrete as it may help in increasing cohesion, and thereby segregation resistance (Felekoğlu et al., 2008; Topçu and Uğurlu, 2003)

2.3.2.2 *Volumetric ratio of coarse aggregate*.

The passing ability between obstacles such as reinforcing bars of SCC is one of the most important performances besides self-deformability. This is because it determines the final filling capacity, which influences the strength and durability of the hardened concrete (Petersson *et al.*, 2006).

Coarse aggregate content is the major factor in determining the passing ability of SCC. As fresh concrete flow approaches reinforcement bars and narrow form works, the paste proceeds faster than the aggregate because of the velocity difference caused by obstruction. The aggregate content is considered to increase locally, since the new aggregate is fed from behind. Hence, the relative viscosity (concrete viscosity/ paste viscosity) of SCC is expected to become higher than the original value when passing through a narrow space (Noguchi *et al.,* 1999).

In densely reinforced areas, the passing ability can be enhanced by reducing the volume and the maximum size of coarse aggregate and/or using round aggregate instead of crushed one (Alyhya 2016). The increase in volume of aggregate to volume of Mortar ratio, Vg/Vm, the v-Funnel flow times as well as u - Box flow time are increased. At the same time, u - Box filling height were decreased significantly.

2.4 Hydration Mechanism

The work of Scrivener *et al*. (2019) shows that the hydration processes of Portland cement (PC) consist of an induction, acceleration and deceleration periods respectively. The inclusion of SCMs significantly influence the hydration process in the composite system. The hydration process in the composite system first starts with the PC being hydrated producing primary hydration products which in turn react with SCMs to produce more secondary hydration products (Pang *et al*., 2022).

The hydration development is influenced by the higher content of powder materials and admixtures. For example, incorporation of limestone powder in SCC leads to an increase in hydration reaction (Poppe and De Schutter, 2005). For example, the hydroxide (OH), acting as an alkali activated generated from PC hydration reacts with GGBFS to dis-construct the glass order of the GGBFS to produce more products. The process releases ions (Ca^{2+}, Al^{3+}, $SiO4^{-4}$ etc.) into the solution for subsequent hydration. The mass reaction product of GGBFS by alkaline is a type of aluminum substitution C- A- S-H gel; which presents a disordered Tobermorite – like C-S-H type structure. The hydration process of FA occurs under the alkali activity of OH- produced by cement hydration. Its activity is less due to high amount of SiO_2 and Al_2O_3 (low Ca/Si+Al) ratio and stable Si-O and Al-O bonds. its contribution to hydration is at a later stage.

2.5 Influence of SCMs on SCC

2.5.1 Microstructure

Concrete basically is made up of three parts, aggregate, interfacial transition zone (ITZ) and cement paste. The ITZ is a thin shell wrapped around the surface of the aggregate and is the lowest in strength part of concrete, whose microstructure determines the performance of the concrete (Mehta & Monteiro, 2014).

The work of Jain *et al.* (2020) shows that the incorporation of SCMs like granite waste and FA can influence the formation and development of the ITZ in SCC; and thus, its resistance to deformation. The influences of SCMs on the ITZ of the concrete originates from these three effects, namely, the filling effect, Pozzolanic reaction and dilution effect. The packing density of the SCC can be increased by the filling effect there by optimizing the mixture proportion of the SCC. Also, the pozzolanic reaction of the SCM consume the CaOH which is a byproduct of PC hydration as it produces C-S-H, thus the ITZ of the SCC is improved. Furthermore, the fact that certain SCM (FA) hydration rate is slow allows for water to participate in PC hydrations which facilitates adequate PC reaction. At the same time, SCMs offer nucleation sites for PC hydration which gives more evenly dispersed reaction products.

As vibration makes water accumulate on the surfaces of coarse aggregate particles, normal vibrated concrete tends to contain a porous matrix and poor interfacial zones, which weaken hardened properties (Alyhya, 2016; Felekoglu, *et al*., 2018)

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2 5.2 Spread flow test

In accordance with the work of Okamura and Ozawa (1996), the spread flow test (also known as paste line test or mini slump flow test) is a classical method used for the evaluation of workability of a mix (Ferarris *et al.*, 2006) and also for the powder constituents water requirement in SCC. For the mix, suspensions produced are made of the Powder to be analyzed with quantities of water. After achieving a homogenous mix, the slump cone cylinder is filled up in three layers with proper tapping as compaction, the cone is allowed to be lifted up for the paste free flow allowance without any disturbance. Two diameters (d_1 and d_2) exactly vertical and or upright (perpendicular) can be examined from the paste spread flow and the slump (Tp) is computed relatively using the mean values with the relation as follows

$$T_p = [d/d_o]^2 - 1; \text{ with } d = d_1 + d_2 \qquad (2.1)$$

where do is base diameter of the cone used. The relative Slump, Tp, is a measure for the deformation of the mixture. This can be related to the ratio of volume of water required to form a suitable mix (consistency) to the volume of powder to obtain a straight-line graph. The ordinate of the graph is the water demand of powder while the slope of the graph is the deformation coefficient of the mix. This is a measure of sensitivity on the water need for a specified flowability. This fact can be used to assess the deformability of a mix due to change in its water content. A Powdered material with a lower slope will respond with a higher change in deformability. This helps to identify materials that tend to bleeding or segregation.

2.5.3 Water demand for powders in concrete.

In concrete, its water demand mainly depends on the fineness and nature of the Powder particles. For SCC type of concrete, Powder content plays a very important role in its formation. The addition of limestone powder improves the particle packing by filling the small pores between cement grains and augment the water retention of fresh mixes (Bradu *et al* 2016). The water demand of a powder in an SCC is composed of the amount of water molecules adsorbed around the particle and the amount required to fill the inter-granular voids of the powder system. For a concrete mix such as SCC, the powder content provides the highest specific surface area, hence strongly influence the water demand. In this light, powder content of SCC should have a low water demand which will lead to attaining the total amount of water that is required for the mix. This amount of water will be enough for the lubrication of powder particles, sufficient water layer thickness and amount required for hydration. For PC, it requires water of about 28 % of its weight for its complete hydration reaction. Hence for total hydration, a water-cement ratio of about 0.40 is required (Taylor, 1997). Hence any Mix with a w/c ratio above 0.40, the excess water is used to lubricate the particles. The water demand specific surface area of the particles, consistency and void volume of a mix are all related to each other.

2.6 Fresh Properties

The workability of concrete incorporated with QD to replace NRS was investigated by Bishnoi and Bala (2015) at a constant w/B ratio. Their test results showed improvement in the workability property of concrete. However, the work of Vijayalakshmi *et al.* (2013)

reported that incorporation of QD in concrete tends to reduce the performance of its workability. Other researchers in their work show that the reduction of fresh properties of concrete when QD is incorporated is due to its excessive fines content and high-water absorption properties as compared to that of NRS (Singh *et al.*, 2016). Furthermore, Singh *et al.* (2016) in their work has stated that due to the physical nature of QD, in terms of being angular and rough in texture increases the internal friction between the particles, which in turn reduces the workability performance of cementitious composites.

When 20 – 40 % replacement of NRS with coarse QD in concrete is made, test results indicate reduction in mechanical strength of the concrete (Raman *et al.*, 2005). This was attributed to poor compaction as a result of poor workability. Poor compaction increases porosity in the microstructure of the cementitious composites, but the work of Bishnoi and Bala (2015) indicates improvement in the mechanical properties of the Cementitious composites when QD replaces NRS up to 55%. The work of Singh *et al.* (2016) also indicates that when QD is used to replace NRS up to 50%, optimum performance is attained but at 50% replacement levels, a reduction in strength is observed. However, few studies have been conducted using 100% replacement of NRS with QD. The work of Manasseh (2010) showed that 20 % replacement of NRS with QD, mechanical strength performance improved. The work of Suman and Srivastava (2015) indicated that there was a superior mechanical strength performance compared to conventional concrete when 50% QD was used to replace NRS in concrete. When replacement level of NRS with QD was increased to 60%, there was no significant improvement in the properties of the concrete. Also, researchers found out that the replacement levels of NRS with QD up to 75% shows a reduction in mechanical strength performance. This is due largely to the increase in water demand which in turn reduce mechanical strength performance. Better performance on the use of QD as a replacement of NRS in concrete is believed to be due to its morphology (angular shape and rough texture). Such physical property improved the compactness and resistivity towards the crack propagation in cementitious composites as seen in the works of Bederinna *et al.* (2013; Domone, 2006). Quarry Dust (QD) containing fines have improved the cementitious composite matrix, filling the voids in the cementitious composite mixture. But beyond the optimal replacement levels, it was noticed that the mechanical performance of composite mixture reduced as reported in the works of Aquino *et al.* (2010) and Singh *et al.* (2016).

To assess the fresh properties of concrete, fluidity is the most common factor researchers always consider primarily. The work of Li *et al.* (2013) has shown that while SCMs in SCC may fill the pores and lower the pore water content thus increasing the quantity of free water and wrapping around the surface of the powder particles producing a uniform water film that lubricates the paste and minimize friction; On the other hand, some SCMs which has high specific surface area improved the water adsorption of SCC, decreasing the water content. This means that the fineness and proportion of SCMs have a significant effect on the fresh properties of SCC. in addition, because some SCMs reduce the fluidity of SCC, Super plasticizers are employed to improve the performance of the fresh mixture. The function of the Super-Plasticizers (SP) mainly, is to disperse the powder particles through steric repulsion The work of Zhang and Kong (2015) and Wang *et al.* (2019) shows that SP is able to achieve the dispersion of the Powder particles when one end of its particle is adsorbed to the surface of the Powder particles while the long chain of the other end generates a physical barrier to prevent the surrounding PC particles from aggregation. The work of Sha *et al.* (2020) has shown that addition of SP to SCC may have negative effect as this could lead to retardation of early hydration and delayed setting. The work of Alexandra *et al.* (2018) show that FA can increase the fluidity of SCC due to its smooth and spherical particles which provides a ball-bearing action in the fresh SCC mix, reducing its frictional resistance of the aggregate particles. However, Silica fume (SF) on the other hand increases the water demand of SCC and decreases its fluidity due to its large specific surface area and rough surface texture. The effect on fresh properties of SCC when ground blast furnace Slag (GBFS) is added is due to its fineness and admixture proportion percentage replacement of PC in SCC. The work of Boukendakdji *et al.* (2012) show that GBFS with a specific surface area of 350 m^2/kg was used to replace PC in SCC at 15%. Test results showed superior water retention effect at increased fineness which minimizes loss of flow slump diameter. The effect of Limestone Powder (LP) on the fresh properties of SCC is due mainly to its Fineness. The fluidity of the Paste is enhanced by the filling ability, but the water requirement increases at higher content of finer powder. The work of Suaiam *et al.* (2013) shows that incorporating LP with a median particle size of 15.63μm in SCC increased water demand and reduce fluidity.

2.6.1 Assessment of fresh properties of SCC

Institutions like Architectural institute of Japan and EFNARC established standards, Specification as well as guidelines for the common use of SCC. For SCC to achieve self-Compaction, three basic criteria are required. These are deformability, flowing ability, high passing ability and high resistance to segregation. To attain good deformation, it is imperative to reduce to the barest minimum the friction between particles during flow. This is because friction between particles during flow can reduce flow ability. This can be achieved by reducing aggregate content and increasing the paste volume content so as to maintain high passing ability. between closely spaced obstacles. High cohesiveness of the particles of the mix can also be achieved by employing or incorporating Viscosity Enhancing Agents (VEA) with High Range Water Resisting Agents (HRWRA) so as to control bleeding, segregation and settlement (Apeh, 2019). The cohesiveness of the mix can also be reduced by reduction of water content, increase volume of fines and cement paste or both. Another means of reducing free water content is the application of fine materials and fillers with greater specific surface area than that of PC. The manufacture requirement, adequate production and use of SCC depends on its dynamic and static stabilization.

The dynamic stability of SCC is its resistance to flow during transportation and placement while static stability is its resistance to segregation and bleeding once it is placed until onset of hardening. The dynamic stability is measured by the V-Funnel test flow time, J-Ring, L-Box, U-Box, and pressure bleed tests. The static stability can be assessed through the determination of surface settlement aggregate segregation and monitoring the in-place changes of electrical conductivity. The technology of SCC is based on adding or partially replacing PC with fine material, fly ash, silica fume (SF) without modifying the water content. This process changes the rheological behavior of concrete. In order to strike a balance, between flow ability and stability, the particles less than 150 μm should be between 520 – 560 kg/m^3 which improves its cohesiveness due to its huge powder content (Apeh, 2019). The use of HRWRA lowers mostly the yield stress value, but slightly affects viscosity, making it possible to have highly flowable concrete with significant reduction in viscosity or cohesiveness. It is essential to reduce coarse aggregates content and hand sand volume, then, increase paste volume to enhance deformability.

Reduction in water- powder (W/P) ratio leads to reduction in deformability of cement paste whereas increase in W/P ratio secures high deformability but may reduce cohesiveness of paste and Mortar, necessitating a balance in W/P ratio to enhance deform ability without substantial reduction in cohesiveness (Esmaeilkhanian *et al*., 2017)

2.6.2 Passing ability

The passing ability or blocking ratio of SCC reduce when it flows through obstacles. This is due to high Collison between various solid particles which increases viscosity thus requiring greater shear stress to maintain a given capacity and deformation speed. The reduction in aggregate content necessitates the use of a higher volume of cement during hydration (Apeh, 2019). However, SCC often contains high volume replacements of Fly ash, limestone filler or stone dust to enhance fluidity and cohesiveness and also limits temperature due to hydration. The combined use of HRWRA and VEA can ensure both high deformability and adequate stability required for high filling capacity, good bond with reinforcement and uniformity of in-situ mechanical properties.

Billberg *et al.* (2004) also concluded that the ability of SCC to pass depends primarily on yield stress rather than viscosity. However, a paste with sufficient viscosity can also prevent local increases in coarse aggregate and hence avoid blocking. The viscosity increases when incorporating powder materials such as fly ash, GGBS, and limestone filler as better distribution and particle packing will be achieved (Edamatsu and Nishida, 1998) reviewed by Alyhya (2016).

2.6.3 Tests for SCC

Just as tests are conducted for normal concrete to determine its value in terms of workability (slump), compacting factors are conducted on SCC to determine its properties such as flowability, passing ability, segregation and stability. These tests after a period, has become standardized.

Researchers has suggested that slump spread flow ranging from between 500 mm – 700 mm is usual for SCC. EFNARC (2005) stipulates that slump flows between 600 mm – 800 mm is considered suitable for construction work. Flow time is also used to measure the suitability of SCC. The flow time T_{500} is the time required for SCC to flow through a diameter of 500 mm. Normally, up to six seconds is considered good for SCC. However, more time could be obtained for SCC containing SCMs which are very cohesive mixes. For the slump flow, the test apparatus is the slump cone. When SCC mix is required to flow through obstacles, the passing ability or blocking ratio is used to measure its passing ability using the L- box apparatus. Fresh SCC, a quantity of six Litres is poured into the vertical portion of the L-Box and left for about 30 – 60 seconds. The trap is then released and the concrete flows to the horizontal portion of the box until it stops flowing. The ratio of the height of concrete at the horizontal to that at the vertical portion of the box, (h_2/h_1) is a measure of the passing ability of the concrete sample. A blocking ratio of 0.80 – 1.0 is an indication of an SCC with a good to excellent passing ability (Apeh, 2019).

Table 2.1: Tests and suggested Limits

Test	Properties	Suggested Limits
Slump flow	Flow ability	Diameter greater than 650 mm-850 mm, less than 12 seconds
	Filling ability	3 to 5 seconds preferably
	Segregation resistance	By visual assessment
L – Box	Passing ability/ Blocking ratio	Blocking ratio: 0.75 - 1.0
U – Box	Filling Ability	Filling height greater than 300 mm
	Passing Ability	Flow time: 10 - 20 seconds
V – Funnel	Passing Ability	Flow time: 2 - 10 seconds
Segregation resistance	Segregation	By visual assessment
Surface settlement	Segregation resistance	Surface settlement < 0.5 %
Penetration Test	Segregation resistance	Penetration depth < 8 mm
Segregation Test	Segregation resistance	Segregation coefficient < 7 % for 700 mm Column in hardened concrete

Source: Domone and Wen (1997)

2.6.4 Fillers used in SCC

Materials with a particle size less than 0.125 mm or 125 μm are called Fillers or powder with examples such as Silica fume (SF), Fly Ash (FA), Lime stone powder (LP) etc. for better stability, any filler that will be used in SCC must have at least 75 % of it passing the 0.063 um sieve. They modify the rheological properties of SCC both in the fresh and hardened states respectively. When a filler such as Limestone powder (LP) is used in large quantity, required properties of SCC are achieved at a lower W/C+ Filler ratio. Reports from Literature (Elyamany, *et al.*, 2014)also showed that compressive strength of 28 days SCC improved due to the filler effect and this then, leads to improved fine particle packing (Rizwan and Bier, 2006).

With LP particles acting as sites for the nucleation for calcium hydroxide (CaOH) and calcium Silicate hydrate (C-S-H), reaction products, this enhances faster hydration. This means that fillers play a role in enhancing hydration of materials even though they do not actively participate in the reaction process. It is also an established fact that replacement of large volume of PC in the range of 100 Kg/m3 with LSP as a filler, reduces PC content required to achieve a given slump flow, viscosity and compressive strength at early age. Also, the increase in LP Filler content can reduce the HRWRA demand necessary to secure a given deformability. The work of Ghezal & Khayat (2002) show that for a given dosage of HRWRA, the loss in slump flow decreases with increase in LP Filler in mixtures containing 360 Kg/m3 of PC with opposite trend observed for concrete with 290 Kg/m^3 of PC.

FA has also been used extensively in SCC Production. FA such as low calcium ASTM class F FA generally reduces the water demand, SP content for a target flow, reduces heat of hydration due to delayed setting because of its high LOI content. SF and RHA can be used with FA by about 20 % of its mass to improve flow and strength properties; SPs are essential for flow and durability.

Silica fume addition to concrete improves its durability through reduction in the permeability and refined pore structure, leading to a reduction in the diffusion of harmful ions, reducing calcium hydroxide content, which results in a higher resistance to sulfate attack (Rasol, 2015).

2.7 Mechanical Properties

2.7.1 Strength properties

SCMs influences the strength properties of SCC in terms of its filler effect and nucleation, pozzolanic reaction and dilution effects respectively. When PC is partially replaced with SCMs, the cementitious component of the paste is reduced, which slow down development of early strength. SCM like FA composed mainly of SiO_2 and Al_2O_3 with low pozzolanic reaction which facilitates post early strength growth. The work of Esquinas *et al.* (2018) show that the use of SF improves the compressive strength of SCC by more than 30%, the flexural strength by about 20%. increased use of SF by 25% can optimize the flexural strength by about 40%. This is because SF contains high content of reactive SiO_2, which might enhance hydration. The work of Esfandiari and Loghmani (2019) showed that SF can efficiently enhance filler effect and improve interfacial transition zone. The research team also indicated that the reactive SiO_2 in SF could react effectively with Ca $(OH)_2$, a byproduct of PC hydration to produce C-S-H Gel. However, when GBFS is used to substitute PC, this results in early strength delay. in other words, compressive strength of SCC decreases with increase in GBFS content but post strength values at 56 and 90 days appreciates in strength. The hydration of PC is stimulated by LP Powder and this enhances the strength development of SCC. This is achieved primarily by the adsorption of Ca^{2+} by $CaCO_3$, which promotes the dissolution of C_3S. At the initial stage of PC hydration, the dissolution and hydration of C_3S produce a substantial quantity of Ca^{2+}. Since the migration capacity of Ca^{2+} is greater than that of SiO_2, the chemical adsorption of $CaCO_3$ to Ca^{2+} takes place when Ca^{2+} diffuses towards the surface of LP particles. However, this adsorption decreases the concentration of Ca^{2+} around the C_3S particles allowing C3S to dissolve and hydrate more quickly. On the other hand, the connection of Ca^{2+} with the surface of LP particles causes them to form ion clusters which continue to expand to construct the crystal nucleus and gradually grow into C-S-H gels. Therefore, the adsorption of Ca^{2+} by the surface of LP highly promotes the hydration of cement and leads to the high-density nucleation and directional growth of C-S-H (Ouyang *et al.*, 2021).

2.7.2 Durability properties

One of the parameters that greatly influences the durability of concrete is its compactness as seen in the works of Pittella *et al.* (2020) and Bossio *et al.* (2017). When high percentages of SCMs is used to replace PC, it leads to a dilution effect which reduce the quantity of PC, lowering its hydration temperature, thus minimizing risk of cracking.

The work of Altoubat *et al.* (2016) has shown that the use of GBFS and FA decreased the internal stress of SCC, which led to better crack resistance. When SCMs are used in SCC, their filling effect reduce porosity, permeability through packing the pores of the Paste and hence improving durability of SCC. When SF is used in SCC, due to its fineness, it acts as a filler by filling all the pores of the concrete, reinforcing its microstructure thus, improving the durability of SCC. it also offers higher resistance to Sulphate attack and chloride ion penetration. Furthermore, the work of Sideris *et al.* (2018) indicates that the filling effect due to the addition of GBFS in SCC decreases the porosity and reduce the carbonation depth and could effectively improve the resistance to Sulphate attack.

The performance of cementitious composites incorporating QD up to a replacement level of 50% has been reported (Singh *et al.,* 2016). The results show that 30 % replacement levels indicated the lowest permeability and water absorption; but at 50 % replacement level, there was improvement in permeability and water absorption. Further studies show that at 55% replacement with QD, there is more improvement in permeability. However, when the replacement level of QD increased to 70 %, there was poor impermeability performance (Singh *et al.,* 2016). Apart from the improvement in durability properties of the cementitious composites, improvement of the pore structure in the paste aggregate interfacial zone (ITZ) has also been reported by Menadi *et al.* (2009). The work of Kou and Poon (2009) investigated the drying shrinkage performance of concrete incorporating QD as a replacement of NRS material from 0–100 % with 25% increment intervals. Test results show that the presence of QD tends to reduce drying shrinkage of the concrete. This is because coarse QD are coarser than NRS and this reduces the total specific area and consequently, reduce the water demand of that particular mix. From the work of Imamoto and Arai (2008), they found that the degree of drying shrinkage of the Cementitious composites is reduced with the presence of lower free water in the cementitious matrix, lesser volume of the free water to the surrounding exist results in better dimensional stability. However, the work of Bonavetti and Irassar (1994) reported that presence of QD tends to increase the length change of the cementitious composites. They investigated the drying shrinkage properties of the concrete with 0 to 25% of QD replacement levels. As the QD replacement increases, the length changes also increase. The application techniques, hydration mechanisms of SCMs were reviewed. Their impacts on fresh, hardened properties, microstructure and performance of SCC were reviewed too. However, not much has been done on GDP and its impact on SCC. it is imperative to explore this apparent gap in Literature so as to enrich it.

2.8 Rheological Properties of SCC

Rheology is defined as the science of deformation and flow (Barnes et al, 1989). Rheology describes the deformation of a body under the influence of stress. The nature of the deformation depends on the body's material conditions (Goodwin *et al.*, 2000) reviewed by Björn *et al*. (2012). Fresh concrete can be described as a particle in suspension. Rheological properties, apart from being a complex phenomenon, is also time dependent because of cement hydration. From this perspective, fresh concrete can be considered as coarse aggregates suspended in a liquid mortar phase, or sand particles in liquid paste. Thus, the evaluation of the paste and Mortar would give useful information in the optimization of Mix proportions of SCC. The work of (Tattersall, 1991) reviewed by Ben-Aicha (2017) has proposed flow properties of concrete to be represented it can flow by the Bingham model. The characteristics of the Bingham parameters are yield stress and the plastic viscosity. According to the model, fresh concrete must overcome a limiting stress (Yield stress, Y_o) before it can flow. With the flow of the concrete, shear stress increases linearly with increase in strain rate as defined in plastic viscosity, U_o. This implies that one target of the rheological property of SCC is to reduce the yield stress to its barest minimum so that it behaves like a Newtonian fluid with zero yield stress. The other target property is adequate viscosity, to hold all the constituents evenly. to describe the behaviour of fresh concrete, use of Bingham parameters is helpful and also in understanding the influence of various mix constituents (Apeh, 2019). However, there is a general consensus on the limiting values approximated for SCC. Furthermore, approximate Bingham parameters/rheological values depend on materials and equipment used. Therefore, to obtain reliable values of rheological parameters for SCC, it is imperative to specify the type of equipment, testing procedure used and the nature of constituent materials used for the mix. There is still no reliable technique to be applied to determine material properties (particularly plastic viscosity) from concrete rheometers, and there is a necessity to develop a universal tool for parameter determination (Vasilić, 2015)

Beside the Bingham Model that is linear, the Hershel-Bulkley model which is more sophisticated is suggested with the relation between shear stress and the strain rate; being non-linear.

For the performance of SCC, Viscosity obviously plays an important role. This is because, a lower viscosity is required so that SCC can deform and flow easily at a reasonable rate. Even with this, SCC requires a sufficiently high viscosity to avoid SCC segregation. Striking a balance between these conflicting requirements is the art and science of SCC mixing proportioning. To achieve this balance, it is important to have a fundamental understanding of the rheology of fresh concrete. Therefore, to obtain reliable values of rheological parameters for SCC, it is imperative to specify the type of equipment, testing procedure and the nature of constituent materials for the mix. Besides, the Bingham Model that is linear, the Hershel-Bulkley Model which is more sophisticated is suggested with the reaction between shear stress and strain rate,

2.8.1 Effect of constituent materials on Rheology of SCC

SCC is a complex composite with different constituents of various types and contents. Generally, these constituent materials can be classified into three major components:

(i) Fine powder materials.

(ii) Water content and superplasticizer.

(iii) Fine and coarse aggregates.

2.8.1.1 *The fine powder material*

This part of SCC is made up of PC and Fillers (inert or reactive). Powder materials consists of particles of PC or Fillers with sizes less than 125 μm. Since SCC has the ability to flow into every corner of Form-work by its self-weight without the need of vibration and compaction, it is therefore imperative to preserve its stability so as to avoid segregation.

Silica fume is having greater fineness than cement and greater surface area so the consistency increases greatly, when silica fume percentage increases (Singh *et al.*, 2016).

This means that SCC should possess low yield stress to achieve better flow ability and sufficient viscosity to maintain its stability. In order to preserve stability and at the same time achieve flow ability, two approaches are involved. When viscosity modifying agents (VMA) is added to SCC, it increased the water phase viscosity as well as the yield stress, which mainly determines the flow. The other approach is to increase the solid fraction of the paste phase of the concrete which increase viscosity of paste phase.

When SCC is compared with normal concrete of the same strength grade, it requires higher powder content to produce desired fresh properties. It requires up to 450 to 600 kg/m3 (Skarendahl & Petersson, 2000). When high cement content is used in SCC, the consequences is thermal cracking, high heat evolution during cement hydration. This is more pronounced in casting of massive concrete structures. This is a major concern for concreting in the tropics, such as Nigeria. This is why it is essential to use inert fine filler as part of the powder content in SCC production; not only for economic purpose but also for other technical reasons. The work of Poppe and De Schutter (2005) on heat of hydration process in SCC show that it generates heat quantity similar to that of normal concrete value of similar strength range due to the incorporation of inert filler so as to achieve powder content in SCC.

2.8.2 Particle fineness of powder

It is of utmost importance to recognize that both yield stress and viscosity are dependent on particle fineness of filler, also for similar mass, when the particles fineness is increased, the specific surface area is increased. The greater the specific surface area is increased. The greater the specific surface area, the more water is required to envelope the total particle surface and subsequently, there is less movable water in the water- cement system (matrix system), which in turn leads to higher resistance when the system is sheared.

2.8.3 Particle shape and surface texture of powder

Other important parameters that affect rheological properties of SCC are the surface roughness and angularity of fine particles as well as their reactivity in the matrix system. It has been observed that SCC incorporated with flaky and elongated shape granite fine powder required a higher dosage of SP than that of cubical shape limestone Filler in order to have similar yield stress (Ho et al, 2002).

2.8.4 Chemical reactivity of Powder

The use of silica Fume (SF) and SP can reduce paste containing PC with SP (Yahia, 1999). the use of FA and Blast furnace Slag in SCC reduces the dosage of SP needed to obtain similar slump flow compared to concrete made with PC alone. High Slag cement is expected to provide similar lowering of heat evolution. However, the user of these mineral admixtures reduced the early strength of concrete and this must be checked for specific applications (Ho et al, 2002).

2.8.5 Water content and superplasticizer (SP)

When water is added to SCC, it reduces both the yield stress and viscosity. However, too much water can reduce the viscosity to an extent which leads to segregation. Segregation resistance between water and solid particles can be increased by increasing the viscosity of water through the incorporation of viscosity modifying agents (VMA). It should be noted that it is the movable water that controls the segregation. resistance and the flow properties as the water in the mix, which is not absorbed or adsorbed onto the surface of solid particles.

3.0 CHAPTER THREE

3.1 MATERIALS AND METHODS

3.1.1 Materials

The SCC Mixtures used in this study was obtained with the following Materials: Portland cement (PC), CEM 1 42.5 N, Granite dust (GDP) Powder form a local Quarry in Minna, Niger State, Nigeria, natural fine aggregate (FA), crushed coarse aggregate (CA), tap water and high range water reducing admixture/ super plasticizer (SP), The Physical properties, chemical composition of PC, GDP are shown in table 4.1.

3.1.2 Mix proportions used in the study.

Presently, there is no standard method or international code for SCC Mix design. However, ACI 237R-07 and European guidelines foe SCC were used to obtain sixteen SCC Mix proportions used for the study. (Table 3.1). The mixes were calculated with a maximum powder content of 400 kg/m^3. Relevant dosage of SP was applied. PC was replaced with 10, 20, 30 and 40 % with QDP. The constituents were mixed manually to obtain the mixes at a room temperature of about 27 ^{o}C. Seventy cubes was casted for five mixes respectively.

Table 3.1: Mix proportions of SCC

Materials	Mixes				
	PC	5QDP	10QDP	20QDP	30QDP
Cement (KG)	470	446.5	423	376	329
QDP (KG)	0	23.5	47	94	141
Sand (KG)	882.9	882.9	882.9	882.9	882.9
Granite (KG) 10 mm	553	553	553	553	553
Granite (KG) 5 mm	277	277	277	277	277
Water (KG)	168	168	168	168	168
Superplasticizer (KG)	4.23	4.23	4.23	4.23	4.23
W/B	0.4	0.4	0.4	0.4	0.4

3.2 Methods

3.2.1 Slump flow

Plate I: Slump cone: used to measure flowability of the Mixes

The test was used to access the flow- ability of SCC mixes by measuring the diameter of flowing concrete in accordance with EFNARC (2005) and ACI 237R-07. The slump cone apparatus was used. The slump cone was filled with the fresh mix to the brim and flushed. After 60 seconds, the cone was lifted vertically. When the concrete stopped flowing, its diameter was measured twice at right angle to each other and a mean value recorded

d1 + d2/2.

3.2.2 Passing ability

Plate II: L – Box: used to measure passing Ability of the Mixes

The l- Box was used to assess the passing ability of SCC through obstacles like congested reinforcement bars in a structural element. A fresh mix of about six Litres was poured into the vertical portion of the l- Box for sixty seconds. A slit cover between the horizontal and vertical portion is removed and the concrete flows from the vertical portion into the horizontal portion of the l- box until flow stops. The height of concrete, H_1 at the vertical portion and height of concrete at the horizontal portion, H_2 are both measured, the ratio of H_2/H_1 measures the flow-ability of the concrete mix (Equation (2). This was repeated for all the mixes.

$$Pa - H_1/H_2 \qquad \text{Equation (2)}$$

3.2.3 Water demand of PC and QDP

The water demand and deformability coefficient of PC and QDP were assessed using the HangerMann Cone. This was achieved through spread flow tests. For each spread flow test, the volume of water and corresponding volume of Powder content for each mix was also measured. Relative slump, Tp for each mix was calculated. The ratio Vw/Vp versus relative slump, Tp was plotted and equation (3) was used to determine the water demand or water retained ratio and deformability coefficient of the mixes.

$$Vw/Vp = €pTp + ßp \qquad (3.1)$$

Where, Vw = volume of water, Vp = volume of powder, ßp = water demand, Tp is relative slump, €p = deformability coefficient. The water demand for the powder is the maximum water that can be retained by the particle powder. For slump to occur, this retained water ratio must be exceeded. The deformability coefficient which is the slope of equation (3) is a measure of the sensitivity on the water need for a specified flow- ability.

3.2.4 Compressive and tensile strengths

A total of seventy-five (75) cubes were cast for five mixes respectively. Three cubes were cast per mix and per curing duration, demolded after 24 hours and then cured, immersed in water for 3, 7, 14, 28 and 56 days respectively. The cubes were then tested for compressive strength using a universal compressive testing Machine in the laboratory. Cylindrical specimens, 150 mm x 300 mm were cast, cured and tested for splitting tensile strength for the aforementioned mixes and curing durations. An average of three cubes was recorded for each mix and curing duration.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

The properties of QDP and PC were compared to determine to what extent, QDP can be used to replace PC. Its degree of reactivity so as to classify the pozzolanic reactivity. The effect of QDP content on fresh and hardened properties of SCC Mixes were discussed. The fresh properties of SCC in terms of flow ability, passing ability, consistency, water demand and deformability coefficient as well as the hardened properties in terms of compressive strength were discussed. Also, the effect of QDP content on the aforementioned parameters are discussed in the following sections:

4.1 Properties of QDP

Table 4.1 show the physical and chemical properties of PC and QDP used in the study. The specific gravity and fineness modulus of QDP is less than that of PC which means that more quantity of QDP is required to replace PC which helps to mitigate or check the adverse effect of production of QDP in the atmosphere. Also, QDP, being smaller in size can easily fill the voids between PC grains and between PC particles and sand particles thereby increasing the compaction of the mix. Figure 4.1 shows the particle size distribution for QDP and PC obtained from laser distribution analysis used for the study. The graph shows that QDP exhibits similar PSD grading as PC, though QDP has a relatively higher fraction of fines content compared with that of PC. The results further indicate that about 70 % of particles of QDP have a diameter lower than 10 µm.

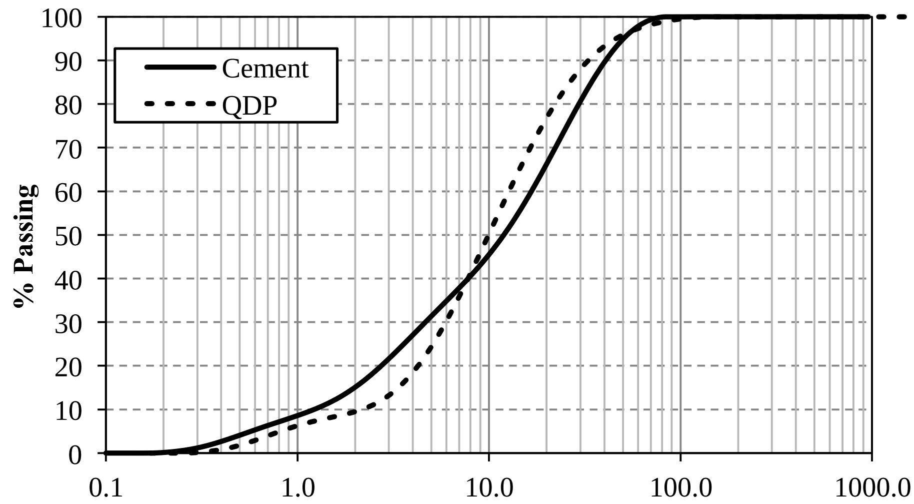

Figure 4.1: Particle size distribution of PC and QDP

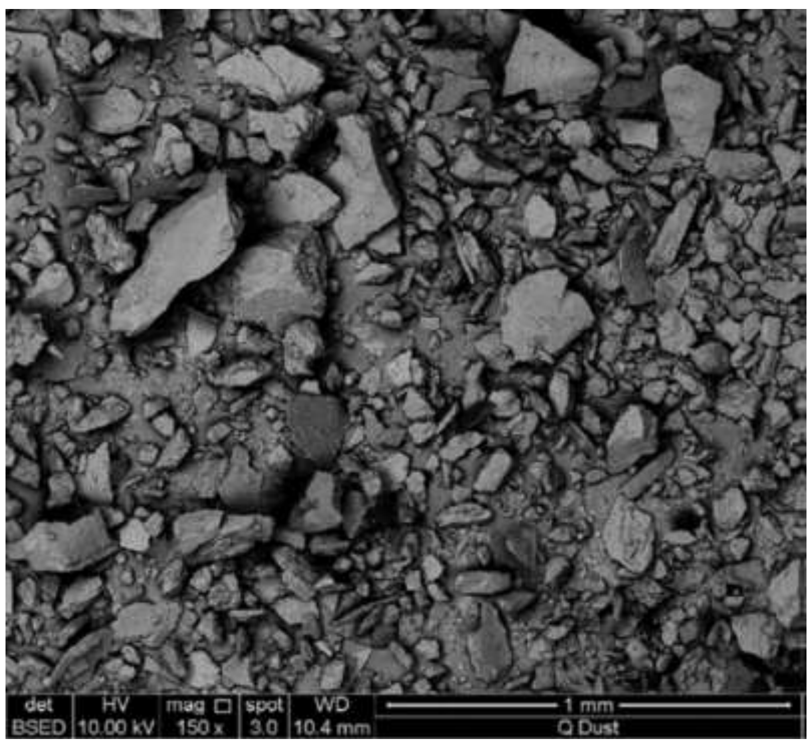

Figure 4.2: Scanning electron microscopy (SEM) of QDP

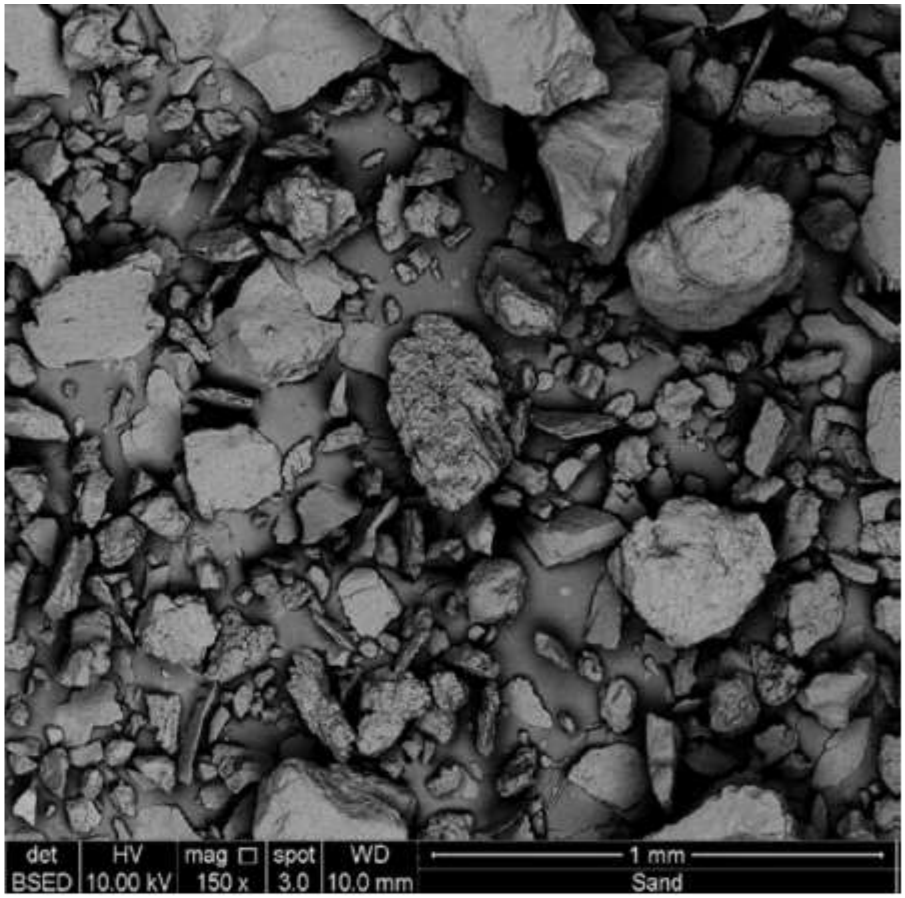

Figure 4.3: Scanning electron microscope of PC

Furthermore, the scanning electron microscope (SEM) test conducted on both QDP and PC samples reveal similarities in morphology (Figures 4.2 and 4.3). Both are granular, irregular and angular in shape, though that of PC is less angular geometrically.

Table 4.1. 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	
TiO_2	0.12	0.18	
P_2O_5	0.06	0.20	
MnO	0.06	0.10	
Loi	1.86	1.57	

From Table 4.1, the chemical properties of QDP and PC are complementary. The SiO_2 content for PC is 20.25 % while for QDP, it is 71.43 %. The CaO content of QDP is 1.55 % while that for PC is 66.84%. This shows that where QDP is deficient, PC will make up and verse –versa. Their combination will enhance the chemical reactivity of SCC. The QDP sample meets the ASTM 618 provisions for Pozzolanic Materials.

4.2 Fresh Properties of SCC

4.2.1 Water consistency and setting times

Table 4.2 shows the water consistency and setting times of the control and blended pastes containing varying contents of QDP. The consistency of the control paste is about 29.20% and slightly reduced to 27.00% when PC is replaced with QDP at 10, 20 30, and 40 percent respectively. The reduction in consistency may be due to reduction in PC content with QDP. QDP though a pozzolanic material has a low reactivity index and only reacts with $Ca\,(OH)_2$ after hydration of PC. The setting times (both initial and final) increase with increase in QDP content when compared with control value. For a 10 -40% QDP replacing PC, an increase in initial setting times of 24, 42, 48 and 50% occurred respectively as compared with control value. The final setting times also increased by 8, 10, 27 and 33% respectively. This is due to the reduction of C_3S and C_3A in cement as a result of reduction in cement content responsible for the acceleration of chemical reaction which in turn determines the setting time of the paste (Apeh, 2019).

Table 4.2: Water Consistency and setting times

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	234	346

4.2.2 Flow-ability

Table 4.3 shows the slump flow test results conducted to evaluation of the SCC filling ability under its own self weight (Plate I). For the control mix, a mean value of 634 mm was obtained. For the mix containing 10% QDP, a 1.20% (648 mm) improvement over control mix value was obtained and for 20% QDP content, a 5.20% (668 mm) improved value was obtained compared with control value. However, for the mix with a 30% QDP content, a mean value of 592 mm was obtained. Acceptable slump values are 600-800 mm (EFNARC, 2005). High specific surface area of the powder waste as affirmed in different literature (Divakar *et al.*, 2012; Keleştemur *et al*., 2018) resulted in its particles acting as a micro filler by packing the transition zone and pores that present in the capillary and hence, causing efficient packing and even distribution of the cement particles by ensuring a flowable concrete with better cohesiveness denser microstructure. This could account for the increase in flowability for 10 and 20% replacement with QDP. However, for the decrease in flowability at 30% QDP replacement of PC, this could be attributed to excess QDP particles in the voids between cement and sand particles resulting in the particles pushing each other apart leading to a reduction in packing density which in turn reduces flowability (Corinaldesi *et al.*, 2010). The work of Uysal and Sumer (2011) affirmed that the volume of the paste in SCC increases owing to the incorporation of pozzolans (mineral admixtures) while led to a decrease in the interface aggregate paste friction and hence, increases the fluidity of concrete. This may be true for QDP, but due to its Morphology and its surface texture that is very rough (Alyamac & Ince, 2020), its water requirement increases consequently decreasing its flowability.

Table 4.3: 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

Plate III: Slump Flow Value of a Test Mix

4.2.3 Passing Ability

The L- Box test was conducted to evaluate the passing ability of SCC through restrictions like reinforcement bars, openings and narrow openings especially in congested reinforced structural elements. The passing ability of SCC was determined by measuring the blocking ratio of the heights of concrete at the vertical and horizontal portions of the l- box, after six litre volume concrete flowed through the L- Box from the vertical portion to the horizontal portion. The results of the tests are shown in Table 4.3. The control mix has a blocking ratio of 0.70 and increase to 0.81 (14 %) over that of control for the mix containing 10 % QDP and for 20 %

QDP Mix, the blocking ratio is 0.86 (19%) and then reduces in value for the rest mixes. The recommended limit (EFNARC, 2005) is 0.80 – 1.0. Up to 20% replacement of PC with QDDP, the mix remains compacted, but at 30 % replacement of PC with QDP, the mixes become denser, leading to less flow-ability, hence less flow from the vertical portion to the horizontal portion of the L- box which implies that the mix might not be able to effectively pass through congested rebars and thus less self-compacted. Generally, it be observed that while the control Mix has a good filling ability (660 mm), its passing ability (0.70) makes it susceptible to pass through congested reinforcement bars and requires dosage of SP to overcome this short coming.

4.2.4 Water demand of QDP and PC mixes

To assess the water demand and deformability of QDP and PC, the Hagerman's cone Slump test was used to measure the relative slump, Tp and the volume ratio, Vw/Vp of the mixes containing the powder. These values were regressed to form equation as thus.

$$Vw\ /Vp = €pTp + ßp \quad (4.1)$$

€p is the deformability coefficient, and ßp is the retained water of the powder, Tp is the relative slump while Vw/Vp is volume of water to powder ratio. Graphs from equation (4.1) was plotted for PC and blended mixes of PC and QDP containing 10, 20 and 30% contents of QDP respectively. From the figures, the ordinate represents the water demand or the retained water ratio, where slump = 0 (Okamura & Ouchi, 2003); that is, the maximum amount of water which can be retained by the particles. When this water unit is exceeded, the mix becomes a concentrated suspension. The slope of the graph is the deformation coefficient which measures the sensitivity of the water need of the mix for a given flow ability. Figures 4.4 to 4.7 show the water demand and the deformability coefficient for PC and PC blended with QDP at 10, 20 and 30% respectively. In figure 4.4, the water demand for PC mix is 0.93 while its deformability coefficient is 0.662. The PC-QDP at 10% has a water demand of (0.83) about 11% less than control value while its coefficient of deformability is (0.0323) about 48% less than control value. For 20% QDP Mix, water demand (0.73) is 21.5% less than control value and its coefficient of deformation (0.018) is 71% less than control value. For PC-QDP mix at 30% has a water demand of 0.80 and a deformation coefficient of 0.058. These results indicates that the water demand and deformability coefficient decrease for a give flow ability.

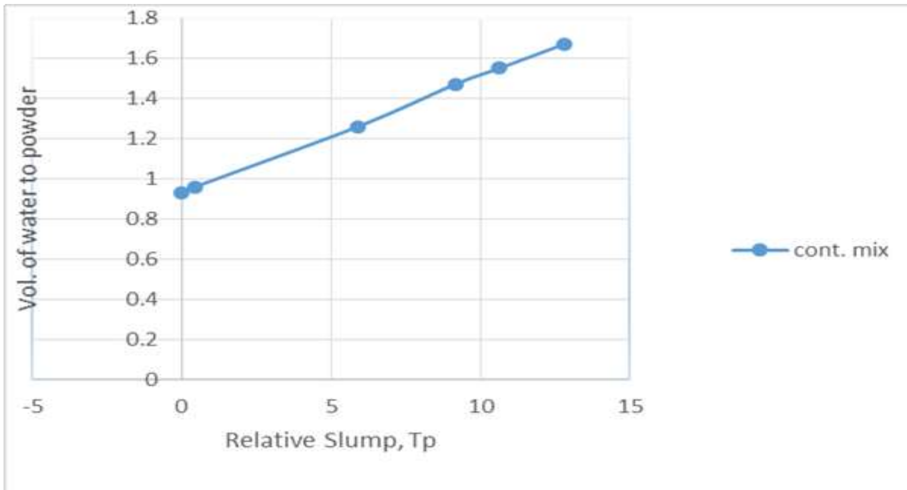

Figure 4.4: Volume of water to powder ratio versus relative slump for PC mix

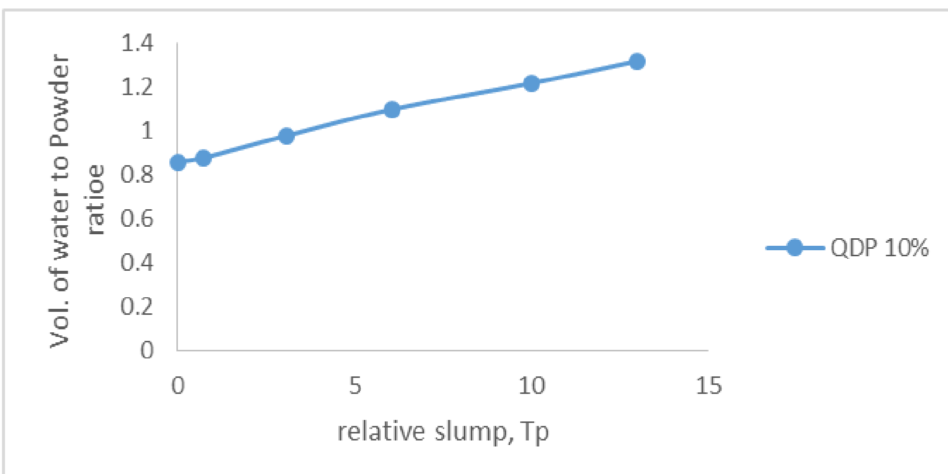

Figure 4.5: Volume of water to powder ratio versus relative slump for 10 % QD mix

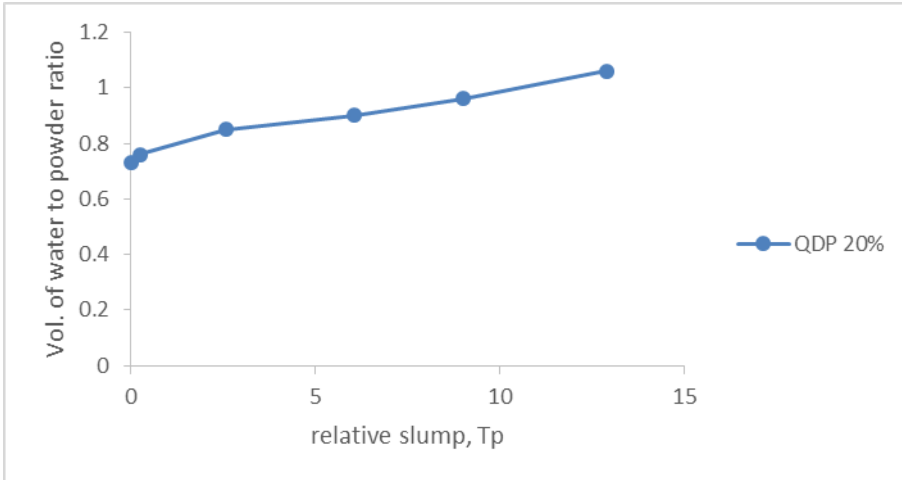

Figure 4.6: Volume of water to powder ratio versus relative slump for 20 % QD mix

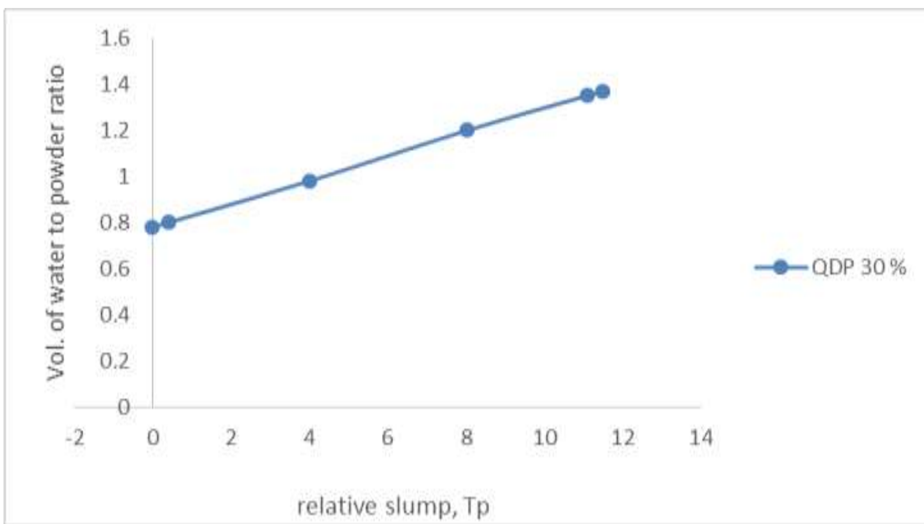

Figure 4.7: Volume of water to powder ratio versus relative slump for 30 % QD mix

The results further show that for mixes QDP at 10 and 20% with corresponding €p of 0.0323 and 0.018 respond with higher change in deformability to a certain change in water dosage compared with control mix and QDP at 30% respectively. In other words, mixes QDP 10% and QDP 20% show strong sensitivity to water changes. This behavior can facilitate the identification of materials having high tendency to bleeding and segregation. These test results also show that QDP content in Mortar or concrete mix influence the water demand and sensitivity on the water need for a specified flow ability.

4.3 Hardened Properties

4.3.1 Compressive strength

The compressive strength, (fc) of each cube was determined in accordance with ACI 318 at ages3, 7, 14, 28 and 56 days respectively. Three cubes per mix were tested and the result of the mean values are as shown in Table 4.4. Test results show that control values are higher than that of blended mixes at early ages. This is due to presence of tri-calcium silicate ions (C_3S) in PC responsible for rapid reactions and the Pozzolan which has to wait for $Ca(OH)_2$ (produced from PC hydration) before reaction to form C-S-H for strength development. Another reason for the reduction in strength for blended mixes at early ages is that the pozzolan particles initially act as depositing points for the $Ca(OH)_2$ produced from PC hydration thereby inhibiting or slowing down reaction. However, at 28 days and more, compressive strength values for mixes containing varying contents of QDP improved, equaled and even surpassed control mix values. This is because, in addition to hydration of PC, pozzolanic reaction between $Ca(OH)_2$, by-product from PC hydration and SiO_2 ions in QDP produce more CSH which accounts for the increase in strength at the later ages. Mix QDP10 has a 6 % increase in strength at 28 days and 9% at 56 days while Mix QDP20 has an improved value of 8 and 23% at 28 and 56 days when compared with control values ; but has an adverse effect due to dilution effects as QDP content increases from 30% - 40% respectively. These results indicate the effect of QDP content in Mortar and concrete.

Table 4.4: 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

4.3.2 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 4.5. The values are apparently of the same trend with that for compressive strength.

Table 4. 5 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

4.3.3 Relationship between flowability and compressive strength

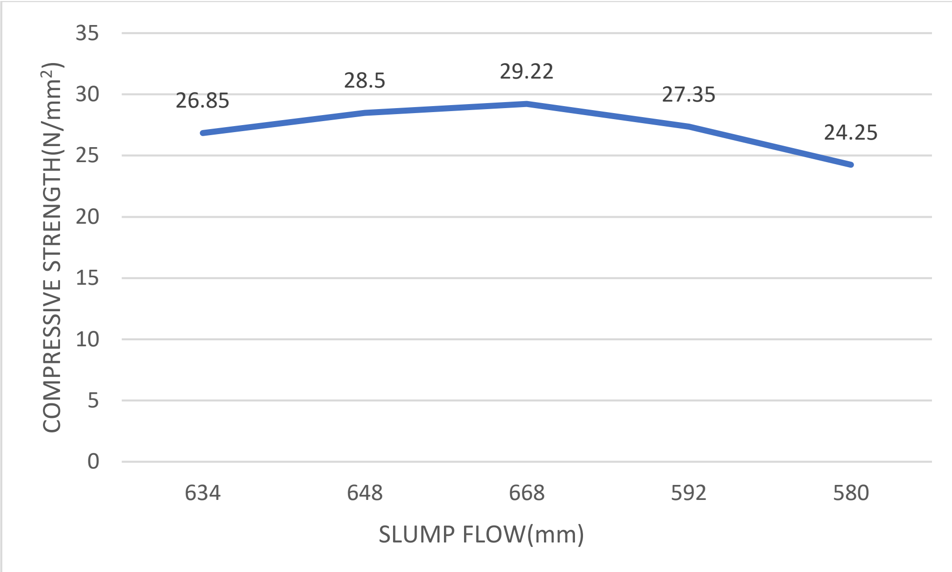

Figure 4.8: Compressive strength at 28 days versus the slump flow

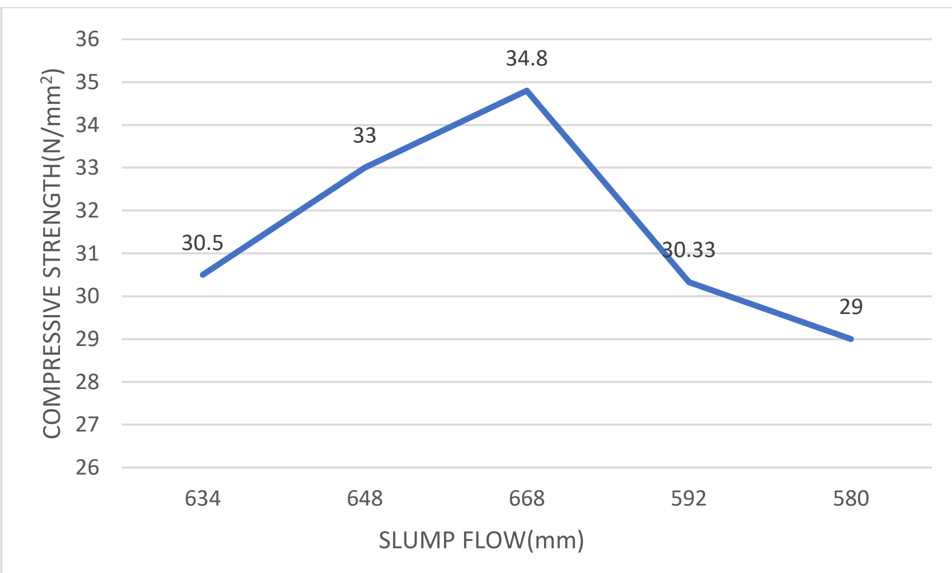

Figure 4.9: Compressive strength at 56 days versus the slump flow

The slump-flow values for the mixes used in the study are related to the compressive strength of their mixes for 28 and 56 days respectively. Figure 4.8 and figure 4.9 show the relationship between the aforementioned variables.

From figure 4.8 compressive strength increased from 26.85N/mm^2 (control) with a slump flow of 634mm to 29.22 N/mm^2 with a slump of 668mm at 20% QD replacement of PC, then, decreased to 24.25 N/mm^2 with a slump of 580mm at 40% QD replacement of PC. Similarly, in fig. 4.9 a similar trend for 56 days curing age

4.4 Summary of Findings

The following are the inferences deduced from the study:

i. The composition of the QDP and PC chemical oxide conforms to class F of ASTM C 618 (2015), minimum requirements for pozzolans and can therefore be used as SCMs with the required physio-chemical 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. The early strength (compressive and splitting tensile) development of the binary SCC discovered to be slow with the values lower in comparism with the reference. However, at 28 days and more, the strength values for mixes containing varying contents of QDP improved, equalled and even surpassed control mix values.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study set out to evaluate the effects of QDP content on the properties of SCC with a view to determining the optimal content of QDP in SCC with no adverse effect on its properties. The inclusion of QD in SCC increase the setting times but does not significantly affect its standard consistency and the water demand and deformability coefficient of SCC containing QD are low and has strong sensitivity to water changes for a given flow ability. Hence, it was affirmed from the results that the 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. This is in agreement with the work of Dadsetan (2017) who obtained an increase in compressive strength in SCC with a 30% GBFS replacement of PC.

5.2 Recommendation

From the summary of findings and conclusions drawn, it is recommended that:

(i) A 20 % QDP content maximum can be used to replace PC in the production of SCC with no adverse effect on its properties.

(ii) SCC should be blended with QDP up to 20% maximum to replace PC, as its mixes has low deformability coefficient and strong sensitivity to water needs for a given flow ability.

5.3 Area for Further Studies

i. The effect of the QDP should be further explored on other mechanical properties such as the flexural strength, shrinkage and creep and modulus of elasticity

ii. The effect should be investigated also on the durability properties of SCC.

5.4 Contribution to Knowledge

A thoroughly explanation and better insight on the flowability and strength development of binary blended SCC among QD and PC with ambient water curing is provided in this research. Therefore, the optimum synthesis of QD and PC binary blended SCC binder is obtained in this research and the outcome of the optimum synthesized can be applied to either mortar or concrete product. Also, the environmental issue associated with Portland cement production is minimized through this research. Maximizing the utilization of QD by proving and promoting the quality and effectiveness of the materials such as QD, LP and GGBS are of great benefit to building structures in terms of flowability and strength as well as eco-friendly technology. Furthermore, SCC contributes to carbon footprint lowering and approximately 9% lower in CO_2-e compare to PC mortar/concrete after taking account of treatment, mining and transportation. Therefore, SCC has great potential in reducing pollution, climate-changing impact and greenhouse effect as caused during the PC production.

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