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Development of Self Compacting Concrete Using Industrial Waste As Mineral And Chemical Additives

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Abstract: *This paper reports a research that investigated the application of industrial waste materials as mineral and chemical additives in the production of Self Compacting Concrete. The flow characteristics of the Self Compacting Concrete investigated were flowability, passing ability and segregation resistance in slump flow test, V-funnel test, L-box test and J-ring test. Pulverized fuel ash, carbide waste and quarry dust were used in concrete production. Compressive strength test was conducted on the hardened concrete after 28 days curing. Concrete mix ratio of 1:2:4 (Cement : Sand : Gravel) was used to produce concrete, using cement partially replaced with 5%, 10%, 15% and 20% pulverized fuel ash, carbide waste and quarry dust. Superplasticizer (Conplast SP 430) used in the mix was kept constant throughout the mixes at 1% of the total volume while water cement ratio of 0.45 was maintained in all mixes. Results of tests shows that the fresh Self Compacting Concrete produced with cement partially replaced with pulverized fuel ash, carbide waste, quarry dust and a combination of pulverized fuel ash and quarry dust satisfied requirements specified for Self Compacting Concrete. Flow ability, passing ability and resistance to segregation increase with pulverized fuel ash, carbide waste and quarry dust content. 28 day compressive strength of self-compacting concrete produced with only cement increased from 31.8* N/mm^2 *to 37.6* N/mm^2*, 35.1* N/mm^2 *and 43.5* N/mm^2 *when cement was partially replaced with 20% pulverized fuel ash and a combination of 15% pulverized fuel ash and 15% quarry dust respectively. However, 28-day compressive strength decreased to 18.6* N/mm^2 *when cement was partially replaced with 20% carbide waste. Optimum 28 day compressive strength value was obtained when cement was replaced with 15% pulverized fuel ash plus 15% quarry dust. Regression analysis was computed on the data obtained from the slump flow test, J ring test, V funnel test and V funnel test using Microsoft Excel software to obtain regression equations for the filling ability, passing ability and segregation resistance.*

Keywords*: Self Compacting Concrete;Flow Characteristics;Industrial Waste; J-ring and V-funnel test.*

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I. Introduction

Self-Compacting Concrete (SCC) differs from the normal concrete as it has the basic capacity to consolidate under its own weight. The increased awareness regarding environmental disturbances and its hazardous effects caused by blasting and crushing procedures of stone, it becomes a delicate and obvious issue for construction industry to develop an alternative remedy as material which can reduce the environmental hazards and enable high-performance strength to the concrete, which would make it durable and efficient for work. A growing trend is being established all over the world to use industrial by-products and domestic wastes as a useful raw material in construction, as it provides an eco-friendly edge to the construction process and especially for concrete[1,2].This evolving construction process paradigm is encapsulated in the **triple R** (i.e. *reduce waste, re-use and recycle construction materials*) that constitute global metrics and are precursor key performance indicators for infrastructure delivery vis-à-vis sustainable construction [3,4]. Self-Compacting Concrete is a rapidly developing research area within the construction industry. In the last four loving paradigm decades, concrete technologies have shown evolutional changes, apart from strength considerations, durability and economy have become important factors in the production of quality concrete. The concept of higher cement content translating to greater strength, and thus, durability has not been proven in true sense for structures when they are exposed to different climatic conditions. Therefore, to make concrete strong and durable at lower cost, supplementary cementitious material such as pulverized fuel ash has been used in practice and is now a proven technology world over. [5]Defined Self Compacting Concrete as a special kind of concrete that does not require any vibration when placing. It is able to flow under its own weight and completely fill the restricted sections as well as the congested reinforcement structures without mechanical vibration. Self-Compacting Concrete has the ability to remain homogeneous during transportation and placement without any significant separation of material constituents. Other advantages of Self Compacting Concrete over conventional concrete include its environmental friendliness, because it doesn't need vibration when placing; it is simple to place in complicated formwork and passes through the highly congested reinforcement which helps to accelerate the construction process. It ensures higher and homogeneous concrete quality across the entire concrete cross section and high early strength. Consistent efforts to improve the performances of concrete have continuously been on the rise in order to meet the society's needs. According to [6], many studies have been made concerning the use of additives and super-plasticizers in concrete. The focus has been on passing the frontier of minimum water content for a good workability of concrete. The outcome of such studies is the development of high performance concretes with superior durability, among which is self-compacting concrete. [7]Asserted that the development of Self Compacting Concrete has recently been one of the most important developments in the building industry. Such innovation offers a rapid rate of concrete placement, with faster construction time and ease of flow around congested reinforcement. The twin characteristics of rapid placement and flowability constitute a major desirability in modern construction, particularly in mega infrastructureprojects that are often characterized with tight and congested reinforcements. Such reinforcements often poseserious constraints to mechanical vibration during concreting. The fluidity and segregation resistance of Self Compacting Concrete also ensures a high level of homogeneity and easy passage to fill tight reinforcements, no concrete voids, and uniform concrete strength, providing the potential for a superior level of finish and durability to the structure. Self-Compacting Concrete is often produced with low water-cement ratio, providing the potential for high early strength, early demoulding and faster use of elements and structures. Other advantages of Self-Compacting concrete according to [8] include; the elimination of vibrating equipment, which improves the environment on and near construction and precast sites where concrete is being placed, thereby, reducing the exposure of workers to noise and vibration. Self-Compacting Concrete is favourably suitable especially in highly reinforced concrete members like bridge decks or abutments, tunnel linings or tubing segments, where it is difficult to vibrate the concrete, or even for normal engineering structures. The improved construction practice and performance, combined with the health and safety benefits, make Self Compacting Concrete a very attractive solution for both precast concrete and civil engineering construction. Based on these facts it can be concluded that Self Compacting Concrete has a bright future. By far the greatest potential in achieving the goals of sustainable development is the capacity of the concrete industry to reuse various industrial by products and absorb large amounts of recycled materials that otherwise would most likely and up in landfills.

Thisresearch investigates the application of industrial waste (pulverized fuel ash, carbide waste and quarry dust) materials as mineral and chemical additives in the production of Self Compacting Concrete. It investigates quantitative model and relationship for given parameters, which can be used to predict self compactability properties of concrete.

II. Literature Review

[9]Defined Self Compacting Concrete as fresh concrete which possesses superior flowability under maintained stability (i.e. no segregation), thus allowing self-compaction - that is, material compaction without addition of energy. [10]Self-Compacting Concrete is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete. Self-Compacting Concrete is a fluid mixture, which is suitable for placing in difficult conditions and also in congested reinforcement, without vibration. In principle, a self – compacting or self – consolidating concrete must: have a fluidity that allows self – compaction without external energy, remain homogeneous in a form during and after the placing process and flow easily through reinforcement. The three properties that characterise concrete as self-compacting are: flowing ability - the ability to completely fill all areas and corners of the formwork into which it is placed; passing ability - the ability to pass through congested reinforcement without separation of the constituents or blocking; resistance to segregation - the ability to retain the coarse components of the mix in suspension in order to maintain a homogeneous material. These properties must all be satisfied for concrete to be designated as Self Compacting Concrete. Other properties of hardened concrete are also applicable to Self-Compacting Concrete in the hardened concrete. The production of Self Compacting Concrete requires chemical admixtures [11]. However, it is not suitable to use different admixtures together, even if they have similar chemical composition [12]. The potential of using limestone and chalk powders could be achieved for production of Self Compacting Concrete [13]. Self-Compacting Concrete mixtures with rice husk ash and

pulverized fuel ash have lower compressive strength values in comparison with Self Compacting Concrete mixture containing Portland cement. While, Self-Compacting Concrete mixtures prepared using pulverized fuel ash gained higher compressive strength than mixture prepared using rice husk ash. This is due to smaller particles of pulverized fuel ash which filled voids within the mixture, thereby decreasing porosity and water demand [14]. Red mud which is residual product of aluminum from bauxite can be used in appropriate quantity to improve the quality and durability of Self Compacting Concrete [15]. The mechanical properties of Self Compacting Concrete follow inverse relations with the glass powder contents for all grades of concrete[16]. [17]found that there is increase in compressive strength, splitting tensile strength of self-compacting concrete by incorporating waste foundry sand as partial replacement of sand up to 15%. Resistance of concrete against sulphate attack and rapid chloride permeability are also improved for concrete mixes. [18], performed a study on making the design mix of self-compacted concrete (SCC) and its performance – economic comparisons with prevailing conventional grade of concrete of M-40 grade. The researcher concluded that, in spite of its short history, self-compacting (or – consolidating) concrete has confirmed itself as a revolutionary step forward in concrete technology. The study also observed that SCC is a relatively new form of concrete which is used for general applications. The main advantage that SCC has over standard concrete is its high compressive strength and self-compacting properties, include high flowability, workability, and passing ability. [1]studied the use and comparative analysis for the performance of concrete with added industrial by products such as Ground Granulated Blast Furnace Slag (GGBFS), Silica fumes (SF) and Marble Powder (MP) in the preparation of SCC. The research investigated prediction of mechanical properties (i.e., compressive, tensile and flexural Strength) of self-compacting concrete by considering four major factors such as type of additive, percentage additive replaced, curing days and temperature using Artificial Neural Networks (ANNs). It was found that the J-ring and V-funnel test results showed that penetration and flow ability for all mixes, especially for MP based mix, are at good levels. Using ANN, we can clearly visualize that Marble powder comes out to achieve successive results. ANN analysis of SF and GGBFS projects the image of predicted behavior by SCC incorporated with these materials as a replacement part to cement and their impact on three major performance indicators of concrete (i.e., compressive, tensile and flexural strength). Predictive strength of ANN provides help in analyzing and predicting SCC strength by multiple inputs and multiple outputs. Importantly, the research work demonstrated a method for helping the environment by introducing eco-friendly SCC and reducing the environmental pollution levels incurred by the cement manufacture and production as it is our main task to develop facilities by using lowest budgets and maximize the reduction of harmful pollutant aspects in Civil Engineering work. The ensuing section discusses the material and methods used in the research.

III. Material And Methods

The technology of Self Compacting Concrete is based on adding or partially replacing Portland cement with amounts of fine material such as fly ash, blast furnace slag, and silica fume without modifying the water content compared to common concrete. This process changes the rheological behaviour of the concrete [19].

A. Materials

The sand and gravel used for this project were obtained from the River Benue deposits. The maximum size of aggregate used was 20mm. Ordinary Portland cement from Benue Cement Company (BCC), Gboko, Nigeria was used as binding agent and water used for mixing was from the Makurdi water works. Coal was sourced from a village around ninth mile in Enugu state and burnt in the laboratory at Scientific Equipment Development Institute (SEDI) Enugu to obtain the pulverized fuel ash. The quarry dust used was obtained from PW construction company quarry site at Mkar community in Gboko local government area Benue State. The carbide waste used for this research was collected in the dry form from an open-dump site at the mechanic village in Makurdi where welders and panel beaters utilize carbide for oxy-acetylene gas welding. The carbide waste was sun-dried for 5 days, grinded and then sieved to cement fineness for use as a partial replacement of cement in the concrete production.

1. Ordinary Portland Cement

Portland cement is foremost among the construction materials used in civil engineering projects around the world. The reasons for it's often use are varied, but among the more important are the economic and widespread availability of its constituents. Other reasons include its versatility and adaptability, as evidenced by the many types of construction in which it is used, and the minimal maintenance requirements during service [19]. Plate 1 shows the cement used in the research.

Plate 1: Cement (Source: laboratory sample)

2.Aggregates

Generally, aggregates occupy 70% to 80% of the volume of concrete and have an important influence on its properties. They are granular materials, derived from natural rock (crushed stone, or natural gravels) and sands, although synthetic materials such as slags and expanded clay or shale are used to some extent, mostly in lightweight concretes [19]. The particle size distribution of aggregates used here in the experiment are as shown in tables 2 and 3. Plates 2 and 3 show samples of the aggregate.

Table 2. Particle Size Distribution for fine aggregates (sand) (source: analysis of laboratory results)

Sieve size (mm)	2.36	1.70	1.18	0.85	0.6	0.425	0.30	0.15	pan
Weight retained (g)	37	28	55	75	167	258	197	61	122
Weight passing (g)	963	935	880	805	638	380	183	122	-
Percentage passing (%)	96.3	93.5	88.0	80.5	63.8	38.0	18.3	12.2	-
Percentage retained (%)	3.7	6.5	12.0	19.5	36.2	62.0	81.7	87.8	-

Table. 3. Particle Size Distribution for coarse aggregates (gravel)

Sieve size (mm)	20.00	14.00	10.00	6.30	5.00	pan
Weight retained (g)	73.4	984	526.6	193.4	132.6	90
Weight passing (g)	1926.6	942.6	416.0	222.6	90.00	0
Percentage passing (%)	96.3	47.1	20.8	11.1	4.5	-
Percentage retained (%)	3.7	52.9	79.2	88.9	95.5	-

Plate 2: Sharp Sand (Source: laboratory sample)

Plate 3: Gravel (Source: laboratory sample)

3. Pulverised Fuel Ash

Pulverized Fuel Ash (PFA) also known as Fly Ash is the finely divided residue that results from the combustion of pulverized coal and is transported from the combustion chamber by exhaust gases. It is produced by coal fired electric and steam generating plants [21]. Typically, coal is pulverized and blown with air into the boiler's combustion chamber where it immediately ignites, generating heat and producing a molten mineral residue. Boiler tubes extract heat from the boiler, cooling the flue gas and causing the molten mineral residue to harden and form ash. Coarse ash particles, referred to as bottom ash or slag, fall to the bottom of the combustion chamber, while the lighter fine ash particles, termed PFA, remain suspended in the flue gas. Prior to exhausting the flue gas, Pulverized Fuel Ash is removed by particulate emission control devices, such as electrostatic precipitators or filter fabric bag houses. [22]. Plate 4 shows the PFA used in the research.

Plate 4: Pulverised Fuel Ash (Source: laboratory sample)

4. Calcium Carbide Waste

Calcium carbide residue is a by-product from an acetylene gas (C_2H_2) production process. This gas is used as fuel for lighting, welding, metal cutting, and space heaters. The whitish color remnant of oxy-acetylene gas is commonly used in the welding industry to join pieces of metal by road side panel beaters. The calcium carbide residue is produced by a simple process, which is obtained from the reaction between calcium carbide (CaC_2) and water (H_2O) presented as equation:

CaC_2 + 2H_2O → C_2H_2 + Ca$(OH)_2$ - - - - - (i)

The calcium carbide waste used in the research is shown in plate 5.

Plate 5: Carbide Waste(Source: laboratory sample)

5. Quarry Dust

Basalt fines, often called quarry or rock dust are by products of the production of concrete aggregates by crushing of rocks. The addition of quarry dust to normal concrete mixes is limited because of its high fineness. The addition of quarry dust to fresh concrete increases the water demand and consequently the cement content for given workability and strength requirement. However potential benefits of using quarry dust include cost, but the material cost varies depending on the source. [22]. Plate 6 shows the quarry dust used in the research.

Plate 6: Quarry Dust(Source: laboratory sample)

6. Superplasticizers

Superplasticizers (high-range water-reducers) are low molecular-weight, water-soluble polymers designed to achieve high amounts of water reduction (12-30%) in concrete mixtures in order to attain a desired slump [24, 25]. These admixtures are used frequently to produce high-strength concrete (> 50 MPa), since workable mixes with water-cement ratios well below 0.40 are possible. They also can be used without water reduction to produce concretes with very high slumps, in the range of 150 to 250 mm (6 to 10 inches). At these high slumps, concrete flows like a liquid and can fill forms efficiently, requiring very little vibration. These highly workable mixtures are called flowing concretes and require slumps to be in excess of 190 mm (8.5 inches) [2].

B. Methods

Concrete mix was designed with a ratio of 1:2:4 (Cement : Sand : Gravel) with different proportions of pulverized fuel ash, carbide waste and quarry dust at 5%, 10%, 15% and 20% to replace cement. Superplasticizer (Conplast SP 430) used in the mix was kept constant throughout the mixes at 1% of the total volume while water cement ratio of 0.45 was maintained in all mixes. The concrete used was produced in the laboratory using an electric mixing machine.

1. Auxiliary Tests

The following auxiliary tests tests were performed in accordance with the relevant sections of British and American Standard Specification as stated; Particle size distribution (BS 812-103.1:1985), Specific gravity test (BS 882:1992), Bulk density (BS 812-2:1995), Standard consistency of cement paste (ASTM C-187), Setting times of cement (ASTM C-187), Chemical composition of cementitious materials.

2. WorkabilityTests

The discussed **workability Tests** tests were performed in accordance with the relevant sections of British and American Standard Specification as stated.

Slump flow test (BS EN 12350-8:2010)

The slump flow is used to evaluate the ability of the Self Compacting Concrete to flow under its own weight in an unconfined condition. It is the most commonly used test, and gives a good assessment of filling ability. The test measures two parameters: flow spread and flow time T_{50} (optional).It gives no indication of the ability of the concrete to pass between reinforcement without blocking, but may give some indication of resistance to segregation.

Plate 7: Slump Cone (Source: prefabricated laboratory equipment)

J- Ring Test

J-ring test aims at investigating both the filling ability and the passing ability of Self Compacting Concrete. It can also be used to investigate the resistance of Self Compacting Concrete to segregation by comparing test results from two different portions of sample. The J-ring test measures three parameters: flow spread, flow time T_{50} (optional) and blocking step. The J-ring flow spread indicates the restricted deformability of Self Compacting Concrete due to blocking effect of reinforcement bars and the flow time T_{50} indicates the rate of deformation within a defined flow distance. The blocking step quantifies the effect of blocking. All the equipment used in the slump flow test described above is required in this test including a J-ring of standard dimension. The J-ring flow spread S_J is the average of diameters *d*max and *d*perp, expressed in mm to the nearest 5 mm.

$$S_J = \frac{(d_{max} + d_{perp})}{2} \qquad \text{(ii)}$$

Plate 9: J Ring (Source: prefabricated laboratory

Plate 10: J Ring Test (Source: prefabricated laboratory equipment)

V funnel test (BS EN 12350-9:2010)

The V-funnel flow time is the period a defined volume of Self Compacting Concrete needs to pass a narrow opening and gives an indication of the filling ability of Self Compacting Concrete provided that blocking and/or segregation do not take place; the flow time of the V-funnel test is to some degree related to the plastic viscosity. This test method is used to measure the flowability and dynamic stability of the Self Compacting Concrete mixture. Though the test is designed to measure flowability, the result is affected by concrete properties other than flow. The inverted cone shape will cause any liability of the concrete to block to be reflected in the result – if, for example there is too much coarse aggregate. High flow time can also be associated with low deformability due to a high paste viscosity, and with high inter-particle friction. The test was carried out using a V-funnel of standard dimensions, a stopwatch, a bucket with a capacity of 12 to 14 litres.

Plate 11: V Funnel (Source: prefabricatedlaboratory equipment)

L box test (BS EN 12350-10:2010)

The test is aimed at investigating the passing ability of Self Compacting Concrete, so that lack of stability (segregation) can be detected visually. This test is used to evaluate the flow properties and passing ability of Self Compacting Concrete when confined by formwork and forced to flow around reinforcing steel. It measures the reached height of fresh Self Compacting Concrete after passing through the specified gaps of steel bars and flowing within a defined flow distance. With this reached height, the passing or blocking behaviour of Self Compacting Concrete can be estimated. The equipment used in the test includes L-box of standard dimensions, trowel and suitable bucket for taking concrete.

Plate 12: L Box (Source: prefabricated laboratory equipment)

Plate 13: L Box Test (Source: prefabricated laboratory equipment)

3. Compressive strength tests (BS 1881-116:1983)

Testing concrete cubes for compressive strength is widely accepted as the most convenient means of quality control of the concrete produced whether on site or at a ready mixed concrete plant. The crushing strength of concrete is influenced by a number of factors in addition to the water/cement ratio and degree of compaction. Compressive strength determination is the mean strength of blocks. Tests were performed in accordance with the relevant sections of British Standard Specification as stated.

IV. Presentation And Discussion Of Results

A. Presentation of Results

The result of the test carried out on the constituent materials, the self-compacting properties of the fresh concrete and the compressive strength of the harden concrete are presented here.

1. Particle Size Distribution

The result of sieve test performed on Makurdi river sand used as fine aggregate and gravel used as coarse aggregate is presented as figure 4.1 and 4.2 respectively.

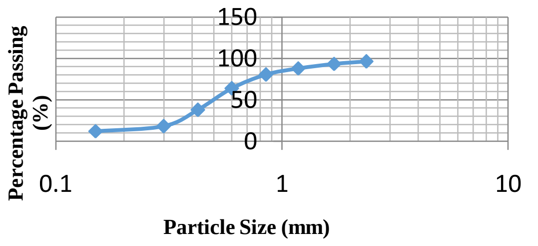

Figure 4.1: Particle Size Distribution Curve of Makurdi River Sand used as fine aggregate(source: analysis of laboratory results)

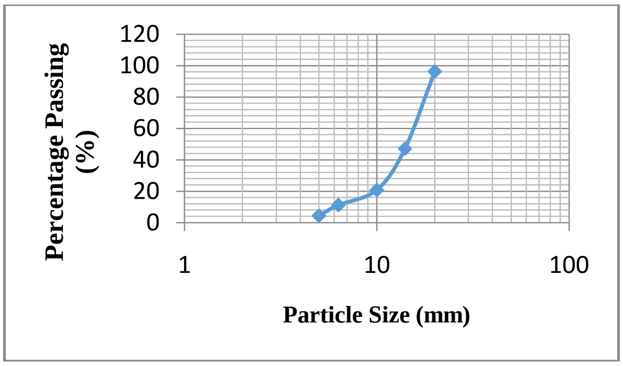

Figure 4.2: Particle Size Distribution Curve of coarse aggregate(source: analysis of laboratory results)

2. Specific Gravity Test

Specific gravity and density values of the different constituent materials used in the production of Self Compacting Concrete as obtained from Specific gravity test is presented in Table 4.1

Table 4.1: Specific Gravities of Constituent Materials (source: analysis of laboratory results)

Material	Specific gravity	Density kg/m^3
Water	1.00	1000
Cement	3.15	3150
Sand	2.65	2650
Gravel	2.82	2820
Pulverised Coal Ash	2.18	2180
Carbide waste	1.92	1920
Quarry Dust	2.55	2550

3. Bulk Density Test

The bulk density values of the performed on the Makurdi river sand and gravel used as fine and coarse aggregates respectively is presented Table 4.2.

Table 4.2: Bulk Density for Sand and Gravel (source: analysis of laboratory results)

Material	Bulk Density (kg/m^3)
Sand	1334
Gravel	1690

4. Chemical Composition of Materials

The chemical composition of cement, pulverized fuel ash, carbide waste and quarry dust are presented in Table 4.3.

Table 4.3: Chemical Composition of Materials(source: analysis of laboratory results)

	SiO_2	Al_2O_3	Fe_2O_3	CaO	P_2O_5	TiO_2	MgO	NaO	K_2O	MnO_2	LOI
Cement	20.51	5.89	4.36	64.74	-	-	1.58	0.52	0.67	0.13	1.70
Pulverised Fuel Ash	50.30	21.36	9.88	2.78	5.14	1.21	1.56	1.40	2.16	0.90	3.70
Carbide Waste	3.42	7.38	0.36	57.34	-	-	1.18	-	0.12	0	30.20
Quarry Dust	46.50	23.72	7.76	6.85	-	2.22	4.56	-	5.16	-	1.48

5. Summary of Flow Tests Result

Table 4.4: Flow Tests Result Summary (source: analysis of laboratory results)

	Slump Flow		J Ring		V Funnel	L Box
	t_{50} (sec)	d (mm)	S_J (mm)	h (mm)	t_v (sec)	H_1/H_2
100% Cement	8	660	510	10	11.8	0.81
5% Pulverised Fuel Ash	5	675	550	8.8	11.2	0.86
10% Pulverised Fuel Ash	4.5	680	572	8.4	10.8	0.89
15% Pulverised Fuel Ash	4	698	580	7.2	10.5	0.93
20% Pulverised Fuel Ash	3.6	720	595	6.7	9.8	0.96
5% Carbide Waste	6.5	665	548	9.0	11.6	0.84
10% Carbide Waste	6.2	672	562	8.4	10.9	0.90
15% Carbide Waste	6.4	680	558	8.6	11.2	0.88
20% Carbide Waste	6.9	687	545	9.2	11.3	0.82
5% Quarry Dust	6.2	670	545	9.7	11.4	0.85
10% Quarry Dust	5.4	684	559	8.9	11.0	0.88

15% Quarry Dust	4.8	698	572	8.0	10.7	0.91
20% Quarry Dust	4.1	710	586	7.6	10.1	0.94
5% Pulverised Fuel Ash 5% Quarry Dust	3.8	690	584	7.0	10.5	0.91
10% Pulverised Fuel Ash 10% Quarry Dust	3.4	735	608	6.2	9.2	0.94
15% Pulverised Fuel Ash 15% Quarry Dust	3.0	760	626	4.0	6.4	0.98
20% Pulverised Fuel Ash 20% Quarry Dust	3.2	748	614	5.2	7.8	0.96

6. Compressive Strength Test

The result of compressive strength of concrete at 28 days is presented as figure 4.3.

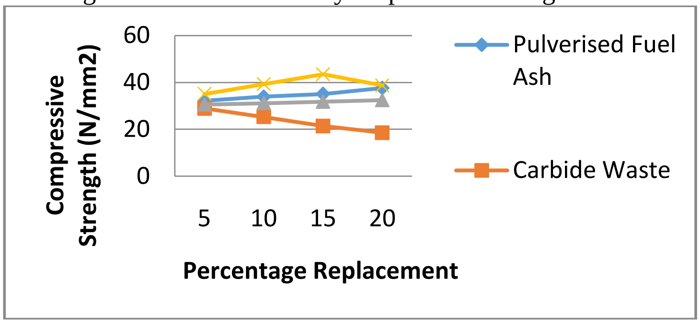

Figure 4.3: Variation of Compressive Strength Test with Percentage Replacement of Pulverized Fuel Ash, Carbide Waste and Quarry Dust(source: analysis of laboratory results)

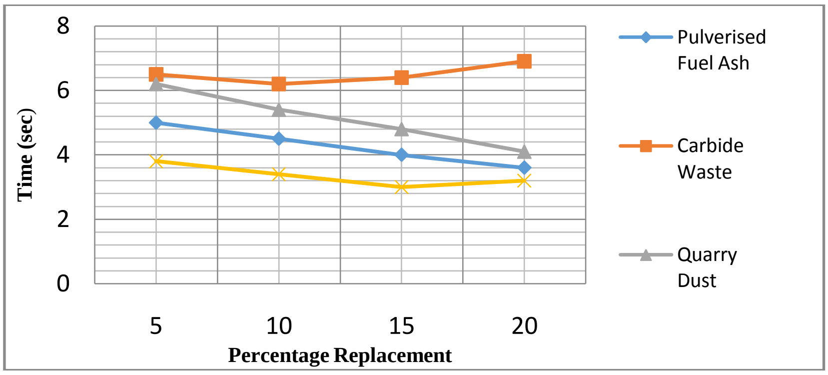

Figure 4.4: Variation of Slump Test Flow Time with Percentage Replacement of Pulverized Fuel Ash, Carbide Waste and Quarry Dust(source: analysis of laboratory results)

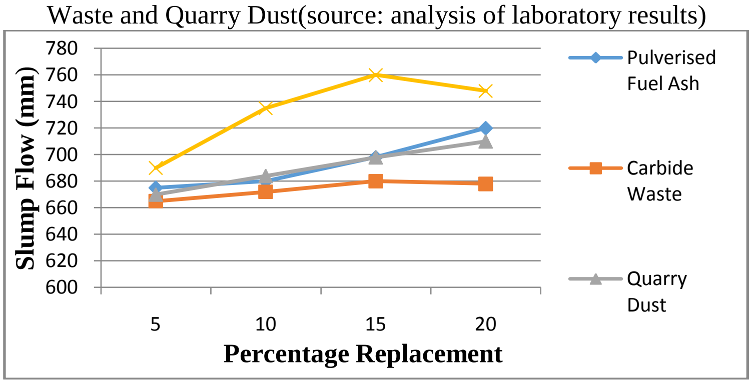

Figure 4.5: Variation of Slump Test Flow with Percentage Replacement of Pulverized Fuel Ash, Carbide Waste and Quarry Dust(source: analysis of laboratory results)

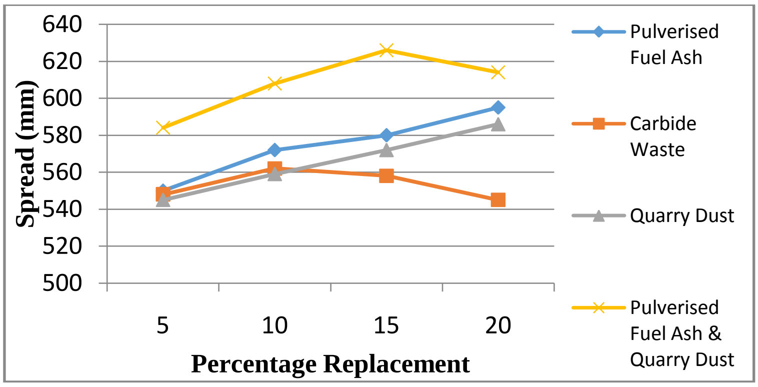

Figure 4.6: Variation of J Ring Test Flow Spread with Percentage Replacement of Pulverized Fuel Ash, Carbide Waste and Quarry Dust(source: analysis of laboratory results)

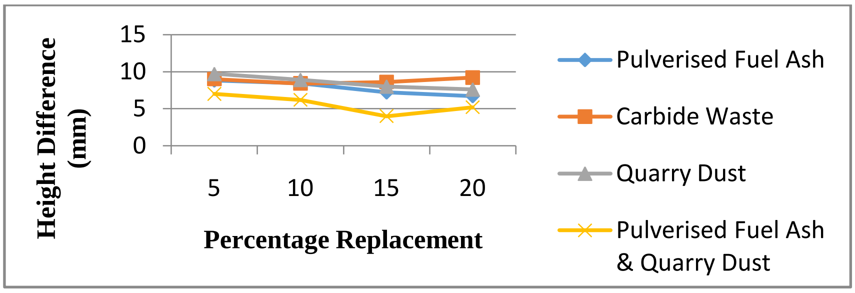

Figure 4.7: Variation of J Ring Test Flow Height Difference with Percentage Replacement of Pulverized Fuel Ash, Carbide Waste and Quarry Dust(source: analysis of laboratory results)

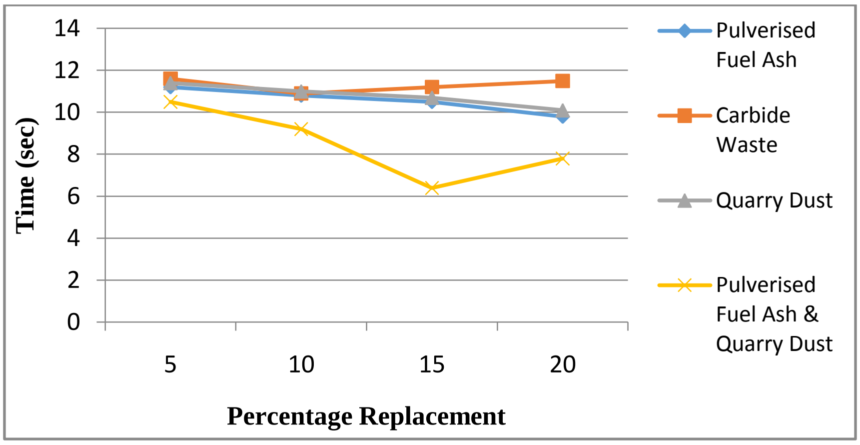

Figure 4.8: Variation of V Funnel Test Flow Time with Percentage Replacement of Pulverized Fuel Ash, Carbide Waste and Quarry Dust(source: analysis of laboratory results)

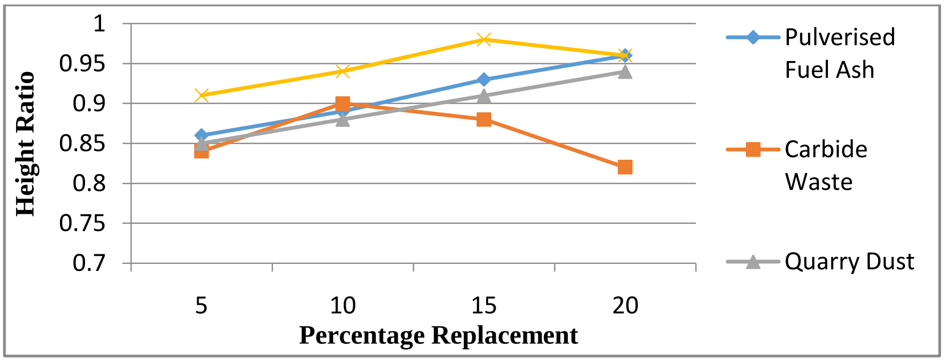

Figure 4.9: Variation of L Box Test Height Ratio with Percentage Replacement of Pulverized Fuel Ash, Carbide Waste and Quarry Dust(source: analysis of laboratory results)

B. Regression Analysis

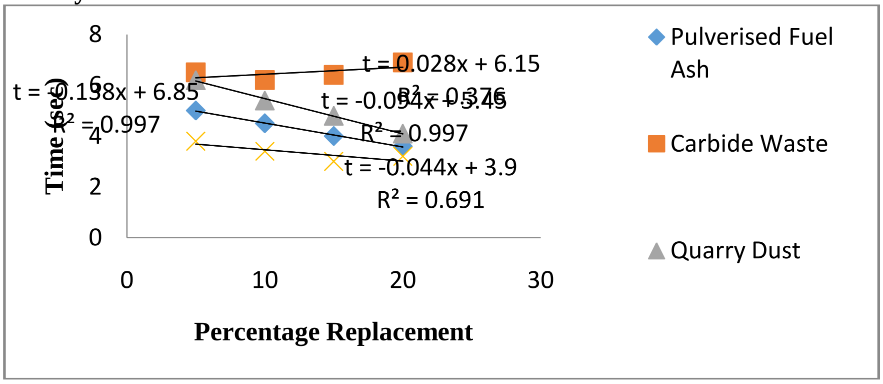

Figure 4.9: Correlation Chart for Slump flow time against Percentage Replacement (source: analysis of laboratory results)

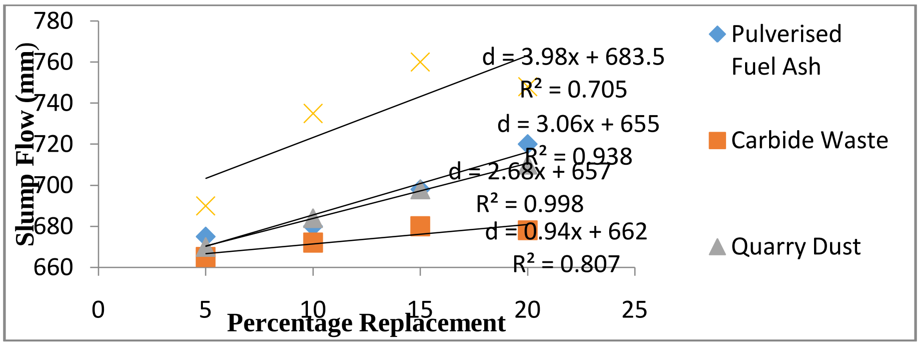

Figure 4.10: Correlation Chart for Slump flow against Percentage Replacement (source: analysis of laboratory results)

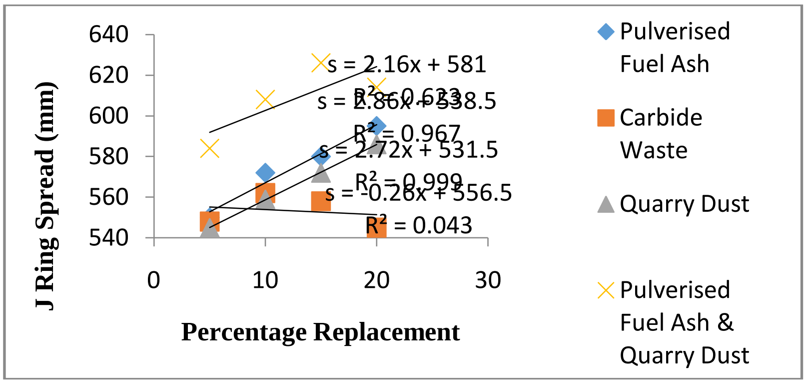

Figure 4.11: Correlation Chart for J Ring Spread against Percentage Replacement s_j (source: analysis of laboratory results)

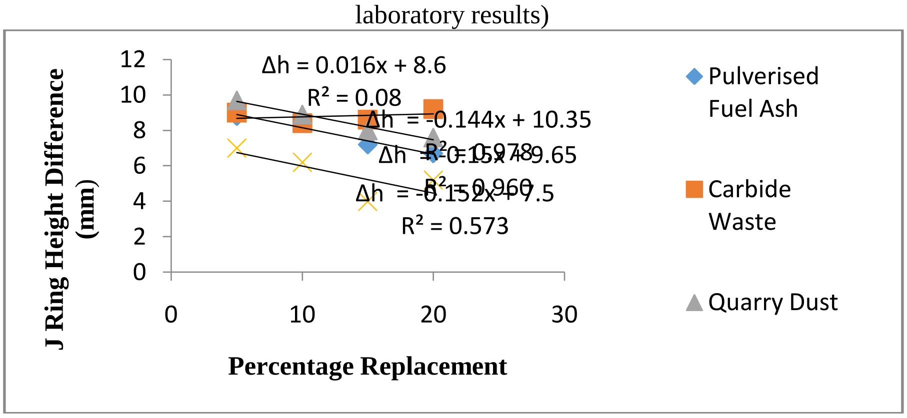

Figure 4.12: Correlation Chart for J Ring Height Difference against Percentage Replacement (source: analysis of laboratory results)

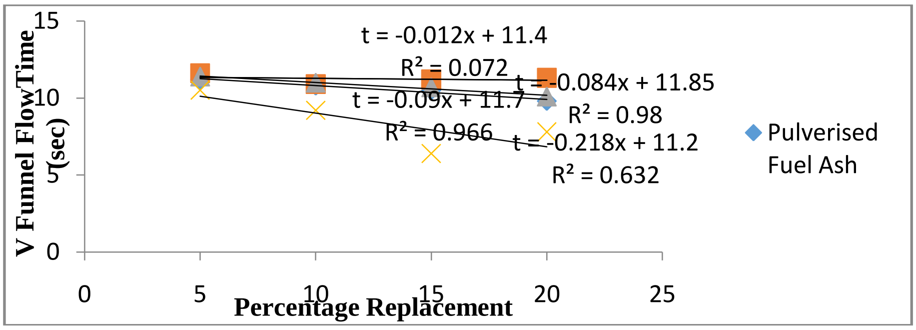

Figure 4.13: Correlation Chart for V Funnel flow Time against Percentage Replacement (source: analysis of laboratory results)

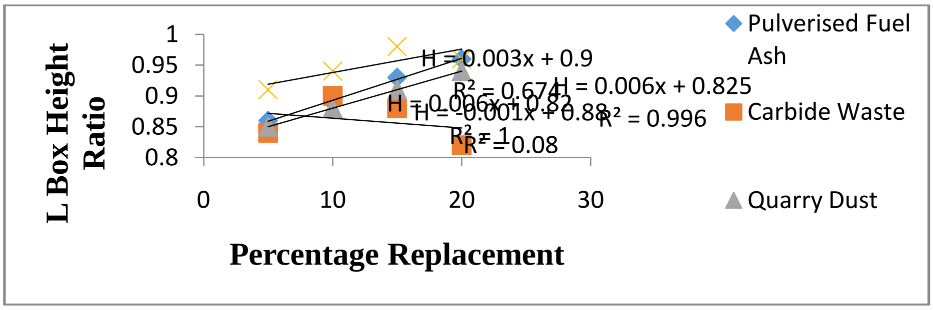

Figure 4.14: Correlation Chart for L Box Height Ratio against Percentage Replacement (source: analysis of laboratory results)

V. Discussion Of Results

From the analysis carried out on the constituent materials, the specific gravity test result of sand and gravel were determined to be 2.65 and 2.85 while the values of cement, pulverized fuel ash, carbide waste and quarry dust were found to be 3.15, 2.18, 1.92 and 2.55 respectively, as presented in Table 4.1. The sand and gravel used had a bulk density of 1334 kg/m^2 and 1690 kg/m^2 as shown in Table 4.2.

The chemical percentage composition of cement and the cementitious materials used in the study is presented in Table 4.3. The pulverized fuel ash is a class F fly ash containing 81.54 % of $SiO_2 + Al_2O_3 + Fe_2O_3$ and LOI of 3.7%. It satisfies the requirement of ASTM C618. $SiO_2 + Al_2O_3 + Fe_2O_3$ and LOI for quarry dust were found to be 77.98% and 1.48 respectively. SiO_2 was found to be the major constituent in the pulverized fuel ash and quarry dust with the values of 50.3% for pulverized fuel ash and 46.5% for quarry dust. The quarry dust therefore meets the ASTM C618 requirement as a natural pozzolana. CaO content in the pulverized fuel ash and quarry dust were determined to be 2.78% and 6.85% respectively, while in carbide waste CaO was found to be the major component with a value of 57.34%.

The workability tests conducted on the fresh concrete and the results are summarized in Table 4.4 and presented through Figures 4.4 to 4.9. It was observed that concrete produced with cement partially replaced with pulverized fuel ash, carbide waste, quarry dust and a combination of pulverized fuel ash and quarry dust at replacement level of 5%, 10%, 15% and 20% conformed to EFNARC recommendations for self-compacting concrete. Self-compacting concrete produced with cement partially replaced with pulverized fuel ash, carbide waste and quarry dust, resulted in increase in the concrete flow ability, passing ability and resistance to segregation. For slump flow test it was observed that the higher the value of slump diameter, the greater its ability to fill formwork under its own weight. In figure 4.5, the slump flow value in increased from 675 to 720 mm, 665 to 687 mm, 670 to 710 mm and 690 to 760mm when cement was replaced with pulverized fuel ash, carbide waste, quarry dust and a combination of pulverized fuel ash and quarry dust respectively. The slump time t_{50} is a secondary indication of flow. A lower time indicates greater flowability. In figure 4.4, the t_{50} value decreased from 5 to 3.6 sec, 6.5 to 6.2 sec, 6.2 to 4.1 sec and 3.8 to 3.0 sec when cement was replaced with pulverized fuel ash, carbide waste, quarry dust and a combination of pulverized fuel ash and quarry dust respectively. For J ring test the measured flow is certainly affected by the degree to which the concrete movement is blocked by the reinforcing bars. The greater the difference in height between the concrete inside and outside the ring, the lessthe passing ability of the concrete. It was observed that the value for the difference in height of the concrete decreased from 8.8 to 6.7 mm, 9.0 to 8.4 mm, 9.7 to 7.6 mm and 7.0 to 4.0 mm when cement was replaced with pulverized fuel ash, carbide waste, quarry dust and a combination of pulverized fuel ash and quarry dust respectively (see figure 4.7). Figure 4.6 shows that the spread flow increased from 550 to

595 mm, 548 to 562 mm, 545 to 586 mm and 584 to 626 mm when cement was replaced with pulverized fuel ash, carbide waste, quarry dust and a combination of pulverized fuel ash and quarry dust respectively.

The V funnel test this test measures the ease of flow of the concrete. In this test, shorter flow times indicate greater flowability. It is observed in figure 4.8 that the time decreased from 11.2 to 9.8 sec, 11.6 to 10.9 sec, 11.4 to 10.1 sec and 10.5 to 6.4 sec when cement was replaced with pulverized fuel ash, carbide waste, quarry dust and a combination of pulverized fuel ash and quarry dust respectively.

In the case of L box test, concrete is expected to flow freely, at rest it will be horizontal, thusH_2/H_1 = 1. Therefore the nearer the test value (blocking ratio), is to unity, the better the flow of the concrete. In figure 4.9, the blocking ratio value increased from 0.86 to 0.96, 0.84 to 0.92, 0.85 to 0.94 and 0.91 to 0.98 when cement was replaced with pulverized fuel ash, carbide waste, quarry dust and a combination of pulverized fuel ash and quarry dust respectively. It was generally observed that the self-compacting properties improved significantly with increase in the percentage replacement of cement with pulverized fuel ash and quarry dust. However, for carbide waste a decrease in the workability properties was observed when cement was replaced at 15% and 20%, though the values were still within the permissible limits recommended by EFNARC. Optimum values were obtained when pulverized fuel ash and quarry dust were combined to replace cement at 15% replacement with pulverized fuel ash and 15% replacement with quarry dust.

Results from the experimental investigation on Self Compacting Concrete produced with cement partially replaced with pulverized fuel ash, carbide waste and quarry dust shows that all the concrete mix satisfied the required performance for self-compacting concrete in the fresh state. It was verified using the slump flow test, J ring test, V funnel test and L box test that the concrete achieved consistency and self compactibility under its own weight, without any external vibration or compaction.

From the results of this study it can be concluded that the use of mineral and chemical admixtures generally improves the performance of Self Compacting Concrete in the fresh state. This further prevents the use of Viscosity Modifying Admixtures. However, a super plasticizer was introduced that is referred to as new generation super plasticizers, and which reduces the cost of Viscosity Modifying Admixtures. At water/cement ratio of 0.45, passing ability, filling ability and segregation resistance were well within the limits for 5%, 10%, 15% and 20% cement replacement with pulverized fuel ash, carbide waste and quarry dust. Optimum performance of the self-compacting properties was obtained when cement was partially replaced with a combination of pulverized fuel ash and quarry dust. The result of the compressive strength test of the concrete showed that the incorporation of the mineral and chemical additives did not negatively influence the strength of the concrete. 28 day compressive strength of self-compacting concrete produced with only cement increased from 31.8 N/mm^2 to 37.6 N/mm^2, and concrete produced with cement, pulverized fuel ash and quarry dust increased from 35.1 N/mm^2 and 43.5 N/mm^2, when cement was partially replaced with 20% pulverized fuel ash and a combination of 15% pulverized fuel ash and 15% quarry dust respectively. However, 28-day compressive strength decreased to 18.6 N/mm^2 when cement was partially replaced with 20% carbide waste. Optimum 28 day compressive strength value was obtained when cement was replaced with 15% pulverized fuel ash plus 15% quarry dust. Finally, regression equations were developed and can be used to predict the parameters for filling ability, passing ability and segregation resistance in slump flow test, J ring test, V funnel test and V funnel test. Figures 4.9 - 4.14 show the regression equations and the associated coefficients of correlation (R).

VI. Conclusion

The research reported in this paper shows that pulverized fuel ash, carbide waste and quarry dust are suitable materials for partial replacement of cement in the production of Self Compacting Concrete. The emergence of self-compacting concrete represents a significant advance in innovative construction to address problems associated with compact reinforced structures, which require concrete that flows through very tiny spaces and also compacts under its own weight. This further reduces the challenges associated with mechanical vibration in such cases. More importantly, production of self-compacting concrete using materials that are normally classified as industrial wastes from other manufacturing/production processes (e.g. quarry dust from quarries, carbides from welding operations, pulverized fuel ash from coal production etc.) represent a step change and contribution to sustainable construction practice vis-à-vis sustainable infrastructure delivery.This research contributes to knowledge and better understanding of evolving construction process paradigm that is encapsulated in the **triple R** (i.e. *reduce waste, re-use and recycle construction materials*). The triple R constitute global metrics and precursor key performance indicators for infrastructure delivery vis-à-vis sustainable construction. However, there is a dire need for further investigations on the life cycle assessment of the materials used to replace cement as reported in this research. This will facilitate better understanding of the behavior of these materials on the concrete and the environment beyond the 28 days period considered in the study.

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