Short-Term Study on Mechanical and Fresh properties of Micro-silica based Self Consolidating Concrete in Nigeria

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Abstract

The ever increasing environmental challenge arising from improper waste management has been a great concern to researchers and the society. One of such industrial waste is micro silica; a bye-product of the Carbothermic reduction of high purity quartz at temperature of about 2000°C in the presence of coke. The fineness of this material and its pozzolanic nature makes it suitable for use in the production of self-compacting concrete. In this research micro silica was introduced in percentages of, 5, 10 and 15% as partial replacement of cement in the production of self-compacting concrete. The fresh properties were examined using slump flow, T50cm, slump flow, V-funnel and blockage ratio using L-Box. As the Micro silica were introduced, T50cm time increased, Slump flow reduced, V-funnel flow time increased and L-Box value reduced, due to increase in viscosity. Comparing the experimental results with European Federation of National Associations of Representing for Concrete EFNARC 2002, blockage ratio for 15% was below 0.8. The compressive stresses at 28days were higher than the control at 28days compressive stress with 8.6%, 19.04% and 11.9% for 5%, 10% and 15% respectively. Thus, cement can be partially substituted with micro silica up to 15% with improvement in compressive strength in self-compacting concrete.

1. Introduction

The volume of cement needed for civil engineering and its related works is snowballing as the population and quest for infrastructure surges. In the works of Mbabi et al (2012) [1], it was told that the volume of cement produced globally had drifted up, to over 3 x 10⁹ tons in 2012 from 1.5 x 10⁹ tons in 2000 representing 100% increase in 12years. Thus, by 2024, over 6 x 10⁹ tons of cement will be consumed. For every ton of cement produced, 1ton of pollutant in the form of CO, SO_x, NO_x (nitrous oxides). These oxides activate greenhouse effect, accounting for 5-7% of total CO emission from cement industry Turner and Collins (2013) [2], respiratory and cardiovascular diseases, acid rain, and etcetera. Of the 3 x 10⁹ tons produced, 1.5 x 10⁹ tons representing 50% is used for concrete works. Thus there is need to reduce these emissions. One of such ways is through the introduction of powdered waste such as micro silica into concrete production, serving as partial replacement of cement in concrete production. This is because the micro silica is not a binder but will in finely divided form react with the Ca(OH)₂ released during hydration of cement to produce Calcium Silicate Hydrate (CSH).

Carbothermic reduction of high purity quartz at a temperature of about 2000°C in an electric arc furnace during the production of silicon and ferrosilicon alloy results in the production micro silica as byproduct. High carbon content material such as Coal, coke, wood-chips, etcetera, are usually present during the reduction. According Fidjestol and Dastol (2008) [3], over 1.5 x 10⁷ cubic metre of micro silica is produced globally and this quantity is expected to rise to over 2.0 x 10⁸ cubic metre by 2020. Micro silicate is a toxic industrial waste. Leading producers of micro silica in the world are China, Norway, South Africa and USA. In Nigeria, silicon deposits abound in Kano, Jigawa, Delta, Lagos, Zamfara, etc. Thus, micro silica can be produced in Nigeria as byproducts of silicon processing. Lots of works have been done on Pozzolanic material use in concrete works. Akshaykumar et al (2016) [4] substituted cement for micro silica in a vibrated concrete in percentage of 3%, 5%, 7%, 9%, 11%, 13% and 15%. They reported best

improvement in compressive strength to be 11% replacement with 39% improvement compared to the bench mark at 28days crushing strength. However, the slump value downsized as the replacement continued. The study also indicated that MS can be blended with cement up to 15% with 16.04% enhanced compressive stress at 28days. Partha (2015) [5], reported that micro silica can be substituted in concrete production for cement up to 20% with better crushing resistance than the control. The improvement was maximum at 15% replacement with 25.85% enhanced compressive stress for the vibrated concrete produced at 28days. The improvement in compressive strength when micro silica were introduced in concrete matrix was attributed to its fineness [6-8]. Thus, the finer the micro silica the better the interstitial locking and thus, better mechanical properties. However, sometimes the equipment needed to grind the micro silica if it is densified might not be available, especially in developing countries. This study is aimed at investigating the suitability of using the micro silica in that form. In this research, densified micro silica shall be included as partial replacement of cement in the making of Self-Compacting Concrete SCC. Self-compacting concrete enhances the durability of concrete due to its filling ability and homogenous property. The production of SCC requires more cement content than vibrated concrete. The construction industry is adopting to this new concrete. Thus the demand for cement will increase and hence pollution.

2. Material and Method

The following concrete making materials were used;

Cement; Dangote brand of Grade 42.5 Portland cement conforming to British Standards Institution 197:1 (2000)[9] was used for the research work. The binder was acquired from building material market in Mile III Diobu Port Harcourt Rivers state Nigeria.

Micro silica; the material was subjected to chemical test to determine its chemical composition as stipulated in ACI committee 234R-96[10].

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Coarse aggregate (crushed granite); this material was obtained from crushed rock Nigeria Limited Akamkpa, Cross Rivers State, Nigeria. Only 12.5mm (50%) and 10mm (50%) were used for the study. The material was washed to remove impurities that may affect its intended use in accordance with BS 882:1992[11].

Fine Aggregate (River sand); River sand conforming to British Standard Institution 882:1992[11], was used.

Only does passing through sieve 4.75mm but retained on sieve 0.06 mm was used.

This material was obtained from Choba sand dredging site Choba, Ikwerre Local Government Area of Rivers State, Nigeria.

Water; the water used for mixing and curing met the standard for drinking water as specified in BS EN 1008:2002 [12].

Conplast SP 430 was used as super plasticizer to enhance the fresh properties of the concrete. The material met the requirements of BS 5075 Section 3 [13] as a high range water decreasing material.

Table 1. Experimental program

Mix	Cement kg/m ³	Micro Silica kg/m ³	Fine Aggregates kg/m ³	Coarse Aggregates kg/m ³	Water kg/m ³	Superplasticizer kg/m ³
MS-0%	514.0		761.0	940	180	6.68
MS-0%	488.3	25.7	761.0	940	180	6.68
MS-0%	462.6	51.4	761.0	940	180	6.68
MS-0%	436.9	77.1	761.0	940	180	6.68

Table 2. Mix Proportion

Experiments	Sample	Mix Ratio				Total Samples	Standard
		MS- 0%	MS- 5%	MS- 10%	MS- 15%		
Particle size distribution specific gravity	River sand						BS EN 933- 1:1997[14] BS 812 (1995)[15]
Bulk density and water absorption	Granite, River sand micro silica						BS 812:1995[15]
Workability Slump flow (SF) mm T50cm Slump flow (SF) sec V-funnel flow (V-FF) mm L-box (L-B)	Fresh concrete						EFNARC (2002)[16]
Compressive stress N/mm ²	Hardened concrete						BS 2002; 1239 0:3,[17]
7 days		3	3	3	3	12	
14 days		3	3	3	3	12	
28 days		3	3	3	3	12	

4. Results and Discussion

4.1. Physical Properties

Summary of the physical properties are as displayed in the table below;

Table 3. Summary of Physical Properties

Figure 2. Particle size distribution curve

4.2. Fresh characteristics

The results of the experimental investigation on the fresh properties of the concrete are as shown in figures 3-6. A closer look into the figures will review that the slump reduced as the quantity of MS in the matrix in form of replacement increased. Also the time taken for the flow to cover 500mm diameter also increased with the introduction of densified MS. Furthermore, the V-funnel flow time also increased while the blocking ratio value were dispersing from unity as the percentage inclusion of MS increased. The above phenomenon can be attributed to higher water absorption capacity of MS compared to the binder used. Thus, this lead to Increase in viscosity of the concrete so produced resulting in the above observed phenomenon. This observation is in line with the findings of Akshaykumar et al (2016) [4] were it was observed that introduction of MS caused higher viscosity. Thus, depending on the flow required, it is important to increase the volume of water needed during concrete production. The blockage ratio for 15%MS was less than the recommended value (0.8-1) by EFNARC 2002 [17].

3. Mix Design

The European federation of national associations of representing for concrete (EFNARC) 2002[17], standard was adopted as a guide which lead to the concrete mix as shown in the table below;

Figure 1. Experimental Flow Chart

Figure 3. Slump Flow In Millimeter

Figure 4: Slump Flow (T_{50cm} Time) in Seconds

Figure 5. V-Funnel Flow

Figure 6. Blockage Ratio Using L-Box

Compressive Strength

Micro silica like other Pozollanic materials are not binder in themselves but in finely divided form react with the Ca(OH)₂ produced during hydration of cement to form a filler material that fill up pores in the concrete. Thus, after Ca(OH)₂ is used up, further addition of micro silica will lead to loss of compressive strength as shown in the table below. At 10% replacement of the compressive strength was at

its peak at all age of curing when compared with the control. However, MS can be added up to 15% in self-compacting concrete production with better compressive strength than the control. The variation in compressive stress with respect to the control is in line with the reports of other researchers like [6-8]. The maximum improvement was 19.04% at 10% replacement of cement. The variation in compressive stress vis-à-vis the percentage reported by Akshaykumar et al (2016) and Partha et al (2015) [4,5] can be attributed to the finess of the densified micro silica used in this study.

Figure 7. Variation of compressive stress with respect to micro-silica inclusion

5. Conclusion

Inclusion of micro silica in concrete as partial replacement can lead to reduction of cement usage in self-compacting concrete production and thus lesser emission of toxic materials from cement producing factories. The introduction of MS into the matrix impacted on the Fresh properties due to increased viscosity arising from the water absorption capacity of micro silica been higher than that of the binder used. Micro silica can be supplemented for cement up to 15% in SCC with superior compressive strength than the control.

At 10% substitution of cement for MS, the compressive strength was maximum with a

19.04% improvement at 28days compared to 8.6% and 11.9% improvement observed for 5% and 15% replacement respectively.

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Instead of disposing off MS with its attendant environmental hazards, it is better utilized as Pozollanic material in SCC production.

Densified micro silica can be used in the production of SCC with improvement in Compressive strength.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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