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Design and Application of Self-consolidating Concrete in Nigeria: A Review Paper

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ABSTRACT

The design and application of Self-Consolidating Concrete (SCC) is limited in building and civil engineering projects in Nigeria due to the absence of self-consolidating concrete manufacturers, limited availability of some raw materials such as limestone powder, silica fume, air entrainment, metakaolin, and high cost of synthetic cementitious materials [1]. However, review of literatures revealed the potentials of locally available cementitious materials in improving the properties of universal concrete but its inclusion in SCC design has not been fully explored. The advantages of using Self-Consolidating Concrete (SCC) is not only limited to its durability but also prominent for mitigating problems of poor segregation, consolidation and homogeneity in congested reinforced concrete structures. Hence, this research reviewed various designs of SCC in Nigeria to enhance the existing knowledge and to create awareness about innovative methods of concrete design and possible areas of applications self-consolidating concrete in Nigeria construction industry. The findings from reviews indicated that lack of awareness, limited research data and instrumentation on SSC production has been the major setback in it applications in Nigeria. Conclusively, Nigeria Construction industry as one of largest sector of economy can benefit from the global market growth of self-consolidating concrete through its design and application.

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Introduction

Self-Consolidating Concrete (SCC) is the largest discoveries in the design and development of concrete technology with its applicability in congested reinforced concrete structures, where traditional concrete may not relatively be appropriately useful [2]. The precast concrete possessed great benefits with the possibilities of casting it with SCC. Self-Consolidating Concrete is an advanced method of concreting with high performance that could be placed and spread into forms under its own weight to obtain better consolidation without vibration and traceable defects of segregation and bleeding (fig. 1.0). Self-Consolidating Concrete also gives properties which include: excellent filling capacities into forms, passing abilities, and sufficient segregation resistance. The adoption of SCC in construction activities can results in enhanced construction productivity, improved safety in jobsite, and enhanced quality of concrete production (Buari et al., 2019). The SCC innovation can help in managing usage of materials, guarantee economic benefits and enhanced economic and environmentally friendly structures due to the reduction of noise, improved constructability and ensuring excellent structural performance. Self-Consolidating Concrete is designed with the use of general concrete materials, in addition with various kinds of organic and non-organic materials. The essence of additional materials in SCC design is to reduce waste and increasing strength and durability characteristics of the concrete. Globally, various researchers have designed SCC by partial replacements of aggregates using recycled concrete aggregates, iron slag, coal fly ash and agricultural wastes. However, in Nigeria, utilizations of SSC potentials through design and application are limited. Hence, this paper reviews.

Figure 1.0: Various applications of SSC (Buari [1])

Significance of The Survey

Sustainability of the construction industry, mitigation of environmental pollution and the challenges of using highly reactive and foreign supplementary cementitious materials in SCC development were the major driving forces for this review

work [1] Recycling waste materials would be a perfect way of overcoming the escalating rate of environment pollutions as well as reducing the cost of producing SCC. Construction industry sustainability is a current trend that requires to be examined in Nigeria. The originality of this study will be to provide awareness on the incorporation of cementitious waste materials in design of SCC and its application in congested reinforced concrete structures that could be an added benefit to the building and civil engineering industry in Nigeria for a long period of time. These benefits can be classified as ecological, economic and environmental impact by reduction in energy required for cement production, mitigation of the emission of greenhouse gas, speed of construction work and reduction in the cost of quality building and Engineering facilities.

Figure 2.0: Disadvantages of Universal Concrete in Congested RC [1]

Design of Self Consolidating Concrete in Nigeria

Previous and recent research related to the design and application of SCC in Nigeria was comprehensively reviewed with conclusions drawn based on their analysis conducted a research on the usage of waste from the industry as mineral and chemical additives in SCC design with principal characteristics measured were; fresh and hardened properties (flowability, passing ability and segregation resistance in slump flow test, V-funnel test, L-box test , J-ring test and compressive strength at 28days hydration period [3]. The Experiment made use of pulverized fuel ash, carbide waste and stone dust as cement replacement at 5%, 10%, 15% and 20% with constant mix ratio of 1:2:4 for the concrete and water-binder ratio, w/b, of 0.45 maintained for the design. The results of this research showed that the passing ability and segregation resistance of SCC are within the stipulated values and SCC decreases significantly only with 20% of carbide waste as the of SCC developed with pulverized fuel ash and quarry dust indicated increase in strength properties studied the impact of Nigerian Limestone and Super-plasticizer on the strength properties of Self Compacting Concrete [4]. The influence of Nigerian limestone powder in SCC was tested and was found similar in compressive strength when compared to that of normal concentration. Finding also shows that the use of Nigerian limestone powder improves significantly the quality of concrete and suitability for used in Nigeria building and civil engineering construction industry.

(Buari et al., 2019) carried out a study on the effect of groundnut shell ash GSA on the strength characteristics of self-consolidating high performance concrete (SCHPC) in acidic and Sulphate environment. The fresh and hardened measured with cement substitution by groundnut shell ash (GSA) at 0-40% after curing in water and three different chemical concentrations **($CaSO_4$, $MgSO_4$ and H_2SO_4)**, the varying concentration of 5% each at 7, 14, 28days hydration period. The results showed that both fresh and hardened properties of SCHPC developed at 10% substitution level is a suitable for SCC design with an improved Engineering Properties in an aggressive environment.

Presented a result on application of Self-compacting concrete in the construction of road pavement construction with the grouping strength of some selected brands of Portland cements [5]. The brands used in the design of SCC were; CEM II/A-L 42.5 (Brand A), CEM II/B-L 32.5 (Brand B) and CEM II/B-L 32.5 (Brand C). The fresh properties off brands sample were measured and conform with obtainable standards with good rheological properties while compressive and flexural strengths examined at 3, 7, 14, 21 and 28 days hydration periods. Pavement designed with Brand A exhibited the optimum early compressive and flexural strengths with Brand B and C exhibited lower characteristics strengths compared with control. The findings concluded that Brand C indicated lowest strength properties and that cement grade lower than 42.5 is not suitable for SCC pavement design.

(Buari et al., 2019) examined the effects of incorporating groundnut shell ash (GSA) and waste glass (WG) on both fresh and hardened properties of self-consolidating high-performance concrete in chloride and sulphates condition. The fine aggregate and cement were substituted respectively by WG and GSA between 0% - 40% in the concrete design. The research adopted similar procedures used by in concrete design and examination of fresh and hardened characteristics of the specimens. Findings shows improved rheological and mechanical properties of SCHPC when compared with the control [6-10]. The study concluded that recycling waste glass and GSA using pore structures of the SCHPC and hence, incorporating these items in SCHPC development would not only solve environmental problems due to production of traditional concrete but also reduce the cost imposed on of concrete production.

Also conducted the rheological properties and compressive strengths of self-compacting concrete (SCC) and traditional cement concrete [11]. The result of compressive strength shows that a SCC obtained strength slowly when compared to traditional cement concrete and this is due to the pressure of admixtures. However, the 28days strength was lower than the traditional cement concrete. But eventually, the SCC had potential of higher strength ahead of 90days. The results also shows that the effect of water cement ratio on plastic characteristics of the self-compacting concrete was negligible when compared to traditional concrete.

Conducted the SCC rheological (fresh) and hardened characteristics with Palm Kernel Shell Ash (PKSA) as additional cementitious material [12]. The procedures used were that of (EFNARC 2002 ; EFNARC 2005) and with an iterative mix design method of 0- 12.5% replacement of Portland cement by PKSA. The use of PKSA up to12.5% improved the workability, Compressive and splitting tensile strengths of SCC [13].

Conducted an experiment study on the impact of the blended of calcium carbide waste (CCW) and sorghum husk ash (SHA) on the fresh characteristics of self-compacting mortar [14]. Fresh properties were measured using Flow cone test and Mini-v-funnel of 3.5% with 70/30 (SHA/CCW) shows a higher mortar flow spreading of 290 mm when compared with the control having 295mm value respectively. The developed strength of samples was examined at 3, 7, 14, 28, 56 and 90 days hydration periods. The agro binder exhibited good binding characteristics with slow hydration rate results of a compressive strength shows that 70/30 (SHA/CCW) proportion has the highest value of 14.08 N/mm2 at 90 days. Self-compacting mortar made with combinations of SHA/CCW as a binder can be used in masonry works as it conforms to type N of ASTM C681 (2017).

Recently reviewed the progress made in the enhancing the use of self-compatibility of SCC in its fresh state [15]. The study adopts the usage of air entrainment, as fly ash, silica fume, ground-granulated blast-furnace slag and rice husk ash in the development of SCC and examined the workability and rheological properties of fresh SCC. The study shows that SCMs possessed the advantages of Pozzolanic and filler effects which are important to entrained air. The study concluded that authours can make use of statistical and intelligent multi-objective optimization strategies for acquiring the best amount of SCMs that will reduce the fresh characteristics when considering its deleterious effect on the hardened properties.

Table 1.0: Summary of findings from reviewed works

Reference	% Replacement of SCM used	Types of SCM/ Admixtures	Chemical admixtures	Conclusion of the research
Onuegbu et al. (2018)	5%, 10%, 15% and 20%	Pulverized Fuel Ash, Carbide Waste and stone dust	1% Conplast SP 430	The research shows that PFA, CW and QD could be replaced partially with cement in the production of Self Compacting Concrete
Ede and Adegbite (2013)	10%,	Limestone	Conplast SP 432 MS	The study shows that SCC could be used in the building and civil engineering construction industry. While, limestone powder and super plasticizer can be adopted to improve the workability and rheological properties of Self-compacting concrete
Buari et al. (2019)	10%,20%,30% and 40%	Groundnut Shell Ash	2% Conplast SP430MS, 1% VMA 358	The study shows that GSA is a material suitable for SCM and can be replaced with up to 30% cement to produce SCHPC with a greater engineering property in any critical environment.
Ayobami et al. (2017)	Not available	CEM II/A-L 42.5 CEMII/B-L32.5 CEM II/B-L 32.5	----------	The research shows that grades of cement lower than the CEM II/A-L 42.5 may probably not be appropriate for self-compacting concrete used for the construction of pavement.
Buari et al. (2019)	10%, 20%, 30% and 40%	Groundnut Shell Ash Recycled Waste Glass	2% Conplast SP430MS, 1% VMA 358	The study shows the relevance of admixture on the properties of SCHPC as fresh concrete and hardened characteristics of cementious material and fine aggregates. The study also shows that the developed SCHPC performed better and hence, are found more suitable for the production of SCHPC in Nigeria civil engineering construction environment.
Buari et al (2020)	5%, 7.5%, 10% and 12.5%	Palm Kernel Shell Ash (PKSA)	COMPLAST SP430	The study revealed that SCC can be made by replacing cement with PKSA for up to 12.5% by altering the workability and the compressive strength of the SSC produced.

Hassan et al (2000)	30%, 40%, 50% 60% and 70%	Sorghum Husk Ash (SHA), Calcium Carbide Waste (CCW),	Super-plasticiser Master Glenium ACE456	The study shows that the alternative binder from agro waste (SHA) when combined with industrial waste (CCW) provide good binding properties and are more suitable for the development and applications of Self-Compacting Mortar (SCM).
Bikila et al (2018)	Not available	fly ash, silica fume, ground,granulated Blast,furnace slag and rice husk ash.	----------	The study shows that any admixture, the useful Pozzolanic and filler SCMs are used to enhance the self-compatibility of fresh concrete.

Application of Scc In Nigeria Construction Industry

With the increase in population growth in Nigeria, the construction industry is also increasing in the production of concrete structures to meet increasing demands for roads, shelter and other infrastructures Hassan et al (2000). [14] Similarly in Nigeria, opportunities of SCC has not been fully explored, despite global recommendation for the use of innovative strength-enhancing admixtures, (which are locally available for the construction industry in Nigeria) in design of ready-mixed and precast SCC, most of the construction companies relied on universal concrete production and thereby increase rate of cement consumption [16,17]. Nigeria with total annual output capacity of 47.8 million tonnes cement production with just three major brands which includes: Dangote: Dangcem. LG (60.6%), Wapco. LG (21.8%) and Buacement. LG (17.6%) respectively. The annual cement demand for the construction sector amounts to 20.7 million tonnes with cement price at 240% above the global average with tons sells for up to $135 in Nigeria [18]. In the universal production of concrete, it is usually about 12% of cement, 8% water (for mixing) and 80% aggregates (fine and coarse aggregate), are required [19]. The overall cost of production of universal concrete is high compared with SCC. The production of concrete in engineering structures requires thorough placement and good consolidation in obtaining required hardened properties. The use of ordinary concretes is disadvantageous in proper placement, adequate compaction, strength and durability, despite the use of skilled labourers [20-23].

Advantages of Application of Self-Consolidating Concrete and Market Dominants

Self-Compacting Concrete (SCC) have several applications in concrete production which includes: saving of construction time and cost enhanced concrete quality concrete production, increased durability, and most significantly, the greener concept. Furthermore, about 40 to 50% of cement content can be substituted by locally available cementitious materials can be used to greatly minimize the cost of the concrete production in Nigeria. Similarly, the number vibrators and skilled construction workers will be reduced drastically, and shuttering could be used for more number of times when compared to traditional concrete. In addition, the cost of maintaining concrete structures is minimised due to the reduction in the number of defects to a greater extent. Generally, the usage of SSC will significantly reduce the overall cost of concrete structures when compared with universal concrete. The construction sector in Nigeria can be part of major documents in SCC market due to its population. Presently, Asia, pacific dominates the SCC market in Asia. The emphasis less noise construction activities and the consultants' recovery of construction and housing sector in Asia pacific are critical factors influencing the growth of the market in the region. In Nigeria, despite having large population that can serve as market driver, advantages of application of SCC have not been utilized been less expensive to produce than universal concrete. Similarly, the rapidly shift in construction techniques and process that includes the usage of modern tools and equipment while observing or including a wide range of chemicals additives, SCC have been designed to give greater opportunities to the construction industry over traditional concrete in any construction industry in Nigeria.

Landscape of Self-Consolidating Concrete Market Trends

Self-consolidating concrete market capacity is projected to reach US$14.6 billion by 2026. Thus, growing at an average CAGR of 6.8% during 2021-2026 with one of the market top companies is Lafargeholcim Ltd. Lafargeholcim Ltd. has a subsidiary in Nigeria and can pilot this innovative means of concrete production and application for the benefit of construction industry in Nigeria. The involvement of companies and institution will go a long way in Design and application of SCC in routine construction work in Nigeria.

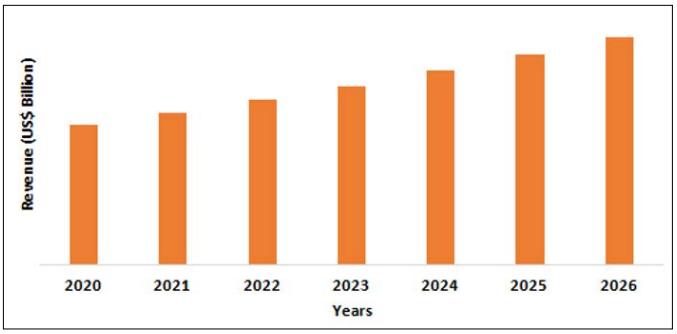

Figure. 3.0: Asia-Pacific SCC Market Revenue projection 2020-2026 (segun [32])

Conclusions

The study concluded that the article reviewed helps to summarize the current level of various SCCs design in Nigeria with analysis of the previous and recent researches on design and application of SCC in Nigeria. Hence, the study draws conclusion which includes the following.

1. A number of investigations have been carried out on the design of SCC/SCHPC with the usage of locally available cementitious material as SCM, VMA and binder with some achievements made.
2. Application of SCC in Nigeria construction industry for

routine construction works is sparse due to limited research data, the lack of instrumentation and awareness compared to other countries like Denmark, Japan, Indian, and Sweden, where self-consolidating concrete is used for the routine construction works. The awareness, availability of research data and instrumentation would help Nigeria construction industry to utilize the various benefits in SCC applications in Building and Engineering structures.

3. Apart from EFNARC, (2002; 2005) and few other methods developed by the researchers and some private institutions in other part of the world (Denmark, Japan, Indian, Sweden etc.) that are using their own methods with one or other limitations, there is no other standard code suitable for the design mix of self-compacting concrete in Nigeria. However, it is not clear fully as at now whether design codes available in Nigeria for structural reinforced concrete can be practical in design of self-compacting concrete and thereby requires a template for design and development of SCC in Nigeria for ease of likely applications in routine construction works.
4. Less Involvement of private institutions, companies and government in Nigeria, has made the application of SCC difficult and expensive for routine construction works.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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