SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V9I7P107

Volume 9 Issue 7, 44-49, July 2022

Original Article

Experimental Study on the Properties of SCC using Meta-Kaolin from Sudan

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Received: 08 June 2022 Revised: 26 July 2022 Accepted: 31 July 2022 Published: 10 August 2022

Abstract *- There is an extensive presence of kaolinite clay (KC) in different locations in Sudan with the appropriate composition to match OPC when converted to Meta-kaolin (MK). The very promising structural results affirm that it has a great potential to be a suitable alternative for cement in normal concrete mixtures. This study aimed to extend MK's utilisation in different forms of concrete mixtures. This paper portrays the results for investigating the potentiality of using MK to produce self-compacting concrete. MK was prepared, tested to verify its pozzolanicity then included in different proportions in the mix design for the SCC sample. Three trials were prepared, and fresh and hardened properties were investigated. Fresh concrete properties provided evidence that the obtained mix is appropriate for unreinforced or slightly reinforced structures, use in vertical applications in very congested structures and for many normal applications. The 28-day compressive strength results exceeded 40MPa confirming its appropriateness as a filler to produce SCC. As an abundantly available material in Sudan, these results suggest that MK is a good alternative to be used to produce SCC in Sudan.*

Keywords *- Kaolinite clay, Meta-kaolin, Cement, Sudan, Self-compacting concrete.*

1. Introduction

Concrete production consumes natural resources such as river sand, clays and rocks, which will be consumed but not returned and involves the emission of huge amounts of CO2 during the production of cement-as one of its major constituents- concerns arise from the associated severe negative impact on the environment.

The worldwide production of concrete is 10 times that of steel by tonnage, while other construction materials such as steel and polymers are more expensive and less common than concrete materials [1,2].

Green concrete is considered one of the solutions leading to sustainable construction because it "... uses waste material as at least one of its components, or its production process does not lead to environment destructions" [2].

2. Literature review and previous studies

Self-compacting concrete was first developed in 1988 to achieve durable concrete structures. Since then, various investigations have been carried out, and this type of concrete has been used in practical structures in Japan, mainly by large construction companies. Investigations for establishing a rational mix-design method and self-compatibility testing methods have been carried out by making self-compacting concrete a standard concrete[3....8].

Self-compacting concrete (SCC) is flowing concrete that does not require vibration and should not be vibrated. It uses super plasticisers and stabilisers to increase the ease and rate of flow significantly. It compresses every part of the mould or formwork by simply using its weight without segregating the coarse aggregate. The consistency of the concrete is specified and measured as a flow rate rather than the normal slump test. SCC offers Health and safety benefits (as no vibration is required, Faster construction times, Increased workability and ease of flow around heavy reinforcement, and Excellent durability.
[https://www.concretecentre.com/Specification/Special-Concrete/self-compacting-concrete-(SCC).aspx, accessed on 17/7/202]

The world kaolin market is unusual in that it is dominated by two large free market economy countries: the United States and the United Kingdom. About one-third of the yearly world kaolin supply is derived from extensive Georgia and South Carolina deposits. Practically all kaolin used by Minnesota paper companies currently comes from Georgia. The second largest producer is the United Kingdom, which accounted for over three million tons or about 13% of world production in 1987. Besides these two major producers, other sources included Brazil, Germany, Australia, and the Eastern Block. [9,10]

The raw material of Meta-kaolin is kaolinite clay. The method of preparation is thermal activation or Calcination.MK is not a by-product. It is obtained by the calcinations of pure or refined Kaolinite clay at a temperature between 650°C and 850°C, followed by grinding to achieve a finesse of 700-900 m2/kg. It is a high-quality pozzolonic material blended with cement to improve the durability of concrete. When used in concrete, it will fill the void between cement particles resulting in more impermeable concrete. Meta-kaolin is an artificial pozzolanic material which can provide many specific features. Meta-kaolin is available in many different locations and qualities. The purity will define the binding capacity of free lime. Meta-kaolin is a valuable admixture when added to the concrete cause of its cementitious properties (behavior).[11....15]

The parameter of strength, i.e. ultrasonic pulse velocity, compressive strength and density of mortar containing the extent of metakaolin as partial replacement of cement, is evaluated. Metakaolin was replaced up to 50% with cement in an increment of 10. For each replacement total of 6 cubes, specimens were cast that were demoulded for curing in water at 20°C for a total duration of 28. The results observed that the higher strength of the mortar cube specimen occurs at 20% replacement with metakaolin. Compressive strength decreased when metakaolin was replaced with more than 30 % cement.[6].

Metakaolin is a highly reactive pozzolanic admixture with significant potential for developing concrete composites such as High Strength High-Performance Concrete (HSHPC) and self-compacting concrete (SCC) if appropriately designed. However, for obtaining the required performance in any of these concrete composites, metakaolin should be properly proportioned so that the resulting concrete would satisfy both the strength and performance criteria requirements of the structure. The present work is an effort toward obtaining a new mix methodology for designing high-strength self-compacting metakaolin concretes based on the efficiency concept. The methodology has been successfully verified through a proper experimental investigation, and the self-compacting metakaolin concretes were evaluated for their self-compactability and strength characteristics. The results indicate that the proposed method can produce high strength SCC of about 120 MPa.[7]

Using metakaolin and silica fume as replacements adds to the cohesiveness of the mixes, workability and durability. It is evident from the experiment that the compressive strength increased with the age of curing days, and the strong increase in the percentage of metakaolin up to 15%, which had the highest strength and further replacement led to a decrease in strength. In comparison, mineral admixture with silica fume had its highest compressive strength at 5%. A further increase in percentage replacement led to a decrease in the concrete strength throughout the curing days.[8]

[9] The Compressive strength of SCC with metakaolin grew quickly during the initial life and remained significantly higher, while the water absorption coefficient and penetration depths remained very low.

SCC susceptibility improved significantly with increased metakaolin replacement levels [10]. The effect of metakaolin and silica fume on the properties of lightweight concrete [11] was also examined. Their results show that using metakaolin to improve concrete's durability and mechanical relationships is a relatively new approach in the field of concrete technology. This paper proposes a new design methodology for developing high-strength SCC using metakaolin by looking at the efficacy factor of metacolin. The newly developed mix design methodology has been validated by appropriate pilot investigation[16,17].

Kaolinite clays, or kaolin as commercially known, are considered one of the most valuable industrial materials in their refined white state. They are found in nature as primary residual or secondary sedimentary deposits laid down in flood plains. Kaolin is a soft, white clay resulting from the natural decomposition of feldspars and other clay minerals. Natural kaolin deposits contain a wide range of impurities that must be removed before they can be industrially used[18-24]. The coarser impurities, i.e. quartz and heavy minerals, are rather easily separated by settling or screening. However, there are usually micron-size impurities such as anatase, limonite, haematite, pyrite, organic matter, etc. The partial or complete removal of these impurities with different technologies enables the production of kaolin products of high quality from deposits formerly regarded as too impure to be mined. For most modern industrial applications, kaolin must be extensively refined and processed from the crude state to enhance whiteness, purity and other characteristics.[25-30]

3. Material Used and Their Properties

Table 1. Materials Used and Their Properties

Materials	properties
Cement	Ordinary Portland cement has a specific gravity of 3.15, satisfying the IS:12269-1987 specifications.
Water	Ordinary potable water free from organic content, turbidity and salts was used for mixing and curing throughout the investigation.
Fine aggregate	Locally available natural sand was tested for conformity according to the BS 812 & 882 specific gravity 2.54. Gradation is shown in figure 1.
Coarse aggregate	Natural gravel from a local source has a specific gravity of 2.9 with a 23% crushing value conforming to the BS 882 - 1992 for grading. The gradation is shown in figure 2.
Meta-kaolin	Kaolinite clay (KC) samples were brought from Merowe in the Northern State of Sudan. In its naturally occurring state, it had a grey to buff colour, and its texture was nearly soft but with a small enumeration of clay stones (refer to figure 3). KC underwent a calcinations process where the raw clay was thermally treated at 750°C for 5 hours, converting it to meta-kaolin (MK). MK was then prepared in a powder form through grinding and then sieving using sieve no.100 (mesh 150 µm) (refer to figure 4).
Chemical admixture	A super plasticiser was used in this experimental work.

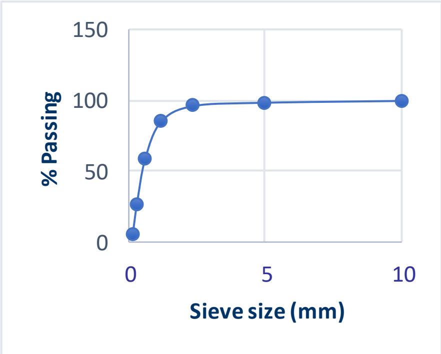

Fig. 1 Fine aggregate gradation

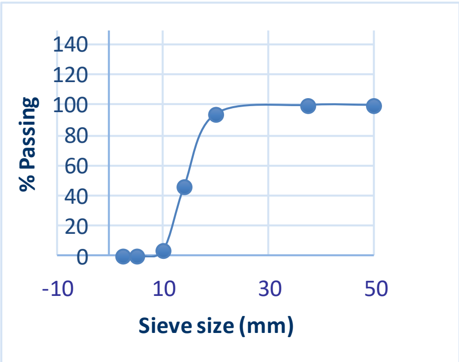

Fig. 2 Coarse aggregate gradation

Fig. 3 Raw Kaolinite Clay

Fig. 4 Meta-Kaolin sample

3.1. Mix proportions, casting and specimen testing

Table 2 shows the proportions for the different scenarios considered to produce SCC. Included in different proportions, 3 mixed trials were considered. The mixing and preparation procedures followed the basic requirements for concrete composition described in section A.5.2 of the ES206-1:2000, and the targeted compressive strength was 40MPa at 28 days. The trials considered a fixed proportion for cement, fine and coarse aggregates, and the variation in the different trials was in the water content, the chemical admixture dosage and the added MK amount

Table 2. SCC mix proportions for the adopted trials with MK inclusion

Trials	Mix proportions (Kg)					
	Cement	Fine aggregate	Coarse aggregate	Water	Meta-Kaolin	Admixture
(1)	7.275	14.66	8.415	3.795	2.025	0.106
(2)	7.275	14.66	8.415	3.855	2.425	0.159
(3)	7.275	14.66	8.415	4.00	2.225	0.126

4. Testing of specimens

The proposed trials were prepared and tested via the standard self-compacting concrete (SCC) tests. Among several tests specified by the European Standards for fresh SCC properties measurement, the flowability was measured using the slump flow and V-Funnel testing methods as specified by EN 206-1: 2000, 5.4.2 to 5.4.4. The first trial (Trial 1) was adopted and tested but failed to satisfy the set standards for the flow ability, passing ability, and viscosity. Accordingly, the proportions of the component were modified. Trials (2) and (3) were prepared and then tested. The tests included the fresh and mechanical properties of the hardened SCC samples. The former tests were conducted following the stated criteria as described in EN 206-1 Table 6, while the latter was conducted under the requirements of EN 206-1: 2000, Clause 5.5.

5. Results

5.1. Meta- Kaolin Properties

As the physical properties of MK depend very much on the quality of the raw material used (KC), the calcinations temperature and the finishing processes, Merowe's KC showed very good results compared to OPC. The tested MK sample included high amounts of SiO_2, Al_2O_3 and Fe_2O_3, exceeding the limits set by the Sudanese, ASTM, and BS limits for cement (refer to Table 3).

Table 3. MK major oxides presence in comparison to OPC

Element	MK Major Oxides (%)	Cement		
		Sudanese manufactures (%)	ASTM C150 (%)	BS EN 197-1 (%)
SiO2	52.6	20.1-21.6	19-23	17-25
Fe2O3	4.25	3.01-3.68	0-6.0	0.5-0.6
Al2O3	36.2	4.44-5.11	2.5-6.0	3-8
MgO	0.82	1.87-2.94	0-5.0	0.1-4.0

With 93% (SiO2+Fe2O3+Al2O3) content, MK could be classified as a highly pozzolanic material according to the ASTM C618. MgO was within the range of the three consulted references (see Table 4). It indicates that MK is a potentially appropriate material for concrete mixtures. However, further tests for SCC properties were necessary

Table 4. Meta-Kaolin Pozzolanicity

Element	Pozzolanicity	
	Meta-kaolin	Limits according to ASTM C618 (%)
SiO2+Fe2O3+ Al2O3	93.05	≥70%
MgO	0.82	≤5%
LOI	4.08	≤6%

5.2. Fresh concrete properties

Flow ability, passing ability and viscosity are the parameters measured for the SCC fresh samples. The first trial was not acceptable; hence second and third trials were conducted. The test results are presented in Tables 5,6 and 7, where the obtained values for each test were presented together with the standard limits for classifications.

5.2.1. Slump Flow Test

The consistency was expressed by slump flow. The test results presented in Table 5 show that trial 1 could not be classified into any of the classes. In contrast, trial 2 proved suitable for vertical applications in very congested structures (class SF3). Trial 3 showed results that put it in the category of SCC for many normal applications (class SF2).

Table 5. Consistency expressed by Slump flow

Trials	Obtained results		Limits according to EN206-1 Table A.1
	Slump flow	Slump flow class	
(1)	520	-no	550-650: SF1 660-750: SF2 760-850: SF3
(2)	790	SF3	
(3)	650	SF2	

5.2.2. Viscosity Measurement Test

The viscosity measurement, presented in Table 6, showed a medium flow rate (VS2) for all trial mixes.

Table 6. Viscosity test results for the fresh SCC samples

Trials	Obtained results		(Viscosity classes) according to EN206-1 Table A.2
	T500 (secs)	Class	
(1)	3	VS2	VS1: T500≤2 VS2: T500>2
(2)	3	VS2	
(3)	3	VS2	

5.2.3. V-Funnel Test

The V-funnel test classifies the sample into two viscosity classes. According to the results shown in Table 7, trial (1) and trial (3) could be classified as class 2 (VF2), while trial (2) is class 1 (VF1).

Table 7. Viscosity Test Results for the Fresh Scc Samples

Trials	Obtained results		(Viscosity classes) according to EN206-1 Table A.2
	V-funnel(secs)	Class	
(1)	15	VF2	VF1: ≤8 sec. VF2: 9-25 sec.
(2)	8	VF1	
(3)	9	VF2	

6. Hardened concrete properties

In its hardened state, the compressive strength test was conducted at different curing ages as one of the mechanical properties' measures. As shown in Table 8, both Trail (2) and trial (3) were acceptable compared to the targeted strength (40MPa).

6.1. Compressive Strength Test

Table 8. Viscosity Test Results for the fresh SCC samples

Trials	Compressive Strength (MPa)		
	Curing age (days)		
	7	14	28
(1)	-	-	-
(2)	29.6	33.4	41.3
(3)	30.7	37.2	46.5

To investigate the effect of the content of MK on the strength of the produced SCC, the results are shown in figure 5. It could be inferred that the optimum content to yield the required strength is within 30-33% of the cement weight range.

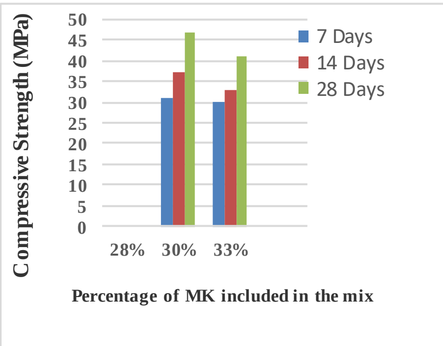

Fig. 5 Compressive Strength for the hardened SCC samples

7. Conclusion

In general, it was noticed that different factors contribute to the produced SCC results. Among these factors are the trial mix design, variations in the cement composition and the quality of the MK used.

The MK produced from KC from Northern Sudan proved to be highly pozzolanic. When incorporated into the mix, it yielded acceptable results for two trials and the optimum dosage of MK to yield the required 28 days of compressive strength was within the range of 30-33% of the weight of cement. In the early ages, the MK reacts slowly, with 33% MK giving lower strength than 30%MK inclusion.

The slump flow test confirmed the possibility of producing MK-included SCC that could suitably be used in vertical applications in very congested structures and many normal applications.

The viscosity measurements indicated a medium rate flow for the tested trials, and the 28 days' compressive strength showed that the successful trial exceeded the targeted strength.

The slump flow values vary between 520 to 790 mm, whereas according to the consulted specifications, 550-850mm. For this reason, the mixed trial yielded a slump flow of less than 550 was excluded.

As the MK dosage increases, the slump flow increases, unlike the compressive strength, which starts to decrease with an MK dosage greater than 30%. The maximum slump flow value obtained was 790 mm for trial (2), 33% MK.

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