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REVIEW ON PERFORMANCE OF SELF-COMPACTING CONCRETE CONTAINING METAKAOLIN AND CEMENT KILN DUST

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ABSTRACT

Self-compacting concrete has been gaining acceptance by engineers and builders due to its simplicity in production and improved strength. This review explored the potential benefits of using metakaolin and cement kiln dust, both from an economic and environmental viewpoint, as well as the potential shortcomings that may be encountered when used in production of self compacting concrete (SCC). The results recorded from various researchers revealed the optimal replacement of cement with Metakaolin and cement kiln dust as 10-20% and 5-10% respectively. In conclusion, Metakaolin and Cement Kiln Dust as an admixture in concrete produced durable, workable and cost-effective concrete.

Keywords: Metakaolin, Cement Kiln Dust, Compressive Strength, Self-Compacting Concrete.

1. INTRODUCTION

There is need for affordable building materials in providing adequate housing for the teaming populace of the world. The cost of conventional building materials continue to increase as the majority of the population continues to fall below the poverty line. Thus, there is the need to search for local materials as alternatives for the construction of functional but low-cost buildings in both the rural and urban areas.

Self-compacting concrete (SCC) is a highly flowable concrete with better strength development and good surface smoothness [1]. The concrete was first launched in early 1990s and since then, it has become one of the most sought types of concrete. SCC gets compacted due to its self-weight and is de-aerated meaning there's no entrapped air when it flows in the formwork of densely reinforced structural members. The concrete helps to fill the voids and gaps completely and maintain concrete and horizontal level after placing. The constituents of self-compacting concrete is same as normal concrete. In spite of a good mix design of concrete mixtures, insufficient compaction of concrete has a very negative effect on the strength and durability of SCC. It lowers the ultimate performance and so almost all concretes require full compaction to avoid the listed problems associated with incomplete compaction of concrete [2]. One of the major benefits of using self-compacting concrete is that it requires little or no mechanical vibration for placing and compaction. It flows under its own weight to fill up formwork completely so as to achieve full compaction in presence of congested reinforcement [2]. SCC requires high amount of cement, a major binder in concrete making it very detrimental to the environment due to emission of poisonous gases during its production in factories [3]. Other problems associated with the use of cement rapid increase in cost, highly susceptible to acid or sulphate attack and high energy consumption [3]. Construction industries are minimizing cost of construction materials by using locally available materials and finally reported that most agricultural waste residues can be converted to a useful materials in concrete production [4]. It can be used to partially replace cement binder. When cement is partially substituted with Metakaolin, it reacts with byproduct calcium hydroxide and produces extra C-S-H gel.

2. LITERATURE REVIEW

2.1 Portland Cement Concrete.

Concrete is a widely used construction material that composed of cement (binder), fine aggregates, coarse aggregates, water and sometimes admixtures. Admixtures are added as constituents in concrete so as to improve its qualities. Portland cement is commonly used material for concrete production. NRMC laid claim that cement Portland contents are venerable to cracking and increases the heat generation [5]. The problems associated with Portland cement production such are high energy consumption, release of carbon dioxide to the atmosphere that causes depletion of the ozone layer [6]. Concrete is divided into the following categories based on compressive strength, they are:

(1) Low strength concrete: < 20 N/mm^2
(2) Moderate- strength concrete: 20 to 45 N/mm^2
(3) High-strength concrete: 45 to 150 N/mm^2
(4) Ultra-high strength concrete :$>$ 150 N/mm^2

Portland cement is regarded as the most widely used cement globally as reported by many researchers [2], [3], and [6]. The cement industry accounts for 5 – 8% of global CO_2 emission. This makes the cement industry the second largest producer of this greenhouse gas [6]. The gases released during production of cement (CO_2, SO_3 and NO_2) can cause serious environment impact such as acid rain and greenhouse effect [7]. Alite (C_3S) is regarded as an essential component of Portland cement clinkers which constitutes 50-70% of all the composition of cement clinker. It is known as tricalcium silicate (Ca_3SiO_5) reformed in crystal structure and composition by ionic substitutions. Belite also known as dicalcium silicate (Ca_2SiO_4). It constitutes around 15-30% of Portland cement clinker. It reacts very slowly with water but helps in later strength development of concrete beyond 28 days of concrete curing. Aluminate is the next set which constitutes 5-10% of Portland cement clinkers is known as tricalcium aluminate ($3CaO.Al_2O_3$), significantly modified in both composition and also in structure by ionic substitution. Aluminate reacts rapidly with water and cause undesirable fast setting unless a set controlling agent such as gypsum is added to it. Ferrite is made up of 5-15% of Portland cement clinkers. It is known as tetracalcium aluminoferrite (Ca_2AlFeO_5), significantly modified in composition by Al/Fe ratio and by ionic substitutions.

2.2 Self-Compacting Concrete (SCC)

Self-compacting concrete (SCC) is a different technology in concrete making that has been developed during the last twenty years. The technology was first established in Japan in the year 1986. Self-compacting concrete is superior to orthodoxly vibrated concrete and is eminently suited for locations of high congestion of reinforcement in structures. In plastic state, self-compacting concrete flows under its own weight and navigating through confined sections without causing segregation or bleeding. This concrete is widely used for many construction projects in many countries around the world because it advantages. Additionally, it has other benefits compared to normal concrete and helps to solve problems associated to insufficient compaction of concrete.

2.2.1 Applications of SCC

Applications of Self-compacting concrete

(i) It is very useful in precast industries.
(ii) It can be used in complicated reinforcement positions.
(iii) It is very good for construction of structural elements in high rise buildings.
(iv) Casting marine structures are made easy with SCC
(v) It reduces manpower on site.

2.2.2 Advantages of SCC

Some advantages of using self-compacting concrete [8]

(1) To achieve faster construction
(2) Reduction in site manpower
(3) It produces concrete with better surface finishes
(4) Stress-free placing of concrete
(5) Improved strength of concrete.

2.2.3 Flow Properties of SCC

There are three essential properties that a self-compacting concrete must fulfil in order to perform its intended functions. These are passing ability, filling ability and resistance to segregation [8]. These three properties are carefully maintained to achieve a good self-compacting concrete.

Filling Ability: The ability of SCC to flow and fill up spaces in concrete completely under its own weight is regarded as filling ability. A highly fluid SCC has ability to flow and fill all voids in vertical position.

Passing Ability: The concrete containing needed an aggregate sizes that can flow through a resisted spaces or in-between restricted reinforcing bars and other embedded objects without blocking and under its own weight.

Resistance to Segregation: SCC must be able to satisfy the requirements for both filling and passing ability and still remains consistent during transport, placing and even after placing.

Table 1: Properties of SCC [8].

Methods/Tests	Property
Slump flow	Filling ability
Slump flow at T50 cm	Filling ability
V-funnel	Filling ability
J-ring	Passing ability
L-Box	Passing ability
U-Box	Passing ability
V-Funnel at T5minutes	Segregation resistance

Table 2: Minimum and Maximum Acceptable Range Values for SCC [8].

Methods/Tests	Unit	Minimum	Maximum
Slump flow	mm	650	800
Slump flow at T50 cm	sec	2	5
V-funnel	sec	6	12
J-ring	mm	0	10
L-Box	(h2/h1)	0.8	1.0
	(h2-h1) mm	0	30
V-Funnel at T5minutes	sec	0	3

2.3 Cement Kiln Dust.

Cement Kiln Dust (CKD) is a waste material generated during production of cement. It is powdered in nature and composed of micro-sized particles that is usually collected from electrostatic particle size which depends on raw material to produce clinker, kiln types and fuels.

2.3.1 Advantages of using Cement Kiln Dust

Advantages of using cement kiln dust in concrete production [9]

(1) CKD opens a value added use option for its utilization.
(2) It assists in reducing the demand for new landfills when used for concrete production.
(3) CKD has micro-sized particles that is very useful for production of SCC.
(4) It improves the corrosion resistance of reinforcing steel in concrete.
(5) It is very useful in production of blended cement

(6) The use of cement kiln dust helps in waste management and also contributes significantly to sustainable development.

2.3.2 Properties of Concrete Containing CKD

Cement was replaced by cement kiln dust in a paste at proportions of 5 and 10% by mass [10]. The normal consistency of cement was at w/c ratio of 24.6%. The w/c ratio marginally increased to 24.9% when cement was replaced up to 10%. The mixes had water /cement ratio of 0.48. Specimen were produced and cured for 1, 3, 7 and 28 days. At all ages, the compressive strength results showed higher values for Cement-CKD blends than the control. At 28 days of curing, the compressive strength values showed an increase of 5% and 11% for 5% and 10% replacement respectively. It was concluded that CKD can replace cement in mortar up to 10% by weight.

The workability effect of CKD substitution at 0%, 20%, 40%, 60%, and 80% of PC in concrete mixes was explored. Each concrete mix was batched according to designed mix ratio of 1:3:4 at water cement ratio of 0.65. The final result showed that as CKD replacement level increased, the value of slump decreased [11].

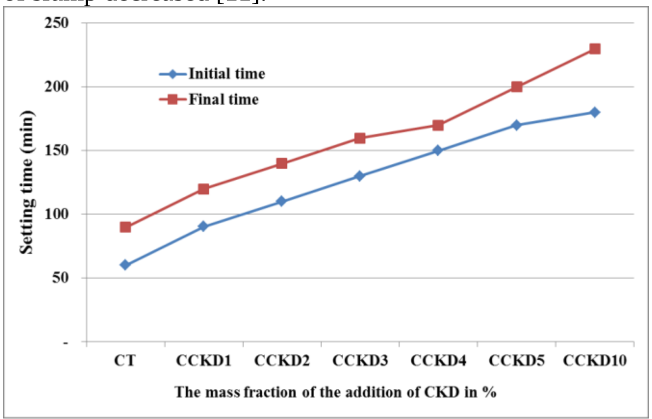

Figure 1: Variation of the setting time of the cement with addition of CKD [12].

2.4 Metakaolin (Mk)

Metakaolin is manufactured from kaolin after calcination under specific condition. Metakaolin can be produced by heating Kaolin at temperature range 0f 650-800ºC and required fineness of 700-900m^2/kg [13]. It reacts rapidly with excess calcium hydroxide produced form portland cement hydration to produce calcium silicate hydrate and calcium aluminosilicate hydrates [14, 15]. Kaolin is a clay material that is available in large quantity in Nigeria. It can be found in most states of Nigeria, such as Bauchi, Ekiti, Plateau, Oyo, Borno, Sokoto etc.[15]. Nigeria has a reserve of over three billion metric tonnes of kaolin deposit found in different parts of the country. If this resource can be tapped, calcined at 700ºC and reuse for cement replacement in concrete production, the cost of concrete would be brought down significantly [15].

Metakaolin increases the strength properties, reduces the hardened cement permeability to liquids and gases resulting in an increase in the service life of buildings. An investigation reported that metakaolin contribute significantly to strength development and reduction of ingress of sulphate solution in concrete when used as partial replacement of cement [16].

2.4.1 Oxide Composition of Metakaolin

Metakaolin has highest percentage of silica oxide and Alumina oxide [16]

Table 3: Oxide composition of Metakaolin.

Composition	Metakaolin (%)
Silica Oxide	54
Alumina Oxide	38
Calcium Oxide	0.4
Ferric Oxide	4.3
Magnesium Oxide	0.1
Potassium Oxide	0.5

2.4.2 Benefits of Adding Metakaolin as Admixture in Concrete.

Advantages of using metakaolin in concrete production

1. It improves the compressive, flexural and tensile strength properties of concrete.
2. It improves the early age strength development.
3. It improves durability by reducing permeability and resistance to chemical attack.
4. It reduces concrete shrinkage and alkali-silica reactivity.
5. It increases concrete density.

2.4.3 Properties of Concrete Containing Metakaolin.

A research was conducted on efficiency of Metakaolin as supplementary cementitious material in production of high strength concrete. Cement was replaced by metakaolin at 2.5% to 10% at different water/cementitious ratios of 0.2, 0.25, 0.3 and 0.35. The superplasticizer content was kept constant for all the mixes. Curing ages and water/cementitious ratios were the factors while the compressive strength was the response variable. The final result revealed that the adopted mix design was good for the production of high strength concrete with the maximum compressive strength of 95N/mm^2 [17].

In the research conducted by [18], metakaolin replaced Portland cement in concrete. The metakaolin used was gotten from Isan-Ekiti, Nigeria and was classified as N pozzolana. Chemical and mechanical tests were conducted on the concrete and the results revealed that the metakaolin exhibited higher percentages of silica oxide and alumina oxide. It was concluded that metakaolin contributed to the strength of concrete at optimal replacement cement at 20% by weight.

Cement with metakaolin and fly-ash in M20 grade concrete. Concrete mix design was done and both metakaolin and fly-ash replaced cement up to 30% by weight replacement Water/cement ratio was kept constant. Flexural and compressive strength tests were conducted at

7 and 28 days of curing. The result showed concrete with better performance when metakaolin replaced cement [19].
Investigation on the use of metakaolin and fly-ash in partial replacement of cement in M20 grade concrete was conducted. Cement was replaced by metakaolin and fly-ash from 5 to 20%. Compressive and tensile strength test were conducted at 7 and 28 days of curing. The optimal result was recorded at 10% replacement. Above 10% replacement, there was reduction in strength of concrete recorded.
An investigation was conducted on the effect of metakaolin and glass powdered in concrete [20]. Concrete specimens were cured at 7, 28, 56 and 90 days. It was reported that increase in curing period contributed immensely to strength development of concrete at later ages. Compressive strength result recorded showed that the optimal replacement was achieved at G10%M15% cured for 90 days. The higher the percentage increase in metakaolin and glass powder beyond the optimal percentage, the decrease in the compressive strength recorded [20].
Hydration and mechanical properties of concrete with metakaolin were experimentally investigated. The metakaolin was used to replace cement at 5%, 10% and 15%. Control specimens of concrete without metakaolin were produced also. Sorptivity, compressive strength and carbonation resistance tests were conducted at two water/cement ratios. The final result of the analysis showed that 10% of metakaolin as optimum replacement improved both the carbonation resistance and sorptivity of concrete [21]. It was also revealed by the researchers that metakaolin improved concrete properties by reducing its porosity through pozzolanic reactions [21].
Experimental research was conducted on properties of self-compacting concrete. Cement was replaced by metakaolin at 5, 10 and 15% replacement. Workability tests was conducted using slump flow, L-box and V-funnel test. Tensile strength and compressive strength test were conducted. The microstructural analysis was conducted by SEM, EDX and XRD. The workability results showed that the fresh concrete mix satisfied EFNARC requirement. The final result showed 10% optimum replacement of cement with metakaolin. The microstructural analysis showed a reduction of cracks in concrete containing metakaolin compared to concrete without metakaolin [22].

3. CONCLUSION

The following conclusions were made after the review:

(1) The oxide composition of metakaolin shows that it is classified as N-pozzolana with high percentages of silica oxide and alumina oxide.
(2) This study revealed that metakaolin replaced cement at 10%, 15% and 20% percentage replacements and cement kiln dust up to 10%. Any increase above the optimal reduces the strength properties of concrete.
(3) Cement kiln dust and metakaolin are both high water demand compared to cement. Therefore, their usage required high dosage of superplasticizer.
(4) Metakaolin contributes significantly to early strength development of SCC.
(5) Cement kiln dust (CKD) can be effectively used as a blended cement material.
(6) Metakaolin and cement kiln dust increase the consistency of cement paste.
(7) CKD decreases the setting time when mixed with cement in a paste.
(8) Metakaolin showed a good resistance to both acid and sulphate attack.
(9) Metakaolin showed better performance of flow ability of concrete, enhances the workability and finishing of concrete.
(10) The use of metakaolin and cement kiln dust help to compensate for environmental, technical and economic issues caused by cement production.

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