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COMPARATIVE STUDY OF PROPERTIES OF SELF COMPACTING CONCRETE WITH METAKAOLIN AND CEMENT KILN DUST AS MINERAL ADMIXTURES

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ABSTRACT

Self compacting concrete is highly flow able yet stable concrete that can spread readily into place and fill formwork without any consolidation and without undergoing significant separations. In general SCC results in reduced construction times and reduced noise pollution.

It is need of time to enhance the utility of SCC in respect with speedy construction such as works of retrofitting and to improve the permeability & early age strength. In view of these, high pozzolanic material as Metakaolin (MK) was used in SCC as a replacement of the cement.

An attempt has been made to study the behavior of SCC with MK & CKD as mineral admixtures and understands the effect of these mineral admixtures on fresh & hardened properties of SCC and also investigate the compatibility of above minerals powders in SCC along with chemical admixture such as super plasticizers. Considerable enhancement in self compact ability & hardened strength of SCC was observed at 10% replacement of cement by MK & CKD.

KEYWORDS: Self Compacting Concrete (SCC), Metakaolin (MK), Cement Kiln Dust (CKD), Modified Nan-Su Method, Flow Ability, Passing Ability, Resistance to Segregation

INTRODUCTION

The self compacting concrete is that which gets compacted due to its self weight and is deaerated (no entrapped air) almost completely while flowing in the formwork. In densly reinforced structural members, it fills completely all the voids and gaps and maintains nearly horizontal concrete level after it is placed. It consist of same components as conventionally vibrated normal concrete i.e. cement, aggregates, water, additives or admixtures.

Almost all concretes rely critically on being fully compacted. Insufficient compaction dramatically lowers ultimate performance of concrete in spite of good mix design. Concrete is the most widely consumed material in the world, after water. Placing the fresh concrete requires skilled operatives using slow, heavy, noisy, expensive, energy-consuming and often dangerous mechanical vibration to ensure adequate compaction to obtain the full strength and durability of the hardened concrete. Self-compacting concrete (SCC) is an innovative concrete that does not requires 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 mechanical properties and durability as traditional vibrated concrete.

The SCC has been described as the most revolutionary development on concrete construction for several decades. Originally to offsets a growing shortage of skilled labour, economically because of,

- Faster construction,
- Reduction in site manpower,
- Better surface finishes,
- Easier placing,
- Improved durability,
- Greater freedom in design thinner concrete sections,
- Reduce noise levels,
- Absence of vibration,
- Safer working environment.

Self-compacting concrete (SCC) offers various advantages in the construction process due to its improved quality, and productivity. SCC has higher powder content and a lower coarse aggregate volume ratio as compared to normally vibrated concrete (NVC) in order to ensure SCC's filling ability, passing ability and segregation resistance. If only cement is used in SCC, it becomes high costly, susceptible to be attack and produces much thermal crack. It is therefore necessary to replace some of the cement by additives, to achieve an economical and durable concrete. Nowadays, the ecological trend aims at limiting the use of natural raw materials in the field of building materials and hence there is an increased interest in the use of alternative materials (waste) from various industrial activities, which presents significant advantages in economic, energetic and environmental terms.

This study aims to focus on the possibility of use of Metakaolin and CKD to improve the properties of SCC.

LITERATURE REVIEW

The 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. The investigations in order to increase the use and to improve the properties of SCC are in vague.

Hagime Okamura & Masahiro Ouchi Investigation for Establishing a rational mix design method and self compact ability testing methods have been carried out from the view point of making SCC a standard concrete.

Naveen Kumar, C. Kiran, et.al The investigation is carried out and proved that SCC can be produced with cement content as low as 200 kg/m^3 of concrete. High Strength SCC can be obtained through incorporation of Metakaolin.

Dr. Hemant Sood, Dr. R K Khitoliya et.al. It is highlighted that the use of European Standards by various researchers for testing SCC in Indian condition.

Vilas V. Karjinni and Shrishail B. Anadinni To avoid number of trials for mixes for lower grade of concrete (below M50) a modified mixture proportion procedure for SCC ingredients is investigated. They have used modified

Nan-su method and obtained mix design in normal grades with different mineral admixtures & the compressive strength and flow properties of SCC are also studied. Kannan V. Ganeshan K It is investigated that the use of Metakaolin and Fly Ash Provides a positive effect on mechanical and transport properties of SCC. It also shows that the sample incorporating the ternary blend of cement with 15% Metakaolin and 15 % Fly Ash proved better compressive strength than that of normal SCC.

RESEARCH SIGNIFICANCE

The advancement in concrete technology to overcome the field problems initiates the use of Self-compacting concrete (SCC). Self-compacting concrete (SCC) has recently been one of the most important developments in the concrete technology. For a newly developing material like Self compacting concrete, studies on durability is of paramount importance for installing confidence among the engineers and builders. The literature indicates that some studies are available on the SCC with different mineral admixture as powder content (filler) but comprehensive studies are not available on fresh properties of self compacting concrete with different percentages of MK and CKD. Hence, considering the gap in the existing literature, an attempt has been made to study the effect of mineral admixture (MK & CKD) on the fresh properties of self compacting concrete.

REQUIREMENTS FOR CONSTITUENT MATERIALS

- Materials
- Cement

Selection of the type of cement will depend on the overall requirements for the concrete, such as strength, durability, etc. In this experimental study, Ordinary Portland cement 53 grade conforming to IS: 8112-1989.

Table 1: Properties of Cement

Physical Property	Results
Fineness (retained on 90-µm) sieve)	8%
Normal Consistency	28%
Vicat initial setting time(minutes)	75
Vicat final setting time (minutes)	215
Specific gravity	3.15
Compressive strength at 7-days	20.6 MPa
Compressive strength at 28-days	51.2 MPa

- **Coarse and Fine Aggregates**

All types of aggregates are suitable. The normal adopted size is ranged 10-12mm and limited to 20mm. Consistency of grading is of vital importance. Locally available natural sand with 4.75 mm maximum size was used as fine aggregate, having specific gravity, fineness modulus as given in Table 2 and crushed stone with 16mm maximum size having specific gravity, fineness modulus as given in Table 2 was used as coarse aggregate.

Table 2: Physical Properties of Coarse and Fine Aggregates

Property	Fine Aggregate	Coarse Aggregate
Specific Gravity	2.66	2.95
Fineness Modulus	3.1	7.69
Surface Texture	Smooth	--
Particle Shape	Rounded	Angular

Table 2: Contd.,

Crushing Value	---	17.40
Impact Value	---	12.50

- **Metakaolin**

Metakaolin is supplementary cementitious material that conforms to ASTM specification. Metakaolin is unique in that it is not the byproduct of industrial process nor is it entirely natural. It is derived from a naturally occurring mineral and is manufactured specifically for cementing applications.

Metakaolin is refined kaolin clay that is fired (calcined) under carefully controlled conditions to create an amorphous aluminosilicate that is reactive in concrete. Like other pozzolans, Metakaolin reacts with the calcium hydroxide (lime) byproducts produced during cement hydration. Calcium hydroxide accounts for up to *25%* of the hydrated Portland cement and calcium hydroxide does not contribute to the concrete's straight or durability. Metakaolin combines with the calcium hydroxide to produce additional cementing compounds, the material responsible for holding concrete together. Less calcium hydroxide and more cementing compounds means stronger concrete

Figure 1: Metakaolin

Metakaolin differs from other supplementary cementitious materials (SCMs), like fly ash, silica fume, and slag, in that it is not a by-product of an industrial process. It is manufactured for a specific purpose under carefully controlled conditions. Metakaolin is produced by heating of the most abundant natural clay minerals, to temperatures of 650-900 °C. Metakaolin also decreases concrete permeability, which in turn increases its resistance to sulfate attack and chloride attack, Metakaolin may reduce autogenous and shrinkage and avoids cracking.

- Main Applications of Metakaolin
- Ornamental concrete components
- Cement or lime based mortars
- High performance concrete
- Self compacting concrete
- Repairing and retrofitting works
- Monumental building construction

Metakaolin is obtained from Golden Micro Chemicals, Mulund West, Mumbai Quantity procured is 250 kg.

Table 3: Physical Properties of Metakaolin

Sr. No.	Physical Properties	Test Results
1.	Specific Gravity	2.5
2.	Fineness	90 µ passing
3.	Colour	White
4.	Bulk Density	330 gm/lit.

Table 4: Chemical Composition of MK

SiO_2	Fe_2O_3	$A1_2O_3$	CaO	MgO	K_2O	LOI
52.80%	4.21%	36.3%	0.1%	0.81%	1.41%	3.53%

- **Cement Kiln Dust (CKD)**

Figure 2: Cement Kiln Dust (CKD)

Cement Kiln Dust (CKD) is a waste product generated by the cement industry; it is a powder mainly composed of micron-sized particles collected from electrostatic precipitators during the manufacture of cement clinker. The chemical composition and particle size depend on the raw materials used to produce clinker, fuels and kiln types. The Environmental Protection Agency (EPA) estimated that the amount of CKD could range from 0 to 25% of the clinker produced. In this work is CKD obtained from Murli Agro Cement, Naranda, Tah. Korpana, Chandrapur. The CKD chemical composition is shown in table 4.

Table 5: Physical Properties of CKD

Sr. No.	Physical Properties	Test Results
1.	Specific Gravity	2.4
2.	Fineness	90 µ passing
3.	Colour	White

Table 6: Chemical Composition of CKD

SiO_2	Fe_2O_3	$A1_2O_3$	CaO	MgO	SO_3	Na_2O	K_2O
14.65%	2.13%	4.75%	41.72%	1.12%	0.72%	0.9%	0.6%

- **Mixing Water**

Water Quality must be established on the same line as that for using reinforced concrete or prestressed concrete.

- **Admixture (Super Plasticizer)**

The most important admixtures are the Super plasticizers (high range water reducers), used with a water reduction greater than 20% (upto 25% without loss of workability). Super plasticizers are essential components of SCC to provide necessary workability. The new generation super plasticizer termed polycarboxylated ether (PCE) is particularly used for SCC. A SP of FOSROC manufacturer of brand name CONPLAST SP 430 G8 was used as a super plasticizer with a density of 1.2 kg/lit. It was used to provide necessary workability, which complies with IS 9103-1999 & BS- 5075, Part – 3, It also confirms to ASTM - C – 494.

Table 7: Physical Properties of Super Plasticizer

Physical Properties	Results
Chloride Content	Nill
Specific Gravity	1.25
Colour	Greenish

MIX PROPORTIONING

The mix proportion was done based on the Modified Nan-Su method. The mix design was carried out for M30 normal grade of self compacting concrete with Metakaolin and CKD as partial replacement of cement with a fraction of 10%, 20% & 30%.

Table 8: Quantities of Materials for 1m^{3}of SCC Mixes (MK)

Mix	Mix-1 (kg/m^3)	Mix-2 (kg/m^3)	Mix-3 (kg/m^3)
Cement	343.8	305.6	267.2
Metakaolin (Filler)	245	245	245
Metakaolin as Cement Replacement	38.2	76.4	114.8
Total Powder Content	627	627	627
Fine Aggregate	710	710	710
Coarse Aggregate	612	612	612
W/P (0.45)	282	282	282
SP (1.2 %)	7.524	7.524	7.524

Mix 1: 10% Replacement of Cement with Metakaolin
Mix 2: 20% Replacement of Cement with Metakaolin
Mix 3: 30% Replacement of Cement with Metakaolin

Table 9: Quantities of Materials for 1m^{3}of SCC Mixes (CKD)

Mix	Mix-1 (kg/m^3)	Mix-2 (kg/m^3)	Mix-3 (kg/m^3)
Cement	343.8	305.6	267.2
CKD (Filler)	295	295	295
CKD as Cement Replacement	38.2	76.4	114.8
Total Powder Content	677	677	677
Fine Aggregate	710	710	710
Coarse Aggregate	612	612	612
W/P (0.38)	258	258	258
SP (1.2 %)	8.124	8.124	8.124

Mix 1: 10% Replacement of Cement with CKD
Mix 2: 20% Replacement of Cement with CKD
Mix 3: 30% Replacement of Cement with CKD

PROPERTIES OF SELF COMPACTING CONCRETE

Properties of Fresh SCC

A concrete mix is called Self Compacting Concrete if it fulfills the requirement of filling ability, passing ability and resistance to segregation.

Filling Ability: The property of SCC to fill all corners of a formwork under its own weight is known as filling ability. (Measured by slump test)

Passing Ability: The property of SCC to flow through reinforcing bars without segregation or blocking. (Measured by L-box test)

Resistance to Segregation: The property of SCC to flow without segregation of the aggregates. (Measured by V-funnel test at T5 minute)

Several test methods are available to evaluate these main characteristic of SCC, The tests have not been standardized by national or international organizations. The more common tests used for evaluating the compacting characteristics of fresh SCC in accordance with the draft standards of the Japan society of civil engineers are described below.

- **Test Method for Fresh SCC**

The main characteristics of SCC are the properties in the fresh state. SCC mix design is focused on the ability to flow under its own weight without vibration, the ability to flow through heavily congested reinforcement under its own weight, and the ability to obtain homogeneity without segregation of aggregates.

Several test methods are available to evaluate these main characteristics of SCC. The tests have not been standardized by national or international organizations. The more common tests used for evaluating the compacting characteristics of fresh SCC are described below.

The Slump Flow Test

L Box-Type Tests

V-Funnel Test

Table gives the recommended values for different tests given by different researches for mix to be characterized as SCC.

Table 10: Recommended Limits for Different Properties (as per EFNARC)

Sr. No.	Tests	Properties	Range
1.	The Slump Flow Test	Filling ability	650-800 mm
2.	V-Funnel Test	Viscosity	6-12 sec.
3.	L-Box H_2/H_1	Passing ability	0.8 - 1.0

- **Slump Flow Test**

Figure 3: Slump Cone

It is the most commonly used test and gives a good assessment of filling ability. The slump cone is held down firmly. The cone is then filled with concrete. No tamping is done. Any surplus concrete is removed from around the base of the concrete. After this, the cone is raised vertically and the concrete is allowed to flow out freely. The diameter of the Concrete in two perpendicular directions is measured. The average of the two measured diameters is calculated. This is the slump flow in mm, the higher the slump flow value, the greater its ability to fill formwork under its own weight. The range is from 650 mm to 800 mm.

Figure 4

- **L Box Test Method**

It assesses filling and passing ability of SCC. The vertical section is filled with concrete, and then gate lifted to let the concrete flow into the horizontal section. When the flow has stopped, the heights ‘H1’ and ‘H2’ are measured. Closer to unit value of ratio ‘H2/H1’ indicates better flow of concrete.

- **V- Funnel and V- Funnel at T5 min**

Figure 5: V-Funnel and V- Funnel T5 Test

The test measures flow ability and segregation resistance of concrete. The test assembly is set firmly on the ground and the inside surfaces are moistened. The trap Figure 2: L Box Test apparatus door is closed and a bucket is placed underneath. Then the apparatus is completely filled with concrete without compacting. After filling the concrete, the trap door is opened and the time for the discharge is recorded. This V-funnel test determines the filling ability of concrete.

This is taken to be when light is seen from above through the funnel. To measure the flow time at T 5minutes, the trap door is closed and V-funnel is refilled immediately. The trap door is opened after *5* Minutes and the time for the discharge is recorded. This is the flow time at T 5 minutes. Shorter flow time indicates greater flow ability. V- Funnel at T5 min indicates the resistance to segregation. It should be 0-3 sec. If concrete segregates, time increases.

RESULTS

Fresh Properties SCC

Metakaolin & CKD was used to replace the cement content by three various percentages (10, 20 and 30%). The partial replacement with Metakaolin & CKD was carried out for M30 grade of concrete. To fulfill the requirement of SCC in fresh state and evaluate flow characteristic using slump cone, V-funnel, & L-box tests and to fix dosage of super plasticizer (HRWRA) as per EFNARC guidelines and fix the dosage of water /powder ratio was needed. The test results are presented in the table 11 & 12.

Table 11: Fresh Properties of SCC with Metakaolin

Types	MK-10%	MK-20%	MK-30%
Slump Flow Test	720 mm	680 mm	710 mm
V-Funnel Test	7.22 sec.	6.34 sec	6.14 sec
L-Box Test	0.85	0.88	0.90

Table 12: Fresh Properties of SCC with CKD

Types	CKD-10%	CKD-20%	CKD-30%
Slump Flow Test	660 mm	660 mm	650 mm
V-Funnel Test	6.6 sec	6.76 sec	6.97 sec
L-Box Test	0.86	0.807	0.80

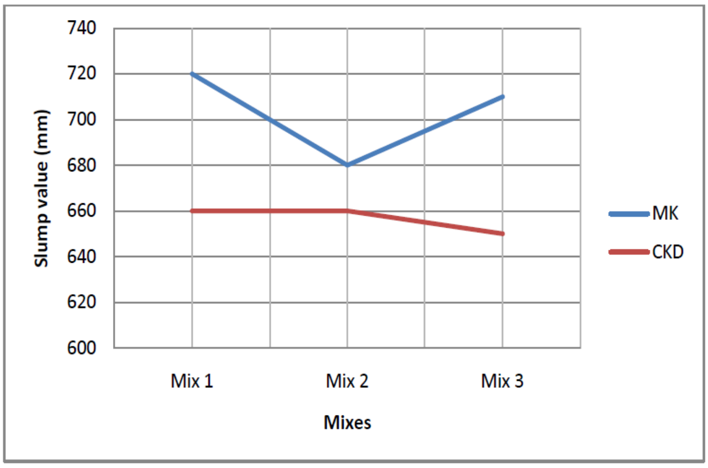

Figure 6: Slump Flow Value with Metakaolin & CKD

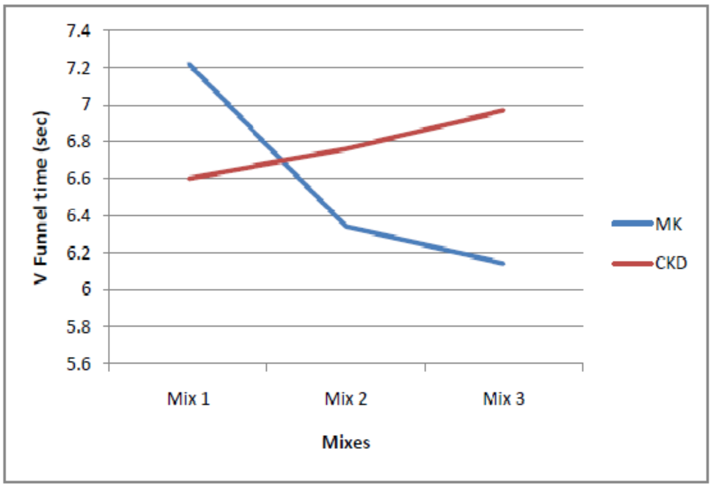

Figure 7: V-Funnel Value with Metakaolin & CKD

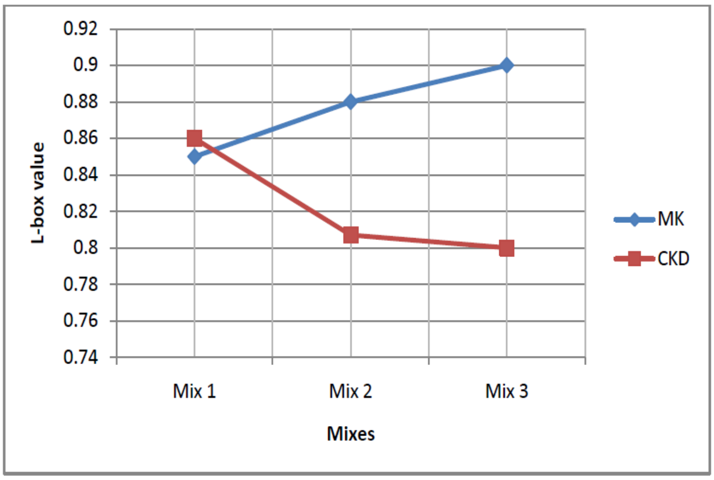

Figure 8: L-Box Value with Metakaolin & CKD

Hardened Properties Metakaolin

Table 13: Hardened Properties (7 Days)

Types	Mix 1		Mix 2		Mix 3	
Compressive Strength	25.5 Mpa	27 Mpa	24 Mpa	24.33 Mpa	15 Mpa	16.66 Mpa
	27.5 Mpa		25 Mpa		18 Mpa	
	28.5 Mpa		24 Mpa		17 Mpa	
Flexural Strength	6.48 Mpa	6.14 Mpa	5.4 Mpa	5.53 Mpa	5.4 Mpa	5.4 Mpa
	5.8 Mpa		5.67 Mpa		5.4 Mpa	
Split Tensile Strength	3.35 Mpa		3.04 Mpa		2.12 Mpa	

Table 14: Hardened Properties: (28 Days)

Types	Mix 1		Mix 2		Mix 3	
Compressive Strength	52 Mpa	40.66 Mpa	45 Mpa	40.66 Mpa	30 Mpa	32 Mpa
	45 Mpa		39 Mpa		32 Mpa	
	40 Mpa		38 Mpa		34 Mpa	
Flexural Strength	7.29 Mpa	7.96 Mpa	7.83 Mpa	7.29 Mpa	6.48 Mpa	6.71
	8.64 Mpa		6.75 Mpa		7.02 Mpa	
Split Tensile Strength	4.24 Mpa		3.82 Mpa		3.54 Mpa	

Table 15: Hardened Properties: (91 Days)

Types	Mix 1		Mix 2		Mix 3	
Compressive Strength	50 Mpa	47.33 Mpa	40 Mpa	40 Mpa	37 Mpa	37 Mpa
	48 Mpa		39 Mpa		36 Mpa	
	44 Mpa		40 Mpa		37 Mpa	
Flexural Strength	8.22 Mpa	8.37 Mpa	7.74 Mpa	7.62 Mpa	7.17 Mpa	7.12
	8.52 Mpa		7.50 Mpa		7.08 Mpa	
Split Tensile Strength	4.88 Mpa		4.1 Mpa		3.68 Mpa	

- **Hardened Properties of Cement Kiln Dust**

Table 16: Hardened Properties: (7 Days)

Types	Mix 1		Mix 2		Mix 3	
Compressive Strength	20 Mpa	21 Mpa	18 Mpa	19.67 Mpa	10 Mpa	11.66 Mpa
	21 Mpa		21 Mpa		12 Mpa	
	22 Mpa		20 Mpa		13 Mpa	
Flexural Strength	3.5 Mpa	3.92 Mpa	2.84 Mpa	3.04 Mpa	2.7 Mpa	2.84 Mpa
	4.32 Mpa		3.24 Mpa		2.97 Mpa	
Split tensile strength	2.12 Mpa		1.7 Mpa		1.42 Mpa	

Table 17: Hardened Properties: (28 Days)

Types	Mix 1		Mix 2		Mix 3	
Compressive Strength	30 Mpa	31.33 Mpa	27 Mpa	29.5 Mpa	18 Mpa	20 Mpa
	31 Mpa		31.5 Mpa		20 Mpa	
	33 Mpa		30 Mpa		22 Mpa	
Flexural Strength	5.28 Mpa	5.88 Mpa	4.27 Mpa	4.57 Mpa	4.06 Mpa	4.26 Mpa
	6.49 Mpa		4.87 Mpa		4.46 Mpa	
Split tensile strength	3.18 Mpa		2.55 Mpa		2.13 Mpa	

Table 18: Hardened Properties: (91 Days)

Types	Mix 1		Mix 2		Mix 3	
Compressive Strength	34 Mpa	31.66 Mpa	28 Mpa	30.33 Mpa	22 Mpa	21 Mpa
	31 Mpa		31 Mpa		20 Mpa	
	30 Mpa		32 Mpa		21 Mpa	
Flexural Strength	5.68 Mpa	5.99 Mpa	5.10 Mpa	5.074 Mpa	4.8 Mpa	4.77 Mpa
	6.30 Mpa		5.04 Mpa		4.74 Mpa	
Split tensile strength	3.39 Mpa		2.68 Mpa		2.68 Mpa	

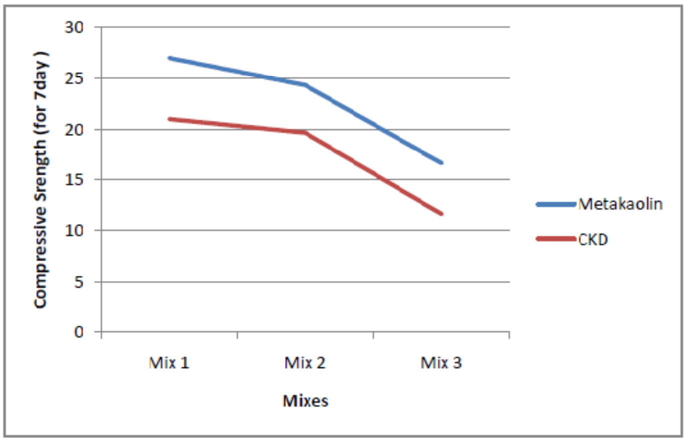

Figure 9: Compressive Strength Value with Metakaolin & CKD (7 Days)

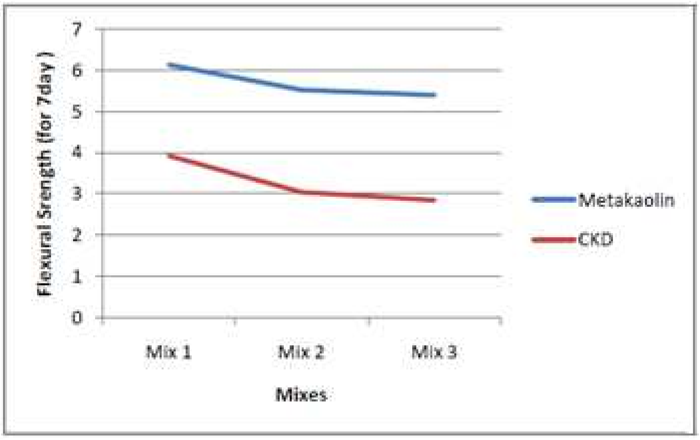

Figure 10: Flexural Strength Value with Metakaolin & CKD (7 Days)

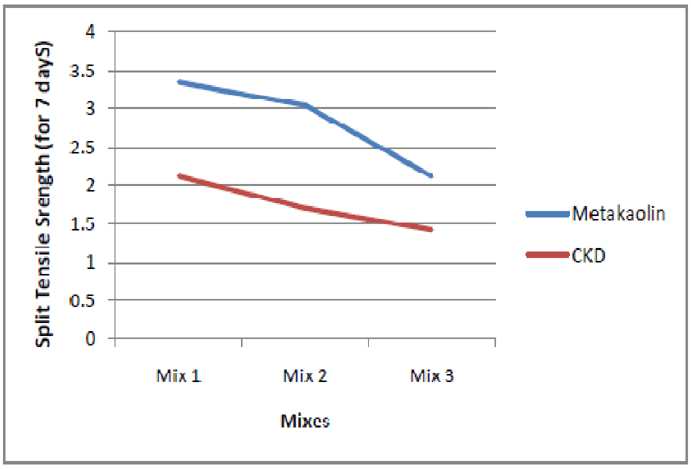

Figure 11: Split Strength Value with Metakaolin & CKD (7 Days)

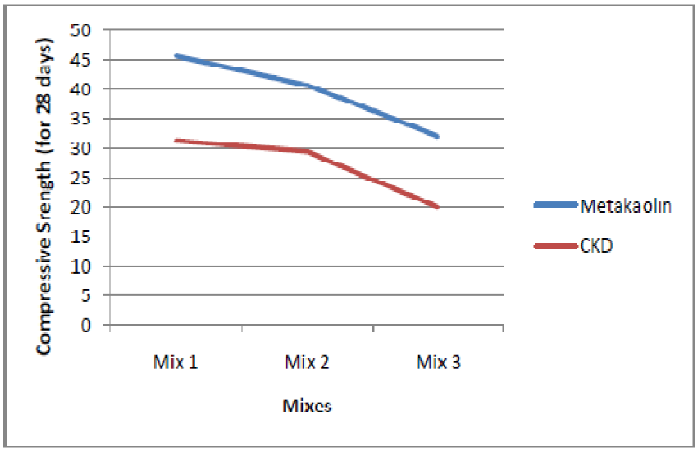

Figure 12: Compressive Strength Value with Metakaolin & CKD (28 Days)

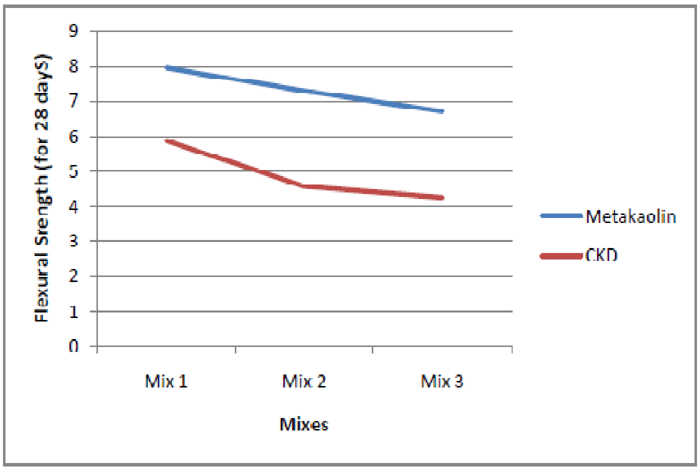

Figure 13: Flexural Strength Value with Metakaolin & CKD (28 Days)

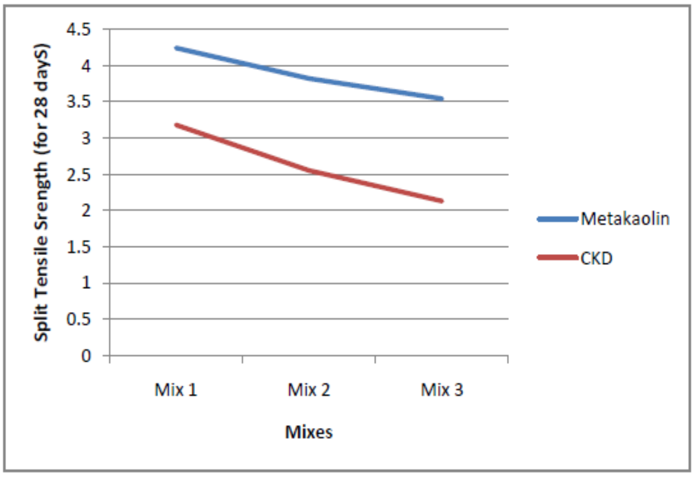

Figure 14: Split Strength Value with Metakaolin & CKD (28 Days)

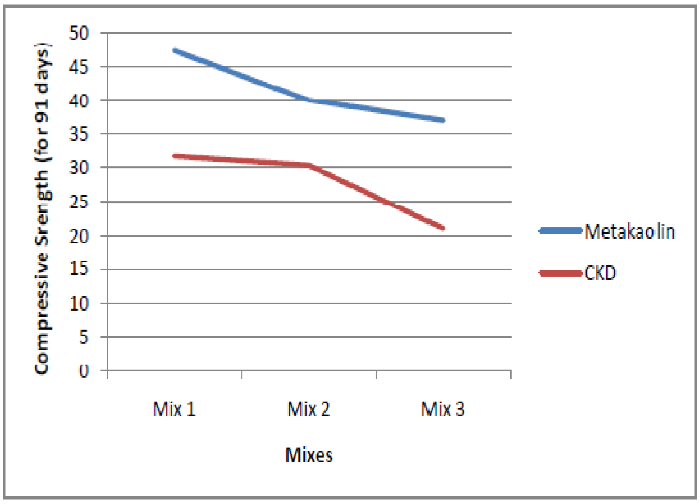

Figure 15: Compressive Strength Value with Metakaolin & CKD (91 Days)

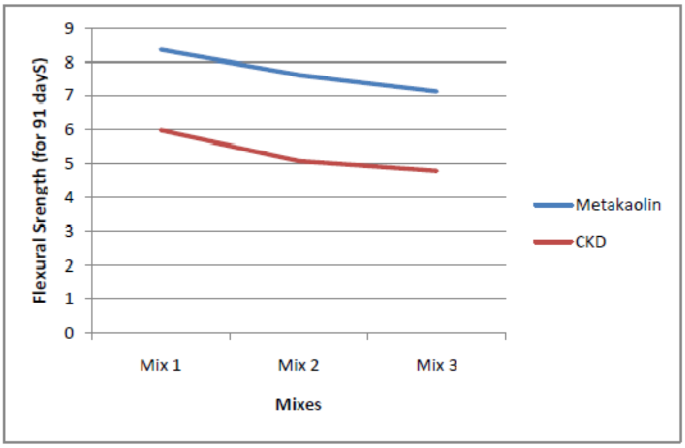

Figure 16: Flexural Strength Value with Metakaolin & CKD (91 Days)

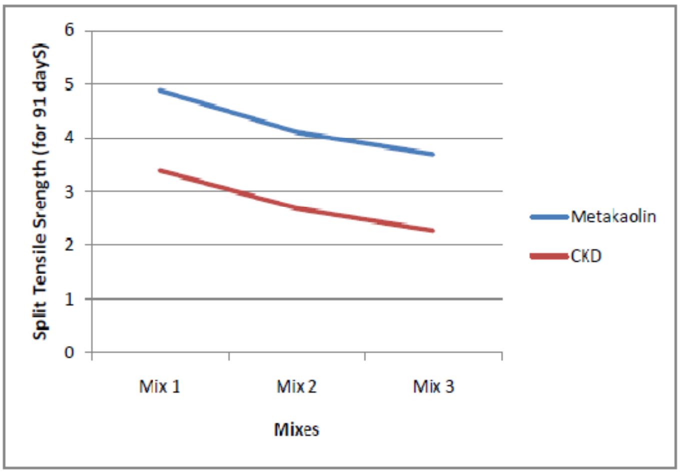

Figure 17: Split Strength Value with Metakaolin & CKD (91 Days)

CONCLUSIONS

- It has been reported that economically competitive SCC can be produced by replacing up to 50% of OPC with CKD an impermeable SCC can be produce by adding 20% Metakaolin compared with normal SCC.
- As long as the correct proportions are used when replacing Ordinary Portland cement with Metakaolin and CKD the durability of the structure will be enhanced, leading to a longer life for the concrete.
- The addition of 10 % Metakaolin and Cement Kiln Dust in SCC mixes increases the self compact ability characteristic like filling ability, passing ability, flowing ability and segregation resistance.
- The compressive strength, flexural strength and split tensile strength of SCC increases for 7 days to 28 days of curing, with replacement levels of 10%, 20%, 30 % of cement by Metakaolin & CKD.
- It can also be seen that compressive strength, flexural strength, split tensile strength is maximum for 10% replacement as compared to 20% and 30 %.

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