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Effect of metakaolin on the properties of conventional and self compacting concrete

S. Lenka[a] and K.C. Panda[*]

Department of Civil Engineering, ITER, SOA University, Bhubaneswar, 751030, Odisha, India

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Abstract. Supplementary cementitious materials (SCM) have turned out to be a vital portion of extraordinary strength and performance concrete. Metakaolin (MK) is one of SCM material is acquired by calcinations of kaolinite. Universally utilised as pozzolanic material in concrete to enhance mechanical and durability properties. This study investigates the fresh and hardened properties of conventional concrete (CC) and self compacting concrete (SCC) by partially replacing cement with MK in diverse percentages. In CC and SCC, partial replacement of cement with MK varies from 5-20%. Fresh concrete properties of CC are conducted by slump test and compaction factor tests and for SCC, slump flow, T500, J-Ring, L-Box, V-Funnel and U-Box tests. Hardened concrete characteristics are investigated by compressive, split tensile and flexural strengths at age of 7, 28 and 90 days of curing under water. Carbonation depth, water absorption and density of MK based CC and SCC was also computed. Fresh concrete test results indicated that increase in MK replacement increases workability of concrete in a constant w/b ratio. Also, outcomes reveal that concrete integrating MK had greater compressive, flexural and split tensile strengths. Optimum replacement level of MK for cement was 10%, which increased mechanical properties and robustness properties of concrete.

Keywords: metakaolin (MK); conventional concrete (CC); self compacting concrete (SCC); compressive strength; flexural strength; split tensile strength

1. Introduction

In recent year, an universal trend has been occurred for advancement of durable, low-priced and pioneering construction materials with respect to conventional materials for building low cost, sustainable and energy proficient structures. This has been done by aiming for fully or partially replacement of main stream construction material of concrete or their constituent's i.e., cement and aggregate. Utilisation of such constituents have improved workability, strength, durability, expected to decrease construction cost and also reduces CO_2 emission up to 30% to promote ecological balance of natural resources. Advance of construction materials that offer technical and environmental benefit is foremost challenge of new-fangled generation, among which sole material is Metakaolin (MK). Utilisation of MK in construction sector as partial replacement of

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[*] Corresponding author, Associate Professor, E-mail: kishoriit@gmail.com
[a] Post Graduate Student

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cement happened in 1960’s and curiosity for this material has substantially improved in contemporary times. MK is a white, amorphous, highly reactive aluminium silicate pozzolana, formed by calcinating kaolin clay at a temperature limit from 700-800°C. Usage of MK as a cement substitute can reduce emission of CO_2 up to 127 kg per ton of cement produced. MK gives high strength in concrete due to higher percentage of silica present in it; so MK increases mechanical strength of concrete due to pozzolanic reaction. MK has pozzolanic characteristics conveying positive consequences on ensuing features of concrete. Pozzolanic properties cause chemical reaction of active constituents through calcium hydroxide as artifact of cement hydration. This response points towards foundation of binding stages. So use of MK has comprehensive scope in its utilisation in an extraordinary strength concrete.

There has been growing interest in the use of MK as a supplementary cementitious material to impart an additional performance of concrete. Wild *et al.* (1996) made research on relative strength, pozzolanic activity and cement hydration in superplasticised MK concrete and concluded that MK shows a maximum strength enhancement at 20% replacement up to 14 days of curing. Roy *et al*. (2001) investigated impact of silica fume, MK and lower calcium fly ash (FA) on chemical resistance of concrete at various replacement levels and found that mortars made from three series, chemical resistance increased in the order of SF to MK to FA series and decreased as the replacement level is increased from 0-10% replacement level to 15-30% level. Qian and Li (2001) reported the tensile, bend, and compressive strength of concrete increases with increasing MK content especially at the early age. The tensile and compressive peak strains also increase with increasing MK content. Li and Ding (2003) explored on property improvement of Portland cement by incorporating MK and slag and showed that ultra-fine slag can advance physical and mechanical physiognomies of MK blended cement. When each MK (10%) and ultra-fine slag (20% or 30%) were incorporated into PC together, not only the compressive strength of the blended cement was increased, but also the fluidity of the blended cement paste was improved comparing to MK blended cement. Asbridge *et al.* (2002) investigated the variations in the microhardness of the hydrated cement matrix component of model mortar as functions of the distance from the aggregate surfaces for specimens in which the binder was Portland cement or a blend of Portland cement and MK. Khatib and Clay (2003) investigated the water absorption by total immersion and by capillary rise of concrete by using MK as replacing substantial of cement up to 20%. Outcomes showed that presence of MK is prominently valuable in dropping water absorption by capillary action. Courard *et al*. (2003) reported the effects of MK on transport properties of mortars. The transport properties and chemical behaviors were analyzed by means of chloride diffusion tests and sulfate immersion and optimum percentage of MK observed between 10% and 15% with regard to inhibition effect on chloride diffusion and sulfate attack. Siddique and Kalus (2009) observed that MK helps in enhancing the early age mechanical properties as well as long-term strength properties of cement paste, mortar and concrete also reported that concrete containing 10% and 15% MK replacements showed excellent durability to sulfate attack. Shekarchi *et al*. (2010) reported at 15% replacement level, compressive strength increased by 20%, while the water penetration, gas permeability, water absorption, electrical resistivity and ionic diffusion had improvements up to 50%, 37%, 28%, 450%, and 47% respectively and the 28-day ASR expansion for this mix was reduced as much as 82%. Melo and Carneiro (2010) studied the effect of the fineness and content of MK in SCC properties with different paste volumes, at fresh and hardened states. It was established that SP consumption increased with higher finesses and content of MK and decreased with lower finesses content of MK. Karahan *et al*. (2012) reported the increases in MK content worsened the filling and passing ability of self-consolidated

Table 1 Physical properties and chemical composition of MK

Physical properties of Metakaolin		Chemical composition of Metakaolin	
Characteristics	Standard values	Oxides	Average percentage
Brightness	85±1	SiO_2	52.8
Oil absorption (%)	60±5	Al_2O_3	36.3
Moisture (%)	0.5	Fe_2O_3	4.21
Ph of 10% solution	6±1	MgO	0.81
Particle size Average (d50)	1±1	CaO	<0.10
<10 Microns (%)	95±2	K_2O	1.41
<2 Microns (%)	80±1	LOI	3.53
Specific gravity	2±0.1		
Bulk Density (gms/lit)	320±20		
Residue on 400	Nil		

light weight concrete (SCLC) and by the addition of MK no positive effect on the strength properties of SCLC. Also, observed that increases in MK content showed significant improvement in chloride ion penetration resistance of SCLC. Hassan *et al.* (2011) reported that highly durable SCC mixtures can be produced using a high MK content with an optimum percentage of around 20%. Also observed that the durability of SCC with high MK content was higher than that of SCC containing SF. Madandoust and Mousavi (2012) conceded out an experiment on fresh and hardened properties of SCC comprising MK and found 10% MK will be considering as appropriate replacement concerning to economic efficacy, fresh and hardened property of MK concrete. Khaleel and Razak (2014) proposed mix design method for SCC utilizing different properties of coarse aggregate and reported optimum MK replacement level for cement was 10% from the viewpoint of workability and strength. Perlot *et al.* (2013) investigated the development of new SCC which combined limestone filler and MK slurry to increase mechanical and durability property in precast industry. Dinakar and Manu (2014) proposed a novel methodology for the design of high strength self compacting MK concrete based on the efficiency concept and reported that the proposed method can be capable of producing high strength SCC of about 120 MPa. Badogiannis *et al.* (2015) evaluated the durability of SCC incorporating MK. MK was utilised as replacing substantial of either cement or limestone powder, at different levels. Test result showed that incorporation of MK improved durability, but not the near surface water permeability of the concrete. Akcay *et al.* (2016) reported that the rigidity of concretes increased with using 8% and 16% of MK, while it decreased in all series (0.42, 0.35 and 0.28 water to binder ratio) with 24% of MK replacement.

However, different aspects of CC containing MK have been reported in the literature but very little information is available about the properties of SCC containing MK. Also the comparative study of CC and SCC is not well documented in the literature. So, the present study is an effort to characterize the fresh, hardened and durability properties of CC and SCC containing MK. Several tests conducted to know the fresh concrete properties of SCC, such as slump flow, T_{500}, J-ring, V-funnel, L-box and U-box test to assess the workability of the concrete mix. The hardened properties were evaluated by compressive, flexural and split tensile strength and also the comparative study is carried out between CC and SCC. The durability of CC and SCC was evaluated by total water absorption and carbonation test. The XRD analysis of MK is carried out to

Fig. 1 Metakaolin sample

know the undissolved ingrediens which are present in the MK.

2. Experimental study

2.1 Materials utilised

In this investigation, Ordinary Portland Cement (OPC) of grade 43 endorsing to IS: 8112-1989 is utilised. Explicit gravity of cement is 3.15, preliminary set time of cement is 165 min and ultimate set time of cement is 360 min. Natural river sand confirming to zone III as per IS:383-1970 is used. Specific gravity of natural sand is 2.67; fineness modulus is 3.03, water absorption is 0.40 and bulk density is 1568 kg/m^3. Natural coarse aggregate (NCA), 20 mm passing confirming to IS:383-1970 is used. Explicit gravity of NCA is 2.86; abrasion value is 34.78%, impact value is 24.00%, crushing value is 23.30%, water absorption is 0.20% and fineness modulus is 7.00. High end super plasticizer-(Cerahyperplast XR-W40), specific gravity of 1.06 and locally available potable water is used for mixing of concrete. MK used in this study is a white powder as shown in Fig. 1. Physical properties and chemical composition of the MK are provided in Table 1.

2.2 Characterization of metakaolin

The X-ray powder diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions. The need of XRD analysis is to show the undissolved ingrediens which are present in the MK. The investigated material is magnificently ground, homogenized, and typical bulk configuration is resolute. XRD test was conducted by taking a few gram of oven dried MK sample. Results were accessible as peak locations at 2θ and X-ray counts (intensity) in custom of x-y strategy presented in Fig. 2. The undissolved ingredient present in the MK such as Quartz, microcline and illite. The existence of both humps and peaks of MK at the diffraction angle of 20° to 35° suggest the amorphous phase in structure with peaks for microcline, quartz and illite. High quartz content is in agreement with the high silica (SiO_2) content (52.8%) measured by the XRF analysis, which enhances the concrete strength.

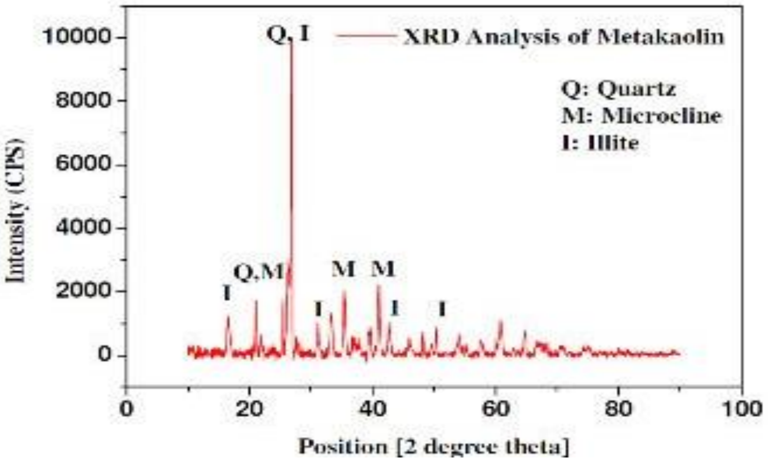

Fig. 2 XRD analysis of MK sample

Table 2 Particulars of concrete mix (C) fraction along with identification

Concrete mix proportions	Mix identity
Cement 100%+NFA 100%+NCA 100%	CM0
Cement 95%+NFA 100%+NCA 100%+MK 5%	CM5
Cement 90%+NFA 100%+NCA 100%+MK 10%	CM10
Cement 85%+NFA 100%+NCA 100%+MK 15%	CM15
Cement 80%+NFA 100%+NCA 100%+MK 20%	CM20
Cement 100%+NFA 135%+NCA 65%+SP (0.35%)	SCM0
Cement 95%+NFA 135%+NCA 65%+MK 5%+SP (0.35%)	SCM5
Cement 90%+NFA 135%+NCA 65%+MK10%+SP (0.35%)	SCM10
Cement 85%+NFA 135%+NCA 65%+MK 15%+SP (0.35%)	SCM15
Cement 80%+NFA 135%+NCA 65%+MK20%+SP (0.35%)	SCM20

2.3 Mix proportion

In this study, MK used as supplementary cementitious materials in concrete. M30 grade concrete is designed for CC as per typical description IS: 10262-2009 to acquire mark mean strength of 39.9 MPa for a tolerance factor of 1.65. Mix proportion 1:1.44:2.91 were taken for this experiment. Five concrete mixes were made for CC by replacing 0%, 5%, 10%, 15% and 20% of cement with MK to optimize properties of concrete. All CC mixes have been tasted in a constant w/b ratio i.e., 0.43. C indicates conventional concrete mix. Also five SCC mixes were prepared. SC indicate self-compacting concrete mix with 0%, 5%, 10%, 15% and 20% replacement of MK in cement in addition of w/b ratio 0.43 and 0.35% of SP producing substantial upgradation in workability and homogeneity of fresh concrete mix as well as mechanical assets and robustness respectively. Mix design have prepared in trial basis. Trials have done by increasing of 35% of NFA by decreasing 35% of NCA with 0.35% of SP. Fresh concrete mix results satisfied EFNARC guidelines. Particulars of concrete mix share along with identification have been designated with respect to replacement as specified in Table 2.

Table 3 Particulars of concrete mix (C and SC) quantity per m^3 of concrete

Mix identity	Cementitious materials per m^3 of concretes		NFA (kg)	NCA (kg)	Water (kg)	SP (kg)
	Cement (kg)	MK (kg)				
CM0	434.32	0	624.77	1264.97	186.76	-
CM5	412.60	21.72	624.77	1264.97	186.76	-
CM10	390.89	43.43	624.77	1264.97	186.76	-
CM15	325.74	65.12	624.77	1264.97	186.76	-
CM20	304.02	86.86	624.77	1264.97	186.76	-
SCM0	434.32	0	843.43	822.23	186.76	1.52
SCM5	412.60	21.72	843.43	822.23	186.76	1.52
SCM10	390.89	43.43	843.43	822.23	186.76	1.52
SCM15	325.74	65.12	843.43	822.23	186.76	1.52
SCM20	304.02	86.86	843.43	822.23	186.76	1.52

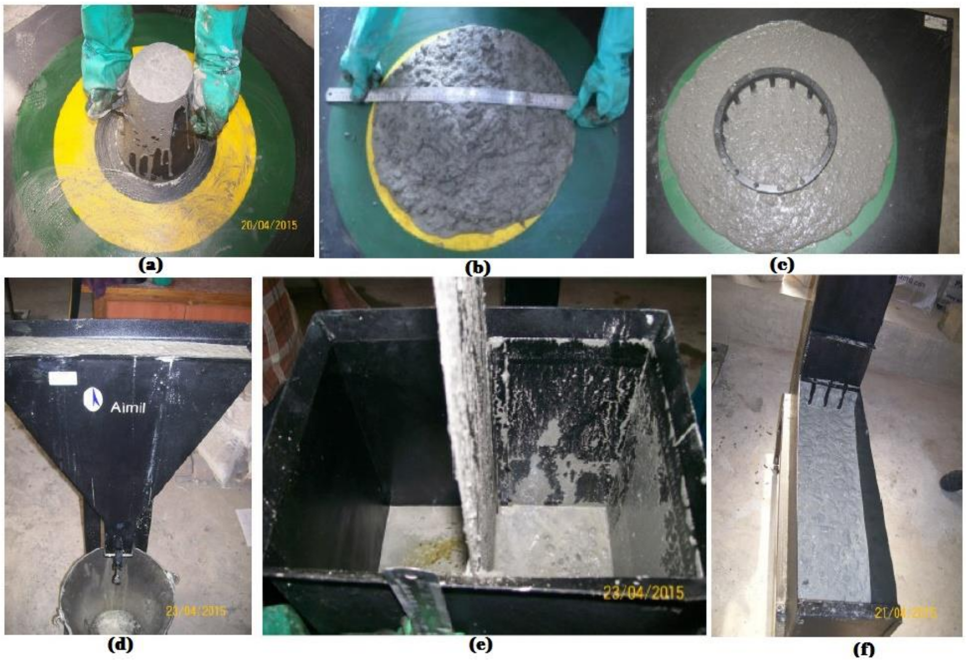

Fig. 3(a) Slump Flow (b) T_{500} (c) J-Ring (d) V-Funnel (e) U-Box (f) L-Box test

Particulars of concrete mix quantity per m^3 of concrete are accessible in Table 3. CM0 indicate 0% of MK and 100% of cement, CM5 indicate 5% of MK with 95% of cement, CM10 indicate 10% of MK with 90% of cement, CM15 indicate 15% MK with 85% of cement and CM20 indicate 20% MK with 80% cement.

2.4 Fresh concrete test

The fresh concrete test was conducted to know the potentiality of CC and SCC.

Table 4 Slump and compaction factor value of conventional concrete

Mix identity	Water binder ratio	Slump value (mm)	Compaction factor
CM0	0.43	45	0.86
CM5	0.43	47	0.87
CM10	0.43	50	0.88
CM15	0.43	53	0.89
CM20	0.43	58	0.91

Table 5 Fresh concrete features of slump flow, T_{500} and J-ring

Mix Identity	Slump Flow (mm)		T_{500} Test (Seconds)		J-ring Test		
	Test Result (mm)	EFNARC (2005) Criteria	Test Result	EFNARC (2005) Criteria	Step height result (mm)	Total flow result (seconds)	EFNARC (2002) Criteria
SCM0	560	550-650	17	>2	10	21	0 – 10
SCM5	575	550-650	16	>2	09	18	0 – 10
SCM10	580	550-650	14	>2	07	15	0 – 10
SCM15	590	550-650	10	>2	08	13	0 – 10
SCM20	600	550-650	9	>2	06	10	0 – 10

Potentiality of fresh concrete is depends upon materials and mix proportions and also on environmental conditions. Potentiality of fresh CC was dignified through means of slump test and compaction factor test. For SCC, six experiments were conducted in laboratory such as slump flow test, T_{500} test, J-Ring test, V-Funnel test, L-Box test and U-Box test. Slump flow is utilised to weigh flowability of SCC in lack of impediments. Slump flow test was conducted for each proportion of mixing. The result was sign of satisfying capability of SCC. T_{500} test is utilised to weigh horizontal free flow in lack of impediments. A greater flowability is an indication of lower time. The J-Ring test is utilised for evaluation of passing ability of SCC. V-funnel test is utilised to weigh viscosity and satisfying capability of SCC. L-Box test measures filling and passing capability of SCC. Test is also applicable for highly flowable concrete. The U-Box test is utilised to regulate confined flowability and capacity of SSC to flow within confined spaces. The slump flow, T_{500}, J-Ring, V-Funnel, U-Box and L-Box test is obtainable in Fig. 3.

2.5 Hardened concrete test

The hardened concrete test was conducted at 7, 28 and 90 days of curing under water. After casting, curing has been done properly to achieve the target mean strength of specimens such as cube (150 mm×150 mm×150 mm) for compressive strength, cylinder (100 mm dia. and 200 mm height) for split tensile strength and prism (100 mm×100 mm×500 mm) for flexural strength. Compressive, flexural and split tensile strengths tests were conducted to recognize strength characteristics of concrete specimens containing MK with various replacement of cement. Water absorption test was conducted in cube specimen. Percentage of total water absorption has computed. Carbonation test was conducted by taking splitting of

Table 6 Fresh concrete features of V-funnel, L-box and U-box

Mix Identity	SP (%)	V- funnel (Seconds)		L-box (Passing Ability)			U-box (Filling Ability)	
		Test Result	EFNARC (2005) Criteria	Test Result H_2/H_1	T40 Sec	EFNARC (2005) Criteria	Test results H_2-H_1	EFNARC (2005) Criteria
SCM0	0.35	17	7 – 27	0.76	18	≥ 0.80	69	≤ 80
SCM5	0.35	15	7 – 27	0.80	17	≥ 0.80	70	≤ 80
SCM10	0.35	14	7 – 27	0.87	14	≥ 0.80	73	≤ 80
SCM15	0.35	12	7 – 27	0.88	11	≥ 0.80	75	≤ 80
SCM20	0.35	9	7 – 27	0.89	10	≥ 0.80	78	≤ 80

cylindrical specimens of different mixes and spraying 1% phenolphthalein solution into splitting surface. Depth of carbonations measured based on change in colour profile and in carbonated spaces in which pH is lesser than 9.2, result persist colourless and in non-carbonated areas in which pH is superior than 9.2, phenolphthalein pointer turned out as purple red.

3. Results and discussions

3.1 Fresh concrete test outcomes of CC and SCC

The fresh concrete test was conducted to know the workability of concrete. Potentiality of fresh CC was dignified with slump test and compaction factor test which is done immediately after mixing. For different concrete mix, cement was moderately replaced by MK 5-20% and variation of slump and compaction factor values are represented in Table 4. MK increases workability as replacement level of MK increases.

The fresh self compacting properties such as slump flow, T_{500} and J-ring for different mixes are presented in Table 5 and V-funnel, L-box and U-box are presented in Table 6.

Table 5 represent slump flow results for MK based concrete. The lower flow time indicates that high flowability nature of concrete. From 5-20% replacement of MK belongs to slump flow classes SF1 according to EFNARC (2005) guidelines. Khaleel and Razak (2013) made research on effect of MK on properties of SCC and indicates that optimum percentage of MK with constant w/c ratio provides more slump flow. T_{500} is classified into two classes in EFNARC (2005) guidelines i.e., VS1 and VS2, for VS1 class outcome is ≤2 and for VS2 class outcome is >2. In this study, outcomes come under VS2 class. It is observed from Table 5 that, as replacement of cement with MK increases in concrete, time of flow to reach the 500 mm diameter decreases, so it indicates increase in flowability of SCC. With respect to EFNARC (2002) rules, J-ring test outcomes should fabricates in amid 0-10 mm. With test outcomes it is indicate that all test outcomes come under EFNARC (2002) guidelines criteria and lies amid 0-10 mm.

Table 6 represents V-funnel, L-box and U-box test results for different composition of MK based concrete. In response to EFNARC (2005) strategies, V-Funnel test outcomes ≤10 s, it comes under VF1 classes and test results in between 7-27 s come under VF2 classes. Present

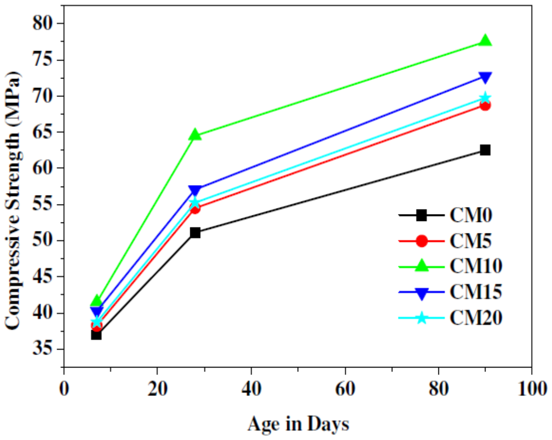

Fig. 4 Compressive strength versus age in days

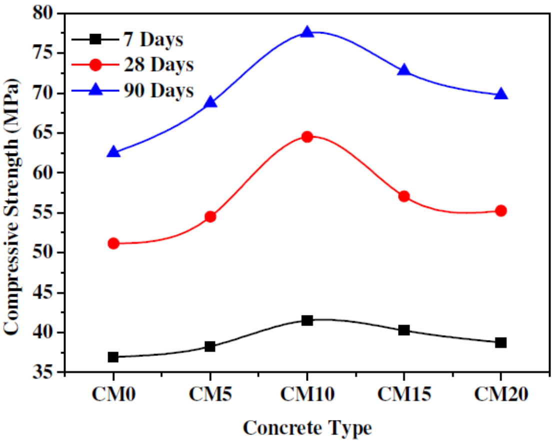

Fig. 5 Compressive strength versus concrete mix

test results come under VF2 classes which satisfy the EFNARC (2005) guidelines. In MK based concrete mix, with increase amount of MK in a concrete mix, decreases flow time in constant amount of SP (35%), to satisfy EFNARC (2005) guidelines criteria. According to EFNARC guidelines, L-Box test results ≥ 0.80 comes under PA1 classes with 2 rebars and the test results ≥0.80 comes under PA2 classes with 3 rebars which satisfy EFNARC (2005) guidelines. Madandoust and Mousavi (2012) made research on fresh and hardened features of SCC encompassing MK and concluded that by increased MK, passing capability of concrete was also increased. Present analysis shows that SCC mixtures encompassing MK were customarily satisfying blocking ratio (H_2/H_1). In U-Box test, modification in loftiness of concrete between two compartments was measured. As per EFNARC (2005) guidelines values should be less than 80 and it satisfied the guideline.

3.2 Hardened concrete test results of conventional concrete

Compressive, split tensile and flexural strength test outcomes were attained by testing cube, cylinder and prism specimens at time interim of 7, 28 and 90 days. Compressive strength versus age in days and compressive strength for different concrete mixes is presented in Figs. 4-5. The results showed that the compressive strength in the case of CM5 slightly increase up to 10% (38.25 MPa, 54.50 MPa and 68.75 MPa). The compressive strength with CM10 drastically increased up to 24% (41.50 MPa, 64.50 MPa and 77.50 MPa) for 7, 28 and 90 days of curing respectively. In other hand as compared to CM10 for the case of CM15 the compressive strength slightly lower (40.25 MPa, 57.05 MPa and 72.75 MPa) and for CM20 also compressive strength is lower (38.75 MPa, 55.25 MPa and 69.75 MPa) for 7, 28 and 90 days of curing. It is perceived that increase of MK, intensifies compressive strength up to 10% replacement due to rapid reaction rate of MK and its ability to accelerate cement hydration. Thereafter the reduction in strength takes place, but the strength is greater than control specimen. However, it is perceived that compressive strength of MK concrete is superior to CM0 at all age. Khatib and Clay (2003) studied about impact of innumerable amount of MK on act of plain cement concrete and reported that compressive strength increases with increase of MK content in hardened concrete.

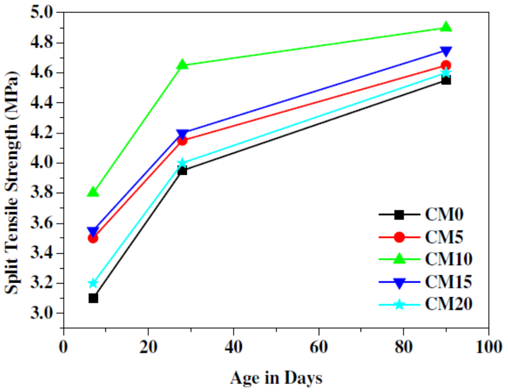

Fig. 6 Split tensile strength versus age in days

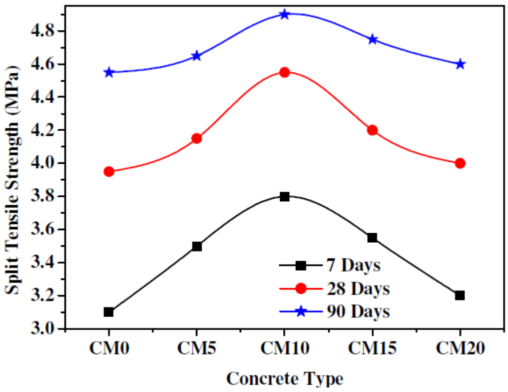

Fig. 7 Split tensile strength versus concrete mix

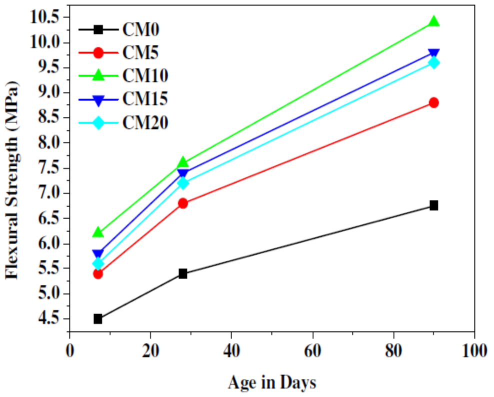

Fig. 8 Flexural strength versus age in days

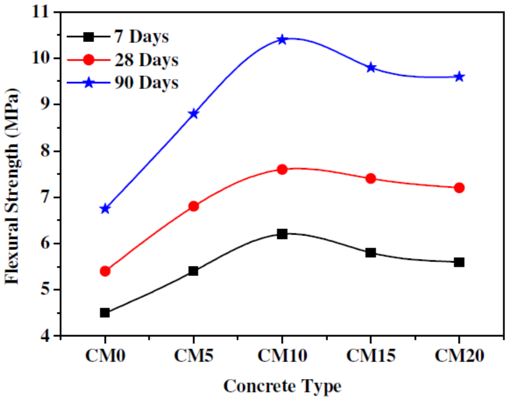

Fig. 9 Flexural strength versus concrete mix

Split tensile strength versus age in days and split tensile strength for diverse concrete mixes is accessible in Figs. 6-7. It is perceived that increase of MK, increases split tensile strength up to 10% replacement of cement (3.80 MPa, 4.55 MPa and 4.9 MPa). CM10 give higher split tensile strength as compared to other concrete mix. Guneyisi *et al*. (2012) studied about tensile strength of MK and reported that highest tensile strength value obtained from concrete made with 15% replacement of MK at a constant w/b ratio.

Flexural strength versus age in days and flexural strength for different concrete mixes is presented in Figs. 8-9. It is perceived that mix CM10 gives maximum flexural strength as compared to other mixes (6.2 MPa, 7.6 MPa and 10.4 MPa for 7, 28 and 90 curing days respectively). Yerramala *et al*. (2013) premeditated about flexural strength of MK concrete and suggested that the highest rate of strength gain was observed at 10% and 15% replacement with corresponding 28 days strength. From the above test result, 10% replacement of cement with MK gives maximum compressive, split tensile and flexural strength of concrete.

3.3 Hardened concrete test results of self compacting concrete

The compressive strength versus age in days and compressive strength for different

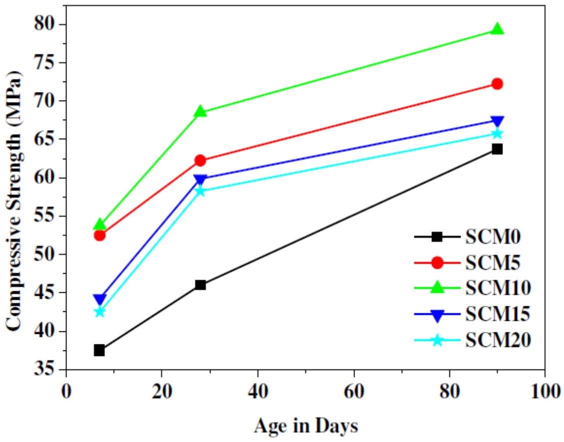

Fig. 10 Compressive strength versus age in days

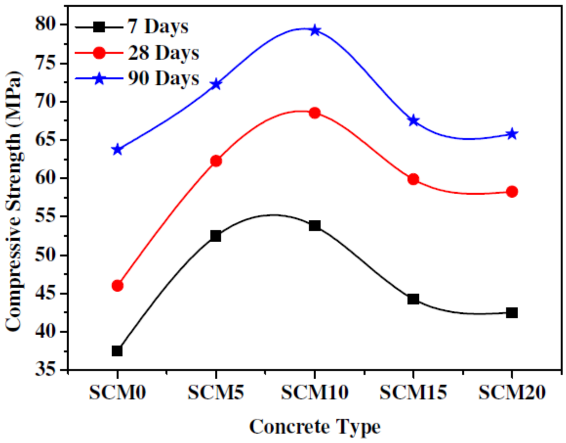

Fig. 11 Compressive strength versus concrete mix

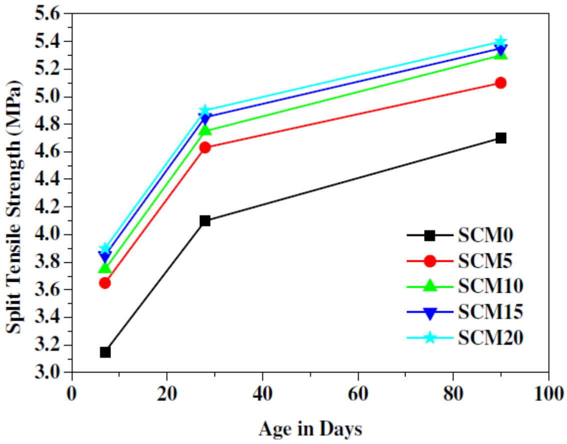

Fig. 12 Split tensile strength versus age in days

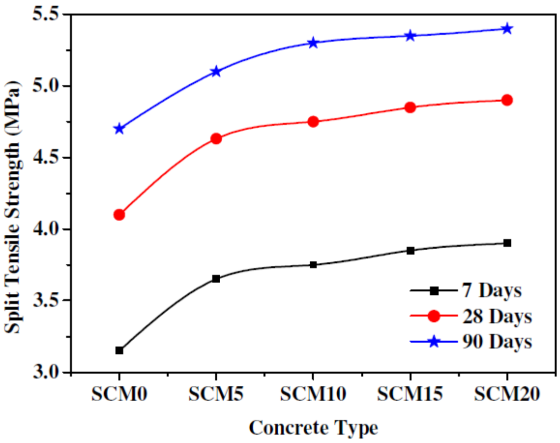

Fig. 13 Split tensile strength versus concrete mix

concrete mixes is presented in Figs. 10-11. Results showed that compressive strength of SCM5 after 7, 28 and 90 days are increased up to 40%, 35.32% and 13.33% (52.50 MPa, 62.25 MPa and 72.25 MPa) respectively as compared with control specimen and for SCM10 increased up to 43.33%, 48.91% and 24.31% (53.75 MPa, 68.5 MPa and 79.25 MPa) respectively. It indicates that MK harshly upsurges compressive strength test results up to 10% replacement of cement. In other hand as compared to SCM10, for case of SCM15 and SCM20 compressive strength lower (40.25 MPa, 57.05 MPa and 72.75 MPa) and (38.75 MPa, 55.25 MPa and 69.75 MPa) for 7, 28 and 90 curing days respectively. It is perceived that increase of MK, upsurges compressive strength up to 10% replacement due to rapid reaction rate of MK and its ability to accelerate cement hydration.

Split tensile strength versus age in days and split tensile strength for various concrete mixes is presented in Figs. 12-13. It is perceived that increase of MK, increases split tensile strength up to 20% replacement of cement (3.9 MPa, 4.9 MPa & 5.4 MPa) compared to other concrete mix at a constant w/b ratio.

Flexural strength versus age in days and flexural strength for various concrete mixes is

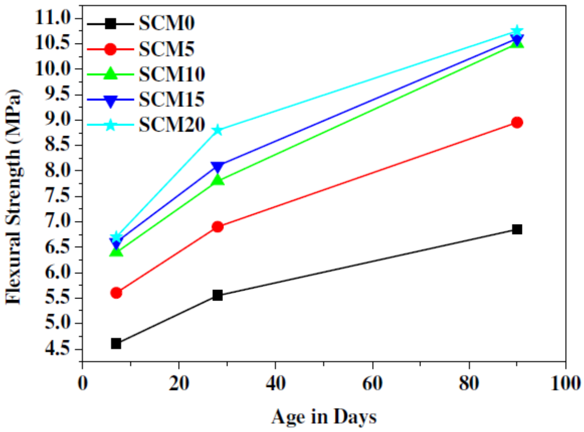

Fig. 14 Flexural strength versus age in days

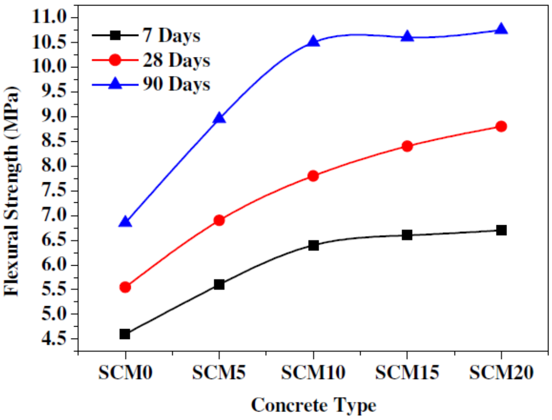

Fig. 15 Flexural strength versus concrete mix

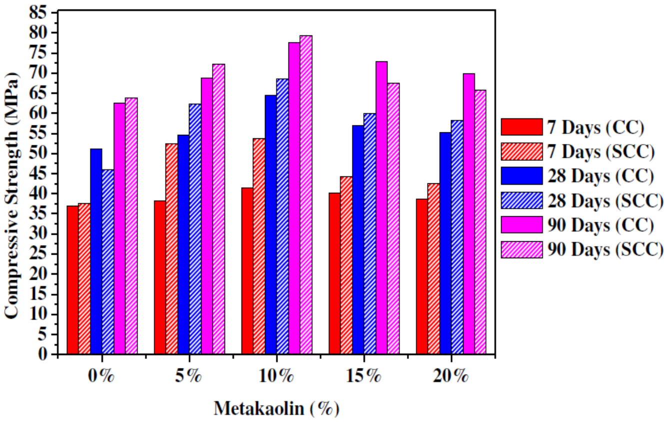

Fig. 16 Comparison of compressive strength amid CC and SCC with MK

obtainable in Figs. 14-15. It is perceived that in SCC, at 20% replacement of cement with MK (6.70 MPa, 8.8 MPa and 10.75 MPa) gives higher flexural strength at all age as compared to other mixes. It is concluded that for SCC, compressive strength attain higher value at 10% replacement of MK, whereas in flexural and split tensile strength, the strength increased up to 20% replacement of MK with cement.

3.4 Comparison between CC and SCC test results

Assessment of compressive strength amid CC and SCC of MK based concrete is shown in Fig. 16. It is observed that for 0% MK based concrete, 7 and 90 days compressive strength of SCC gives superior value than CC, whereas at 28 days CC gives higher value than SCC. MK is replaced between 5-20% for CC and SCC. Replacement of 10% MK in SCC gives higher value than CC in 7 days tests. For 7 days, 0%, 5%, 10%, 15% and 20% replacement of MK, SCC value gives higher than that of CC values. For 28 days, only 0%, CC value shows higher than that of SCC values but 5%, 10%, 15% and 20% replacement of MK, SCC value gives higher than that of CC values. For 90 days, at 0%, 5% and 10% replacement of MK, SCC gives higher strength than that of CC, but

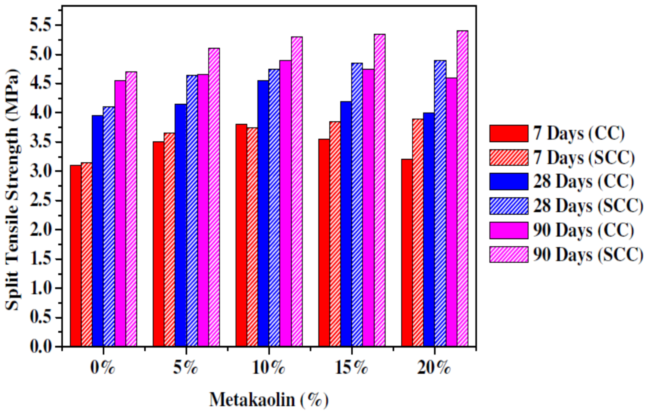

Fig. 17 Comparison of split tensile strength amid CC and SCC with MK

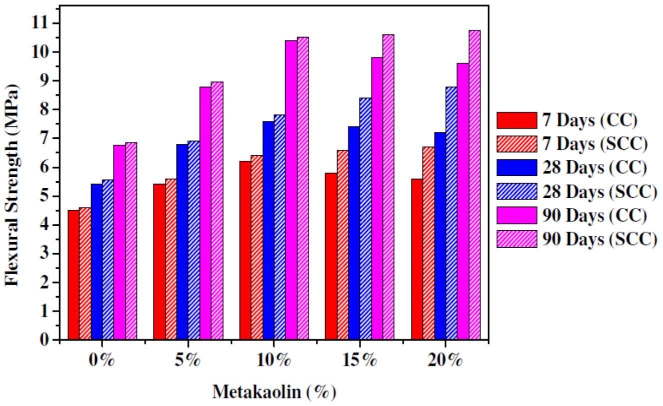

Fig. 18 Comparison of flexural strength amid CC and SCC with MK

at 15%, and 20% replacement of MK, CC gives higher strength than that of SCC. Li and Ding (2003) reported that concrete accomplished uppermost compressive strength with 10% MK contents. Poon *et al*. (2001) also concluded that concrete encompassing 5% to 20% of MK had greater compressive strength to control at ages, with paste encompassing 10% MK performing finest outcome. At 10% replacement of MK, CC and SCC gives higher compressive strength than that of all other mixes.

Comparison of split tensile strength amid CC and SCC of MK based concrete is observed in the Fig. 17. The amount MK is replaced in between 5-20%. The split tensile strength result of SCC after 7, 28 and 90 days is more than CC. At 5%, 10%, 15% and 20% replacement of MK for 7, 28 and 90 days, SCC gives the higher values than that of CC respectively. But at 20% replacement of MK, SCC gives maximum value than that at all other mixes. Guneyisi *et al.* (2013) observed maximum split tensile strength of concrete was gained in 10% replacement MK with OPC. Here results showed in the graph clears that the SCC gives more split tensile strength than that of CC.

Comparison of flexural strength amid CC and SCC of MK based concrete is observed in Fig. 18. The flexural strength result of 7, 28 and 90 days for SCC is more than CC of all mixes. At 5%, 10%, 15% and 20% replacement of MK for 7, 28 and 90 days SCC gives higher values than that of CC respectively. But at 20% replacement of MK, SCC gives maximum value as compared to all

Table 7 Unit weight, water absorption and carbonation depth of CC and SCC

Specimen	Average weight of normal concrete (kg)	Unit weight of concrete (kg/m^3)	Total water absorption in (%)	Carbonation depth in (mm)
CM0	8.385	2484	0.356	5
CM5	8.414	2493	0.338	4
CM10	8.656	2564	0.330	3
CM15	8.607	2550	0.294	3
CM20	8.388	2485	0.290	5
SCM0	7.873	2332	0.250	4
SCM5	8.009	2373	0.236	2
SCM10	8.285	2454	0.225	2
SCM15	8.280	2453	0.213	3
SCM20	8.136	2410	0.210	3

other mixes. Yerramala *et al.* (2013) observed that highest rate of flexural strength was gained at 10% and 15% replacement of MK. Here results showed that SCC gives more flexural strength than that of CC.

4. Durability test results

The average weight of concrete, unit weights (density) of concrete, percentage of total water absorption and carbonation depth of CC and SCC are presented in Table 7.

4.1 Unit weight

Density directly related to strength of concrete and it also depends upon the degree of compaction. In CC and SCC, 10% replacement of MK with OPC gives higher density than 5%, 15% and 20%. The replacement of MK with OPC increased density value up to 10% thereafter it decreased, due to high viscosity of cement paste and creation of pores stalled. Kim *et al.* (2012) observed that density of hardened concrete depends upon replacement ratio of MK and primarily exaggerated by formation of air bubbles. From the above results it is concluded that CC has higher density than SCC, because SCC contains some air bubbles in pore spaces.

4.2 Water absorption

Percentage of total water absorption assessment outcomes of CC and SCC mixes are given in Table 7. If preliminary water absorption less than 3% that is categorized as worthy quality concrete. From the results it is perceived that final water absorption of 0%, 5%, 10%, 15% and 20% of CM was varied in 0.356, 0.338, 0.330 0.294 and 0.290 and for SCM was varied in 0.250, 0.236, 0.225, 0.213 and 0.210 respectively. It is perceived that as MK replacement increases, percentage of total water absorption decreases both in CC and SCC. Khatib and Clay (2003) studied about water absorption through capillary rise integrating MK as replacing

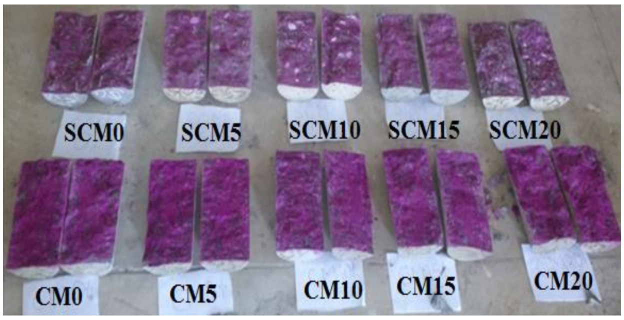

Fig. 19 CM and SCM sample after testing carbonation test

substantial of cement up to 20%. Courard *et al.* (2003) investigated water absorption of concrete mixture improved with rise in MK amount at 28 days. Shekarchi *et al.* (2010) testified water absorption lessened by 28% for customary concrete mixture per 15% MK. Similar trends were testified by Guneyisi *et al.* (2012) that for customary concrete encompassing MK promoting filling upshot of MK and pozzolanic reaction as well. In SCC, advantageous outcome of MK on water absorption lessening was further substantial due to inferior porosity and advanced pore size circulation of MK blended matrix, related to normal concrete. SCC absorbed less water than CC. So it indicates that SCC gives a good quality concrete. Result shown that, presence of MK is prominently advantageous in dropping water absorption by capillary action.

4.3 Carbonation

Carbonation of concrete is associated with the corrosion of steel reinforcement and with shrinkage. Carbonation of concrete involves a physiochemical reaction between atmospheric carbon dioxide and the calcium hydroxide generated in cement hydration process. The rate of carbonation in concrete is influenced by both physical properties and exposure condition. The carbonation test was performed by taking splitting cylindrical specimens after 90 days curing period and 7 days atmospheric exposure condition and spraying phenolphthalein solution into the splitting surface. The concrete was filled in to the cylindrical mould in layer approximately 5 cm deep. Each layer was compacted by needle vibrator. It was stored under shed for 24 hours. Then the cylinder removed from the mould at the end of 24 hours & immersed in clean water at a temperature (27-30℃) till the 90 days. After the 90 days test, ten samples of CC and SCC cylinder were taken for carbonation test. The samples were exposed to atmosphere for 7 days. Than 1% phenolphthalein indicator solution has sprayed over the freshly exposed split surface area of the concrete cylinder. After some time (2 min) the solution became pink colour in the carbonated concretes can be differentiated. A carbonation depth has measured the distance from the surface to the colour-changed area. The average value was calculated based on each specimen by ages and types. The depth of carbonation*s* estimated based on the change in colour profile and it is measured in mm.

The carbonation test results of CC and SCC are presented in Table 7. In CC, and SCC 5%, 15% and 20% gives more carbonation depth than 10% replacement of cement with MK. Carbonation depth of all MK based concrete is lower as compared to control specimen except M20, which is equal to control specimen. In case of carbonation, durability becomes lower as carbonation depth increased. The progress of carbonation occurred due to CO_2 diffusion in concrete porosity. Nicolas *et al.* (2014) observed that MK replacement in cement tends to increase depth of accelerated carbonation. The test results showed that CC has more carbonation depth than that of SCC, so that CC gives low durability than SCC. Fig. 19 shows carbonation test of CM and SCM concrete samples.

4. Conclusions

Based on the above results the following conclusions can be drawn:

- The increase in MK replacement increases workability of CC and SCC in a constant w/b ratio.
- Increase in MK, decreases the T_{500} flow time and V-funnel time in addition of 0.35% of SP which belongs to VS2 and VF2 classes and satisfy EFNARC (2005) guidelines. The decrease in flow time indicates good flowability of SCC.
- Increase in MK increase filling height of U-funnel and L-box it comes under PA2 classes with 3 rebars in constant SP (0.35%) which satisfies the EFNARC guidelines.
- Compressive, split tensile and flexural strengths of CC and SCC higher as compared to control specimen at all age of curing.
- Replacement of MK up to 10% in cement increases compressive and split tensile and flexural strengths of CC. But after that increase in replacement results in a decrease in strength. This might be because of filler weight, hastening of PC hydration and also pozzolanic reaction of MK.
- Compressive strength of SCC is improved up to 10% of MK replacement compared to CC and thereafter the strength decreases whereas at 15% and 20% compressive strength of CC is greater than SCC.
- The maximum split tensile and flexural strength of SCC observed at 20% replacement but in CC, it improved up to 10% of replacement of MK and thereafter the strength decreases.
- In CC and SCC, 10% replacement of MK with OPC gives higher density value than 5%, 15% and 20%. The replacement of MK with OPC increased the density value up to 10% after that it decreased.
- As the MK replacement increases, the total water absorption decreases w.r.t w/b ratio in both CC and SCC. In SCC, valuable consequence of MK on water absorption lessening was further substantial because of inferior porosity and advanced pore size dissemination of MK blended matrix, as compared to normal concrete, so SCC absorbed less water than CC.
- The test results showed that CC has more carbonation depth than that of SCC. It indicates the durability of CC is lower than that of SCC.

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CC