DURABILITY PROPERTIES OF SELF-COMPACTING CONCRETE USING DIFFERENT MINERAL POWDERS ADDITIONS IN TERNARY BLENDS

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This investigation was carried out to find the effect of various admixtures on the durability properties of Self-Compacting Concrete (SCC) with ternary blends of powders. In this investigation SCC was prepared with Metakaolin (MK), Fly Ash (FA) as partial replacement of cement and Waste Marble Powder (WMP) as a filler material (replacing partial the sand). The MK and FA contains higher concentrations of Silica and Alumina and are therefore considered as congenial Supplementary Cementing Materials (SCM's). Seven different proportions of MK were used in this investigation. The partial replacement of 15% FA with cement was kept constant for all the mixes (M1- M7) except control mix (M0). The efficiency of FA was evaluated by designing a control mix with 15% FA substitution (M8) of cement. The fine aggregate was replaced partially by 20% WMP. A total of nine mixes were designed. The specimens were tested in the hardened state at different ages for assessing the durability characteristics of SCC such as water absorption and porosity, sorptivity and resistance to acid attack. The results of this investigation revealed that the influence of above admixtures used was quite effective in production SCC with improved durability properties.

Keywords: *Self-compacting concrete (SCC); Admixtures; Fly Ash (FA); Metakaolin (MK); Waste Marble Powder (WMP); Durability.*

1. Introduction

The development of Self-Compacting concrete (SCC) was a milestone in the history of concrete industry. SCC flows over a long distance due to its own weight without segregation and bleeding. It does not need any external vibration for compaction. This revolutionary concrete was first introduced in the construction industry in 1988 [1] and had a significant impact on the placement of concrete in particular and on construction process in general. SCC has many advantages in comparison with normal concrete such as allowing complex forms in structural design, reduction of noise pollution in absence of vibrators, decrease in construction time, better surface finish, improvement in strength and durability and fewer work hazards [2]. SCC is believed to lower the chances of corrosion in reinforced structures, besides restricting the segregation and honeycombing of concrete by eliminating poor workmanship [3].

In terms of the EFNARC specifications EN 206-1: 2013 [4], the durability properties are of prime importance for judging the performance of SCC in addition to the mechanical properties. During the last two to three decades the researchers have made efforts to produce SCC with enhanced mechanical as well as durability properties with the incorporation of admixtures. The addition of mineral admixtures can produce more cohesive, consistent and dense concrete resulting in reducing of permeability and increasing its hardened properties due to their high pozzolanic activity and filling effect [5,6].

In this study which forms a part of wide research investigation on SCC, the Supplementary Cementing Materials (SCM's) like Metakaolin and Fly Ash were used. Besides the Waste Marble Powder (WMP) was used as sand replacement (partial). In order to achieve the fluidity and cohesiveness of the SCC, Poly Carboxyl Ether (PCE) based superplasticizer was used [7]. The bleeding and segregation of SCC was reduced with the use of Viscosity Modifying Admixture (VMA) [8,9].

The calcination of Kaolinitic clay at a moderate temperature of 650-800^{o}C results in the formation of Metakaolin. MK being thermally activated pozzolanic material is characterized by its high reactivity with $Ca(OH)_2$ and its capacity to accelerate cement hydration. The use of metakaolin as a pozzolanic material has gained importance in the cement or concrete after early 1980's [10,11]. Metakaolin contains higher concentrations of Silica and Alumina to the tune of 50-55% SiO_2 and 40-45% Al_2O_3 [12], which contribute to its significant pozzolanic action compared to other SCM's. This pozzolan reacts with CH and forms additional Calcium Silicate Hydrate (C-S-H gel). The higher Calcium Silica ratio of this additional C-S-H gel produced leads to the improvement of the microstructure of the concrete and finally enhancing the overall strength of the concrete, chloride ion diffusivity, permeability, porosity and resistance against freezing and thawing [13, 14]. Moreover, this pozzolan due to the micro filler effect densifies the

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Interfacial Transition Zone (ITZ) by its significant contribution to filling of small pores and voids. This action of the MK is referred as its physical action [15]. The production process of MK involves a very little emission of carbon dioxide, making it as environment friendly and sustainable material. The durability of the concrete is enhanced with the use of MK and a decline in overall emission of carbon dioxide is significantly achieved. In a study, the use of MK reduced permeability with an improvement in durability [16]. The resistance of SCC to sulphate attack and chloride penetration were reported with the higher replacements of MK content. A decrease in water absorption was also reported [17]. An increase in the resistance against sorptivity and a reduction in chloride penetration, open porosity and gas permeability was reported with the use of MK as partial replacement of cement at different percentages [18]. The use of 10% MK as partial replacement of cement significantly improved the strength and durability of SCC [7, 18].

Fly Ash (FA) is a by-product obtained from burning of coal in thermal power stations. FA is a pozzolanic mineral admixture and is used as a partial replacement of cement in SCC because of its pozzolanic properties. The addition of FA in SCC as partial replacement of cement has been observed to promote workability and lessen the cracking because of the lower heat of hydration. The concrete in which FA is used as cement replacement (partial) takes more time to gain the maximum strength than the normal concrete made with Portland cement (PC) due to its slow pozzolanic reaction. The use of FA in SCC increases the rheological properties of SCC and reduces the demand of water due to its small spherical shape [19]. The workability of the super flowing concrete was greatly achieved by 30 percent FA replacement of cement [20]. The reactivity of SCC is increased with the addition of FA which enhances the compressive strength, improves durability and reduces drying of SCC [21]. The decrease in bleeding and developing constancy has also been reported with the use of FA in SCC [22]. In a study [23] FA was used in SCC at 0-80 % of the cement replacement and an enhancement of water absorption was noticed with the increase in the levels of FA replacements. The same study showed a decrease in compressive strength. Therefore, an inverse relationship between water absorption and strength was suggested. Similar variations between strength and sorptivity were also observed [24].

Among the different forms of stones used as building materials, marble is one of the famous, attractive and preferred stone and as such marble industry has a significant market throughout the globe. A huge quantity of marble waste is produced during the processing of marble in the factories or in queries and the quantity is so high, that it is almost impossible to manage its storage. As a result, this marble waste gets accumulated and consequently adds to the environmental pollution [25]. Environmental pollution, environmental health, and economic losses are the three major concerns posed by the accumulation of waste marble powder. Thus, it is essential to find some means where this marble waste sludge can be re-used [26, 27]. In a marble block which weighs about 15-20 tons, about 70 percent is wasted during manufacturing process of marble [28]. The use of the Waste Marble Powder (WMP) in cementitious products has gained the attention of many researchers who have been investigated the use of WMP to partially replace sand or cement in these products [26, 27, 29]. It was observed that 10% of WMP used as sand replacement (partial) was more effective than that of the partial cement replacement [30]. The optimum percentage of WMP as partial replacement for cement by most of the researchers has been found to be 10% [31-33]. The increase in the percentage of WMP used as sand replacement in SCC has resulted in increasing the compressive strength, modulus of elasticity with reduced sorptivity [34]. Although most of the researchers have used WMP in concrete but main problem confronted in this context is high powder fineness. As such superplasticizers are used to curtail the requirement of water in SCC. On the other hand, the cohesiveness of SCC is enhanced due to the high fineness of these powders [35-37]. The Portland cement contributes to the major portion of CO_2 emission into the atmosphere which leads to adverse environmental impact. So many approaches of reduction in cement content in SCC have been studied with the aim of reducing negative environmental impacts [38, 39].

2. Research significance

This research investigation attempts to find out the effect of mineral admixtures in SCC in terms of assessing its durability characteristics. The availability of the data regarding the durability characteristics of SCC containing various admixtures forms the basis for application of SCC in concrete industry. A limited research information about the use of mineral admixtures in SCC in terms of durability considerations is available which therefore warrants further research in the subject. As such a detailed investigation was carried out to study the durability characteristics of SCC using different mineral additions in ternary blends of powders. The results of this investigation covering the durability properties of SCC are therefore presented in this paper.

3. Experimental Investigations

3.1 Materials

OPC (Ordinary Portland cement) which confirmed to IS 12269:2009 [40] of 53 grade was utilized in this study. Gravel with a size of 10 and 12.5 mm and locally available river sand were used as coarse and fine aggregate respectively which satisfied the requirement for grading zone II of IS: 383-2016 [41]. Metakaolin (MK) confirming to ASTM C 618 [42] of class N pozzolana was used. Class C Fly Ash (FA) collected from thermal power plant Neyveli Lignite Corporation Indian Limited (NLC), Neyveli was used (IS 3812:2003) [43]. Waste Marble Powder (WMP) procured from marble cutting factory near Vellore, Tamil Nadu, India was used. In order to gain high workability Polycarboxylic Ether (PCE) based Superplasticizer (IS: 9013, 2014) [44] was used. Viscosity Modifying Admixture (VMA) was used to obtain bleed free mixes. The properties of all the constituent materials are depicted in Table 1-4. The micro-structure and chemical composition of OPC, MK, FA and WMP was studied by using Scanning Electron Microscopic (SEM) and EDAX. Also, the shape and texture of the particles was identified by taking the images of the specimens at various magnifications. The SEM images and EDAX spectra of OPC, MK, FA and WMP are shown in Figure 1.

Table 1

Chemical compositions (%) of OPC, MK, FA and WMP using EDAX.

Chemical Compound	OPC	Metakaolin	Fly Ash	WMP
Calcium oxide (CaO)	62.90	0.09	5.30	55.15
Silica oxide (SiO_2)	20.50	52.0	51.55	3.12
Aluminium oxide (Al_2O_3)	5.10	46.0	15.30	0.35
Iron oxide (Fe_2O_3)	3.24	0.60	10.05	0.09
Magnesium oxide (MgO)	1.10	0.03	0.50	-
Suplhur anhdrite (SO_3)	2.01	0.30	0.30	-
Chloride (Cl)	0.002	-	-	-
Insoluble residue	0.25	-	-	-
Loss on ignition (LOI)	1.80	1.00	2.50	38.5

Table 2

Physical Properties of OPC, MK and FA

Properties	OPC	Metakaolin	Fly Ash
Particle average size, µm	20-100	1.2- 2.5	4-7
Specific gravity	3.15	2.60	2.18
Blaine's fineness (m^2/Kg)	256	19-20	330
Soundness (Autoclave %)	0.02	0.010	0.017
Residue on 45 micron sieve, %	-	0.4	17.6

Table 3

Physical Properties of sand, WMP and gravel

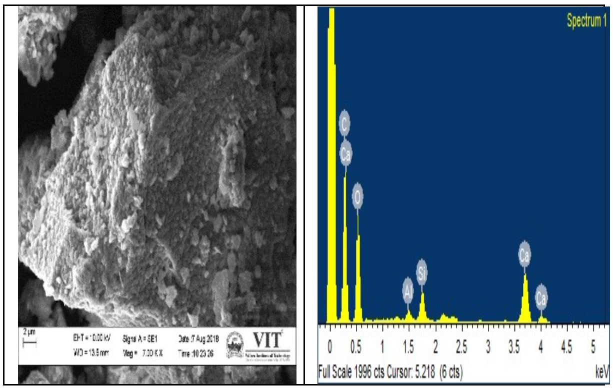
Properties	Fine Aggregate	WMP	Coarse Aggregate
Specific gravity	2.58	2.68	2.65
Fineness modulus (%)	2.66	2.51	5.8
Water absorption (%)	1.0	1.36	0.65
Loosely piled dry density (Kg/m^3)	1497	1280	1399
Dry Density (Kg/m^3)	1580	1365	1508
Aggregate Impact Value	-	-	11.95
Aggregate Crushing Value	-	-	23.98

Table 4

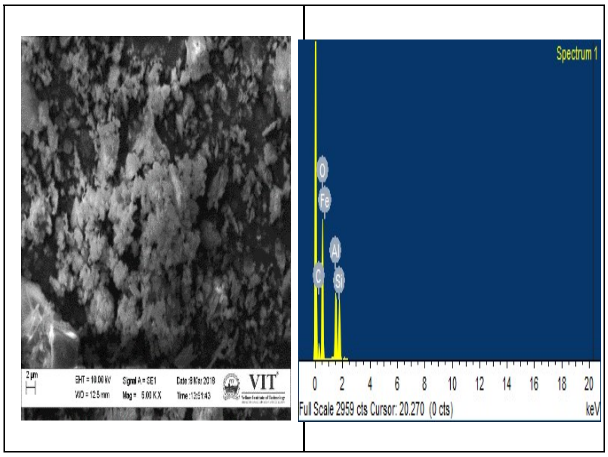
Properties of Superplasticizer (HRWRA) and VMA

Properties	HRWRA	VMA
Specific gravity	1.08	-
Aspect	Reddish Brown Liquid	Colourless free flowing liquid
pH	≥ 6	≥ 6 at 25 °C
Relative Density	1.08 ± 0.02 at 25ºC	1.01 ± 0.01 at 25ºC
Chloride ion content	< 0.2%	< 0.2%

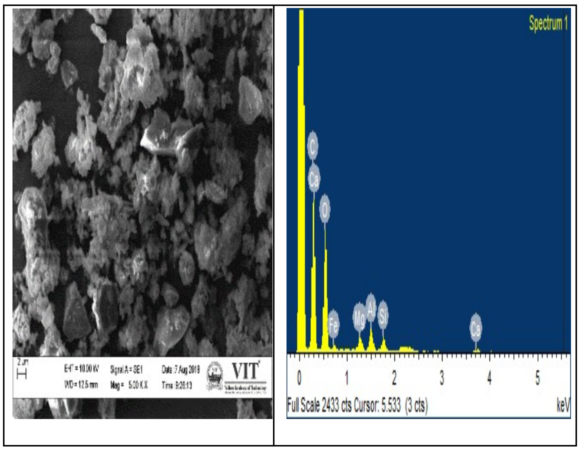
* As per the manufacturer's manual



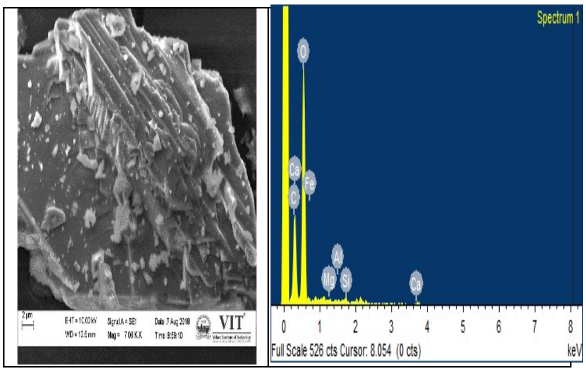
(a) Cement



(b) Metakaolin



(c) Fly Ash



(d) Waste Marble Powder

Fig. 1 - SEM images and EDAX spectra of the Materials used.

4. Mix Design

SCC mixtures were designed in such a way that the binder content was kept fixed at 498 kg/m^3 for all SCC mixes with w/b ratio of 0.42. In order to find out mix design, 65 trial mixes were carried out and a total of nine SCC mixes including control mix (M0) were produced for the study. Cement was partially replaced by seven different proportions of MK. Viz; 5% (M1), 7.5% (M2), 10% (M3), 12.5% (M4), 15% (M5), 17.5% (M6) and 20% (M7). The fly ash replacement level was kept constant at 15% (by the weight of total binder) and fine aggregate was partially replaced by 20% WMP. To evaluate the influence of FA, control mix with 15% FA (M8) substitution of cement was also designed. The partial replacement percentages of FA and WMP were determined on the basis of studies forming a part of this research investigation. The mix design is done in such a way that it follows and comes under the guidelines of EFNARC [45, 46]. The mix proportions of SCC are depicted in Table 5.

5. Test Procedures

5.1 Water Absorption

The cube specimens of 100 x 100 x 100 mm sizes were used to perform this test. The specimens were tested as per ASTM C 642- 13 [47] after different intervals of curing in water. The cube specimens were oven dried at 105 ± 5 ^{o}C till a constant weight was achieved. After drying, the specimens were allowed to cool at room temperature and then weighed (W1). The cooled specimens were then immediately immersed in tanks containing tap water. The specimens were periodically taken out from tank, surface dried and weighed as shown in Figure 2. This process was continued till a constant weight was obtained. The water saturated weight of the specimens was recorded (W2). The water absorption was worked out as shown below:

Water Absorption (%) = [(W2–W1) / W1] x 100
Where W1 = Dried weight of cube (Kg)
W2 = Water Saturated weight of Cube (Kg)

Fig. 2 - Water Absorption test on concrete cubes

Table 5

Mix Proportion of SCC

Mix Designation	Type of mix	w/b	Cement (Kg/m^3)	Metakaolin (Kg/m^3)	Fly Ash (Kg/m^3)	Fine aggregate (Kg/m^3)	WMP (Kg/m^3)	Coarse aggregate (Kg/m^3)	S.P. (%)	VMA (%)
M0	Control mix	0.42	498	-	-	960	-	700	1	0.25
M1	SCC5MK	0.42	398.40	24.90	74.7	768	192	700	1.05	0.35
M2	SCC7.5MK	0.42	385.95	37.35	74.7	768	192	700	1.1	0.40
M3	SCC10MK	0.42	373.50	49.80	74.7	768	192	700	1.25	0.45
M4	SCC12.5MK	0.42	361.05	62.25	74.7	768	192	700	1.30	0.45
M5	SCC15MK	0.42	348.60	74.70	74.7	768	192	700	1.35	0.50
M6	SCC17.5MK	0.42	336.15	87.15	74.7	768	192	700	1.45	0.55
M7	SCC20MK	0.42	323.37	99.60	74.7	768	192	700	1.55	0.60
M8	Control mix +15%FA	0.42	423.3	-	74.7	960	-	700	0.90	0.25

5.2. Sorptivity

The ingress of water from one side of the unsatured concrete through capillary pores is determined by sorptivity. The disc samples were obtained by cutting the cylinder specimens of sizes 100 x 200 mm with the help of saw cutting machine as shown in Figure 3. The disc samples of 100 mm x 50 mm sizes were used for carrying out this test as per ASTM C 1585-13 [48] after different intervals of curing. The disc samples were oven dried at 105 ± 5 °C for 1 day till a constant weight of the samples was observed between the two successive readings. The samples were cooled at room temperature. The circumferential area of sample was coated with epoxy paint, also the top and circumferential area of the sample was wrapped with polythene sheet to prevent evaporation from surface not exposed to water. The initial weight of the sample was recorded and the sample was kept on support device maintaining 1-3 mm level of water above the support device in pan. As soon as the water touched the sample, the stop watch was started and the readings were recorded by taking out the sample from the pan at the time period of 1, 5, 10, 20, 30, 60 mins., and each hour for a period of six hours and after 3 days from the beginning of the test time. The sorptivity (mm/$S^{1/2}$) of the specimen was worked out from the average of three samples by taking into account the slope of the water against square root of time.

Fig. 3 - Sorptivity Test performed after 28 and 90 days.

5.3 Acid Attack

The acid attack was carried out as per ASTM C 642 for all SCC specimens. The cube specimen of 100 x 100 x 100 mm sizes were used to carry out this test after 28 and 90 days of curing as shown in Figure 4. The specimens were weighed before their exposure to the acid solution containing 2% sulphuric acid (H_2SO_4). The specimens were put in the acid solution for eight weeks and the concentration of solution was maintained by replacing the solution as and when required. The pH value of acid solution was maintained in the range 1.4-1.60. After every week the specimens were taken out of acid solution and rinsed with water to remove the loose surface. The specimens were then weighed and the resistance of the SCC specimens were then accessed in terms of mass loss and strength loss performance.

Fig. 4 - Acid Attack test performed after 28 and 90 days.

6. Experimental test results and discussions

6.1 Water Absorption and volume of permeable pore space voids

The resistance of SCC to the ingress of aggressive ions is most vital factor influencing the durability of SCC. The characteristics of the concrete leading to the absorption indirectly represents the porosity. The result of this study in reference to the water absorption is depicted in Table 6 and is shown in Figure 5 and Figure 6. There is an appreciable decrease of water absorption in SCC mixes where admixtures have been used as replacements of cement than in control mix (M0). The pozzolanic reaction takes place between $Ca(OH)_2$ and SiO_2 to form C-S-H gel resulting in denser concrete by filling voids. This is in connate to the findings of (Guneyisi et. al 2008) [49] on conventional concrete by justifying the filling effect of MK as well as its pozzolanic reaction. Similar findings were also reported by Kannan and Ganesan (2014) [50] in SCC containing metakaolin and rice husk ash. The low water absorption in concrete is considered as 'good' concrete durability [51]. The reduced water absorption of SCC blended with admixtures is probably due to the minimum connectivity of the pores and porosity reduction of the mixes. The results of this investigations indicate that the highest water absorption of 4.84% at 28 days and 4.04% at 90 days was observed in control mix (M0), whereas the lowest water absorption of 2.02% at 28 days and 1.60% at 90 days was observed in M5 mix (15% MK). This was followed by M4 mix (12.5% MK) where the water absorption of 2.15% and 2.00% at 28 and 90 days respectively was recorded. The water absorption of 3.28% and 2.86% at 28 and 90 days respectively was observed in M8 (15% FA) which is significantly lower than control mix (M0). Thus, incorporation of MK and FA in SCC mixes was most appropriate in reducing the water absorption. The results are in agreement with the results of Siddique and Klaus (2009) [52] who state that MK modified pore structure with significant reduction in permeability, thus inhibiting the transportation of water and other harmful ions. The water absorption levels increase with the increase of MK replacement levels beyond 15%. This is probably due to MK having higher surface area, lesser fineness modulus value and ultimate necessity for water in the concrete mixing process. The gradual reduction of the workability of SCC mixes with increased percentages of MK results in the creation of voids in the concrete and hence may be held responsible for poor resistance to water absorption [50]. The decrease in the absorption with the positive effect of MK in SCC was also reported by Madandoust and Mousavi (2012) and Siddiqui and Klaus (2009) [7,52] in case of ordinary concrete. A reduction of water absorption by 28% was reported by Shekarchi et.al (2010) [53] by incorporating 15% MK as cement replacement.

Table 6

Permeable Properties of various SCC mixtures

Mix ID	Water Absorption (%)		Volume of Permeable Voids (%)		Sorptivity index (mm/min$^{1/2}$)	
	28 days	90 days	28 days	90 days	28 days	90 days
M0	4.84	4.04	6.97	4.95	0.068	0.039
M1	4.24	3.55	5.71	4.51	0.065	0.035
M2	3.77	3.24	5.15	4.3	0.060	0.030
M3	3.31	3.03	4.5	3.8	0.047	0.026
M4	2.15	2.00	3.52	3.01	0.042	0.021
M5	2.02	1.75	3.45	2.93	0.036	0.015
M6	3.14	2.95	4.52	3.2	0.038	0.018
M7	3.86	3.27	4.6	3.5	0.041	0.021
M8	3.28	2.86	5.2	3.8	0.051	0.031

The results of porosity depicted in Table 6 reveal that the highest porosity was observed in control mix (M0) and is shown in Figure 7. The porosity of 6.97% and 4.95% at 28 and 90 days respectively was found in M0. The use of admixtures has a positive impact on the porosity in SCC mixes. A minimum porosity of 3.45% and 2.93% was attained at 28 and 90 days respectively for M5 mix (15% MK) followed by M4 mix (12.5% MK) having a porosity of 3.52% and 3.01 at 28 and 90 days respectively. A porosity of 5.2% and 3.8% at 28 and 90 days respectively was found in M8 mix (15% FA) which is significantly lower than control mix (M0). A direct relationship exists between durability and water absorption and porosity. An enhancement in the porosity of the mix will tend to have more water absorption thus resulting an expansion in the mix. A porosity network will be created due to pores in the mix which will favour passage of water or any other liquid like sulphuric acid etc. This will result in lowering the strength of mix and also in deterioration in its durability. So, the use of the SCM's like metakaolin, fly ash and the use of filler material as waste marble powder in this investigation has decreased both water absorption and porosity of SCC and ultimately a surge in the durability of SCC.

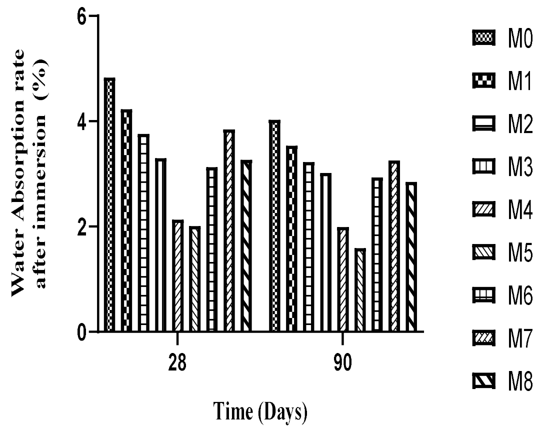


Fig. 5 - Variation in water absorption of SCC

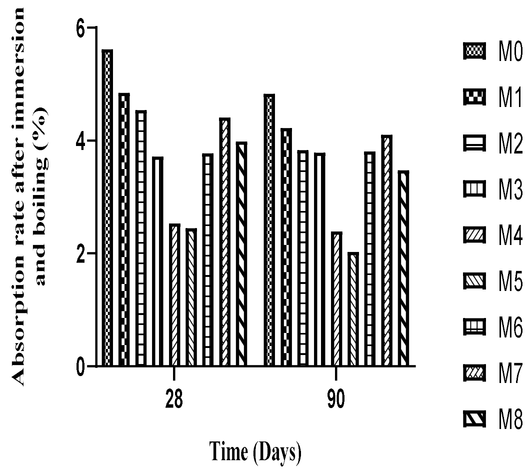


Fig. 6 - Variation in water absorption after immersion and boiling of SCC

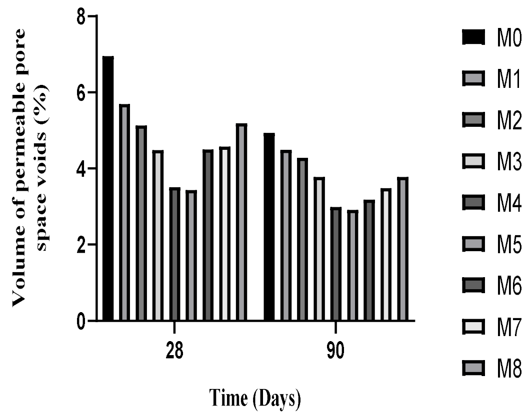


Fig. 7 - Variation in permeable voids of SCC

6.2 Sorptivity

The property of the concrete to measure the ingression of water through the capillary pores with respect to time is referred to as sorptivity. So, the sorptivity is connected with the volume of the capillary pores and higher the pore lowest sorptivity

The results depicted in Table 6 and shown in Figure 8 and Figure 9. reveal that the water absorption through capillary pores was remarkably high in controlled mix (M0). The sorptivity for control mix was observed to be 0.068 and 0.039 mm/min$^{1/2}$ at the curing age of 28 and 90 days respectively. The lowest sorptivity level was observed in M5 mix (15% MK). In this case a marked improvement in resistance to water absorption through capillary pores in order of 52.94 % and 38.46 % at 28 and 90 days of curing respectively was observed. Similar improvement though marginally less than M5 was observed in M4 mix (12.5%). These results are in consonance with the results of Ramenziampour and Bahrami (2012) [54] where the investigators observed an improved sorptivity (local minimum) for the 10% MK replacement of cement. The improvement in the sorptivity by the partial replacement of cement with MK in SCC is attributed to the fact that the use of MK enhances the microstructure by refinement of pores through the process of filling [55] and due to secondary pozzolanic reaction of MK. The incorporation of 15% fly ash in M8 mix has improved its sorptivity in comparison with control mix (M0). The reasons being that the fly ash particles fill up the micro-air voids inside the concrete matrix thereby reducing water absorption. Similar effects were observed by the Khatib (2008) [23] and Wongkeo et.al (2014) [56]. These results indicate that the partial replacement of MK in SCC plays a vital role in reducing the sorptivity and water absorption.

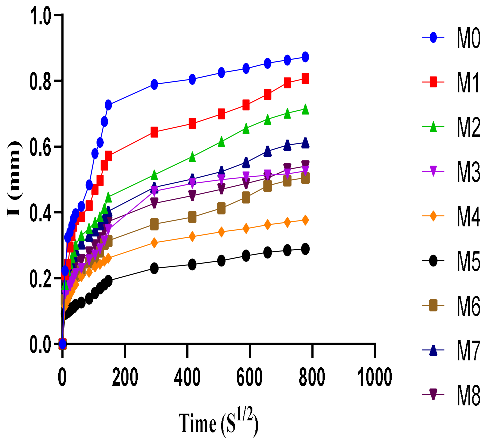


Fig. 8 - Sorptivity of SCC at 28 Days

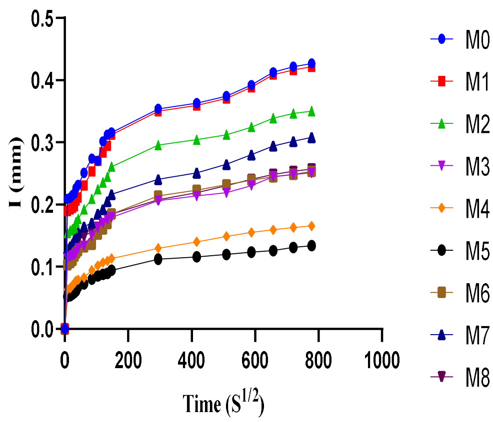


Fig. 9 - Sorptivity of SCC at 90 Days

6.3 Acid Attack

The performance of the SCC specimens which were exposed to sulphuric solution was evaluated in terms of weight loss and strength loss.

6.3.1 Weight Loss

The assessment of change in mass of SCC specimens exposed to sulphuric acid solution for certain period of time is most widely accepted method for determine the resistance of concrete exposed to this aggressive condition. Figure 10 shows the results as the percent mass loss of SCC specimens immersed in 2% H_2SO_4 for eight weeks. The mass loss percent was worked out at the age of 1, 2, 3, 4, and 8 weeks. The maximum weight loss was observed in control mix (M0) at all the ages compared to the SCC mixes blended with admixtures. The maximum weight loss of 23.1% was observed for the control mix (M0) at 8 weeks. The incorporation of the admixtures in SCC has reduced the weight loss and a minimum of 8.01% was observed for M5 SCC mix blended with 15% MK followed by the weight loss of 9.52% in case of M4 mix blended with 12.5% MK. Similar trend was observed for M9 SCC mix blended with 15% FA while 13.11% weight loss was observed after 8 weeks of immersion in H_2SO_4 solution. Thus, the incorporation of admixtures like MK, FA and WMP have significantly contributed to the resistance of SCC specimens to the attack of sulphuric acid which is evident from the results depicted in Figure 10.

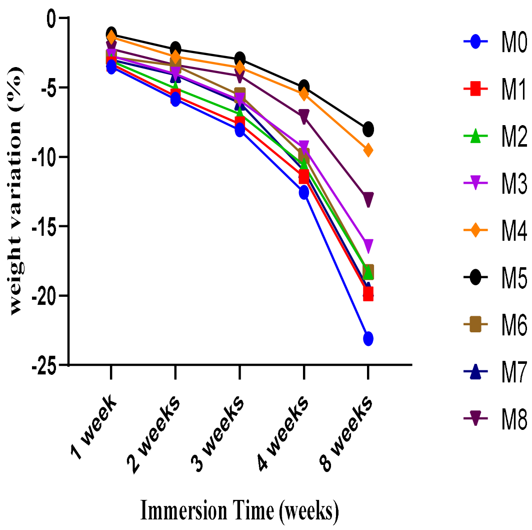


Fig. 10 - Weight variation in H_2SO_4 solution

The results are in consonance with the investigations carried out by Dinakar et.al 2008 [57]. They replaced cement with high volumes of FA and observed a reduced weight loss due to the acid attack with the reduction in cement content, because of the fact that the reaction compounds like Calcium hydroxide are less owing to the lesser cement content during the deterioration process. The C_3A of the cement which is prone to the intrusion of sulphate ions resulting in the formation of secondary ettringite is reduced with the use of MK and FA as partial cement replacement. The pozzolanic reaction of the MK also tends to decrease the amount of $Ca(OH)_2$. Also, the formation of secondary C-S-H gel due to the pozzolanic reaction that refines the pore structure, reduced the larger capillary pores to smaller ones and ultimately blocking these pores plays a key role in resistance of the concrete to the ingression of harmful chemicals [58].

6.3.2 Strength Loss

The strength loss was determined after the SCC specimen were exposed to the 2% sulphuric acid at 1, 2, 3, 4 and 8 weeks as presented in Figure 11.

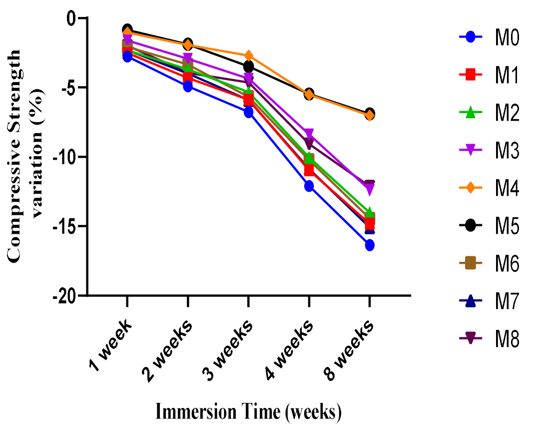


Fig. 11 - Compressive strength variation in H_2SO_4 solution.

The results revealed that the compressive strength of all the SCC mixes gradually decreased with increase in the exposure periods of these. However, a lower rate of decrease was observed for the SCC mixes blended with admixtures. The overall review of the results shows that among all the SCC mixes, the maximum loss of strength was observed for control mix (M0) at each interval of time. The strength loss of 16.35% was found for control mix after 8 weeks of acid exposure. Among all the mixes, the minimum loss of 6.9% compressive strength was observed in M5 mix followed by 7.03% loss of compressive strength in M4 mix after 8 weeks of immersion in H_2SO_4. The SCC blended with FA (M8) has also shown better results compared to control mix (M0) and a loss in compressive strength to the extent of 12.13% was observed after 8 weeks of exposure of H_2SO_4. The higher resistance to the sulphuric acid attack of MK and FA blended mixes in comparison with the control mix can be attributed to the higher pozzolanic reaction of these pozzolans resulting in the production of more hydrates due to which the micro structure is refined thereby reducing the rate of ingress of acid solution into the concrete. These results are in agreement with the studies of Murthi and Sivakumar (2008) [59]; Chatveera and Lertwattanaruk (2011) [60] who obtained the similar results with the use of other pozzolans like rice husk ash, fly ash and silica fume in ternary blended forms.

7. Conclusions

This investigation was undertaken to determine the behaviour of SCC with the addition of admixtures. The durability characteristic of the SCC blended with mineral additions were assessed and the following conclusions could be drawn:

• Addition of MK and FA proved to be beneficial for reducing the water absorption and porosity of SCC. The water absorption of SCC containing 15% MK (M5) was 2.02% and 1.60% at 28 and 90 days respectively which was minimum among all the SCC mixes. Similarly, a minimum porosity of 3.45% and 2.93% was attained at 28 and 90 days respectively for M5 mix.

• The resistance to the water absorption through capillary pores significantly improved in the MK blended SCC mixes as compared to control mix. In M5 mix, a remarkable improvement in the water absorption through capillary pores in order of 52.94% at 28 days and 38.46% at 90 days was observed.

• A marked improvement in the resistance to acid attack was exhibited by the SCC blended with mineral additions. The minimum weight loss of 8.01% was exhibited by M5 mix at 8 weeks of exposure to sulphuric acid solution. The compressive strength loss was also influenced positively for SCC mixes blended with mineral additions and a minimum compressive strength loss of 6.9% was observed for M5 mix at 8 weeks of exposure to sulphuric acid solution.

• The use of WMP as a non-pozzolanic filler material (partially replaced of fine aggregate) in SCC has proved beneficial from economical, ecological and environmental point of view.

• The utilization of MK and FA provided an excellent alternative for reduction of cement consumption, thus making the SCC an environmental friendly concrete.

The results demonstrate that MK and FA can provide significant enhancement in respect of durability properties of SCC. As such the results suggest that an optimum level of 12.5%-15% MK and 15% FA combine can be used in SCC to harvest the maximum benefits.

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