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# Fresh and Hardened Properties of Ternary Blended Fast Setting Early Strength Fibre Reinforced Self Compacting Concrete

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**Abstract** Cement, used for engineering the concrete structures has become the most demanded construction material, the production of which consumes enormous quantity of raw materials and thereby emits approximately 7% of greenhouse gas emissions into the environment. Determinations are being made to use, as much quantity as possible, the supplementary cementitious materials (SCM), like ground granulated blast furnace slags (GGBFS), flyash (FA), metakaolin (MK), silica fume (SF), rice husk ash (RHA), etc., which are industrial by-products and hold pozzolanic properties, and are capable to be used as a part replacement of ordinary portland cement (OPC). The consumption of OPC has significantly increased all over the world due to construction of infrastructure facilities on massive scales. Also for the aged infrastructure, constructed decades before, necessities maintenance and repairs thereby further increase the demand of OPC and thus cause higher impact on the environment. Researches all over the world are trying experimentations in finding out suitable combinations of various proportions of potential materials like finer SCMs viz. FA, GGBFS etc. and ultrafine SCMs like SF, MK, RHA etc. which are being investigated along with different types of fibres to produce fibre reinforced self-compacting concrete for use in fast track constructions and repair works. In this study on ternary blended SCC and FSCC (fibre reinforced SCC), concrete mixes were established with OPC ranging from 64% to 74%, combinations of proportions of MK (as ultrafine SCM), as a part replacement of OPC, varying from 2.5%, 5%, 7.5% and 10%; Fly ash (as fine SCM) fixed at 25%, without fibre and with 1% of Alkali resistant (AR) fibre. The established concrete mixes were set a target to achieve maximum final setting time of 10 hours, 1 day compressive strength of 25 N/mm$^2$ and flexural strength of 2.5 N/mm$^2$ besides meeting SCC characteristics of slump flow of 550mm-650 mm (SF1), V Funnel flow 9-25 Seconds (V2 class) for use in fast track concrete construction and repair of infrastructure facilities.

**Keywords** Supplementary Cementitious Materials (SCM), Metakaolin, Ultrafine SCM, Alkali Resistant (AR) Glass Fibre

## 1. Introduction

In recent decades, ever growing population, all over the world, is driving its impact on material demand in order to meet the infrastructure requirements to fulfil the basic needs of population like housing, transportation, water

supply, sewerage etc. [1]. This has led concrete, the most popular construction material [2], to occupy second position in terms of material consumption after water [3]. Hence, the binding material, cement, used for engineering the concrete construction and in production of concrete, globally, has become the most demanded construction material and the same being consumed in enormous quantities over the past few decades [4]. Owing to this large consumption of cement, huge quantities of non-renewable raw materials are being expended for the manufacture of cement, triggering the release of, both directly and indirectly, vast volumes of greenhouse gases ($CO_2$), into the environment and causing serious environmental concerns [5]. Researchers, world over, are constantly experimenting and researching the ways to reduce $CO_2$ emissions from cement manufacturing plants, construction sites and to realize the practicability of the same [6]. Determinations being made to use, as much quantities as possible, the industrial by-products, supplementary cementitious materials(SCM) like SF, GGBFS, RHA, FA, MK etc. which retain potential pozzolanic properties, are capable to be used as part replacement of OPC [7]. The utilization of pozzolanic materials lessens the OPC usage and additionally increases concrete strength and durability [8-9]. Slags or pozzolans are admixed to cement to improve properties of concrete [10] by manifesting the microstructure of concrete or cement paste, thereby altering the interfacial transition zone (ITZ) and reducing the pore structure by pozzolanic reactions with $Ca(OH)_2$ - liberated during hydration reactions cement [11]. The application of these supplementary cementitious materials or pozzolans has thus become a necessity to improve the strength as well as durability properties of concrete structures, particularly under aggressive environmental conditions [12]. Also the development of SCC has significantly changed the way of concreting (without need of compaction) [13]. SCC's development, was done in mid 1980s, in a thrive to attain superior concrete surface finishes-even in the packed reinforced portions of structural members- to reduce the construction time and labour [14-17]. SCC has led better quality of concrete and resulted in an efficient construction process and thus attracted several researchers to further innovate the SCC making materials and proportions so as to consume more quantities of SCMs, which indirectly reduces the $CO_2$ loads from cement and building materials manufacturing plants, and reduces energy consumptions [5-6]. SCC consumes large quantities of powder materials (less than 125 micron size), and SCMs (besides the binding material -cement), in order to attain the required fluidity and cohesiveness of the mix [15, 17]. Conventional reinforced concrete structures considerably deteriorate with time, compelling regular and often costly maintenance [14]. Tensile load and impact load carrying capacity of both conventional concrete as well as SCC is less [16]. Further to extend the possible fields of applications of SCC, various types of fibres, either in mono combinations or in hybrid combinations, were added to the concrete [14]. Incorporation of fibres into conventional concrete as well as SCC mixes, improves the tensile load and impact load carrying capability [18-22]. Adding diligently and equivalently spread discontinuous detached fibres, in small quantities, to concrete, expressively improves the performance against static and dynamic loads [23-25]. The consequences of fibre inclusion in the SCC mixes are explored on its mechanical properties such as compressive strength, split tensile strength and flexural strength of fibre reinforced SCC and established that incorporation of fibres into SCC though reduces workability (which can be counteracted through effective use of PCE based chemical admixtures), effectively increases the mechanical properties [26]. The influence of alkali-resistant (AR) glass fibre, as discrete reinforcement, at 0.03%, 0.06% and 0.1% on durability characteristics of concrete was explored and reported that, for all the grades of concrete, incorporation of AR fibres at 0.1%, maximum enhancement in durability characteristics of concrete was achieved [26-28]. This contradicts with the outcome of the study [26] stating that 1% AR fibres incorporation improves the durability performance of concrete [28], hence further research may be required to ascertain the effects of AR fibres in SCC. The studies conducted on AR glass fibre inclusion in concrete on mechanical characteristics like compression, flexural strength tests, free shrinkage (with and without air flow over the sample) and crack control tests termed that the addition of low quantities of fibre did not change the flowability and mechanical properties of concrete [29]. It was also established that marginal quantity of AR glass fibre displayed the highest cracking control, where it was noticed that the fibre efficiency was not increased at higher dosage of fibres [30]. Further, a new generation SCMs, ultrafine slag is catching the attention of researchers in order to advance the experiments on its effect in SCC in fresh and hardened states. Ultrafine slag, finely formed particles of solid glassy material, consisting chiefly of non-crystalline polymorph or amorphous of $SiO_2$, has ultrafine particle sizes with specifically organized granulation to significantly enhance the strength as well as durability properties even better than with other conventional SCMs like FA, GGBFS, etc., which are generally adopted by construction industry [31]. Finer SCMs demonstrate startling effects in improving the complete performance of concrete both in fresh and hardened states [32]. The greater the specific surface area of SCM particles is, the more will be its effect on both fresh and hardened state properties of concrete [28]. Most of these SCMs are industrial by-products that can be used as mineral admixtures, as they exhibits pozzolanic properties, aiding in increasing strength and durability characteristics of the concrete with time [29-31]. Hence, the recipe of diverse mineral admixtures with OPC may have clues to numerous paybacks such as decrease in usage of OPC, reusing the waste by-products from industries,

enhancement in mechanical characteristics besides with the boost to rheological, durability of concrete and thereby reducing environmental impact from side to side lessening of greenhouse gas emissions [32]. As per the gathered information through literature survey on the early strength concretes, it was noted that there were less number of studies carried out on the influence of varied proportions of MK in a cementitious system consisting of OPC and fixed percentage of flyash and fibres. The significance of the present study is discussed in the subsequent section hereunder.

## 2. Research Significance

Nowadays, reducing the construction time and cost in infrastructure projects is highly demanded in order to deliver the projects well before the scheduled time of completion and get the returns, on investments made, at the earliest [33]. Thus fast track construction technologies and material proportions for reduction in construction time as well as reducing the time required for repairing or maintenance of aged structures are catching the attention of various research fraternities all over the world [34]. Tailor made concrete mix proportions by using or admixing various cost effectively and reactive materials like highly reactive SCMs such as MK, SF etc., and incorporating mono fibres [35] as well as combinations of hybrid fibres into the SCC mixes is such an example of fast track construction material [36-38]. MK, an anhydrous calcined system of the clay mineral kaolinite, as present in MK, possesses high-level pozzolanic reactivity [34]. Incorporation of MK in concrete develops its performance by emerging further CSH gel formation by consuming $Ca(OH)_2$, formed during the process of cement hydration, and thereby densifying the matrix resulting in reduced porosity [25]. MK develops pozzolanic reactions in fresh state and quickens the hydration reactions of cement [27]. It was demonstrated that higher silica, as present, in MK mends pozzolanic responses of concrete thereby enhancing strength and durability of concrete [32]. Inclusion of MK in concrete develops the resistance against sulphate ion ingression into the body of concrete [40]. Also it was proven that combining MK in concrete, with other binding materials and SCMs, diminishes the penetrability and admission of chloride ions into the body of concrete owing to the development of sophisticated pore structure in such concrete mix [41]. The influence of MK on the fresh, mechanical and durability characteristics of SCC mixes comprising 5%, 10% and 15% of MK, was experimented in a study and outcome of the same revealed that fresh and hardened state characteristics of 10% MK incorporated SCC mix improved [42]. Incorporation of MK in SCC develops macro and micro level properties quickly [43]. The partial replacement of OPC with MK in SCC mixes fixes its durability [44]. In recent decades both SCC and fibre reinforced concrete (FRC) were vital innovations in the field of concrete technology [18]. SCC has the unease of bleeding and segregation, if not properly proportioned [20], while FRC has the issue of diminished workability thereby effecting its placement in thin sections and congested reinforcement locations [29]. SCC, is an outstanding solution for precast plants, as well, due to high-quality control that can be ensured in the precast concrete production plants [32]. The characteristics of SCC highly depend on the constituents, their proportions, and mixing procedure [12, 14]. A concrete mix that has fast setting, high early strength and has self-compacting nature possibly doubles the production output of precast plants by decreasing the time by half the time required to reach the requisite demoulding strength and thereby reducing the amount of labour needed, so that the condensed placement time is feasible [35]. To find feasible solutions to these problems simultaneously, researchers industrialized in fibre incorporated SCC mixes, in order to get the benefits of flowability, and self compactability, improving the crack resistance and tensile load carrying capacity [39-43]. Achieving these mechanical properties at six hours cuts the amount of time, before demoulding, in half; therefore, the same moulding platforms can be used two times per day [6]. This high early strength mix must be of self-compactability, prearranged with the limited placement time available before initial setting [14]. Such a mix is not readily available, most likely because self-compaction and fast setting concrete mixes have contradicting mix design requirements and fresh properties [15]. For instance, low water/binder (w/b) ratio, which is a key element to achieve high early strength [13], leads to low workability that hinders self-compaction [8]. Hence to compensate the low water in the SCC and to achieve flowable SCC mixes, PCE based chemical admixtures with high range water reducing nature (HRWRA) was found to be an essential component for a successful SCC mix [10]. Fibre reinforcement was prevalent in high-early-strength concrete to control shrinkage and improve flexural strength and ductility [19]. However, it was well known that fibres restrict the flowability of concrete [15, 20] and require a longer mixing time that reduces the already short workable time of high early strength concrete [10]. The recommended demoulding compressive strength can vary from 10 to 17 $N/mm^2$ for different applications [44] with at least a 12-24 hour waiting period beforehand demoulding[43]. Thus for fast track concrete construction or fast track repair works of concrete, attaining compressive strength of 25 $N/mm^2$ at 1 day and flexural strength of 2.5 $N/mm^2$ can be targeted [45]. The appropriate mix of SCC can be realized by experimental procedures [4]. Various techniques have been established to study the behaviour of SCC [27]. Hence, every mix design of fibre reinforced SCC needs to be established by a series of trials to achieve various workability factors [46-48]. Thus there is a huge scope of research on developing fast setting early strength fibre reinforced SCC with various potential fine SCMs and ultrafine SCMs [7]. Hence this research study was planned

to proportion and study the M60 grade ternary blended SCC and FSCC(fibre reinforced SCC) with a total cementitious material content of 560kg/$m^3$, water/cementitious materials(cm) ratio of 0.33, as per provisions of IS 10262:2019 [49]- to achieve maximum final setting time of 10 hours, a 1 day targeted compressive strength of 25 N/$mm^2$ and flexural strength of 2.5 N/$mm^2$ besides attaining 28 days target mean strength compressive strength of 68.25 N/$mm^2$, with a standard deviation of 5 N/$mm^2$. The proportioned SCC and FSCC mixes were also set a target of meeting SF1(slump flow 550mm-650 mm), V2 class (V Funnel flow 9 -25 Seconds). SCC and FSCC, mixes were proportioned with OPC ranging from 64% to 74%, combinations of proportions of MK (as ultrafine SCM), as a part replacement of OPC, by varying from 2.5%, 5%, 7.5% and 10%; Fly ash (as fine SCM) fixed at 25%, 0% fibre and with 1% of Alkali resistant (AR)fibre. Materials used and their respective properties are discussed in the following sections.

# 3. Materials

Following concrete making materials were used in proportioning the SCC and FSCC mixes.

### 3. 1. Cement

Reputed brand of 53Gr Ordinary Portland Cement (OPC) complying with IS 269-2015[50] was used in this study. Specific gravity of the OPC was 3.14 and Blaine's fineness was 340$m^2$/kg. Particle size of OPC was $D_{10}$=7. 4 microns, $D_{50}$=30.8 microns and $D_{90}$=63.2 microns.

### 3. 2. Fly Ash

Locally available fly ash, as procured by reputed RMC plant from nearby thermal power station, was used in this study. Flyash was confirming to IS 3812:2013[51]. Specific gravity of flyash was 2.08 and Blaine's fineness was 330$m^2$/kg. Particle size of flyash was $D_{10}$=6.2 microns, $D_{50}$=45.2 microns and $D_{90}$=58.6 microns.

### 3. 3. Metakaolin (MK)

Obtained from local suppliers, MK was complying to IS 16354:2018[52]. MK's specific gravity was 2.26. Particle size of MK was $D_{10}$=1.1 microns, $D_{50}$=6.8 microns and $D_{90}$=13.7 microns.

### 3. 4. Alkali Resistant (AR) Glass Fibre

AR fibre was procured from local supplier. AR fibre's diameter was 15microns, length 15mm, and specific gravity was 2.7.

### 3. 5. Coarse and Fine Aggregates

Locally available crushed angular coarse aggregate 10 mm MSA and natural sand (river sand) having a powder content (<125 Micron) of 8% were used in this study. Coarse aggregate specific gravity was 2.74 and water absorption was 0.4%. Natural sand (fine aggregate)-specific gravity was 2.63, water absorption was 1.2% and was meeting the Zone III grading of IS 383: 2016 [53]. Coarse and Fine aggregates were found complying to the IS 383: 2016.

### 3. 6. Water

Tap water confirming to IS 456:2000 [54] was used in the preparation of SCC and FSCC mixes.

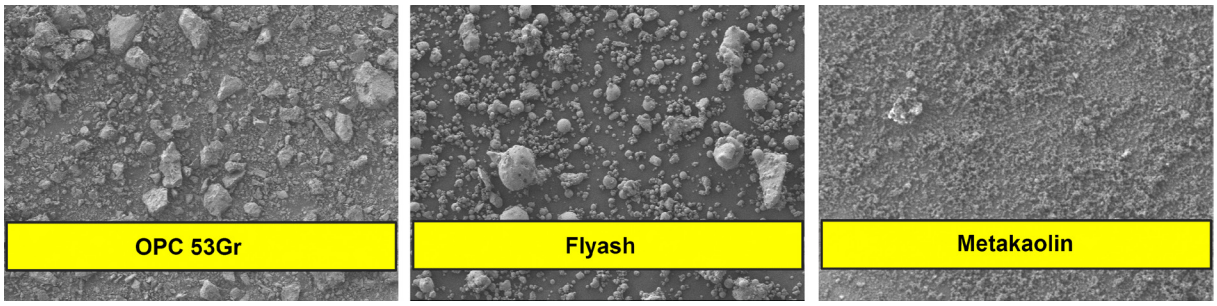
### 3. 7. Super-plasticizer (SP)

Locally available reputed brand of PCE based high range water reducing (HRWR) SP complying to IS 9103:1999 [55] having a water reduction capacity of 35%. SP's specific gravity was 1.15.

Material characteristics of OPC, Flyash, MK is presented in Table 1. SEM images of materials used for the study like OPC, Flyash and Metakaolin, at 10-micron magnification, is presented in Fig. 1 and particle size distribution of the same is presented in Fig. 2.

**Table 1.** Material characterization

| Compounds | OPC 53Gr(%) | MK % | Flyash % |
|---|---|---|---|
| CaO | 63. 06 | - | 5. 10 |
| $SiO_2$ | 22. 38 | 53. 26 | 63. 82 |
| $Al_2O_3$ | 4. 86 | 42. 19 | 22. 51 |
| MgO | 4. 31 | 0. 40 | 0. 17 |
| $Fe_2O_3$ | 4. 25 | 0. 12 | 6. 21 |
| LOI | 1. 27 | 1. 40 | 0. 22 |
| Chloride | 0. 004 | 0. 072 | 0. 009 |
| Specification | IS 269 :2015 | IS16354 :2015 | IS3182 :2013 |




(a) (b) (c)

**Figure 1.** SEM images OPC, Flyash and Metakaolin (at 10-micron magnification)

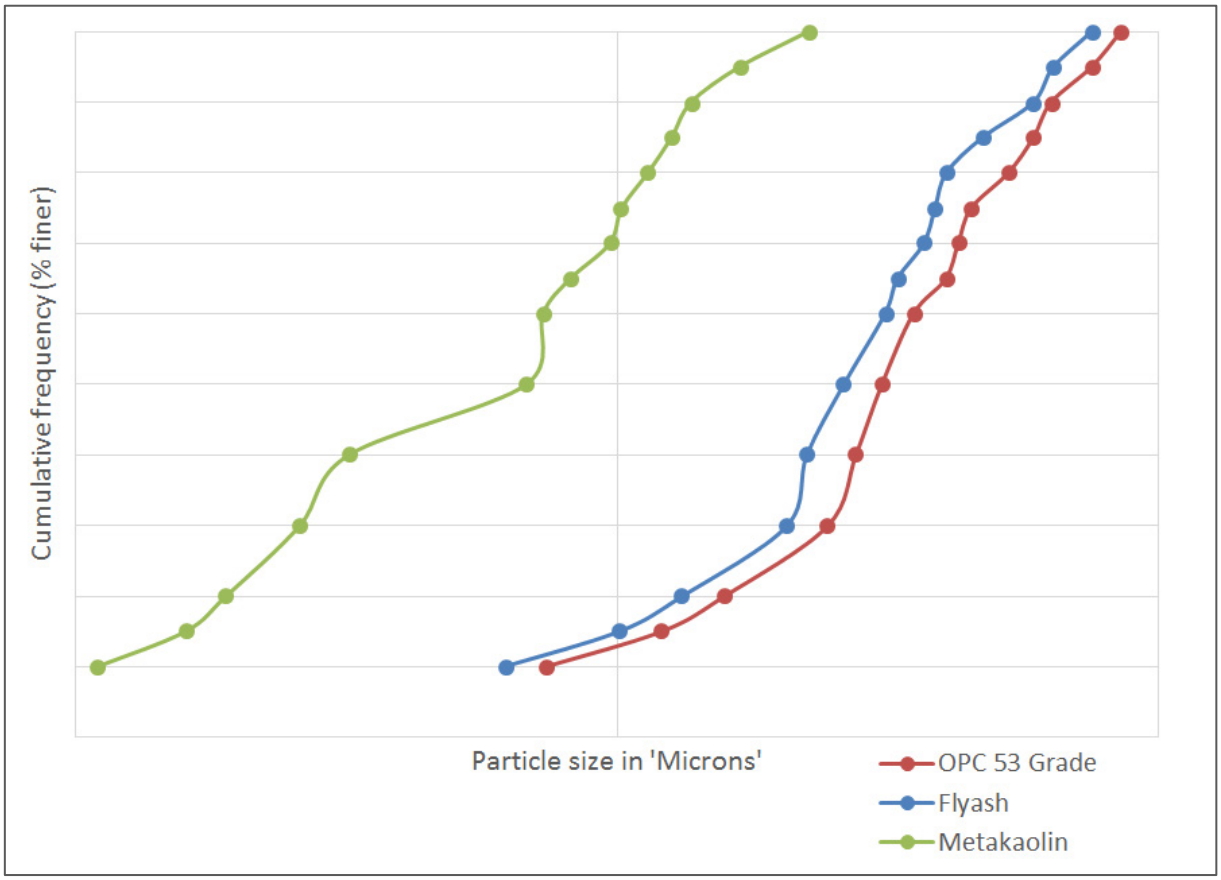



**Figure 2.** Particle size distribution of OPC, Flyash and Metakaolin

## 4. Methodology

In this experimental investigation, control SCC mix proportioned with coarse aggregates of 10mm size(CA10mm) of 720 Kg/m$^3$, fine aggregate (river sand) of 910 Kg/m$^3$, with a free w/cm as 0.33, and PCE based chemical admixture, 1.2% by weight of total cm. Control SCC mix was used for comparison and the mix was consisting of 420 Kg/m$^3$ of OPC 53 grade, 140 Kg/m$^3$ of flyash (as fine SCM) and 1% of AR fibres. The resulting control mix was designated as $FSCC_0$. Two types of ternary blended M60 grade SCC mixes were established, one type with 1% AR fibres and other type without AR fibres for the intended experimental study for experimenting the influence of addition of MK, with fibres and without fibres, in SCC mixes. In proportioning of first type of M60 grade of SCC (with a fixed 25% flyash content and 0% of AR fibres), part replacement of OPC was done with 2.5%, 5%, 7.5% and 10% MK (as ultrafine SCMs) in each trial. Free w/cm was maintained at 0.33 and PCE based high range water reducing chemical admixture, at 1. 2% by weight of total cm, was used to maintain the qualifying characteristics of SCC in all the above mixes. The above SCC mixes were designated as $SCC_{MK2.5}$, $SCC_{MK5}$, $SCC_{MK7.5}$ and $SCC_{MK10}$. Similarly, in proportioning the second type of M60 grade of SCC (with a

fixed 25% flyash content and 1% of AR fibres), part replacement of OPC was done with 2.5%, 5%, 7.5% and 10% MK in each trial. Free w/cm and PCE content of the above second type SCC kept similar to first type of SCC and the resulting SCC mixes were designated as $FSCC_{MK2.5}$, $FSCC_{MK5}$, $FSCC_{MK7.5}$ and $FSCC_{MK10}$. So in this way a total 8 nos. of SCC mixes i.e. 4 nos of SCC mixes without addition of AR fibres and 4 nos of SCC mixes with fibre were proportioned for comparing the performance with reference to control mix of $FSCC_0$. Although SCC with various types of fibres had been experimented in the past [19], SCC with blends of OPC, FA, MK and AR fibre was observed to be a less experimented mix for establishing various properties of SCC in fresh state and hardened state. In this present study, the fresh state properties of SCC, such as slump flow (spread), V-funnel flow time, and L-box hindering ratio were tested using relevant Indian Standards and EFNARC guidelines [49]. Three numbers of tests were conducted for each of the fresh state tests on SCC and FSCC mixes and average of the results was calculated and recorded as the tested value. After conducting the slump flow, V funnel flow time and L-Box test on proportioned SCC and FSCC mixes, fresh mixes were discharged into the steel moulds complying to the specifications of IS 1199 [46] for fabricating the specimens of SCC and FSCC. All the specimens were kept in standard curing chambers maintained with a RH of 95 ± 5% and temperature 27±2°C for a period of 24 $\pm$ 0.5 hours and after this period the specimens were demoulded and kept in standard water curing tank maintained with a temperature 27 ± 2°C till corresponding testing ages as planned in this study. Hardened state SCC properties like compressive strength, flexural strength at various ages like at 1 day, 3days, 7 days, 28 days and 56 days were investigated using relevant Indian Standards [57]. Three numbers of specimens were casted for each period of tests on hardened state SCC and FSCC mixes and average of the results was calculated and recorded as the tested value. Also indirect durability characteristics like volume of permeable voids, water absorption, permeability and water sorptivity at ages of 28 days and 56 days were investigated using relevant Indian Standards and ASTM standards [56-58]. The test results were analysed, presented and discussed in the subsequent paras. Experimented SCC mixes and proportion of various incorporated materials in the SCC mix is presented in Table 2. Methodology of mixing SCC and FSCC is presented in Fig. 3 and Fig. 4.

**Table 2.** Mix Proportions of SCC and FSCC Mixes

| Sl. No | Mixture ID | Cementitious Materials composition | | | Fibre | Concrete Making Materials (Kg/Cum) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | OPC 53 Gr (%) | Flyash (%) | MK (%) | AR (%) | Total Cementitious Materials | CA 10mm | Sand | PCE Admixture | Free Water |
| 1 | $FSCC_0$ | 74. 0 | 25. 0 | 0. 0 | 1. 0 | 560 | 720 | 910 | 6. 72 | 185 |
| 2 | $SCC_{MK2. 5}$ | 72. 5 | 25. 0 | 2. 5 | 0. 0 | 560 | 720 | 910 | 6. 72 | 185 |
| 3 | $FSCC_{MK2. 5}$ | 71. 5 | 25. 0 | 2. 5 | 1. 0 | 560 | 720 | 910 | 6. 72 | 185 |
| 4 | $SCC_{MK5}$ | 70. 0 | 25. 0 | 5. 0 | 0. 0 | 560 | 720 | 910 | 6. 72 | 185 |
| 5 | $FSCC_{MK5}$ | 69. 0 | 25. 0 | 5. 0 | 1. 0 | 560 | 720 | 910 | 6. 72 | 185 |
| 6 | $SCC_{MK7. 5}$ | 67. 5 | 25. 0 | 7. 5 | 0. 0 | 560 | 720 | 910 | 6. 72 | 185 |
| 7 | $FSCC_{MK7. 5}$ | 66. 5 | 25. 0 | 7. 5 | 1. 0 | 560 | 720 | 910 | 6. 72 | 185 |
| 8 | $SCC_{MK10}$ | 65. 0 | 25. 0 | 10. 0 | 0. 0 | 560 | 720 | 910 | 6. 72 | 185 |
| 9 | $FSCC_{MK10}$ | 64. 0 | 25. 0 | 10. 0 | 1. 0 | 560 | 720 | 910 | 6. 72 | 185 |

### 4.1. Methodology of Mixing SCC and FSCC

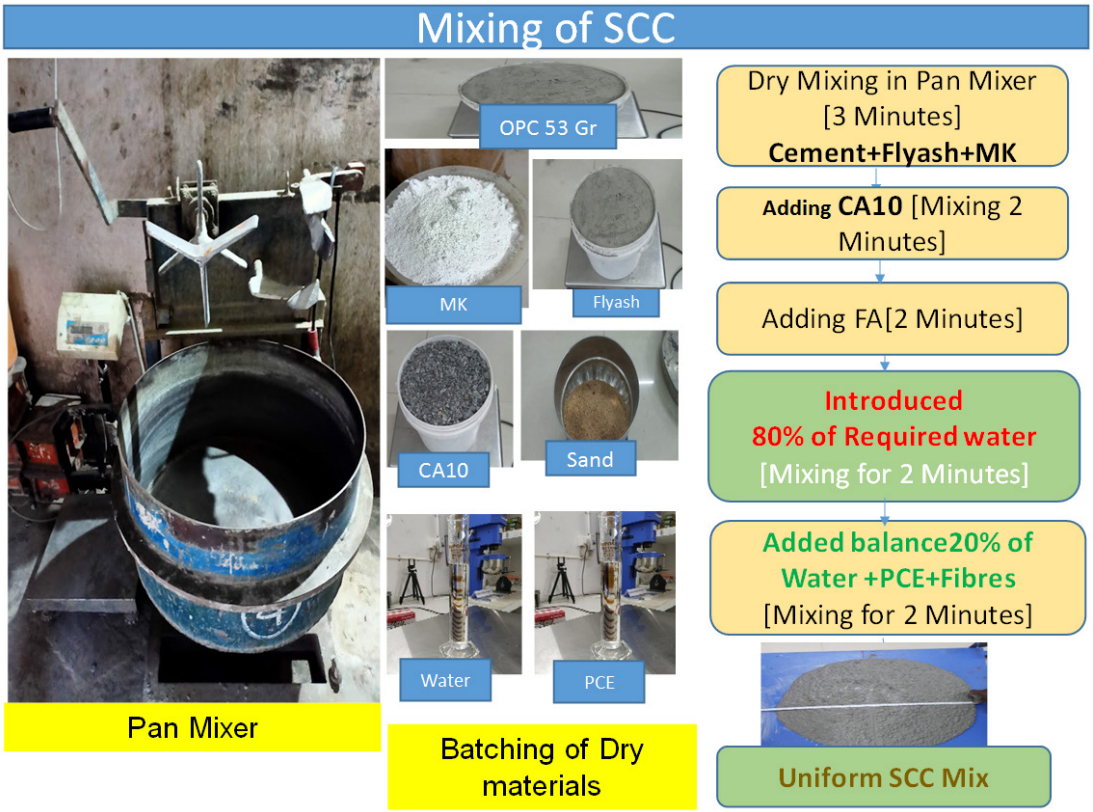



**Figure 3.** Methodology of mixing SCC

**Figure 4.** Methodology of mixing FSCC

# 5. Results and Discussions

## 5.1. Fresh State Properties of SCC and FSCC

### 5.1.1. Slump Flow (Diameter Spread)

It was observed that water demand of concrete mix reduced, to maintain a desirable flow, with addition of fine SCMs as partial replacement of OPC. Whereas the water demand of concrete mix increased, with addition of ultrafine SCMs as partial replacement of OPC, as compared to water demand of control mix $FSCC_0$. Chemical configuration and fineness of these SCMs were the key characteristics that affected the water demand for maintaining flowable mix [9]. Slump flow of various SCC and FSCC mixes, investigated in this work, are presented in Table 3. It can be perceived from Table 3 that, for the SCC mixes, wherein 0% fibre addition was made, when %MK varied from 2.5% to 10% i.e. for the mixes $SCC_{MK2.5}$ to $SCC_{MK10}$, improved cohesiveness of mix was observed [15, 20]. It was noted that slump flow of mixes was initially increased for the mixes $SCC_{MK2.5}$ to $SCC_{MK7.5}$ by 5.08% to 1.69%, in an increasing order of %MK in the mix, as compared to control mix $FSCC_0$. This slight increase in slump flow as was observed during the trials, indicates that OPC's replacement by MK up to 7.5% does not affect the flowability of the mix[38]. This is in alignment with the outcome of numerous research works on ultrafine SCMs incorporation in SCC, wherein it was mentioned in the research works outcome that the higher water demand of the mix, upon incorporation of reactive SCMs like MK, Silica fume, RHA etc., was attributed to the increased finer materials in the experimented blend, which has resulted an increase of surface area of particles in the blend, and thereby requiring more water in order to satisfy the its cohesiveness and attainment of flowing nature [9]. The outcome of slump flow results from the present study under taken by the author also confirms the above except that in the present study a fixed quantity of flyash was present in the cementitious system which was helping the proportioned blend to be more mobile and flowable due to the spherical sized particles of flyash which can also be seen in the SEM image of flyash as presented in Fig1(b). In this present study, it was also observed that as the % MK was increased in the mix from 7.5% to 10%, the slump flow was reduced by 3.39% as compared to control mix $FSCC_0$. This observation was indicating the probable initiation of early hydration reactions due to availability of sufficient quantity of MK (ultrafine SCMs) in the mix [32]. For FSCC mixes, wherein for each such mix, 1% of AR fibre was incorporated in addition to the variable %MK from 2.5% to 10%, slump flow reducing from 1.69% to 6.78% as compared to control mix of $FSCC_0$. This indicates that in presence of discrete AR fibres in such mixes, the water demand further increases due to the fibre's geometry, size, dispersion and with an increase in %MK in the mix to maintain the desired flow. This outcome is in fair agreement with the results [18] except that in the present study a fixed proportion of AR fibre is incorporated into the FSCC mix as against the variable proportion of fibres in the cited study.

### 5.1.2. V Funnel Flow Time (Passability)

V funnel flow time of various SCC and FSCC mixes, investigated in this work, are presented in Table 3. As can be seen from Table 3 that, for the SCC mixes prepared with 0% AR fibre incorporation, when %MK varied from 2.5% to 10% i. e. for the mixes $SCC_{MK2.5}$ to $SCC_{MK10}$, V funnel flow time decreased for all the mixes from $SCC_{MK2.5}$ to $SCC_{MK7.5}$ by 10% to 0%, in the increasing order of %MK in the mix, as compared to control mix $FSCC_0$. It was also noticed that beyond 7.5% of MK in the SCC mix, the V funnel flow time started increasing. This increase in V funnel flow time indicates that OPC's replacement by MK beyond 7.5% slowly affects the passability of the mix, and thus indicating the turn of early hydration reactions [38].

**Table 3.** Fresh state properties of SCC and FSCC Mixes

| Sl. No | Mix ID | Slump flow | 'V'funnel flow time | L box flow | Initial setting time (IST) | Final setting time (FST) |
|---|---|---|---|---|---|---|
| | | mm | seconds | h2/h1 | minutes | minutes |
| 1 | $FSCC_0$ | 590 | 20 | 0. 86 | 440 | 520 |
| 2 | $SCC_{MK2.5}$ | 620 | 18 | 0. 90 | 410 | 500 |
| 3 | $FSCC_{MK2.5}$ | 580 | 21 | 0. 85 | 360 | 495 |
| 4 | $SCC_{MK5}$ | 620 | 18 | 0. 88 | 370 | 470 |
| 5 | $FSCC_{MK5}$ | 560 | 22 | 0. 86 | 350 | 440 |
| 6 | $SCC_{MK7.5}$ | 600 | 20 | 0. 88 | 320 | 450 |
| 7 | $FSCC_{MK7.5}$ | 550 | 23 | 0. 84 | 310 | 400 |
| 8 | $SCC_{MK10}$ | 570 | 22 | 0. 82 | 300 | 330 |
| 9 | $FSCC_{MK10}$ | 550 | 24 | 0. 80 | 290 | 310 |

This contradicts with the outcome [39] where in it was indicated that %MK up to 15% will not affect appreciably the flow properties of SCC. This increase in flow time was due to the increase in finer material (as increases with increase% MK) in the experimented blends in case of SCC mixes and in addition to the existence of fibres in case of FSCC mixes. This is in fair agreement with the outcome [22]. In this present study, it was observed that there was also a significant increase in the obstruction observed to the flow and hence the same was resulting in higher V funnel flow time of mix to pass through the narrowed section of V funnel. While for FSCC mixes, wherein for each such mix, 1% of AR fibre was incorporated in addition to the variable %MK from 2. 5% to 10%, V funnel flow time increased from 5% to 20% as compared to control mix of $FSCC_0$. This indicates that in presence of discrete AR fibres in such mixes, the water requirement, to maintain flowability of mix increases [28], which may further increase with an increase in %MK in the mix. The results achieved for V funnel flow time test, in this study, was principally associated with outcome recognized by [30] except the variation is that in the study 0. 3% steel fibres and 0. 5% of cellulose fibres were used in the SCC.

5.1.3. L Box Flow (Hindering ratio)

Obstructed flow depth ratio in L box test was tested as per EFNARC guidelines [28] and the results are presented in Table 3. As can be seen from Table 3, for the SCC mixes prepared with 0% AR fibre, when %MK varied from 2.5% to 10% i. e. for the mixes $SCC_{MK2.5}$ to $SCC_{MK10}$, flow depth ratio in L box increased for all the mixes from $SCC_{MK2.5}$ to $SCC_{MK7.5}$ by 4.65% to 2.33%, in the increasing order of %MK in the mix, as compared to the control mix $FSCC_0$. It was noted that, beyond 7.5% of MK in the SCC mix, the flow depth ratio in L box started decreasing. This decrease in flow depth ratio in L box indicates that OPC's replacement by MK beyond 7.5% slowly affects the flow behaviour of the mix due to increased finer material content in the blend (with increase in %MK in the mix) and also indicates the turn of early hydration reactions [38]. This is in contradiction with the findings of the study[39] wherein it was stated that %MK up to 15% will not significantly affect the flow characteristics of SCC. While for FSCC mixes, wherein for each such mix, 1% of AR fibre was incorporated in addition to the variable %MK from 2.5% to 10%, flow depth ratio in L box decreased from 1.16% to 6.98% as compared to control mix of $FSCC_0$. This indicates that in presence of discrete AR fibres in such mixes the water requirement, to maintain flow depth ratio of mix, increases with an increase in %MK in the mix due to the fineness of cementitious blend besides the dispersed fibres present in the mix [28]. This is in fair agreement with the outcomes [9].

5.1.4. Initial Setting Time (IST)

IST conducted as per IS 1199:2018. IST values of experimented mix are presented in Table 3. As can be seen from Table 3, for the SCC mixes prepared with 0% AR fibre, when %MK varied from 2. 5% to 10% i.e. for the mixes $SCC_{MK2.5}$ to $SCC_{MK10}$, IST decreased for all the mixes from $SCC_{MK2.5}$ to $SCC_{MK10}$ by 6.82% to 34. 09%, in the increasing order of %MK in the mix, as compared to control mix $FSCC_0$. This decrease in IST was attributed to the higher fineness of the blend, and chemical composition of ultrafine MK [33]. This is in fair agreement with the outcome of the study [26] except that the ultrafine material used was silica fume and the % replacements of OPC with silica fume was from 5% to 20%. In this present study, it was noticed that the higher % of decrease in IST beyond 5% of MK addition into the mix indicates that OPC's replacement by MK beyond 5% quickens the setting time of mix, and thus indicating the turn of early hydration reactions[38]. This was due to the reason that, as the MK content in the mix increases, the fineness of the cementitious blend increases and also the chemical nature of MK prompts the early reactions in the cementitious blend[42]. While for FSCC mixes, wherein for each such mix, 1% of AR fibre was incorporated in addition to the variable %MK from 2.5% to 10%, IST decreased from 18.18% to 34.09% as compared to control mix of $FSCC_0$. This indicates that in presence of discrete AR fibres in such mixes, IST decreases with increase in %MK in the mix. This was in just agreement with the outcomes [33] except that the proportion of MK was varied from 5% to 25% in the referred citation. It can also be seen that for $SCC_{MK10}$ and $FSCC_{MK10}$ the decrease in the IST compared to control mix $FSCC_0$ is equal. This may be due to the reason that at 10% MK, in the present experimented cementitious system, the saturation replacement level might have attained.

5.1.5. Final Setting Time (FST)

FST was conducted as per IS 1199: [56] and the test results are presented in Table 3. As can be seen from Table 3, for the SCC mixes prepared with 0% AR fibre, when %MK varied from 2.5% to 10% i.e. for the mixes $SCC_{MK2.5}$ to $SCC_{MK10}$, FST was decreased for all the mixes from $SCC_{MK2.5}$ to $SCC_{MK10}$ by 3.85% to 36.54%, in the increasing order of %MK in the mix, compared to control mix $FSCC_0$. This decrease in FST was attributed to the higher fineness of the blend, and chemical composition of ultrafine MK. The higher % of decrease in FST beyond 5% of MK's addition to the mix indicates that OPC's replacement by MK beyond 5% effects the setting time of mix, and thus indicating the turn of early hydration reactions [38]. This is in contradiction of the findings of the study [39] wherein it was mentioned that MK's proportion in concrete mix up to 15% significantly will not affect the fresh state properties of SCC. While as observed in this present study for FSCC mixes, wherein for each such mix, 1% of AR fibre was incorporated in addition to the variable %MK from 2.5% to 10%, FST decreased from 4. 81% to 40.38% as compared to control mix of $FSCC_0$. This indicates that in presence of discrete AR fibres in such mixes, FST decreases with increase in %MK in the mix

due to the fineness of the blend, and chemical nature of MK besides the dispersion of fibres in the mix [28]. This is in fair agreement with the outcomes [26] except that fibres used in the referred work were PVA and Steel fibres.

## 5. 2. Hardened State Properties of SCC and FSCC Mixes

### 5.2.1. Compressive Strength

Compressive strength test results for the experimented SCC and FSCC mixes are presented in Table 4.

It can be seen from Table 4 that, in all the experimented mixes of SCC and FSCC, there was continuous increase in the compressive strength from 1 day to 56 days, but as compared to initial % increase in the compressive strength from 1 day to 7 days, the % increase in the strength from 7 days to 28 days as well as % increase in strength from 28 days to 56 days was less. This is because of early age reactions caused by the MK in the mix due to higher finer materials in the blend and chemical composition of MK which prompts early age hydration reactions [38]. This is fairly agreeing with the outcome of the study [35]. For the SCC mixes prepared with 0% AR fibre, when %MK varied from 2.5% to 10% i.e. for the mixes $SCC_{MK2.5}$ to $SCC_{MK10}$, compressive strength from 1 day to 7days was increased for all the mixes from $SCC_{MK2.5}$ to $SCC_{MK10}$ by 0.16% to 8.28%, as compared to control mix $FSCC_0$. Similarly compressive strength for the same mixes, from 7days to 28 days, there was an increase in compressive strength, but at reduced rate as compared to gain in initial age (1 day to 7 days) compressive strength. Compressive strength gain from 28days to 56 days was observed to be marginal. The above results of compressive strength right from early age i.e. 1day, during maturity i.e. from beyond 1 day to 28days and after maturity age i.e. from 28 days to 56 days, can be attributed to the quickness of chemical reactions, in the early ages, as prompted by the presence of MK, due to higher finer materials in the blend and chemical nature of MK. The increase in compressive strength, though at slower pace, can be attributed to the presence of flyash in the experimented blend. This was somewhat contradicting with the outcomes [18] wherein RHA was used as the ultrafine material and the % replacement level of RHA was from 10% to 20% and the concrete experimented was geopolymer concrete. This may be due to the chemical nature of RHA with reference the chemical nature of MK. In this present study, it was noted that the higher % of compressive strength gain in the initial age of 1day to 7days indicated that early hydration reactions prompted by MK in the cementitious blend almost completed [14]. While for FSCC mixes, wherein for each such mix, 1% of AR fibre was incorporated in addition to the variable %MK from 2.5% to 10%, compressive strength gain was more as compared to control mix of $FSCC_0$. Also the compressive strength gain for all the ages for FSCC mixes was more than the compressive strength gains of SCC mixes. This indicates that in presence of discrete AR fibres in such mixes, compressive strength increases with the increase in %MK in the mix. This may be due to the reason that the MK and AR fibres were more compatible in the experimented cementitious blends [22]. This contradicts with the outcome of the study [4] wherein ultrafine FA was used as part replacement of OPC from 0% to 20% and the fibres used was steel fibres. In this present study, it was observed from the test results that the maximum early age compressive strength gains of 20.53% was for the $FSCC_{MK7.5}$. 1 day targeted compressive strength of 25 $N/mm^2$ was achieved at 7.5% MK in case of SCC mix and at 5% MK in case of FRSCC Mix. Thus addition of AR fibre in marginal quantity of 1% and 5% MK was helpful in achieving early age compressive strength of FRSCC mixes due to fibre geometry, dispersion, and compatibility besides the chemical nature of MK. This was in contradiction with the outcome of the study [13] wherein it was stated that fibre addition to the concrete mix will not increase the compressive strength.

**Table 4.** Compressive Strength of SCC and FSCC Mixes at various ages

| Mix ID | Compressive Strength($N/mm^2$) | | | | |
|---|---|---|---|---|---|
| | 1 Day | 3 Days | 7 Days | 28 Days | 56 Days |
| $FSCC_0$ | 23. 3 | 32. 5 | 56. 8 | 58. 1 | 59. 2 |
| $SCC_{MK2. 5}$ | 23. 9 | 36. 4 | 58. 3 | 64. 5 | 70. 1 |
| $FSCC_{MK2. 5}$ | 24. 2 | 37. 8 | 59. 4 | 66. 2 | 70. 9 |
| $SCC_{MK5}$ | 24. 7 | 38. 5 | 59. 9 | 68. 8 | 71. 1 |
| $FSCC_{MK5}$ | 25. 2 | 38. 8 | 60. 2 | 68. 6 | 72. 6 |
| $SCC_{MK7. 5}$ | 25. 9 | 38. 9 | 60. 4 | 69. 8 | 72. 8 |
| $FSCC_{MK7. 5}$ | 27. 1 | 40. 1 | 60. 5 | 69. 9 | 73. 4 |
| $SCC_{MK10}$ | 26. 2 | 41. 5 | 61. 7 | 70. 2 | 74. 8 |
| $FSCC_{MK10}$ | 27. 4 | 43. 2 | 61. 9 | 70. 8 | 75. 2 |

5.2.2. Flexural Strength

Flexural strength test results for the experimented SCC and FSCC mixes presented Table 5.

It can be seen from Table 5 that, in all the experimented mixes of SCC and FSCC there was continuous increase in the flexural strength from 1 day to 56 days, but compared to initial % increase in the flexural strength from 1 day to 7 days, % increase in the flexural strength from 7 days to 28 days as well as from 28 days to 56 days was less. The early age flexural strength gain of the experimented mixes may be due to the presence of discrete fibres [14] besides the quickness of reactions prompted by MK. The above results of flexural strength right from during maturity i.e. from beyond 7 days to 28 days and after maturity age i.e. from 28 days to 56 days can be attributed to the presence of flyash in the mix causing the secondary hydration reactions [15]. This is alignment with the outcome of the study [43] except that the RHA was used as ultrafine SCM at a varying proportion of 5% to 20%. In this study, it was noted that, for the SCC mixes prepared with 0% AR fibre, when %MK varied from 2.5% to 10% i.e. for the mixes $SCC_{MK2.5}$ to $SCC_{MK10}$, flexural strength, from 1 day to 7days, was increased for all the mixes from $SCC_{MK2.5}$ to $SCC_{MK10}$ by 2.89% to 20.56%, as compared to control mix $FSCC_0$. Similarly for the flexural strength of the same mixes from 7days to 28 days, there was an increase in flexural strength but at reduced rate as compared to initial age (1 day to 7 days) flexural strength gain. Flexural gain from 28days to 56 days was observed to be marginal. This may be due to the reason that most of the pozzolanic reactions as resulted due to the presence of MK in the mix ceases upon reaching 7 days maturity [14]. The higher % of flexural strength gain in the initial age of 1day to 7days indicates that OPC's replacement by MK effects early age hydration reactions. While for FSCC mixes, wherein for each such mix, 1% of AR fibre was incorporated in addition to the variable % MK from 2.5% to 10%, flexural strength gain was more as compared to control mix of $FSCC_0$. Also the flexural strength gain for all the ages for FSCC mixes was more than the flexural strength gains of SCC mixes. This indicates that in presence of discrete AR fibres, in such mixes, flexural strength increases with the increase in %MK in the mix. This was due to the reason that dispersed discrete fibres in the concrete mix aids in attainment of higher flexural strength, than that of the concrete mix without fibres, owing to the fibre geometry, size besides the compatibility achieved with the fibres and other cementitious materials in the proportioned mixes. This is in fair agreement with the outcome of the study [45] except that the fibres used in the study were steel fibres and the proportion was 0.3%, 0.60% and 0.9%. In this present study it was observed that the maximum early age flexural strength gain was 29.13% which was for the $FSCC_{MK10}$. 1 day targeted flexural strength of 2.5 N/mm$^2$ was achieved at 7.5% MK in case of SCC mix and at 5% MK in case of FRSCC Mix. Thus addition of AR fibre in marginal quantity of 1% and 5% MK was helpful in achieving early age flexural strength of FSCC mixes.

**Table 5.** Flexural Strength of SCC and FSCC Mixes at various ages

| Mix ID | Flexural Strength(N/mm$^2$) | | | | |
|---|---|---|---|---|---|
| | 1 Day | 3 Days | 7 Days | 28 Days | 56 Days |
| $FSCC_0$ | 1. 61 | 1. 97 | 2. 16 | 5. 24 | 5. 30 |
| $SCC_{MK2. 5}$ | 1. 94 | 2. 08 | 2. 62 | 5. 28 | 5. 34 |
| $FSCC_{MK2. 5}$ | 2. 13 | 2. 41 | 2. 71 | 5. 41 | 5. 46 |
| $SCC_{MK5}$ | 2. 47 | 2. 46 | 2. 88 | 5. 56 | 5. 61 |
| $FSCC_{MK5}$ | 2. 52 | 2. 61 | 2. 94 | 5. 59 | 5. 64 |
| $SCC_{MK7. 5}$ | 2. 59 | 2. 98 | 3. 14 | 6. 20 | 6. 30 |
| $FSCC_{MK7. 5}$ | 2. 61 | 3. 01 | 3. 36 | 6. 63 | 6. 74 |
| $SCC_{MK10}$ | 2. 64 | 3. 08 | 3. 68 | 6. 65 | 6. 76 |
| $FSCC_{MK10}$ | 2. 67 | 3. 12 | 3. 72 | 6. 66 | 6. 79 |

**Table 6.** %Volume of permeable pores(%VPV), % water absorption(WA), permeability and water sorptivity results

| Mix ID | %VPV | % WA | Permeability | Water Sorptivity |
|---|---|---|---|---|
| | Tested As per | | | |
| | ASTM C642 | ASTM C642 | IS 516 | IS 516 |
| | 28Days | 28Days | 28Days $10^{-12}$ $m^2/s$ | 28Days ($10^{-4}$ $g/mm^2/min^{1/2}$) |
| $FSCC_0$ | 5. 4 | 3. 2 | 0. 79 | 1. 2 |
| $SCC_{MK2. 5}$ | 5. 1 | 3. 2 | 0. 17 | 1. 1 |
| $FSCC_{MK2. 5}$ | 4. 9 | 3. 1 | 0. 19 | 1. 0 |
| $SCC_{MK5}$ | 4. 6 | 3. 1 | 0. 16 | 0. 9 |
| $FSCC_{MK5}$ | 4. 4 | 2. 8 | 0. 15 | 0. 7 |
| $SCC_{MK7. 5}$ | 4. 1 | 2. 7 | 0. 13 | 0. 5 |
| $FSCC_{MK7. 5}$ | 4. 1 | 2. 5 | 0. 11 | 0. 3 |
| $SCC_{MK10}$ | 3. 8 | 2. 5 | 0. 09 | 0. 3 |
| $FSCC_{MK10}$ | 3. 8 | 2. 4 | 0. 06 | 0. 2 |

### 5.3. Durability Properties of SCC and FSCC Mixes

%Volume of permeable pores (%VPV), % water absorption (WA), permeability and water sorptivity tests, which are considered to be indirect indicative parameters of durability of concrete, were conducted for all the experimented mixes of SCC and FSCC and the results are presented in Table 6.

It can be seen from the Table 6 that, for the SCC mixes prepared with 0% fibre combination, when %MK varied from 2.5% to 10% i.e. for the mixes $SCC_{MK2.5}$ to $SCC_{MK10}$, %VPV was decreased for all the mixes from $SCC_{MK2.5}$ to $SCC_{MK10}$ by 5.56% to 29.63%, in the increasing order of %MK in the mix, as compared to control mix of $FSCC_{0.}$ The higher % of decrease in VPV beyond 5% of MK addition to the mix indicates that OPC's replacement by MK beyond 5% indicates the turn of early hydration reactions and pore size refinement [38]. This is in agreement with the outcome of the study [44] except that the ultrafine material in the cited case was SF from 5% to 20% and RHA was 5% to 20%. In this study, it was noted that for FSCC mixes, wherein for each such mix, 1% of AR fibre was incorporated in addition to the variable %MK from 2.5% to 10%, and %VPV decreased from 9.26% to 29.63% as compared to control mix of $FSCC_0$. This indicates that in presence of MK and due to its fineness the voids in the matrix of FSCC mixes were filled to the possible extent. Hence the effect of discrete AR fibres was not so significant on the durability properties of the mix in such mixes. Thus the resulting %VPV decreased for all the mixes experimented in this study. It can also be seen that for $SCC_{MK10}$ and $FSCC_{MK10}$ the decrease in the %VPV compared to control mix $FSCC_0$ is equal. Similar trends are observed in case of both SCC and FSCC mixes in terms of WA, permeability and water sorptivity test values.

## 6. Conclusions

The following conclusions are framed from the experimental study on SCC and FSCC mixes incorporating OPC, Flyash (as fine SCM) and Metakaolin (as ultrafine SCM) and AR Fibre as discrete fibre reinforcement:

(1) OPC's replacement by MK up to 7.5% does not affect the flowability of the SCC mix but improves the cohesiveness of concrete.

(2) Incorporation of AR fibre, in addition to fine and ultrafine SCMs, in the concrete mixes decreases the flow marginally.

(3) Presence of discrete AR fibres in FSCC mixes increases the water demand for maintaining the require flow of SCC. Water demand further increases with increase in %MK in the mix.

(4) 1 day targeted compressive strength of 25 $N/mm^2$ is achieved at 7.5% MK in case of SCC mix and for FRSCC mix the same is conveniently achieved at 5% MK. Thus addition of AR fibre in marginal quantity of 1% and 5% MK is helpful in achieving early age compressive strength of FRSCC mixes.

(5) 1 day targeted flexural strength of 2.5 $N/mm^2$ is achieved at 7.5% MK in case of SCC mix and for FRSCC mix the same is conveniently achieved at 5% MK. Thus addition of AR fibre in marginal quantity of 1% and 5% MK is helpful in achieving early age flexural strength of FRSCC mixes.

(6) For both SCC mixes and FRSCC mixes, %VPV, %WA, permeability and water sorptivity, all of which are considered as indirect durability parameters, decreased with the % increase in MK.

## Conflicts of Interest

Authors declare that they have no conflicts of interest.

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