Development of An Environmental-Friendly Durable Concrete

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Abstract

In this experimental study on Self Compacting Concrete (SCC), the Manufactured sand (M-sand) and Fly ash (FA) were utilised for partial replacement of Natural sand (N-sand) and Ordinary Portland Cement (OPC), respectively. N-sand was partially replaced by M-sand at various percentage levels, after the dose of FA in the mix was optimized. In terms of compressive strength, the optimum replacement level of OPC by FA was 20%, while for replacement of N-sand by M-sand it was 50%. Two types of mixes were made to compare the macro and micro level properties of SCC, i.e., SCC-I (100%OPC+100%N-sand), and SCC-II (80%OPC+20%FA+50%N-sand+50%M-sand). The characteristics of fresh concrete mixes were determined using Slump flow, T_{50} time, V-funnel, L-box, U-box, and J-ring tests. After 28 days of curing in tap water, both type of specimens were exposed in solution of Ammonium Sulphate $[(NH_4)_2SO_4]$ containing Sulphate salt concentration of 2.0g/l for 360 days to test their durability. Loss in compressive strength, weight change, sorptivity, and micro-structural changes (XRD, SEM, and EDS) all were evaluated up to 360 days. It was found that the use of FA and M-sand in concrete makes it more environment friendly and durable, as well as having higher performance in a sulphate environment.

Introduction

Cement and N-sand are the two basic ingredients in concrete. CO_2 emissions rise as a result of increased cement manufacturing, resulting in air pollution. Large-scale depletion of natural resources due to the use of N-Sand also causes environmental issues. Governments have placed limits on mining of N-Sand from river beds because of growing national concerns, and worldwide consensus on environmental protection. To address these issues, cost-effective alternative materials are required to make durable structures without compromising other quality parameters. Fly ash is used as an alternative/ a supplementary cementitious material in the production of SCC, which increases its performance. It also addresses the issue of FA disposal as well as pollution of the environment. If found suitable, M-sand is another potential resource that could solve the problem of N-Sand scarcity.

Concrete is one of the most often utilized building materials on the planet. However, the manufacture of portland cement, a necessary component of concrete, results in the release of a considerable amount of CO_2 , a greenhouse gas; one ton of portland cement clinker is estimated to produce approximately one ton of CO_2 and other greenhouse gases (GHGs). Environmental challenges have a significant influence on cement and concrete industry's long-term viability. A sustainable concrete structure is one that is built with the least possible adverse environmental effects over its full life cycle. Concrete is a sustainable material because: it has a low inherent energy demand; it is made from some of the world's most abundant resources; it has a high thermal mass; it can be made using recycled materials, and is totally recyclable. Structures that are designed and built sustainably have a low environmental effect. Low energy costs are embodied in the use of "green" materials. The concrete must be long-lasting, incurring low-maintenance cost. High-performance concretes can help in reducing the amount of cement used, and the overall volume of concrete needed. Concrete must continue to evolve in order to meet the ever-

increasing demands of all the users. To make even "greener" concrete, post-consumer trash and industrial by-products must be reused in the mix. Coal ash, rice husk ash, wood ash, natural pozzolans, GGBFS, silica fume, and other similar pozzolanic ingredients can be used to reduce the amount of portland cement, and also in producing more durable concrete. Greener concrete also improves air quality, reduces solid waste, and promotes the cement and concrete industry's long-term viability.

SCC is a specific type of concrete that, due to its superior deformability, can be laid and consolidated under its own weight without any vibration effort, while also being cohesive enough to be handled without segregation or bleeding. Only if all the three workability qualities are met, for example, 1. filling ability, 2. passing ability, and 3. segregation resistance, can a concrete mix be designated as SCC. SCC, in general, has a lot of power ingredients and a super plasticizer. Mineral admixtures such as FA, slag, and other admixtures are frequently used to augment the high powder content.

Mineral admixtures, such as FA, can be used to raise the slump of concrete without raising the cost. Using FA in cement manufacturing has at least three advantages: extends the life of the concrete; keeps FA out of landfills; minimizes the amount of energy and water used to make concrete. Further, it reduces not only carbon dioxide, but also nitrogen oxides and sulphur dioxide, which are precursors to ozone formation and acid rain. Certain FA operations can generate carbon credit under both statutory and voluntary carbon trading regimes, besides making the concrete economical. There are various advantages of using FA in concrete. It reduces/eliminates the problem of FA disposal and pollution besides improving the concrete. Most industrial wastes are now utilized without fully exploiting their properties, or are disposed off rather than used.

SCC's strengths parameters were improved at 15% OPC replacement with FA (Khatib 2008). FA has been discovered to be the most suited pozzolana for the development of long-term SCC (Mohammed and Dawson 2013). It was found that, in comparison to the control mix, adding mineral admixtures improved the permeability properties and compressive strength significantly (Güneyisi et al. 2015). FA applied as a partial replacement for OPC increases the concrete's workability and mechanical performance (Sonebi 2004, Güneyisi 2010, Siddique 2011). By combining large volumes of Class F-FA, a cost-effective SCC can be created (Bouzouba and Lachemi 2001). When OPC was partially replaced with ultra pulverised FA, the flowability of the SCC mix improved, and the V-funnel time was in the range of EFNARC limits (Xie et al. 2002). The addition of FA to binary blends improved the flow diameter of the mixtures marginally (Güneyisi et al. 2008). For workability, mechanical properties, and durability, a 30% replacement level of OPC by FA could be optimum. Grinding produced the finest FA, which was determined to be the most effective in fostering stability and had the highest compressive strengths at all ages. (Paulo et al. 2019).

M-sand was successfully used as a filler material in the preparation of the SCC, improving concrete's hardened characteristics and increasing its durability. It has a good environmental impact as well (Nanthagopalan and Santhanam 2011, Deep et al. 2021). The strength of M-sand mixed concrete is higher than the N-sand concrete with the same paste composition (Shen et al. 2016, Tripathi et al. 2020). When M-sand was utilized as a fine aggregate in the concrete, Cortes et al. 2008, found that appropriate

flow and compressive strength were achieved. Huang et al. 2017, investigated the effect of particle shape of M-sand on concrete preparation and found that N-sand was more spherical and smooth, but M-sand was slim, flat, and rough. When the slump and cement dose are taken into account, M-sand concrete uses more water. Ding et al. 2016, found that when the powder content in M-sand was less than 13 %, the long-term compressive strength of M-sand mixed concrete was positive. When FA (greater than 20%) is used to partially replace OPC, it is observed that, there is a significant decrease in sorptivity (Leung et al. 2016). The most critical aspect affecting the durability attributes of FA concrete was the curing conditions. A 40% FA mixed concrete reduces sorptivity by 37%, when proper curing was provided. The sorptivity was observed to increase by 60% when the curing was insufficient (Gopalan 1996).

Leung et al. 2016, studied the sorptivity of SCC containing FA and SF and reported that when only FA is used to partially replace OPC, a more noticeable reduction in sorptivity is found when the FA content is greater than 20%. Water absorption decreases with increasing the FA content (Dhiyaneshwaran et al. 2013) [35]. According to Xie et al. 2002, adding ultra pulverized FA to SCC resulted in improved impermeability, freezing resistance, and decreased drying shrinkage. From a durability point of view, the optimum dose of FA in SCC as an OPC replacement material was 30% (Razak and Madhukeshwara 2017). The strongest resistance to Magnesium sulphate attack was reported in high performance concrete containing 20% FA (Sheng et al. 2017). According to Bassuoni et al. 2012, SCC's physical resistance (low penetrability) decreased in the Ammonium sulphate solution, and SCC specimen exposure to the Ammonium sulphate solution had negative effects on the physico-mechanical properties. The combined acid-sulphate attack caused by Ammonium sulphate is characterized by decomposition/softening, expansion, cracking, and spalling. Allahverdia et al. 2018, investigated the effect of Magnesium sulphate on a chemically activated phosphorus slag-based composite cement concrete and found that the compressive strength of specimens increased initially during the first few months of exposure. The limited increase in compressive strength is attributed primarily to the progress of hydration reactions within the specimen and, to a lesser extent, to the deposition of Gypsum in regions close to the exposed surfaces, resulting in densification; however, continued exposure resulted in continuous compressive strength reduction. Almost all SCC specimens displayed surface scaling; however, depending on the exposure time, some specimens had minor mass growth. Few specimens experienced a little increase in mass at the start of the test, followed by a fall at the end; however, no serious mass loss was seen. The engineering properties of specimens that lost mass did not always suffer a considerable loss (Bassuoni and Nehdi 2009). The SCC specimens were immersed in Ammonium sulphate solution for 54 weeks; all of the specimens experienced a little mass increase at the beginning of the test, followed by a declining trend as the test progressed (Bassuoni and Nehdi 2012). The presence of supplemental cementitious materials (SCMs) has been shown to diminish the amount of portlandite generated, which could be due to dilution of the cement component or increased pozzolanic activity, resulting in the formation of additional or secondary C-S-H gel. Because SCMs are incorporated into SCC, it has a low penetrability, allowing it to control the deterioration process when exposed to Ammonium Sulphate-based salt solutions (Sheba et al. 2020).

Table 1 Chemical compositions of binders

Chemical Composition (%)	OPC	FA
Silicon dioxide (SiO ₂)	20.04	59.50
Calcium oxide (CaO)	62.93	5.1
Aluminum oxide (Al ₂ O ₃)	5.26	20.36
Iron oxide (Fe ₂ O ₃)	4.02	5.90
Magnesium oxide (MgO)	1.6	1.6
Potassium oxide (K ₂ O)	0.93	1.94
Sodium oxide (Na ₂ O)	0.25	0.63
Loss of ignition	3.13	0.36

Mixture proportioning

This study used 43 grade OPC to make M25 grade SCC mix, which met the standards of EFNARC, 2005/ BIS Draft-2017. In per m³ concrete made, the constituents were: Binder content= 450 kg; Sand= 890 kg; Coarse Aggregate= 750 kg; Superplasticizer= 4.95 kg; Water/Binder ratio= 0.43. The final mix was 1: 1.98: 1.66 (Binder: Fine aggregate: Coarse aggregate).

Test procedure

100 mm cubes of various combinations were prepared. In tap water, the SCC- I and SCC- II specimens were cured for 28 days (Fig. 1). Following that, these were exposed to Ammonium Sulphate solution containing sulphate salt concentration 2.0g/l (Fig. 1) for 360 days to investigate their durability and micro-structural changes.

The compressive strength of specimens, at different ages, was determined in accordance with IS: 516-1959. To determine the change in weight, three specimens from each mix category was weighed before exposing to Ammonium Sulphate solution and tap-water. After the required exposure, the mass of specimens was found. The weight change of specimens at specified time intervals was calculated. Sorptivity of the specimens were also determined as per the provisions given in ASTM C 1585, Fig. 2 shows the samples and test setup for sorptivity measurement. The micro-structural analyses were conducted by using XRD, SEM and EDS.

Results And Discussion

Preparation of specimens

Five separate mixes were produced for varied levels of OPC replacement by FA in order to optimize FA dosages. By mass, the replacement levels of OPC with FA were 5, 10, 15, 20, and 25%. The compressive strengths of 30 cubes were determined at 7 and 28 days after they were cast and cured in tap water for 28 days. In terms of compressive strength, the optimum dose of FA was found to be 20%. M-sand was used to partly replace N-sand (30, 40, 50 and 60%, by mass), once the dose of FA was optimized. The best replacement level of N-sand was found to be 50% in terms of compressive strength after 24 cubes were cast and tested (Tripathi et al. 2021).

Finally, two types of specimens were prepared for further studies i.e., SCC-I consisting of 100%OPC+100%N-sand, SCC-II consisting of 80%OPC+20%FA+50%N-sand+50%M-sand.

Fresh and hardened properties

Fresh properties

The workability parameters of SCCs were found by performing different tests, and are included in Table 2. It was found that the workability of SCC-II improved in comparison to SCC-I.

Table 2 Workability parameters of SCCs

Tests	Results	
	SCC-I	SCC-II
Slump flow	670 mm	690 mm
T ₅₀ time	4.0 sec	3.0 sec
V- funnel	11.0 sec	9 sec
L-box (h_2/h_1)	0.87	0.96
U-box (h_2-h_1)	27 mm	19 mm
J-ring	9.0 mm	5 mm

It is concluded from detailed workability tests (Slump flow, T50 time, L-box, U-box and J-ring) performed on SCC with incorporating FA that as FA content increases in the mix its workability increases (Bouzoubaa and Lachemi 2001, Siddique 2011, Kumar and Prakash 2016). The incorporation of M-sand instead of N-sand slightly decreases its workability. These findings are in concurrence with the observations of some authors (Cortes et al. 2008, Nanthagopalan and Santhanam 2011, Shen et al. 2016, Huang et al. 2017).

Hardened properties

From the detailed experimental investigation on loss in compressive strength of both type of concrete specimens exposed to Sulphate salt solution (2.0g/l) up to 360 days, it was found that as exposure period increases loss in strength is also increases because of with time C-S-H gel production decreases which is mainly responsible for strength and subsequent leaching of Portlandite. These findings are in concurrence with the observation of some authors (Boudali et al. 2016, Allahverdia et al. 2018). In the hydration of cement at initial stage some Ettringite is also formed but these are unstable and with reaction of remaining Tricalcium aluminate it forms Mono sulphoaluminate, Its crystals are stable in Sulphate deficient solution but in the presence of excessive Sulphate ions in the environment, these crystals revert back in the Ettringite which is responsible for deterioration in long term. Same is identified in XRD and SEM analysis.

The maximum loss in strength was observed for SCC-I specimens throughout the exposure period, it may be due to porous structure of concrete and there is no supplementary cementitious material added in the mix and the least loss in compressive strength was found for SCC-II specimens which contains FA and M-sand, these alternative materials improves the pore structure, fulfil the pores and densified the transition zone due to additional C-S-H gel formation so that there is very less chance of ingress of aggressive materials in concrete. Similar findings are also reported by Amin et al. 2017.

Weight change

Figure 4 shows the variation in weight change of, SCC-I and SCC-II samples in Tap-water and Sulphate solution (2.0g/l) with age. An increasing trend of weight was observed for tap-water curing up to 90 days, thereafter, it is almost constant; whereas, for sulphate exposure specimen, the maximum weight change was found at 90 days, thereafter, a decrement was observed.

At advanced stages of the test, most specimens first showed a continuous increase in mass followed by a decreasing tendency. The former could be owing to reaction product absorption and deposition on the surface of specimens, whereas the latter could be due to surface loss and leaching into the surrounding solution. This result is comparable to Roy et al, 2001, findings.

In examination of the weight change characteristics of both the SCCs exposed to Sulphate salt solution (2.0g/l) in long term it was found that SCC-I specimens shows more weight change in comparison to SCC-II specimens it may be due to more permeable structure of SCC-I, so Sulphate ions/ solution easily ingress in the concrete and after reactions some new products formed which deposited on the surface due to which mass gain was observed at initial stage. Sulphate ingress triggers a series of chemical reactions that involves dissolution of soluble Calcium bearing phases for Ettringite and Gypsum precipitation. To maintain the equilibrium of the system, hydroxide ions released from Portlandite dissolution diffuse towards the external solution, causing mass reduction at later stages. Similar was also found by some researchers (Bassuoni and Nehdi 2009, Bassuoni and Nehdi 2012, Amin and Bassuoni 2017).

Lowest weight change was observed for SCC-II specimens followed by SCC-I, It may be due to incorporation of FA and M-sand in the mixes of SCC. FA present in the mix reacts with released Calcium hydroxide at the time of hydration and forms additional C-S-H gel which is mainly responsible for strength gain of concretes. Due to consumption of Calcium hydroxide leaching reduces so less corrosion and least mass reduction was observed in these specimens. Some researchers reported the similar findings (Dinakar et al. 2008, Behfarnia and Farshadfar 2013, Vivek and Dhinakaran 2017).

Measurement of sorptivity

To determine the capillary absorption of the water sorptivity test was performed. The test was performed as per the provisions given in ASTM C 1585. The slope of the best-fit line in the plot of absorption against square root of time is the sorptivity. Figs 5, 6 and 7 show the sorptivity plot for SCCs after 56, 180 and 360 days of water curing. The sorptivity values for the mixes are presented in Table 4.

Table 4 Sorptivity ($\times 10^{-3}$ mm/ $\sqrt{s}$) values of different mixes

Sl. No.	Mix IDs	Curing Period		
		56 days	180 days	360 days
1.	SCC-I	0.265	0.262	0.251
2.	SCC-II	0.171	0.165	0.156

From Table 4, it was found that at 56, 180 and 360 days, the decrement in sorptivity of SCC-II in comparison to SCC-I is 35.47, 37.02 and 37.85%, respectively. It is thus concluded that sorptivity of the specimens decreases with the curing period, more improvement is observed in SCC incorporating FA and M-sand (SCC-II) in comparison to SCC without any replacement (SCC-I). Similar trends of results were also found by some researchers (Gopalan 1996, Leuang et al. 2016).

From Figs. 5-7, it is observed that sorptivity value of concretes decrease with curing period for all type of specimens and the decrement is significantly observed for SCC-I specimens. The least sorptivity identified for SCC-II specimens which incorporates FA and M-sand, thats refines the pore structure of the concrete. Sheba et al. 2020 reported the similar results.

The improvement in sorptivity for SCC-II specimens upto 360 days tap water curing varies between 3-9%, in comparison to their sorptivity at 56 days tap water curing. In comparison to SCC-I specimens the improvement in sorptivity for SCC-II specimens upto 360 days tap water curing is lies in the range of 35-38%. It was found that the improvement in sorptivity varies between 28 to 35%, when FA and M-sand used in combination in making SCC.

Micro-structural analysis

For the micro-structural analysis of the specimens XRD, SEM and EDS tests were performed after different days of water and sulphate solution curing.

At 56, 180 and 360 days, the XRD analysis was performed on both the SCC-I and SCC-II samples, which were cured independently in tap water and ammonium sulphate solution containing sulphate salt concentration of 2.0g/l. The standard XRD results are shown in Figures 8 and 9. Quartz, Calcium Silicate Hydrate (C-S-H), Calcium Hydroxide (CH), Aluminum Sulphate, Stratlingite, Potassium Aluminum Sulphate Hydrate, and Ettringite are some of the prominent crystalline phases identified. The SCC-II specimen, exposed to the Sulphate solution, had decreased Gypsum, Ettringite, and Brucite intensities, which are primarily responsible for concrete expansion and cracking. In contrast to the SCC-II, higher peaks of Ettringite were observed in SCC-I after exposure to the Sulphate solution. Same findings are reported by Paul and Hooton, 2004.

In order to validate the internal microstructure obtained by XRD, SEM and EDS studies on both the SCC-I and SCC-II was performed. The morphological changes in the specimens after curing in tap-water for 56, 180 and 360 days are presented in Fig 10; while, the similar data for the specimens exposed to the Sulphate solution 2.0g/l for 56, 180 and 360 days are included in Fig 11. The corresponding EDS spectrum also verifies the formation of Ettringite and Aluminum sulphate in the specimens exposed to Sulphate solution. In SCC-II specimen, the needle like crystals of Ettringite were rarely seen; however, in SCC-I specimen, these are clearly visible. These are similar to the findings of Mathew, 2016.

From the detailed XRD analysis of both the samples cured in tap water upto 360 days it is observed that the dominating compounds which are identified are Quartz, Calcium silicate hydrate (C-S-H), Calcium Aluminium Oxide Sulphate, Dicalcium silicate, Stratlingite, Gismondite, Dolomite, Calcite, Tricalcium aluminate etc. and the highest peaks of Quartz and C-S-H is identified in SCC-II specimens which are containing FA and M-sand, inclusion of FA, forms additional C-S-H gel which is mainly responsible for strength, fine particles of these also refines the pore structure. So more resistant to Sulphate attack. This agrees the findings of some researchers (Pedro et al. 2015, Marcos et al. 2020).

The XRD of the specimens exposed to Sulphate solution shows the compounds Quartz, Calcium silicate hydrate, Aluminium sulphate, Monosulpho aluminate, Ettringite, Stratlingite, Gesmondine, Ammonium sulphate hydrate, Tricalcium aluminate, Calcite, Anhydrite etc. The intensities of Anhydrite, Ammonium sulphate hydrate and Ettringite are increases with exposure period. Similar observations were made by some researchers (Ping et al. 2016, Marcos et al. 2020). At the hydration process Portlandite reacts with Sulphate, forms Gypsum. The presence of Gypsum is increased with the time of exposure of samples to the Sulphate solutions for all types of specimens, which reacts with Tricalcium aluminate and forms Monosulpho aluminate which further reacts which excessive Sulphate present in the environment and forms Ettringite. Which is responsible for expansion, cracking, deterioration of surface and strength loss. The concrete specimens containing FA shows better resistance to Ammonium-sulphate solution. Addition of FA to the OPC makes the product more resistant to the Sulphate environment. This may be due high reactivity and pozzolanacity of FA which refines the pore structure and makes concrete more compacted

and forms additional C-S-H gel, these all are responsible for Sulphate resistant SCC-II specimens. These findings are in concurrence with the observations of some researchers (Mileti et al. 1999, Sina et al. 2017, Shen et al. 2017).

In all the specimens, the SEM images in Figs 10 and 11 demonstrate the production of porous and permeable cement matrix and aggregate ITZ, C-S-H phase, Calcium hydroxide (CH) crystal, and ettringite. More C-S-H gel (fibrous morphology) phase is observed in SCC-II which contains FA, this may be responsible for strength gain. The EDS analysis of respective specimen after 56 and 180 days exposure to tap water and sulphate solution 2.0g/l is also presented in Figs 10 and 11, It shows that the element Si is found in large quantity in SCC-II type specimens followed by Ca, whereas the other elements are found in small quantities.

The SEM and EDS images of concrete specimens exposed upto 360 days of Sulphate solution (2.0g/l) are represented in Figs. 10 and 11. The Ettringites can cause internal disruption of hydrated cement paste. Pores and acicular (needle shaped) is identified and Ettringites are formed on the micro-structure. C-S-H phase, densified fractured surface and large pores on the micro-structure may be observed from the image.

The lower peaks of Calcium hydroxide and higher peaks of SiO₂ indicate acceleration in the rate of pozzolanic activity by FA contributing to an enhancement of hardened and durability properties. Thus, better correlation is found with respect to both micro-level and macro-level studies made in this investigation on mixes containing FA in SCC preparation. This agrees with the findings of Kannan et al. 2014.

All SEM images reveals the pores, fractures and cracks on the micro structure of SCC-I specimens exposed in Sulphate solution which may be due to Sulphate attack. Calcium hydroxide, Gypsum, Ettringite and C-S-H morphology are also detected in images, these are formed during hydration and Sulphate attack mechanism. The effects of these compounds are also observed in strength gain/ loss, weight change and sorptivity. Specimens containing FA and M-sand shows more compacted, less porous and C-S-H gel in SEM images. Kavitha et al. 2015 also reported the similar findings for mineral admixture mixed concrete.

EDS graphs of all images reveals the elements such as Si, Ca, Al, O, H, S etc. These elements also confirms the compounds detected in SEM images. Specimens containing FA and M-sand shows decreases Ca:Si ratio which accelerates the pozzolanic reactions and one of the cause of strength gain so more resistant to Sulphate attack. Similar finding was also observed by Sina et al. 2017 and Shen et al. 2017.

Conclusion

Followings are concluded from the present study,

- Fly ash and M-sand can be successfully utilized in the preparation of SCC.
- The workability of fly ash and M-sand mixed SCC is improved in comparison to referral SCC (SCC-I).
- The loss in compressive strength of SCC-I is more in comparison to the SCC-II and increases with the exposure period.
- The weight of SCCs increases up to 90 days, and then it decreases in sulphate solution of 2.0g/l.
- The sorptivity of the specimens decreases with the curing period, improvement is observed in SCC incorporating FA and M-sand (SCC-II) in comparison to SCC without any replacement (SCC-I).
- XRD analysis reveals that Ettringite, Aluminum sulphate and Ammonium sulphate hydrate are formed in the specimens exposed to the Sulphate solution, and these are more dominant in SCC-I than SCC-II.
- SEM and EDS show the morphological and elemental composition of compounds formed and confirms the XRD results.
- With incorporation of Fly ash and M-sand in SCC, an environmental-friendly and durable concrete is developed.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

All data generated are analysed during this study are included in this present article.

Competing interest

The authors declare no conflict of interest in experimental procedure and report generation.

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Authors contribution

The contribution of the authors are as follows;

Deep Tripathi- Writing- Original draft preparation, Methodology, Visualization, Investigation

Rakesh Kumar- Conceptualization, Supervision

Pradeep Kumar Mehta- Writing- Reviewing and Editing, Supervision

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Figure 3

Compressive Strength loss of SCCs

Figure 4

Weight change of SCCs

Figure 5

Plot for sorptivity of SCCs after 56 days water curing

(a) SCC-I

(b) SCC-II

Figure 6

Plot for sorptivity of SCCs after 180 days water curing

(a) SCC-I

(b) SCC-II

Figure 7

Plot for sorptivity of SCCs after 360 days water curing

Figure 8

XRD traces of SCC- I and II at 56, 180 and 360 days tap water

Figure 9

XRD traces of SCC- I and II at 56, 180 and 360 days exposed in solution containing Sulphate salt concentration 2.0g/l

Figure 10

SEM and EDS of SCC- I and II at 56, 180, 360 days tap water

Figure 11

SEM and EDS of SCC-I and II at 56, 180 and 360 days exposed in solution containing Sulphate salt concentration 2.0g/l

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