PERFORMANCE IMPROVEMENT OF SELF COMPACTING CONCRETE: A REVIEW

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ABSTRACT. Now a days, Self Compacting Concrete (SCC) is most widely being used in construction. So, it is important to optimise the cost of production and improve the performance of SCC. The performance of SCC can be improved by using different mineral admixtures and quarry dust to suit different environmental exposure conditions. A review of literature shows that the durability and strength of SCC can be improved using different mineral admixtures viz., fly ash (FA), silica fume (SF), Rice husk ash (RHA), Metakaolin (MK) etc for partial replacement of cement. Marble powder (MP), Stone Dust (SD) etc can also be used for replacing a part of the fine aggregate. Use of such waste materials in SCC not only optimises the cost of production but also improves the durability. The sulphate and acid resistance of SCC are investigated to consider the durability aspect. The behaviour of fresh and hardened SCC is also discussed. Workability tests such as slump flow, V-funnel, L-Box, U-Box and J-Ring are performed to evaluate the filling ability, passing ability and segregation resistance of SCC. It is found that by using the industrial by-products/ waste material in SCC, a durable, sustainable and cost effective concrete can be produced. This paper presents a review of various studies conducted on the use of different mineral admixtures / materials on strength and durability aspects of SCC.

Keywords: Self compacting concrete (SCC), Durability, Fly ash (FA), Silica fume (SF), Rice husk ash (RHA) and Metakaolin (MK)

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INTRODUCTION

SCC has high filling ability to completely fill the formwork and high passing ability even in the presence of dense reinforcement. It maintains homogeneity without any additional compaction or vibration. Basically, the SCC consists of the same constituents as a normally vibrated concrete. However, there is a clear difference in the concrete composition. It requires a higher proportion of fine materials and the incorporation of chemical admixtures, particularly a high range water reducer. SCC has proved to be beneficial from the following points of view: faster rate of construction; reduction in skilled man power; better surface finish; easier placing; improved durability; thinner concrete sections; reduced noise level; and safer working environment. SCC was first developed in Japan in 1986 by Prof. Hajime Okamura and now it is used worldwide [1]. Due to its bulk use in construction, further research have been carried out to improve the performance of SCC and to optimize the cost of production.

Some waste materials and industrial by-products have been used in the production of SCC as supplementary cementitious material. Due to high cost of cement and high rate of emission of CO_2 during production, the mineral admixtures viz.; FA, SF, RHA, MK etc have been used. Due to restricted availability of natural river sand, some alternative materials such as MP, quarry dust (QD) and recycled sand (RS) have been used in SCC production. The fresh and hardened properties of SCC were checked by different investigators. For the determination of fresh properties or workability, Slump flow, V-funnel, L-Box, U-Box and J-Ring tests are performed to ensure SCC behaviour as per EFNARC guidelines [2]. Thus, by using these alternative materials, sustainable, cost effective, eco friendly and durable concrete can be produced.

PROPERTIES OF FRESH SCC

Workability is the main feature of SCC. For the determination of workability of SCC mixes, the following tests are performed in the laboratory;

i) Slump flow and T_{50} time
ii) V-Funnel Test
iii) L-box Test
iv) U-box Test
v) J-ring Test

The slump flow, T_{50} time and V-funnel tests are performed to check the flowability or filling ability of SCC mixes while L-box, U-box and J-ring tests are performed to check the passing ability of the mix. The typical range of all the tests are given in Table 1.

Table 1 Typical values of different tests on fresh SCC. EFNARC- 2002[2]

SI. NO.	TESTS	TYPICAL RANGE OF VALUES		UNITS
		MIN	MAX	
1	Slump flow	650	800	mm
2	T50 time	2	5	sec
3	V-funnel	6	12	sec
4	L-box	0.8	1.0	(h_2/h_1)
5	U-box	0	30	(h_2-h_1) mm
6	J-ring	0	10	mm

Slump Flow and T_{50} Time

Slump flow test is performed to estimate the flowability of SCC. In this test, the diameter of flowing concrete is measured in two orthogonal / perpendicular directions. The typical value shall fall between 650-800 mm [2]. The test apparatus is shown in Figure 1. T_{50} is the time (sec) taken by SCC to achieve a diameter of 500 mm.
A viscosity-enhancing admixture was used to investigate the SCC property at water/cementitious material ratio (w/cm) 0.41 to increase the stability of the mix. Further, the properties were also measured, without using any viscosity-enhancing admixture, at w/cm ratio between 0.35-0.38 to reduce the free water content. The SCC with higher w/cm and low coarse aggregate showed higher flowability [3]. SCC with high volume FA showed slump flow in the range of 500-700 mm, and T_{50} time in the range of 3-7 sec [4]. Sheinn et al [5] investigated the utilization of QD in SCC and reported that 35% replacement level was best form the flowability point of view. The use of steel fibers was found to improve the property of fresh SCC. The slump flow of steel fiber included SCC is shown in Figure 2 [6].

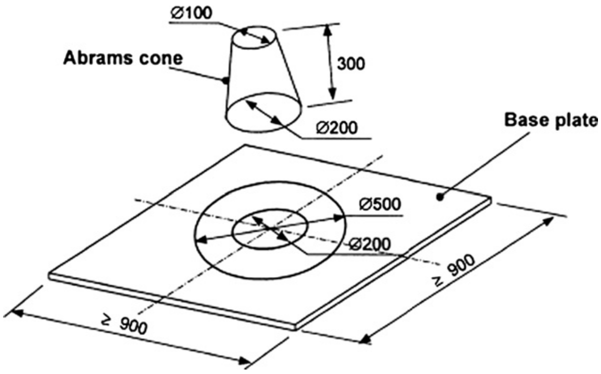


Figure 1 Slump flow apparatus

Figure 2 Slump flow for Steel Fiber-Reinforced mix [6]

The bottom ash was used to partially replace the natural sand in SCC. The slump flow time (T_{50}) of the SCC was found to increase with the increase in bottom ash content [7]. A SCC mix containing Limestone powder (LP) and limestone aggregate (LA) was found to give 21% more slump flow value as compared to a mix containing FA and basalt aggregate (BA) [8]. Melo et al. [9] reported that as fineness and content of MK was increased in SCC mix, the consumption of superplastisizer increased to maintain the flowability. Uysal et al. [10] investigated a SCC in which the cement was replaced in part by FA, granulated blast furnace slag (GBFS), limestone powder (LP), basalt powder (BP) and MP in various proportions and reported that 20% replacement showed good flowability for all LP, BP and MP cases. Figure 3. shows the slump flow and T_{50} time values for different replacement levels by LP, BP and MP. This indicates that 20% replacement of cement by LP gives highest slump flow.

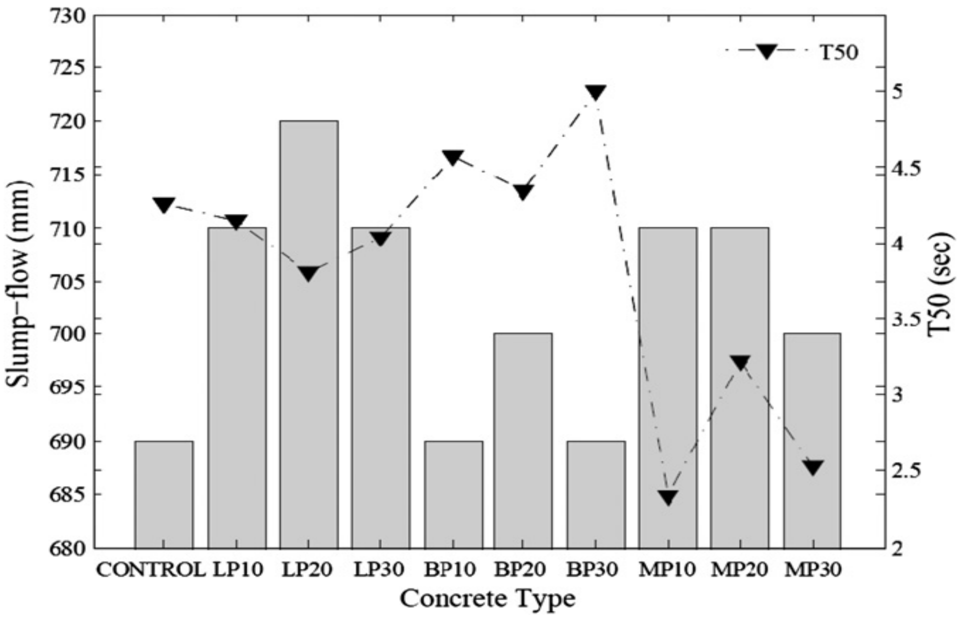
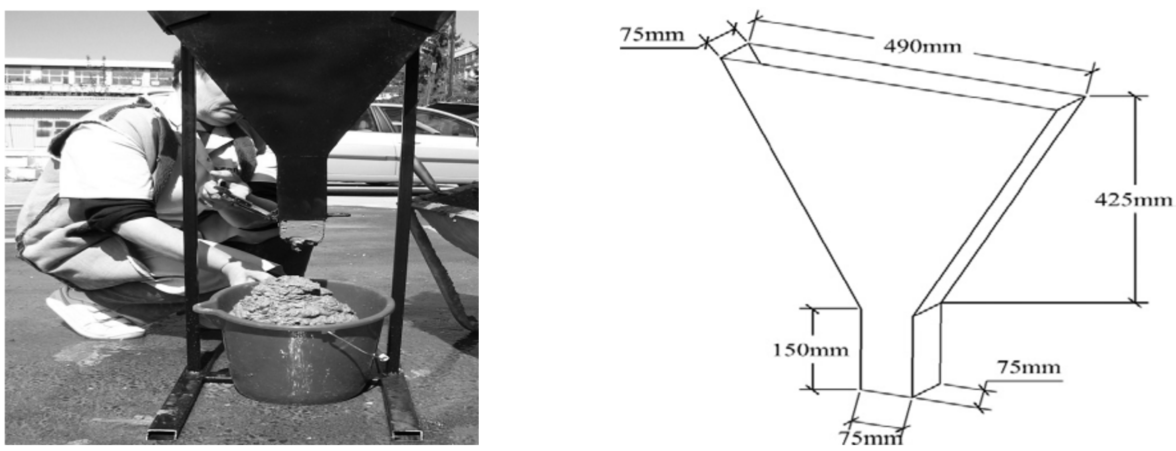


Figure 3 Slump-flow and T_{50} time of SCC mixes containing LP, BP, and MP [10]

The slump flow value was found to increase as replacement level of fine aggregate by recycled glass waste increased [11]. Rahmat et al. [12] investigated the effect of partial replacement of cement by MK in SCC and reported that as MK content increases, the slump flow decreased however, upto 10% replacement level, it is within limits. Benchaa et al. [13] reported that with increases in dune sand (DS) the flow ability of SCC mix decreased in comparison to the mix containing crushed sand (CS) and river sand (RS). The SCC made with partial replacement of fine aggregate by bottom ash at 0, 10, 20 and 30% showed adequate flowability within the limits. The T_{50} time for all the mixes was found to lie between 2.4-4.5 sec [14]. Kumar et al. [15] reported that with increase in FA content upto 30%, the slump flow increased.

V- Funnel Test

V- funnel test is performed to check the flowability or filling ability of the fresh SCC mixes. It is the time taken by the SCC mixes to pass a narrow opening. The test apparatus of V-funnel is shown in Figure 4. The desirable limit of V-funnel time is 6-12 sec as per Ref [2].
The flowability of the SCC mix was found to improved when cement was replaced in part by ultra pulverised FA. Its V-funnel time was in the range of 6-12 sec [16]. Bekir et al. [17] used waste MP as a filler material in SCC and reported that MP amount below 200 kg/m^3 was suitable for achieving good filling ability. SCC made with 10% RHA, as a cement replacement, shows good flowability [18].



(a) (b)

Figure 4 V-funnel apparatus : (a) and (b)

Ali et al. [11] found that the V-funnel test time increases in comparison to the control mix, when cement was replaced in part by recycled glass waste. However, the results still meet the flowability standard time. Benchaa et al. [13] reported that as limestone fines content increases in fresh mortar, the flow time increased. However, for limestone fines content more than 15%, a loss of flowability was observed.

L- Box Test

For checking the passing ability of SCC mixes, L-box test is performed i.e. blocking ratio (h_2/h_1). It measures the height of SCC mixes reached after passing through the restrictions and flowing within a specified distance. The test apparatus is shown in Figure 5. The L-box values shall lie between 0.8-1.0 [2].
The L-box values (blocking ratio) for 35% and 50% replacement of fine aggregate by granite and lime stone are slightly increased; however, it is found within the limits [5]. Ratchayut et al. [7] reported that by using bottom ash as a part replacement of natural sand, the L-box passing ability reduced. Figure 6 shows the L-box values with different replacement levels of natural sand.

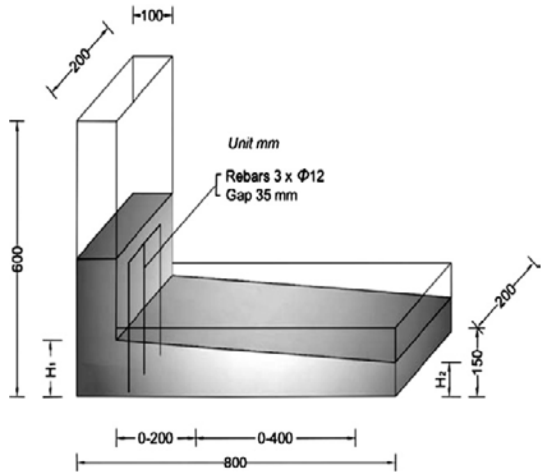


Figure 5 L-box apparatus

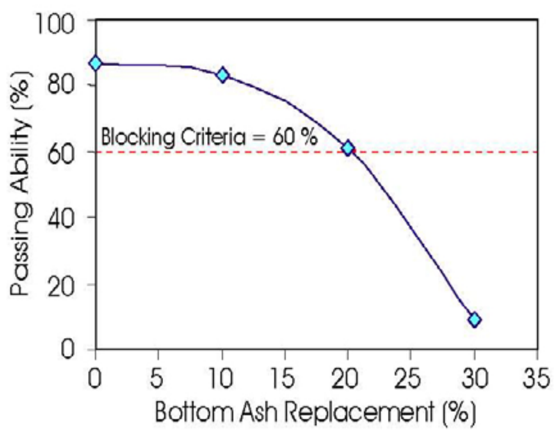


Figure 6 L-shape passing ability of the mixtures [7]

Ali et al. [11] reported that the blocking ratio varied between 0.83-0.89, by using recycled glass as part replacement of cement and was found within the desirable limits. Johnsirani et al. [19] reported that up to 50% replacement of fine aggregate by QD, the blocking ratio values were within the limits, prescribed by EFNARC [2].

U- Box Test

U-box test is performed to check the passing ability of the fresh SCC mix. In this test, the height of concrete in both the compartments is measured, and the difference is found i.e., h_2-h_1. The test apparatus is shown in Figure 7. The typical range of U- box values is in the range of 0-30 mm [2].

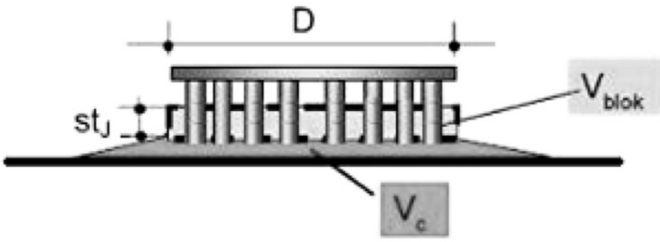
The U-box values are not affected upto 200 kg/m^3 of MD as filler material replacement in SCC [17]. SCC made with different replacement levels of sand by bottom ash has U-box values in the range of 5–30 mm [14]. The U-box values are found to increase with RHA content upto 20%, and are within the limits [20].

(a) (b)

Figure 7 U-box apparatus : (a) and (b)

J- Ring Test

This test is performed to check the passing ability of SCC in the presence of obstruction. In this test, the difference in concrete height inside and outside the apparatus is measured. The apparatus is shown in the Figure 8. The typical range of J-ring values is 0-10 mm [2].
For different replacement levels of fine aggregate by bottom ash, the J- ring values were in the range of 2.0–9.5 mm [14]. Tayfun et al. [21] reported that for LS and marble waste (MW) combination, the J-ring values were in the range 0-10mm.



(a) (b)

Figure 8 (a) Measurement of concrete blocking in J-ring test [21], (b) J-ring apparatus

PROPERTIES OF HARDENED CONCRETE

The properties of the hardened SCC specimens have been determined by performing the compressive, tensile and flexural strength tests.

Compressive Strength

SCC with 50% replacement of cement by FA developed the same compressive strength (35 MPa) at 28 days as control mix [4]. Ho et al. [5] reported that at 35% replacement of fine aggregate by QD (granite and limestone, separately), higher values of compressive strength were in case of granite replacement in comparison to the lime stone replacement. Ahmadi et al. [22] compared the compressive strength of conventional concrete (CC) and SCC with and without replacement of cement by RHA and reported that SCC developed higher compressive strength (31-41%) in comparison to the CC and the optimum dose was 20%. The improvement in compressive strength of SCC was observed after 60 days. Khatib et al. [23] reported that compressive strength of SCC increased with 40% replacement level of cement by FA. Kasemchaisiri et al. [7] reported that with increase in bottom ash, as part replacement of fine aggregate in SCC, the compressive strength of SCC decreased, except at 10 % replacement level. The results are shown in Figure 9.

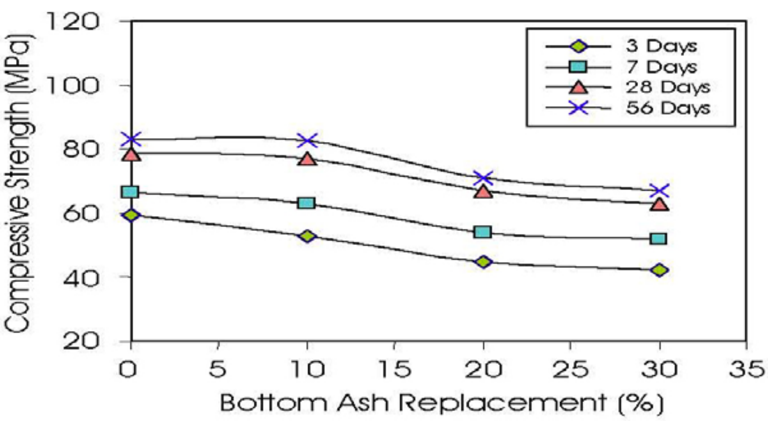
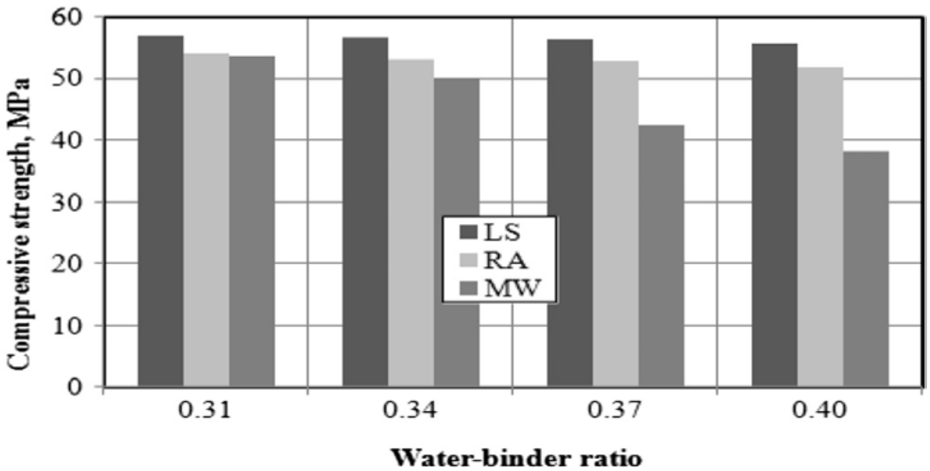


Figure 9 Compressive strength of the different SCC mixes containing bottom ash [7]

The use of MP (as a filler material) up to 200 kg/m^3 improves both early and later ages compressive strengths [17]. The compressive strength of SCC made using LA and FA combinations are about 15 to 27% higher than those of the control mix, at the age of 28 days [8]. Gowda et al. [18] reported that SCC made with MK and QD developed higher compressive strength than the control mix. Rahmat et al. [12] reported that the compressive strength of SCC enhanced upto 27% within first 14 days, with inclusion of MK. Benchaa et al. [13] investigated the effect of various types of sands- CS, RS, DS and a mixture of different sands- on compressive strength of SCC and reported that mortar made with RS at different contents had higher compressive strength than that of mortar made with CS or DS. It was also reported that the use of binary and ternary sands provided a positive effect in improving the compressive strength, and the optimum dose of dune sand was limited to 25%. The compressive strength of SCC decreases with increase in bottom ash as a replacement of fine aggregate [14]. The optimum level of replacement of fine aggregate by QD is 25% and beyond this replacement level the strength decreases [19]. The use of FA and SF increases the compressive strength of SCC [24]. The SCC made with LS, RA and MW shows highest compressive strength for LS, and with increasing water/binder ratio, its value decreases abruptly for MW, as shown in Figure 10 [21].



Where;

LS- Lime stone

RA- Recycled aggregate

MW- Marble waste

Figure 10 Comparison of compressive strength of 28 aged specimens [21]

Hafez et al. [25] reported that there was no significant variation between compressive strength of SCC made using pozzolanic fillers (SF and MK) and non-pozzolanic fillers (LP, granite dust and MP). However there is a noticeable increase in compressive strength as SF content increases. The optimum replacement level of cement by MK was 10% with respect to compressive strength [26]. Boudali et al. [27] reported that the addition of fine recycled concrete in SCC and self-compacting sand concrete (SCSC), up to 40% has improved the strength. The compressive strength decreases by 13%, when all the natural coarse aggregates (NCA) were replaced with the recycled coarse aggregates (RCA). However, this negative effect can be mitigated by replacing cement (10%) by SF or MK. [28]. Kumar et al. [15] reported that with the inclusion of SD and FA, the compressive strength was not affected at early ages; however, at later ages, it improved due to pozzolanic action. The optimum dose of replacement for SD and FA was 40 and 30%, respectively.

Tensile Strength

To find the split tensile strength, cylinders are cast. Ali at el [11] reported that the splitting tensile strength of concrete decreased by 5% at 28 days, at 60% replacement of natural sand by recycled glass. The tensile strength of SCC containing MK was higher than that of the control SCC and the maximum increment was 11.1% [12]. Johnsirani et al. [19] reported that the optimum replacement level of sand by QD was 25%, in the respect of split tensile strength. Tayfun et al. [21] investigated the effect of MW, RA and LA inclusion in production of SCC containing LA and RA was lower than that of the SCC made using LS and MW. The split tensile strength of SCC increases with RHA content till 15% replacement level and a further increase is observed with increase in curing age [20]. The results are shown in Figure 11.

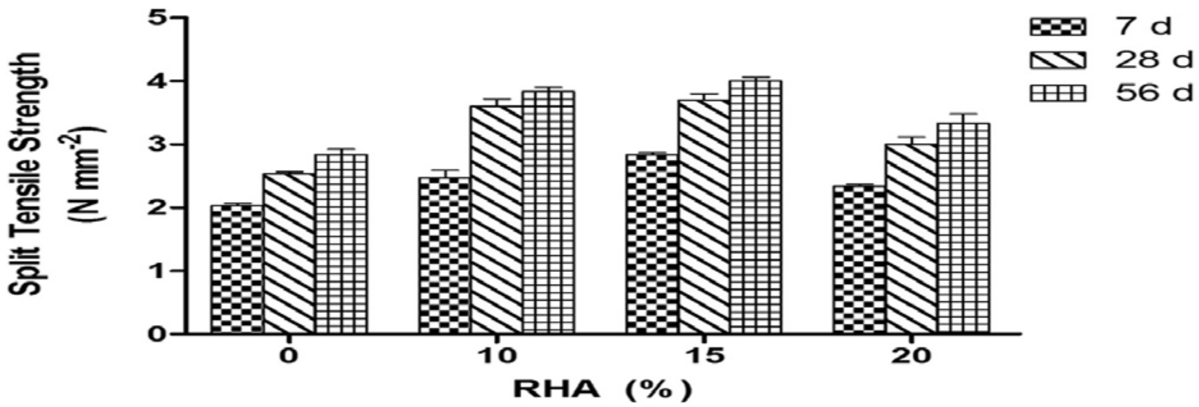
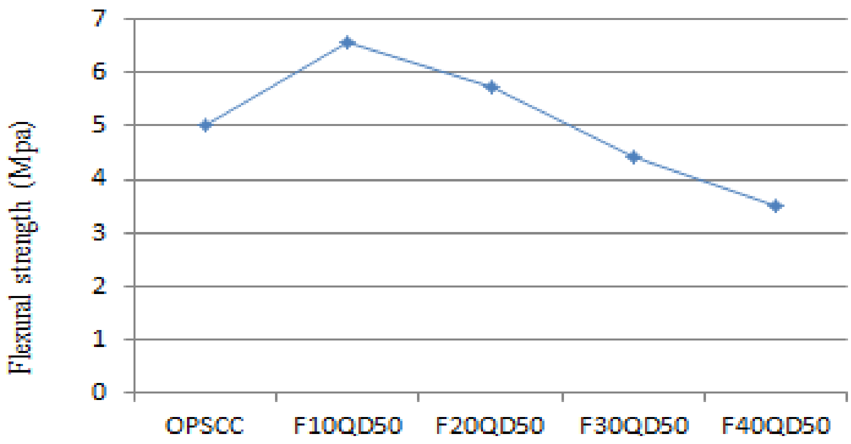


Figure 11 Split tensile strength of SCC mixes with RHA at various ages [20]

Flexural Strength

To determine the flexural strength, beams are cast in the laboratory. Ahmadi et al [22] investigated the effect of RHA inclusion on both SCC and CC. It was reported that the flexural strength of SCC was 12-20% higher than the CC; however, it decreased after RHA inclusion. It increases once again after 60 days. The optimum replacement level was 20% [22]. The use of MP (as a filler material) up to 200 kg/m^3 improves the flexural strength [17]. The results of SCC mix prepared with two mineral admixtures FA and LP and two types of coarse aggregates limestone and olivine basalt are compared. The lowest flexural strength was found for basalt aggregate combination [8]. The flexural strength of SCC decreased with increase in recycled glass waste as compared to the control mix [11]. The flexural strength was found to increases when 10% of cement was replaced with FA and 50% of fine aggregate was replaced with QD [29]. The results are shown in Figure 12.



Where;
OPSCC: SCC without replacement
F10QD50: 10%FA+50%QD
F20QD50: 20%FA+50%QD
F30QD50: 30%FA+50%QD
F40QD50: 40%FA+50%QD

Figure 12 Flexure strength of different mixtures of SCC [29]

FACTORS AFFECTING DURABILITY OF CONCRETE

Durability is associated with the ability to resist weathering action, chemical attack, abrasion or any process of deterioration. Durability of the SCC specimens have been found in different environmental exposure conditions. To check the durability of the SCC, different tests are performed viz.; Acid resistance, sulphate resistance, Rapid chloride ion permeability test (RCPT), Carbonation Test, water absorption test etc. To improve the durability of SCC, different mineral admixtures are used. Xie et al. [16] reported that inclusion of ultra pulverised FA in SCC showed excellent impermeability, freezing resistance, and lower drying shrinkage. Tamimi et al. reported that the performance of SCC in sulphuric acid solution was better as compared to CC; however, in hydrochloric acid solution, the CC performs better. The results are shown in Figure 13 and 14 [30].

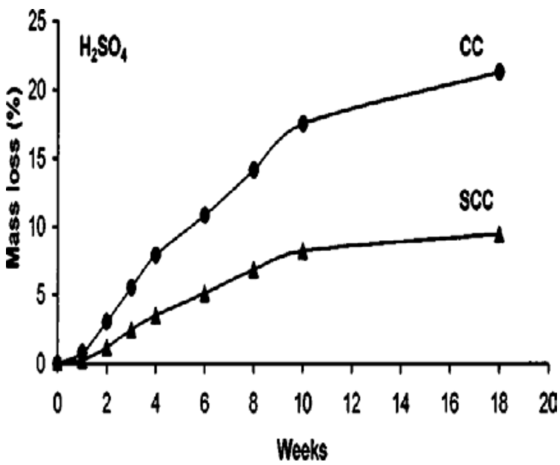


Figure 13 Sulphuric acid resistance [30]

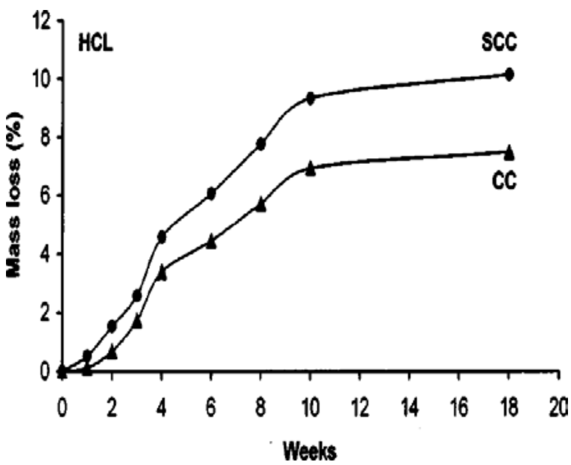


Figure 14 Hydrochloric acid resistance [30]

Gupta et al. [31] had reported that the SCC had good resistance against HCl and H_2SO_4 solution as compared with normally vibrated concrete. Nehdi et al. [32] had studied the effect of the replacement of ordinary Portland cement (OPC) by FA, GGBS, SF and RHA. It was reported that the SCC made with binary, ternary and quaternary cements showed low sulphate expansion, lower chloride ion penetrability and resistance against deicing salt surface scaling in comparison to SCC made with only OPC. Khatib [23] reported that with increase in FA content, the water absorption increased at 56 days of curing. The chloride ion permeability, carbonation depth and shrinkage in drying environment of most of the bottom ash included SCC mixtures were larger than those of the control SCC, except for the mix with 10% bottom ash [7]. It is mainly due to increased porosity and resistance against sodium sulphate with increase bottom ash content [7]. Figure 15 shows the variation of chloride ion permeability of different SCC mixes with bottom ash content.

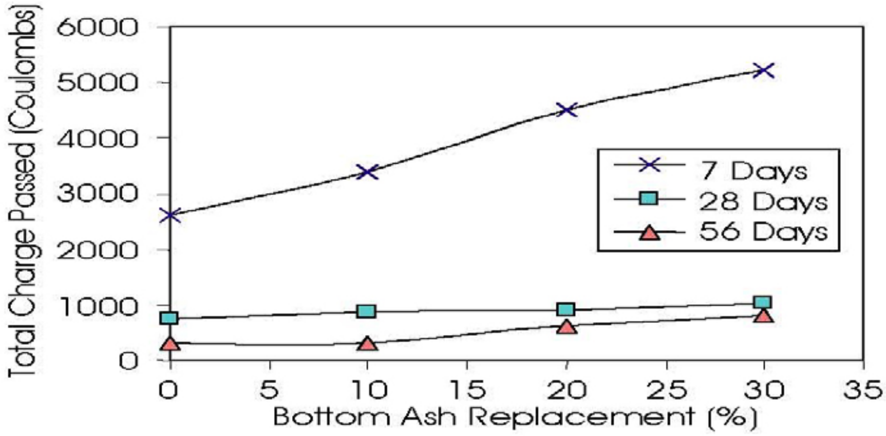


Figure 15 Rapid chloride ion permeability of the mixtures with bottom ash [7]

The SCC mix with 40% GBFS and 60% PC showed best resistance against the sulphate attack [10]. Rahmat et al. [12] reported that a low absorption value (below 3%) was found in SCC containing MK. The water absorption and sorptivity of SCC mixes were found to increase with bottom ash content. Water absorption varied between 5.8-7.1%, whereas sorptivity varied between 0.055-0.145 $mm^3/mm^2/min^{1/2.}$ The Abrasion resistance was found to decrease with increase in bottom ash content [14]. Chopra et al. [20] reported that with increasing RHA content in SCC, the chloride ion permeability decreased, and the optimum dose was 15%. The optimum dose of FA in SCC was 30% from the durability point of view [33]. Kavitha et al. [26] reported that the optimum replacement level of OPC by MK was 10% from the durability point of view. It is because of pozzolanic action of MK improves the microlevel properties significantly by increasing the formation of additional C–S–H gel and reducing the microcrack. Boudali et al. [27] reported that SCC made with recycled aggregate showed better performance in sodium sulphate solution than the mixture with natural aggregate. Kapoor et al. [28] have reported that improved all durability properties at 50% replacement level of NCA with RCA and 10% replacement of OPC by SF or MK improved all durability properties in comparison to 100% replacement of NCA with RCA. MK shows most enhancing effect on micro structural properties than GGBS, which improves durability [34]. Diego et al. [35] reported that the 20% replacement of fine aggregate by recycled sand was best from the durability point of view.

CONCLUSION

Based on the literature review on SCC, made using different mineral admixtures, RA, QD etc., the following conclusion can be drawn:

SCC made using high volume replacement composite cements shows good workability, high strength, good deicing salt surface scaling resistance, low sulphate expansion and very low chloride ion penetrability. The use of fibers in SCC improves fresh state state properties. The optimum dose of replacement of cement by RHA is 20% and it improves the performance of SCC after 60 days. The optimum replacement level of fine aggregate by bottom ash is 10 %, by weight, from the strength and durability points of view. The fresh properties of SCC containing LP and LA are better than other combinations. The compressive strength is improved (15-27%) for FA and LA combination. The slump flow value of SCC increases while the compressive, splitting tensile and flexural strengths decrease with the increase in the recycled glass content. The compressive strength and abrasion resistance decreases with increase in bottom ash content. Water absorption and sorptivity of SCC mixes increase with bottom ash content. With the inclusion of MP, an economic, sustainable and environmental friendly SCC with improved engineering properties can be produced. The use of non-pozzolonic fillers (SF and MK) in SCC decreases the segregation and bleeding compared with the pozzolanic fillers (LP, MD and granite dust); however, both the fillers increase the compressive strength. The optimum dose of FA as a replacement of cement in SCC is 30% to maintain all the desirable properties. Upto 40% addition of fine recycled concrete in SCC and SCSC improves the strength. A 50% replacement of NCA by RCA and 10% replacement of OPC by SF or MK improve all the durability properties in comparison to the 100% replacement of NCA with RCA. A 40% replacement of OPC by GBFS is best for sulphate resistance. The slump flow of SCC increases with increase in FA content and the compressive strength not affected at early ages but at later ages it is improved due to pozzolanic action. The mechanical properties are affected by the incorporation of RS in SCC. The influence is low in case of 20% replacement; however, for larger substitutions, the losses are severe.

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