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A Review: Recent Innovations in Self Compacting Concrete:

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Abstract— The use of agro-industrial waste materials in concrete is common solution for waste disposal as well as economy purpose. Various research studies have been conducted on the use of agro-industrial waste as an innovative material to produce good quality of concrete whether it is plain concrete or self compacting concrete. The present paper explores the recent innovations in self compacting concrete containing agro-industrial waste materials. The paper also reviewed latest application of admixtures and their performance on SCC quality. Application of various innovative materials as ingredients in SCC and their effect on the fresh and hardened properties are discussed here. SCC is a special type of highly flowable concrete that does not require vibration for placing and compaction. Innovative materials are generally used for partial replacement of cement or sand or aggregate or combination of two or more. They may be used as additional filler to enhance the physical and mechanical properties of the SCC. The goal that expected from the paper is to compile the recent innovations in SCC, study their effect on the properties of SCC and establish an international benchmarking for further research work in this regard.

Index Terms— Admixtures, Fly-ash, Mineral additives, Recent innovations, Self compacting concrete, Super-plasticizers

1 Introduction

SCC was defined by K C Panda et al. [14] is a kind of concrete with excellent deformability and segregation resistance. It is able to flow under its own weight and can completely fill the framework even within congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete Krishna Murthy N et al. [24].

SCC consists basically 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 ultra fine materials and the incorporation of chemical admixtures, particularly an effective high range water reducer H. A. F. Dehwah et al. [28].

There are several concepts for producing SCC. For all concepts, some kind of high-efficient water reducing and dispersing super plasticizer is used. Super plasticizers aim at increasing the dispersing effect and furthermore decreasing the friction between the particles. There has been an intense development of super plasticizers during the last decades making SCC feasible. Conventional type of SP, e.g. sulphonated naphthalene formaldehyde condensates (SNFC) and sulphonated melamine formaldehyde condensates (SMFC) disperse cement particles by electrostatic repulsing mechanisms.

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The parameter that varies most between different mix concepts for SCC concerns the viscosity-controlling ability that aims at achieving robust non segregating SCC. There are, in main, three methods for controlling the viscosity, i.e. increased powder content, usage of viscosity-modifying agent and a combination of the two methods. For all three methods there is a no. of materials such as fly ash, silica fume, iron slag, plastic waste, tyre rubber waste, granite powder, marble powder, quarry dust powder, recycled concrete aggregates, super plasticizers and admixtures are recently used. However for best result which material or admixture should be used is not clearly known. Therefore the objective of this research is to review the latest study of SCC containing innovative material and to compile them in such a way that it would be beneficial for selection of best material among all studied in this paper.

2 RECENT INNOVATIONS IN SELF COMPACTING CONCRETE

2.1 SCC containing tyre rubber waste

A no. of studies carried out to investigate the fresh and hardened properties of rubberized concrete but very few studies have been carried out on self compacting rubberized concrete SCRC so far [1].

Najim et al. [2] reviewed the fresh and hardened properties of rubberized concrete. They also studied application for plain rubberized concrete and self compacting rubberized concrete. Mehmet G et al. [3] investigated permeability properties of self compacting rubberized concrete. Topcui B et al. [4] and Bignozzi M C et al. [5] also used recycled tyre rybber waste in a self compacting concrete and investigated properties of self compacting rubberized concrete.

N ganeshan et al. [1] investigated the fatigue behaviour of SCRC with and without steel fibres. The result showed signifi-

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cant improvement of 15% and 25 % in the fatigue performance of SCRC and steel fibre reinforced self compacting rubberized concrete (SFRSCRC) as compared to self compacting concrete.

2.2 SCC containing plastic waste

Application of plastic waste to mortar and concrete is very common and a no. of studies has been conducted to evaluate the performance characteristic of the plastic concrete.

Choi et al. [6] conducted experimental study to investigate the effect of plastic waste (PET bottles) as aggregate on properties of concrete.

Batayach et al. [7] used plastic waste as partial as partial replacement of sand in concrete. Result showed that 20% substitution of sand can reduce compressive strength upto 70% as compared to normal concrete. [8, 9, 10 and 11] also used consumed plastic bottle for sand substitution within composite materials for building application.

Brahim Safi et al. [12] used plastic waste 0 to 50% for sand substitution in self compacting rubberized mortar and investigated the effect on physical and mechanical properties. Result showed that, in terms of of the density for materials the mortar with 50 % of plastic waste give better results than other proportion of the waste.

2.3 SCC using recycled concrete aggregate

Christos G. Fakitsas et al. [13] Conducted experimental study on SCC using natural rock aggregate (NR-SCC) and recycled-concrete aggregate (RC-SCC). All mixes tested were found to be highly flowable and stable. Cylinders and push off specimens were tested. The result showed superior compressive and frictional characteristics of RC-SCC, indicating the beneficial effects of internal curing. However, the unconfined shear strength of NR-SCC was found to be superior to that of the RC-SCC. The higher shear strength of the natural rock aggregate resulted in superior unconfined shear strength of the NR-SCC. However, the superior frictional characteristics of RC-SCC resulted in a reversal of this observation for the clamped (confined) specimens.

K C Panda et al. [14] used recycled concrete aggregate in self compacting concrete for M-25 grade of concrete. Natural aggregates were replaced by RCA in various % (10, 20, 30and 40) and effect on physical and mechanical properties were found. The properties of SCC containing RCA investigated include compressive strength, flexural strength and split tensile strength. Results were compared with normal vibrated concrete (NVC). Result showed that compressive strength, flexural strength and split tensile strength of SCC containing RCA is less than NVC and these strengths decreases with increase in the amount of RCA. 30 % mixing of RCA in SCC gives desirable characteristic strength. RCA show higher water absorption compared to conventional NVC.

Similarly Kou et al. [15] and Grdic et al. [16] investigated properties of SCC prepared with recycled concrete aggregates. Fonseca et al [17] investigated the influence of curing conditions on the mechanical properties of concrete using recycled concrete wastes. Uysal et al [18] investigated effect of mineral admixtures on properties of SCC. Zhao et al [19] and Uysal [20] investigated the effect of coarse aggregate gradation and type on the properties of SCC.

2.4 SCC containing fly ash, slag & silica fume

Several investigations have been contributed by the researcher on properties of self compacting concrete containing fly ash slag and silica fume. The brief literature reviews of the latest studies are as follows.

Neelam Pathak et al. [21] conducted experimental study to investigate the properties of Self-Compacting-Concrete with (class F fly ash ranging from 30% to 50%) and without fly ash. The property investigated were compressive strength, splitting tensile strength, rapid chloride permeability, porosity, and mass loss when exposed to elevated temperatures. The variables included were the temperature effects (20 LC, 100 LC, 200 LC, and 300 LC) using Ordinary Portland Cement. Test results showed little improvement in compressive strength within temperature range of 200–300 LC as com-pared to 20–200 LC but there were little reduction in splitting tensile strength ranging from 20 to 300 LC and with the increase in percentage of fly ash.

Heba A Mohamed [22] conducted experimental study on SCC under three curing conditions (7 and 28 days curing under water and 28days curing in air) with three types of mixes first with different % of fly ash, second with different % of silica fume and third with different % combinations of fly ash and silica fume. The result showed that SCC with 15 % of silica fume shows high compressive strength than those with 30% of fly ash and water cured specimens for 28 days give higher compressive strength.

Yuan Yuan Chen et al. [23] investigated the effect of paste amount on the properties of SCC containing fly ash and slag. Performances of SCC containing fly ash and slag under different water to cementitious material ratio and different cement paste were compared. Concrete designed by DMDAC (Mixture design Algorithm). Result showed that the less the cement paste amount as well as the denser the blended aggregate, the lower the early age compressive strength will be on the contrary, the higher the long- term compressive strength becomes. For good quality concrete the amount of cement paste and water should be minimised for as low as possible to obtain the high ultra-sonic pulse velocity.

Krishna Murthy N et al. [24] designed a simple tool for SCC with high reactive metakaolin and fly ash as an admixture for cement replacement. They provide detailed steps for mix design with 29% of coarse aggregate with three cement replacement ratio 5-20%(by MK), 10-30% (by FA) and different

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% combination of MK+FA. Authors developed a user friendly mix design tool which is capable of calculating all quantities required in the mix design.

Raharjo D et al. [25] Optimized the composition of SCC containing fly ash, silica fume and iron slag. Using Optimal Composition SCC were prepared with silica fume (0-20% of fly ash weight) and super plasticizers (0.5 -1.85 of cement weight) and each composition tested by slump cone L-box and V-funnel apparatus to meet the requirements of SCC. Hardened cylindrical specimens were prepared and tested at the age of 3, 7, 14, 28 and 56 days. Authors provide a formula for optimal composition.

Ahmed Ibrahim et al. [26] investigated relationship between high strength self compacting concrete and macroscopic internal structure. They prepared mixes with high volume cement replacement (up to 70%) by slag, fly ash and silica fume. They use a flatbed digital scanner for 2-D digital image of internal structure of HSSCC (high strengths self compacting concrete) cylindrical specimen. Images were analysed by *iPas* software. The result showed good correlation between HSSCC macroscopic structure and compressive strength.

Rafat Siddque et al. [27] predicted the compressive strength of SCC containing bottom ash using Artificial Neural Network. They developed two models with input parameters (material) and output parameters (compressive strength). First (ANN-I) to predict 28 days compressive strength through ANN technique using data taken from literature and second (ANN-II) developed experimentally for SCC containing bottom ash as partial replacement of sand. Result showed that model developed from literature data could be easily extended to the experimental data with some modifications

2.5 SCC incorporating filler additives

H. A. F. Dehwah et al. [28] investigated mechanical properties of SCC containing fly ash silica fume and quarry dust powder. Various trial mixes were prepared with fly ash only, quarry dust powder (QDP) only and combination of silica fume and quarry dust powder. Tests were conducted to find compressive strength, split tensile strength, flexural strength and homogeneity by ultra-sonic pulse velocity test. The result showed better performance of SCC incorporating QDP (8-10%) as compared to other two categories of trial mixes.

Muceteba Uysal [29] conducted experimental study to evaluate the performance of SCC at elevated temperature (200, 400, 600 and 800 degree centigrade) at the age of 56 days.They replaced Portland cement by lime stone powder (LP) basalt powder (BP) and marble dust powder (MP) in various proportion. Result showed severe strength loss for all SCC mixture after exposure to 600 degree centigrade. At higher level replacement lower residual strength was observed.

Mayur B. Vanjare et al. [30] used glass powder (GP) in different percentage for partial replacement of cement for production of self compacting concrete. The paper deals with the ingredient of these mixtures (Glass powder, fly ash, super plasticizer, cement) by examining their specific role in self compacting concrete. Various properties of the glass powder integrated SCC mixes such as self compactability, compressive strength, and flexural strength were evaluated and compared with those of conventional SCC. Result showed that the addition of glass powder in SCC mixes reduces the self compactability characteristics like filling ability, passing ability and segregation resistance. The compressive strength and flexural strength of SCC with the glass powder also decreases.

L. García et al. [31] investigated the robustness of a SCC made with VMAs and with high limestone filler content and less cement. Properties were compared with commercial SCC. Three types of SCCs with water/cement (w/c) = 0.6 were produced with water contents varying between −7.5% and +7.5%. Authors constructed a linear regression model from the experimental data for easy method of calculating water-content variation in concrete that satisfies certain robustness requirements. The results show that variations in flow ability and compressive strength due to changes in water content were very similar in the three concrete types. When filler was replaced by VMA, the material's cohesive properties (viscosity and segregation resistance) showed improvement. t was also investigated that segregation resistance and compressive strength do not play a significant role in the robustness of SCCs under consideration.

M. Nepomuceno et al. [32] investigated comparative performance for lime stone powder, fly ash, granite filler and micro silica in different % with binary and ternary blends of powder materials. They proposed methodology for the mix design of mortar on the basis of results obtained.

V Corinaldesi et al. [33] prepared several concrete mixtures using lime-stone powder , fly ash and recycled aggregate powder as mineral addition in the presence of an acrylic-based super plasticizer at a dosage ranging from 1% to 2% by weight of very fine material fraction (maximum 150 lm). The fresh concrete properties were evaluated through slump flow, L-box test and segregation resistance. Compressive strength of con-crete was determined at 1, 3, 7 and 28 days of wet curing. Results obtained showed that an optimization of self-compacting concrete mixture seems to be achievable by the simultaneous use of rubble powder and coarse recycled aggregate with improved fresh concrete performance and unchanged concrete mechanical strength.

2.6 SCC using fibers

R Deeb et al. [34] conducted experimental study to develop to SCC with high ultra performance concrete with and without steel fibres. Ten deferent mixes were prepared and tested to meet the SCC requirements. Results showed 30 mm long 0.55 mm dia steel fibres with crimped ends significantly increases

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the viscosity of SCC mixes with fibres. They also showed that mixes with fibres meet the flow ability criteria and resistance to segregation.

M. Pajak et al. [35] reviewed the flexural behaviour of SCC reinforced with straight and hooked end steel fibres at levels of 0.5 %, 1.0 % and 1.5 %. Results were compared with NVC (normally vibrated concrete). On the basis of result obtained they proposed equation to predict the deflection-CMOD relationship of SCC and NVC. Result showed that the SCC achieves the maximum crack mouth displacement for lower deflection than NVC. They also proposed a formula to describe fracture energy of SCC.

Valeria Corinaldesi et al. [36] prepared self-compacting concretes mixes using three different types of fibers made of steel, poly-vinyl-alcohol (PVA) and high toughness polypropylene (PPHT) and two different types of mineral addition (limestone powder and powder from recycled concrete). Result showed that the use of recycled-concrete powder instead of limestone powder for producing SCC seems to be promising, particularly for fresh concrete flow ability. The mixture containing PVA fibers and recycled concrete powder showed best performance. However, this mixture was the worst in terms of mechanical performance.

2.7 SCC with different types of admixtures and superplasticizers

Ali Mardani-Aghabaglou et al. [37] investigated the effect of four different types (same main chain and same polymer structure but different molecular weight and different side chain groups) of super plasticizer on fresh, rheological and strength properties of SCC. The result showed that V-funnel flow time, plastic viscosity and slump retention of SCC mixtures were affected by the side chains density of polymer considerably. It was also found that SCC mixtures also influenced by the type super plasticizers at early ages.

Mary Barfield et al. [38] investigated effect of three slump flows (559mm, 635mm and 711mm) and four admixture on the fresh properties of air entrained SCC. Various mixes were prepared by varying dosage of admixtures like HRWR (high range water reducing admixture), VMA (viscosity modifying agent) and AEA (air entraining admixtures). Result showed significance difference between admixtures with similar chemical composition, It was found that the slump flow of SCC decreased stability and air void characteristic.

3 ANALYSIS OF RESULTS AND DISCUSSION

3.1 Analysis of Results in fresh and hardened state

SCC containing tyre rubber waste

Table 1 shows the results obtained from characterization tests of SCC in fresh state. It should be noted that slump value in fresh state fall within the limit of SCC (650-700mm) for all mix. V-funnel time is more than 6 second for all mix showing a little margin in passing ability test. Moreover, the values obtained by L-box test satisfied the segregation criteria of SCC.

Sand replacement by tyre rubber waste had negative effect on compressive strength. Results showed reduction in compressive strength on the addition of rubber waste. However increase in compressive strength was observed when steel fibres were added with rubber waste.

TABLE 1: SOURCE [1]
Fresh and hardened properties of SCC containing tyre rubber waste.

Partial sand replacement By rubber waste	Slump flow (mm)	V-funnel time (s)	L-box Value	Compressive Strength at 28 Days (MPa)
0 %	700	9	0.86	58.86
15 %	690	11	0.89	54.83
20 %	685	11	0.9	51.10
15 %+ a	670	12	0.91	56.58
15 %+ b	650	14	0.93	58.20

a- 0.5 % steel fibre
b- 0.75 % steel fibre

SCC containing tyre plastic waste

Table 2 shows that the physical property such as porosity and water absorption decreases up to 30 % sand replacement by plastic waste after that slight increase was observed in both properties. Bulk density also decreases and reduction in bulk density was observed 37.5% at 50 % sand replacement.

Mechanical property such as sound velocity, compressive strength and flexural strength were also found to be decreased when sand is replacement by plastic waste. Sound velocity becomes at 30% replacement. Reduction in compressive strength was observed 15% and 33 % at 30 % and 50 % sand replacement respectively. Slight increase in flexural strength was observed after age of 28 days.

TABLE 2: SOURCE [12]
Physical and mechanical properties observations of SCC containing plastic waste.

Physical properties	Sand replacement Observations
Bulk density	Up to 50 % reduces to 37.5 %
Porosity	Up to 30 % decreases then slightly increases
Waterabsorption	Up to 30 % decreases then slightly increases
Sound velocity	Up to 30 % decreases then constant
Compressive strength	decreases at 30 % reduction is 15 % and at 50 % % reduction is 33%
Flexural strength	decreases then slightly increases strength after 28 days of mixture

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SCC containing recycled concrete aggregate (RCA)

Table 3 shows mechanical properties of SCC (M-25) containing RCA. Regarding compressive strength, flexural strength and split tensile strength, it was observed that with increase in % of natural aggregate replacement by RCA all strength values goes on decreasing to reach a minimum value for all replacement ratios.

TABLE 3: SOURCE [14]
Mechanical properties of SCC (M-25) containing recycle concrete aggregate (RCA).

TABLE 3: SOURCE [14]
Mechanical properties of SCC (M-25) containing recycle concrete aggregate (RCA).

Natural aggregate replacement By RCA	Compressive Strength at 28 Days (MPa)	Flexural Strength at 28 Days (MPa)	Split Tensile Strength (MPa)
0 % (NVC)	~ 35	~ 4.25	~ 4.50
0% (SCC)	~ 31	~3.7	~ 4.25
10 % (SCC)	~ 29	~3.6	~ 4.00
20 %(SCC)	~ 27	~ 3.2	~3.75
30 %(SCC)	~ 26	~ 3.1	~ 3.50
40 %(SCC)	~ 22	~ 2.9	~ 3.00

** Values are taken from graph therefore they may differ from actual values.*

SCC containing fly ash, silica fumes and slag.

Table 4 shows fresh and hardened properties of SCC containing fly ash, silica fume and slag. All replacement ratios indicate variation in performance of fresh properties.

For hardened properties all mixes showed superior performance as compared to the control mix (basic mix with 0 % replacement). The maximum compressive strength was recorded 81.17 MPa that resulted from replacing the cement by 70 % slag.

The contact point at the aggregate cement interface also shows good correlation with compressive strength. For mix M-2 (with 60 % FAC) contact points decreases. Whereas for M-3 (50% FAC+10% SF) valve of contact point increases by 32 % as compared to the control mix. The maximum increase in contact point was found to be 90 % and 89% for M-5((50% FAC+30% SL+10% SF) and M-4 (70 % SL) respectively.

Table 5 shows compressive strength of SCC containing fly ash, silica fume and their combination. The maximum compressive strength was found to be 5 MPa for SCC with 15 % SF.

SCC containing filler additives.

Table 6 shows hardened properties of SCC containing QDP, FA and SF and their combinations. The result for flexural strength and split tensile strength had almost similar pattern. The mix M-2 showed highest flexural strength and M-5 showed lowest flexural strength. Remaining mixes M-1, M-3 and M-4 showed almost same level of performance. The split tensile strength of M-2 was found to be highest and which is followed by M-3, M-4 M-1and M-5.

The table also shows the effect of age (7, 14, 28 and 90 days) on compressive strength and sound velocity. The compressive strength and sound velocity increased linearly with age up to 28 days. Thereafter the increase in strength was not that much significant. The maximum value of compressive strength and sound velocity was noted in M-2 while the minimum value of these two properties was noted in M-5.

Table 7 shows various SCC mixes containing LP, BP and MP ranges from 0 to 30 % that was tested for hardened properties after exposure to high elevated temperature (200, 400, 600 and 800). It was observed that at higher replacement ratio of LP, Bp and MP the weight loss were also high. Lime stone powder (LP) showed higher weight loss as compared two BP and MP. Weight loss in containing filler additives with PP fibers was lower as compared to those of without of PP fibres for all replacement ratios. Moreover control mix showed better performance for weight loss for all replacement ratios.

Result showed that UPV of heated specimens decreases with increase in temperature. After 400 C reductions in UPV is noticeable. LP series showed higher reduction in UPV as compared to BP series and MP series here also. SCC containing additive filler with PP fibres also shows higher reduction in UPV for all replacement ratios.

TABLE 4: SOURCE [26]
Fresh and hardened properties of SCC containing fly ash and silica fume.

Partial sand replacement By FAC, FAF SF & SL	Slump flow (in)	(T 50) J-ring (s)	Segregation Index	Air content (%)	Unit weight (kg/m³)
Control mix 0 %	27.00	6.50	0.00	2.90	2413.6
60%FAC	22.00	4.50	0.00	3.00	2407.0
50%FAC+10%SF	16.50	7.00	0.00	4.70	2348.0
30%FAC+30%SF+10%SF	17.00	6.00	0.00	3.10	2321.4
70% SL	24.00	23.0	0-1	2.20	2462.9
60%SL+10%SF	20.25	10.0	0.00	2.70	2423.6
60%FAF	25.50	8.00	0-1	0.50	2445.0
50%FAF+10%SF	27.00	6.25	0-1	2.10	2346.4
30%FAF+30%SL+10%SF	23.00	15.0	0.00	4.70	2342.9

Partial sand replacement By FAC, FAF SF & SL	Compressive Strength at 28 Days (MPa)	Contact points
Control mix %	64.73	101
60%FAC	72.22	89
50%FAC+10%SF	74.71	133
30%FAC+30%SF+10%SF	79.53	196
70% SL	81.17	191
60%SL+10%SF	72.76	99
60%FAF	68.82	139
50%FAF+10%SF	71.35	79
30%FAF+30%SL+10%SF	72.66	103

FAC- class C fly-ash
FAF-class F fly ash
SF-silica fume
SL- blast furnace slag

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TABLE 5: SOURCE [22]
Fresh and hardened properties of SCC containing fly ash and silica fume.

Material composition	Slump flow (mm)	The spread diameter (T 50)	L-box Value	Compressive Strength at 28 Days (MPa)
PC+30 % FA	N A	N A	N A	~ 32
PC+15 % SF	N A	N A	N A	~ 35
15% SF +15% FA	N A	N A	N A	~ 24

FA- fly ash
SF-silica fume
NA- not available

TABLE 6: SOURCE [29]
Hardened properties of SCC containing filler additives.

Partial sand replacement by filler additives	W/C ratio	Flexural Strength at 28 Days (MPa)	Split Tensile Strength (MPa)
8 % QDP	0.40	6.59	5.5
8 % QDP	0.38	6.87	6.5
10 % QDP	0.40	6.70	6.4
8 % QDP +5 %SF	0.40	6.59	5.8
30% FA	0.40	5.23	4.9

Partial sand replacement by filler additives	Compressive Strength (MPa)			
	7 Days	14Days	2 8Days	90Days
8 % QDP	~55	~56	~62	~ 64
8 % QDP	~ 64	~ 68	~70	~ 78
10 % QDP	~55	~58	~64	~ 68
8%QDP+5%SF	~ 55	~ 60	~ 64	~ 66
30% FA	~35	~45	~52	~ 54

Partial sand replacement by filler additives	Pulse Velocity (m/s)			
	7 Days	14Days	2 8Days	90Days
8 % QDP	~4560	~4640	4725	4876
8 % QDP	~ 4650	~ 4750	4808	5008
10 % QDP	~4500	~4675	4752	4912
8%QDP+5%SF	~ 4580	~ 4675	4735	4910
30% FA	~4550	~4630	4700	4869

** Values of compressive strength and split tensile strength are taken from graph therefore they may differ from actual values*
FA- fly-ash
SF-silica fume
QDP- Quarry dust powder

At higher temperature reduction in compressive strength was observed for all replacement ratios. For 200 to 400 C decrease in compressive strength was observed 16-23 % of original strength. At 400 to 600 C strength loss was within range of 47-53 %. Here BP series performed better as compared to other two series. At 600 to 800 C the average loss was 78 %. At this temperature all series experienced extensive cracking and spalling and their residual strength was less as compared to control mix. Residual strength for SCC with PP fibres was also found lower than those of concrete without PP fibres for all replacement ratios.

At temperature 200 – 400 C visible cracking or spalling was not observed. After that at 600 C hairline cracks started to appear and continued to grow until temperature reduces up to 800 C. It was observed that crack increases with the increase in temperature and decreases with the increases of % of LP, BP and MP.

SCC using fibers

Table 8 shows fresh property of high and ultra high SCC with and without steel fibres. Mix M-1 to M-6 refers to High strength performance. Result showed significant improvement in the performance with addition of fibres. However practically it was observed that mixes 3 and 4 satisfied the flow ability criteria and no signs of segregation to ensure that they were able to pass through narrow gaps between reinforcing bars. In M-4 some blocking was found. The bulk of fibres and coarse aggregate lumped in the centre of flow spread. Trail mix 5 and 6 meet the passing ability criteria as per EFNRC and PCI.

M-7 to M-8 refers to ultra high performance. The M-7 satisfies the passing ability criterion. The mix without fibres easily and smoothly flowed through the gap between the steel rods. However some fibres nested around the steel rod in mix 8. M-9 and M-10 were prepared by increasing the super plasticizer content. Both of them meeting the flow ability, passing ability and resistance to segregation criterion.

Table 9 shows fresh property of SCC with two types (straight and hooked end) of steel fibres. The fibre type used by author for straight fibre was KrampeHarex (aspect ratio 31.25) and for hooked end was steelbet (aspect ratio 37.5). It can be seen from the table that all mixes satisfy the T-50 time. Highest slump flow was found at 0.5 % ddition of fibres (both straight and hooked end).

The compressive strength increases with increase in fibre content for both types of steel fibre. SCC reinforced with hooked end fibre showed higher strength and maximum compressive strength found was 98.20 MPa at 0.5 % addition of hooeked end steel fibres. The flexural strength also increases with increase in fibre content. The maximum flexural strength found was 8.31 MPa at 1.5 % addition of hooked end steel fibres.

Table 10 shows fresh and hardened properties of SCC contain-

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ing three different types of fibres made of steel (S), high toughness poly propylene(PPHT) and poly-vinyl-alcohol (PVA) with two types of mineral additives lime stone powder (LP) and powder from recycled concrete (RP). All mixes satisfy the slump flow criteria and no *sombrero effect* was observed by the authors. V-funnel time was also satisfactory. All mixes showed good results in terms of mobility through narrow sections.

TABLE 7: SOURCE [29]
Hardened properties of SCC containing filler additives

Partial sand replacement By FAC, FAF SF & SL	W/C ratio (in)	Hardened properties tested at 200, 400, 600 and 800 C
Control mix 0 %	0.33	
LP 10	0.37	
LP 20	0.41	Weight loss
LP 30	0.47	Change in UPV
BP 10	0.37	Change in compressive strength
BP 20	0.41	
BP 30	0.47	Surface characteristics
MP 10	0.35	
MP 20	0.37	
MP 30	0.39	

LP- lime stone powder
BP-basalt powder
MP- Marble dust powder

TABLE 8: SOURCE [34]
Fresh properties of high and ultra high SCC with and without steel fibres (30 mm long with crimped ends).

Mixes	Dramix steel fibers	Slump flow	T-500 (s)
M-1	0 %	600	3
M-2	0.5 %	560	3
M-3	0 %	780	3
M-4	0.5 %	770	3
M-5	0 %	805	3
M-6	0.5 %	760	3
Mixes	Cement Replacement By GGBS	Slump flow	T-500 (s)
54			
M-7	36.5 %	905	3
M-8	36.5% +2.5 % fibres	780	3
M-9	36.5 %	910	3
M-10	36.5 % + 2.5 % fibres	830	3

TABLE 9: SOURCE [35]
Fresh & Hardened properties of SCC containing steel fibres].

Fibre volume Fraction (%)	Slump Flow		Cmpressive Strength at 28 Days (MPa)	Flexural Strength at 28 Days (MPa)
	T_{50} (S)	SFD (mm)		
0 %	1.5	690	73.40	2.45
0.5% (straight)	3	680	80.10	3.66
1.0 % (straight)	5	660	84.60	4.27
1.5 % (straight)	6	640	87.50	5.42
0.5% (hooked end)	2	680	98.20	3.80
1.0 % (hooked end)	3.5	670	96.50	6.14
1.5 % (hooked end)	4.5	640	88.60	8.31

Compressive strength at 28 days was higher than the reference mix for SCC containing PPHT and steel fibres. Mix containing PVA fibres showed relatively less strength. SCC with steel fibres showed superior performance for flexural strength and SCC with PPHT and PVA fibres showed reduced strength as compared to steel fibres.

SCC with different types of admixtures and superplasticizers

Table 11 shows the fresh and hardened properties of SCC containing four types of polycarboxylate ether based super plasticizer admixtures having same main chain and same polymer structure but different molecular weight and different side chain density of carboxylic acid groups. As per authors all the mix satisfied the desired slump (730± 10 mm). V-funnel time decreases with increase in SP dosage. Minimum time V- funnel time was found 27 seconds for mix D with 1.67 % dosage of SP. The mix B and D did not satisfy the lower limit 0.80 by EFNARC guidelines.

The mix B and C showed superior performance for both hardened properties (compressive strength and ultrasonic pulse velocity) with comparatively lower side chain density 1:3 and 1:4.5 respectively.

Table 12 shows the fresh and hardened properties of twelve different mixes of SCC prepared with variable admixture combination (High Range Water Reducer HRWR + Viscosity Modifying Admixtures VMA + Air Entraining Admixtures AEA) for three slump flows 559 mm, 635mm and 711mm.

Various combinations of all mix A, B, C D shows relatively good performance with respect to fresh properties however in relation to the compressive strength mix A, B, C, and D for 635 slumps shows better performance as compred to other two groups.

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TABLE 10: SOURCE [36]
Fresh and hardened properties of SCC containing three types of fibres.

Mix	Slump Flow			V-funnel test	L-box Test DH_{fin}
	U_{fin} (mm)	T 500 (s)	f_{fin} (s)	(s)	(mm)
Reference mix	670	2	10	8	70
S-RP	700	3	13	5	65
S-LP	700	3	13	5	65
PPHT-RP	680	3	13	8	40
PPHT-RP	680	3	13	7	60
PVA-RP	680	2	12	8	30
PVA-LP	680	2	12	8	50

Mix	Compressive Strength at 28 Days (MPa)	Flexural Strength at 28 Days (MPa)
Reference mix	53	11
S-RP	62	14
S-LP	60	13
PPHT-RP	61	6.7
PPHT-RP	62	6.8
PVA-RP	51	6.5
PVA-LP	56	7.5

TABLE 11: SOURCE [37]
Fresh and hardened properties of SCC containing four types of super plasticizers.

Mix with SP dosage (%) by weight of cement	Slump Flow (mm)	L-box test			V-funnel test (s)
		20 cm (s)	40 cm (s)	H2/H1	
Mix A (1.42 %)	730	2	5.5	0.95	40
Mix B (1.33 %)	720	2.5	6.5	0.76	47
Mix C (1.24 %)	740	1.5	5	0.90	44
Mix D (1.67 %)	720	1	3	0.58	27

Mix with SP dosage (%) by weight of cement	Compressive Strength at 28 Days (MPa)	U. Pulse Velocity Km/s
Mix A (1.42 %)	~ 55	~ 4.9
Mix B (1.33 %)	~ 58	~ 4.9
Mix C (1.24 %)	~ 58	~ 5.0
Mix D (1.67 %)	~ 45	~ 4.8

** Few values are taken from graph therefore they may slightly differ from actual values.*

3.2 Discussion

In relation to the fresh and hardheaded properties studied (table 1 and 2), the use of tyre rubber waste and plastic waste for sand replacement has positive effect to some extent on fresh SCC but hardened properties such as compressive strength and flexural strength reduces with increase in percentage of replacement. The use of RCA (Recycled Concrete Aggregate) in SCC had also negative effect on compressive strength, flexural strength and split tensile strength (table 3). Use of fly ash, silica fumes and iron slag has positive effect on both fresh and hardened properties (table 4 and 5). SCC prepared with fly ash, silica fume and iron slag in various combinations satisfies the requirement of SCC. Addition of the material results in increase in compressive strength.

TABLE 12: SOURCE [38]
Fresh and hardened properties of SCC prepared with variable admixture combination for three slump flows.

Mix with variable SP Dosage for Three slump flow	Slump Flow (mm)	J-Ring (mm)	SF-J-Ring (mm)	T-50 (s)	Air content (%)
A-SF559	552	508	44	2.35	6.0
B-SF559	565	518	48	2.53	6.0
C-SF559	562	498	64	3.13	6.4
D-SF559	572	527	44	2.73	6.0
A-SF635	638	600	38	1.93	6.3
B-SF635	648	610	38	2.26	6.4
C-SF635	640	608	32	2.50	6.5
D-SF635	624	586	38	1.92	6.2
A-SF711	709	671	38	1.77	6.1
B-SF711	715	684	32	2.02	6.0
C-SF711	714	676	38	2.25	6.4
D-SF711	711	699	13	1.71	6.0

Mix with variable SP Dosage for Three slump flow	Compressive strength		
	7 days	28 days	90 days
A-SF559	28.6	40.5	50.4
B-SF559	31.9	40.5	52.9
C-SF559	30.2	39.7	49.7
D-SF559	33.2	42.6	53.6
A-SF635	32.6	41.9	55.5
B-SF635	29.3	37.8	48.0
C-SF635	29.7	39.5	48.6
D-SF635	29.6	41.1	51.8
A-SF711	28.5	38.2	50.7
B-SF711	27.0	36.4	43.1
C-SF711	31.7	41.3	51.6
D-SF711	29.2	39.6	51.1

** A-SF559 means mix A with variable admixture combination (High Range Water Reducer HRWR + Viscosity Modifying Admixtures VMA + Air Entraining Admixtures AEA) for slump flow 559 mm.*

Addition of steel fibres results in reduced slump flow which can be increased by increasing the amount of super plasticizers. Using steel fibres it is possible to produce high strength and ultra high strength SCC. Regarding shape of fibres hooked fibres performed well.

In relation to the use of various admixtures and super

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plasticizers the performance of SCC depends on the physical properties of SP and SP dosage.

4 CONCLUSION

In the present paper recent innovations in SCC using various agro-industrial wastes and their effect on fresh and hardened properties have been reviewed. In summary the use of various agro-industrial wastes in SCC has positive effect on fresh and hardened properties. It is possible to produce medium strength, high strength and even ultra high strength good quality of SCC using the wastes.

5 FURTHER WORK

The reviewed literature broadly signifies the recent innovations in SCC. The paper is focused on use of innovative materials in SCC and their effect on fresh and hardened properties of SCC. The reviewed literature indicates broad variation in behavior and performance of fresh and hardened properties of SCC containing different innovative materials. The generated database will be beneficial for selection of best innovative material for production of good quality of SCC and also for further research work in this particular area.

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