Review on the Durability Parameters of Self-compacting Concrete

Reshul Raj, Mayur Bhat, Achal Agrawal, and Narayan Chandak

Abstract The disposal of toxic environmental waste is one of the main challenges at present. The use of various kinds of waste as a substitute for aggregate or cement in concrete is a proven way to manage the waste. Various research experiments have been carried out using waste material in self-compacting concrete, resulting in improved strength and resilience, whether it is traditional concrete or self-compacting concrete. This paper highlights the improvements in the durability of self-compacting concrete through the use of different combinations of various waste materials. The study also explains the influence of mineral and chemical admixtures on self-compacting concrete. It also addresses the effect of waste materials, fiber content, and type of admixtures on the durability parameters such as Rapid Chloride Penetration Test (RCPT), sulfate attack, water penetration, and carbonation test on the self-compacting concrete.

Keywords Self-compacting concrete · Super-plasticizers · RCPT · Sulfate attack · Water penetration · Acid attack · Fibers

1 Introduction

Self-compacting concrete (SCC) is a front runner of concrete that does not require any vibratory concrete machine to be installed. Because of this concrete consistency, this type of concrete settles under its own weight and is commonly used in the field of construction. Particularly in congested formwork, where compaction is not fissile, it is a good alternative to conventional concrete and work with self-compacting concrete is preferred in this situation.

The use of waste materials from construction industries in making of self-compacting concrete can reduces tons of accumulated construction waste. The present review paper is a research on durability properties of self-compacting

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concrete after partial replacement of natural aggregates and cementitious content with different mineral admixtures and waste aggregates.

Most research work have shown that partial replacement of cement and natural aggregates with waste mineral admixtures, and waste aggregates improves the durability properties of self-compacting concrete.

2 Review Significance

This paper gives a review on self-compacting concrete (SCC) mix made using various mineral admixtures and materials as partial replacement. A concrete which when poured from a certain height, compacts with its own weight due to gravity and does not require any external vibrations is known as self-compacting concrete. Different authors review papers and case studies are included in this paper, and it shows that effects of minerals admixtures and waste materials on the durability properties of SCC.

The main objective of this review is to find the change in durability of SCC on partial replacement of cement and aggregates with mineral admixtures and recycled materials.

3 Materials Used

Table 1 shows variety of material used by the authors in their research work, which gives a better understanding of different combination and effects of proportions of mineral admixtures and waste/recycled aggregates on the durability of SCC. A detailed review of 145 mixes is done in this study where 23 research studies are reported. Table 2 shows the mix design proportion used by different authors. The cement that was used widely for mix design was Ordinary Portland Cement. Mineral admixtures are also used in different combination with OPC. Fly ash, limestone powder, rice husk ash, pumice, zeolite, coal fly ash, silicon fillers, metakaolin, and waste asphalt filler was used in specific proportion with OPC.

Here, Fig. 1 shows the frequency of mineral admixtures used with the cement by different authors. It clearly shows that frequency of fly ash with cement and limestone powder with cement is used the most at 28 and 22%, respectively. Another frequently used material is metakaolin at 14%. The graph shows that fly ash, limestone powder, and metakaolin was used frequently in combination with OPC and other mineral admixtures by most authors.

In some SCC mixes, addition of silica fume and rice husk ash are used as mineral admixture in specific proportion. Pumice in SCC has superior resistance to harsh weather conditions like freezing and thawing. Pumice powder has pozzolanic properties, especially if it is used as combination with silica fume.

Table 1 Materials use by different authors

Reference	Year	SP type	Material used			
			Fine aggregates	Coarse aggregates	Cement	Mineral admixtures
Siddique [1]	2013	PCE	Bottom ash, Natural aggregate	Natural	OPC	Fly ash
Frazão et al. [2]	2015	Ether polycarboxylate (ViscoCrete 3005)	Fine river sand (< 1.19 mm), Natural aggregates	Coarse river sand (< 4.76 mm), Natural aggregates	CEM I 42.5 R Portland cement	Limestone filler, Steel fibers
Singh et al. [3]	2016	Polycarboxylate-based SP	Natural	RCA, NA	OPC grade 43	Fly ash, Metakaolin
Kapoor et al. [4]	2016	PCE	Natural	RCA, NA	OPC	Fly ash, Metakaolin, Silica fumes
Kannan et al. [5]	2014	SNP	Natural	Natural	OPC ASTM C 150 (Type1)	Rice husk Ash, Metakaolin
Samimi et al. [6]	2017	Polycarboxylate ether (PCE 180)	Natural	Natural	Portland cement type II	Limestone powder, Pumice, Zeolite
Kou et al. [7]	2009	SP ADVA-109	Recycled aggregates, Natural aggregates	Recycled aggregates, Natural aggregates	OPC	Fly ash
Persson [8]	2003	Polycarboxylic ether—brand Glenium 51	Natural	Natural	OPC	Limestone filler
Gupta et al. [9]	2020	Auramix-400	Copper slag	Natural	OPC 43 grade	Fly ash
Siddique [10]	2011	Polycarboxylicether-based SP	Natural	Natural	OPC (Grade 43)	Fly ash
Sharma et al. [11]	2017	Glenium SKY 8765 based on PCE	Copper slag	Natural	OPC of 43 grade ASTM Type I	Fly ash

(continued)

Table 1 (continued)

Reference	Year	SP type	Material used			
			Fine aggregates	Coarse aggregates	Cement	Mineral admixtures
Pereira-de-Oliveira et al. [12]	2014	Modified polycarboxylate-based SP	Natural	RCA, NA	Portland cement type CEM I 42.5R	Limestone powder
Chopra et al. [13]	2015	Conplast SP430 based on SNP	Natural	Natural	OPC grade 43	Rice husk ash
Assie et al. [14]	2006	Polycarboxylate modified superplasticizer	Natural	Natural	CEM II/A-LL 32.5 R and CEM I 52.5 N	Limestone filler
Valcuende et al. [15]	2010	Polycarboxylate with polyethylene condensate defoamedGlenium C303	Natural	Natural	CEM II/B-M (V-LL) 32.5 N and CEM II/B-M (V-LL) 42.5R	Limestone powder
Esquinas et al. [16]	2018	Glenium 303 based on PCE	Natural	Natural	OPC type CEM I 42.5 R/SR	Non-conforming fly ash, Siliceous filler
Esquinas et al. [17]	2018	Glenium 303 PCE	Natural	Natural	OPC CEM I 42.5 R/SR	Waste asphalt filler
Gill et al. [18]	2018	Conplast SP400	Natural	Natural	OPC	Rice husk ash, Metakaolin
Sasanipour et al. [19]	2019	PCE	RCA, NA	RCA, NA	OPC type II	Limestone powder, Silica fumes
Ofuyatan et al. [20]	2015	Conplast SP432MS	Natural	Natural	OPC type I	Palm oil fuel ash

(continued)

Table 1 (continued)

Reference	Year	SP type	Material used			
			Fine aggregates	Coarse aggregates	Cement	Mineral admixtures
Vaidevi et al. [21]	2020	Master glenium SKY 8233 based on PCE	NA, Marble waste	Natural	OPC grade 53	Fly ash
Tang et al. [22]	2018	Master glenium 51con 35%, BASF	Natural	NA, Artificial aggregates	OPC CEM I 42.5 N	Coal fly ash
Kapoor et al. [23]	2018	PCE	RCA, NA	RCA, NA	OPC grade 43	Fly ash

Table 2 Mix design proportions used by authors

Reference mix		Water (kg/m^3)	Total powder content (kg/m^3)	Aggregates						Super-plasticizer		Viscosity modifying agents	
				FA (kg/m^3)	CA (kg/m^3)	Replaced aggregates				Type	%	Type	(kg/m^3)
						Type	FA (kg/m^3)	CA (kg/m^3)	%				
				913	589	BA	0	0	0	PCE	2	N M	N M
	SCC2	260.9	550	821	589	BA	91	0	10	PCE	1.85	N M	N M
	SCC3	281.4	550	730	589	BA	183	0	20	PCE	1.9	N M	N M
	SCC4	300.5	550	639	589	BA	274	0	30	PCE	1.88	N M	N M
Frazão et al. [2]	SCC	127.8	766	N M	648	RS	198	722	N M	PCE	1.02	N M	N M
	SFRSCC	127.8	766	N M	640	RS	195	713	N M	PCE	1.02	N M	N M
Singh et al. [3]	CF-RCA0	277	615	846	646	RCA	0	0	0	PCE	0.28	N M	1.72
	CF-RCA25	277	615	846	484.5	RCA	0	150.5	25	PCE	0.29	N M	1.72
	CF-RCA50	277	615	846	323	RCA	0	301	50	PCE	0.31	N M	1.72
	CF-RCA75	277	615	846	161.5	RCA	0	451.5	75	PCE	0.35	N M	1.93
	CF-RCA100	277	615	846	0	RCA	0	602	100	PCE	0.35	N M	1.93
	CFM-RCA25	277	615	846	484.5	RCA	0	150.5	25	PCE	0.35	N M	1.72
	CFM-RCA50	277	615	846	323	RCA	0	301	50	PCE	0.41	N M	1.72
	CFM-RCA75	277	615	846	161.5	RCA	0	451.5	75	PCE	0.46	N M	1.8
	CFM-RCA100	277	615	846	0	RCA	0	602	100	PCE	0.46	N M	2.15
Kapoor et al. [4]	C-RO	277	615	846	602	RCA	0	0	0	PCE	0.8	N M	1.72
	C-R50	277	615	846	301	RCA	0	280	50	PCE	1	N M	2.58

(continued)

Table 2 (continued)

Reference mix		Water (kg/m^3)	Total powder content (kg/m^3)	Aggregates						Super-plasticizer		Viscosity modifying agents	
				FA (kg/m^3)	CA (kg/m^3)	Replaced aggregates				Type	%	Type	(kg/m^3)
						Type	FA (kg/m^3)	CA (kg/m^3)	%				
	C-R100	277	615	846	0	RCA	0	560	100	PCE	1.2	N M	3.44
	C-SFR0	277	594.5	846	602	RCA	0	0	0	PCE	0.8	N M	1.72
	C-SFR50	277	594.5	846	301	RCA	0	280	50	PCE	1	N M	2.58
	C-SFR100	277	594.5	846	0	RCA	0	560	100	PCE	1.2	N M	3.44
	C-MKR0	277	604.5	846	302	RCA	0	0	0	PCE	0.8	N M	1.72
	C-MKR50	277	604.5	846	301	RCA	0	280	50	PCE	1	N M	2.58
	C-MKR100	277	604.5	846	0	RCA	0	560	100	PCE	1.2	N M	3.44
Persson [8]	KN	163	601	1169	363	N M	N M	N M	N M	PCE	0.49	N M	N M
	KOB	167	802	1007	371	N M	N M	N M	N M	PCE	0.51	N M	N M
	KN8	160	589	1145	355	N M	N M	N M	N M	PCE	0.54	N M	N M
	KO	165	609	1184	367	N M	N M	N M	N M	PCE	0.56	N M	N M
	KOT	163	603	1171	363	N M	N M	N M	N M	PCE	0.61	N M	N M
	SO	162	510	1208	402	N M	N M	N M	N M	PCE	0.59	N M	N M
	RO	168	431	861	862	N M	N M	N M	N M	PCE	1.7	N M	N M
Gupta et al. [9]	0CS-SCC	168	500	960	760	CS	0	0	0	PCE	1.2	N M	N M

(continued)

Table 2 (continued)

Reference mix		Water (kg/m^3)	Total powder content (kg/m^3)	Aggregates						Super-plasticizer		Viscosity modifying agents	
				FA (kg/m^3)	CA (kg/m^3)	Replaced aggregates				Type	%	Type	(kg/m^3)
						Type	FA (kg/m^3)	CA (kg/m^3)	%				
	10CS-SCC	168	500	864	760	CS	96	0	10	PCE	1.2	N M	N M
	20CS-SCC	168	500	768	760	CS	192	0	20	PCE	1.2	N M	N M
	30CS-SCC	168	500	672	760	CS	288	0	30	PCE	1.2	N M	N M
	40CS-SCC	168	500	576	760	CS	384	0	40	PCE	1.2	N M	N M
	50CS-SCC	168	500	480	760	CS	480	0	50	PCE	1.2	N M	N M
	60CS-SCC	168	500	384	760	CS	576	0	60	PCE	1.2	N M	N M
Siddique [10]	SCC1	205	550	910	590	N M	N M	N M	N M	PCE	1.95	N M	N M
	SCC2	205	550	910	590	N M	N M	N M	N M	PCE	2	N M	N M
	SCC3	210	550	910	590	N M	N M	N M	N M	PCE	1.8	N M	N M
	SCC4	215	550	910	590	N M	N M	N M	N M	PCE	1.8	N M	N M
	SCC5	220	550	910	590	N M	N M	N M	N M	PCE	1.8	N M	N M
Sharma et al. [11]	OF-CS0	247.5	550	0	700	CS	0	0	0	PCE	0.8	N M	N M
	OF-CS20	247.5	550	0	700	CS	284.4	0	20	PCE	0.8	N M	N M
	OF-CS40	247.5	550	0	700	CS	568	0	40	PCE	0.6	N M	N M
	OF-CS60	247.5	550	0	700	CS	853.2	0	60	PCE	0.5	N M	N M

(continued)

Table 2 (continued)

Reference mix		Water (kg/m^3)	Total powder content (kg/m^3)	Aggregates						Super-plasticizer		Viscosity modifying agents	
				FA (kg/m^3)	CA (kg/m^3)	Replaced aggregates				Type	%	Type	(kg/m^3)
						Type	FA (kg/m^3)	CA (kg/m^3)	%				
	OF-CS80	247.5	550	0	700	CS	1137.6	0	80	PCE	0.4	N M	N M
	OF-CS100	247.5	550	0	700	CS	1422	0	100	PCE	0.4	N M	N M
Pereira-de-Oliveira et al. [12]	SCC	161.3	655.1	730.8	807.9	RA	0	0	0	PCE	0.52	N M	N M
	SCC20	163.2	655.1	730.8	646.3	RA	0	149.6	20	PCE	0.73	N M	N M
	SCC40	160.7	655.1	730.8	484.8	RA	0	299.3	40	PCE	0.7	N M	N M
	SCC100	162.4	655.1	730.8	0	RA	0	808.5	100	PCE	0.93	N M	N M
Chopra et al. [13]	0RHA	226	550	910	590	N M	N M	N M	N M	SNP	1	N M	N M
	10RHA	226	550	910	590	N M	N M	N M	N M	SNP	1	N M	N M
	15RHA	226	551	910	590	N M	N M	N M	N M	SNP	1	N M	N M
	20RHA	226	550	910	590	N M	N M	N M	N M	SNP	1	N M	N M
Assie et al. [14]	SCC 20	205	465	900	771	N M	N M	N M	N M	PCE	1.72	N M	N M
	SCC 40	191	490	888	791	N M	N M	N M	N M	PCE	2.57	N M	N M
	SCC 60	189	520	884	793	N M	N M	N M	N M	PCE	2.6	N M	N M
Valcuende et al. [15]	S-65-32	178.75	486.67	911.87	816.06	N M	N M	N M	N M	PCE	0.96	N M	N M
	S-55-32	178.75	522.6	902.06	797.94	N M	N M	N M	N M	PCE	1	N M	N M

(continued)

Table 2 (continued)

Reference mix		Water (kg/m^3)	Total powder content (kg/m^3)	Aggregates						Super-plasticizer		Viscosity modifying agents	
				FA (kg/m^3)	CA (kg/m^3)	Replaced aggregates				Type	%	Type	(kg/m^3)
						Type	FA (kg/m^3)	CA (kg/m^3)	%				
	S-55-42	178.75	522.6	902.06	797.94	N M	N M	N M	N M	PCE	0.93	N M	N M
	S-45-42	180	580.09	879.89	769.43	N M	N M	N M	N M	PCE	1.03	N M	N M
Esquinas et al. [16]	SCC-1	176.93	410	938.1	807.65	N M	N M	N M	N M	PCE	2.25	N M	N M
	SCC-12	179.4	503.53	933.65	797.81	N M	N M	N M	N M	PCE	1.8	N M	N M
	SCC-2	182.75	482.94	942.98	789.07	N M	N M	N M	N M	PCE	1.8	N M	N M
Esquinas et al. [17]	SCC-SF	180.41	510.01	922.11	793.88	N M	N M	N M	N M	PCE	1.8	N M	N M
	SCC-RF	183.38	512.29	922.11	793.88	N M	N M	N M	N M	PCE	1.8	N M	N M
Gill et al. [18]	Control mix	211.2	480	900	670	N M	N M	N M	N M	SNP	1.5	N M	N M
	5MK10RHA	250.8	570	810	670	N M	N M	N M	N M	SNP	2	N M	N M
	10MK10RHA	250.8	570	810	670	N M	N M	N M	N M	SNP	2	N M	N M
	15MK10RHA	250.8	570	810	670	N M	N M	N M	N M	SNP	2	N M	N M
Ofuyatan et al. [20]	A1	9.76	18.97	20.54	42.78	N M	N M	N M	N M	SNP	0	N M	N M
	A2	9.76	18.97	20.54	42.78	N M	N M	N M	N M	SNP	0	N M	N M
	A3	9.76	25.41	20.54	42.78	N M	N M	N M	N M	SNP	2	N M	N M
	A4	9.76	24.46	20.54	42.78	N M	N M	N M	N M	SNP	2	N M	N M

(continued)

Table 2 (continued)

Reference mix		Water (kg/m^3)	Total powder content (kg/m^3)	Aggregates						Super-plasticizer		Viscosity modifying agents	
				FA (kg/m^3)	CA (kg/m^3)	Replaced aggregates				Type	%	Type	(kg/m^3)
						Type	FA (kg/m^3)	CA (kg/m^3)	%				
	A5	9.76	24.33	20.54	42.78	N M	N M	N M	N M	SNP	2	N M	N M
	A6	9.76	25.41	20.54	42.78	N M	N M	N M	N M	SNP	2	N M	N M
	A7	9.76	25.42	20.54	42.78	N M	N M	N M	N M	SNP	2	N M	N M
	A8	9.76	27.32	20.54	42.78	N M	N M	N M	N M	SNP	2	N M	N M
	Control SCC	193	640	738	847	MA	0	0	0	PCE	2	N M	N M
	SCCMFA25	193	640	553	847	MA	185	0	25	PCE	2	N M	N M
	SCCMFA50	193	640	369	847	MA	369	0	50	PCE	2	N M	N M
	SCCMFA100	193	640	0	847	MA	738	0	100	PCE	2	N M	N M
Tang et al. [22]	Mix 1 30%	139.5	489	572.9	816.09	AA	0	241.43	30	PCE	1.2	N M	N M
	Mix 1 60%	139.5	489	572.9	558.37	AA	0	483	60	PCE	1.2	N M	N M
	Mix 2 30%	139.5	489	572.9	816.09	AA	0	234.29	30	PCE	1.2	N M	N M
	Mix 2 60%	139.5	489	572.9	558.37	AA	0	468.71	60	PCE	1.2	N M	N M
	Mix 3 30%	139.5	489	572.9	816.09	AA	0	236.14	30	PCE	1.2	N M	N M
	Mix 3 60%	139.5	489	572.9	558.38	AA	0	472.14	60	PCE	1.2	N M	N M
Kapoor et al. [23]	C0F0	277	615	846	602	RCA	0	0	N M	PCE	0.8	N M	1.72

(continued)

Table 2 (continued)

Reference mix		Water (kg/m^3)	Total powder content (kg/m^3)	Aggregates						Super-plasticizer		Viscosity modifying agents	
				FA (kg/m^3)	CA (kg/m^3)	Replaced aggregates				Type	%	Type	(kg/m^3)
						Type	FA (kg/m^3)	CA (kg/m^3)	%				
	C50F0	277	615	846	301	RCA	0	278	N M	PCE	0.9	N M	2.15
	C50F25	277	615	635	301	RCA	193	278	N M	PCE	1	N M	2.15
	C50F50	277	615	423	301	RCA	386	278	N M	PCE	1	N M	2.15
	C100F0	277	615	846	0	RCA	0	556	N M	PCE	1.1	N M	2.58
	C100F25	277	615	635	0	RCA	193	556	N M	PCE	1.1	N M	3.01
	C100F50	277	615	423	0	RCA	386	556	N M	PCE	1.2	N M	3.01

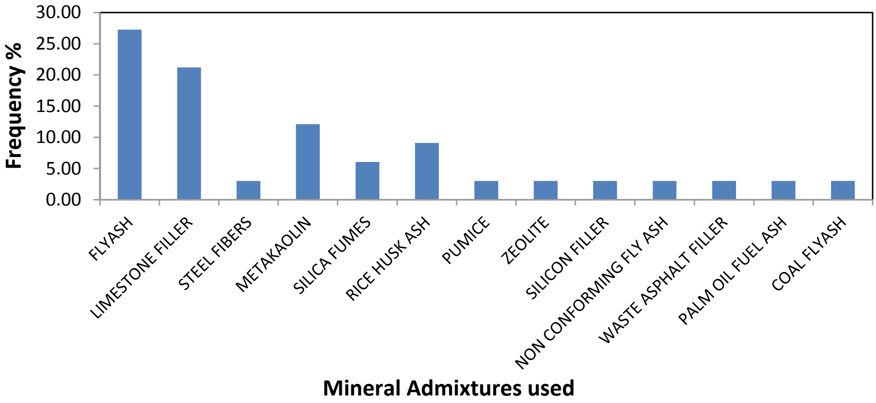

Fig. 1 Frequency of mineral admixtures used as partial replacement for cement

Figure 2 shows the frequency of materials used as partial replacement to natural aggregates by different authors. Recycled concrete aggregates were used frequently by authors in combination with natural aggregates. Other materials used as partial replacement to natural aggregates include bottom ash, copper slag, marble aggregate, and artificial aggregate.

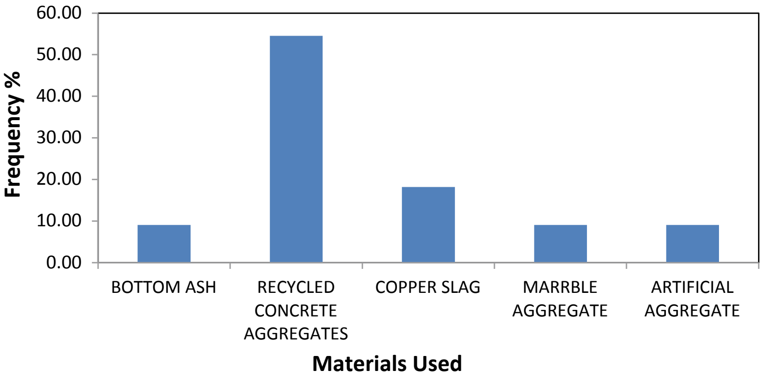

Fig. 2 Frequency of materials used as partial replacement for aggregates by 11 authors

4 Durability Test

4.1 Carbonation Depth Test

The process in which atmospheric carbon-dioxide (CO_2) reacts with hydrated cementitious mineral in the presence of moisture is known as carbonation. Calcium carbonate is formed when calcium hydroxide and carbon dioxide reacts together. Carbonation prevents corrosion of reinforcement as it reduces alkalinity and increases mechanical strength. Carbonation proves to be not good for concrete structure.

To check for carbonation depth, multiple specimens are prepared for different mix designs. After respective days of curing, cube specimens were split prior to testing, conditioning of specimen was done. Phenolphthalein was used as an indicator for carbonation, and then the depth of carbonation was measured. Figure 3 shows the result obtained by different authors for the carbonation test performed by on their mix samples.

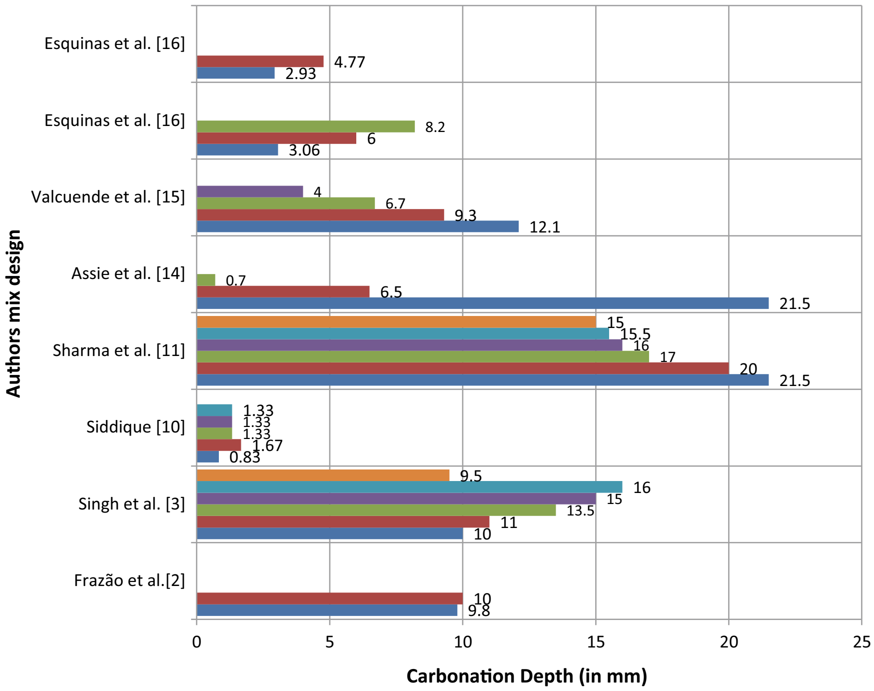

Fig. 3 Carbonation depth test (28 days curing)

4.2 Rapid Chloride Penetration Test

Chloride penetration leads to corrosion of reinforced steel and corrosion related damages to concrete, and it is a very common issue. This issue of durability has drawn attention toward it due to its frequent occurrence and high repair costs. Chlorides will even penetrate a crack free concrete by kind of mechanisms appreciate capillary absorption, fluid mechanics pressure, diffusion, etc. Diffusion is caused once the chloride concentration on the skin of the SCC concrete structure is higher than that on the inside.

For the purpose of Rapid Chloride Penetration Test (RCPT), cylindrical specimens of self-compacting concrete were selected (100 mm diameter, 50 mm thick). As per ASTM C1202, the tests were conducted at different intervals. The results obtained by different authors are shown in Fig. 4. Table 3 shows Chloride ion penetrability

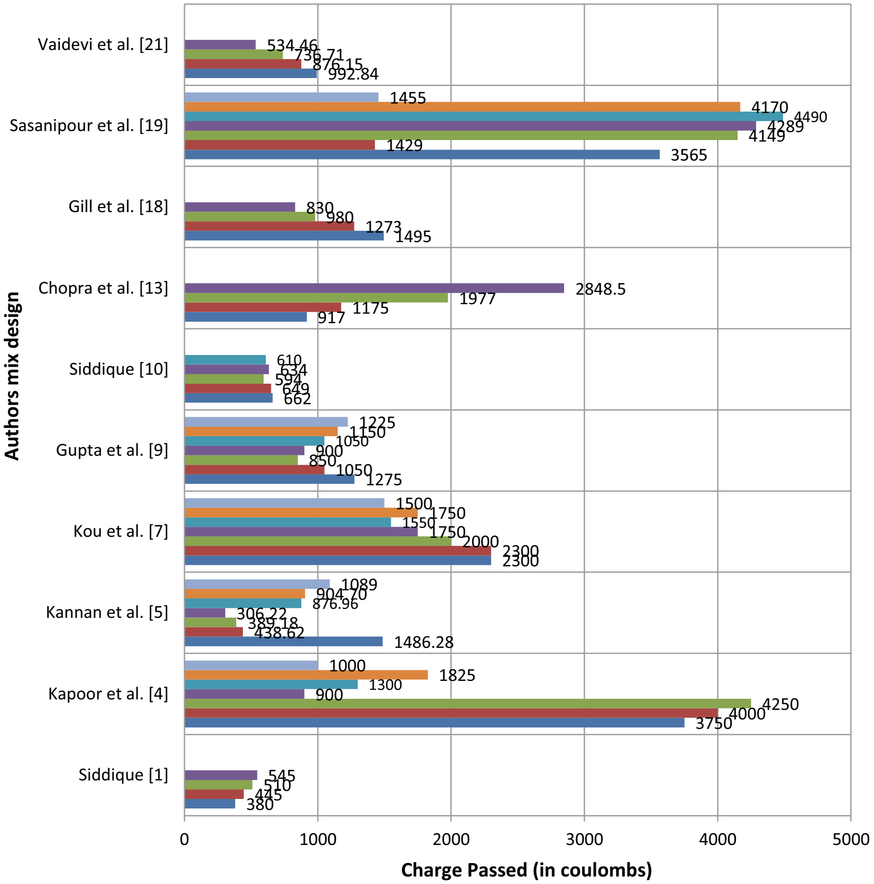

Fig. 4 Rapid chloride penetration test

Table 3 Chloride ion penetrability based on charge passed

Charge passed (Coulomb)	Chloride ion penetrability
> 4000	High
2000–4000	Moderate
1000–2000	Low
100–1000	Very low
< 100	Negligible

Source ASTM 1202-97

based on charge passed (ASTM 1202-97).

4.3 Sulfate Attack Test

According to ASTM C1012, the test for checking percentage mass change due to sulfate attack was performed. Cube specimens of size 150 mm × 150 mm × 150 mm were immersed in 5% Na_2SO_4 solution. Change in weight percentage of the specimens were noted down at an exposure period of 28, 56, 90, 120, and 365 days. Figure 5 shows the result for sulfate attack test performed by various authors on their respective mixes.

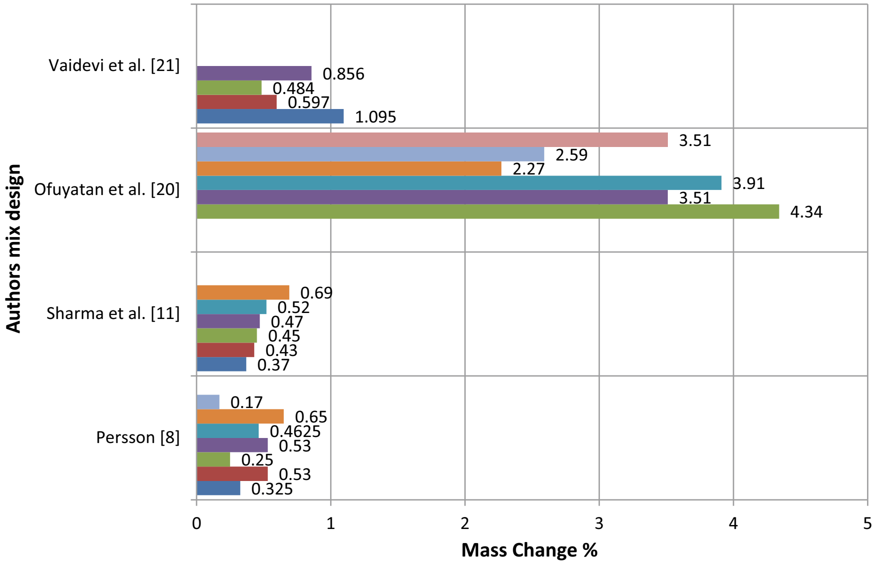

Fig. 5 Sulfate attack test (28 days)

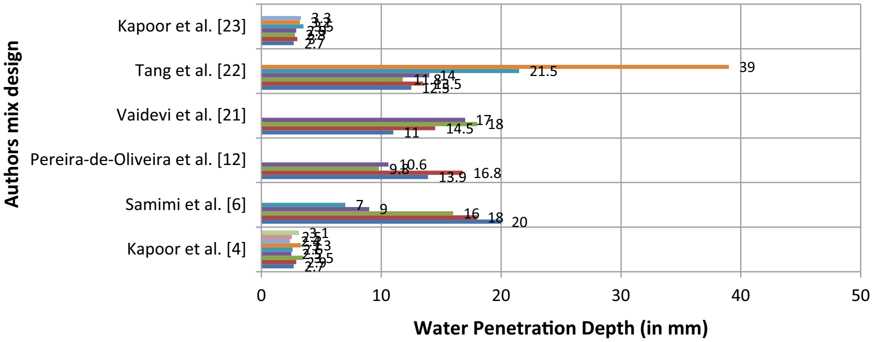

Fig. 6 Water penetration depth test (28 days)

4.4 *Water Penetration Test*

According to BSEN12390-8:2000, specimen of size 150 mm × 150 mm × 150 mm were selected for curing ages of 28, 56 and 120 days. A constant water pressure of 0.5 MPa was maintained over the specimen for 72 h. After 72 h, the specimens need to be removed from the apparatus and needs to split in two halves, perpendicular to the face on which the water pressure was applied. As soon as the split face had dried to such an extent that the water penetration front could be clearly seen, the waterfront was marked on the specimen. The reading for maximum water penetration depth was recorded to the nearest millimeter. The result of depth of penetration performed by different author son their mix is reported in Fig. 6.

5 Conclusion

By reviewing all the papers, it was concluded that addition of waste/recycled aggregates and mineral admixtures as partial replacement to cement and natural aggregates will improve the durability properties of self-compacting concrete. As shown in the tables and figures, it is clear that most suitable cement used is ordinary Portland cement in combination with various mineral admixtures such as fly ash, silica fumes, limestone powder, silica fumes, etc. The use of super plasticizer or high range water reducer to maintain the lower water to cement or water to powder ratio and achieve desired property to qualify as a SCC. Following inferences were derived from the study:

- Addition of recycle concrete aggregates reduces the durability of self-compacting concrete mix, but on addition of 30% of total binding material as powdered mineral admixtures such as fly ash, metakaolin, silica fumes or combination of the three, alongside recycled aggregates makes the specimen less vulnerable to chemical attacks;

- Addition of 10% metakaolin along with 20% fly ash or limestone powder to the mix increases the resistance of mix against carbonation by 17.5%, rapid chloride ion penetration by 60% and water penetration by 10%;
- Addition of 20% silica fumes in self-compacting concrete increases resistance against carbonation up to 70%, chloride ion penetration by up to 70% and water penetration by up to 10%;
- Addition of steel fibers in self-compacting concrete reduces resistance against carbonation attack by up to 20%.
- Major change in properties were observed when 30% fly ash was added as partial replacement to cement. Fly ash decreases the coulomb value of concrete in rapid chloride penetration test from 3000 coulombs to below 1000 coulombs which lies in very low range of chloride ion penetration according to ASTM 1202-97.
- Addition of 15% rice husk ash reduced the penetration of chloride ions by up to 80%. 15% was found to be optimum value of rice husk ash, increase or decrease in this value reduced the resistance of the mix. It was also found that every mix with rice husk ash lied in very low range of chloride ion penetration.

Abbreviations

NM	Not Mentioned
OPC	Ordinary Portland Cement
SP	Super-Plasticizer
FA	Fly Ash
BA	Bottom Ash
LF	Limestone Filler
FS	Fine River Sand
PC	Portland Cement
RCA	Recycled concrete aggregate
PCE	Polycarboxylate Ether
RHA	Rice Husk Ash
MK	Metakaolin
SNP	Sulphonated Naphthalene Polymer
LP	Limestone Powder
FO	Fatty Oils
SF	Silica Fumes
CS	Copper Slag
MA	Marble Aggregate
AA	Artificial Aggregate
RA	Recycled Aggregate

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