THE EFFECT OF MINERAL ADDITIONS AND ADDING VARIOUS TYPES, LENGTH AND VOLUME OF FIBERS ON FRESH PROPERTIES OF SELF COMPACTING CONCRETE

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ABSTRACT

A thorough research has been conducted to understand the effect of adding various types of fibers and mineral additions to SCC mixes. Forty SCC mixes were prepared with two types of mineral admixtures and three different types of fibers. Metakaoline and silica fume were used as mineral admixtures while polypropylene, glass and carbon fibers were used as fiber inclusions. Two different fiber length (6 mm and 12 mm) and fiber volume (0,1 % and 0,5 %) were used. Then, fresh state properties of the mixes were evaluated by means of different methods such as slump flow, V-funnel, L-box and U-box. Effect of adding mineral admixtures and different types of fibers on these parameters were quantitatively represented. Tables were prepared to give percentage increase/decrease in the fresh state values with addition of different type/dosage/length of fibers and mineral admixtures. These tables were used to evaluate the effect of adding certain type of fiber with certain volume and length on the fresh state properties.

Keywords; SCC, Fibers, Mineral Admixtures, Silica Fume, Metakaoline, Fresh State

INTRODUCTION

Self compacting concrete (SCC) is expected to be one of the most widely used materials of concrete industry in the near future. Extensive research is being done to better understand, define and model the behavior of these materials. Adding supplementary materials and/or fibers to SCC mixes are also becoming common causing an increase of the number of effective parameters on the material performance. Mineral admixtures and fibers are advantageous in many ways (1-5), unfortunately; they generally alter fresh state properties of mixes (2) and negatively affect overall performance. The extent of the negative effect caused by various types of mineral admixtures and fibers is also different. This study aims to help potential readers about the effects of adding mineral admixtures (silica fume and Metakaoline), and different types of fibers (polypropylene, glass and carbon) with various volumes and aspect ratios, on the fresh state performance by giving quantitative information. Tables are given in the following pages to represent the percentage variations in the fresh state properties with addition of mineral admixtures, increasing fiber length, and volume. The methods used to assess fresh state performance are chosen after examining different guidelines. Unfortunately, there is not one single method to characterize the fresh state properties of SCC (5,6), a combination of tests is needed for a full understanding (7). Several guidelines proposed in different countries, discuss the most used methods to measure and assess the fresh state properties of SCC (5-7). These guidelines define limit values and/or a range for data obtained from the tests. However, comparisons of the methods which are used to evaluate similar properties were not given.

MATERIALS , MIXTURE DESIGN AND PROPORTION , MIXING AND CURING, APPLIED TESTS

Ordinary Portland cement (OPC) type (I) manufactured in Turkey is used which corresponds to ASTM Type I cement. Local natural sand and gravel were used as fine and coarse aggregate. The maximum aggregate size was 9 mm; coarse and fine aggregate had specific gravities of 2,68 and 2,65 kg/m^3, water absorptions of 3% and 2,16%, and sulfate content of 0,08 and 0,05, respectively. Copolymer based Super plasticizer Glenium 51 is used. Its relative density is 1,1 g/cm^3 @ 20 °C and has a PH value of 6,6 . The Metakaoline used in this study had a specific gravity of 2,62 kg/m^3 and surface area of 19000 cm^2/g. also Silica fume was used in this study and had a specific gravity of 2,45 kg/m^3. Three different types of fibers (polypropylene (PP), glass (G), and carbon (C)) were used. Properties of fibers are given in Table (1). A total of forty mixes were prepared in four series with different cementations materials constitutions (Table 2). The mixing procedure which developed by Joost C. Walraven and Stefan Grunewald (8) was adopted. Fresh state properties of SCC mixes were evaluated by using some of the most commonly used methods (5). The methods used for measured fresh state properties were slump flow, V-funnel, L-box and U-box.

Table 1. properties of the fibers used.

Physical properties	Polypropylene	Glass	carbon
Specific gravity (g/cm3)	0,91	2,78	1.78
Young modulus (GPa)	5,5	70	231
Tensile strength (MPa)	350	2500	4100
Elongation at break (%)	15	3,5	1.7
Design thickness (mm)	0,04	0,4	0.12
Fiber length (mm)	6-12	6-12	6-12
Aspect ratio (L/D)	150-300	15-30	50-100

Mix	No of mixes	Mixes code	PC kg/m³	SF (%)	MK (%)	Sand kg/m³	Gravel kg/m³	w/b	Sp (%) Of C	Length of fiber(mm)	Vf (%)
Group 1 Ref. mixes	1	N	500	-	-	1040	480	0,52	-	-	-
	2	R(SCC)	500	-	-	1040	480	0,35	8	-	-
	3	M(SCC+MK)	500	-	10	1040	480	0,35	9	-	-
	4	S(SCC+SF)	500	10	-	1040	480	0,35	10	-	-
Group 2 SCC+PP fiber	5	R1P6	500	-	-	1040	480	0,35	8	6	0,1
	6	M1P6	500	-	10	1040	480	0,35	9	6	0,1
	7	S1P6	500	10	-	1040	480	0,35	10	6	0,1
	8	R1P12	500	-	-	1040	480	0,35	8	12	0,1
	9	M1P12	500	-	10	1040	480	0,35	9	12	0,1
	10	S1P12	500	10	-	1040	480	0,35	10	12	0,1
	11	R5P6	500	-	-	1040	480	0,35	8	6	0,5
	12	M5P6	500	-	10	1040	480	0,35	9	6	0,5
	13	S5P6	500	10	-	1040	480	0,35	10	6	0,5
	14	R5P12	500	-	-	1040	480	0,35	8	12	0,5
	15	M5P12	500	-	10	1040	480	0,35	9	12	0,5
	16	S5P12	500	10	-	1040	480	0,35	10	12	0,5
Group 3 SCC+G fiber	17	R1G6	500	-	-	1040	480	0,37	10	6	0,1
	18	M1G6	500	-	10	1040	480	0,37	11	6	0,1
	19	S1G6	500	10	-	1040	480	0,37	12	6	0,1
	20	R1G12	500	-	-	1040	480	0,37	10	12	0,1
	21	M1G12	500	-	10	1040	480	0,37	11	12	0,1
	22	S1G12	500	10	-	1040	480	0,37	12	12	0,1
	23	R5G6	500	-	-	1040	480	0,37	10	6	0,5
	24	M5G6	500	-	10	1040	480	0,37	11	6	0,5
	25	S5G6	500	10	-	1040	480	0,37	12	6	0,5
	26	R5G12	500	-	-	1040	480	0,37	10	12	0,5
	27	M5G12	500	-	10	1040	480	0,37	11	12	0,5
	28	S5G12	500	10	-	1040	480	0,37	12	12	0,5
Group 4 SCC+C fiber	29	R1C6	500	-	-	1040	480	0,38	12	6	0,1
	30	M1C6	500	-	10	1040	480	0,38	13	6	0,1
	31	S1C6	500	10	-	1040	480	0,38	14	6	0,1
	32	R1C12	500	-	-	1040	480	0,38	12	12	0,1
	33	M1C12	500	-	10	1040	480	0,38	13	12	0,1
	34	S1C12	500	10	-	1040	480	0,38	14	12	0,1
	35	R5C6	500	-	-	1040	480	0,38	12	6	0,5
	36	M5C6	500	-	10	1040	480	0,38	13	6	0,5
	37	S5C6	500	10	-	1040	480	0,38	14	6	0,5
	38	R5C12	500	-	--	1040	480	0,38	12	12	0,5
	39	M5C12	500	-	10	1040	480	0,38	13	12	0,5
	40	S512	500	10	-	1040	480	0,38	14	12	0,5

Table 2. Mixture proportions of concrete.

RESULTS AND DISCUSSION

Results of the fresh state tests are given in Table 3. The addition of mineral admixtures to concrete was found to negatively affect fresh state properties . As can be seen in the Table 4, slump flow of SCC mixes was not very much affected with addition of mineral admixtures. However, the mixes with Silica fume were found to have lower slump flows compared to the mixes with Metakaolin.

Table 3. Fresh state properties of concrete mixes.

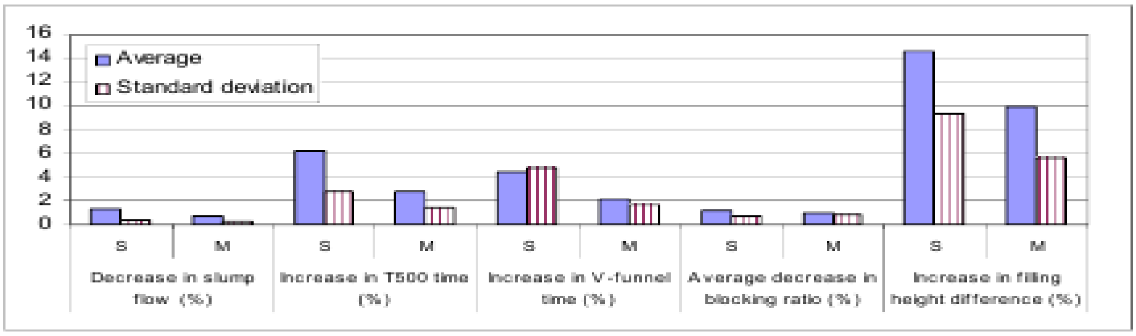
Mix	No of Mi.	Mixes code	w/b	Sp	Slump Flow(mm)	T500 (Sec)	Blocking Ratio(H2/H)	Filling Height(R1-R2)	V-Funnel Time(Sec)
Group 1 Ref. Conc.	1	N	0,52		185	-	-	-	-
	2	R(SCC)	0,35	8	800	2,20	0,970	3	6,2
	3	M(SCC+M)	0,35	9	795	2,30	0,950	5	6,4
	4	S(SCC+SF)	0,35	10	790	2,40	0,940	8	6,5
Group 2 SCC+PP	5	R1P6	0,35	8	780	2,60	0,920	10	7,0
	6	M1P6	0,35	9	776	2,70	0,915	12	7,1
	7	S1P6	0,35	10	770	2,80	0,910	14	7,2
	8	R1P12	0,35	8	770	2,90	0,900	13	7,6
	9	M1P12	0,35	9	764	3,00	0,894	14	7,7
	10	S1P12	0,35	10	760	3,20	0,890	16	7,8
	11	R5P6	0,35	8	695	3,90	0,860	19	9,2
	12	M5P6	0,35	9	690	3,95	0,856	20	9,3
	13	S5P6	0,35	10	685	4,00	0,850	22	9,4
	14	R5P12	0,35	8	680	4,10	0,850	23	9,7
	15	M5P12	0,35	9	674	4,30	0,844	24	9,9
	16	S5P12	0,35	10	670	4,50	0,840	25	10,1
Group 3 SCC+G	17	R1G6	0,37	10	770	3,10	0,910	13	7,7
	18	M1G6	0,37	11	766	3,20	0,904	14	7,8
	19	S1G6	0,37	12	760	3,30	0,900	15	7,9
	20	R1G12	0,37	10	761	3,40	0,890	16	7,9
	21	M1G12	0,37	11	756	3,46	0,885	19	8,0
	22	S1G12	0,37	12	750	3,50	0,880	17	8,2
	23	R5G6	0,37	10	680	4,20	0,840	21	9,7
	24	M5G6	0,37	11	674	4,30	0,834	23	9,8
	25	S5G6	0,37	12	671	4,40	0,830	24	9,9
	26	R5G12	0,37	10	660	4,90	0,830	25	10,1
	27	M5G12	0,37	11	656	5,10	0,826	27	10,2
	28	S5G12	0,37	12	651	5,30	0,820	28	10,3
Group 4 SCC+C	29	R1C6	0,38	12	750	3,30	0,880	17	8,2
	30	M1C6	0,38	13	744	3,40	0,875	18	8,4
	31	S1C6	0,38	14	740	3,50	0,870	19	8,5
	32	R1C12	0,38	12	740	3,66	0,860	20	8,9
	33	M1C12	0,38	13	736	3,70	0,856	21	9,2
	34	S1C12	0,38	14	732	3,79	0,850	23	9,3
	35	R5C6	0,38	12	656	5,00	0,810	27	11,7
	36	M5C6	0,38	13	653	5,06	0,820	28	11,8
	37	S5C6	0,38	14	650	5,10	0,815	30	12,0
	38	R5C12	0,38	12	612	6,40	0,710	36	15
	39	M5C12	0,38	13	605	6,70	0,720	41	16
	40	S5C12	0,38	14	602	6,80	0,714	40	18

Both V-funnel time and T500 time were found to be negatively affected when mineral admixtures used. The average values of each column of Table 4 together with standard deviation values are given in figure 2 to represent the difference of the methods used to measure fresh state parameters. As can be seen from figure 2, V-funnel time is slightly less sensitive to the addition of mineral admixture when compared to T500 time. The results showed that L-box test results were not very much affected when mineral admixtures added. However, U-box test results were highly affected with addition of silica fume and mineral admixtures. Again, figure 2 could be used to compare the two methods. According to figure 2, filling height difference parameter of U-box test is much more sensitive to the addition of mineral admixtures when compared to blocking ratio parameter of L-box test. All the methods showed that the effect of silica fume was more pronounced when compared to Metakaolin. This is probably due to the smaller particle size and the larger surface area of silica fume.

Table 4. Effect of mineral admixture addition on the fresh state performance of the mixes.

		Mix. Code	Decrease in slump flow(%)		Increase in T500 time (%)		Increase in V-funnel time (%)		Average decrease in block ratio %		Increase in filling height(%)	
			S	M	S	M	S	M	S	M	S	M
Effect of mineral admixture addition	Group 1	R	1,3	0,6	9,1	4,5	4,8	3,2	3,1	2,1	-	-
	Group 2	1P6	1,3	0,5	7,7	3,8	2,9	1,4	1,1	1,1	40,0	20,0
		1P12	1,3	0,8	10,3	3,4	2,6	1,3	1,1	1,1	23,1	7,7
		5P6	1,4	0,7	2,6	1,3	2,2	1,1	1,2	1,2	15,8	5,3
		5P12	1,5	0,9	9,8	4,9	4,1	2,1	1,2	1,2	8,7	4,3
	Group 3	1G6	1,3	0,5	6,5	3,2	2,6	1,3	1,1	1,1	15,4	7,7
		1G12	1,4	0,7	2,9	1,8	3,8	1,3	1,1	1,1	6,3	18,8
		5G6	1,3	0,9	4,8	2,4	2,1	1,0	1,2	1,2	14,3	9,5
		5G12	1,4	0,6	8,2	4,1	2,0	1,0	1,2	1,2	12,0	8,0
	Group 4	1C6	1,3	0,8	6,1	3,0	3,7	2,4	1,1	1,1	11,8	5,9
		1C12	1,1	0,5	3,6	1,1	4,5	3,4	1,2	1,1	5,0	15,0
		5C6	0,9	0,5	2,0	0,9	2,6	0,9	0,0	0,0	11,1	3,7
		5C12	1,6	1,1	6,3	1,6	20,0	6,7	0,0	-1,4	11,1	13,9

Figure 2. Average values and standard deviation for the columns of Table 4.

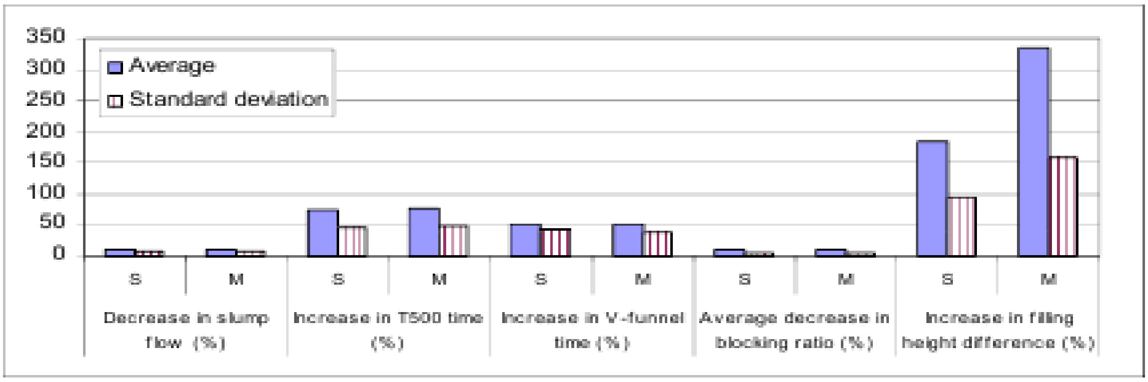


Effect of fiber addition to the reference mixes were also examined by calculating percentage increase/decrease in calculated fresh state parameters with respect to reference mixes. Ex; percentage decrease in slump flow value with respect to reference mix when 0,1 volume of 6 mm long PP fibers added (ex: Table 3., by comparing the mixes 2/5, 3/6, 4/7, 2/8, 3/9, 4/10, etc). Table 5 shows the results of calculations. When Table 8 is examined, it is seen that the effect of adding carbon fibers on the fresh state performance is more pronounced than the effects of adding glass and PP fibers. PP fibers created the least pronounced effect on the fresh state performance. Effect of fiber addition became more important with increasing fiber volume and fiber length. The polypropylene fibers used in this study showed the least pronounced effect on the fresh state performance although they had the highest aspect ratio. Figure 3 shows the average values of each column of Table 5 together with standard deviation values and was used to evaluate fresh state properties of the mixes. Results observed are also very similar with the results given in figure 2.

Table 5. Effect of fiber addition on the fresh state performance of the mixes.

		Mix. Code	Decrease in slump%		Increase in T500 %		Increase in V-funnel %		Decrease in Blocking %		Increase in filling height%	
			S	M	S	M	S	M	S	M	S	M
Effect of Fiber addition	Group 2	1P6	2,5	2,4	16,7	17,4	10,8	10,9	3,2	4,2	75	140
		1P12	3,8	3,9	33,3	30,4	20,0	20,3	5,3	6,3	100	180
		5P6	13,3	13,2	66,7	71,7	44,6	45,3	9,6	10,5	175	300
		5P12	15,2	15,2	87,5	87,0	55,4	54,7	10,6	11,6	213	380
	Group 3	1G6	3,8	3,6	37,5	39,1	21,5	21,9	4,3	5,3	88	180
		1G12	5,1	4,9	45,8	50,4	26,2	25,0	6,4	7,4	113	280
		5G6	15,1	15,2	83,3	87,0	52,3	53,1	11,7	12,6	200	360
		5G12	17,6	17,5	120,8	121,7	58,5	59,4	12,8	13,7	250	440
	Group 4	1C6	6,3	6,4	45,8	47,8	30,8	31,3	7,4	8,4	138	260
		1C12	7,3	7,4	57,9	60,9	43,1	43,8	9,6	10,5	188	320
		5C6	17,7	17,9	112,5	120,0	84,6	84,4	13,8	13,7	275	460
		5C12	23,8	23,9	183,3	191,3	176,9	150,0	24,5	24,2	400	720

Figure 3. Average values and standard deviation for the columns of Table 5.



To understand the effect of increasing fiber length and volume on the fresh state properties, percentage decrease/increase in the measured parameters were again calculated. Results are given in Tables 6 and 7, respectively. The mixes with same materials combinations but with different fiber lengths were compared (ex: for 0,1% volume of PP fibers, percentage decrease/increase in the parameters were calculated from the mixes 5/8, 6/9 and 7/10 of Table 3 and minimum and maximum % variations were given). A similar procedure is followed to easily evaluate the effect of fiber volume. This time, the mixes with same materials combinations but with different fiber volumes were compared such as the mixes 5/11, 6/12, 7/13 (from Table 3). Same procedure is followed for each type of fiber. It is clearly seen on Table 6 that fresh state properties are negatively affected when fiber length/aspect ratio is increased for the same type of fibers. This effect becomes more pronounced when higher volumes of fibers are included into the mix. If three types of fibers are compared by means of increased length/aspect ratio, carbon fibers (when high volumes are used) are the ones which created the worst effect on the fresh state properties. Filling height difference was again found to be the most sensitive to the increase of fiber length. The effect of increasing fiber volume from 0,1 to 0,5 % was found to be much higher than increasing fiber length. Again, the most pronounced effect was seen when long carbon fibers are used. Increasing fiber volume from 0,1 to 0,5 % highly affected deformability and flow ability.

Table 6. Effect of increasing fiber length from 6 mm to 12 mm on the fresh state performance .

	Fiber type	Fiber vol. (%)	Decrease in slump flow (%)	Increase in T500 time (%)	Increase in V – funnel time(%)	Decrease in blocking ratio (%)	Increase in filling height (%)
Effect of fiber length	PP	0,1	1,3 – 1,5	11,1-14,3	8,3 – 8,6	2,2-2,3	14,3 – 30
		0,5	2,2 – 2,3	5,1 – 12,5	5,4 – 7,4	1,2-1,4	13,6 – 21,1
	G	0,1	1,2 – 1,3	6,0 – 9,7	2,6 – 3,8	2,1-2,2	13,3 – 35,7
		0,5	2,7 - 3,0	16,7 – 20,5	4,0 – 4,1	1,0-1,2	16,7 – 19,0
	C	0,1	1,1 – 1,3	8,3 – 10,9	8,5 – 9,5	2,2-2,3	16,7 – 21,1
		0,5	6,7 – 7,9	28 – 34,0	28,2 – 50,0	12,2-12,4	33,3 – 46,4

Table 7. Effect of increasing fiber volume from 0,1 to 0,5 % on the fresh state performance.

	Fiber type	Fiber length (mm)	Decrease in slump flow (%)	Increase in T500 time (%)	Increase in V – funnel time (%)	Decrease in blocking ratio (%)	Increase in filling height(%)
Effect of fiber length	PP	6	10,9-11,1	42,9-50,0	30,6-31,4	6,4-6,6	57,1-90,0
		12	11,7-11,8	40,6-43,3	27,6-29,5	5,5-5,6	56,3-76,9
	G	6	11,7-12	33,3-35,5	25,3-26,0	7,7-7,8	60,0-64,3
		12	13,2-13,3	44,1-51,4	25,6-27,8	6,6-6,8	42,1-64,7
	C	6	12,2-12,5	45,7-51,5	40,5-42,7	5,8-8,0	55,6-58,8
		12	17,3-17,8	74,9-81,1	68,5-93,6	15,3-17,4	73,9-95,2

CONCLUSIONS

1. From the two mineral admixtures used, the effect of silica fume was more pronounced for almost all of the parameters. Only exception was seen on the blocking ratio results. Average decrease (%) in blocking ratio was almost the same for silica fume and Metakaolin. From these results it can be concluded that the effect of Metakaoline on fresh state properties is less pronounced when compared to silica fume.

2. Addition of fibers and increasing fiber volume were found to cause the most pronounced effect on the fresh state parameters. The parameters were found to be less sensitive to the addition of mineral admixtures and increasing fiber length.

3. The aspect ratios of the fibers used in this study were 150-300 (6-12mm), 15-30 (6-12mm), and 50-100 (6-12mm), respectively. From the three different types of fibers used in this study, polypropylene fibers with the highest aspect ratio showed the least pronounced effect while the carbon fibers showed the most pronounced effect on the

fresh state performance. From these results it can be concluded that the type of fiber is at least as decisive as fiber aspect ratio on the fresh state performance.

4. Results of this study show that T500 time is more sensitive to the variations in mix design when compared to V-funnel time. Only exception is observed when high volumes of long carbon fibers are used. High volumes of long carbon fibers are blocking the exit of V-funnel apparatus resulting in a decrease of flow time.

5. This study shows that slump flow is not very much affected with addition of mineral admixtures and increasing fiber length. However addition of fibers and increasing fiber volume (from 0,1 to 0,5%) cause more pronounced effects (up to 24 %) on slump flow.

6. Filling height parameter of U-box test was found to be much sensitive to the modifications made on mix designs."The European Guideline for Self-Compacting Concrete" suggests to use L-box test to assess passing ability of SCC. According to the results of this study, using only one of the two methods (L-box or U-box) as suggested by The European could be more advantageous by means of having comparable results.

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