A Study on Investigation of Strength Properties of Polypropylene Fiber Reinforced Self-Compacting Concretes

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Abstract

In this study, Self-Compacting Concrete (SCC), which is believed to be an indispensable element of retrofitting projects of buildings in our country, which is located in the earthquake zone, was investigated. In this study, the strength properties of concretes produced with four different mixtures (hyper plasticizer admixture, hyper plasticizer admixture + fly ash, hyper plasticizer admixture + polypropylene fiber, hyper plasticizer admixture + fly ash + polypropylene fiber) were compared with each other. Four different dosages (450, 475, 500, 525; 350+115.5, 375+112.5, 400+120, 425+115; 450, 475, 500, 525; 350+112, 375+112.5, 400+120, 425+119) were used for each mixture. 16 Different experiments were performed and 12 specimens (6 pieces15x15x15 cm Cubes, 3 pieces 15x30 cm Cylinders and 3 pieces 10x10x50 cm Beams) were produced for each experiment, totaling 192 specimens. The specimens were subjected to compressive strength, splitting tensile strength and flexural strength tests and the results were compared with each other. As a result of the study, the following conclusions were reached by considering the compressive strengths, splitting tensile strengths and flexural strengths used in the evaluation of the strength criteria of SCC. Considering the 28-day compressive strengths of SCC, the most suitable mixture is group 1 (SCC produced using hyperplasticizer additive), and considering the flexural strength and average splitting tensile strength, the most suitable mixture is group 3 (SCC produced using hyperplasticizer additive + polypropylene fiber).

Keywords: Self-compacting concrete, Hyperplasticizing admixture, Polypropylene fiber, Fly ash, Construction.

1 Introduction

Developments in chemistry and the advancement of polymer technology have led to the discovery of very effective plasticizers since the mid-80s. These plasticizers, which have a high water-shearing ability, also increase the workability of fresh concrete. This effect provided by the new generation of plasticizers has led scientists to conduct research to eliminate the compaction required during the placement of fresh concrete. Thus, the concept of Self-Compacting Concrete (SCC) emerged. SCC is a special type of concrete with a very fluid consistency that can settle into tightly reinforced narrow and deep sections with its own weight, self-compress without the need for internal or external vibration, and maintain its cohesion without creating problems such as segregation and perspiration while providing these properties.

SCC is finding more and more applications in different branches of construction, especially in the ready-mixed concrete sector, repair-reinforcement works and

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prefabricated sector. SCC, which enables the production of high performance concrete due to its easy settlement without the need for a vibrator, high segregation resistance and high durability, has started to be recognized and used in our country. The composition of SCC differs from conventional concrete in terms of parameters such as total amount of fine material, use of viscosity increasing admixtures, water/binder ratio, maximum aggregate size, sand/total aggregate ratio and total amount of coarse aggregate in addition to an effective superplasticizer.

Numerous studies have been conducted in the world and in Turkey to investigate the properties and performance of SCC. Some of these studies are given below. Felekoğlu et al. [1] investigated the abrasion, freezing and thawing resistance of SCC s. Ramyar and Andiç [2] interpreted the relationships between the minimum fly ash utilization rate, fly ash fineness and alkali-silica reaction (ASR) expansions, which reduce the expansion below the acceptable limit. Unal et al. [3] investigated the effect of using polypropylene and steel fibers on the mechanical and durability properties of road pavement concrete. Yazıcı et al. [4] investigated both the utilization of fly ash, a waste material, in SCC and the effect of Class C fly ash used in SCC on concrete. Sertbaş [5] investigated the effect of polypropylene fiber use on workability in self-compacting concrete. Aktürk [6] investigated the performance properties of polypropylene fiber reinforced self-compacting concretes. Güneş [7] investigated the engineering properties of self-compacting fiber reinforced concrete. Altalabani [8] investigated the mechanical properties and load deflection relationship of polypropylene fiber reinforced lightweight self-compacting concrete. Atalay [9] investigated the high temperature resistance of mixed fiber reinforced self-compacting concrete. Karimipour et al. [10] investigated the effect of polypropylene fibers on compressive strength, impact and heat resistance of SCC. Latifi [11] investigated the effect of synthetic polypropylene fibers on the fresh and hardened properties of concrete mixtures. Muhammet [12] investigated the effect of poly-propylene fiber on workability and high temperature resistance of self-compacting concrete. Karimipour et al. [13] investigated the biaxial mechanical behavior of polypropylene fiber reinforced SCC. Kazim [14] analyzed the relationship between workability and engineering properties of mixed fiber reinforced SCC blends. Kumar [15] conducted a laboratory study on the mechanical properties of self-compacting concrete using marble waste and polypropylene fiber.

In this study, self-compacting concrete specimens in the form of 15x15x15 cm cubes, 15x30 cm cylinders and 10x10x50 cm beams were produced by adding different ratios of hyper plasticizer (Glenium 51), fly ash (Tuncbilek fly ash), polypropylene fiber (obtained from İzmit Beksa Company) to PC 42.5 cement. In order to determine the strength criteria of concrete, compressive strength, tensile strength in splitting and flexural strength tests were performed on these specimens. Aggregate, fresh concrete properties determination tests and hardened concrete compressive strength determination tests were carried out in KONBETON Corporation Ready-Mixed Concrete Plant Quality Control Laboratory. The determination of tensile strength in splitting from hardened concrete properties was carried out at the Konya Branch Laboratory of the Chamber of Civil Engineers. The determination of tensile strength in bending was carried out at the Construction Laboratory of Selcuk University, Faculty of Engineering, Department of Civil Engineering.

2 Experimental Studies

2.1 Materials and properties

Aggregates with 0-4 mm and 8-16 mm grain diameters were used in the concrete specimens produced during the test phase. Table 1 shows the properties of these aggregate diameters.

Table 1. Aggregate diameters and properties used in the experiments

Aggregate Diameter (mm)	**Compacted Unit Weight (kN/m^3)**	**Loose Unit Weight (kN/m^3)**	**Dry Specific Gravity (kN/m^3)**	**Saturated Dry Surface Specific Gravity (kN/m^3)**	**Apparent Specific Gravity (kN/m^3)**	**Water Absorption %**
0-4	18.70	15.87	26.0	26.5	27.3	1.9
8-16	15.60	13.92	26.7	26.8	27.0	0.3

Clear, colorless, odorless, borehole water with a Ph of 7.2 was used as the concrete mixture water used in the experiments.

PC 42.5 (CEM I) cement with a specific gravity of 30.6 kN/m^3 was used in the production of SCC. The cement produced by Konya Cement Corporation was tested in the factory laboratory for compliance with [19]. Table 2 shows the values found in the produced cement and the values required in [19].

The mineral additive was Tuncbilek fly ash and the chemical analysis results are shown in Table 3. The specific gravity of fly ash is 20.0 kN/m^3. The plasticizing chemical admixture is YKS GLENIUM 51, which is a 3rd generation hyper plasticizing concrete admixture developed for the ready-mixed concrete and prefabricated industry, suitable for high water reducing/hyper plasticizing admixture and hardening accelerator admixture class according to [22].

The fibers used in the research were obtained from İzmit Beksa Factory. These fibers, which are not currently manufactured in Turkey, are produced by the Belgian "Dramix" company and represented in Turkey by Beksa Factory.

Table 2. Values of cement found in Konya Cement Company laboratories and values required in [19]

Chemical properties	**Values obtained**	**Desired values in [19]**	
		At least	**Most**
Glow loss (%)	4.33		5.00
Insoluble residue (%)	0.26		5.00
Sulfur trioxide (SO3) (%)	2.85		3.50
Chloride (Cl) (%)	0.0120		0.10
Physical properties			
2-day compressive strength (N/mm^2)	22.7	10.0	
7-day compressive strength (N/mm^2)	35.0		
28-day compressive strength (N/mm^2)	45.3	42.5	62.5
Start of setting (min)	145	70	
Volume expansion (mm)	1		10

Table 3. The values found by the company authorities for Tuncbilek fly ash and the values required in [21]

Chemical properties	Values obtained	Desired values in [21]
SiO_2 (%)	53.66	> 25
Al_2O_3 (%)	18.93	
Fe_2O_3 (%)	11.2	
CaO (%)	2.32	
MgO (%)	6.95	
SO_3 (%)	1.41	< 3
Cl (%)	-	< 0.10
Na_2O (%)	0.16	
K_2O (%)	1.27	< 1
P_2O_5 (%)	0.14	
TiO_2 (%)	-	
Mn_2O_3 (%)	0.18	
Glow Loss (%)	0.4	< 5
Total (%)	96.2	

3 SCC Test Methods

SCC has a higher consistency than the consistency values in [20]. Therefore, it should have some properties not given in the standard. These values and all necessary information about SCC are given in [23]. The information in this publication was taken as reference in the experimental studies. Spreading tests were performed to determine the fluidity of fresh concrete and to obtain the spreading time in relation to viscosity. V-funnel flow tests were performed to determine the discharge time from the funnel in relation to viscosity. L-box experiments were conducted to determine the self-settling ability, filling ability, migration ability and resistance to segregation. Figures 1-3 show the construction stages of these experiments on the pictures.

Figure 1. Slump Spread Test

Figure 2. V-Funnel Flow Test

Figure 3. L-Box Experiment

4 SCC Experimental Results

In order to understand whether the produced samples meet the 3 criteria (filling ability, resistance to segregation, transition ability) required for the SCC to fulfill its expected performance, they were subjected to Slump Spreading test, V Funnel Flow test and L Box tests. The results of these experiments are given in Table 4-7.

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Table 4. Material mixture quantities (kg/m^3), results of Slump Spreading test, V Funnel Flow test and L Box tests, compressive strength, tensile strength at splitting and flexural strength results (N/mm^2) in SCC produced using hyper plasticizer additive

Mixture No		**1. Group Mixture**			
		1	**2**	**3**	**4**
Cement (CEM I 42,5) (kN/m^3)		4.50	4.75	5.00	5.25
Water (kN)		1.89	1.95	2.00	2.05
Water/Cement (%)		42	41	40	39
Hyper plasticizer (G 51) (kN/m^3)x10-2		6.3	6.65	6.5	7.35
Hyper plasticizer/total binder (%)		1.4	1.4	1.3	1.4
0-4 mm fine aggregate (kN/m^3)		11.58	11.31	11.09	10.84
8-16 mm coarse aggregate (kN/m^3)		5.75	5.61	5.50	5.38
Air content (%)		1.2	1.2	1.2	1.2
Unit weight (kN)		23.783	23.686	23.655	23.593
Spreading test T 500 mm reaching speed (2–5 sec)		4.71	3.95	2.99	4.52
Final spreading diameter (650–800 mm)		700	680	670	720
L-box test time to reach 20 cm (0.6 sec)		0.58	0.60	0.50	0.60
L-box test time to reach 40 cm (1.2 sec)		1.2	1.2	1.1	1.2
h1/h2 ratio (>0.80		0.92	0.94	0.96	0.94
Average compr. strength (N/mm^2)	7 days	42.14	41.66	42.18	41.11
	28 days	49.65	49.17	49.65	45.46
Aver. splitt. tensile strength (N/mm^2)	28 days	3.299	3.310	3.501	3.861
Average flexural strength (N/mm^2)	28 days	4.663	5.602	5.767	5.665

Chart 1. Material mixture quantities in SCC produced using hyperplasticizing additives (kN/m^3)

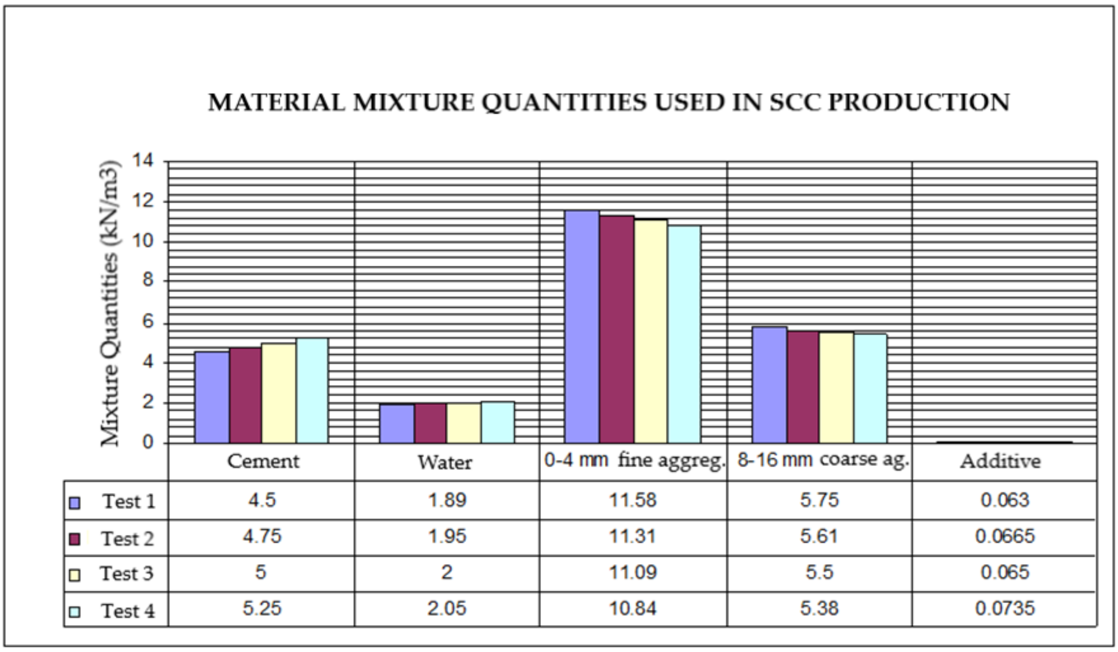
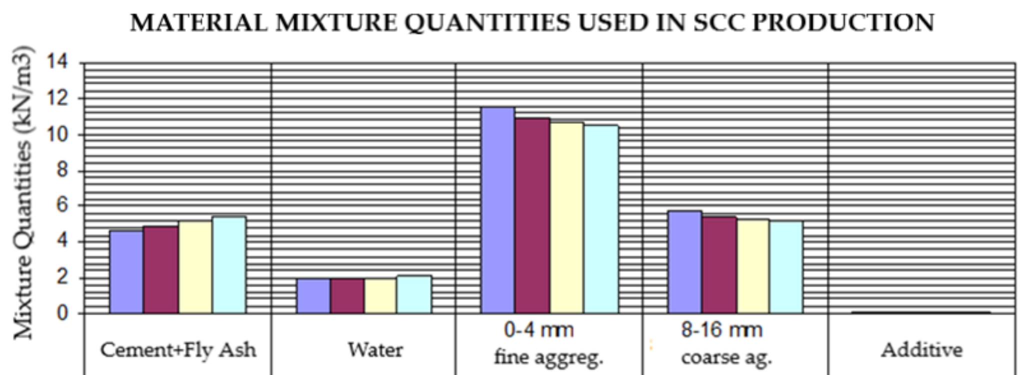


Table 5. Material mixture quantities (kg/m^3), results of Slump Spreading test, V Funnel Flow test and L Box tests, as well as compressive strength, tensile strength at splitting and flexural strength results (N/mm^2) in SCC produced using hyper plasticizer additive + fly ash

Mixture No		**2. Group Mixture**			
		1	**2**	**3**	**4**
Cement (CEM I 42.5) (kN/m^3)		3.50	3.75	4.00	4.25
Fly Ash (kN/m^3)		1.155	1.125	1.20	1.15
Fly Ash/Cement (%)		33	30	30	27
Fly Ash/Total binder (%)		24.8	23	23.1	21.3
water (kN)		2.00	2.00	2.03	2.10
Water/Cement (%)		43	41	39	39
Hyperplasticizer (G 51) (kN/m^3) x10-2		6.98	6.82	6.76	7.02
Hyperplasticizer/Total binder (%)		1.5	1.4	1.3	1.3
0-4 mm fine aggregate (kN/m3)		11.57	10.95	10.72	10.49
8-16 mm coarse aggregate (kN/m^3)		5.70	5.45	5.32	5.20
Amount of air (%)		1.2	1.2	1.2	1.2
unit weight (kN)		23.9948	23.3432	23.3376	23.2602
Expansion test T 500 mm reaching speed (2–5 sec)		4.41	3.28	3.01	2.85
Final span diameter (650–800 mm)		660	690	720	740
L-box test Time to reach 20 cm (0.6 sec)		0.60	0.60	0.50	0.50
L-box test Time to reach 40 cm (1.2 sec)		1.2	1.2	1.1	1.1
h1/h2 ratio (>0.80)		0.94	0.96	0.95	0.96
Average compr. strength (N/mm^2)	7 days	35.16	35.58	33.09	40.83
	28 days	46.44	50.63	41.82	51.93
Aver. splitt. tensile strength (N/mm^2)	28 days	3.473	3.486	3.183	2.626
Average flexural strength (N/mm^2)	28 days	5.674	5.490	5.649	5.363

Graphic 2. Material mixture quantities in SCC produced using hyperplasticizer additive + fly ash (kN/m^3)



	Cement+Fly Ash	Water	0-4 mm fine aggreg.	8-16 mm coarse ag.	Additive
Test 1	4.655	2	11.57	5.7	0.0698
Test 2	4.875	2	10.95	5.45	0.0682
Test 3	5.2	2.03	10.72	5.32	0.0676
Test 4	5.4	2.1	10.49	5.2	0.0702

Table 6. Material mixture quantities (kg/m^3) in SCC produced using hyperplasticizer additive + Polypropylene Fiber, results of Slump Spread test, V-Funnel Flow test and L Box tests and results of compressive strength, splitting tensile strength and bending strength (N/mm^2)

Mixture No		3. Group Mixture			
		1	2	3	4
Cement (CEM I 42,5) (kN/m^3)		4.50	4.75	5.00	5.25
Water (kN)		2.025	2.09	2.15	2.20
Water/Cement (%)		45	44	43	42
Hyperplasticizer (G 51) (kN/m^3) x10^{-2}		6.75	7.125	7	7.35
Hyperplasticizer/total binder (%)		1.5	1.5	1.4	1,4
Polypropylene Fiber (kN/m^3) x10^{-3}		6.00	7.20	7.20	8.40
0-4 mm fine aggregate (kN/m^3)		11.50	11.24	11.00	10.77
8-16 mm coarse aggregate (kN/m^3)		5.70	5.57	5.46	5.35
Amount of air (%)		1,2	1,2	1,2	1,2
Unit weight (kN)		23.7925	23.7212	23.61	23.4435
Expansion test T 500 mm reaching speed (2–5 sec)		5	4,2	3,37	4,14
Final span diameter (650–800 mm)		650	650	650	650
L-box test Time to reach 20 cm (0.6 sec)		0,60	0,60	0,50	0,50
L-box test Time to reach 40 cm (1.2 sec)		1,2	1,2	1,12	1,2
h1/h2 ratio (>0,80)		0.88	0.90	0.92	0.94
Average Compr. strength (N/mm^2)	7 days	39.65	39.72	38.91	43.43
	28 days	45.62	41.30	47.12	50.96
Aver. Splitt. Tensile strength (N/mm^2)	28 days	2.814	3.050	3.458	3.471
Average Flexural strength (N/mm^2)	28 days	5.748	6.558	6.385	6.425

Graphic 3. Material mixture quantities in SCC produced using hyperplasticizer additive + polypropylene fiber (kN/m^3)

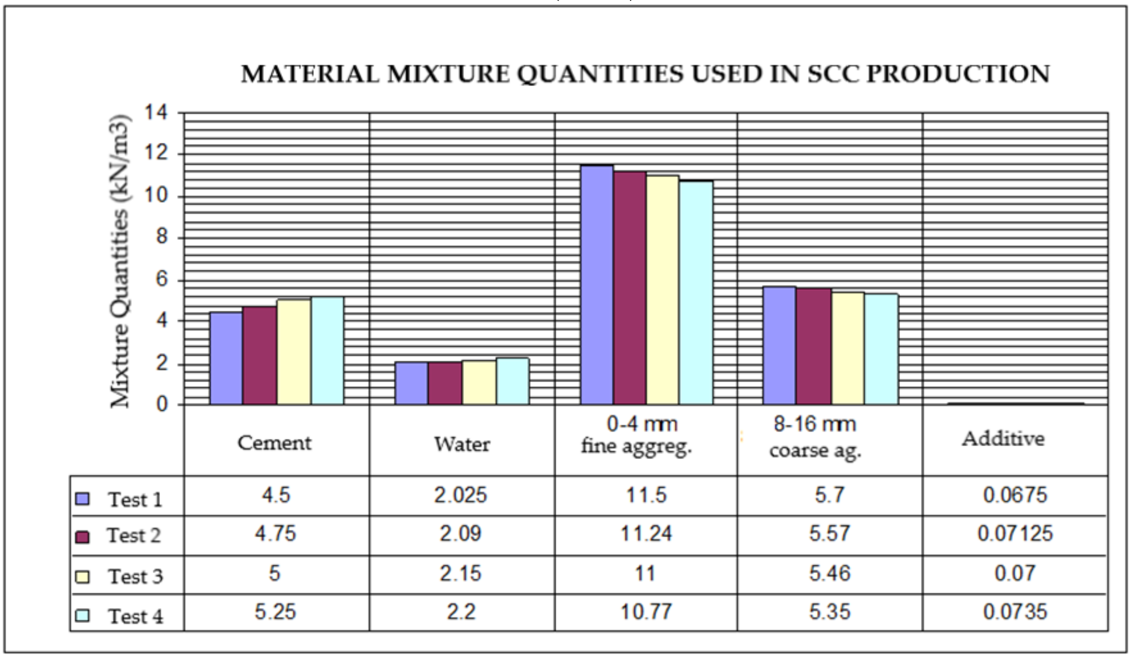
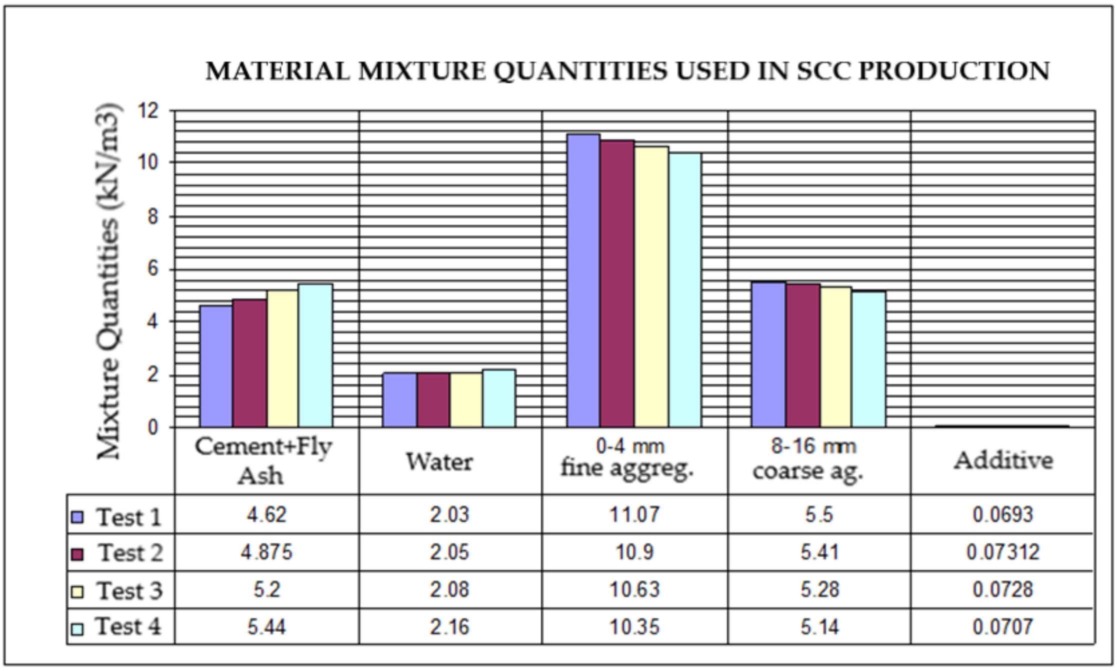


Table 7. Material mixture quantities (kg/m^3) in SCC produced by using hyperplasticizer additive + fly ash + polypropylene fiber, Results of Slump Spread test, V Funnel Flow test and L Box tests and results of compressive strength, splitting tensile strength and bending strength (N/mm^2)

Mixture No		**4. Group Mixture**			
		1	**2**	**3**	**4**
Cement (CEM I 42,5) (kN/m^3)		3.50	3.75	4.00	4.25
Fly Ash (kN/m^3)		1.12	1.125	1.20	1.19
Fly Ash /Cement (%)		32	30	30	28
Fly Ash / total binder (%)		24,2	23,1	23,1	21,9
Polypropylene Fiber (kN/m^3) x10^{-3}		6.00	7.20	7.20	8.40
Water (kN)		2.03	2.05	2.08	2.16
Water/Cement (%)		44	42	40	40
Hyperplasticizer (G 51) (kN/m^3) x10^{-2}		6.93	7.312	7.28	7.07
Hyperplasticizer/total binder (%)		1.5	1.5	1.4	1,3
Polypropylene Fiber (kN/m^3) x10^{-3}		6.0	7.20	7.20	8.40
0-4 mm fine aggregate (kN/m^3)		11.07	10.90	10.63	10.35
8-16 mm coarse aggregate kN/m^3)		5.50	5.41	5.28	5.14
Amount of air (%)		1,2	1,2	1,2	1,2
Unit weight (kN)		23.2893	23.3081	23.2628	23.1607
Expansion test T 500 mm reaching speed (2–5 sec)		5	3.89	3.17	3.46
Final span diameter (650–800 mm)		660	670	690	670
L-box test Time to reach 20 cm (0.6 sec)		0.50	0.50	0.50	0.60
L-box test Time to reach 40 cm (1.2 sec)		1.2	1.1	1.12	1.2
h1/h2 ratio (>0,80)		0.94	0.96	0.96	0.96
Average Compr. strength (N/mm^2)	7 days	30.63	33.48	34.38	36.24
	28 days	39.95	44.34	44.85	47.43
Aver. Splitt. Tensile strength (N/mm^2)	28 days	2.632	2.758	2.200	3.241
Average Flexural strength (N/mm^2)	28 days	5.739	6.383	6.468	5.696

Chart 4. Material mixture quantities in SCC produced using hyperplasticizer additive + fly ash + polypropylene fiber (kN/m^3)



5 Examination of SCC Experiment Results

1. Based on the 1st slump spread test, it was determined that SCC produced by using the 2nd group (hyperplasticizer additive + fly ash) mixture showed a superiority between 15% and 24% compared to other mixtures in fulfilling the criteria expected from it.

2. When the compressive strengths of SCCs produced in 4 groups are taken into account and the extent to which they can provide target strengths, it has been observed that SCCs produced in the 1st group easily provide target strengths at a dosage of 450, 475, 500 according to the binders (cement dosages). It was observed that SCC produced at 525 dosage provided 91% of the target strength. According to the binders (cement + fly ash) produced in the 2nd group, they provide target strengths at 350+115.5= 465.5, 375+112.5= 487.5, 425+115= 540 dosages, and 400+120= 520, 84% of the target strength. found to be provided. According to the binders (cement dosages) produced in the 3rd group, it was observed that they provided target strengths at a dosage of 450, 525. It has been determined that it provides 92% in 475 dosage and 94% in 500 dosage. According to the binders (cement + fly ash) produced in group 4, it achieves 89% of the target strength at a dosage of 350+112= 462, 98% of the target strength at a dosage of 375+112.5= 487.5, 400+120= It was observed that it provided 90% of the target strength at the 520 dosage, and 95% of the target strength at the 425+119= 544 dosage.

3. It has been determined that the compressive strength of the samples in the 1st group mixture (SCC produced by using hyperplasticizer additives) is 5% higher on average compared to the other groups.

4. When the tensile strength in bending is taken into account, it has been determined that the tensile strength in bending increases between 27% and 30% when the amount of binder (cement) is increased in SCCs produced using group 1 (hyperplasticizer additive). 2.,3. and 4th doses (375 + 112.5= 487.5, 400+120= 520, 425+119= 544) tensile strength values in bending were observed to decrease between 0.2% and 0.5%. When the amount of binder (cement) is increased in SCCs produced using Group 3 (hyperplasticizer additive + polypropylene fiber), when the first dose (450) is passed to the second dose (475), the tensile strength value in bending increases by 15%, from the second dose (475). It was determined that the tensile strength value in bending decreased between 0.1% and 0.2% when the 3rd (500) and 4th (525) were passed. In SCCs produced using Group 4 (hyperplasticizer + fly ash + polypropylene fiber), when the amount of binder (cement + fly ash) is increased, until the 2nd and 3rd doses (375+112.5= 487.5, 400+120= 520) are reached. It was determined that the tensile strength values in bending increased by 11% to 12%, and when the 4th dose was reached, the tensile strength value in bending decreased by 0.1%.

5. Considering the compressive strength and splitting tensile strength of the SCC, the mixture with the best performance is the 1st group (SCC produced by using hyperplasticizer additive), and when the tensile strength in bending is taken into account, the best mixture is the 3rd group (hyperplasticizer). Additive + SCC produced using polypropylene fiber) was observed. It has been obtained that the bending tensile strength of this group is 10.81% higher on average than the other groups.

6 Conclusion

Due to the frequent occurrence of destructive earthquakes in various parts of the world and their painful consequences, rapid steps have been taken to increase the quality of buildings with different methods. In parallel with the improvement of the building quality, new technology materials have been used in the world and in our country. Self Compacting Concrete (SCC) is one of these products.

In the study, it can be said that SCC produced using only hyperplasticizer additives is ideal if compressive strength and splitting tensile strength are the first priorities. However, when the criteria expressing the SCC (filling ability, resistance to separation, ability to pass) are considered, it is seen that this alternative will cause problems especially in the application phase. According to the criteria expressing SCC, it has been determined that the most suitable mixture is the mixture in which hyperplasticizer additive and fly ash are used together, since it increases the ratio of fly ash to fine material. Considering the tensile strength in bending, it is seen that the most suitable mixture is the mixture in which hyperplasticizer additive and polypropylene fiber are used together. However, due to the structure of polypropylene fiber, it has been observed that SCC inhibits its fluidity.

Use of polypropylene fibers in SCC; It reduces shrinkage and shrinkage cracks in concrete, reduces segregation, protects concrete against impacts, prevents concrete from crumbling by preventing surface abrasions, increases the energy absorption capacity of the structure against sudden and severe impact loads such as earthquakes by working in parallel with the stirrup system in skeleton systems such as columns and beams of prefabricated and conventional structures aspects is extremely important.

As a result, when the production and application phases are considered together, it becomes necessary to use hyperplasticizer additive and fly ash together in SCC production. The use of polypropylene fiber in SCC, which does not affect the fluidity of SCC, is very important, especially in terms of increasing the tensile strength of concrete in bending.

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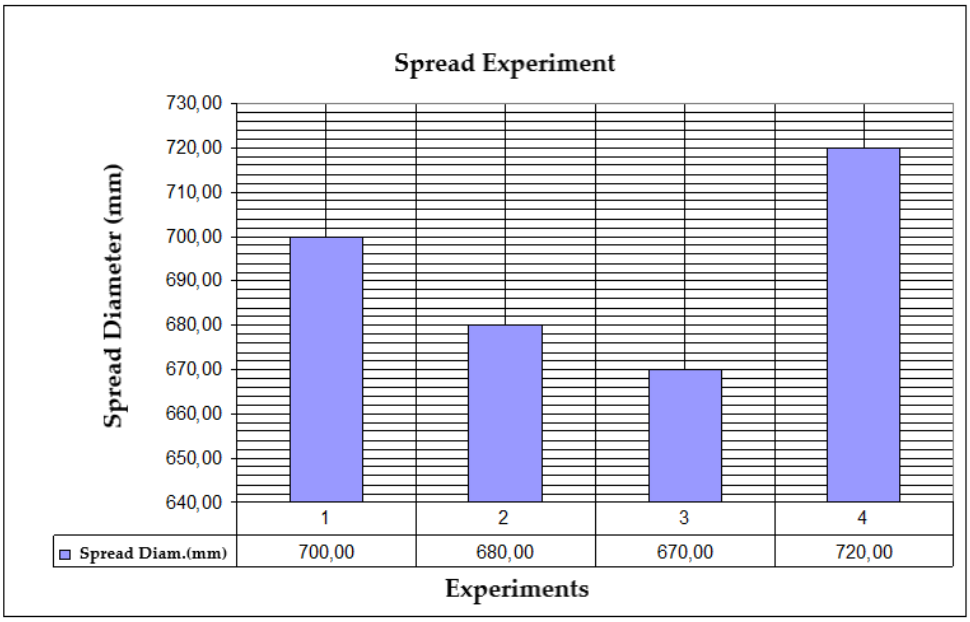
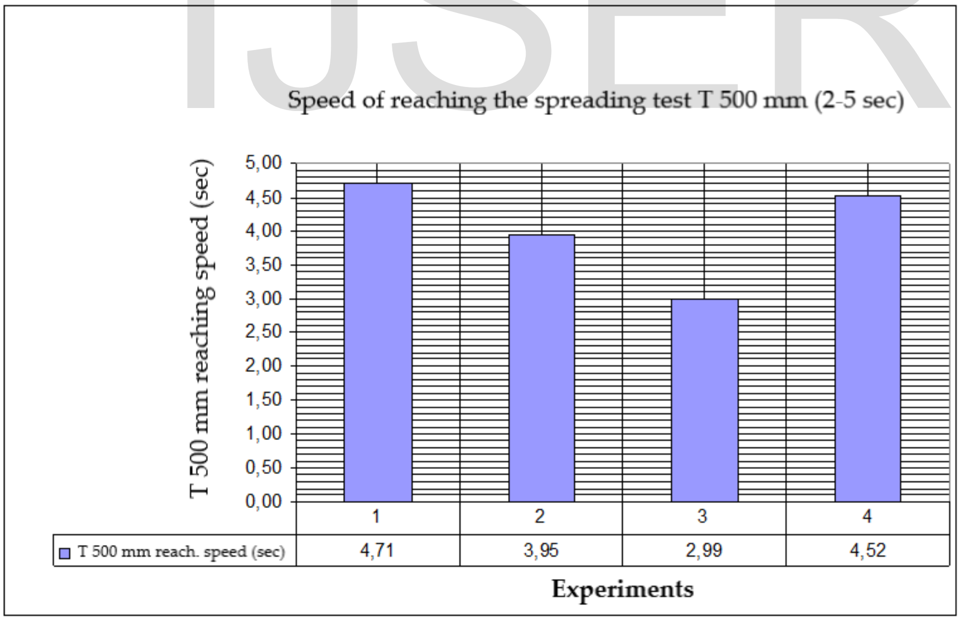
APPENDIX:

Chart 1. Slump Spread of SCC produced using hyperplasticizer additive experiment results



Graphic 2. The speed of reaching T 500 mm in Slump Spread test (2-5 sec) of SCC produced by using hyperplasticizer additive



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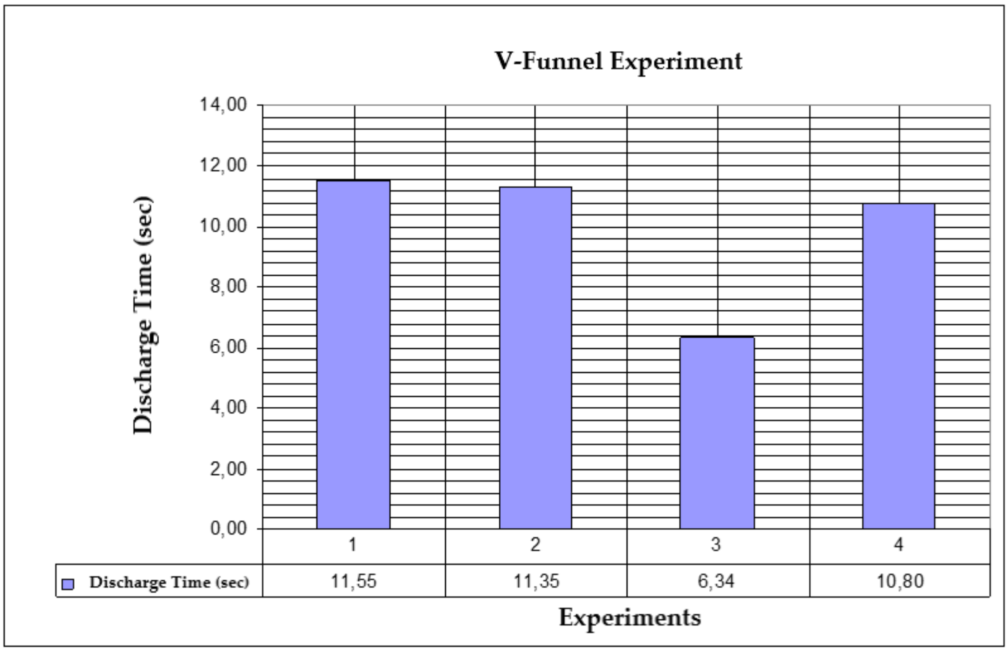
Graphic 3. Results of V-Funnel Flow test produced using hyperplasticizer additive



Graphic 4. L-box test results of SCC produced by using hyperplasticizer additive

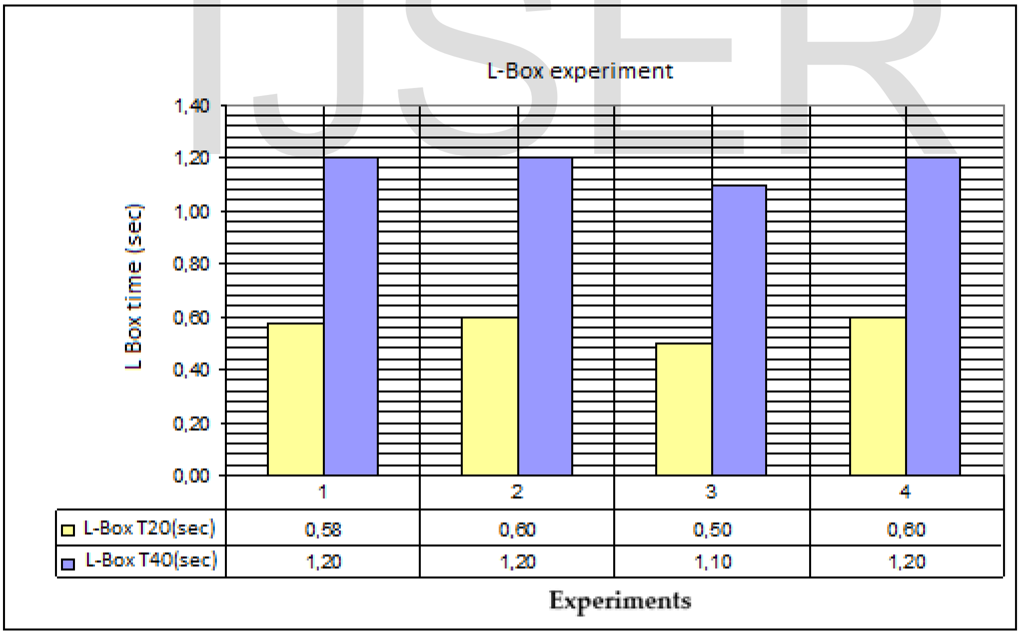
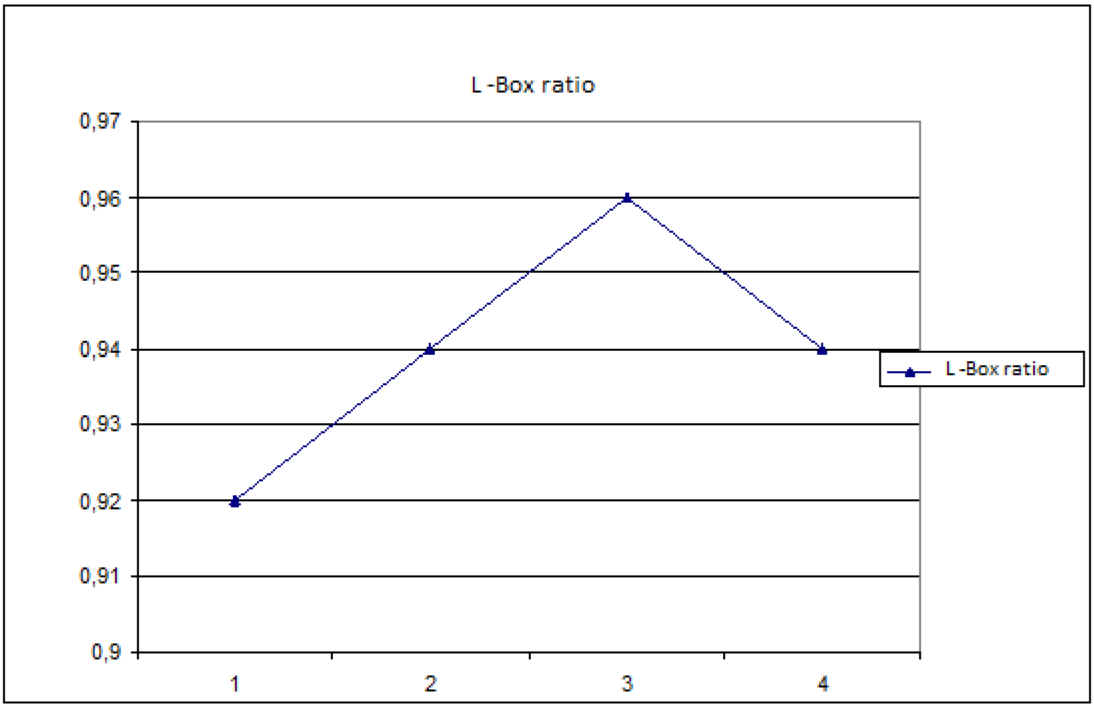
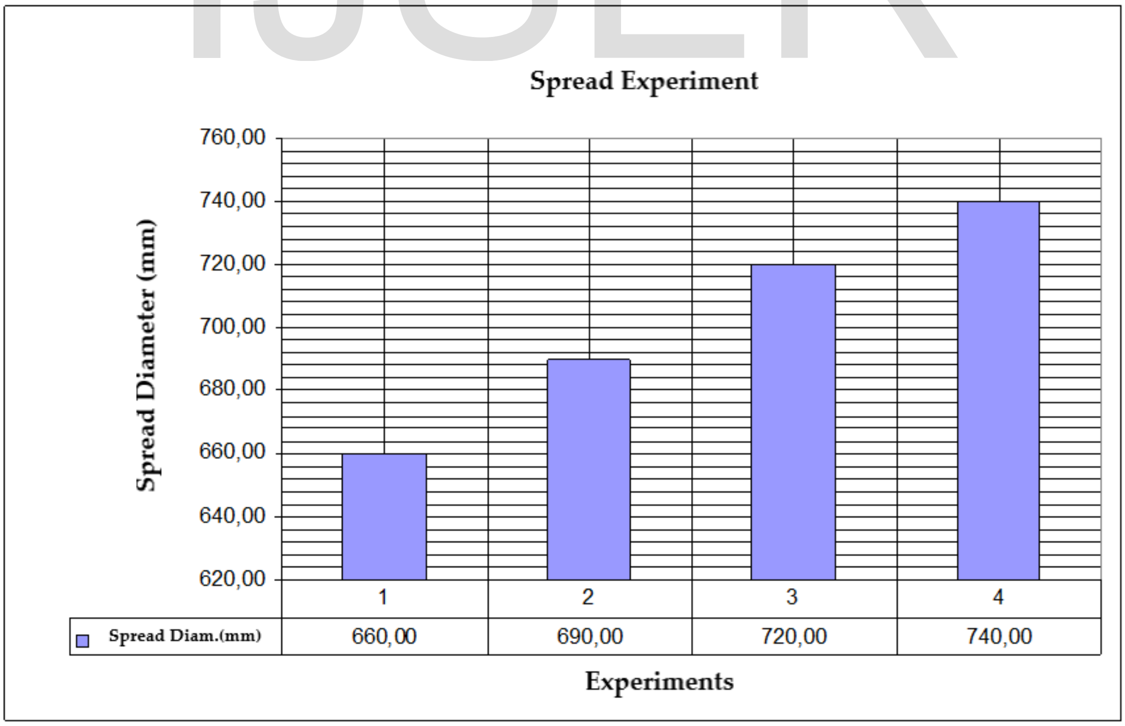


Chart 5. L-Box test L-Box Ratio of SCC produced by using hyperplasticizer additive (H1/H2>0.80)

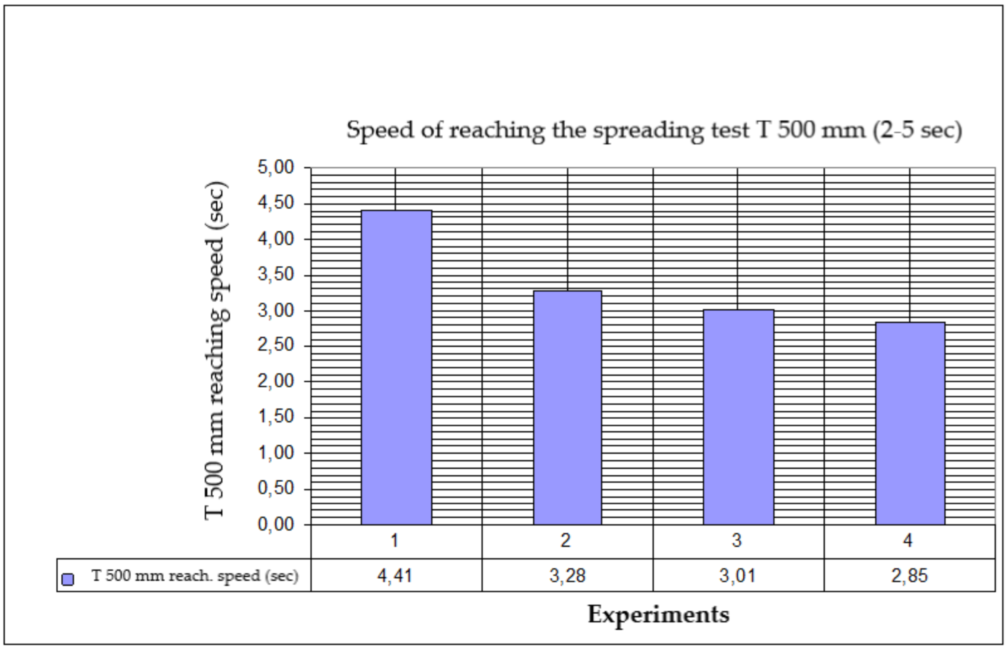


SECOND GROUP

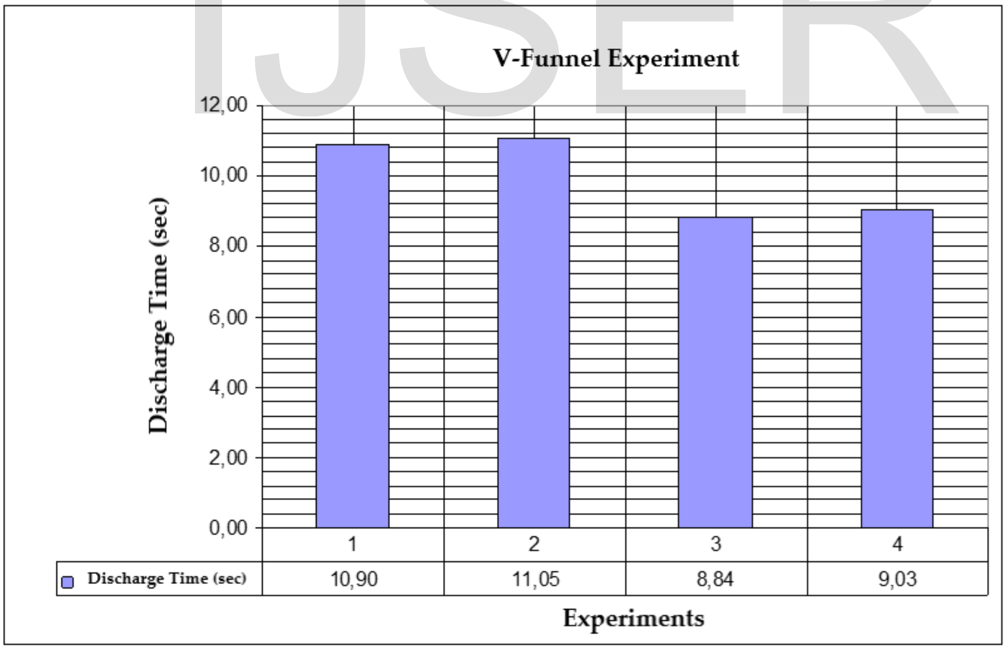
Graphic 6. Slump Spread test results of SCC produced using hyperplasticizer additive + fly ash



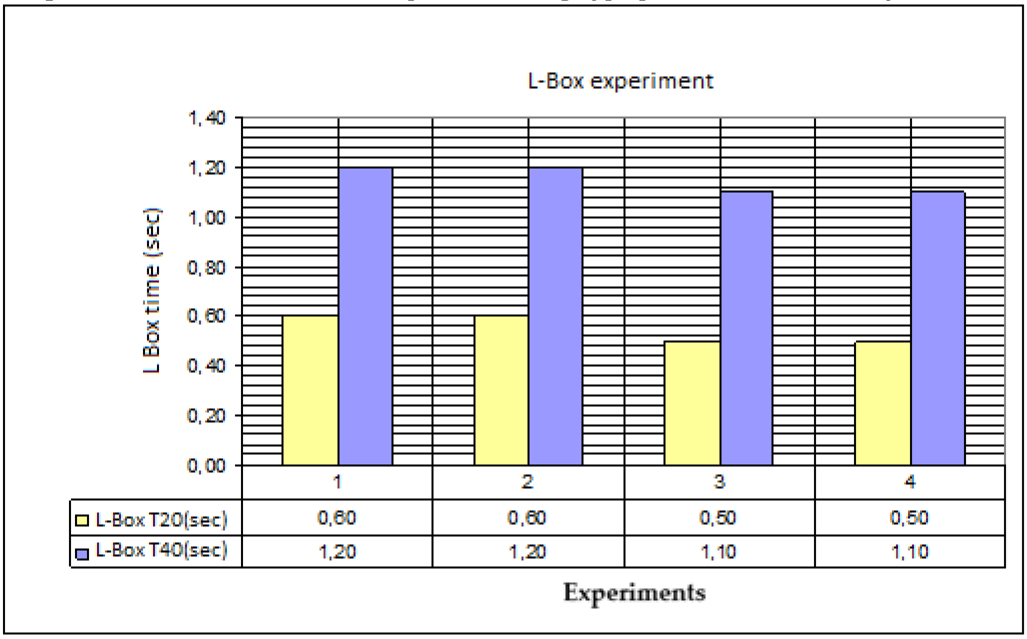
Graphic 7. The speed of reaching T 500 mm in Slump Spread test (2-5 sec) of SCC produced by using hyperplasticizer additive + fly ash



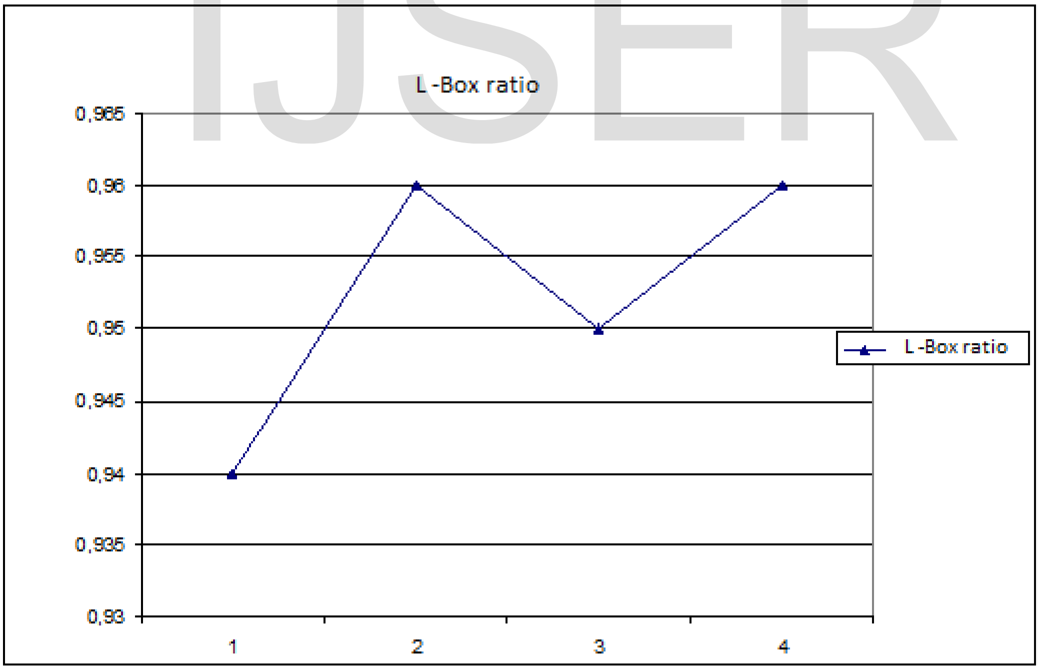
Graphic 8. V-Funnel Flow test results of SCC produced using hyperplasticizer additive + fly ash



Graphic 9. Box L test results of SCC produced using hyperplasticizer additive + fly ash

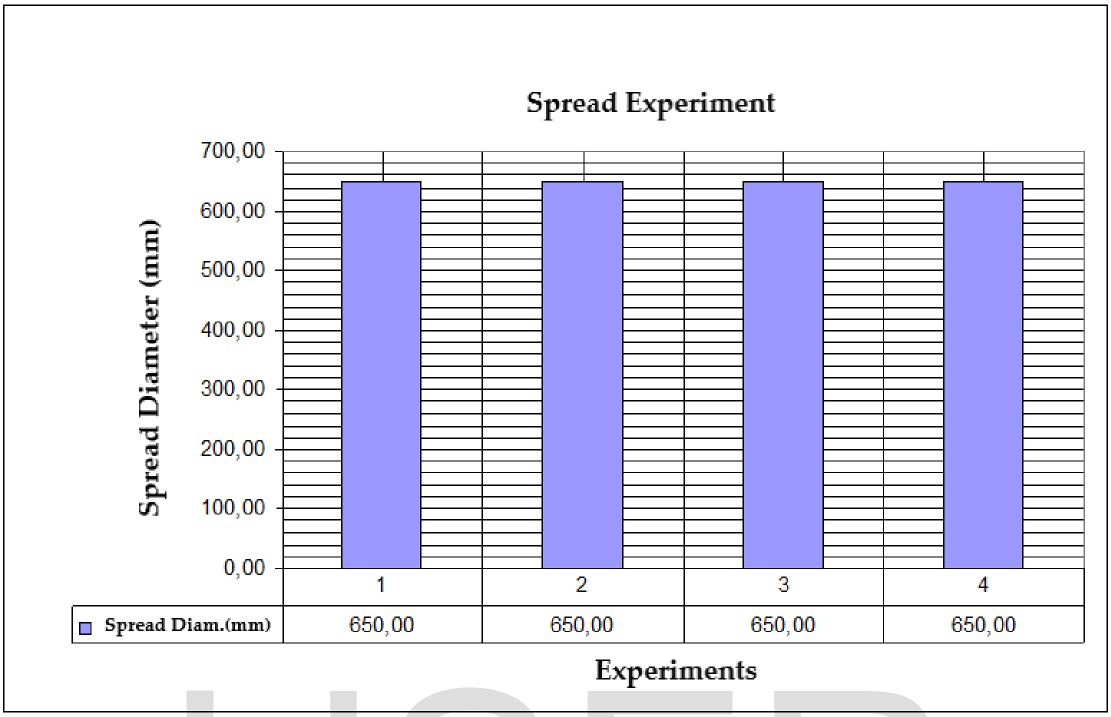


Graphic 10. L-Box test L-Box Ratio of SCC produced using hyperplasticizer additive + fly ash (H1/H2>0.80)

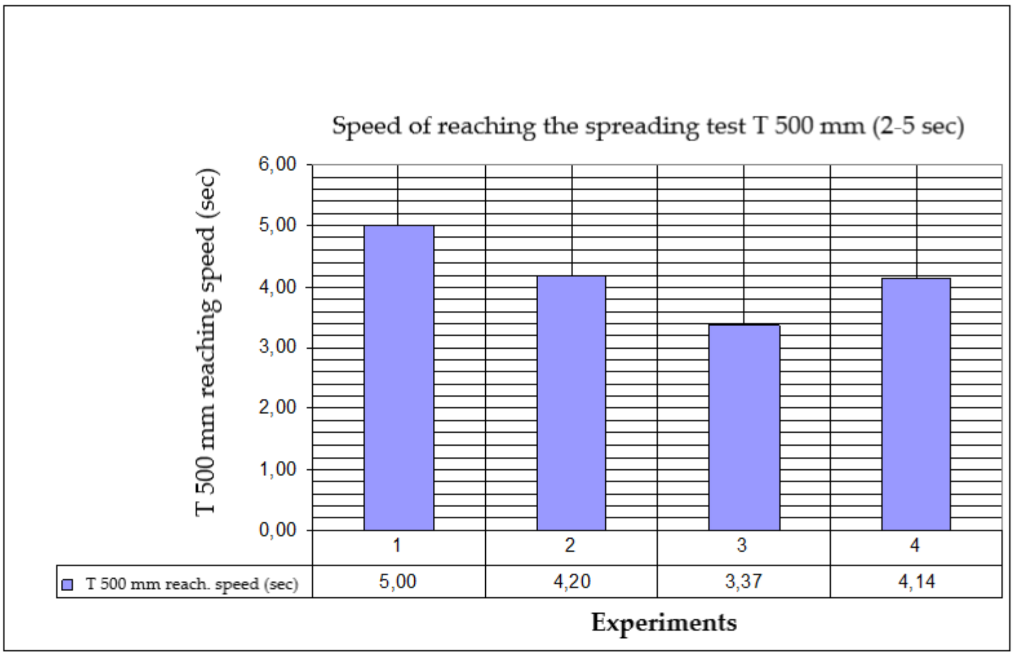


THIRD GROUP

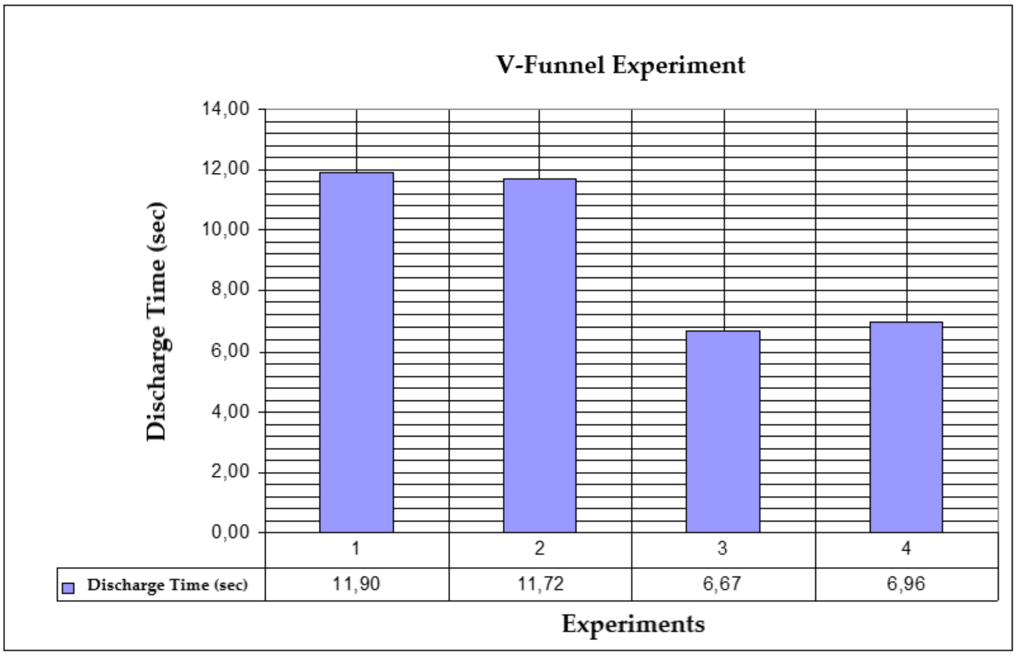
Graphic 11. Slump Spread test results of SCC produced using hyperplasticizer additive + Polypropylene Fiber



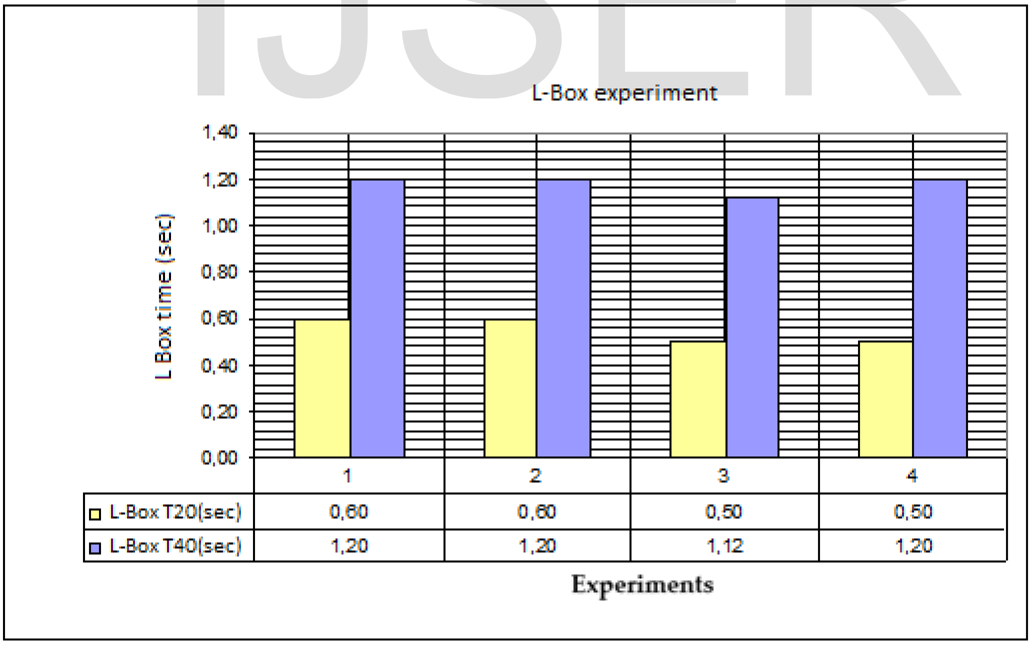
Graphic 12. The speed of reaching the Slump-Spreading test T 500 mm (2-5 sec) of SCC produced by using hyperplasticizer additive + polypropylene fiber



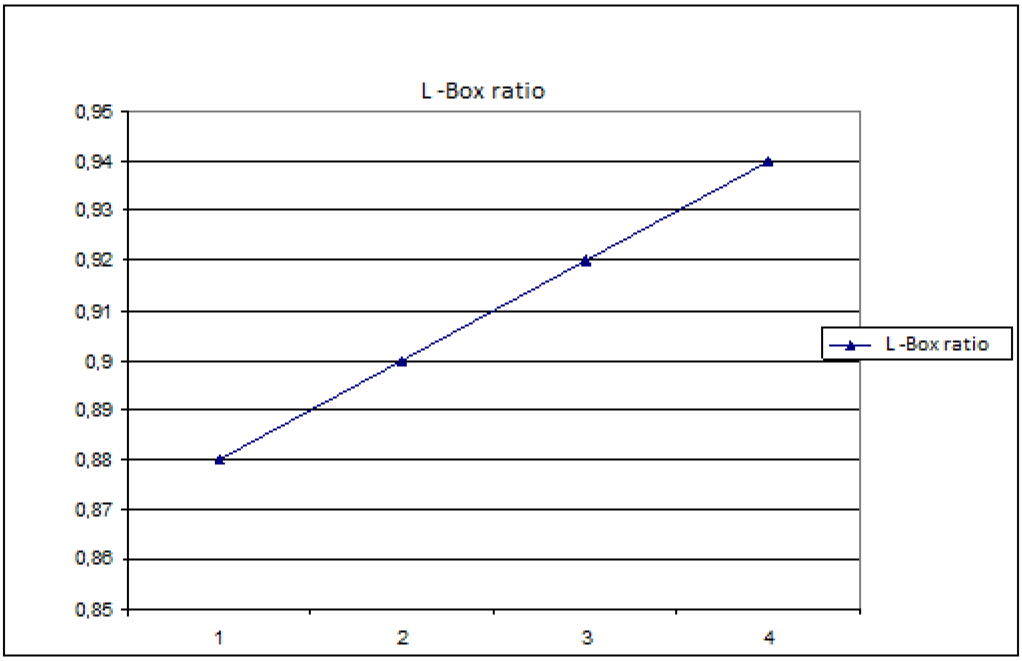
Graphic 13. V Funnel Flow test results of SCC produced using hyperplasticizer additive + polypropylene fiber



Graphic 14. Box L test results of SCC produced using hyperplasticizer additive+polypropylene fiber

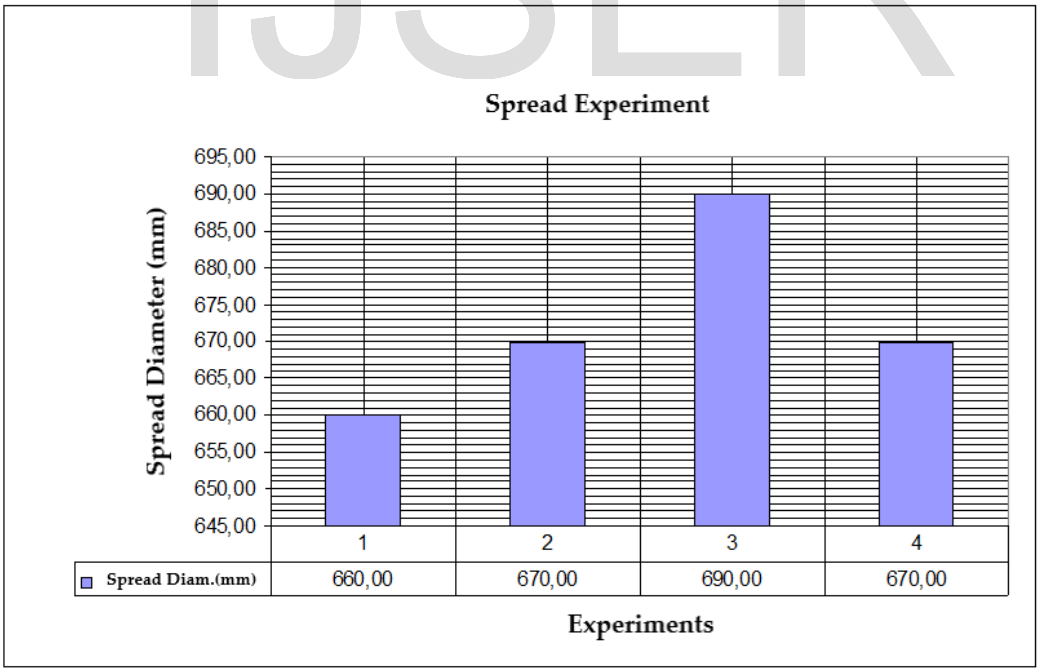


Graphic 15. L-Box test L-Box Ratio of SCC produced by using hyperplasticizer additive + polypropylene fiber (H1/H2>0.80)

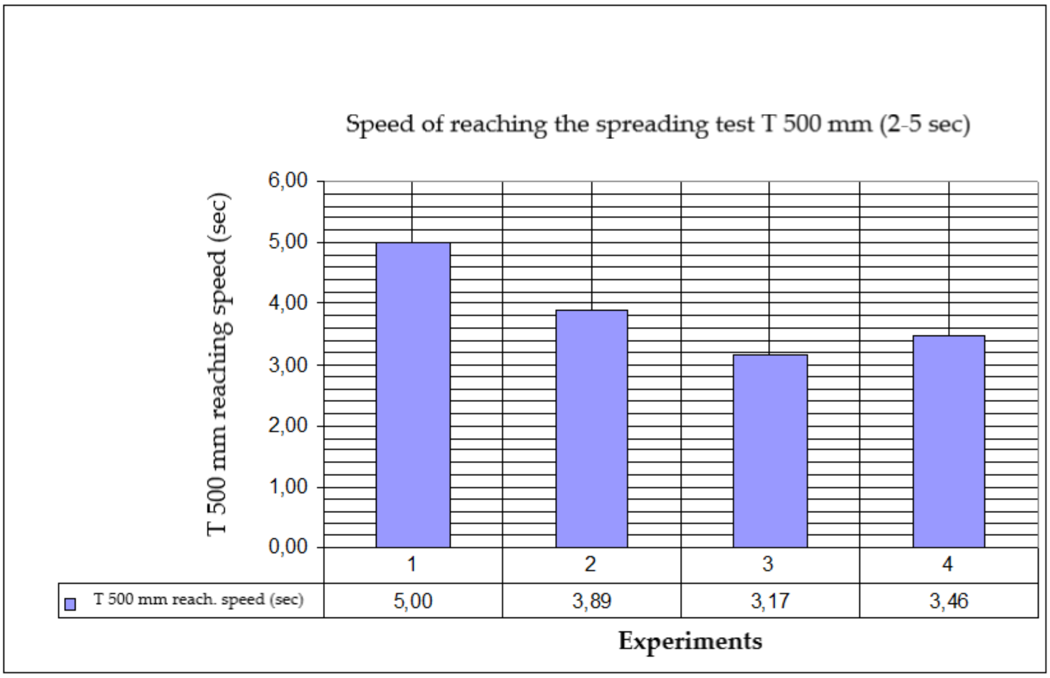


GROUP FOUR

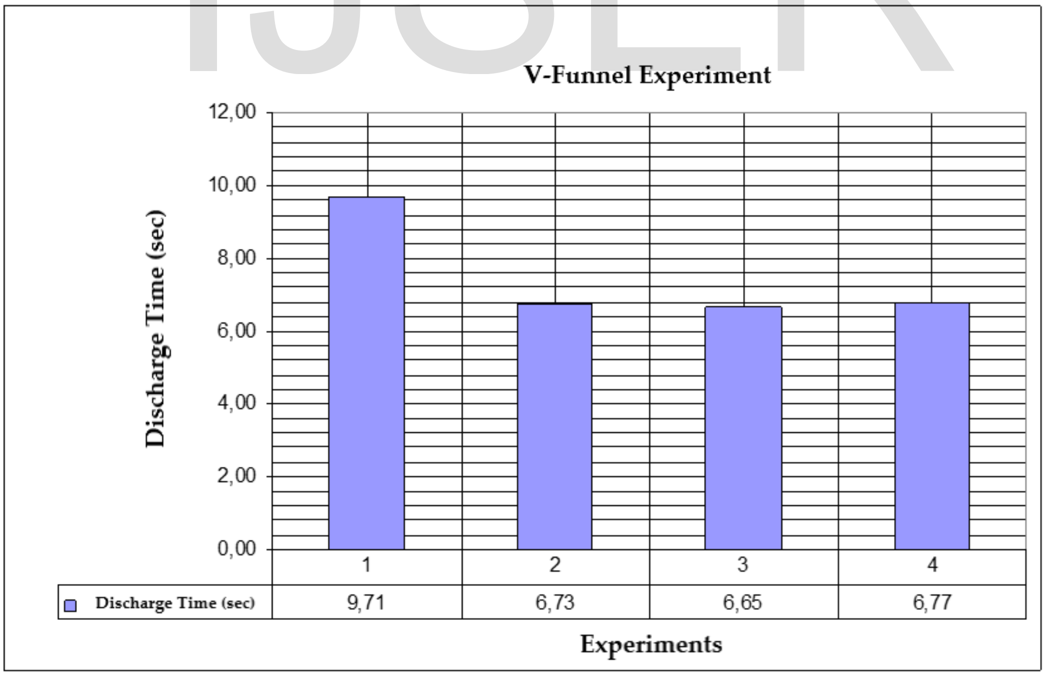
Graphic 16. Slump Spread test results of SCC produced using hyperplasticizer additive + fly ash + polypropylene fiber



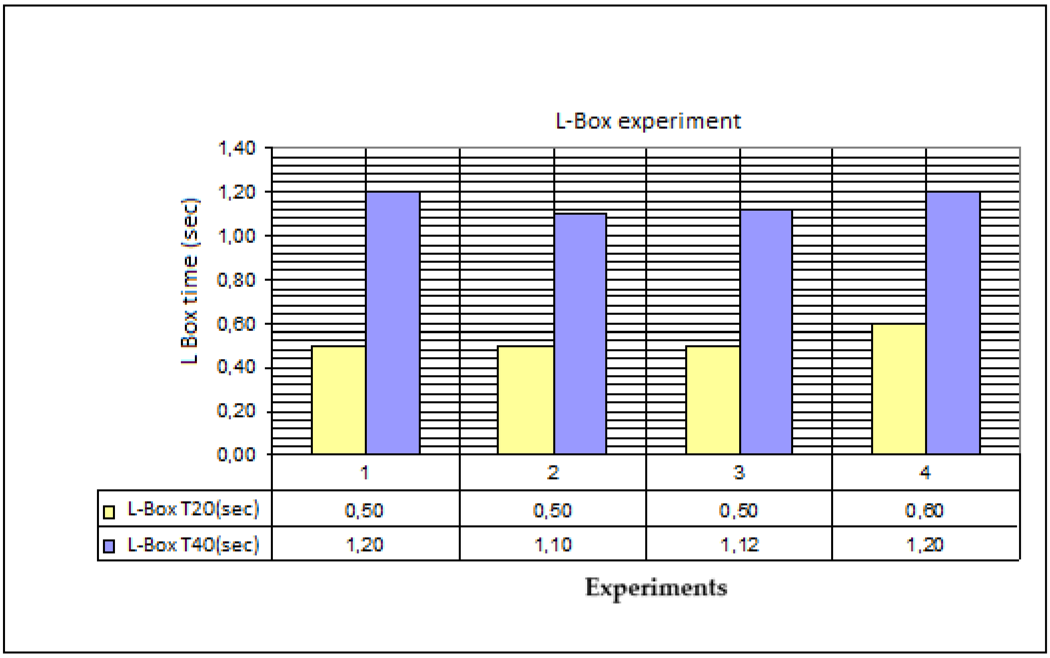
Graphic 17. The speed of reaching T 500 mm (2-5 sec) to the Slump Spread test of SCC produced using hyperplasticizer additive + fly ash + polypropylene fiber



Graphic 18. V Funnel Flow test results of SCC produced using hyperplasticizer additive + fly ash + polypropylene fiber



Graphic 19. Box L test results of SCC produced using hyperplasticizer additive + fly ash + polypropylene fiber



Graphic 20. L-Box test L-Box Ratio of SCC produced using hyperplasticizer additive + fly ash + polypropylene fiber (H1/H2>0.80)