High Strength Self-Compacting Concrete's (HSSCC) Fluidity and Mechanical Properties: An Experimental Study

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In this study, high strength self-compacting concrete (HSSCC) is made using components that are readily available locally. Work was done in three different concrete mixtures, and it was determined how to use of powder materials and hyperplasticizer affected on the characteristics of paste, mortar, and concrete. Investigations were done into how silica fume and hyperplasticizer additives affected the characteristics of both hardened and soft concrete. We developed the new concrete testing tools and devices (L-box, J-ring, and V-funnel) after performing general testing because they didn't already exist. The tests for slack flow diffusion, capacity, L-box, J-ring, and V-funnel tests were used to determine the fluidity, while the tests for ability to pass and passability were used to determine the ability to pass. So, trial mix 3 gives the optimum characteristics in both hardened and fluidity from other trials according to international specifications and standards for fluidity EN1235010(2010), ASTM C1611/1611M- 18 2018, ASTM C1621 2017, (ACI 237.2007). The earlier research and development suggested mixing ratios, Trail Mix 1 taken from the previous studies and we are suggesting (Trail Mix 2 and Trail Mix 3) and it resulted in concrete that showed better strength, hardness, fluidity and durability. High compressive strength was reached with enhancing percentages of 68% for the compression test, 100% for the tensile test, and 72% for the flexural test.

Keywords: Fluidity and hardening, self-compacted concrete, High-strength concrete, hyperplasisazer, self-compacted Concrete, Silica Fume.

1. Introduction

In the field of concrete construction, self-compacting concrete (SCC) is a novel and developing material that is defined by its excellent flow, passage, and stability qualities without the need for great strength or endurance. SCC flows with a creeping movement and resembles "honey" when it is horizontally flowing. Hardened SCC often has a smooth surface finishing as a result. It fills all spaces without vibrating, bleeding, or segregating since it may pass through crowded reinforced sections or places with intricate structural components. High deformability of paste or mortar, sufficient viscosity between constituents, and good passage through bars are the means by which it can attain self-compatibility. According to Mehta (2006) (Mehta, 2006), it yields high-strength concrete (HSC), a kind of high-performance concrete with a compressive strength of 50 to 100 MPa. The aggregate used to make concrete does not always have to be very strong; rather, it just has to be extremely durable and compatible with the cement paste in terms of stiffness and strength. Additionally, while the elasticity of its constituent parts varies only a little, concrete may also have a high strength when it has a low water-cementitious ratio (w/c) and a high cementitious content (cement + powder).

Using high cementitious content with low water powder ratios (w/p) and high doses of superplasticizer to create superior compatibility, which in turn enhances strength and durability, are the combined variables for producing high-strength and self-compacting concrete. Because each component has a greater impact on self-compacting concrete than on regular concrete, concrete ingredients should be chosen carefully. As a result, restrictions should be made known about the characteristics and composition (mix ratios) of certain ingredients. The first kind is a physical impact that happens when fillers seep into spaces created by cement particles. As a result, this may make cement denser, which would enhance the qualities of both fresh and hardened concrete. The second kind is known as the surface chemical reaction effect, which means that the hydration process is indirectly impacted by the additional particles.

The mechanism that makes up the cement paste is how the particles function as nucleation sites on the cement particles, causing this result. The third kind is the chemical reaction effect, in which some cement components react with the fillers to create cement gel. To produce the strength, pozzolan elements such as fly ash, silica fume, and meta-kaolin react with Ca (OH)2 to generate C-S-H. The mix design should take into account the physical characteristics of powders, such as the shape, fineness, and distribution of particle sizes. In situations when the surface area of the powders is greater than that of the cement, more water will be needed to retain the same workability. Numerous aggregate characteristics, including kind, maximum size, particle size distribution, form, and reactivity, have a major impact on concrete (Tokyay, 1998). Both when concrete is new and has hardened, aggregate has an impact. Aggregate significantly influences flow, passage, and stability in SCC. Compared to high-strength concrete, coarse aggregate qualities have far less of an impact on standard-strength concrete.

Paste in HSC has a low water-to-cement ratio, which gives it great strength. Thus, from a strength standpoint, aggregate qualities become crucial (Tokyay, 1998). In light of this, the current study examined these properties in both fresh and hardened High Strength Self-compacting concrete.

2. Experimental Works

The next experimental program involved doing the essential experiments related to the high-strength self-compacting concrete (HSSCC) and mortar (HSSCM) systems while maintaining a consistent emphasis on the study objectives. This study sought to determine how silica fume, hyperplasticizer, and w/c affected HSSCC. Three different types of mineral admixture were. Tests were conducted in order to ascertain the HSSCC in both its fresh and hardened states. The mini-slump cone, V- funnel box instruments and setting time test were used to evaluate the fresh properties of mortar. Compressive strength, density and absorption tests were conducted in order to assess the hardened properties of mortar. The slump flow, V-funnel, J-ring, and L-box, were conducted for concrete during its fresh state. Destructive tests were also conducted to assess the quality of concrete in its hardened state. The destructive tests used were compressive strength, flexural strength, and splitting tensile strength. The non-destructive tests consist. (“Effect of Coarse Aggregate Characteristics on Mechanical Properties of High-Strength Concrete”, 1990; Türkel & Kandemir, 2010)

3. Contents

The qualities of each material utilized have to be taken into account while choosing the ideal proportions in accordance with the mix design techniques. Achieving a satisfactory HSSCC required careful material selection, excellent quality control, and proportioning. (“Effect of Coarse Aggregate Characteristics on Mechanical Properties of High-Strength Concrete”, 1990)

3.1 Cement

The Type I ordinary Portland cement of the "krasta" brand was utilized in this investigation. The sacks containing the cement weighed around fifty kilograms each. After that, in order to keep it dry and safe from moisture exposure, it was kept in airtight steel drum containers. In accordance with the Kaolin and Metakaolin, the cement was evaluated and observed.

3.2 Fine-grained material

The used fine aggregate Every silica sand bag Measurements were made in the base of the second and third concrete mixtures (1.20-2.3 mm) and in the first concrete mixture (2.3-1.2 mm) (Mustafa Tokyay, 1998; Tasdemir et al., 1996; Xie, 2005).

3.3 Coarse Aggregate

The coarse aggregate used in this study is crushed gravel, and the sizes were divided from (4.75-9.5) mm according to the American standard. (Mustafa Tokyay, 1998; Tasdemir et al., 1996; Xie, 2005)

3.4 Water

The water used in this study was tap water which is free from impurities that can affect the properties of both mortar and concrete samples.(“Effect of Coarse Aggregate Characteristics on Mechanical Properties of High-Strength Concrete", 1990)

3.5 Hyper Plasticizer

This study employed a polycarboxylic based plasticizer and water reducer as a chemical combination. (Ouchi et al., 1997; Şahmaran et al., 2006)

3.6 Silica fume

For concretes with exceptional performance, MasterRoc MS 610 is a premium silica fume powder. Concrete becomes denser and more resilient to outside influences as a result of the modification to its porosity structure. (Atalla Almayah & Sadiq Latief, 2018; Tasdemir et al., 1996)

4. Mixing

Our work focused on the mixed proportion that is mentioned in the literature review. So, the overall components of the weighted mixtures were converted to the corresponding volumetric mixture. The quantities represented the weight per one cubic meter of volume. (Madhur J. Kansagara 1 *, 2018)

At the same time, all specimens were cast, along with three cubes measuring 150 x 150 x 150 mm for compression strength, one prism measuring 530 x 150 x 150 mm for flexural strength, and three cylinders measuring 150 mm in diameter and 300 mm in length for tensile strength. This process was repeated for each of the three trails that we used.

Table 1 Amounts of materials used for trail mixes

Materials	First Mix of Trails	Second Mix of Trails	Third Mix of Trails
cement (kg / $m^{3)}$	1	1	1
Fine Aggregate (kg / $m^{3)}$	1.32	1.32	1.32
Coarse Aggregate (kg / $m^{3)}$	1.32	1.32	1.32
Water (kg/m^3)	0.317	0.288	0.32
Silica fume (kg/m^3)	0.11	0.20	0.25
Hyper plasticizer (kg/m^3)	0.028	0.020	0.025

Table 1 above shows the three trials, the first one depended on the best previous study (Abdullah Karim Mohammed and Eman Ibrahim Faris, [s.d.]), and the second and third trials have been suggested by us (the optimum effects of increasing or decreasing the silica fume, hyper plasticizer and water) as that noted the changes happened to the water, silica fume and hyper plasticizer.

The following is a summary of the mixing process: -

1-Mixing of all dried material.

2-Addition of liquid (approximately silica fume + Hyper – plasticizer).

3-Additional Mixing for about 4 minutes.

4- An increase in the amount of leftover liquid (2.5 percent hyperplasticizer and 25% silica fume).

5-Further mixing until the mixture is met.

The precast industries were a good fit for the aforementioned process ("Direct Tension Test of Concrete", 2001). The ACI Committee report 544 advocated a similar technique.

5. Casting and Curing

To ascertain the mechanical qualities of the concrete, multiple 150 mm dia. x 300 mm high cylinders, 150 × 150 × 150 mm cubes, and 150 × 150 × 530 mm prisms were cast on the same day as the beams.

Figure 1. Casting of cylinders, cubes & prisms

Figure.1 above has been shown the casting of samples, Cubes for compression test, cylinder for indirect method for tensile test and prisms for fracturing (flexural) test during the casting and molding process.

After casting of the concrete, it was compacted by the electric vibrator machine. Then, the top surface was leveled. All cast elements (cylinders, cubes, and prisms) were covered with a sheet. In the first days, the sheet was wetted by water to keep the required condition of the humidity for curing.

After 48 hours of casting process, all casted elements were de-molded and were kept in similar conditions of humidity up to testing's time. The RO water (Reverse Osmosis, is a water purification technology) was utilized in the casting process.

6. Findings and Discussions

6.1 HSSCC's Compressive Strength

Three (150 x 150 x 150 mm) cubes were used to assess the compressive strength at 28 days during normal curing and the behavior of compressive strength with age during normal curing (28 days). The concrete laboratory at the Technical Institute in Maysan was the site of the experiments. The used equipment was a universal ELE Compression Machine model with a capacity of 2000 KN. In case of cylinder specimen, the testing of HSSCC has a concern in their end conditions. The existing of workability of the mix prevented the obtaining a clean surface. (Madhur J. Kansagara 1 *, 2018)

6.2 Tensile Strength and Flexural Strength

The tensile strength of the concrete had taken wide range of values. In this work, it was evaluated by splitting tensile tests on cylindrical specimens and by the flexural tensile strength of prismatic specimens. The used equipment to find the splitting tensile strength was a universal ELE machine. The one-point load was used to measure the flexural strength. The date that was acquired was indicated in Table 2.

Table 2 Three trails' experimental values for compressive, tensile, and flexural strengths.

Trail 1 (Experimental Work but the mix ratio from previous study) (Abdullah Karim Mohammed and Eman Ibrahim Faris, [s.d.])

Mixtures for trails	Number	Densities (kg / m$^{3)}$	Load (kN)	Stress (MPa)	Average (MPa)
	1	2265	933.4	44.45	
Cubes	2	2265	1050.2	46.67	47.123
(Compressive strength)	3	2265	1130.7	50.25	
Cylinders	1	2283.2	154.4	2.184	
(Tensile strength)	2	2283.2	163.3	2.31	2.25
	3	2283.2	159.5	2.256	
	1	2276.6	84.045	16.06	
Prisms	2	2286.55	88.12	16.84	16.85
(Flexural strength)	3	2243.54	92.44	17.66	

Trail 2 Trail mixes 2 from our suggestion- Our contribution

Mixtures for trails	Number	Densities (kg / m$^{3)}$	Load (kN)	Stress (MPa)	Average (MPa)
	1	2321.3	1894.5	84.2	
Cubes	2	2321.3	1746	77.6	79.43
(Compressive strength)	3	2321.3	1721.25	76.5	
	1	2330.4	340.7	4.82	
Cylinders	2	2330.4	336.46	4.76	4.64
(Tensile strength)	3	2330.4	306.77	4.34	
	1	2350.82	158.2	30.23	
Prisms	2	2336.59	145.66	27.83	29.06
(Flexural strength)	3	2346.95	152.44	29.13	

Trail 3 (Trail mix 3 from our suggestion- Our contribution)

Mixtures for trails	Number	Densities (kg / m$^{3)}$	Load (kN)	Stress (MPa)	Average (MPa)
	1	2301.4	1671.75	74.3	
Cubes	2	2301.4	1557	69.2	74
(Compressive strength)	3	2301.4	1766.2	78.5	
	1	2293.1	268.6	3.8	
Cylinders	2	2293.1	247.4	3.5	3.63
(Tensile strength)	3	2293.1	254.4	3.6	
	1	2322.5	134.47	25.7	

Prisms	2	2331.22	130.12	24.86	25.48
(Flexural strength)	3	2321.11	135.44	25.88	

Table 2 above has been shown the mechanical properties for three trails, density, compression strength, tensile strength and flexural strength, so we are concluding the second trail gives the best result in all tests as shown in Figure 1, 2 and 3 because decreasing the W/C ratio and increase the silica fume and hyper plasticizer compare with trial one Table 1.

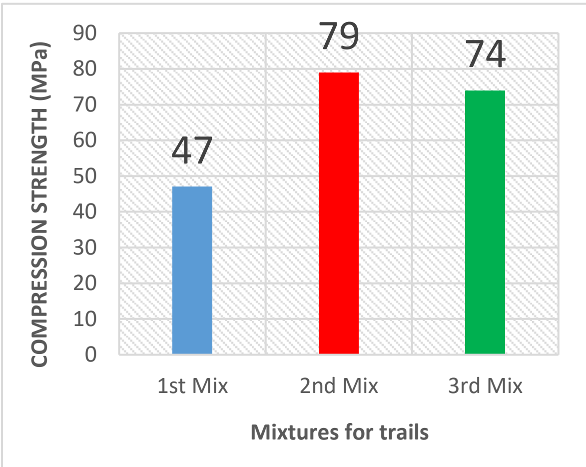

Figure 2 Compressive Strength Test for Different Trail mix

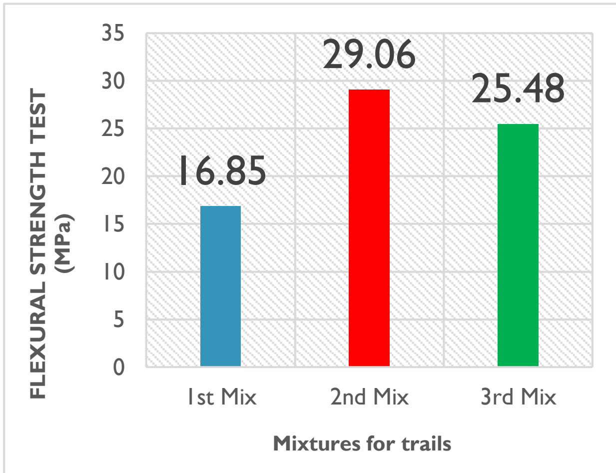

Figure 3 Flexural Strength Test for Different Trail mix

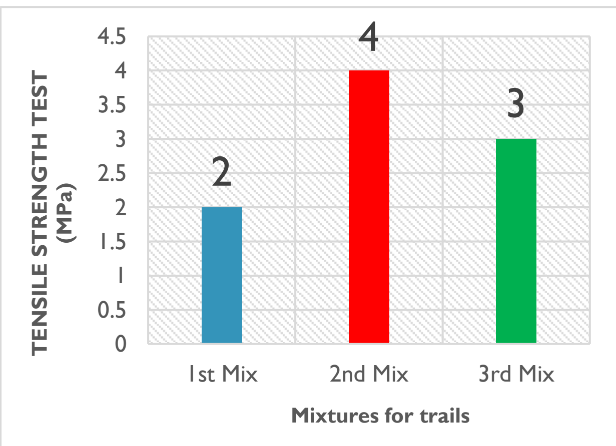

Figure 4 Tensile Strength Test for Different Trail mix

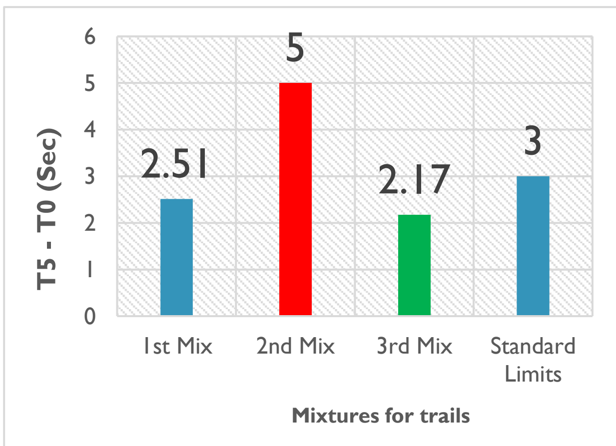

Figure 5 V-Funnel Test for Different Trail mix

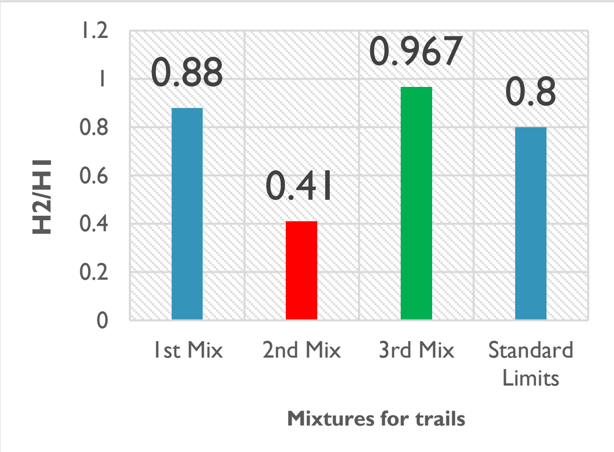

Figure 6 L-Box Test for Different Trail mix

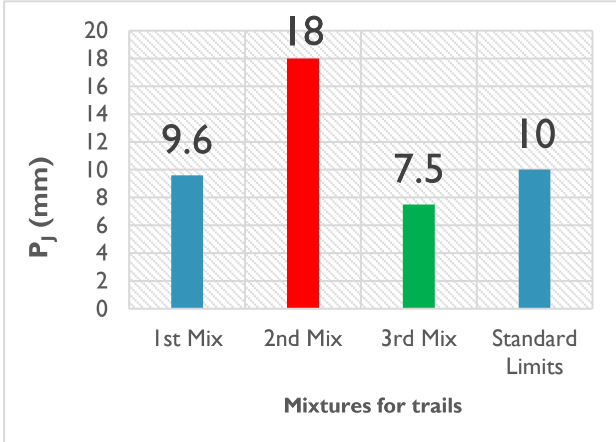

Figure 7 J-Ring Test for Different Trail mix

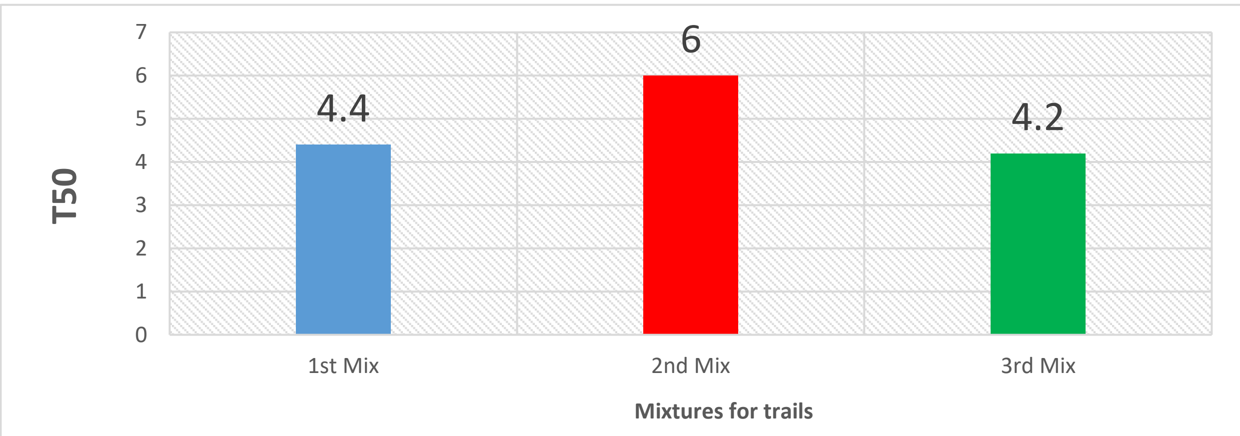

Figure 8 Slump Flow Test for Different Trail mix

The Figures above Figure 5,6,7,8 shown the results of soft properties Table 3 for three trails and we are concluding the third trial was the best in both sides fluidity and hardened properties according to standard specifications Table 4, Indeed the second trial better than third trail in hardened properties but it's not good in soft properties out of the standard specification Table 4.

6.3 Fresh Mortar Tests

Fresh concrete tests were carried out and its soft properties were determined. The results in the first and third mixtures were within the limits of acceptance and conformed to the approved specifications. In the second mixture, the results were outside the specification by a small difference due to the reduction in the percentage of water and the hyperplasticizer additive. The results can be seen in the figure (5,6,7,8).

Table 3 Experimental values for the Fresh mortar tests

Trail Mix	V-funnel	L-box	J-ring	Slump flow
Trail 1	2.51	0.88	9.6	4.4
Trail 2	5	0.41	18	6
Trail 3	2.17	0.967	7.5	4.2

Table 4 Standard Specifications for fluidity tests

Test Type	Specification	Acceptance Limits
L-BOX	EN12350-10(2010)	$H_2/H_1 = 0.8$
SLUMP FLUW	ASTM C1611/1611M- 18 2018	Access time stream diameter to 500 mm (2_s-5_s)
J-RING	ASTM C1621 2017	PJ should have a blocking step that is smaller than 10 mm
V-FUNNEL	(ACI 237.2007)	To (6 – 12 sec), T5 – T0 < 3 sec

7. Conclusions

The main conclusions obtained in this work are described below:

1. After comparing two suggested combinations to a mixture from earlier study, we came to the conclusion that the two proposed mixtures performed better in tests on both fresh and hardened concrete than the first mixture.
2. With rates of 68% for Compression testing, 100% for tensile testing, and 72% for bending testing, the two suggested mixes demonstrated that their behaviors in bending, compression, and tensile tests are better than the findings of earlier research.
3. It was determined that the initial cohesion time and the cohesiveness of the mixture's component parts are affected by the proportion of hyperplasticizer added above the typical percentage.
4. The best combination has excellent mechanical and soft qualities and uses a water ratio of 0.32 and hyperplastisazer of 0.025.
5. Reducing the amount of water results in an increase in strength at the price of concrete's soft characteristics.
6. It was determined that the optimal silica fume ratio for raising the resistance to 68% in the compression test, 100% in the tensile test, and 72% in the flexural test is (0.11 to 0.25).
7. Using crushed and sieved aggregates (4.75 - 9.5 - 12.7) and (1.2_2.3) for fine aggregates.

8. Recommendations

1. We advise understanding the structural behavior of the curvature of bridges, columns, and ceilings and applying the third combination while creating bridges.
2. We advise researching the characteristics of 56- and 91-year-old long-lived hardened concrete.
3. We advise using heat therapy to see its impact on young and old ages.
4. For this kind of concrete, non-destructive testing is advised.
5. To improve sustainability, lower construction costs, and increase the usage of recycled materials, we advise switching out the gravel for recycled aggregate.

Funding Details

None

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