International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 3 Issue 10, October-2014, pp: (7-14), Impact Factor: 1.252, Available online at: www.erpublications.com

The Effect of Various Percentages of Fly Ash on the Fresh and Hardened Properties of Self Compacting Concrete

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Abstract: The aim of this research is to study the effect of using the fly ash to the fresh and hardened properties of self compacting concrete. Self compacting Concrete (SCC) is a new category of concrete which flows under its own weight. It does not require any external vibration for compaction. Due to many advantage of this concrete, it is appropriate for the case where the reinforced concrete used in congested area. In this study the self compacting concrete is improved by adding various percentages of fly ash, 20%, 25% and 30% by weight of cement as partial replacement of cement. Experimental results indicated that, The fresh properties for different mixes which tested with The slump flow, T_{50} time, V-funnel time and L-box height ratio tests shows better by increasing the fly ash contents and that will led to improving the flow and passing abilities. However, the compressive and splitting tensile strengths decreased by the tests results at 28 days and 90 days for SCC samples.

Keywords: Self Compacting Concrete, Fly ash, Slum Flow Test, V−funnel, Compressive Strength.

1. Introduction

Self compacting concrete (SCC) is considerably a new technology in concrete that was developed in the last two decades. The technology was first realized in 1986 by Japanese investigators to rise concrete durability by increasing concrete workability and thus by enlarging the quality of construction [1]. However, using mineral admixtures such as blast furnace slag, fly ash, etc could decrease SCCs material cost and also enhanced concrete's fresh and hardened properties [2,3].

Self compacting concrete (SCC) is considered as a concrete which can be placed and compacting under its self weight with little or no vibration effort, and which is at the same time cohesive enough to be handled without segregation or bleeding of fresh concrete [4].

Concrete technology has undergone several changes in its formulation and it becomes stronger and durable with the aid of mineral and chemical admixtures [5]. The previous researches conclusions shows that the addition of the fly ash to the concrete leads to reduce the compressive and tensile strengths of early aged concrete samples [6,7].

The objective of this study is to understand the fresh state properties of SCC containing fly ash in various proportions as partial replacement of cement and small quantity of super plasticizer . An experimental program has been developed to investigate the behavior of self compacting concrete containing fly ash. The fresh state properties like slump flow, T_{50} time, V-funnel and L-box blocking ratio have been assessed using the methods as per EFNARC[8] specification. The properties of hardened concrete have also have been evaluated the compressive strength at 28 days and 90 days has also assessed for the mixes containing different percentages of fly ash i.e. 20%, 25% and 30% of the weight of cement.

2. Experimental Program

2.1. Materials

2.1.1. Cement and fly ash

Ordinary Portland cement was used in this study (PC CEM,I 42.5R) .It had a specific gravity of 3.15 g/cm^3 and Blaine fineness of 326 m^2/ kg. It was utilized in the production of concretes. Fly ash (FA) used in concrete as a cement blender 20%,25%,30% from total binder content consistent for all mixtures was a class F type according to ASTM C618-08 [9], supplied from Ceyhan Sugözü thermal power plant. It had a specific gravity of 2.04 g/cm^3 and the Blaine fineness of 379 m^2/ kg. Physical and chemical properties of the cement and fly ash are given in (Table1).

2.1.2. Aggregates

The coarse aggregate used was river gravel with a nominal maximum size of 16 mm. Two types of fine aggregate were used for all the mixtures in this study. First type was crushed limestone sand and second type was natural river sand. The specific gravity and water absorptions of natural river sand and crushed limestone were 2.66 g/cm^3 and 2.45 g/cm^3, and 0.55% and 0.92% respectively. The particle size gradation obtained through the sieve analysis of the fine and coarse aggregates are given in Table 2.

2.1.3. Super Plasticizer

A poly carboxylic ether type super plasticizer (SP) with a specific gravity of 1.07 g/cm^3 was employed to achieve the target workability in all concrete mixtures. The properties of superplasticizer are given in (Table 3).

Table 1: Chemical Compositions and Physical Properties of Portland Cement and Fly Ash

Chemical analysis (%)	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Na_2O	Loss on ignition	Specific gravity	Fineness (m^2/kg)
Portland cement	63.84	19.79	3.85	4.15	3.22	2.75	-	-	0.87	3.15	326*
Fly ash	2.24	57.2	24.4	7.1	2.4	0.29	3.37	0.38	1.52	2.04	379*

*Blaine specific surface area

Table 2: Sieve Analysis of Aggregates

Sieve Size (mm)		16	8	4	2	1	0.5	0.25	Fineness Modulus	Specific gravity	Absorption %
Fine aggregate	**River Sand**	100	100	86.6	56.7	37.7	25.7	6.7	2.87	2.66	0.55
	Crushed Sand	100	100	95.4	63.3	39.1	28.4	16.4	2.57	2.45	0.92
Coarse aggregate		100	31.5	1.0	0.5	0.5	0.5	0.4	5.66	2.72	0.45

Table 3: Properties of Super Plasticizer

Properties	Name	Color tone	State	Specific gravity	Chemical description
High Range water reducer admixture	Glenium 51	Dark brown	Liquid	1.07 *g /cm^3*	Polycarboxylic-ether

2.2. Concrete Mixture Design

Three different types of SCC mixtures were designed having a constant water–cementitious material ratio of 0.35 and total cementitious materials content of 500 kg/m^3. In first , second and third series of concretes, ordinary Portland cement were replaced with 20%, 25%, and 30% of [FA] as a binder, respectively. The details of the mixtures were given in Table 4.

Table 4: Mix Proportions for Self Compacting Concrete (kg/m^3)

Mix no	Fly ash (kg/m^3)	Cement (kg/m^3)	Water (kg/m^3)	SP (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate	
						River sand (kg/m^3)	Crushed sand (kg/m^3)
M1	100	400	175	2.5	847.2	593.1	254.2
M2	125	375	175	3.6	842.5	589.75	252.75
M3	150	350	175	4.2	851.6	596.1	255.5

2.3. Concrete mixing proportioning and casting

The production of self-compacting concrete, the mixing sequence and duration are very important. Thus, the procedure for batching and mixing proposed by Khayat et al. [10] was employed to supply the same homogeneity and uniformity in all mixtures. The batching sequence consisted of homogenizing the river sand, crushed sand and coarse aggregates for 30 seconds in a rotary planetary mixer, then adding about half of the mixing water into the mixer and continuing to mix for one more minute. Thereafter, the fine and coarse aggregates were left to absorb the water in the mixer for 1 min. After cement and fly ash were added, the mixing was resumed for another minute. Finally, the SP with remaining water was introduced, and the concrete was mixed for 3 min and then left for a 2 min rest. Eventually, the concrete was mixed for additional 2 min to complete the mixing sequence. The laboratory testing consists of tests for both fresh and hardened concrete. Fresh concrete tests are Slump flow, T_{50} slump flow time, V-funnel, and L-box were used to test the workability, passing ability, viscosity, and setting time of SCC. The tests for hardened concrete include compressive strength, indirect tensile tests (Split cylinder test). From each concrete mixture, six cube specimens with dimensions (150×150×150) mm for compressive strength test and cylinders specimens with 150 mm diameter and 200 mm high for splitting tensile strength were cast full without any vibration or compaction. The test specimens were demoulded 24 h after casting and then water cured until the time of testing.

2.4. Test Specimens and Methods

2.4.1. Tests for Fresh Properties

The slump flow, T_{50} time, V-funnel time and L-box height ratio tests was carried out to identify the required properties and the characteristics of fresh SCC mixtures with the recommendations given in EFNARC [8] .
Slump flow value describes the flow ability of a fresh mix in unconfined conditions. It is a sensitive test that can normally be specified for all self-compacting concretes, as the primary check that the fresh concrete consistence meets the specification. Visual observations during the test and/or measurement of the T_{50} time can give additional information on the segregation resistance and uniformity of each delivery. T_{50} is a measured time that shows the concrete has flowed to a diameter of 500 mm [8]. According to EFNARC, there are three typical slump flow classes for the range of applications. The upper and lower limits and typical application areas of these classes are given in Table 5.

Table 5: Slump flow, viscosity, and passing ability classes with respect to EFNARC [8]

Class	Slump Flow Diameter (mm)	
Slump flow classes		
SF1	550-650	
SF2	660-750	
SF3	760-850	
Class	T_{50} (sec)	V-funnel time (sec)
Viscosity classes		
VS1/VF1	≤ 2	≤ 8
VS2/VF2	≥ 2	9-25
Passing ability classes		
PA1	≥ 0.8 with two rebar	
PA2	≥ 0.8 with three rebar	

Viscosity of the produced self-compacting concrete can be measured together with the T_{50} slump flow time and V-funnel flow time. These values do not measure the viscosity of SCC directly but are related to it by describing the rate of flow. When performing the V-funnel test, a V shaped funnel is filled with fresh concrete and the time taken for the concrete to flow out of the funnel is measured and recorded as the V-funnel flow time. There are two viscosity classes in the EFNARC [8] self-compacting concrete guide according to the measured V-funnel and T_{50} slump flow times. Viscosity classification was also given in Table 6.
L-box test demonstrates the passing ability of the fresh mix to flow through confined spaces and narrow openings such as areas of congested reinforcement without segregation, loss of uniformity or causing blocking. In the L-box test, a measured volume of fresh concrete is allowed to flow horizontally through the gaps between vertical, smooth

reinforcing bars and the height of the concrete beyond the reinforcement is measured. Passing ability classes according to the L-box height ratio values was also given in Table 6. The slump flow test, V-Funnel test and L-box test were conducted as presented in Figure 4,5 and 6 respectively.

Table 6: Self Compacting Criteria

	Method	Unit	Typical range of values	
			Minimum	Maximum
1	Slump Flow by Abrams cone	mm	650	800
2	T_{50} Slump Flow	sec	2	5
3	J-ring	mm	0	10
4	V-funnel	sec	6	12
5	Time increase, V-funnel at $T_{5minutes}$	sec	0	+3
6	L-box	(h_2/h_1)	0.8	1.0

Figure 1: Cylinder tested for Splitting tensile

Figure 2. Tension failure concrete cylinder

Figure 3. Concrete cube under compression machine

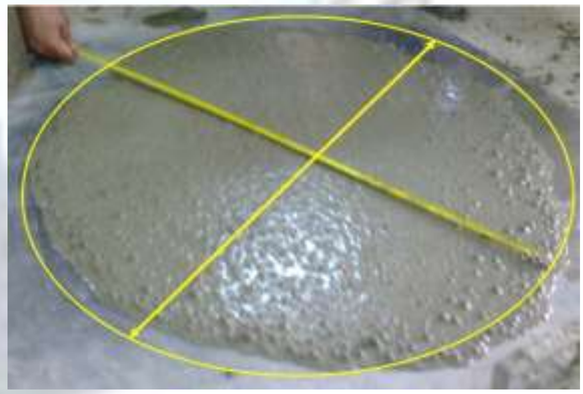

Figure 4. Photographic expression of slump flow diameter measurement

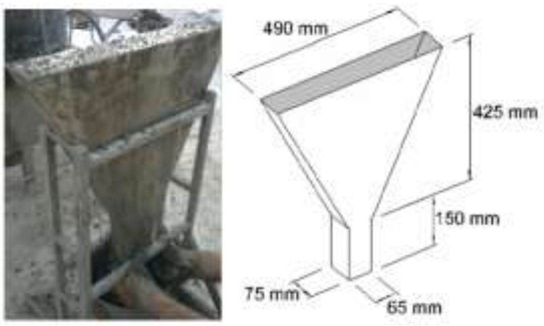

Figure 5. V-Funnel Test Apparatus

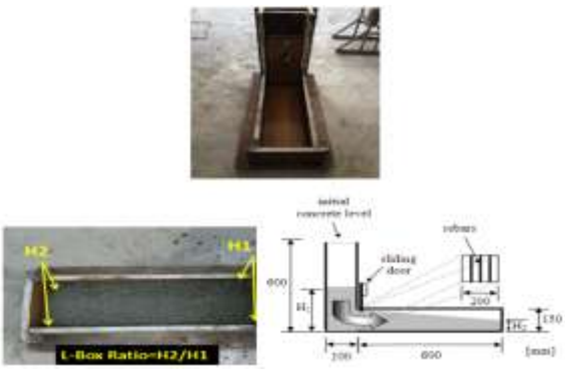

Figure 6. Photographic view of L-box apparatus and testing procedure

2.4.2. Tests for Hardened Properties

Compressive tests were conducted on the concrete mixtures at the end of 28 and 90 days curing periods. These tests were made on three 150 mm cubes for each mixture and age with respect to ASTM C 39 [11]. The loading rate was constant and same for all concretes.

The splitting tensile strength determination was generally carried out in accordance with the ASTM C 496 [12]. three 100x200 cylinders for each mixture were tested at the ages of 28, and 90 days. The tensile strength was calculated by the equation (1):

$$f_t = \frac{2P}{\pi DL} \dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (1)$$

Where f_t is the tensile strength in MPa; P is the maximum load applied in N; and D and L the diameter and the length of the cylindrical specimen, in mm. The result is given as the average of samples in this study.

3. Results and Discussion

Series of tests were carried out on the concrete cubes, cylinders, and beams to evaluate the fresh and hardened properties of Self Compacting Concrete. This section discusses the results obtained from the testing program. The results were observed from the slump flow test and T_{50} test, V-funnel, L-box, compression test and tensile tests. The results of the SCC mixes prepared are summarized in Table 7.

Table 7: Workability and Compressive Strength Results

Mix no.	Fly ash	f_c' 28days (Mpa)	Splitting tensile 28days (Mpa)	f_c 90days (Mpa)	Splitting tensile 90 days (Mpa)	Slump flow		V-funnel (sec)	L-Box blocking ratio (H_2/H_1)
						T_{50} cm (sec)	D (cm)		
M1	20%	66.9	3.77	70.7	4.33	8	70	20	0.89
M2	25%	59.8	3.34	62	3.54	7	75	15.5	0.93
M3	30%	55	3.20	58	3.35	2.2	79	11.54	0.98

3.1. Fresh Properties Tests Results

Three different doses of fly ash replacing by mass (20%, 25%, and 30%) the Portland cement and three doses of super plasticizer (0.5%, 0.72%, and 0.84%) have been used to explore the influence on the filing ability of SCC. The water/cement ratio 0.35 was kept constant for all mixtures. Among this study, the design limits for all concrete mixtures were to give a slump flow diameter of 75±5 cm, as seen in Table 7, slump flow diameter of the concretes ranged from 70 to 79 cm, conforming EFNARC recommendations, which state lower and upper approval limit of slump flow diameter to be in between 55 and 85 cm, respectively.

From Figure 7 we can note that there is a direct trend for the effect of fly ash and super plasticizer on the filling ability (Slump flow) of SCC, using this Figure it is clear that the optimum percentage of fly ash and super plasticizer can be selected. As we can deduce from finding result that the lowest slump flow diameter was measured for the mixture with 20% fly ash, namely (M1) while the mixture had the maximum slump flow diameter was for (M3) with 30% fly ash. Figure 7 showed that the target slump flow diameters were able to be achieved for all the mixtures so that the fresh SCCs appeared to match SF2&SF3 slump flow class as planned according to Table 5. Such concretes are applicable for greater part of R.C structural members [8].

Table (7) Shows the V-Funnel time results for several mixtures, and these results also reflect the concrete viscosity ratio which is inversely proportional with the V-Funnel time, in other words when the V-Funnel time increases the concrete loses its viscosity.

Figure 8 shows the effect of adding 20%, 25% and 30% of fly ash (by mass of cement) and 0.5%, 0.72%, and 0.84% super plasticizer doses on the SCC V-Funnel time. It also shows that the mixtures suffer from losing its viscosity when the fly ash percentage equal or under 20% with super plasticizer 0.5% .
The viscosity of the SCC can be measured through the T_{50} Slump flow time and V-funnel flow time tests. From Figure9 we can see that the T_{50} slump flow time decreases when the content of fly ash increases.

For example, at the first mixture group (M1) when FA content equal to 20%, the T_{50} slump flow time and V-funnel flow time was 8 and 20 s, respectively. However, these values decreased to 7 and 15.5 s at 25% FA content for the second mixture group (M2). Also when we compared the third mixture group (M3) results with pervious groups results we see the decreasing at both T_{50} slump flow time and V-funnel flow time tests results that means the increasing of the fly ash content ratio in the SCC mixture due to decreasing the both T_{50} slump flow and V-funnel flow times, also increasing the self compacted concrete mixtures flow ability, passing ability properties as shown in Figure 9. So that the T_{50} slump flow time and V-funnel flow time appeared to match VS2/VF2 Viscosity classes as planned according to Table 5.

The L-box test is used to assess the passing ability of self-compacting concrete to flow through tight openings including spaces between reinforcing bars and other obstructions without segregation or blocking. To declare that a self-compacting concrete has the passing ability, L-box height ratio must be equal to or greater than 0.8. It should be noted that this ratio being 1.0 for perfectly fluid behavior of the concretes. It was obviously that all of the mixtures satisfied the EFNARC limitation given for the L-box height ratio. Findings of this test pointed up that incorporation of FA provided a systematic increase in the L-box height ratio up to 89% as listed in Table 7. Since the maximum height ratio had been reached at that replacement level, increasing FA amount to 98% also yielded the same height ratio as expected as shown in Figure 12.

3.2. Hardened Properties Tests Results

To determine the strength range of the self compacting concretes, a compression test was conducted on 150mm cube specimens for all mixtures. The results obtained from compressive strength tests for all self compacted concrete mixtures to both 28 and 90 days ages are summarized in the Table 7.
It was observed from Figure 10 that there was a symmetric reduction in compressive strength for SCC samples with the increase of fly ash [FA] content. Compressive strength of the first [M1], second [M2] and third [M3] mixture groups that fly ash contents equal to 20%, 25% and 30% respectively at 28 days age was 66.9, 59.8 and 55 MPa respectively, also the compressive strength of the first [M1], second [M2] and third [M3] mixture groups that fly ash contents equal to 20%, 25% and 30% respectively at 90 days age was 70.7, 62 and 58 MPa respectively. That means the increasing of fly ash contents decreases the compressive strengths of SCC samples for all 28 and 90 days testes as shown in Figure 10. pervious researches also indicated similar negative effects of fly ash [FA] on the compressive strength of concrete [13,14,15].
The tensile strength results for the three types of self compacting concrete, M1 and M2 and M3 , in two different SCC sample 28 and 90 day ages as shown in Figure 11. It was seen that tensile strength of the concretes decreased with increasing fly ash amount in the mixtures.

4. Conclusions

Based on the results of the study, the following conclusions may be drawn:

1- All of the SCC mixtures were designed to give a slump flow diameter of 700 ± 50 mm, which was achieved by adjusting the dosage of the super plasticizer used for the trial batches. In order to stay within the limits of the targeted slump flow diameter, the amount HRWRA (High Range Water Reducers Admixture) was increased with the increase amount of fly ash content level.

2- The fresh state properties for different mixes which tested with The slump flow, T_{50} time, V-funnel time and L-box height ratio tests are as per EFNARC Guidelines better with the increase in fly ash content flow ability and passing ability is obtained.

3- Compressive and splitting tensile strengths of self compacting concrete decrease significantly at 28 and 90 days when Fly ash contents increase from 20% to 30% with constant water/cement ratio 0.35. The 28 days compressive strength decrease by 25-26 % as the Fly ash amount increases from 20% to 30%. Also The 90 days compressive strength decrease to 17-18 % as the Fly ash amount increased from 20% to 30%.

5. References

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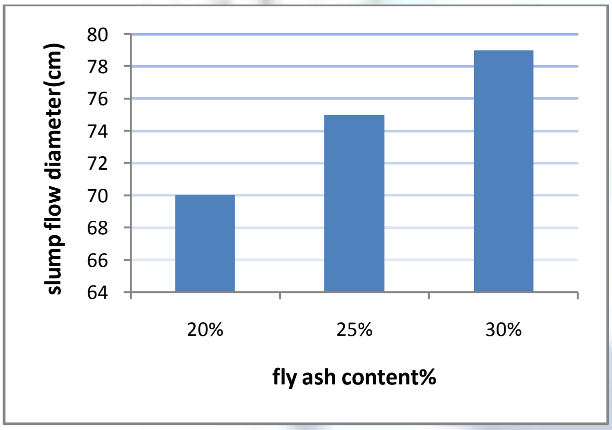


Figure 7. Slump Flow test results

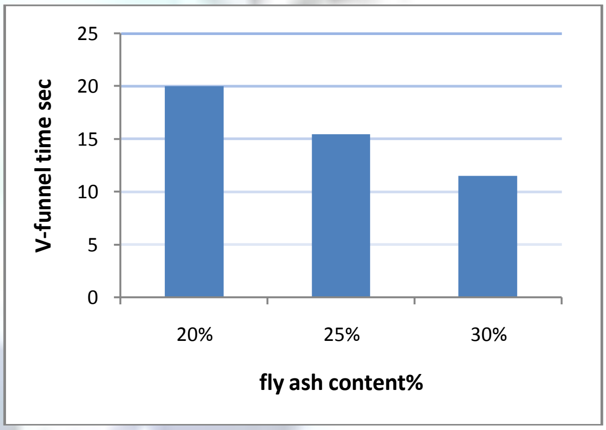


Figure 8. V-funnel time test results

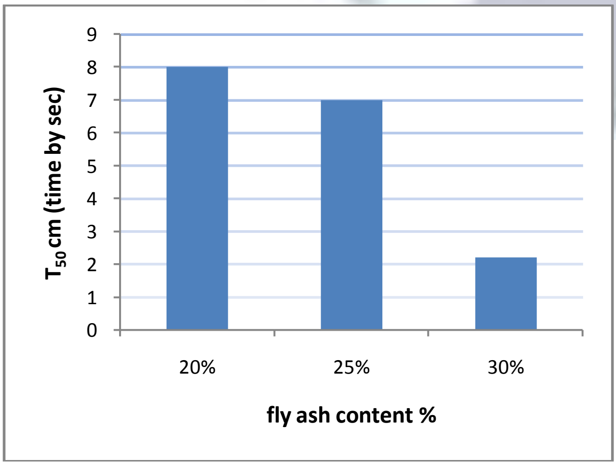


Figure 9. T_{50} Slump Flow time test results

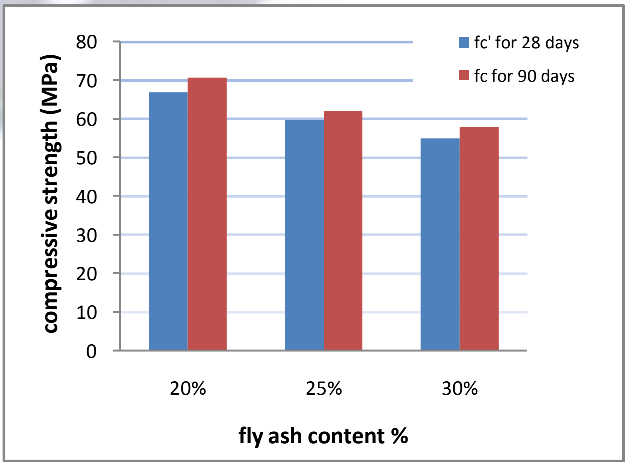
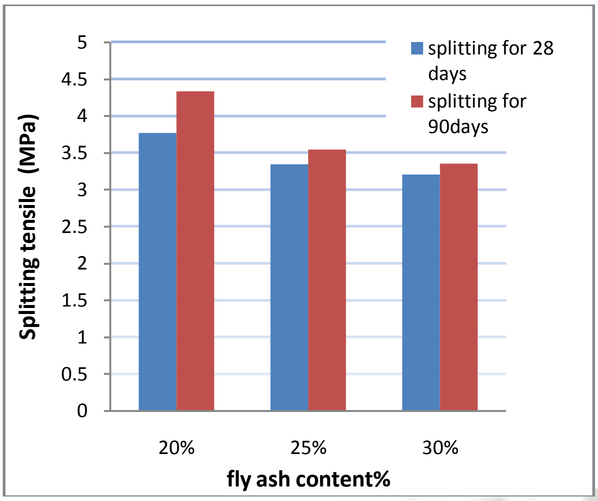


Figure 10. Variation of compressive strength with Fly ash contents



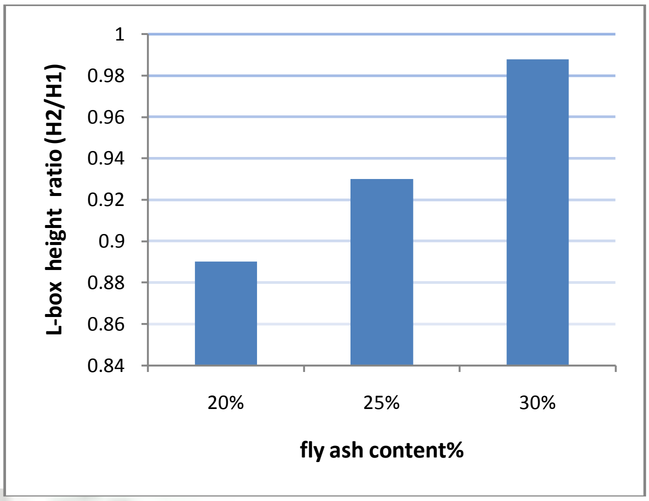


Figure 11. Variation of splitting tensile strength with Fly ash contents

Figure 12. L-box height ratio test results