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Experimental Investigation of Silica Fume and Steel Slag in Concrete

D. Karthik[1], J. Doraikkannan[2]
[1]Departmentof civil engineering,N.S.N College of engineering and technology,Tamilnadu,India
[2]Department of civil engineering,N.S.N College of engineering and technology,tamilnadu,India

ABSTRACT: *This paper gives a review on replacements in concrete made out of various industrial by-products like silica fume and steel slag in concrete Through my study a combined replacement of steel slag and silica fume in (40, 50, 60, and 70) % and (10, 15, 20, and 25) % and conduct a detailed experimental study on Compressive strength, split tensile strength, flexural strength at age of (7, 28, 56 and 90) days and durability study on acid attack was also determinedand investigates the potential use and optimum usage of steel slag and silica fume in the production of concrete.*
Keywords: *Compressive strength,Flexural strength, Silica fume,Steel slag,Split tensile strength*

I. INTRODUCTION

The use of concrete is increasing day by day, so our natural resources get depleted due to the production of concrete. In order to reduce this environmental problem we should find out materials that can substitute the natural resources, steel slag is an industrial by-product formed during the manufacturing of steel and silica fume are also one of the industrial by-product formed during the production of alloys of silicon. Various studies were carried out for the replacement of cement and aggregate and some of the literatures are have been discussed briefly, many studies have been carried out in this area from early 1980's.

Many steel plants have been set up in our country. However, production of iron and steel is associated with the generation of solid waste materials like slag. Big steel plants in India generate about 29 million tonnes of waste material annually. In addition, there are several medium and small plants all over the country. Slag reduces the porosity and permeability of soil, thus increasing the water logging problem.. Industrial area around major cities there are several small and large scale industries wasting nearly thousands of metric tonne steel slag daily. Problem of disposing this slag is very serious which can be reduced by utilizing steel slag for concrete construction. The final properties of concrete, such as strength, durability and serviceability depend mainly on the properties and the quality of the materials used. Steel slag can be used in conventional concrete to improve its mechanical, physical, and chemical properties.

Steel slag is generated as a melt at about 1600°C during steelmaking from hot metal in the amount of 15%–20% per equivalent unit of steel. The function of this slag is to refine the steel of sulphur and to absorb the oxides formed as a result of deoxidation during steel production. Steelmaking slags are composed principally of calcium silicates, calcium aluminoferrites, and fused calcium oxides, iron, magnesium, and manganese.

More recently strict environmental pollution controls and regulates have produced an increase in the industrial wastes and sub graded by-products which can be used as (supplementary cementitious material) SCMs such as fly ash, silica fume,ground granulated blast furnace slag etc. The use of SCMs in concrete constructions not only prevents these materials to check the pollution but also to enhance the properties of concrete in fresh and hydrated states. The SCMs can be divided in two categories based on their type of reaction: hydraulic and pozzolanic. Hydraulic materials react directly with water to form cementitious compound like ground granulated blast furnace slag (GGBS). Pozzolanic materials like fly ash, silica fume...etc. Do not have any cementitious property but when used with cement or lime react with calcium hydroxide to form products possessing cementitious properties.

STEEL SLAG

Steel slag, a by-product of steel making, is produced during the separation of the molten steel from impurities in steel-making furnaces. The slag occurs as a molten liquid melt and is a complex solution of silicates and oxides that solidifies upon cooling. Virtually all steel is now made in integrated steel plants using a version of the basic oxygen process or in specialty steel plants (mini-mills) using an electric arc furnace process. The open hearth furnace process is no longer used. Steel slag is produced in large quantities during the steel-making operations which utilize Electric Arc Furnaces (EAF). Steel slag can also be produced by smelting iron ore in the Basic Oxygen Furnace (BOF). Steel slag can be used in the construction industry as aggregates in concrete by replacing natural aggregates.

SILICA FUME

Silica fume, also known as microsilica, It is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. It is an ultrafine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm. The main field of application is as pozzolanic material for high performance concrete. Addition of silica fume to concrete has many advantages like high strength, durability and reduction in cement production. When pozzolanic materials are incorporated to concrete, the silica present in these materials react with the calcium hydroxide released during the hydration of cement and formsadditional calcium silicate hydrate (C – S – H), which improve durability and the mechanical properties of concrete.

II. EXPERIMENTAL INVESTIGATIONS

MIX COMBINATIONS

In this study various mix combinations of steel slag and silica fume was prepared under various mix ratios. Each mix is denoted by 'M' and M1 denotes the conventional mix 'M_{30}' and from M2 to M5 cement is replaced by 10% of silica fume and sand is replaced by 40-70 % of steel slag. The combinations are shown in table1

Table .1 Mix combinations

SI NO	SAMPLE DESIGNATION	PERCENTAGE OF REPLACEMENT	
		SILICA FUME	STEEL SLAG
1	M1	0	0
2	M2	10	40
3	M3	10	50
4	M4	10	60
5	M5	10	70
6	M6	15	40
7	M7	15	50
8	M8	15	60
9	M9	15	70
10	M10	20	40
11	M11	20	50
12	M12	20	60
13	M13	20	70
14	M14	25	40
15	M15	25	50
16	M16	25	60
17	M17	25	70

TEST RESULTS

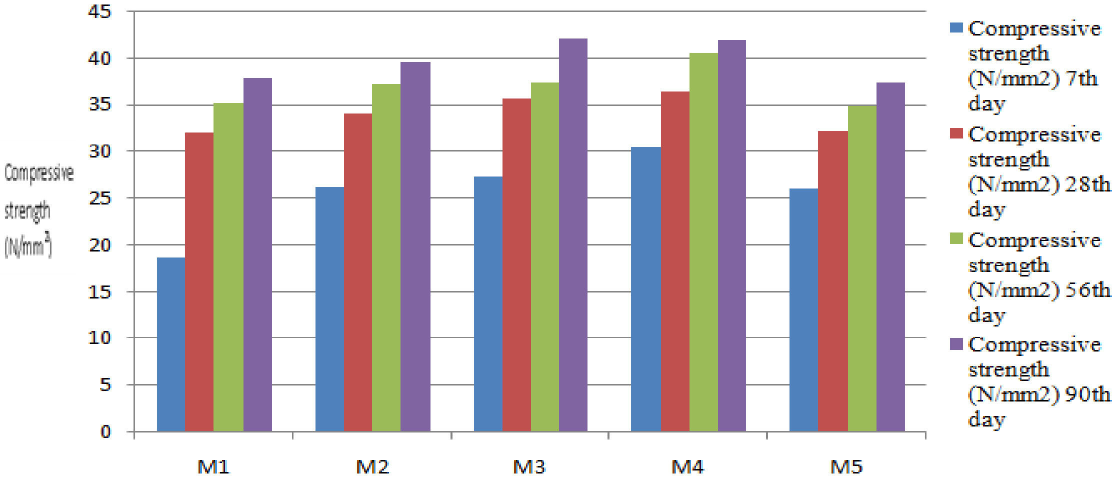
In the experimental study mainly the mechanical strength of the concrete was found out forall mix combinations. Mechanical strength deals with compression, tension and flexural strength of concrete specimens and also durability studies are done to find, the most efficient combination of silica fume and steel slag.

Compressive strength test results

Through my study I have been found that, due to the presence of silica content in steel slag and silica fume,there is a great increase in the silica content in concrete and it reduces the strength of concrete, but the effective usage of both the materials, improve the strength of concrete.By considering the strength aspects the best combination is M8 ie, silica fume 15% and steel slag 60% and for optimum replacent level of steel slag content the best combination is M9 ie,silica fume 15% and steel slag 70%.

Table.2 Compressive strength test results for M1 - M5 mix

Sample designation	Compressive strength (N/mm²)			
	7th day	28th day	56th day	90th day
M1	18.6	32	35.2	37.76
M2	26.2	34.1	37.16	39.55
M3	27.3	35.6	37.38	[1] 42
M4	30.4	36.4	40.40	[2] 41.86
M5	26	32.2	34.77	[3] 37.35



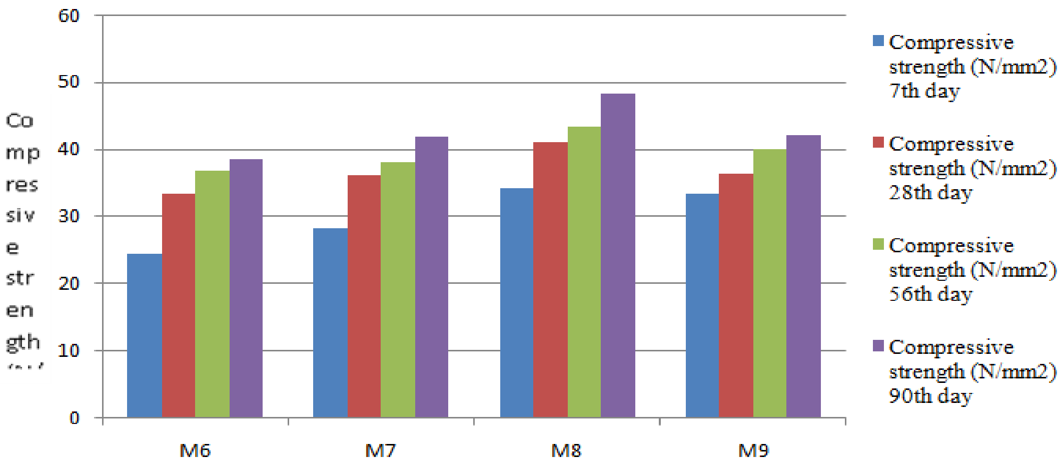
Mix combinations

Graph showing compressive strength of mixes M1 –M5

As per the study, for the third set of combination ie, silica fume 20% and steel slag 40 - 70% maximum strength obtained is M12 mix ie, silica fume 20% and steel slag 60% and by compairing it with conventional mix it shows an increase in strength upto 10 % and obtained maximum replacement of steel slag in M12 mix ie, steel slag 60%.

Table 3 Compressive strength test results for M6 – M9 mix

Sample designation	Compressive strength (N/mm²)			
	7th day	28th day	56th day	90th day
M6	24.5	33.4	36.74	38.41
M7	28.4	36.2	38.01	42
M8	34.35	41	43.46	48.38
M9	33.5	36.4	40.04	42.22



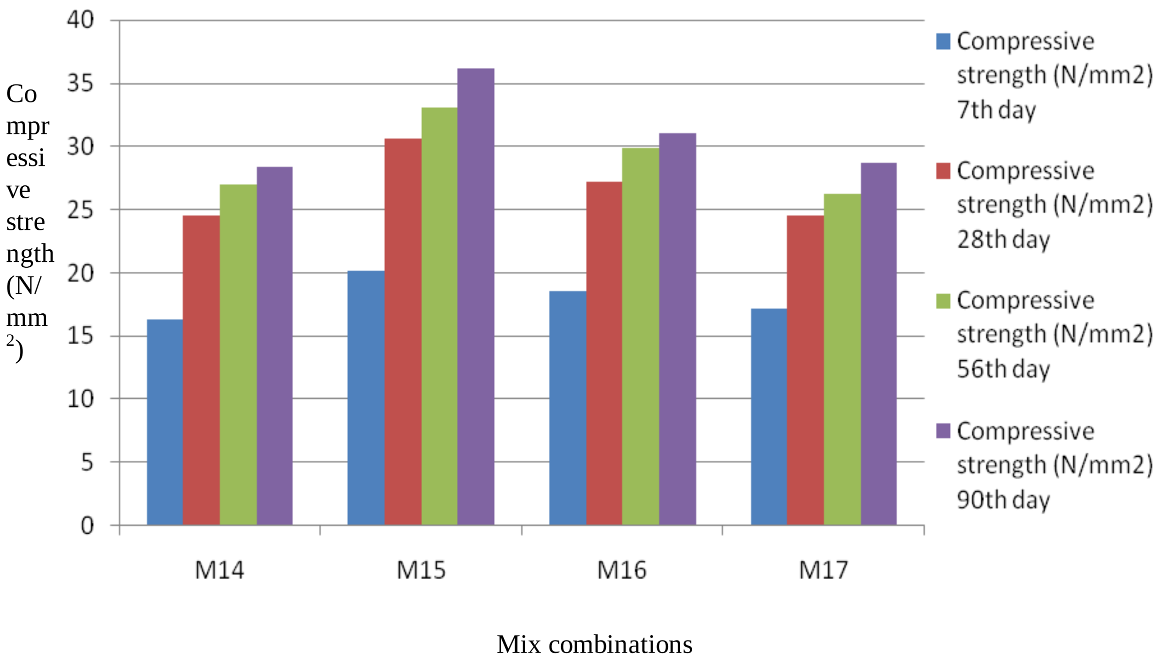
Mix combinations

Graph showing Compressive strength of mixes M6-M9

As per the study, for the third set of combination ie, silica fume 20% and steel slag 40 - 70% maximum strength obtained is M12 mix ie, silica fume 20% and steel slag 60% and by compairing it with conventional mix it shows an increase in strength upto 10 % and obtained maximum replacement of steel slag in M12 mix ie, steel slag 60%.

Table. 5 Compressive strength test results for M14 – M17 mix

Sample designation	Compressive strength (N/mm^2)			
	7th day	28th day	56th day	90th day
M14	16.3	24.5	26.95	28.42
M15	20.2	30.6	33.05	36.12
M16	18.6	27.2	29.92	31.01
M17	17.2	24.5	26.22	28.66



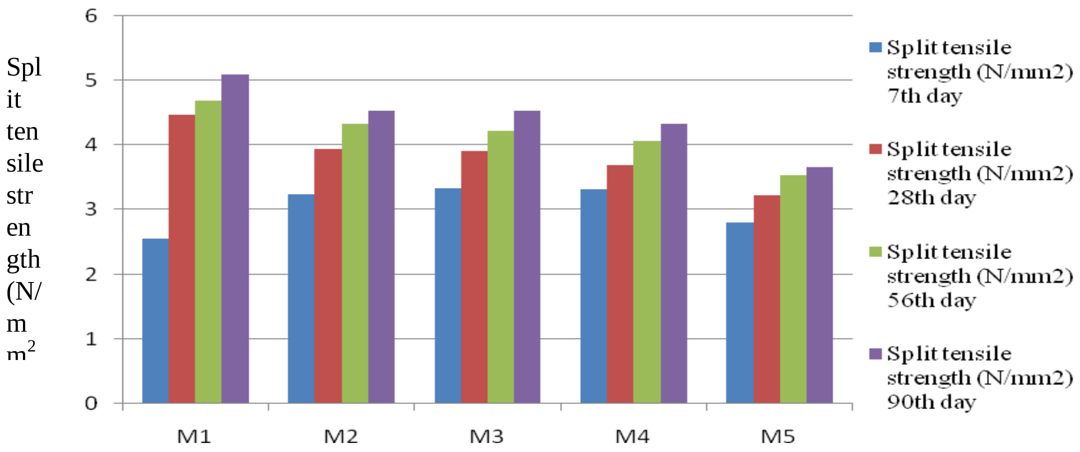
Graph showing Compressive strength of mixes M14 - M17

As per the study, for the last set of combinationsie, silica fume 25% and steel slag 40 - 70% the 'M15' mix shows a similar strength as conventional mix,there is no increase in strength but the maximum replacement of steel slag is 50%.

Split tensile strength test results

Table. 6 Split tensile strength test results for M1 - M5 mix

Sample designation	Split tensile strength(N/mm^2)			
	7th day	28th day	56th day	90th day
M1	2.551	4.47	4.69	5.09
M2	3.24	3.94	4.33	4.53
M3	3.34	3.91	4.22	4.53
M4	3.32	3.7	4.07	4.33
M5	2.8	3.22	3.54	3.67

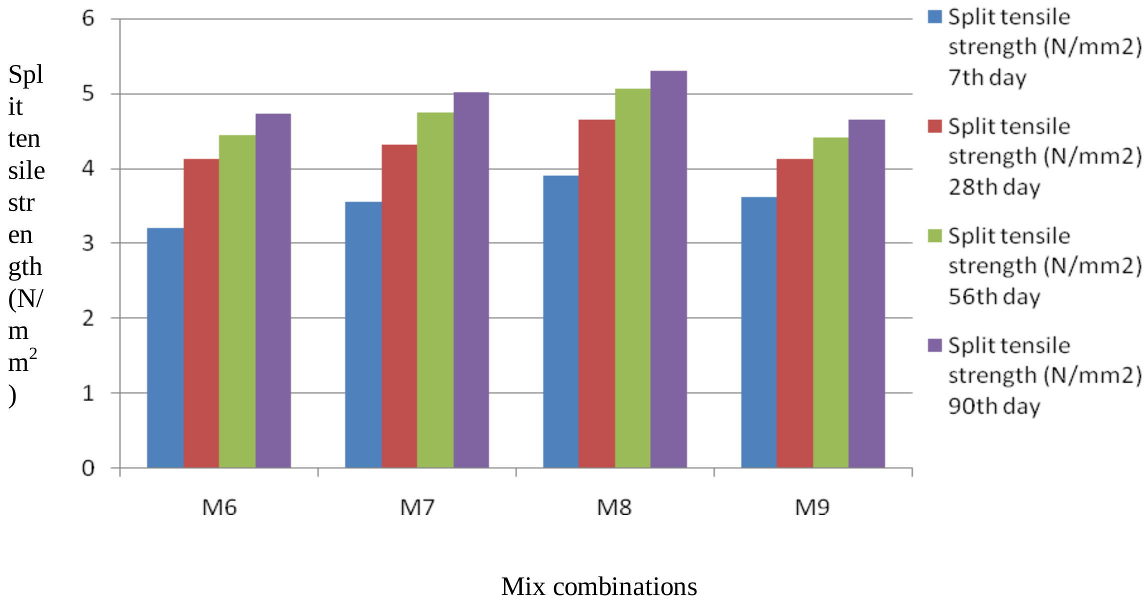


Graph showing Split tensile strength of mixes M1 –M5

According to the studies there is no increase in the split tensile strength and for the first set of combinations there is a small reduction in split tensile strength by comparing with the conventional mix and from these 'M2' mix shows high strength ie, 10% silica fume and 40% steel slag.

Table. 7 Split tensile strength test results for M6 – M9 mix

Sample designation	Split tensile strength(N/mm^2)			
	7th day	28th day	56th day	90th day
M6	3.21	4.12	4.44	4.73
M7	3.55	4.32	4.75	5.01
M8	3.91	4.65	5.06	5.30
M9	3.62	4.12	4.41	4.65

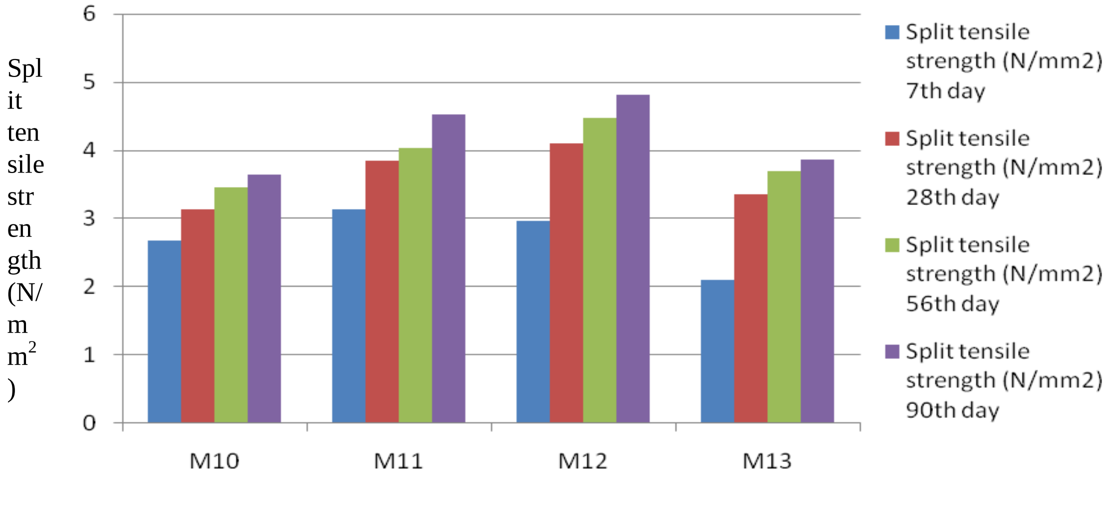


Graph showing Split tensile strength of mixes M6 –M9

As per the study, for the second set of combination ie, silica fume 15% and steel slag 40 - 70% maximum strength obtained is M8 mix ie, silica fume 10% and steel slag 60% and by compairing it with conventional mix it shows an increase in split tensile strength upto 15 % and also obtained maximum replacement of steel slag in M9 mix ie, steel slag 70%.

Table. 8 Split tensile strength test results for M10 – M13 mix

Sample designation	Split tensile strength(N/mm^2)			
	7th day	28th day	56th day	90th day
10	2.68	3.14	3.45	3.64
M11	3.14	3.84	4.03	4.53
M12	2.96	4.11	4.47	4.81
M13	2.11	3.36	3.69	3.86

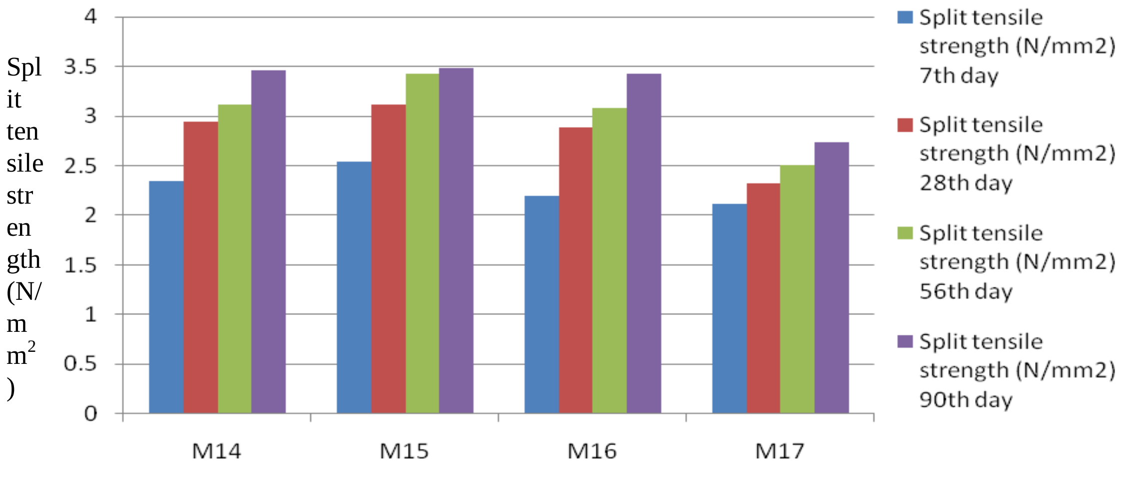


Graph showing Split tensile strength of mixes M10 –M13

According to the studies there is no increase in the split tensile strength and for the third set of combinations there is a small reduction in split tensile strength by comparing with the conventional mix and from these 'M12' mix shows high strength ie, 20% silica fume and 60% steel slag.

Table 9 Split tensile strength test results for M14 – M17 mix

Sample designation	Split tensile strength(N/mm^2)			
	7th day	28th day	56th day	90th day
M14	2.34	2.94	3.12	3.46
M15	2.54	3.12	3.43	3.48
M16	2.19	2.88	3.08	3.42
17	2.11	2.32	2.51	2.73



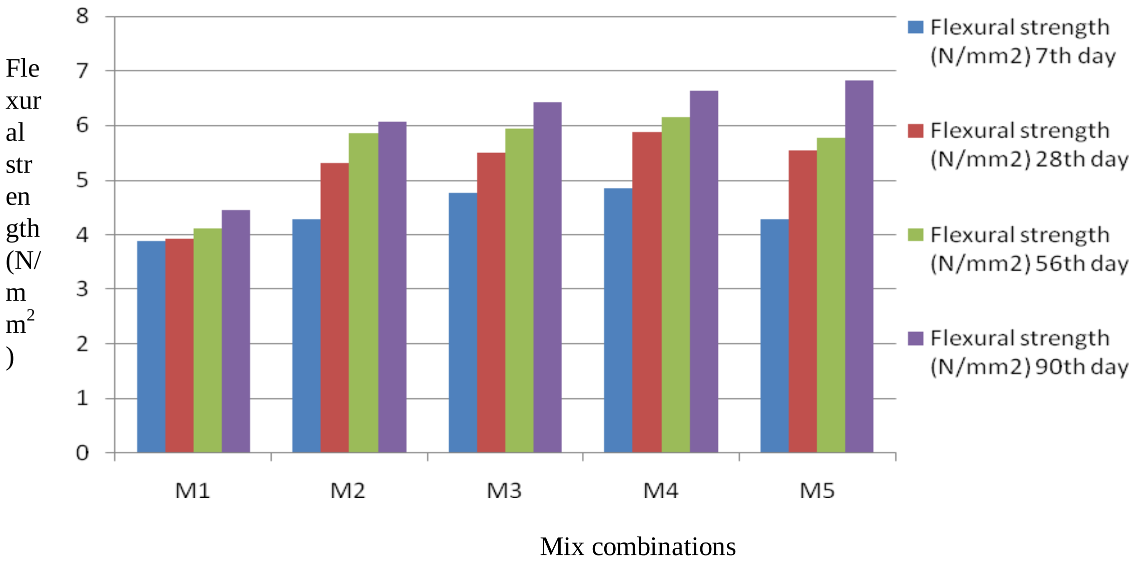
Graph showing Split tensile strength of mixes M14 –M17

According to the studies there is no increase in the split tensile strength and for the last set of combinations there is a small reduction in split tensile strength by comparing with the conventional mix, and from these 'M15' mix shows high strength ie, 25% silica fume and 50% steel slag.

Flexural strength test results

Table.10 Flexural strength test results for M1 - M5 mix

Sample designation	Flexural strength (N/mm^2)			
	7th day	28th day	56th day	90th day
M1	3.89	3.92	4.12	4.46
M2	4.28	5.32	5.85	6.06
M3	4.76	5.50	5.94	6.43
M4	4.86	5.87	6.16	6.63
M5	4.29	5.55	5.77	6.82

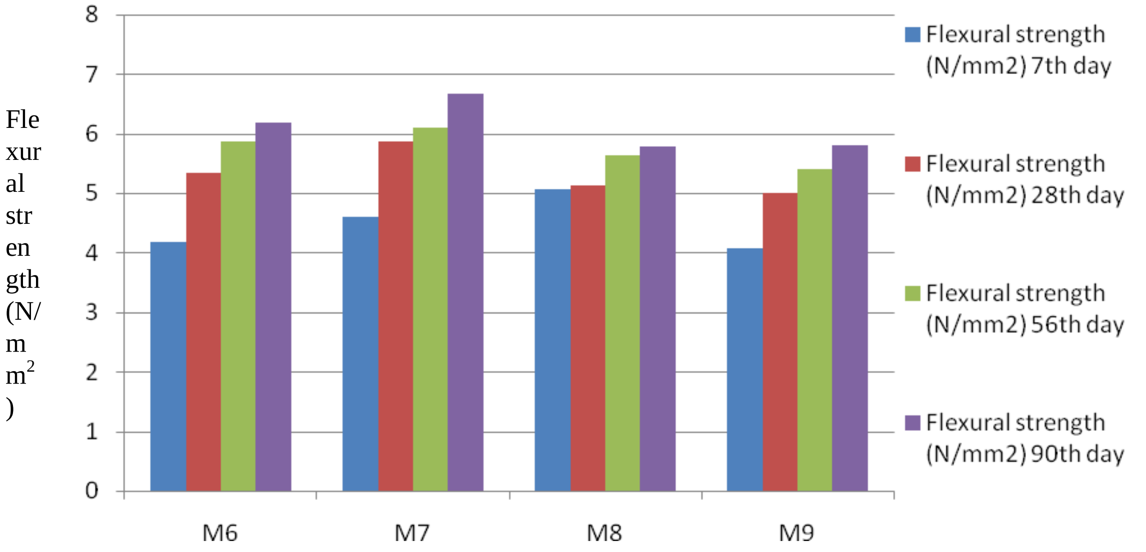


Graph showing flexural strength of mixes M1 –M5

As per the study, for the first set of combination ie, silica fume 10% and steel slag 40 - 70% maximum flexural strength obtained is M4 mix ie, silica fume 10% and steel slag 60% and by compairing it with conventional mix it shows an increase in flexural tensile strength upto 33 % and also obtained maximum replacement of steel slag in M5 mix ie, steel slag 70%.

Table.11 Flexural strength test results for M6 – M9 mix

Sample designation	Flexural strength (N/mm^2)			
	7th day	28th day	56th day	90th day
M6	4.18	5.33	5.86	6.18
M7	4.60	5.86	6.09	6.68
M8	5.07	5.12	5.63	5.78
M9	4.08	5.01	5.41	5.81



Graph showing Flexural strength of mixes M6 –M9

According to the studies there is no increase in the flexural strength and for the second set of combinations there is a small reduction in flexural strength by comparing with the conventional mix, and from these 'M7' mix shows high strength ie, 15% silica fume and 50% steel slag.

Table.12 Flexural strength test results for M10 – M13 mix

Sample designation	Flexural strength (N/mm^2)			
	7th day	28th day	56th day	90th day
M10	3.82	3.12	3.43	3.68
M11	4.23	3.63	3.92	4.24
M12	3.87	3.86	4.05	4.59
M13	3.56	3.25	3.64	3.83

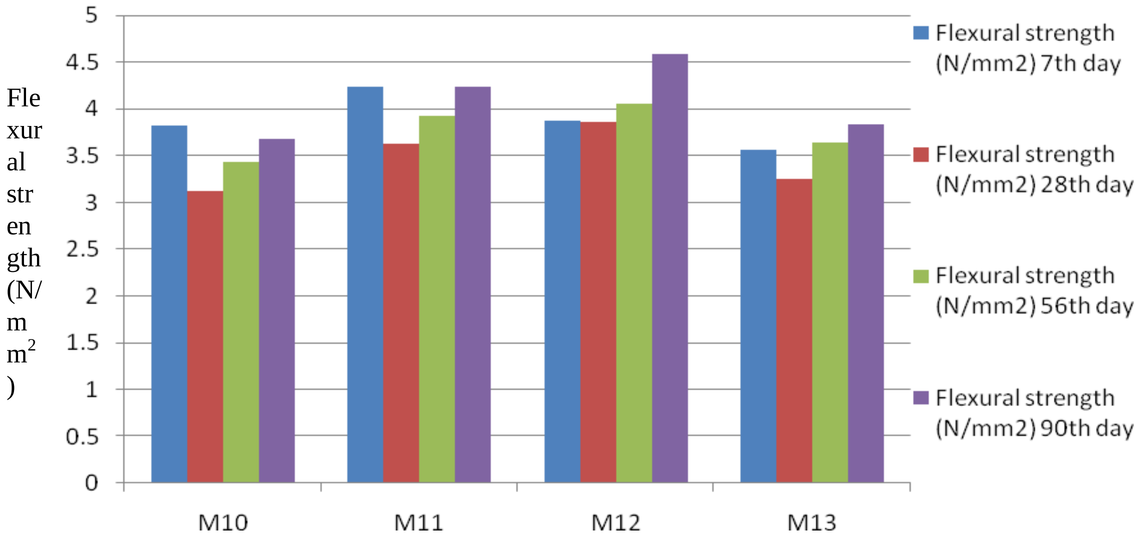
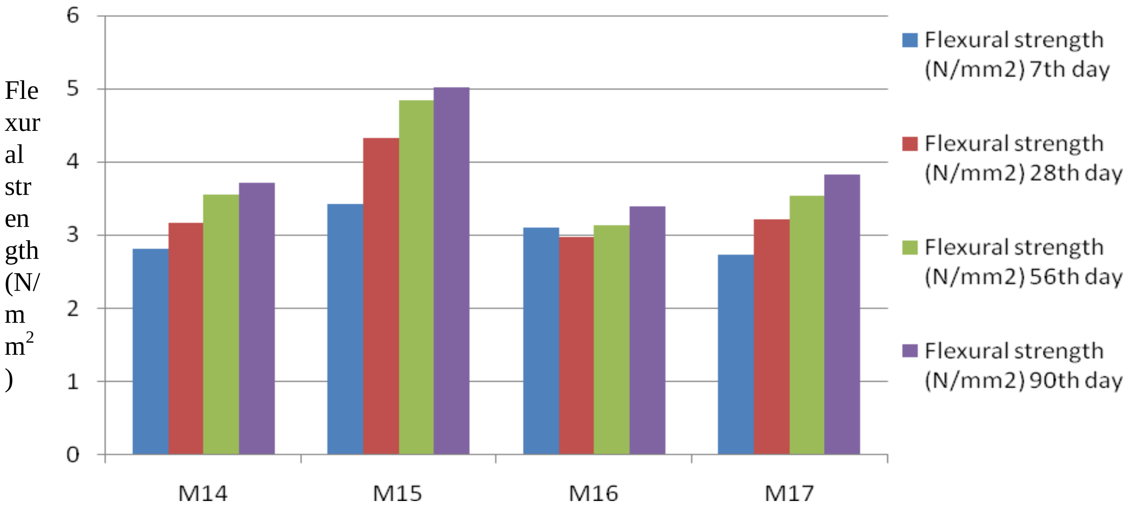


Figure 4.16 Graph showing flexural strength of mixes M10 –M13

According to the studies there is no increase in the flexural strength and for the third set of combinations there is a small reduction in flexural strength by comparing with the conventional mix, and from these 'M12' mix shows high strength ie, 20% silica fume and 60% steel slag.

Table.13 Flexural strength test results for M14 – M17 mix

Sample designation	Flexural strength (N/mm^2)			
	7^{th} day	28^{th} day	56^{th} day	90^{th} day
M14	2.81	3.17	3.55	3.71
M15	3.43	4.33	4.84	5.02
M16	3.11	2.98	3.13	3.4
M17	2.73	3.22	3.54	3.83



Graph showing flexural strength of mixes M14 –M17

As per the study, for the last set of combination ie, silica fume 25% and steel slag 40 - 70% maximum flexural strength obtained is M15 mix ie, silica fume 20% and steel slag 50% and by compairing it with conventional mix it shows an increase in flexural tensile strength upto 10 % and also obtained maximum replacement of steel slag in M15 mix ie, steel slag 50%.

Test result for durability studies

For the durability studies we consider the percentage of weight loss for every concrete mix and also loss in strength to find optimum mix. According to the durability studies we have been found that the optimum mix combination is M7 ie,silica fume 15% and steel slag 50%. Apart from the strength aspect of concrete mixes, the steel slag replacement level reduced upto 10%.

Table.14 Durability test results for M1 - M5 mix

Sample designation	Loss in Weight (%) At 30 Days	[4] Loss in Compressive strength (%) At 30 days
M1	4.34	11.29
M2	3.80	9.8
M3	3.12	8.72
M4	2.80	8.11
M5	2.94	8.72

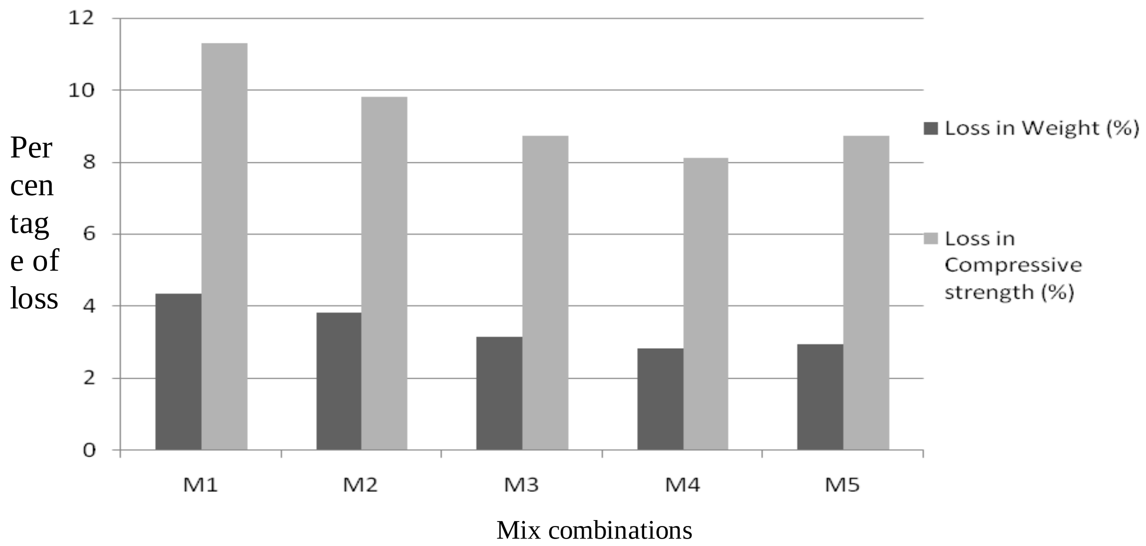


Figure 4.18Graph showing durability studies for M1-M5 mix

As per the study, for the first set of combinations mix M4 ie, silica fume 10% and steel slag 60% shows the least weight loss and it is more durable than the conventional mix.

Table.15 Durability test results for M6 – M9 mix

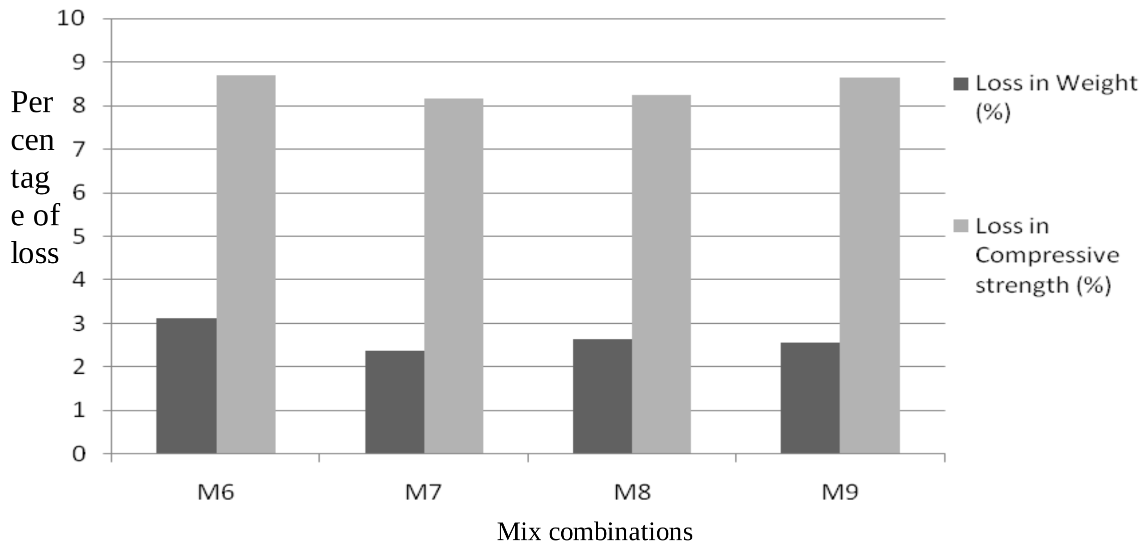


Figure 4.19Graph showing durability studies for M6-M9mix

As per the study, for the second set of combinations mix M7 ie, silica fume 15% and steel slag 50% shows the least weight loss and it is more durable than the conventional mix.

Table.16 Durability test results for M10 – M13 mix

Sample designation	**Loss in Weight (%) At 30 Days**	**Loss in Compressive strength (%) At 30 days**
M10	4.15	11.32
M11	3.86	9.78
M12	3.92	9.99
M13	4.17	11.22

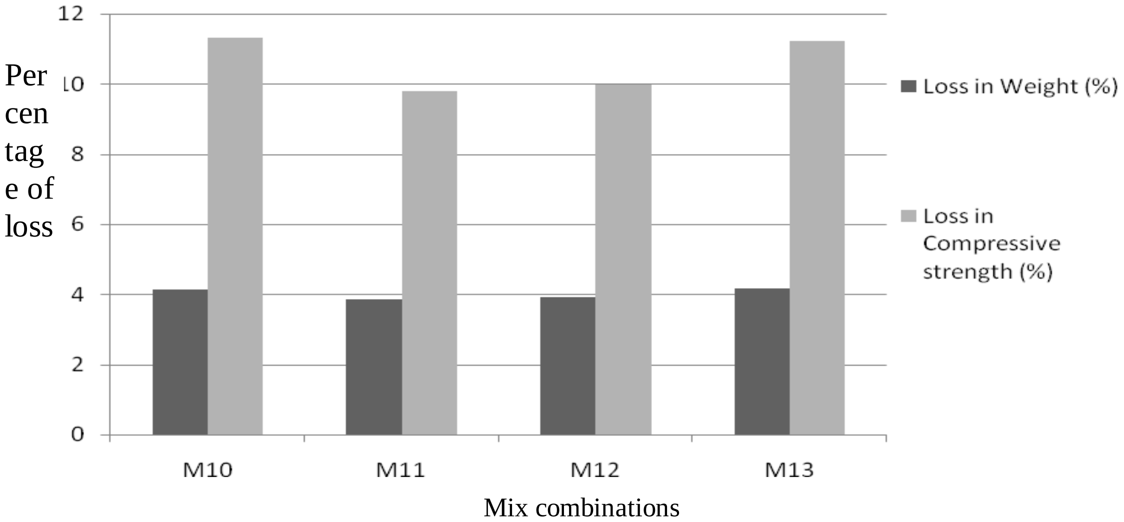


Figure 4.20Graph showing durability studies for M10-M13 mix

As per the study, for the third set of combinations mix M11 ie, silica fume 20% and steel slag 50% shows the least weight loss and it is more durable than the conventional mix. When we consider the other mixes the increase in silica fume content reduces the durability property of concrete.

Table.17 Durability test results for M14 – M17 mix

Sample designation	Loss in Weight (%) At 30 Days	Loss in Compressive strength (%) At 30 days
M14	4.72	12.01
M15	4.14	11.95
M16	3.94	9.13
M17	4.18	11.83

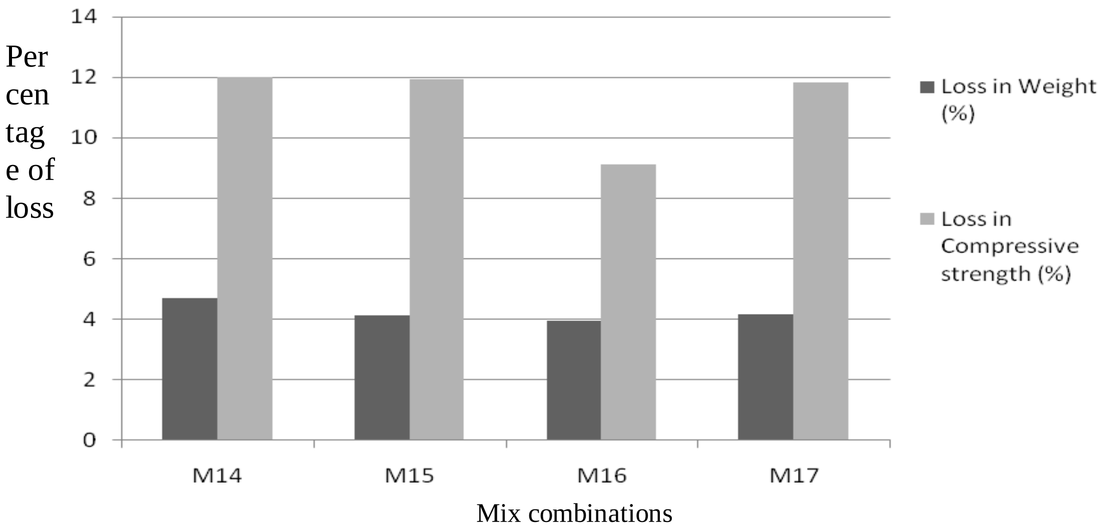


Figure 4.21Graph showing durability studies for M14-M17 mix

As per the study, for the last set of combinations mix M16 ie, silica fume 25% and steel slag 60% shows the least weight loss and it is shows almost same durability property as conventional mix. When we consider the other mixes the increase in silica fume content reduces the durability property of concrete. Throughout the study the optimum mix combination is found to be the mix M7 ie,silica fume 15% and steel slag 50%.

III. CONCLUSION

- As the steel slag content increases, the strength and durability of concrete decreases.
- The increase in amount of silica fume affect the optimum replacement level of steel slag.
- While comparing the results with conventional mix there is no significant improvement in the split tensile strength but the flexural strength is improved by 30%.
- The increase in steel slag content above 50% reduces the durability of concrete.Durability of concrete get reduced due to the porous nature of steel slag.
- The increase in silica fume content above 15% reduces the durability of concrete.
- The silica fume and steel slag content do not affect the long term strength of concrete.
- While comparing the results with conventional mix the best combination obtained is silica fume 15 % and steel slag 50%.
- Moreover with 15% replacement of cement by silica fume and 50% of sand by steel slag the performance of concrete get improved and also it will help to reduce the construction cost and the environmental pollution caused by industrial by products.

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