Mechanical Properties of Concrete by Silica Fume and Partial Replacement of Coarse Aggregate by Steel Slag

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Abstract

Our natural resources are running out, therefore using alternative materials as a partial substitute would result in concrete that is stronger, more environmentally friendly, and has a lower carbon footprint. To safeguard natural resources like coarse aggregates, we are partially substituting coarse aggregates with steel slag of 0, 10, 20, 30, 40 and 50% by weight. Silica fume is used as a mineral additive in varied percentages of 0, 5, 7.5 and 12.5% by weight of cement. Because of the depletion of our natural resources, concrete made partially from alternative materials would be more durable, eco-friendly, and low in carbon emissions. We are partially substituting coarse aggregates with steel slag at weights of 0, 10, 20, 30, 40 and 50% in order to save natural resources like coarse aggregates. Silica fume is used as a mineral component in cement at various weight percentages of 0, 5, 7.5 and 12.5%.

Keywords: Compressive Strength, Silica Fume, Steel Slag Aggregates, Split Tensile Strength

1. Introduction

The manufacture of cement, which accounts for a net 8% of world emissions, is particularly notable for producing high levels of greenhouse gas emissions. A lot of work is being put into research and development to try to lower emissions or make concrete a source of carbon sequestration. Numerous illegal sand mining operations, negative effects on the environment, such as increased surface runoff or the urban heat island effect, and potentially harmful components are some more environmental worries. Concrete is also used to reduce pollution from other sectors by trapping pollutants including silica fume and residue, coal fly ash, and bauxite tailings.

Due to excessive quarrying and resource depletion, we are partially substituting steel slag for natural aggregates in this experiment and silica fume for cement to a certain level in order to increase concrete strength and decrease permeability and thermal cracking (caused by heat of cement hydration). Thus, silica fume and steel slag can be used in place of some of the cement and natural stone aggregates to create environmentally friendly, sustainable concrete (an industrial waste product).

2. Objectives

(a) To maximise the silica fume substitution for cement in some areas.
(b) To maximise the steel slag replacement of coarse aggregate.
(c) To examine the strengths of concrete that has an ideal percentage of silica fume and steel slag mixed with partial replacements of cement and coarse aggregate.

3. Materials

3.1. Cement

The properties of cement are presented in Table 1.

Table 1: Properties of Cement

Sr. No.	Property	Cement (53 Grade)
1	Specific gravity	3.15
2	Fineness	6%
3	Consistency	35%
4	Initial setting time	54 min
5	Final setting time	412 min

3.2. Silica Fume

In the manufacturing of silicon and ferrosilicon alloys in electric arc furnaces, the carbothermic reduction of high-purity quartz with carbonaceous materials such as coal, coke, and wood chips produces silica fume as a by product. The physical properties of silica fume is shown in Table 2.

Table 2: Physical Properties of Silica Fume

Sr. No.	Property	Value
1	Specific gravity	2.2
2	Mean Grain Size (Micrometers)	0.15
3	Specific Surface Area (cm^2/gm)	150,000-300,000
4	Colour	Light to Dark Grey

3.3. Steel Slag

Steel slag is a by-product created during the steel making process. It is non-metallic ceramic substances created when flux, such calcium oxide, reacts with the inorganic non-metallic elements found in steel scrap. The use of steel slag lessens the need for natural rock as a building material, protecting our natural rock resources, and the rapid development of slag utilisation is due to the best possible utilisation and recycling of by-products and recovered waste materials for economic and environmental reasons. The physical and mechanical properties are presented in tables 3 and 4.

Table 3: Physical Properties of Steel Slag

Property	Value
Specific Gravity	> 3.2 -3.6
Dry Rodded Unit Weight (kg/m^3)	.1600-1920
Water Absorption	Up to 3%

Table 4: Mechanical Properties of Steel Slag

Property	Value
Los Angeles Abrasion	20 -25
Sodium Sulphate Soundness Loss	< 12
Angle of Internal Friction	40°-50°
Hardness	6-7

4. Concrete Mix Design

The mix design adopted is 1: 2.56: 3.27.

5. Experimental Investigations

5.1. Compressive Strength Results

The compressive strength conducted in compression testing machine for the cast and cured specimens and are furnished in tables 5 to 7.

Table 5: Compressive Strength of Concrete for Silica Fume

Mix. No.	Silica Fume (% Replacement of Cement Content)	Compressive Strength, N/mm^2		
		28 Days	56 Days	90 Days
1	0%	48.15	52.46	56.12
2	5%	50.43	54.94	58.94
3	7.5%	55.82	60.62	65.24
4	12.5%	52.25	56.81	61.07

Table 6: Compressive Strength of Concrete for Various Proportions of Steel Slag

Mix. No.	Steel Slag	Compressive Strength, N/mm^2		
		28 Days	56 Days	90 Days
1	0%	48.15	52.46	56.12
2	10%	50.43	54.91	58.89
3	20%	53.23	57.72	62.10
4	30%	54.18	58.46	63.37
5	40%	56.51	61.47	66.05
6	50%	53.11	57.77	62.12
7	60%	52.27	56.95	61.01

Table 7: Compressive Strength of Concrete for Combined Partial Replacement of Cement and Coarse Aggregate by 7.5% of Silica Fume and 40% by Steel Slag Aggregates

Mix. No.	**Combined Replacements (%)**	**Compressive Strength, N/mm²**		
		28 Days	**56 Days**	**90 Days**
1	0%	48.15	52.46	56.12
2	40% Steel Slag + 7.5% SF	60.35	65.68	70.48

5.2. Split Tensile Strength Results

Cylindrical specimens of 150 mm diameter and 300 mm height were casted and tested under CTM for tensile strength of concrete and presented in table 8 to 10.

Table 8: Split Tensile Strength of Concrete for Various Proportions of Silica Fume

Sr. No.	**Silica Fume**	**Split Tensile Strength, N/mm²**		
		28 Days	**56 Days**	**90 Days**
1	0%	4.71	5.12	5.48
2	5%	4.96	5.39	5.82
3	7.5%	5.35	5.81	6.24
4	12.5%	5.06	5.51	5.91

Table 9: Split Tensile Strength of Concrete for Various Proportions of Steel Slag

Mix. No.	**Steel Slag**	**Split Tensile Strength, N/mm²**		
		28 Days	**56 Days**	**90 Days**
1	0%	4.71	5.12	5.48
2	10%	4.96	5.36	5.76
3	20%	5.11	5.55	5.94
4	30%	5.25	5.69	6.11
5	40%	5.59	6.09	6.53
6	50%	4.77	5.18	5.56
7	60%	4.70	5.11	5.49

Table 10: Split Tensile Strength of Concrete for Combined Partial Replacement of Cement and Coarse Aggregate by 7.5% of Silica Fume and 40% by Steel Slag Aggregates

Sr. No.	**Combined Replacements**	**Split Tensile Strength, N/mm²**		
		28 Days	**56 Days**	**90 Days**
1	0	4.71	5.12	5.48
2	40% Steel Slag + 7.5% SF	5.95	6.48	6.89

6. Conclusions

- The compressive strength of normal concrete at the age of 28, 56 and 90 days are 48.15, 52.46 and 56.12 N/mm^2.
- The split tensile strength of normal concrete at the age of 28, 56 and 90 days are 4.71, 5.12 and 5.48 N/mm^2.
- At 7.5% partial replacement cement with silica fume, the compressive strength of concrete is 55.82, 60.62 and 65.24 N/mm^2 at 28, 56 and 90 days.
- At 40% partial replacement of concrete with steel slag, the compressive strength of concrete is 56.51, 61.47 and 66.05 N/mm^2 at 28, 56 and 90 days.
- At 40% partial replacement of concrete with steel slag, the split tensile strength of concrete is 5.59, 6.09 and 6.53 N/mm^2 at 28, 56 and 90 days.
- By combination of 7.5% silica fume and 40% steel slag, the compressive strength of concrete is 60.35, 65.68 and 70.48 N/mm^2 at 28, 56 and 90 days.
- By combination of 7.5% silica fume and 40% steel slag, the split tensile strength of concrete is 5.95, 6.48 and 6.89 N/mm^2 at 28, 56 and 90 days.

7. References

1. N. Pannirselvam, K. Chandramouli, V. Anitha, "Pulse Velocity Test on Banana Fibre Concrete with Nano Silica", International Journal of Civil Engineering and Technology, 2018, 9(11), 2853-2858.
2. T. Fujii, T. Ayano, K. Sakata, "Strength and durability of steel-slag hydrated matrix without cement", Proceedings of 29th Conference of Our World Concrete & Structures, Jan 2004, 253-258.
3. T. Fujii, T. Tayano, K. Sakata, "Freezing and Thawing Resistance of Steel Making Slag Concrete", Journal of Environmental Sciences for Sustainable Society, December 2007, 1, 1-10.
4. N. Pannirselvam, K. Chandramouli, V. Anitha, "Experimental Investigation on Special Concrete using Steel Nail", International Journal of Recent Technology and Engineering (IJRTE), March 2019, 7(6S).
5. Q. Hisham, S. Faissal, A. Ibrahim, "Use of low CaO unprocessed steel slag in concrete as fine aggregate", Construction and Building Materials, September 2009, 23, 1118-1125.
6. K. Chandramouli, "Chloride Penetration Resistance Studies on Concretes Modified with AR-Glass Fibres", American Journal of Engineering and Applied Science, 7(3), 2010, 371-375.
7. Anvesh Poralla, Ch. Lakshmi Sowjanya, Dr. K. Chandramouli, "Improvement of Strength Properties on the Partial Replacement of Cement with Copper slag in Concrete", IJATIR, April 2017, 9(5), 752-757.
8. Sri Padma Nilaya Pasupuleti, Dr. K. Chandramouli, "Utilization of Bagasse Ash as Partial Replacement of Cement in High Strength Concrete", SSRG International Journal of Civil Engineering (SSRG-IJCE), Special Issue ICITSET, September 2018.
9. P. Sridevi, Dr. K. Chandramouli, "Experimental Study on Partial Replacement of Cement with Fly Ash and Complete Replacement of Sand with M-Sand", SSRG International Journal of Civil Engineering (SSRG-IJCE), Special Issue ICITSET, September 2018.