Compressive Strength Analysis of Mortar with Partially Replaced Slag Sand and Slag

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Abstract

This study investigates the viability of partially replacing GBFSS (Granulated Blast Furnace Slag Sand) and GGBFS (Ground Granulated Blast Furnace Slag) with M-Sand (Manufactured Sand) and OPC, both individually and in combination, using different mix proportions. The cement mortar cubes were tested to carry out compressive strength test at the end of 3, 7, 28, 56 and 90 day curing. The compressive strength of 30% and 35% mix replaced proportion of individually and blending (GBFSS and GGBFS) were 20.4%, 18.3% and 5.8% (46.3N/mm2, 45.5N/mm2 and 40.7N/mm2) higher than the referenced for 90-day curing. The obtained results are analysed using Anova The partial replacement of Slag Sand and Slag to M-Sand and OPC not only eliminates the waste management complications and its impact on the environment, but also lead towards the sustainable development through the conservation of natural resources.

Keywords: *Slag, Slag Sand, M-Sand, OPC, Compressive Strength, Anova*

1. Introduction

The need for concrete demand is increasing every year due to urbanisation and rapid growth in the industrialization. To meet the utmost in demand, the number of products were produced in industries has also increased. [1] Concrete is the most abundantly produced and used as construction material in this present world, for its feasibility, strength and durability properties [2]. The invention of Cement, i.e. OPC had gained its importance in the production of cement concrete. The unique property of binding aggregates is found. The large amount of cement utilization had caused pollution in to the environment. About 2.10L thousand metric tons of Co_2 per every year is being emitted to atmosphere. In order to manufacture eco - friendly cement/concrete, the ingredients of cement/concrete can be replaced with industrials by-products/wastes like GGBFS, Fly-ash etc. [2,4]. Slag and Slag Sand are termed as an inorganic polymers and waste products generated form iron ore industry, which has significant impact on characteristics like strength and durability. For these characteristics, it is categorized as “Green” binder with extensive capacities for engineering viable materials and the purpose of construction which could be eco-friendly [5, 6]. The feasibility of using Ground Granulated Blast Furnace Slag (GGBS) to replace fine aggregate in concrete, affects the various properties of concrete, such as strength, workability, and durability [7]. Previous researchers have reported the loss of strength by high replacement of BOS (Basic Oxygen Furnace) steel slag alone as replacement of OPC but its use along with GGBS have shown very encouraging results in the studies conducted internationally. The compressive strength, the changes in mineralogy due to hydration, the setting times and the volume stability are discussed based on the available literature. There is a need to study the effect of these ternary mixes to know the optimum level of replacements [8,9].

2. Materials

The materials were used in this research work are OPC (Brand - Coromandel) of 43 Grade. The Slag was procured from JSW Cement Ltd.

3. Methodology

Table 1 and 2 indicate characteristics of OPC and Slag. M-Sand and Slag Sand were sieved using 4.75µ and used as fine aggregates. The samples were casted using CM 1:3. The mortar cubes were tested to carry out compression test using compression testing machine, at the very end of curing age 3, 7, 28, 56 and 90 days. In totality, 465 mortar cubes were cast and tested to get the average values. The methodology adopted in this research work is as per BIS.

Table 1: Characteristics of Slag

Sl No.	Characteristics	Test Results	Requirements as Per IS : 12089
1	SiO_2 (%)	33.30	-
2	Al_2O_3 (%)	21.74	-
3	Fe_20_3 (%)	0.80	-
4	Cao (%)	34.50	-
5	Mgo (%)	8.30	17.0 (Max)
6	Loss on Ignition (%)	0.33	-
7	IR (%)	0.31	5.0 (Max)
8	Manganese Content (%)	0.09	5.5 (Max)
9	Sulphide Sulphur (%)	0.45	2.0 (Max)
10	Glass Content (%)	90	85 (Min)
11	Moisture Content (%)	11.74	-
12	Particle Size Passing 50.0 mm	100%	95%
13	Chemical Mouli (CaO + MgO + Al_2O_3)/ SiO_2	1.93	Greater than or equals to 1.0

*(**Source:** JSW Cement Ltd.)*

Table 2: Characteristics of OPC

Sl. No	Characteristics	Specification as per IS: 269-2015	Test Results
1	LSF (Lime Saturation factor)	0.66-1.02	0.90
2	Alumina Modulus	Min 0.66	1.23
3	Insoluble residue (%)	Max 5.0	2.64
4	Magnesia (%)	Max 6.0	1.16
5	Sulphuric Anhydride (%)	Max.3.5	2.49
6	Loss on Ignition (%)	Max 5.0	2.84
7	Chloride (%)	Max 0.10	0.04

*(**Source:** Coromandel Cement Ltd.)*

In this study Ordinary Portaland Cement was used (Brand:- Coromandel Cement). The characteristics studies resulted the compositions of LSF, Alumina Modulus, Insoluble residue, Magnesia, Sulphuric Anhydride and, Chloride. These are found to be well within the specified limits as per IS: 269-2015

The ingredients used in this study includes OPC, M-Sand, Slag, Slag Sand and, Water. To cast one mortar cube the quantity of ingredient's proportions were indicated in Table 2.3.

Table 3: Ingredients used for one mortar cube of mix

Volume	OPC	M-Sand	SLAG	SLAG SAND	Water (mL)
	in kg				
350.4cm^3 of Mortar	0.164	0.656	0.164	0.669	82.1

To find the optimum compressive strength of partially replaced Slag and Slag Sand mortar cubes the various mix proportions were considered. First From M1 to M10 indicates the partial replacement of Slag Sand to M-Sand with an incremental increase of 5% which ranges from 5% to 50%. Secondly From M11 to M20 indicates the partial replacement of Slag to OPC with an incremental increase of 5% which ranges from 5% to 50%. Finally in combination of both Slag and Slag Sand were partially replaced to OPC and M-Sand with an incremental increase of 5% which ranges from 5% to 50%. The combinations were indicated in the Table 4.

Table 4: Varied Mix proportion of mortar with W/B of 0.5

Proportion, %					Proportion, %				
MIX	**OPC**	**M-Sand**	**SLAG**	**SLAG SAND**	**MIX**	**OPC**	**M-Sand**	**SLAG**	**SLAG SAND**
CM	100	100	-	-	M24	80	80	20	20
					M25	75	75	25	25
					M26	70	70	30	30
M1	100	95	-	5	M27	65	65	35	35
M2	100	90	-	10	M28	60	60	40	40
M3	100	85	-	15	M29	55	55	45	45
M4	100	80	-	20	M30	50	50	50	50
M5	100	75	-	25					
M6	100	70	-	30					
M7	100	65	-	35					
M8	100	60	-	40					
M9	100	55	-	45					
M10	100	50	-	50					
M11	95	100	5	-					
M12	90	100	10	-					
M13	85	100	15	-					
M14	80	100	20	-					
M15	75	100	25	-					
M16	70	100	30	-					
M17	65	100	35	-					
M18	60	100	40	-					
M19	55	100	45	-					
M20	50	100	50	-					
M21	95	95	5	5					
M22	90	90	10	10					
M23	85	85	15	15					

LEGEND

- M-Sand – Manufactured Sand
- OPC - Ordinary Portland Cement
- CM - Control mix
- M1-M10 – Replacement of M-Sand by Slag Sand
- M11-M20 – Replacement of OPC by Slag
- M21-M30 - Replacement of OPC & M-Sand by Slag & Slag Sand in Combination

4. Results and Discussion

4.1 Basic properties

Before mixing and preparing for the production of mortar the basic tests to be conducted. The basic tests includes Sp. Gravity, Std. consistency (%),Initial setting time (min.), Final setting time (min.), Fineness (%),Fineness Modulus, Water absorption (%),Bulk density, (g/cc) and, % air voids for OPC, the results obtained were all well within the limits as per the specifications of IS code.

Table 5: Basic test results of OPC, Slag, M-Sand and Slag Sand

Property	OPC	Slag	Fine Aggregate		Threshold Value	Specification
			M-Sand	Slag Sand		
Sp. Gravity	3.14	3.24	2.71	2.61	Fine Aggregate: 2.6-2.8	IS 383(1970) IS 2386-3(1963)
Std. consistency (%)	32.3	30.3	-	-	26-33	IS 4031-4 (1988)
Initial setting time (min.)	39.7	80.3	-	-	30 (Minimum)	IS 4031-5 (1988)]
Final setting time (min.)	497	1080	-	-	600 (Maximum)	IS 4031-5 (1988)]
Fineness (%)	5.4	5.2	-	-	<10	IS 4031-1 (1996)
Fineness Modulus	-	-	2.81	2.7	Fine sand: 2.2-2.6 Medium sand: 2.6-2.9 Coarse sand: 2.9-3.2	IS: 383(1970)
Water absorption (%)	-	-	0.38	0.56	Coarse aggregate: <1.4 Fine Aggregate:<2	IS 2386-3(1963)
Bulk density, (g/cc)	-	-	1.43	1.4	-	IS 2386-3(1963)
% air voids	-	-	27.1	2.9	-	IS 2386-3(1963)

4.2 Sieve analysis of M-Sand and Slag Sand

The sieve analysis test is to calculate the gradation of the fine aggregates. In current study Slag Sand and M-Sand were subjected to the sieve analysis and the results showed that both fall under zone II category and the gradation curve drawn for Slag Sand and M-Sand represented in Figure 1.

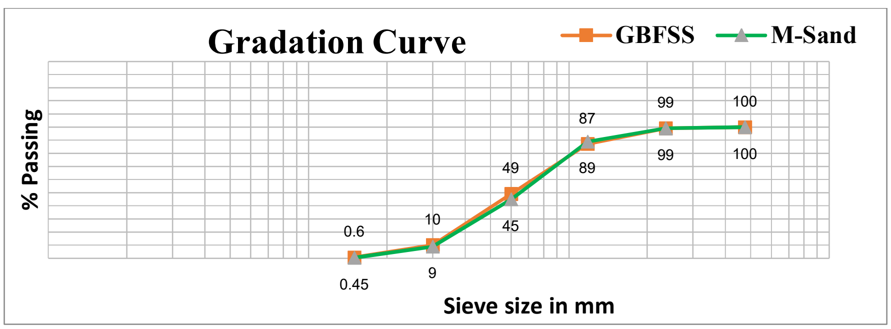

Figure 1: Gradation curve of Salg Sand and M-Sand

4.3 Compressive strength

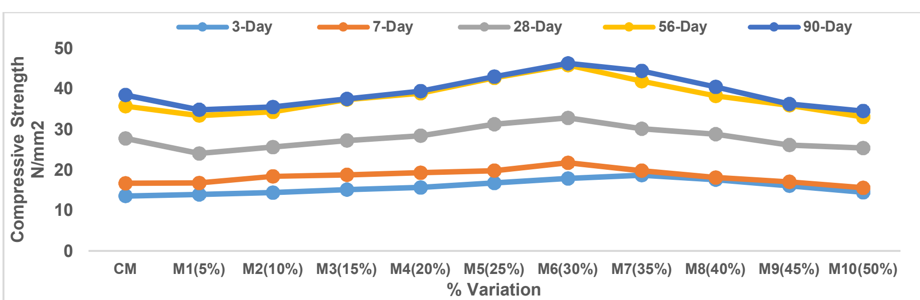

Figure 2: Compressive strength of partially replaced Slag Sand to M-Sand

With the increase in replacement of Slag Sand to M-Sand, gain in strength was seen. This was observed up to 30% replacement, then onwards, decline in strength for all the curing ages were obtained. The maximum compressive strength result obtained at the end of 90-day curing and was 46.3N/mm^2 which was 17% higher than the reference. The partially replaced compressive strength of Slag Sand to M-Sand were represented in Figure 2.

Table 6: Anova of Compressive strength of partially replaced Slag Sand to M-Sand

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5098.001	4	1274.5	138.5249	2.12E^{-26}	2.557179
Within Groups	460.0258	50	9.200515	-	-	-
Total	5558.027	54	-	-	-	-

The partially replaced compressive strength of Slag Sand to M-Sand were subjected to ANOVA test the result showed that, P value is less than 0.05(Significant Level) reject the null hypothesis (Ho) and accept alternative hypothesis (Ha). There is a significant variation among the compressive strength of partially replaced GGBFSS to M-Sand.

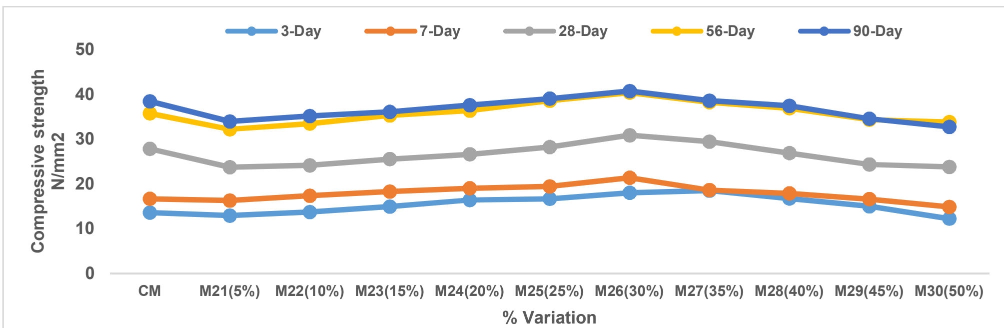

Figure 3: Compressive strength of partially replaced Slag to OPC

When Slag replaced to OPC delay in setting time was observed. With every increase in replacement percent for a constant W/C ratio of 0.5% the initial setting time got increased. When the replacement level was 35%, maximum gain in strength was observed for all the curing ages. For 90-day curing, a maximum compressive strength of 45.5N/mm^2 was observed. Further for all the replacement levels the strength declined. The compressive strength results obtained for partial replacement of Slag to OPC is indicated in Figure 3.

Table 7: Anova of Compressive Strength of Partially Replaced Slag to OPC

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4103.208	4	1025.802	104.5305	1.21E^{-23}	2.557179
Within Groups	490.6711	50	9.813422	-	-	-
Total	4593.879	54	-	-	-	-

The compressive strength results obtained for partial replacement of Slag to OPC was subjected to ANOVA test, the results indicates P value is less than 0.05(Significant Level) so reject the null hypothesis Ho and accept alternative hypothesis Ha. Stating that there is a significant variation among the compressive strength of partially replaced GGBFS to OPC

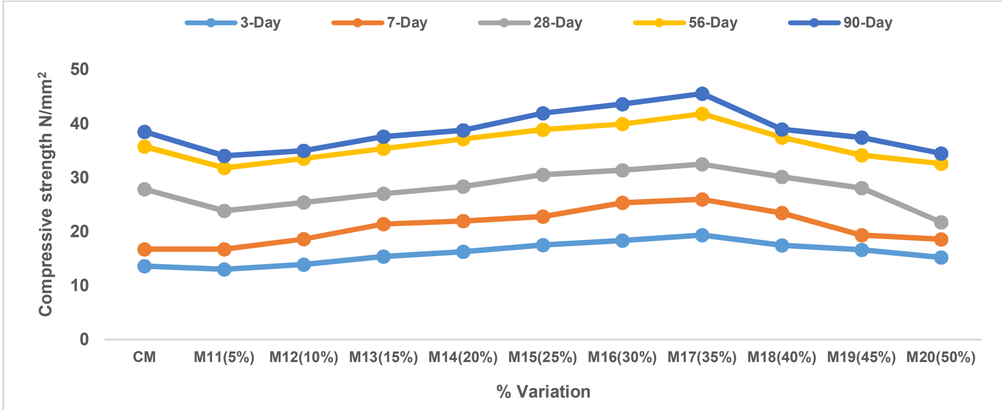

Figure 4: Compressive strength of replacement of Slag Sand& Slag for M-Sand& OPC

At 30% (M26) maximum gain in strength was 40.7N/mm^2, observed at the end of 90 day curing when compared to controlled. Further increase in replacement decrease in strength was noted. Figure 4 represented the compressive strength result of combined both Slag and Slag Sand when partially replaced to M-Sand and OPC.

Table 8: Anova of Compressive strength of replacement of Slag Sand& Slag for M-Sand & OPC

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4320.244	4	1080.061	211.2849	1.17E^{-30}	2.557179
Within Groups	255.5935	50	5.111869	-	-	-
Total	4575.838	54	-	-	-	-

The compressive strength results of combined both Slag and Slag Sand when partially replaced to M-Sand and OPC the obtained P value is less than 0.05(Significant Level) reject the null hypothesis Ho and accept alternative hypothesis Ha. Saying that there is a significant variation among the compressive strength of partially replaced Slag Sand& Slag to M-Sand& OPC

Conclusion

Based on experimental investigations conducted in this research paper following conclusions and recommendations were made for the potential use of Slag and Slag Sand.

1. Slag Sand when partially replaced (30%) to M-Sand the optimum compressive strength results for 3, 7, 28, 56 and 90 day curing were 17.9N/mm^2, 21.7N/mm^2, 32.9N/mm^2, 45.8N/mm^2 and 46.3N/mm^2 on par with that of control mix.

2. Slag when partially replaced (35%) to OPC optimum compressive strength results for 3, 7, 28, 56 and90day curing were 19.3N/mm^2, 26N/mm^2, 32.5N/mm^2, 41.8N/mm^2 and 46 N/mm^{2}when compared to controlled mix.

3. Slag Sand and Slag when partially replaced (30% and 30%) to M-Sand and OPC in combined, the peak compressive strength results for 3, 7, 28, 56 and 90-day curing were

18.1N/mm^2, 21.3N/mm^2, 31N/mm^2, 40.4N/mm^2 and 41N/mm^2 when compared to controlled mix.

4. All the significant P-values for compressive strength were smaller than 0.05 we have enough evidence to reject Ho and accept Ha.

5. To conclude that there is some significant difference between the different mix proportions which had significantly impacted on the compressive strength of mortar.

6. As the percentage of replacement increased beyond optimum the compressive strength got declined.

7. Final conclusion can be drawn that when partial replacement of Slag as cementitious material and Slag Sand as fine aggregate in cement mortar, not only reduces the waste handling problems and its impacts on environment, but also we can reduces the consumption of natural resources, to achieve sustainable development.

References

1. Walid Deboucha., Mohamed Nadjib Oudjit., Abderrazak Bouzid & Larbi Belagraa, (2015), "Effect of incorporating blastfurnace slag and natural pozzolana on compressive strength and capillary waterabsorption of concrete", *Procedia Engineering*, 108, pp. 254 – 261.
2. Guo Xiaolu., Shi Huisheng & Wu Kai, (2014), "Effects of steel slag powder on workability and durability of concrete", *Journal of Wuhan University of Technology-Materials Science Edition*, 29(4), pp. 733–739.
3. Alexander Brand S and Ebenezer Fanijo O, (2020), "A Review of the Influence of Steel Furnace Slag Type on the Properties of Cementitious Composits", applied sciences, 12(3), pp. 1–27.
4. Sabet Divsholi., Bahador., Lim Darren & Teng Susanto, (2014), "Durability Properties and Microstructure of Ground Granulated Blast Furnace Slag Cement Concrete", *International Journal of Concrete Structures and Materials*, 8(2), pp. 157–164.
5. Juan Lizarazo-Marriaga., Peter Claisse & Eshmaiel Ganjian, (2011), "Effect of steel slag andportland cement in the rate of hydration and strength of blast furnace slag pastes", *Journal of Materials in Civil Engineering*, 23(2), pp. 153–160.
6. Subathra Devi V., & Gnanavel B. K, (2014), "Properties of concrete manufactured using steelslag", *Procedia Engineering*, 97, pp. 95–104.
7. Sanbir Manhas and Amir Moohmed, (2018), "A Research-Vaguely Replacement of Fine Aggregate with GGBS in Concrete", *International Journal of Civil Engineering and Technology,* 9(3), pp.65-69.
8. Palod R., Deo S. V & Ramtekkar G. D, (2015), "Preliminary Investigation on Steel Slag:Production, Processing and Cementitious Properties", *Recent Trends in Civil Engineering& Technology*, 6(2), pp. 17-22.
9. Amit Rai., Prabakar J., Raju C. B & Morchalle R. K, (2002), "Metallurgical slag as acomponent in blended cement", *Construction and Building Materials*, 16(8), pp. 489–494.
10. Ganesh Babu K & Sree Rama Kumar V, (2000), "Efficiency of GGBS in concrete", *Cement Concrete Research*, 30, pp. 1031–1036.
11. Rajesh., Rajamallu C and Asadi S. S, (2018), "Experimental Investigation of Self Compacting Concrete (SCC) with Confinement by Partial Replacement of Cement with GGBS, Lime Stone and Fine Aggregate with Pond Ash", *International Journal of Civil Engineering and Technology,* 9 (3), pp. 489-501.
12. Tadepalli Naga Srinu and Kallempudi Murali, (2018), "Mechanical Properties of Steel

Fiber Reinforced Geopolymer Concrete Incorporated with Fly-Ash & GGBS”, *International Journal of Civil Engineering and Technology,* 9 (3), pp. 789–797.

13. Gopalakrishnan R, (2018), “Influence of Concentration of Alkaline Liquid on Strength of GGBS and Fly Ash Based Alumina Silicate Concrete”, *International Journal of Civil Engineering and Technology,* 9 (6), pp. 1229–1236.
14. Ravi and Amudhavalli N. K, (2018), “Study on High Performance Concrete Using GGBS and Robo-sand (M50GRADE)”, *International Journal of Civil Engineering and Technology,* 9 (8), pp. 551-561.
15. Christopher Daniel Raj R., Narne Maruthi Chand and Amudhan V, (2018), “Mechanical Properties of High Volume GGBS Concrete with Micro and Nano Silica”, *International Journal of Civil Engineering and Technology*, 9 (9), pp. 1320-1326.