Compressive Strength Analogy of Mortar by Partially Replaced Slag Sand and Slag to M-Sand and OPC - Anova

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Abstract

Present study is undertaken to investigate the viability of partially replacing GBFSS (Granulated Blast Furnace Slag Sand) and GGBFS (Ground Granulated Blast Furnace Slag) to M-Sand (Manufactured Sand) and OPC (Ordinary Portland Cement) individually and amalgamated in varied mix proportions. The cement mortar cubes were subjected to compressive strength test at the end of 3, 7, 28, 56 and 90 day curing. The compressive strength of 30% and 35% mix proportion of individually and blending (GBFSS and GGBFS) were 20.4%, 18.3% and 5.8% (46.3N/mm^2, 45.5N/mm^2 and 40.7N/mm^2) higher than the reference for 90-day curing. The obtained results were analysed using Anova The partial replacement of Slag Sand and Slag to M-Sand and OPC not only eliminates the waste management problems and its impact on the environment, but also lead towards the sustainable development through conservation of natural resources.

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

1. Introduction

The 20th century will be remembered as a period that saw rapid growth in industrialization. The standard of living has been increasing ever since the evolution of industries. To meet the increase in demand, the number of products produced in industries 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 has gained its importance in the production of concrete. The unique property of binding aggregates is notable. The large amount of cement utilization is causing pollution to the environment. About 2.10L thousand metric tons of Co_2 per 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 polymer and waste product generated form iron ore industries, 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].

2. Materials and Methods

The materials used in this research work are OPC (Brand - Coromandel) of 43 Grade used as a binding material. The Slag was procured from JSW Cement Ltd. Table 2.1 and 2.2 indicate characteristics of OPC and Slag. M-Sand and Slag Sand were sieved using 4.75µ and used as fine aggregates. The cubes were cast using CM 1:3. Laboratory tap water (Source - Borewell) was used for mixing and curing. The mortar cubes were subjected to compression test using compression testing machine (2000kN, Aimil, 2014), at the curing ages of 3, 7, 28, 56 and 90 days. In totality, 465 mortar cubes were cast. For each curing, cubes were cast in triplicate and tested to get the concordant values. The methodology adopted in this research work is as per Bureau of Indian Standards specifications.

Table 2.1: Characteristics of Slag.

Sl No.	Characteristics	Specification as per IS: 12089 -1987	Test Results
1	SiO_2 (%)	-	33.30
2	Al_2O_3 (%)	-	21.74
3	Fe_2O_3 (%)	-	0.80
4	CaO (%)	-	34.50
5	MgO (%)	17.0 (Max)	8.30
6	Loss on Ignition (%)	-	0.33
7	IR (%)	5.0 (Max)	0.31
8	Manganese Content (%)	5.5 (Max)	0.09
9	Sulphide Sulphur (%)	2.0 (Max)	0.45
10	Glass Content (%)	85 (Min)	90
11	Moisture Content (%)	-	11.74
12	Particle Size Passing 50.0 mm	95%	100%
13	Chemical Moduli ($CaO + MgO + Al_2O_3$) / SiO_2	> or equal to 1.0	1.93

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

Table 2.2: 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.)*

The quantity of ingredients used to cast one cube for varied mix proportion of M-Sand, Slag and Slag Sand is indicated in Table 2.3 and 2.4, respectively.

Table 2.3: Ingredients used for one mortar cube of mix.

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

Table 2.4: 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

3. Results and Discussion

3.1 Basic properties

It is observed from Table 3.1, all the parameters were well within the threshold limits. The Initial and final setting time of Slag exceeded the threshold value. It is almost double the value of that of cement. This is due to lack of calcium chloride content.

Table 3.1: 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)

3.2 Sieve analysis of M-Sand and Slag Sand

The sieve analysis results Slag Sand and M-Sand belongs to zone II and the gradation curve obtained is represented in Figure 3.2.

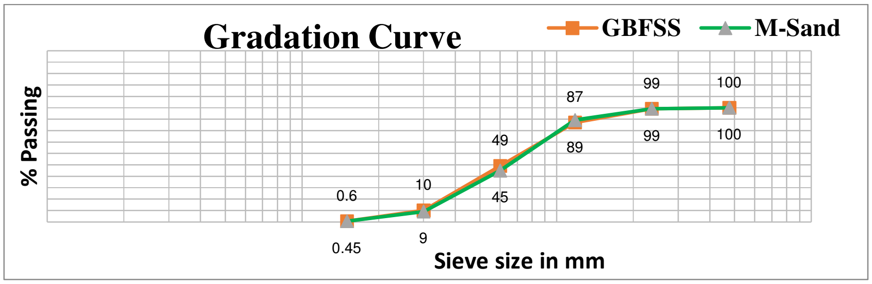

Figure 3.2: Gradation curve of Salg Sand and M-Sand

3.3 Compressive strength

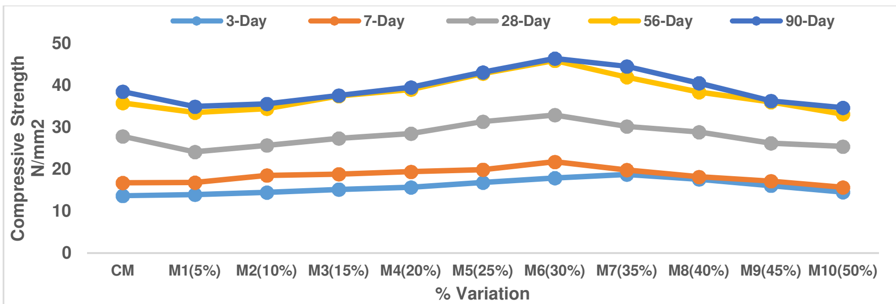

Figure 3.3.1: Compressive strength of partially replaced Slag Sand to M-Sand

Compressive strength of partially replaced Slag Sand to M-Sand is represented in Figure 3.3.1. With the increase in replacement level of Slag Sand to M-Sand, gain in strength was observed. This increase in strength was observed up to 30% replacement of Slag Sand. Then onwards, it started decline in strength for all the curing ages. The maximum value of compressive strength obtained at the end of 90-day curing was 46.3N/mm^2 which was 17% higher than the reference.

Table. 3.3.1 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				

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.

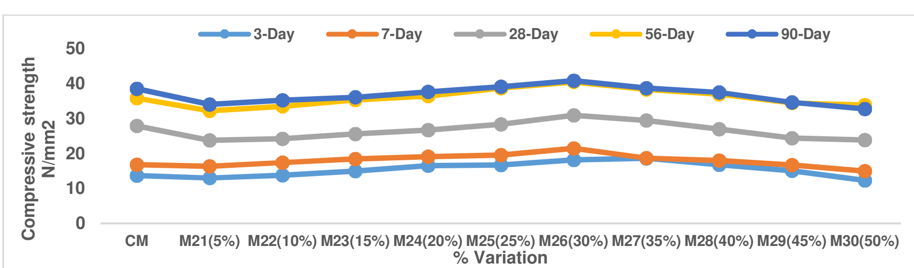

Figure 3.3.2: Compressive strength of partially replaced Slag to OPC

The compressive strength results obtained for partial replacement of Slag to OPC is indicated in Figure 3.3.2. 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.

Table. 3.3.2 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				

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 GGBFS to OPC

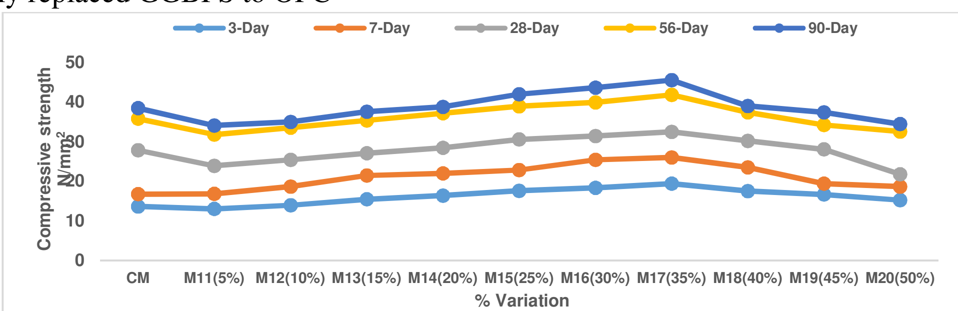

Figure 3.3.3: Compressive strength of replacement of Slag Sand& Slag for M-Sand& OPC

Figure 3.3.3 represents the compressive strength result of combined both Slag and Slag Sand when partially replaced to M-Sand and OPC. The maximum gain in strength observed at 30% (M26) was 40.7N/mm^2 at the end of 90 day curing when compared to controlled specimens. Further increase in replacement decrease in strength was observed.

Table. 3.3.3 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				

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 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 blending, the optimum 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. The significant P-value for compressive strength are greater than 0.05 we have enough evidences to accept Ho and conclude that there is no remarkable differences between number of replacements.

5. All the significant P-value for compressive strength was smaller than 0.05 we have enough evidence to reject Ho and accept Ha.

6. To conclude that there is some significant difference between the different mix proportions which have significant impact on compressive strength.

7. As the percentage increased beyond optimum the compressive strength declined.

8. Finally, it can be concluded that partial replacement of Slag as cementitious material and Slag Sand as fine aggregate in construction industry, not only reduces the waste management problems and impacts on environment, but also reduces the consumption of natural resources leading towards sustainable development.

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