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Evaluating Concrete Strength by Replacing Coarse Aggregate with Steel Slag and Cement with Bentonite Powder

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Abstract: This research investigates the mechanical strength of concrete by partially replacing cement with bentonite powder and coarse aggregate with steel slag.

Bentonite is used at replacement levels of 0%, 10%, 20%, and 30%, while steel slag is uniformly incorporated at 60%. To assess the performance, tests such as compressive strength, split tensile strength, and flexural strength are performed. The results demonstrate enhanced strength properties compared to traditional concrete. Prior studies on the use of bentonite and steel slag highlight their promising potential, and this experiment aims to specifically analyze the strength behavior of concrete incorporating these alternative materials.

Keywords: Induction furnace slag; Super plasticizer; Compressive Strength; Split Tensile Strength; Flexural Strength; Slump Test.

I. INTRODUCTION

Concrete is one of the most widely utilized construction materials globally, known for its ability to be cast into various forms. It is a composite mixture of cement, sand, coarse aggregates, and water, combined in precise ratios to achieve optimal workability, strength, durability, and cost-efficiency.

Its adaptability makes it a cornerstone of the construction industry. Concrete offers advantages such as high compressive strength, rigidity, low thermal conductivity, and fire resistance; however, it falls short in tensile strength, ductility, and crack resistance. In light of increasing environmental concerns and the urgency of combating global warming, the development of sustainable construction methods has become essential.

Rising demand for natural aggregates has made cost-effective construction more challenging. This study addresses these issues by investigating the partial substitution of cement with bentonite powder and coarse aggregates with steel slag as a viable approach for producing environmentally friendly and sustainable concrete.

A. Objectives

The primary objectives of this investigation are:

1) To evaluate the extent of strength enhancement in concrete with the incorporation of steel slag and bentonite powder.
2) To compare the properties of conventional M30 concrete with those of modified concrete, where coarse aggregates and cement are partially replaced with steel slag and bentonite powder, respectively.
3) To determine the optimal percentage of bentonite powder that can effectively replace cement without compromising concrete performance.

B. Problem Statement

In this study, bentonite powder is explored as a supplementary binding material to partially replace cement. The primary objective is to analyze the fresh and hardened properties of M30-grade concrete, incorporating bentonite powder as a partial cement substitute and steel slag as a partial replacement for coarse aggregates.

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II. RESEARCH METHODOLOGY

Figure 2.1 Split tensile testing machine

A. *Material Required Per Cube Of Concrete*

The quantities of material used per cube, cylinder, and beam specimen are expressed in the Table 2.1.1, Table 2.1.2, and Table 2.1.3 below.

Volume of Cube: 0.15x0.15x0.15 = 0.003375 m3

Sr. No.	Water (Lit.)	Replacement %	Cement (kg)	Bentonite (kg)	Fine Aggregate (kg)	Replacement (%)	Coarse Aggregate (kg)	Steel slag (kg)
1	0.675	00%	1.687	00	2.173	00%	3.321	00
2	0.675	10%	1.518	0.169	2.173	60%	1.325	1.993
3	0.675	20%	1.350	0.337	2.173	60%	1.325	1.993
4	0.675	30%	1.181	0.506	2.173	60%	1.325	1.993

Table 2.1.1 Material required for per cube

Volume of cylinder: $\pi/4 \times d^2 \times l = \pi/4 \times 0.15^2 \times 0.3 = 5.301 \times 10^{-3}\ m^3$

Sr. No.	Water (Lit.)	Replacement %	Cement (kg)	Bentonite (kg)	Fine Aggregate (kg)	Replacement (%)	Coarse Aggregate (kg)	Steel slag (kg)
1	1.06	00%	2.651	00	3.414	00%	5.216	00
2	1.06	10%	2.386	0.265	3.414	60%	2.086	3.130
3	1.06	20%	2.121	0.530	3.414	60%	2.086	3.130
4	1.06	30%	1.867	0.785	3.414	60%	2.086	3.130

Table 2.1.2 Material required for per cylinder

Volume of beam: $0.15 \times 0.15 \times 0.7 = 0.01575\ m^3$

Sr. No.	Water (Lit.)	Replacement %	Cement (kg)	Bentonite (kg)	Fine Aggregate (kg)	Replacement (%)	Coarse Aggregate (kg)	Steel slag (kg)
1	3.15	00%	7.875	00	10.143	00%	15.498	00
2	3.15	10%	7.088	0.787	10.143	60%	6.20	9.298
3	3.15	20%	6.3	1.575	10.143	60%	6.20	9.298
4	3.15	30%	5.513	2.362	10.143	60%	6.20	9.298

Table 2.1.3 Material required for per Beam

III. RESULTS AND DISCUSSIONS

A. *Effect Of Bentonite Powder And Steel Slag On Workability Of Concrete*

The workability of M30-grade concrete is assessed using the commonly used Slump Cone test. This test is conducted with a constant water-to-cement (W/C) ratio of 0.40 while incorporating varying percentages of bentonite powder and steel slag. The results for different mix proportions are presented in Table 3.1.

Percentage of Replacement	W/C Ratio	Slump Value	Nature of Collapse
Conventional concrete	0.40	70	True
10% Bentonite 60%Steel Slag	0.40	68	True
20% Bentonite 60%Steel Slag	0.40	72	True
30% Bentonite 60%Steel Slag	0.40	65	True

Table 3.1 Slump cone test on fresh concrete

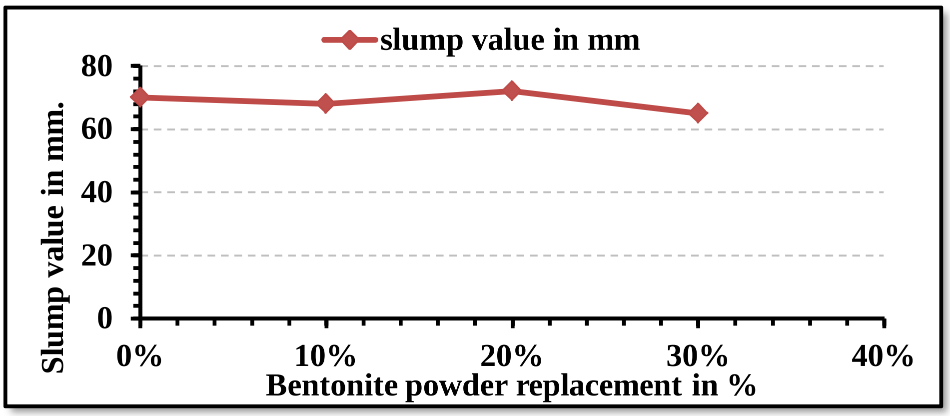

Figure 3.1 Slump of concrete in mm

B. *Compressive Strength*

Sr. No.	Percentage of replacement	Compressive strength in N/mm^2	Average compressive strength in N/mm^2
1	Conventional Concrete	23.98	26.11
		28.92	
		25.44	
2	10% Bentonite 60%Steel slag	31.31	29.44
		29.26	
		27.74	
3	20% Bentonite 60%Steel slag	27.29	30.48
		34.01	
		30.14	
4	30% Bentonite 60%Steel slag	23.95	23.47
		24.94	
		21.53	

Table 3.1.1 Compressive strength of concrete for Different percentage of Bentonite powder and 60% of Steel slag constant for 7 curing days.

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Sr. no.	Percentage of replacement	Compressive strength in N/mm^2	Average compressive strength in N/mm^2
1	Conventional Concrete	38.46	35.88
		36.03	
		33.12	
2	10% Bentonite 60%Steel slag	38.97	37.86
		38.05	
		36.56	
3	20% Bentonite 60%Steel slag	38.75	40.83
		42.92	
		40.83	
4	30% Bentonite 60%Steel slag	34.46	31.44
		29.48	
		30.38	

Table 3.2.2 Compressive strength of concrete for Different percentage of Bentonite powder and 60% of Steel slag constant for 28 days curing.

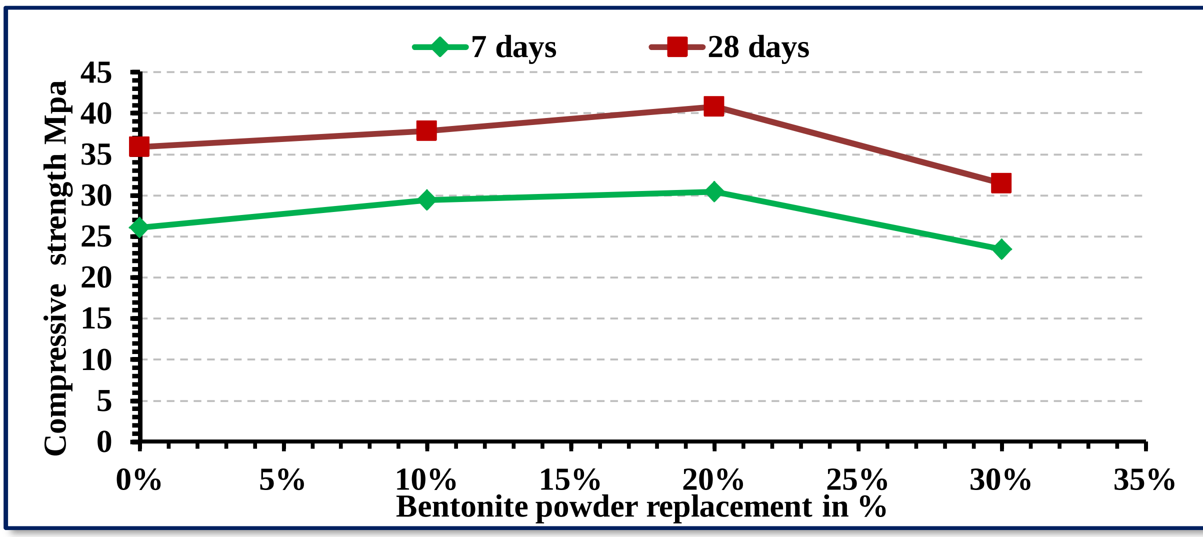

Figure 3.2 Average Compressive strength in MPa.

C. *Split Tensile Strength*

Sr. no.	Percentage of replacement	Tensile strength in N/mm^2	Average Tensile strength in N/mm^2
1	Conventional Concrete	2.52	2.43
		2.06	
		2.70	
2	10% Bentonite 60%Steel slag	2.80	2.79
		2.62	
		2.95	
3	20% Bentonite 60%Steel slag	3.20	2.97
		3.55	
		2.16	
4	30% Bentonite 60%Steel slag	1.92	1.88
		2.12	
		1.61	

Table 3.3.1 Split tensile strength of concrete for Different percentage of Bentonite powder and 60% of Steel slag constant for 7 days curing.

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Sr. No.	Percentage of replacement	Tensile strength in N/mm^2	Average Tensile strength in N/mm^2
1	Conventional Concrete	2.82	2.92
		2.91	
		3.05	
2	10% Bentonite 60%Steel slag	3.20	3.20
		3.57	
		2.83	
3	20% Bentonite 60%Steel slag	3.71	3.85
		3.54	
		4.31	
4	30% Bentonite 60%Steel slag	2.22	2.20
		2.56	
		1.82	

Table 3.3.2 Split tensile strength of concrete for Different percentage of Bentonite powder and 60% Steel slag of constant for 28 days curing.

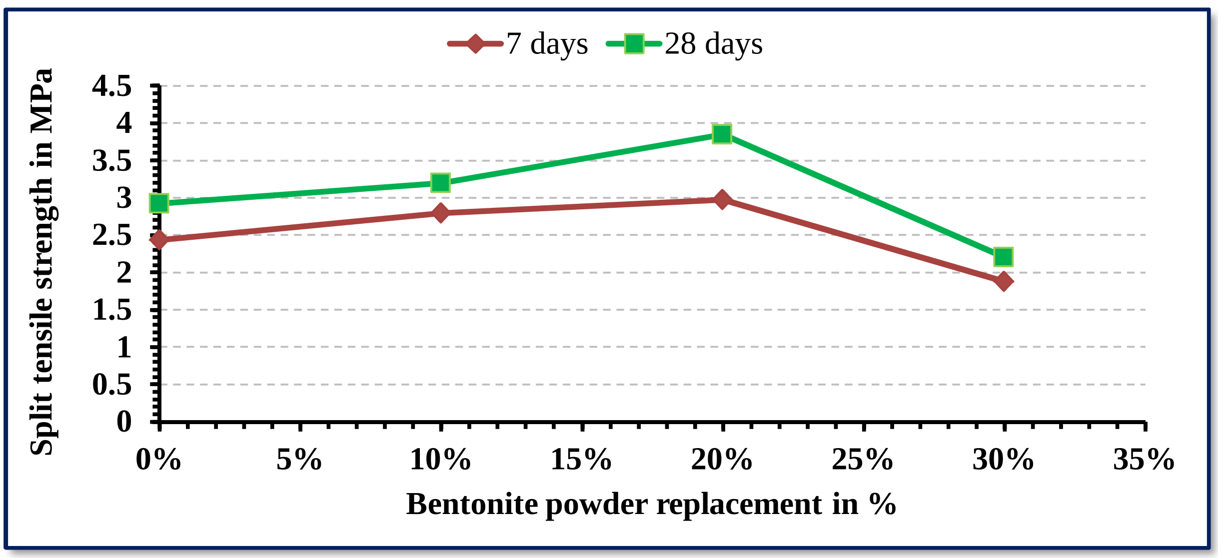

Figure 3.3 Average Split tensile strength in MPa.

D. Flexural Strengt

Sr. no.	Percentage of replacement	Flexural strength In N/mm2	Average Flexural strength in N/mm2
1	Conventional Concrete	4.52	4.65
		5.03	
		4.43	
2	10% Bentonite 60%Steel slag	4.73	4.82
		5.29	
		4.45	
	20%	5.73	

3	Bentonite 60%Steel slag	4.74	5.58
		6.28	
4	30% Bentonite 60%Steel slag	3.87	3.07
		3.09	
		2.28	

Table 3.4.1 Flexural strength of concrete for Different percentage of Bentonite powder and 60% of Steel slag constant for 7 days curing.

Sr. no.	Percentage of replacement	Flexural strength In N/mm^2	Average Flexural strength in N/mm^2
1	Conventional Concrete	5.77	5.34
		5.44	
		4.83	
2	10% Bentonite 60%Steel slag	5.55	5.73
		6.01	
		5.64	
3	20% Bentonite 60%Steel slag	6.79	7.11
		8.10	
		6.49	
4	30% Bentonite 60%Steel slag	4.65	4.29
		4.14	
		4.08	

Table 3.4.2 Flexural Strength of concrete for Different percentage of Bentonite powder and 60% of Steel slag constant for 28 days curing.

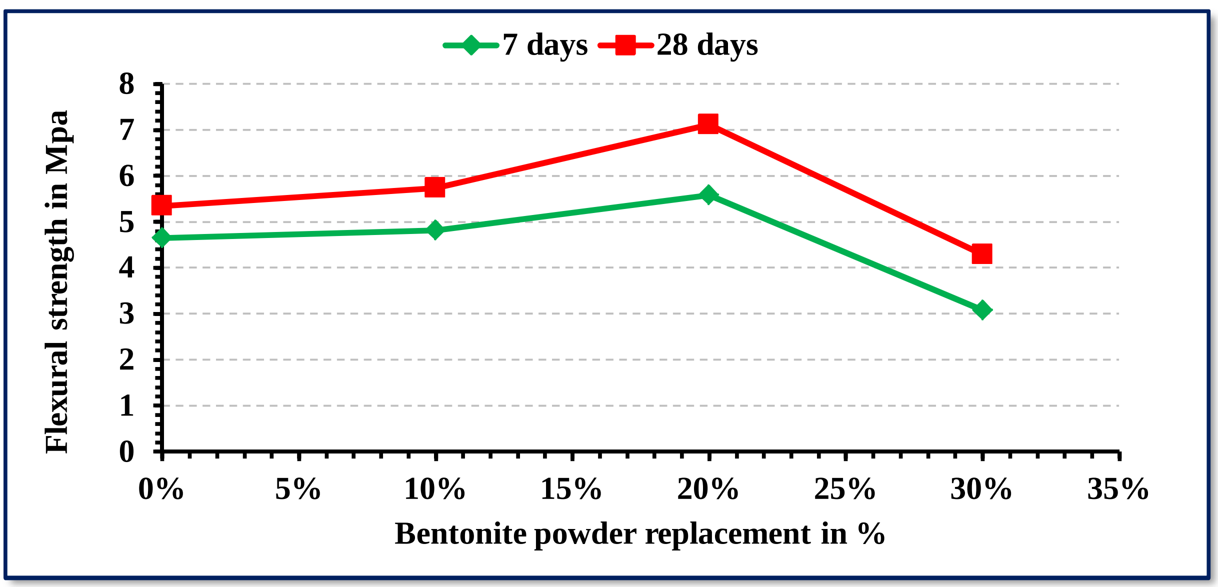

Figure 4.4 Average Flexural strength in MPa.

IV. CONCLUSIONS

Based on the findings and observations from this experimental study, the following conclusions have been drawn:

1) This research demonstrates an effective method for producing strong and durable concrete while addressing the disposal issues associated with steel slag.
2) Test results indicate that replacing cement with up to 20 percent bentonite enhances compressive strength and split tensile strength. However, using bentonite in equal proportion to conventional cement proves to be inefficient.
3) The study confirms that bentonite can partially replace cement without significantly affecting the concrete's strength characteristics.
4) The compressive, split tensile, and flexural strengths of cubes, cylinders, and beams improve when 10 percent and 20 percent of cement is replaced with bentonite and 60 percent of coarse aggregates with steel slag. However, replacing 30 percent of cement with bentonite and 60 percent of coarse aggregates with steel slag results in a decline in strength.
5) A 14.23 and 13.85 percent increase in compressive strength is observed at 20 percent cement replacement with bentonite and 60 percent coarse aggregate replacement with steel slag at 7 and 28 days, respectively, compared to conventional concrete. However, strength decreases by 10.11 and 12.37 percent when 30 percent cement is replaced with bentonite and 60 percent coarse aggregate with steel slag, using an aggregate-to-cement (A/C) ratio of 3.25 and water-to-cement (W/C) ratio of 0.40.
6) An increase of 15.63 and 10.52 percent in split tensile strength and 13.33 and 12.86 percent in flexural strength is recorded at 20 percent cement replacement with bentonite and 60 percent coarse aggregate replacement with steel slag at 7 and 28 days, respectively. However, a reduction of 10.68 and 8.26 percent in split tensile strength and 19.32 and 9.84 percent in flexural strength is noted when 30 percent cement is replaced with bentonite and 60 percent coarse aggregate with steel slag, maintaining an A/C ratio of 3.25 and W/C ratio of 0.40.

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