

Assessing Concrete Strength Through Substituting Coarse Aggregate with Steel Slag and Cement with Bentonite Powder

Krishna Sahebrao Rathod^{1*}, Vaibhav B. Chavan²

Abstract

This study investigates the strength characteristics of concrete by partially replacing cement with bentonite powder and coarse aggregate with steel slag. The research aims to evaluate the mechanical performance of concrete through compressive strength, split tensile strength, and flexural strength tests. Bentonite powder is substituted at varying levels of 0, 10, 20, and 30%, while steel slag is incorporated consistently at 60% as a replacement for coarse aggregate. The objective is to determine the optimal replacement ratio that enhances the overall strength properties of concrete. Bentonite powder, known for its pozzolanic properties, improves concrete's binding capacity and durability, while steel slag, a byproduct of the steel industry, enhances mechanical strength and sustainability by reducing reliance on natural aggregates. The experimental results indicate a significant improvement in the mechanical properties of concrete with these material substitutions. Compared to conventional concrete, the modified mixes exhibit enhanced compressive, tensile, and flexural strengths, demonstrating the feasibility of using bentonite powder and steel slag in structural applications. Furthermore, the study contributes to sustainable construction practices by utilizing industrial byproducts, thereby reducing environmental impact and promoting resource efficiency. The findings suggest that optimizing the replacement levels of bentonite powder and steel slag can lead to high-performance concrete suitable for various construction applications. The promising results encourage further research into durability aspects, microstructural analysis, and long-term performance evaluation. This study underscores the potential of alternative materials in enhancing concrete properties while promoting sustainability in the construction industry.

Keywords: Induction furnace slag, super plasticizer, compressive strength, split tensile strength, flexural strength, slump test

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INTRODUCTION

Concrete is one of the most widely used construction materials globally, known for its versatility in being shaped into different forms. It is a composite material comprising cement, sand, coarse aggregates, and water in specific proportions to ensure the desired workability, strength, durability, and cost-effectiveness. Due to its versatility, concrete holds significant importance in the construction industry. It exhibits high compressive strength, stiffness, low thermal conductivity, and non-combustibility; however, it has limited tensile strength, low ductility, and poor resistance to cracking [1–3].

With growing concerns about global warming, the development of eco-friendly technologies is crucial for sustainable resource management. Achieving cost-effectiveness in construction requires a comprehensive approach, especially given the increasing demand for natural aggregates. To address this challenge, this study explores the partial replacement of cement with bentonite powder and coarse aggregates with steel slag, offering a potential solution for sustainable concrete production [4–6].

OBJECTIVES

The primary objectives of this investigation are:

- To evaluate the extent of strength enhancement in concrete with the incorporation of steel slag and bentonite powder.
- 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.
- To determine the optimal percentage of bentonite powder that can effectively replace cement without compromising concrete performance.

PROBLEM STATEMENT

This study investigates the use of bentonite powder as a supplementary binding material to partially replace cement. The main objective is to evaluate the fresh and hardened properties of M30-grade concrete by incorporating bentonite powder as a partial cement substitute and steel slag as a partial replacement for coarse aggregates [7–9].

RESEARCH METHODOLOGY

Material Required Per Cube of Concrete

The quantities of material used per cube, cylinder, and beam specimen are expressed in the Tables 1–3 and Figure 1.



Figure 1. Split tensile testing machine.

Table 1. Material required for per cube.

S.N.	Water (l)	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

Volume of Cube: $0.15 \times 0.15 \times 0.15 = 0.003375 \text{ m}^3$.

Table 2. Material required for per cylinder.

S.N.	Water (l)	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

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

Table 3. Material required for per Beam.

S.N.	Water (l)	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

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

RESULTS AND DISCUSSION

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 4 and Figure 2 [10–14].

Compressive Strength

Compressive strength is essential for evaluating the load-bearing capacity of concrete. The results indicate that strength improves with 10 and 20% bentonite replacement, peaking at 20%. However, a decline at 30% suggests that excessive replacement negatively impacts concrete performance (Tables 5 and 6 and Figure 3) [14–17].

Split Tensile Strength

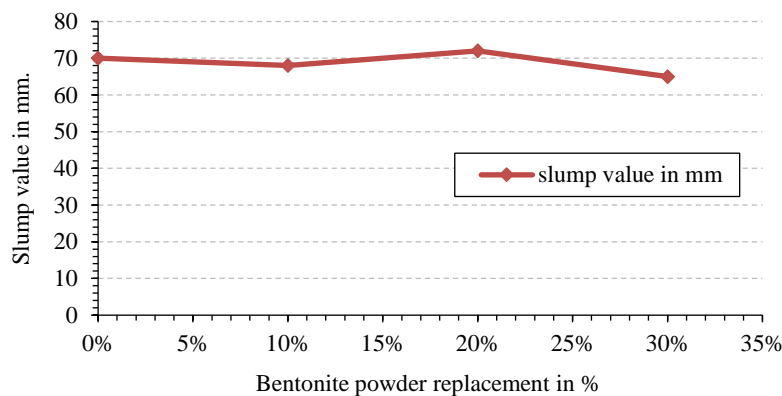
Split tensile strength is an important measure of concrete's resistance to tensile stresses. The results indicate an improvement in strength with 10 and 20% bentonite replacement, with the highest value observed at 20%. However, a decrease is noted at 30%, highlighting the need for an optimal replacement ratio to maintain structural integrity (Tables 7 and 8 and Figure 4) [18–22].

Flexural Strength

Flexural strength is an essential property that determines a concrete mix's resistance to bending forces. The test results show that replacing cement with bentonite powder and coarse aggregate with steel slag affects strength development over time. The highest flexural strength is observed at 20% bentonite replacement, while a decline occurs at 30%, indicating the need for an optimal balance in material substitution (Tables 9 and 10 and Figure 5).

Table 4. Slump cone test on fresh concrete.

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

**Figure 2.** Slump of concrete in mm.**Table 5.** Compressive strength of concrete for Different percentage of Bentonite powder and 60% of Steel slag constant for 7 curing days.

S.N.	Percentage of replacement	Compressive strength (N/mm ²)	Average compressive strength (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 6. Compressive strength of concrete for Different percentage of Bentonite powder and 60% of Steel slag constant for 28 days curing.

S.N.	Percentage of replacement	Compressive strength (N/mm ²)	Average compressive strength (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	

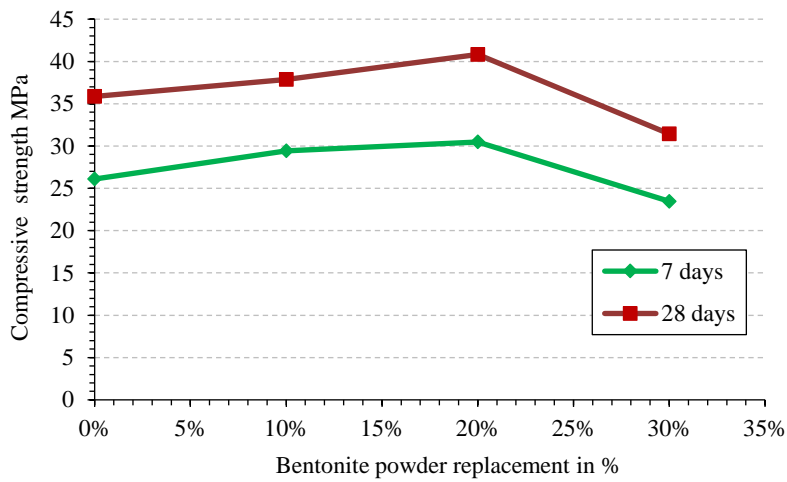


Figure 3. Average compressive strength in MPa.

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

S.N.	Percentage of replacement	Tensile strength (N/mm ²)	Average tensile strength (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 8. Split tensile strength of concrete for Different percentage of Bentonite powder and 60% Steel slag of constant for 28 days curing.

S.N.	Percentage of replacement	Tensile strength (N/mm ²)	Average tensile strength (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	

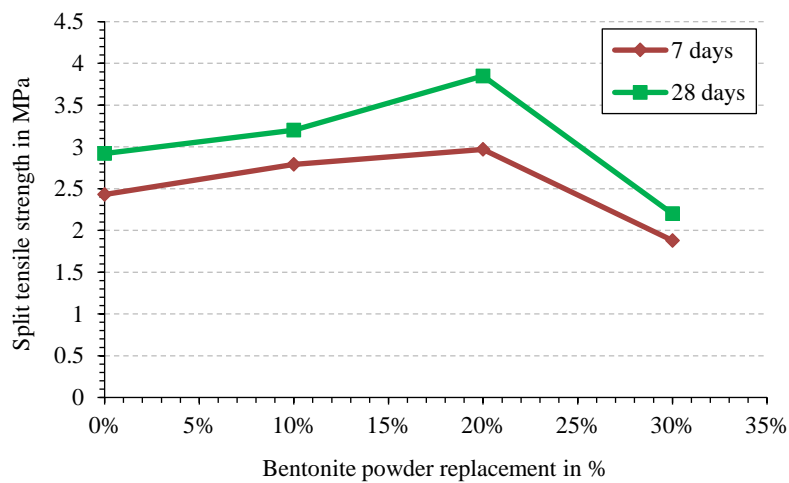


Figure 4. Average Split tensile strength in MPa.

Table 9. Flexural strength of concrete for Different percentage of Bentonite powder and 60% of Steel slag constant for 7 days curing.

S.N.	Percentage of replacement	Flexural strength (N/mm ²)	Average flexural strength (N/mm ²)
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	
3.	20% Bentonite 60% Steel slag	5.73	5.58
		4.74	
		6.28	
4.	30% Bentonite 60% Steel slag	3.87	3.07
		3.09	
		2.28	

Table 10. Flexural Strength of concrete for Different percentage of Bentonite powder and 60% of Steel slag constant for 28 days curing.

S.N.	Percentage of replacement	Flexural strength (N/mm ²)	Average flexural strength (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	

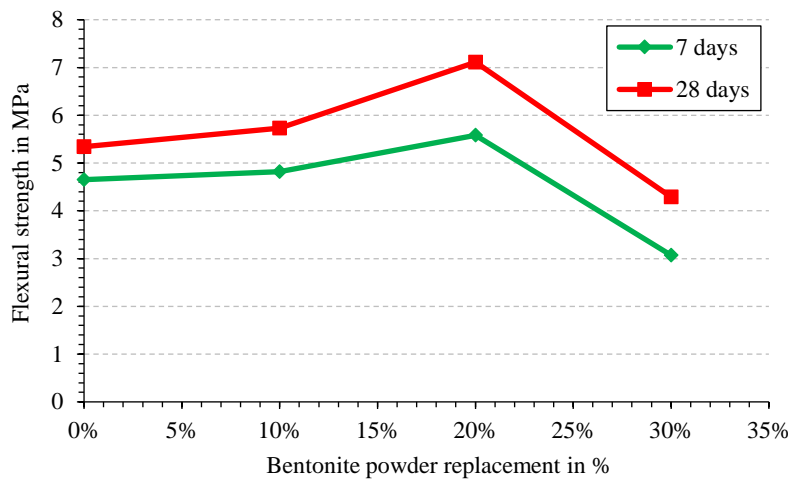


Figure 5. Average flexural strength in MPa.

CONCLUSION

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% 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 and 20% of cement is replaced with bentonite and 60% of coarse aggregates with steel slag. However, replacing 30% of cement with bentonite and 60% of coarse aggregates with steel slag results in a decline in strength.
5. A 14.23 and 13.85% increase in compressive strength is observed at 20% cement replacement with bentonite and 60% 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% when 30% cement is replaced with bentonite and 60% 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% in split tensile strength and 13.33 and 12.86% in flexural strength is recorded at 20% cement replacement with bentonite and 60% coarse aggregate replacement with steel slag at 7 and 28 days, respectively. However, a reduction of 10.68 and 8.26% in split tensile strength and 19.32 and 9.84% in flexural strength is noted when 30% cement is replaced with bentonite and 60% coarse aggregate with steel slag, maintaining an A/C ratio of 3.25 and W/C ratio of 0.40.

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