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Research Article

Experimental Investigation Into The Mechanical & Durability Characteristics Of Alkali Activated Slag Concrete With Partial Replacement Of Waste Marble Powder And Bagasse Ash Powder Under Ambient Temperature Curing

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ARTICLE INFO **ABSTRACT**

This study investigates the utilization of slag as a primary binder in concrete, both individually and in combination with other materials, through activation with alkaline solutions. The research delves into the performance of Alkali Activated Slag Concrete (AASC) specimens, employing various compositions including 100% ground granulated blast furnace slag (GGBS) as well as partial replacements of GGBS with Waste Marble Powder (WMP) and Bagasse Ash Powder (BAP), all cured at ambient temperature. The experimental parameters include 5% and 10% WMP, and 5%, 10%, and 15% BAP as replacements for GGBS, alongside 100% slag sand as fine aggregate. The study employs a 10M sodium hydroxide solution with an alkaline to binder ratio of 0.4. Mechanical properties such as compressive strength, split tensile strength, and flexural strength are assessed at intervals of 1, 3, 7, and 28 days, while durability performance is evaluated through immersion in HCl and $MgSO_4$ solutions for 90 days. Comparative analysis is conducted between mixes of Ordinary Portland Cement (OPC) and AASC mixes containing 100% GGBS or partial replacements. Results indicate that AASC mixes with 10% Waste Marble Powder and 5% Bagasse Ash Powder exhibit higher mechanical strengths, with lower reductions in weight and compression strength compared to OPC mixes.

Keywords: AASC; GGBS; WMP; BAP; sodium hydroxide.

Introduction

In contemporary society, concrete stands out as the predominant construction material, with Ordinary Portland Cement (OPC) traditionally serving as its primary binder, typically comprising 10% to 15% of traditional concrete mixes. However, the widespread use of OPC poses significant environmental challenges, as each ton of OPC production generates roughly an equivalent amount of CO_2 emissions, contributing to environmental degradation. To address this issue, alternative materials such as fly ash and Ground Granulated Blast Furnace Slag (GGBS) are increasingly employed as partial substitutes for OPC due to their ability to enhance the properties and characteristics of cements and concretes. Recent research has demonstrated that through a polymerization process, fly ash or slag can function as standalone binder materials in concrete when activated with alkali activators. Fly ash, abundant in silica and alumina, undergoes a reaction with alkaline activator solutions to form a solid binder via geopolymerization. Similarly, activating slag with highly alkaline materials leads to the formation of a C-S-H gel containing silicate and calcium, akin to what is observed in OPC. However, unlike other types of alkali-activated materials, the final products of geopolymerization are polymers rather than C-S-H gel.

Numerous studies have explored alkali-activated slag concrete as a substitute for Ordinary Portland Cement concrete. However, these studies have utilized various parameters in mix design, lacking clear guidelines or codes to delineate the steps of the mix design procedure. Consequently, there is a pressing need for further research into the mix design of Alkali Activated Slag Concrete (AASC) incorporating GGBS, particularly focusing on ambient temperature curing and the partial replacement of binders with materials such as Waste Marble Powder (WMP) and Bagasse Ash Powder (BAP). This research presents the findings of experimental work on AASC utilizing 100% GGBS and partial replacements of WMP and BAP as binder materials, all cured at ambient temperature. Comparative analysis is conducted between OPC and AASC mixes to assess their respective performances.

2. Experimental Investigation

2.1 Materials

The materials employed in this investigation encompassed GGBS, WMP, BAP, sodium hydroxide, sodium silicate, and superplasticizer. The GGBS utilized in this research originated from JSW and constitutes a by-product of blast furnaces utilized in steel or iron production. The process involves feeding a mixture of iron ore, coke, and limestone into blast furnaces operating at a controlled temperature of approximately 1500°C. Waste marble powder was sourced from local sites in the vicinity, while Bagasse Ash Powder was obtained from Attur (Salem).

Solid sodium hydroxide (NaOH) was dissolved in water to prepare the NaOH solution, with the concentration measured in molar (M) units. For this investigation, a 10M NaOH solution was utilized. The alkaline solution was created by mixing sodium silicate solution with the prepared NaOH solution, and this mixture was left to stand for 24 hours before application. Pelletized sodium hydroxide was dissolved in water. The sodium silicate solution consisted of Na2O at 14.7%, SiO2 at 29.4%, and water at 55.9%, with a Na2O to SiO2 weight ratio of 1:2, ensuring a minimum total soluble solids content of 99%. Workability of the fresh mix was enhanced using a Lignosulfonate-based superplasticizer.

GGBS

Waste Marble Powder

Bagasse Ash

Slag Sand

Sodium Hydroxide Sodium Silicate

Figure 1: Materials

Table 1: Chemical Composition of GGBS, WMP & BAP

Specification	GGBS	WMP	BAP
CaO	37.12%	45.36%	---
Al_2O_3	14.60%	0.41%	9.76%
Fe_2O_3	1.29%	0.27%	3.82%
SiO_2	37.91%	11.56%	70.38%
Magnesium Oxide (MgO)	8.89%	0.38%	--
Magnesium Oxide (MnO)	0.20%	-	--
Loss on Ignition	1.59%	43.78%	5.38%
Insoluble Residue	1.77%	-	2.10%
Sulphide Sulphur	0.57%	0.188%	--

2.2 Mix Proportions

Previous research has established the alkaline to binder ratio at 0.4, with a NaOH molarity of 10M. Additional parameters influencing concrete mix design include a Na2SiO3 to NaOH Ratio of 2.5 and a Fine Aggregate to Binder Ratio of 1.5. To enhance workability, a Lignosulfonate-based Superplasticizer, VARAPLST SP651 (A), was employed. Table 2

Table 2: Details of concrete mix Proportion

MIX ID	DESIGNATION	GGBS (%)	WMP (%)	BAP (%)	ALKALI(M)	SH/SS	S/B	T (^{0} C)
1	OPC (100%)	-	-	-	-	-	0.4	MOIST
2	G100	100	-	-	10	2.5	0.4	AMBIENT
3	G95W5B0	95	5	-	10	2.5	0.4	AMBIENT
4	G90W10B0	90	10	-	10	2.5	0.4	AMBIENT
5	G95W0B5	95	0	5	10	2.5	0.4	AMBIENT
6	G90W0B10	90	0	10	10	2.5	0.4	AMBIENT
7	G85W0B15	85	0	15	10	2.5	0.4	AMBIENT
8	G85W10B5	85	10	5	10	2.5	0.4	AMBIENT

2.3 Specimen preparation and testing

The compressive strength test involves cubes of standard dimensions measuring 100mm × 100mm × 100mm, while split tensile strength is assessed using cylinders with a diameter of 100mm and a height of 200mm. Flexural strength testing utilizes beams sized at 100mm × 100mm × 500mm. Curing of the concrete specimens takes place at ambient temperature. Vibrating the specimens is necessary to ensure adequate quality and compactness due to the rapid setting and high viscosity of Alkali Activated Slag Concrete (AASC). However, the workability of AASC is relatively low. Mixing procedures follow those outlined in a previous study [12], totaling 10 minutes, including 8 minutes of actual mixing time and the casting process.

Compressive strength tests on 100 × 100 × 100 mm^3 concrete cubes are conducted using a Compression Testing Machine with a capacity of 200 tons, while split tensile and flexural strength tests are carried out using a Universal Testing Machine with a capacity of 60 tons. Each mix proportion entails testing three concrete cubes for all properties. The specimens undergo testing at intervals of 1, 3, 7, and 28 days under ambient curing conditions, continuing until failure occurs.

Figure 3 Mixing & Casting of Specimen

The mix design process involves the manipulation of various factors including the percentage of Waste Marble Powder (WMP), the proportion of Bagasse Ash (BGA), and the age of the concrete, all aimed at achieving an optimal blend that not only enhances workability but also improves overall performance.

Test Methods & Methodology

Examining setting time is crucial for understanding the behavior of binding materials. In accordance with IS 4031 standards, both initial and final setting times of the binding paste were determined using the Vicat apparatus across all mixes. Workability, a fresh property of concrete, was assessed using the Slump cone method. To evaluate the characteristics of hardened concrete, tests for compressive, split tensile, and flexural strength were conducted following IS 516 and IS 5816 guidelines. Additionally, durability tests, such as chloride and sulfate attack, were performed over a 90-day immersion period. The experimental methodology is outlined in a flowchart depicted in Figure 4.

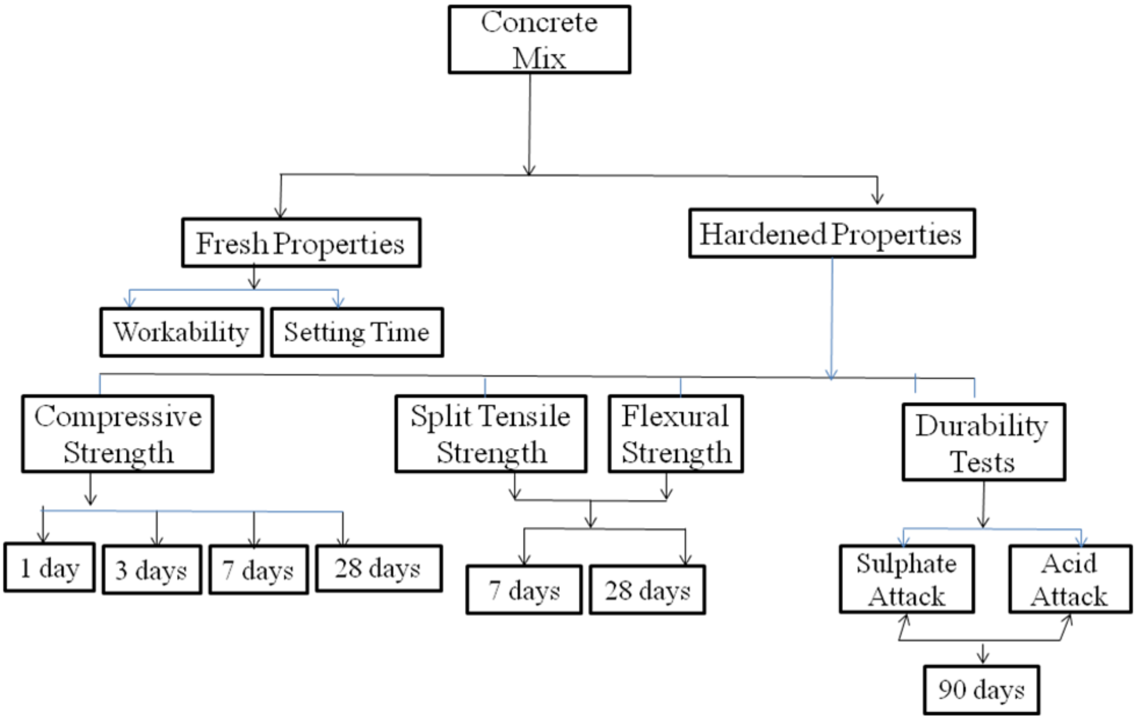

Figure 4 Methodology Flowchart of experimental work

Setting time

Compressive Strength

Split Tensile Strength **Flexural Strength**

Figure 5 Instrumental setup

3. Result and Discussion:

3.1 Setting Time: Identifying characteristics like initial and final setting times is vital in assessing binder materials. The Vicat apparatus, conforming to IS: 4031 (Part 4) – 1988 standards, is employed to perform these tests. Upon analysis, it's evident that alkali-activated slag concrete containing slag, WMP, and BAP sets much faster compared to OPC mixtures. The final setting time of AASC mixes is shorter than the initial setting time of OPC mixtures.

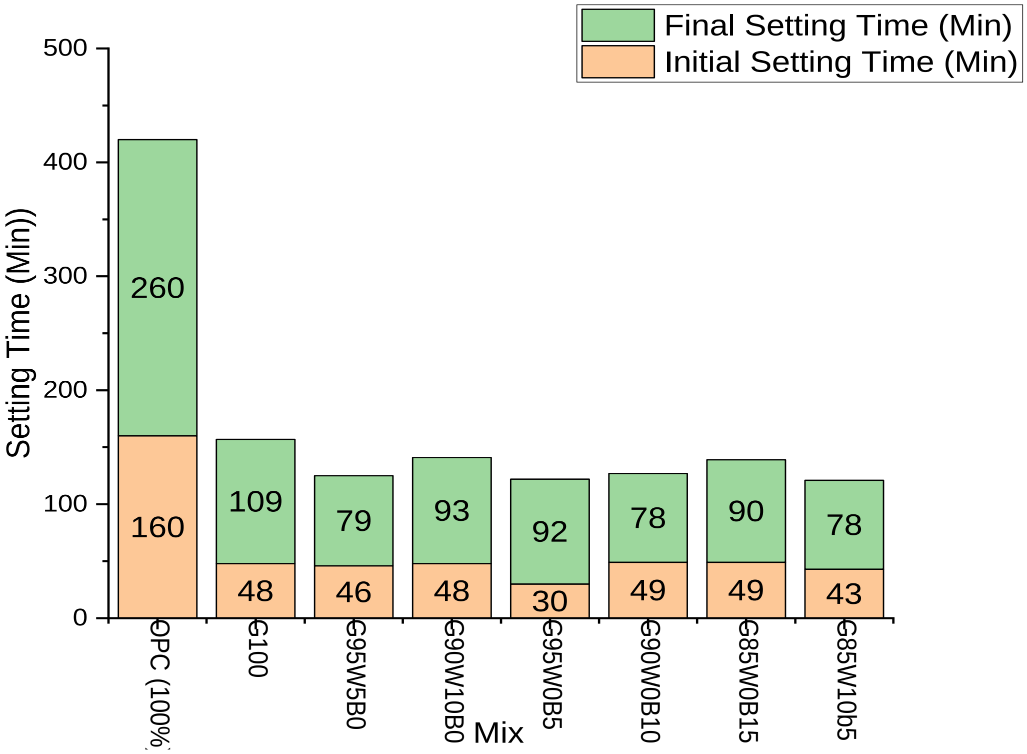

Figure 6 Initial and Final Setting Time

3.2 Compressive Strength: The compressive strength of various concrete mix proportions is assessed at intervals of 1, 3, 7, and 28 days using a Compression Testing Machine with a capacity of 200 tons. Observations indicate that an increase in Waste Marble Powder (WMP) content leads to a corresponding increase in compressive strength, while an increase in Bagasse Ash Powder (BAP) content results in a decrease in compressive strength. A comparison between Ordinary Portland Cement (OPC) and Alkali Activated Slag Concrete (AASC) reveals that AASC samples exhibit strengths of up to 20 MPa at early ages of 1 and 3 days. Notably, acement of WMP yields the highest compressive strength, reaching 60.42 MPa.

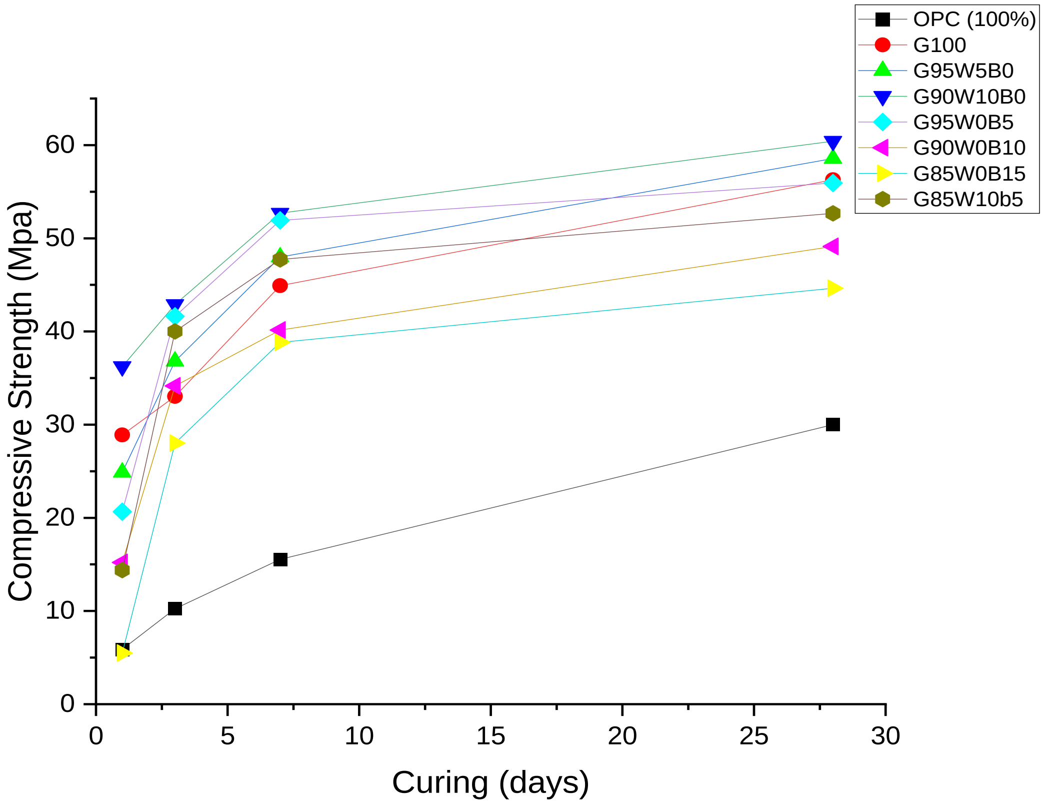

Figure 7 Compressive Strength of all Mixes

3.3 Split Tensile Strength: Split tensile strength measurements for different mixes are obtained at 7 and 28 days of curing. Notably, the tensile strength of AASC mixes is twice that of OPC mixes, with no significant enhancement observed beyond 7 days of curing. The highest split tensile strength is recorded for the AASC mix containing 10% BGA, reaching 12.39 MPa at 7 days and 13.9 MPa at 28 days, while the mix with 100% GGBS achieves a maximum of 13.9 MPa at 28 days.

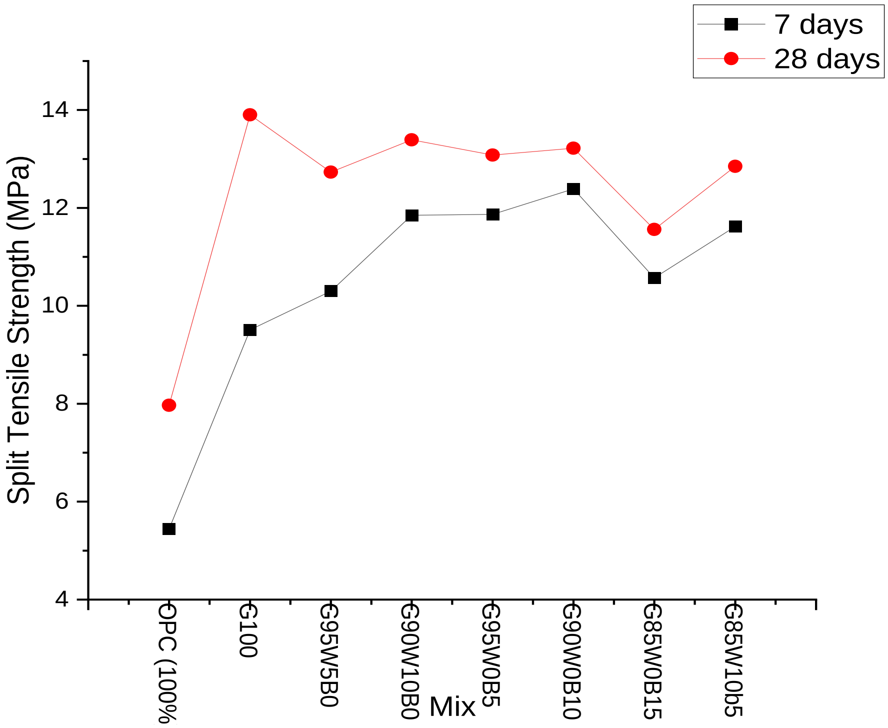

Figure 8 Split Tensile Strength of all Mixes

3.4 Flexural Strength: Flexural strength assessments are conducted on samples after 7 and 28 days of curing. Analysis reveals that AASC mixes incorporating WMP replacement exhibit strengths of 3.6 MPa at 7 days and 6 MPa at 28 days. Moreover, it is evident that there is minimal enhancement in flexural strength beyond the initial 7-day curing period.

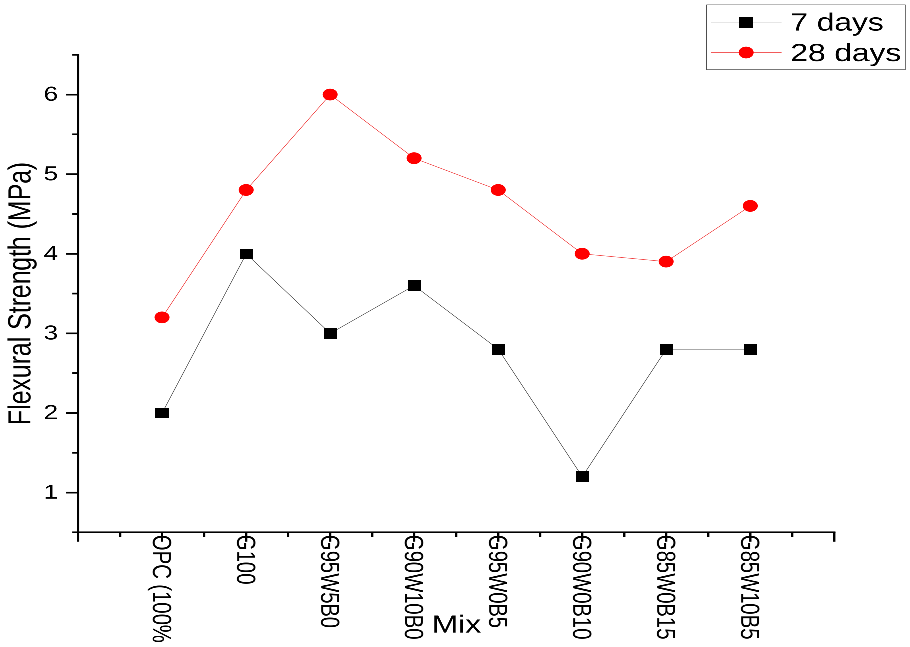

Figure 9 Flexural Strength of all Mixes

3.5 Durability: The durability of both OPC and AASC mixes is evaluated through chloride and sulfate attack tests following a 90-day immersion period. Interestingly, OPC mixes exhibit greater weight reduction compared to AASC mixes, indicating a higher susceptibility to deterioration. When subjected to MgSO4 exposure, compressive strength decreases by up to 50% in OPC mixes. Conversely, reductions in strength are less pronounced in ternary mixes containing 10% WMP and 5% BAP. Notably, AASC mixes display the formation of white patches, as depicted in Figure 10.

Table 3: Durability Test Results

Mix	Wet Wt.(kg)	Dry Wt.(kg)	Wt. After 90 days immersion (kg)		Compressive Strength (Mpa)		Reduction in Wt. (%)		Reduction in Strength (%)	
			HCL	MgSO4	HCL	MgSO4	HCL	MgSO4	HCL	MgSO4
OPC (100%)	2.28	2.39	2.2	2.38	26.06	14.37	19	1.5	13.13	52.10
G100	2.44	2.44	2.42	2.41	49.51	36.7	1.7	2.7	12.04	34.80
G95W5B0	2.46	2.42	2.4	2.41	38.96	43.99	1.8	0.8	33.47	24.88
G90W10B0	2.48	2.39	2.37	2.38	31.2	47.65	2	1	48.36	21.14
G95W0B5	2.46	2.43	2.39	2.41	44.64	46.89	3.6	1.6	20.19	16.16
G90W0B10	2.37	2.36	2.35	2.32	42.11	38.87	1	4	14.27	20.87
G85W0B15	2.51	2.4	2.39	2.38	32.66	35.87	1	2	26.84	19.65
G85W10B5	2.48	2.45	2.42	2.44	42.25	48.74	3	1	19.80	7.48

Figure 10 Flexural Strength of all Mixes

4. Conclusions

1. AASC mixes exhibit an earlier setting time compared to OPC mixes, typically not exceeding 93 minutes in both binary and ternary compositions.
2. The inclusion of waste marble powder leads to an increase in compressive strength, while the addition of bagasse ash powder results in a decrease, with peak values reaching 60.42 MPa and 44.64 MPa, respectively.
3. Split tensile and flexural strengths are notably higher in compositions comprising 100% GGBS and 10% marble powder, registering values of 13.9 MPa and 6 MPa, respectively.
4. AASC mixes demonstrate minimal reductions in weight and compressive strength, indicating robust durability characteristics.

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