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The effect of using Ground Granulated Blast Furnace Slag (GGBFS) in mortar mixes on setting time

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Abstract
This study highlights the potential of GGBFS as an additive to speed up cement hydration, improve cement durability, and lessen the environmental impact of more widely used cement. This study aims to analyze the effect of varying percentages of GGBFS on the setting time of mortar. We chose GGBFS as an additive because of its environmentally friendly properties and its efficiency in enhancing the mechanical characteristics of mortar. This study uses an experimental method with variations in the GGBFS composition of 0%, 10%, 20%, and 30%. We conducted laboratory tests using a Vicat apparatus on 12 samples to measure the initial and final setting times and analyze the slump value. The research results show that the addition of GGBFS significantly affects the setting time of the mortar. A GGBFS composition of 10% resulted in the fastest initial setting time (145 minutes) and the fastest final setting time (245 minutes), compared to the control without GGBFS. (215 menit dan 315 menit). Slump testing indicates that GGBFS reduces the slump value by up to 20% (8.7 cm) but increases at a 30% composition. (11.3 cm). ANOVA analysis shows a significant effect with a calculated F-value (12.14) greater than the F-table (4.07).

Keywords:
ANOVA;
GGBFS;
Mortar;
Setting Time;
Slump;

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INTRODUCTION

Mortar is one of the important building materials that serves as a binding or adhesive agent in construction, consisting of cement, lime, sand, and water. However, Ohemeng et al. [1] research explains how the composition of mortar has evolved with technological advancements. The study investigated the use of Waste Concrete Powder (WCP) and Ground Granulated Blast Furnace Slag (GGBFS) as a mortar mix. The study investigated the use of waste concrete powder (WCP) and Ground Granulated Blast Furnace Slag (GGBFS) as a mortar mix. Journals [2, 3, 4] and studies [5, 6, 7, 8, 9, 10] have published similar research on Ground Granulated Blast Furnace Slag (GGBFS). These studies also measured the setting time of the mortar and came to the same conclusions.

One of the biggest problems with mortar is its low adhesion and tensile tolerance under extreme weather conditions; mortar tends to crack, become brittle, and is less durable, especially in harsh environmental conditions. Therefore, we need additional materials to enhance mechanical characteristics, adhesion, and resistance to environmental influences. Ground Granulated Blast Furnace Slag (GGBFS) is one of the efficient and environmentally friendly mortar additives. In research [11], demonstrated that calcium oxide (CaO), a reactive alkaline earth metal oxide, can act as a potential activator for Ground Granulated Blast Furnace Slag (GGBFS) and serves as an environmentally friendly binding material for mortar mixes. Yao et al [12] conducted a mix design using metakaolin (MK) and Ground Granulated Blast Furnace Slag (GGBFS) as alternative cement materials.

Işıkdağ dan Yalghuz [13] strengthened and extended the life of geopolymer mortar (GM). The things they used were metakaolin (MK), silica fume (SF), ground calcined perlite (GCP), raw perlite (RP), potassium hydroxide (KOH), sodium metasilicate (Na_2SiO_0), normal sand, and tap water. Meanwhile, Chen et al [14] utilized the geopolymerization process to recycle waste products for construction applications, thereby making it environmentally friendly. The results showed that Ground Granulated Blast Furnace Slag (GGBFS) contributed more to the mechanical properties of the geopolymer than fly ash. The results of research made by Sharmin et al [15] talks about other binding materials besides Ground Granulated Blast Furnace Slag (GGBFS). Waste clay brick powder (WCBP) is one of these, demonstrating its effectiveness as a binding material. In research conducted by Zou et al [16] also conducted research on replacing Portland cement to reduce environmental pollution by using waste brick powder (WBP) and ground granulated blast furnace slag (GGBFS). Observations made by Yang et al [17] showed that the strength of Ground Granulated Blast Furnace Slag (GGBFS) is stronger than normal concrete.

Among several types of Portland cement substitutes, this journal uses Ground Granulated Blast Furnace Slag (GGBFS) as a mortar mix. Researchers [18] used experimental methods to investigate the potential use of Ground Granulated Blast Furnace Slag (GGBFS) as a mortar mix. They found that Ground Granulated Blast Furnace Slag (GGBFS) meets the compressive strength requirements of the planned type M mortar. Research [19] looks at what happens when you change the amount of liquid binder in geopolymer mortar that is made with Ground Granulated Blast Furnace Slag (GGBFS) as the base material. Research [20] explains the binder material Ground Granulated Blast Furnace Slag. (GGBFS). A study was published in a journal [21] to find out how the carbonation process changes the physical and chemical properties of radionuclides in mortar that contains ground-granulated blast furnace slag (GGBFS). A study [22] looked at what happened to the structure of mortar made with a mix of ground granulated blast furnace slag (GGBFS) and fly ash when it was heated up. Studies [23, 24, 25, 26, 27, 28, 29, 30, 31, 32] are conducting research on the compressive strength of Ground Granulated Blast Furnace Slag (GGBFS).

Based on several previous articles, it is clear that using Ground Granulated Blast Furnace Slag (GGBFS) as a binding material is a beneficial way to make mortar stronger and last longer. However, the main focus of this research is on the setting time characteristics of mortar, which often becomes a determining factor in the construction process. To ensure that the mortar can achieve sufficient initial strength before applying the load, it is crucial to determine the optimal setting time. The study's results should help a lot in making building materials that work better and are better for the environment. They may also lead to more research on how to combine other ingredients in mortar. This research aims to observe the effect of adding varying percentages of 0%, 10%, 20%, and 30% Ground Granulated Blast Furnace Slag (GGBFS) on the setting time of mortar.

METHOD

This research method employs an experimental method with independent variables. The independent variable represents the percentage variation of GGBFS in the mixture composition (0%, 10%, 20%, and 30%), while the dependent variable is the setting time. This variable measures the time required for the mortar to achieve sufficient stability and initial strength to support construction. Setting time can be measured using a Vicat apparatus or other setting time testing methods. This research will involve the treatment of 4 samples with 3 repetitions of mortar test specimens for setting time testing. Using a composition of 1 cement, 2 sand, and 0.4 water, with the addition of varying percentages of GGBFS: 0%, 10%, 20%, and 30%. The number of test specimens used in this study is 12 mortar setting time test specimens. Table 1 displays the research design table for reference.

Most previous studies have looked at how adding extra binding materials like Ground Granulated Blast Furnace Slag (GGBFS) affects mechanical properties like compressive strength and durability [12][17]. This study, on the other hand, looks at setting time, which is usually just an extra and hasn't become the main focus for optimizing hydration kinetics. The efficiency of applying a faster setting time reduces project delays, especially in construction settings that require high speed.

Material

The materials used for the research are cement, sand, and water. We used Lumajang sand, which satisfies the SNI ASTM C136-2012 standard and has a silt content of less than 3%.

Table 1. Research Design

Variations in GGBFS Presentation (%)	**Weight-based composition ratio**		**Care duration (minutes)**	**Test Object**
	S/C	W/C		Setting Time
0	2	0.4	45,90,135 ...	3
10	2	0.4	45,90,135 ...	3
20	2	0.4	45,90,135 ...	3
30	2	0.4	45,90,135 ...	3

Clean water with drinking requirements, in accordance with the SNI 7974: 2013 specification. At the same time, the cement used is Gresik Brand Portland Composite Cement (PCC), and the slag used as a cement substitute is Ground Granulated Blast-Furnace Slag (GGBFS). GGBFS is in the form of fine granules from PT Krakatau Semen Indonesia (KSI).

Figure 1 displays the image of Ground Granulated Blast Furnace Slag (GGBFS). Fine aggregate, Lumajang sand, can be seen in Figure 2. and the cement in this study is Portland Cement (PC) produced by PT. Semen Gresik type I, which can be seen in Figure 3.

(a) (b)

Figure 1. (a) and (b) Ground Granulated Blast Furnace Slag (GGBFS)

Figure 2. Fine Aggregate, Lumajang sand

Figure 3. Semen Portland (PC)

Research Procedures

We conducted the research in the laboratory to obtain the desired data. The research stages include conducting material tests consisting of cement, water, sand, and GGBFS; performing slump tests; making test specimens; testing the test specimens; and data processing, as shown in Figure 4.

To ensure the mortar mix components meet the desired specifications, the first stage involves inspecting the materials. The material inspection includes testing the sand gradation, moisture content, specific gravity, absorption, and aggregate mud content, which will be conducted at the Brawijaya University Laboratory in Malang. The process of testing the gradation of fine aggregate can be seen in Figure 5.

The second stage is to conduct a concrete slump test using a device called an Abrams cone and a steel tamping rod according to SNI 03-2458-2008. The Abrams cone is a frustum-shaped cone with an open top and bottom, approximately 30 cm high, with an upper diameter of approximately 10 cm and a lower diameter of approximately 20 cm. The tamping rod measures approximately 900 mm x 900 mm, 60 cm long, with a rounded end and a flat base that does not absorb water.

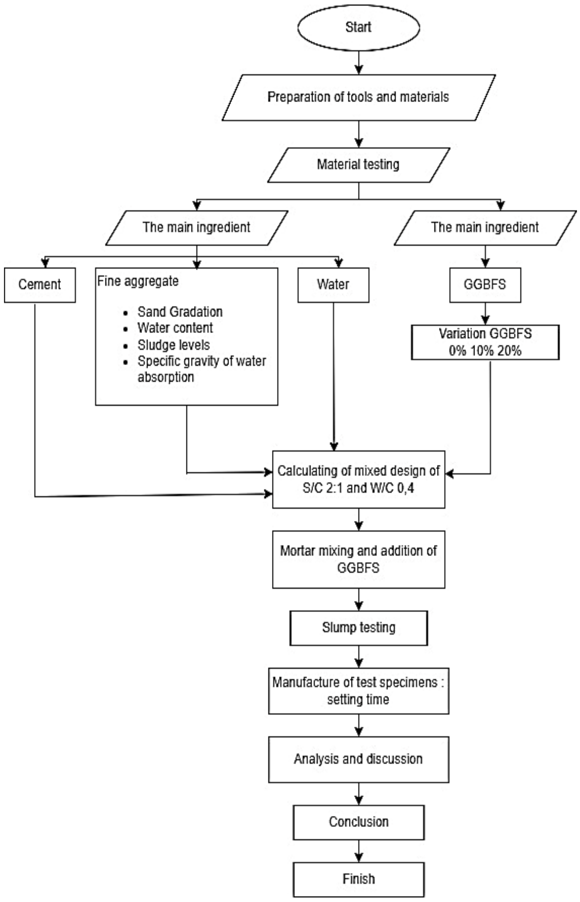


Figure 4. Research Flow Diagram

(a) (b)

Figure 5. Fine Aggregate Gradation Test. (a). the process of sieving fine aggregate; (b). fine aggregate sieve analysis results

Concrete slump is an indicator of the workability of fresh concrete. The slump test begins by wetting the mold and the plate, then placing the mold firmly on the plate. the mold is filled completely in three layers, each layer about one-third the volume of the mold, and each layer is punctured 25 times evenly with a tamping rod. Once the puncturing is complete, we level the concrete surface, slowly lift the mold vertically upwards, and measure the resulting slump.

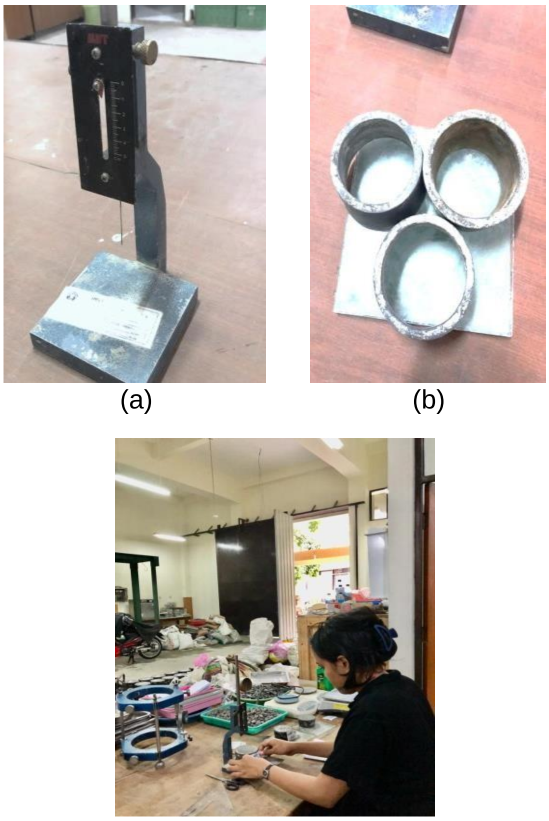
The third step involves preparing the mortar. This includes getting tools and materials ready, like scales, cube molds, mixing tubs, pressing machines, iron plates that are at least 2 cm thick, scoops, buckets, testing machines, leveling spoons, trays, and fine aggregates (sand), water, Gresik cement, and GGBFS as additives. Then conduct fine aggregate inspection, including sieve analysis, unit weight, specific gravity, aggregate absorption, water content, and silt content. Next, conduct a slump test with a maximum limit of 12 cm and take 12 test samples for setting time testing using a Vicat apparatus. Then the testing process involves measuring the setting time after 30 minutes. At that point, we can conduct an analysis of the binding time test results and draw conclusions from them.

The fourth stage is conducting the setting time test, where the preparation of the setting time test specimen for mortar using the Vicat apparatus involves several steps. First, we prepare materials like cement, sand, water, and GGBFS, ensuring their quality meets the applicable standards. The Vicat apparatus must also be in clean and excellent condition, with the appropriate measuring needle (for example, 10 mm or 1 mm). Next, the mortar is made by mixing cement, sand, and water according to the design or standard proportions, using a mixing tool until homogeneous and achieving the appropriate consistency for testing. The mortar is then placed into molds or flat containers, leveled, and compacted to eliminate air voids before the Vicat apparatus is placed on top of it. The testing begins by recording the time since the mixing of water with cement, and then the measuring needle is slowly lowered to record the time it takes for the needle to reach a certain depth (e.g., 5–10 mm). After completion, the measurement results are evaluated and compared with applicable standards or specifications and analyzed to assess the suitability of the mortar for the project's or application's needs. Figure 6 illustrates the process of testing the setting time using a Vicat apparatus.

The fifth stage involves conducting analysis and processing the collected data using Microsoft Excel, incorporating hypothesis testing to examine the effect of GGBFS addition on setting time. This is done using one-way ANOVA (Analysis of Variance) statistical analysis. We then conduct an evaluation based on the research results to draw conclusions.

RESULTS AND DISCUSSION

After conducting the tests, we obtained results from which we could draw conclusions. The results of the laboratory tests include aggregate material testing, slump tests, and setting time measurement.



(a) (b)

(c)

Figure 6. (a), (b) and (c) set Vicat apparatus

Results of Fine Aggregate Testing

This study conducted various tests on fine aggregates, including tests for mud content, water content, gradation, and specific gravity. Table 2 displays the results of the fine aggregate tests. The analysis of fine aggregate grading tests and the limits according to ASTM C-33 can be seen in Table 3.

The results have met the standards set by ASTM C33-03, indicating that the fineness of the fine aggregate is within the range of 1.5% to 3.8%. Figure 7 displays the fine aggregate gradation test graph, demonstrating that the test gradation limits align with the lower and upper limits mandated by ASTM C33-03.

Slump Test Result

We conduct the slump test using an Abrams cone, measuring approximately 10 cm for the top diameter, 20 cm for the bottom diameter, and 30 cm for the height. We perform the slump test for each variation of the mortar mix to evaluate its workability level.

The following is a table showing the effect of adding cement with Ground Granulated Blast Furnace Slag (GGBFS) on the slump value at variations of 0%, 10%, 20%, and 30%. Table 4 displays the results of the slump test. The results of the slump test can be found in Table 4. Figure 8 shows the results of the slump test at GGBFS percentage changes of 0%, 10%, 20%, and 30%.

Table 2. Fine Aggregate Test Results

Test name	Test result	Condition	Information
Water Content	1.60%	-	
Sludge levels	0.20%	Max 5%	Qualify
Specific gravity		2.5 - 2.7	Qualify
Bulk type	2.67		
SSD type	2.69		
Pseudo type	2.7		
Absorption	0.65%	-	

Table 3. Fine Aggregate Gradation Test

No Filter	Left behind		Cumulative	
	Heavy (gr)	Heavy (%)	Left behind (%)	Filter through (%)
8	50	5	5	95
16	193	19.3	24.3	75.7
30	225.5	22.6	46.9	53.2
50	272.5	27.3	74.1	25.9
100	242	24.2	98	2
Pan	17			
Amount	1000		248.30	

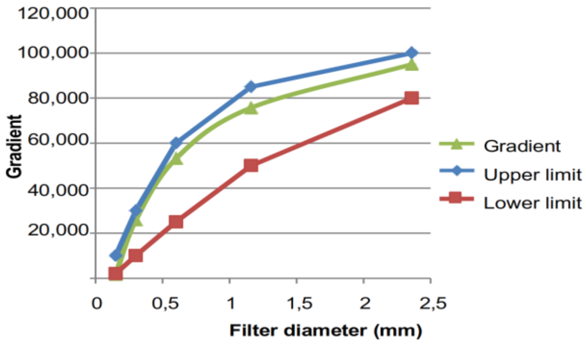


Figure 7. Fine aggregate gradation

Figure 8 shows that when 10% and 20% Ground Granulated Blast Furnace Slag (GGBFS) were added to the mixture, the slump value of the mortar went down by 9.7 cm and 8.7 cm, respectively. When 30% Ground Granulated Blast Furnace Slag (GGBFS) was added, the slump value went up by 11.3 cm, but it did not go above the slump value of 0% Ground Granulated Blast Furnace Slag (GGBFS).

Table 4. Slump Test Result

Composition			Water (kg)	Test Object	Slump (cm)
Cement	Sand	GGBFS			
1	2	0%	2.859	3	14.8
1	2	10%	2.859	3	9.7
1	2	20%	2.859	3	8.7
1	2	30%	2.859	3	11.3

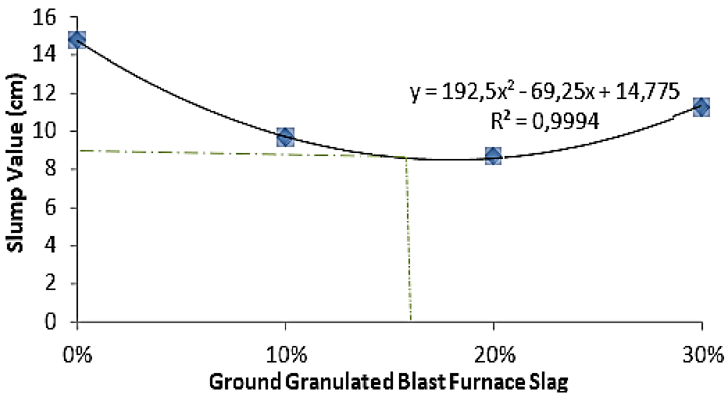


Figure 8. Slump values with variations in Ground Granulated Blast Furnace Slag (GGBFS)

Setting Time Test Results

Following the slump test, a Vicat apparatus tests the setting time of the mortar mixture. We perform the test to determine the initial and final setting times of the mortar. The initial setting time of the mortar should not be less than 45 minutes with a slump of 25 mm, and the final setting time should not exceed 375 minutes with a slump of 10 mm.

The results of the Ground Granulated Blast Furnace Slag (GGBFS) 0% setting time calculations can be seen in Table 5. Table 6 displays the results of the Log Pr and Log t calculations for each time interval and the decrease in Ground Granulated Blast Furnace Slag (GGBFS) 0%. Table 7 displays the results of the Log Pr and Log t calculations for each time interval and the 10% decrease in Ground Granulated Blast Furnace Slag (GGBFS).

Initial Setting Time and Final Setting Time Test Results

The final setting time test can be conducted when the penetration needle value reaches 10 ± 1 mm, while the initial setting time is 25 ± mm using a Vicat apparatus. Table 8 summarizes the initial and final setting time tests using Ground Granulated Blast Furnace Slag (GGBFS) mixtures of 0%, 10%, 20%, and 30%.

Table 5. GGBFS Setting Time 0%

Drop Time (minute)	Decline (mm)
45	50
90	50
135	50
180	40
225	21
270	16
315	11
360	10

Table 6. Pr Log and t Log GGBFS Testing 0%

Drop Time (minute)	Decline (mm)	Log Pr	Log t
45	50	1.70	1.65
90	50	1.70	1.95
135	50	1.70	2.13
180	40	1.60	2.26
225	21	1.32	2.35
270	16	1.20	2.43
315	11	1.04	2.50
360	10	1.00	2.56

Table 7. Log Pr and Log t GGBFS Testing 10%

Drop Time (minute)	Decline (mm)	Log Pr	Log t
45	50	1.70	1.65
90	43	1.63	1.95
135	30	1.48	2.13
180	20	1.30	2.26
225	10	1.00	2.35

Table 8. Setting Time Test Results

GGBFS additive	Initial Sett (minute)	Final Sett (minute)	Interval
0%	215	315	100
10%	145	245	100
20%	185	295	110
30%	175	285	110

Figure 9 shows the graph of the mortar's initial and final setting times for various Ground Granulated Blast Furnace Slag (GGBFS) mixtures. Based on Figure 9, it can be seen that the addition of 10% Ground Granulated Blast Furnace Slag (GGBFS) results in the mortar experiencing a rapid initial and final setting time, specifically 145 minutes and 245 minutes, respectively. Meanwhile, the addition of 20% and 30% Ground Granulated Blast Furnace Slag (GGBFS) causes the mortar to experience a faster initial and final setting time compared to 0% GGBFS, but not faster than 10% GGBFS.

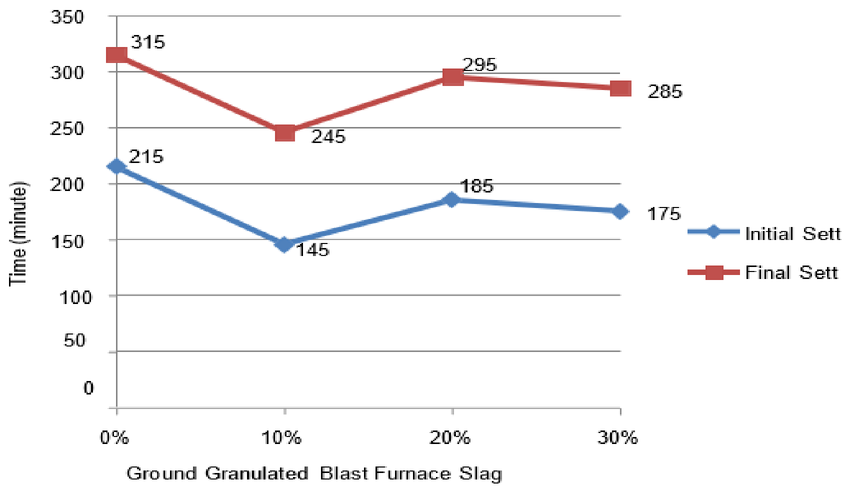


Figure 9. Effect of Ground Granulated Blast Furnace Slag (GGBFS) Percentage on Setting Time

Completely Randomized Design (CRD) Mortar Setting Time

Based on the calculation results of the mortar setting time, a random design result was obtained, as shown in Table 9. Based on Table 9, the ANOVA calculation results are listed in Table 10. The above ANOVA results show that the calculated F value of 12.140293 is higher than the table F value of 4.066181. This means that H1 is true and HO is false. This shows that Ground Granulated Blast Furnace Slag (GGBFS) affects the setting time of the mortar.

Table 9. Completely Randomized Design (CRD) Mortar setting time.

Sampel	GGBFS 0%	GGBFS 10%	GGBFS 20%	GGBFS 30%
1	3,323	2,912	3,120	3,210
2	3,464	3,112	3,225	3,220
3	3,527	3,000	3,290	3,130

Table 10. ANOVA Results

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
GGBFS 0%	3	10,314	3,438	0,010911
GGBFS 10%	3	9,024	3,008	0,010048
GGBFS 20%	3	9,635	3,211666667	0,007358333
GGBFS 30%	3	9,56	3,186666667	0,002433333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0,27999158	33	0,09333052	812,1402925	0,002395	4,066181
Within Groups	0,06150133	38	0,007687667			
Total	0,34149291	711				

Chemical Reaction

When cement, GGBFS, and water are mixed together, clinker compounds in the cement (like C3S and C2S) react with the water to make calcium silicate hydrate (C-S-H) and calcium hydroxide ($Ca(OH)_2$). The reaction process is more complicated when GGBFS is added because it acts as a pozzolanic material and a chemically active substance when it mixes with water and $Ca(OH)_2$.

DISCUSSION

Mortar Setting Time

Based on the setting time tests, the addition of Ground Granulated Blast Furnace Slag (GGBFS) with variations of 0%, 10%, 20%, and 30% resulted in significantly different initial and final setting times. The 10% Ground Granulated Blast Furnace Slag (GGBFS) variation demonstrated the fastest initial setting time of 145 minutes and a final setting time of 245 minutes, in contrast to the 215 minutes and 315 minutes for the 0% Ground Granulated Blast Furnace Slag (GGBFS) variation. Because the setting time is shorter, this means that 10% Ground Granulated Blast Furnace Slag (GGBFS) is the best way to speed up the cement hydration reaction without making the mortar less stable.

Slump Value

The slump test shows that when the 10% and 20% Ground Granulated Blast Furnace Slag (GGBFS) changes were made, the slump values went down to 9.7 cm and 8.7 cm, respectively, compared to the control group that did not have Ground Granulated Blast Furnace Slag (GGBFS). (14.8 cm). This decrease indicates that the use of GGBFS reduces the workability of the mortar, which may be due to its finer particle nature and its higher water absorption in the mix. Conversely, at the 30% variation, the slump value increased to 11.3 cm, but it was still lower than the control. This indicates that a high Ground Granulated Blast Furnace Slag (GGBFS) content can alter the water distribution mechanism in the mortar mix.

Statistical Analysis (ANOVA)

An ANOVA test shows that the F-calculated value (12.140) is higher than the F-table value (4.066). This means that adding Ground Granulated Blast Furnace Slag (GGBFS) has a big impact on how long the mortar takes to set. This conclusion supports the hypothesis that variations in Ground Granulated Blast Furnace Slag (GGBFS) composition can alter the rheological properties and hydration kinetics of the mortar.

Implications

Ground Granulated Blast Furnace Slag (GGBFS) can be considered an efficient and environmentally friendly cement substitute material, especially for accelerating setting time and enhancing the durability of mortar in construction applications.

CONCLUSION

The results of this study indicate that the addition of Ground Granulated Blast Furnace Slag (GGBFS) significantly affects the initial and final setting times of the mortar. The 10% Ground Granulated Blast Furnace Slag (GGBFS) variation resulted in the fastest initial setting time (145 minutes) and the fastest final setting time (245 minutes) compared to other variations, including the control (0% GGBFS). This shows that the 10% Ground Granulated Blast Furnace Slag (GGBFS) mix can speed up the process of cement hydration without making the mortar less stable.

The addition of Ground Granulated Blast Furnace Slag (GGBFS) resulted in a decrease in the slump values, which dropped to 9.7 cm and 8.7

cm at 10% and 20% changes, respectively, compared to 14.8 cm for the control group without the addition. This means that the mortar is harder to work with because Ground Granulated Blast Furnace Slag (GGBFS) has smaller particles and can soak up more water. Conversely, the addition of 30% Ground Granulated Blast Furnace Slag (GGBFS) increased the slump value to 11.3 cm but still lower than the control.

The ANOVA analysis revealed that GGBFS significantly influences the setting time of mortar. The F-value (12.140) is higher than the F-table value (4.066). This supports the hypothesis that the variation of Ground Granulated Blast Furnace Slag (GGBFS) in the mortar mix significantly affects the properties of the mortar.

SUGGESTIONS AND RESEARCH LIMITATIONS

This study only looks at Ground Granulated Blast Furnace Slag (GGBFS) as an additive in mortar mixtures. It doesn't look at how other additives, like fly ash or metakaolin, affect the mixtures. Additionally, this study prioritizes the analysis of mortar setting time as the main variable.

The research suggests that to get a better mortar mix, more research should be done by testing different combinations of Ground Granulated Blast Furnace Slag (GGBFS) with other additives like fly ash, silica fume, or waste clay brick powder (WCBP).

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