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Mix Design of Geopolymer No-fines Concrete with Fly Ash and Ground Granulated Blast Furnace Slag

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ABSTRACT

The use of geopolymers as a cement replacement in no-fines concrete can be a solution to address the impact of cement production on global warming. The absence of standardized mix designs for geopolymer paste poses a challenge, particularly concerning workability in no-fines geopolymer concrete mixes, where insufficient workability can hinder compacting, while excessive workability may cause segregation. Additionally, geopolymer often exhibits a quick hardening time, necessitating the use of retarders such as borax. This study aims to evaluate the impact of varying the ratio of alkali activator to cementitious material (*A*) at 0.25, 0.30, and 0.35, with the addition of borax (*C*) at 3% and 5%, on the flow and hardening time of geopolymer paste. Furthermore, this study also aims to investigate the effect of the cement-to-aggregate volume ratio (*P*) on geopolymer no-fines concrete properties, particularly compressive strength and unit weight. In no-fines geopolymer concrete formulation, the absolute volume of geopolymer paste is equivalent to the volume of cement paste with a 0.4 water-to-cement (w/c) ratio, with a cement-to-aggregate volume ratio of 1:4 and 1:6. The geopolymer mixture consists of fly ash and GGBFS in a 50:50 ratio. The geopolymer activator consist of NaOH (10 M) and Na_2SiO_3 in a *SS/SH* (*R*) ratio of 2. The research results indicate that reducing the *A* ratio from 0.35 to 0.25 decreases flow and accelerates the hardening time of the geopolymer paste. Increasing the borax (*C*) content from 3% to 5% can prolong the hardening time and reduce flow (from 20.25 to 19.25 cm at an A ratio of 0.30). The test results of geopolymer no-fines concrete properties that increasing the volume ratio (*P*) from 1:4 to 1:6 can reduce the compressive strength from 30.95 to 13.27 MPa and the unit weight from 2158.83 to 1843.38 kg/m³ at (*A*) 0.35. However, in the concrete samples at this ratio, some voids were covered by paste. Therefore, it is recommended to use ratio (*A*) 0.30.

1. Introduction

Concrete is the most commonly used construction material worldwide. The development of special concrete is increasing with the growth of the economy and technology [1]. One of the development formulations of specialty concrete is concrete without sand. Concrete without sand is also known as no fine concrete, pervious concrete, porous concrete, and permeable concrete. No-fines concrete requires only a small amount of cement paste to envelop each aggregate grain, so no-fines concrete is classified as lightweight concrete with a unit weight between 1800 kg/m³ and 2200 kg/m³ [2]. No-fines concrete is one of the development formulations of environmentally friendly concrete used in various civil engineering and architectural projects, such as non-structural concrete, tennis courts, pedestrian paths, brick, concrete block, retaining wall, and low-traffic garden areas [3]. No-fines concrete also has special properties, namely heat insulation, fast and simple manufacture, and permeability to water, which has pores in the concrete reaching about 20-25% [4].

In the manufacture of no-fines concrete, Ordinary Portland Cement (OPC) is generally used as a binder. However, cement production is responsible for approximately 7% of global CO_2 emissions [5], highlighting the need for more sustainable alternatives. Research is required to replace OPC with other binders, such as geopolymer binders, to create a more environmentally friendly and sulfate-resistant no-fines concrete. Geopolymer binders, made from industrial byproducts like fly ash and ground granulated blast furnace slag (GGBFS), offer a sustainable

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option that reduces the carbon footprint of concrete production while enhancing its durability [6].

Geopolymer binders like fly ash have been discovered to enhance the bond strength of no-fines concrete by improving the quality of the hardened binder paste through the pozzolanic reaction [7]. Moreover, the addition of 20% class F fly ash has shown to have positive effects on the mechanical strength of no-fines concrete [8].

Class F fly ash, known for its low reactivity, requires additional CaO from mineral additives to speed up the dissolution of alumina and silica components [9]. To overcome the drawbacks of class F fly ash, the addition of ground granulated blast furnace slag (GGBFS), which contained high levels of CaO, was effective in addressing its weaknesses [10]. The addition of GGBFS increased the CaO content and accelerated the reaction, enabling curing under ambient temperature, which is more practical for in-situ applications. This research also observed that the addition of GGBFS could improve the reactivity of binders. The addition of GGBFS improved the FA reactivity and increased the compressive strength development under ambient curing conditions. The optimal FA/GGBFS ratio was found to be 0.50, determined from the optimal flowability and compressive strength test results of the mixture, achieving a compressive strength of 80 MPa at 28 days.

In the context of no-fines geopolymer concrete, research showed that an increase in the amount of GGBFS increased the strength in each ratio, while taking into account the compaction factor as well. The strength also exhibited a gradual increase as the cement/aggregate ratio was raised from 1:8 to 1:4. Reducing the size of the aggregate led to significant improvements in compressive strength. For instance, with a 20% replacement of fly ash with GGBFS, compressive strength reached 21.5 N/mm^2, whereas using large-sized aggregate at the same ratio with 30% GGBFS resulted in only 15.1 N/mm^2 of compressive strength [11]. Furthermore, studies have indicated that when the aggregate size is reduced to 10 mm and 20 mm, compressive strength can further increase, with a 39.9 MPa compressive strength achieved under optimized conditions, demonstrating the impact of aggregate size on the performance of no-fines geopolymer concrete [12].

The use of larger-sized aggregates is ideal for producing geopolymer pervious concrete that offers improved permeability and tensile strength. Additionally, it is possible to decrease the amount of paste in the geopolymer pervious concrete without compromising, and potentially even enhancing, its mechanical strength [13]. To further optimize the mechanical properties, the choice of activator is also crucial in influencing the geopolymer binder's performance.

In addition to the effects of aggregate size and binder content, the type of activator used plays a significant role in enhancing the properties of the geopolymer binder. According to the study, FA-GGBFS geopolymer exhibits superior properties when activated with $NaOH+Na_2SiO_3$ compared to NaOH alone. This difference could be attributed to the additional silica in the mixture supplied from the Na_2SiO_3 source, as it increases the SiO_2 content in the paste. This addition facilitates the formation of a closely packed anion structure, resulting in a cross-linked configuration and consequently improving compressive strength. Therefore, this study utilized the combination of $NaOH+Na_2SiO_3$ as the activator [14].

Weaknesses in the combination of FA and GGBFS were observed, where GGBFS addition accelerated the polymerization process and thus contributing to rapid setting time. The effect of increased GGBFS in accelerating setting time could be explained in terms of the increased reactive Ca content from the GGBFS source in the mixture [10]. Hence, it necessitates the incorporation of a retarder, such as borax.

A study investigated the influence of borax as a retarder on the setting time of geopolymer paste. Several parameters were investigated, including the sodium hydroxide molarity ranging from 10 M to 14 M with increments of 2 M and borax addition of 1, 3, and 5% by binders. The results revealed that the addition of 1, 3, and 5% borax resulted in an increase in initial setting time duration by 23, 44, and 52 minutes, respectively [15] .

Although extensive research has been conducted on the application of geopolymer binders in no-fines concrete, a comprehensive understanding of the combined effects of binder composition, retarder dosage, and cement-to-aggregate ratios on fresh and hardened properties remains limited. Furthermore, the optimization of mechanical performance and permeability for practical non-structural applications has not been adequately addressed. These research gaps highlight the need for further investigation to develop sustainable and high-performance no-fines geopolymer concrete.

To address these gaps, this study aims to ascertain the optimal composition of geopolymer paste in no-fines concrete, focusing on the flow and setting time of geopolymer paste as the investigated parameters. Upon identifying the optimal geopolymer paste, subsequent testing will involve comparing different cement-to-aggregate ratios to evaluate the mechanical properties of the concrete, specifically compressive strength and density. This study utilized geopolymer binders comprised of fly ash and GGBFS in a 50:50 ratio, with the addition of borax (3% and 5%) for the production of no-fines concrete.

2. Methods

2.1. Material

Binder is a material used to bind or unite other components in a substance. In this study, the binder used for geopolymers consists of fly ash (FA) and ground granulated blast furnace slag (GGBFS). The fly ash was obtained from the PLTU Paiton in East Java, Indonesia, while the ground granulated blast furnace slag (GGBFS) material used originated from PT. Krakatau Semen Indonesia. The chemical compositions of these materials are provided in Table 1**.**

X-ray fluorescence (XRF) analysis, as detailed in Table 1 provided a breakdown of the oxide composition of fly ash. The categorization of fly ash into Class C and F was based on ASTM C618-22 standards, where the differentiation relied on the CaO content. According to ASTM C618-22, Class F fly ash, with a maximum CaO content of 18%, exhibited pozzolanic properties, while class C fly ash, having a higher CaO content (>18%), showed both pozzolanic and cementitious properties. The minimum required sum of SiO_2, Fe_2O_3, CaO, and Al_2O_3 for both classes was 50%. The fly ash utilized in this study was classified as class F due to its CaO content being below 18% (specifically, CaO 12.7%) and meeting the minimum sum of SiO_2, Fe_2O_3, CaO, and Al2O3, which amounted to 83.5% [16]. The former ASTM C618-12, which specified a maximum CaO content of 10% for class F, suggests that under this previous guideline, it would have been categorized as class C. It is noteworthy that despite being classified as class F in this study, the fly ash displays a short setting time and can be cured under ambient temperature, characteristics typically associated with class C fly ash [17].

2.2. Alkali Activator

To activate the binders, a combination of alkali activators including sodium hydroxide (NaOH), sodium silicate (Na_2SiO_3), and borax pentahydrate was employed. High-purity NaOH pellets (98%) were obtained from PT AKR Corporindo Tbk, while the Na_2SiO_3 solution, with a density of 1.68, was obtained from PT Sinar Sakti Kimia. Borax pentahydrate ETIMADEN, with a purity of 99.9%, was acquired from Intiprimacool, an online e-commerce platform.

The NaOH solution was prepared by dissolving NaOH pellets in distilled water until achieving a concentration of 10 M. Molarity of 10 M was chosen as it was the optimum concentration based on previous studies [18]. Borax is added to the solution while still hot to aid in its dissolution and homogenization, with the weight of borax calculated as a percentage of 3% and 5% relative to the weight of the binder in the mixture. The borax mixture used has a purity of 99.9%, with a B_2O_3 content ranging between 48-49.35%, and particle size between 0.075-1.180, originating from production by Eti Maden. After the molar mixture is prepared, the solution is allowed to cool to room temperature for 24 hours before use. Subsequently, the solution is combined with the Na_2SiO_3 solution in a ratio of R (Na_2SiO_3/NaOH) = 2 and left to cool for at least an hour before being ready for mixing. The alkali to binder ratio (A) in the setting time and flow tests is varied to 0.25, 0.30, and 0.45 to ensure optimal workability and adequate setting time.

2.3. Aggregates

This study used coarse aggregate from Merapi with aggregate size 10-20 mm. The use of lightweight and porous aggregates is preferred for the production of no-fines concrete. The tests for coarse aggregates carried out were sieve analysis, specific gravity, unit weight and abrasion. The properties of aggregates can be seen in Table 2.

Table 1. Chemical compositions of fly ash and GGBFS from XRF analysis *(% mass)*

Component	Fly Ash	Ground Granulated Blast Furnace Slag
Al_2O_3	23.8	15.45
SiO_2	48.7	36.52
Fe_2O_3	11.0	0.98
CaO	12.7	44.38
SO_3	1.34	0.07
K_2O	0.97	0.33

Table 2. Properties of aggregates

No	Test	Results	Standards
1	Sieve Analysis	6.5	SNI 03-1968-1990
2	Specific gravity	2.4	SNI 1969:2008
3	Compacted unit weight	1371.46 kg/m^3	SNI 03-4804-1998
4	Abrasion	58%	SNI 2417:2008

2.4. Geopolymer paste mix design

Until now, there has been no standard geopolymer paste mix design. Therefore, this study's geopolymer paste mix design was calculated using the absolute volume method [19]. According to studies, the calculation of paste can be based on the proportion of absolute volume and each constituent material in 1 m^3. In this study, the constituent materials of the geopolymer paste mixture consisted of class F fly ash (*FA*), GGBFS, sodium hydroxide (*SH*), and sodium silicate (*SS*). In calculating the ratio required in the paste design, the design calculation can be done using the absolute volume method using Equation (1), as follows:

$$V_{fa} + V_{ggbfs} + V_{ss} + V_{sh} = 1\ m^2 \quad (1)$$

Based on the Equation (1), knowing the specific gravity and unit weight of each material, Equation (2) can be written as follows:

$$\frac{W_{fa}}{Gs_{fa}\ \gamma_w} + \frac{W_{fa}}{Gs_{ggbfs}\ \gamma_w} + \frac{W_{fa}}{Gs_{ss}\ \gamma_w} + \frac{W_{fa}}{Gs_{sh}\ \gamma_w} = 1\ m^3 \quad (2)$$

The ratio of fly ash to GGBFS *(B)* was 50:50. The weight of GGBFS (W_{ggbfs}) can be calculated by its ratio to the weight of fly ash (W_{fa}), Equation (3) as follows:

$$W_{ggbfs} = (B)\ W_{fa} \quad (3)$$

$$B = \frac{W_{ggbfs}}{W_{fa}} \quad (4)$$

B is the percentage of GGBFS to fly ash. The alkaline solution ratio *(R)* is 2. The ratio of alkaline/ weight of GGBFS + fly ash *(A)* and ratio *(R)* can be calculated by Equations (5) and (6), as follows:

$$R = \frac{W_{ss}}{W_{sh}} \quad (5)$$

$$A = \frac{W_{ss}+W_{sh}}{W_{fa}+W_{ggbfs}} \quad (6)$$

The W_{ss} and W_{sh} can be calculated as follows:

$$W_{ss} = R.\ W_{sh} \quad (7)$$

$$A\ (W_{fa} + W_{ggbfs}) = W_{ss} + W_{sh} \quad (8)$$

Equations (3) and (7) are explained in conjunction with Equation (8).

$$A\ (W_{fa} + (B)\ W_{fa}) = R.\ W_{sh} + W_{sh} \quad (9)$$

$$A\ (1+B)\ W_{fa} = (R + 1)\ W_{sh} \quad (10)$$

Thus, W_{sh} and W_{ss} are obtained by the following formula:

$$W_{sh} = \frac{A(1+B)}{1+R} W_{fa} \quad (11)$$

$$W_{ss} = \frac{AR(1+B)}{1+R} W_{fa} \quad (12)$$

Equation (13) of geopolymer paste mix design based on absolute volume is obtained.

$$\frac{W_{fa}}{Gs_{fa}\ \gamma_w} + \frac{(B)W_{fa}}{Gs_{ggbs}\ \gamma_w} + \frac{\frac{AR(1+B)}{1+R}W_{fa}}{Gs_{ss}\ \gamma_w} + \frac{\frac{A(1+B)}{1+R}W_{fa}}{Gs_{sh}\ \gamma_w} = 1m^3 \quad (13)$$

The proportion of the binder material determines the percentage of borax *(C)*. In this investigation, borax weight is calculated based on the weight of fly ash and GGFFS in the mixture. Hence, the calculation can be derived as Equation (14). The geopolymer paste proportion tested in this study can be seen in Table 3.

$$W_{br} = C\ (W_{fa} + W_{ggbfs}) \quad (14)$$

Table 3. Mixing Proportion of Geopolymer Paste

Sample code	Alkaline/Binder *(A)*	Borax *(C)*
B5050M10R2A35C5	0.25	3%
B5050M10R2A35C3		5%
B5050M10R2A30C5	0.30	3%
B5050M10R2A30C3		5%
B5050M10R2A25C5	0.35	3%
B5050M10R3A25C5		5%

2.5. Geopolymer No-fines Concrete Mix Design

In the absence of a standardized mix design for no-fines concrete geopolymer, the design of this composition refers to the calculation of no-fines concrete using Portland cement. In the design of the mixture of no-fines concrete using Portland cement, the Portland (*w/c*) value is used with a range of values between 0.36 and 0.46 [20]. The more cement or paste used, the denser and higher the compressive strength, and vice versa; if the paste is too thick, there could be a risk of segregation and resulted in low compressive strength [21]. The absolute volume of geopolymer paste is equivalent to the volume of cement paste with a 0.4 water-to-cement (*w/c*) ratio, with a volume ratio of (*P*) 1:4 and 1:6. In this calculation, the volume ratio of coarse aggregate (V_k) is 1 m^3, so the weight of the paste follows the variation of the volume ratio of the cement weight ratio (V_{pca}) (cement weight as the standard reference for calculation) is 0.25, 0.167, and 0.125 m^3. The calculation of material requirements for no-fines concrete can use Equations (15), (16), and 17). Where B_{sagk} is the unit weight of coarse aggregate, B_{spc} is the unit weight of cement, W_{agk} is the weight of cement, W_{pc} is the weight of cement, W_a is the weight of water, and W_b is the weight of concrete. The calculation results of no-fines concrete using Portland Cement (OPC) as reference can be seen in Table 4.

$$W_{agk} = V_k \times Bs_{agk} \quad (15)$$

$$W_{pc} = \left[\frac{V_k}{R}\right] \times Bs_{pc} \quad (16)$$

$$W_a = W_{pc}\ ({}^{W}/_{C}) \quad (17)$$

Table 4. No-fines Concrete OPC Mix Design per m^3

Vol. Cement: Vol. Aggregates *(P)*	V_k (m^3)	Bs_{agk} (kg/m^3)	W_{agk} (kg)	V_{pca} (m^3)
(1)	(2)	(3)	(4) = (2)(3)	(5)
1:4	1.00	1371.46	1371.46	0.25
1:6	1.00		1371.46	0.17
Bs_{pc} (kg/m^3)	W_{pc} (kg)	W_a (kg)	W_b (kg)	
(6)	(7) = (5)(6)	(8) = (w/c)(7)	(9) = (4)+(7)+(8)	
1250	312.50	125.00	1808.96	
	208.33	83.33	1663.13	

Table 5. Concrete Mix Design Converted to Absolute Volume

(P)	V_{agk} (m^3)	V_{pc} (m^3)	V_a (m^3)	V_{ragk} (m^3)	V_p (m^3)	V_r (%)
1:4	0.6095	0.0992	0.1250	0.3905	0.2242	16.63
1:6	0.6095	0.0661	0.0833	0.3905	0.1495	24.10

Table 6. Geopolymer no-fines concrete mix design

(P)	V_{agk} (m^3)	Bs_{agk} (kg/m^3)	W_{agk} (kg)
(1)	(2)	(3)	(4) = (2)*(3)
1:4	1.00	1371.46	1371.46
1:6	1.00		1371.46
V_p (m^3)	W_p (kg/m3)	W_p (kg)	W_b (kg)
(5)	(6)	(7) = (5)(6)	(8) = (6)(7)
0.22	2380.29	533.68	1905.14
0.15		355.78	1727.24

Table 7. Design of no-fines geopolymer mix per m^3

Sample	B1 (1:4)	B2 (1:6)
Fly ash (W_{fa})	197.66	131.77
Sodium silicate (W_{ss})	92.24	61.49
Sodium hydroxide (W_{sh})	46.12	30.75
Coarse Aggregate (W_{agk})	1371.46	1371.46
GGBFS (W_{ggbfs})	197.66	131.77
Borax (*C*)	19.77	13.18
Total	1905.14	1727.24

Table 8. Mix design proportions of geopolymer no-fines concrete

Sample Code	Ratio Vol. *(P)*	Alkaline/Binder *(A)*	Borax *(C)*
B5050M10R2A30C5P14	1 :4	0.30	5%
B5050M10R2A30C5P16	1 :6	0.30	
B5050M10R2A35C5P14	1 :4	0.35	
B5050M10R2A35C5P16	1 :6	0.35	

The calculation of the material proportion of no-fines concrete mix at Table 4**.** It is then converted to the absolute volume using Equation (18) to Equation (20).

$$V_{agk}=\frac{W_{agk}}{Gs_{agk}\,\gamma_w} \quad (18)$$

$$V_{pc}=\frac{W_{pc}}{Gs_{pc}\,\gamma_w} \quad (19)$$

$$V_a=\frac{W_a}{Gs_a\,\gamma_w} \quad (20)$$

The volume ratio of geopolymer paste (V_p) is equivalent to the sum of the volume of cement (V_{pc}) and the volume of water (V_a), can be calculated by Equation (22). The void volume of concrete (V_r), can be found after calculating the volume of coarse aggregate voids, using Equations (21) and (23). The results of the mix design conversion can be seen in Table 5.

$$V_{ragk} = (1 - V_{agk}) \quad (21)$$

$$V_p = V_{agk} + V_{pc} \quad (22)$$

$$V_r = (V_{ragk} - V_p)100\% \quad (23)$$

The cement volume weight ratio (V_{pca}) in Table 4, was replaced with the geopolymer paste volume (V_p) obtained in Table 5. The unit weight of cement (Bs_{pc}) was replaced with the unit weight of geopolymer paste per m^3 (W_p); (can be calculated with Equation 13). Hence, the geopolymer no-fines concrete mix design could be seen in Table 6. The results of design of geopolymer no-fines concrete per m^3 can be seen in Table 7.

The proportions of the tested for concrete mixes were carried out after the more optimal geopolymer paste was determined. Table 8 shows the proportions mixes tested to determine the effect of geopolymer paste on concrete characteristics, namely compressive strength and unit weight. The concrete sample code B5050M10R2A30C5P14 is designed to simplify the understanding of the concrete mixture composition. The B represents the binder mix ratio of fly ash and GGBFS at 50:50, M10 denotes a molarity of 10 M for the sodium hydroxide (NaOH) solution, R2 indicates the addition of 2% retarder (borax), A30 corresponds to an alkaline/binder ratio of 0.30, C5 refers to the inclusion of 5% borax in the binder, and P14 represents a porosity volume ratio of 1:4.

2.6. Mixing

The preparation of the alkaline solution was carried out by dissolving NaOH flakes at a set concentration of 10 Moles of distilled water, then 3% and 5% borax were added while the solution was still hot and the NaOH+ borax solution was allowed to cool for a day before mixing. Sodium silicate and sodium hydroxide were dissolved before mixing the dry ingredients, with the mixing ratio set at 2. The preparation of paste samples for setting time and flow tests was conducted using a Hobart N50 mixer. Mixing was done by mixing all the dry ingredients (fly ash and ground granulated blast furnace slag) and then adding the alkaline activator solution to the mixture and stirring for ± 4 minutes.

Flow table testing, conducted in accordance with ASTM C230 standard, was performed after mixing to evaluate the consistency of the fresh geopolymer paste [22]. Secondly, fresh paste setting time testing was assessed to measure the bonding characteristics of the geopolymer paste under controlled laboratory conditions. This examination followed ASTM C191 guidelines, with data recorded at intervals of every one minute [23].

Concrete samples for compressive strength testing were mixed using the CreteAngle Multi Flow Mixer, with a capacity of 0.2 m^3. The mixing method for no-fines concrete involved combining all dry binders (fly ash and GGBFS), and coarse aggregates. The mixture is then mixed for about 30-60 seconds. When mixed the concrete, it should not be too long because the coarse aggregate used is porous, so mixed too long may cause damage to the aggregate. Then, add the alkali activator to the mixture. The mixture was then mixed for 3-6 minutes until homogeneous. The prepared concrete mixture was cast into 100 x 200 mm cylindrical molds in three layers with standard compaction according to SNI 4810:2013. After casting, the molds were covered with plastic film to prevent water evaporation and left overnight for demolding the following day. Once demolded, the specimens were fully wrapped with plastic sheeting and cured under ambient laboratory conditions. Compressive strength testing was conducted at ages 28 days.

2.7. Unit Weight Testing

The unit weight of no-fines concrete ranges from 1.5 to 2.25. The unit weight value of the test specimen was calculated based on SNI 03-1974-2011, unit weight testing obtained weight and volume data and calculated using Equation (24) with W_c: concrete unit weight, W_{sb}: cylinder weight, V_{sb}: concrete cylinder volume [24].

$$W_c = \frac{W_{sb}}{V_{sb}} \qquad (24)$$

2.8. Concrete Compressive Strength Test

According to Indonesian concrete regulations, SNI 03-2847-2002, the compressive strength of concrete is measured using cylindrical test specimens (f'_c) with units of MPa. The compressive strength of concrete indicates the quality of concrete structures. Testing the compressive strength of concrete is done by gradually applying a compressive load to a cylindrical specimen until collapse occurs [25].

The compressive strength of concrete can be calculated by the formula in Equation (25), where P is the compressive load, and A is the cross-sectional area.

$$f'_c = \frac{P}{A} \qquad (25)$$

3. Result and Discussion

3.1 Setting Time and Flow Test Results

The use of binder material can affect the flow consistency of geopolymer paste. It also depends on the type of concrete to be used. In this study, if we refer to previous research with fly ash binders and OPC concrete, the amount of flow considered optimal is 110 ± 5%. However, with the use of fly ash binder and GGBFS, the optimal amount of flow is in the range of 90 ± 5% because, in the range of 110 ± 5% flow value, the consistency of concrete paste becomes too liquid so that it can cover the concrete cavity. Therefore, to avoid this, no-fines concrete requires a concrete mix that has a smaller consistency. No-fines concrete requires a concrete mix with a small consistency so that the concrete paste does not cover the no-fines concrete voids [26].

Flow tests were carried out using a Flow Table Test tool; the results obtained for the sample of B5050M10R2A35C5 and B5050M10R2A35C3, was 21.5 cm (Figure 1) and 23.5 cm and (Figure 2). Flow sample B5050M10R2A30C5 and B5050M10R2A30C3, was 19.25 cm (Figure 3) and 20.25 cm (Figure 4). It is known that the higher borax content, the smaller the flow value obtained. In the B5050M10R2A25C5 and B5050M10R2A25C5 the sample could not be mixed (Figure 5 and Figure 6); this is because the alkali mixture is fewer compared to the binder. Setting time test results were measured using the Vicat needle apparatus; the results obtained for each borax addition showed an increase in duration for the setting time test B5050M10R2A35C3 is 33 minutes and increased at B5050M10R2A35C5 is 44 minutes. The B5050M10R2A30C3 setting time test also increased at 40 minutes and increased for 49 minutes at B5050M10R2A35C5. The chart of setting time result can be seen at Figure 7. The test results of setting time and flow paste can be seen in Table 9. The research about the effect of sodium hydroxide mentioned that the increase setting time is increasing in geopolymer paste is due to the high molarity of the dissolution process of alumina and silica compounds in fly ash and GGBFS materials [27]. Still, the leaching process of calcium compounds is inhibited, so that it can delay and increase setting time. Another research of also showed an increase in the duration of hardening time with each increase in borax percentage [15]. The increase in setting time, and the addition of borax volume in an alkaline solution as an activator, was also confirmed in another research [28]. The addition of 5% borax is considered more optimal with a smaller flow value and a longer setting time, therefore in the proportion of no-fines geopolymer concrete only uses the addition of 5% borax.

Figure 1. B5050M10R2A35C5

Figure 1. B5050M10R2A35C3

Figure 2. B5050M10R2A30C5

Figure 3. B5050M10R2A30C3


Figure 4. B5050M10R2A25C5


Figure 5. B5050M10R2A25C3

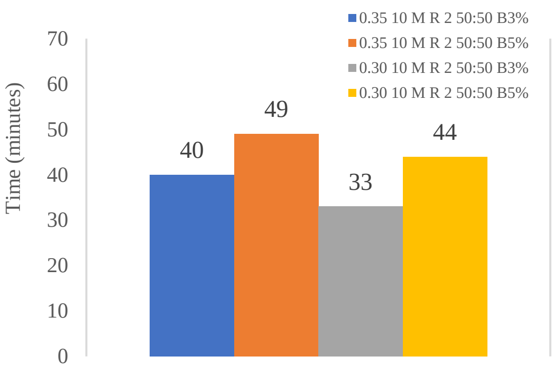

Figure 6. Setting time chart result

Table 9. Flow Paste and Setting Time Testing Results

Sample Code	Flow Mortar (cm)	Consistency (%)	Setting time (minutes)
B5050M10R2A35C5	21.5	112.45	33
B5050M10R2A35C3	23.5	132.21	44
B5050M10R2A30C5	19.25	90.22	49
B5050M10R2A30C3	20.25	100.1	40
B5050M10R2A25C5	0	0	-
B5050M10R3A25C5	0	0	-

3.2 Compressive Strength Testing Results

The mixing process of the no-fines concrete involved blending all dry ingredients, including Fly Ash, GGBFS, and Coarse Aggregate, followed by the addition of the Activator. Table 10 shows that the highest compressive strength at 28 days was 30.95 MPa, achieved by the sample B5050M10R2A35C5P14. The results obtained for the samples of B5050M10R2A30C5P14, B5050M10R-2A35C5P16, B5050M10R2A35C5P16, 28,55, 13,27, and 6,71 MPa, respectively. The concrete ratio (*P*) 1:4 with this strength can be used for parking equipment according to SNI 03-0691-1996 with the classification of quality B concrete bricks [29]. (The appearance of concrete samples can be seen in Figure 8 to Figure 11. The result show that Increasing the volume ratio (*P*) from 1:4 to 1:6 can reduce the compressive strength. Lowering the (*A*) ratio can also affect the compressive strength. The paste-aggregate volume ratio plays an important role in determining the compressive strength. A decrease in compressive strength can be caused by a reduced amount of paste, which leads to reduced adhesion and potential detachment of the aggregate bond with the paste. Optimal paste function occurs when all aggregate grains are homogeneously coated.

These findings are consistent with research where it was observed that reducing the cement/aggregate ratio improves compressive strength. In addition, studies have shown that compressive strength increases as the aggregate size decreases, further corroborating the results found in this study [11]. Research on the compressive strength of no-fines concrete with OPC, utilizing the same aggregate, yielded a similar result of 29.28 MPa [30]. Different research studies utilizing aggregates of the same size have shown lower compressive strength [21]. The density of concrete significantly influences its strength. Inadequate compaction processes can lead to less dense concrete with voids and reduced compressive strength. Conversely, excessive compaction may cause an accumulation of excess paste at the bottom of the mold, leading to clogging. The results obtained for the samples of B5050M10R2A30C5P14, B5050M10R2A35C5P16, B5050M10R2A35C5P14, and B5050M10R2A35C5P16 were 1651.50, 1843.38, 2054.91, and 2158.83, respectively. The results of this study are still included in the criteria for no-fines concrete, namely compressive strength between 1800 kg/m^3 and 2200 kg/m^3. According to SNI 1969: 2008 this unit weight can be used for the use of lightweight structures [31]. The unit weight of geopolymer concrete has approximately the same value as OPC no-fines concrete with same type aggregate the values obtained for the ratio of (*P*) 1:4 and 1:6 was 2170 and 2000, respectively [32].

In the B5050M10R2A35C5P14, some of the concrete surface remains covered by paste, thus not fulfilling the intended purpose of creating cavity concrete as shown in Figure 8. This can be caused by a higher paste consistency, poor mixing or poor compaction during the test. On the other hand, with B5050M10R2A30C5P14, the result showed a thicker paste mixture, ensuring even distribution and producing a satisfactory cavity surface. The result indicates that the alkaline/binder sample ratio (*A*) 0.30 is more optimal and recommended for the manufacture of geopolymer no-fines concrete.

4. Conclusion

Based on the testing conducted for setting time, the B5050M10R2A35C5 borax achieved a setting time of 44 minutes and a flow of 21.5 cm. In contrast, the B5050M10R2A30C5 borax exhibited a longer setting time of 49 minutes and a slightly lower flow of 19.25 cm. These results suggest that the (*A*) 0.30 mix has a lower viscosity or consistency compared to the (*A*) 0.35 mix. Therefore, it is recommended to use the (*A*) 0.30 mix for paste applications due to its more favourable properties. In the no-fines concrete of B5050M10R2A35C5P14, it was observed that some of the paste did not uniformly cover the aggregate, resulting in an inconsistent mix and failing to achieve the intended cavity concrete structure. Conversely, the (*P*) 1:6 aggregate paste ratio exhibited a more consistent mix, although with a slightly lower compressive strength compared to the (*P*) 1:4 ratio. The geopolymer no-fines concrete sample B5050M10R2A35C5P14 achieved its highest compressive strength at 30.95 MPa, with a unit weight of 2158.83 kg/m³. The compressive strength results are not much different from sample B5050M10R-2A35C5P14 which is 28.55 MPa with a unit weight of 2054.91 kg/m^3. This level of strength and unit weight makes it suitable for use as non-structural concrete in various applications according to SNI 1969: 2008. According to SNI 03-0691-1996 both samples can be used for parking equipment with the classification of quality B concrete bricks. During the compaction process, it is crucial to pay close attention and ensure it is executed correctly to achieve uniform compaction of the concrete. In future research, it is recommended to conduct permeability testing of no-fines concrete.

Figure 7. Sample B5050M10R2A35C5P14

Figure 8. Sample B5050M10R2A35C5P16

Figure 9. Sample B5050M10R2A30C5P14

Figure 10. Sample B5050M10R2A30C5P16

Table 10. Test Results of No-fines Concrete

Volume ratio (*P*)	Compressive strength (MPa)			
	Mount Merapi 10-20 mm [21]	Ape Bakar (10-20 mm)	(*A*) 0.35	(*A*) 0.30
1:4	20.28	15.6	30.95	28.55
1:6	16.23	7.67	13.27	6.71
(*P*)	Unit weight (Kg/m^3)			
1:4	2170.00	2052.00	2158.8	2054.9
1:6	2000.00	1962.00	1843.3	1651.5

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