

The Effects of Bottom Ash on Setting Time and Compressive Strength of Fly Ash Geopolymer Paste

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Abstract. This research is to find out the contribution of waste energy utilization of fly ash and bottom ash coal as binding agent of geopolymer concrete. This research methodology uses experimental approach in laboratory by making cylinder paste test object with dimension diameter of 2.5 cm x height 5 cm with some combination of fly ash and bottom ash mix with time setting test (ASTM C 191-04a) and compressive strength (ASTM C 39-04a). The research concludes that the effect of bottom ash on fly ash-based geopolymer paste shows good results in setting time and compressive strength.

1. Introduction

Coal has a major role as a primary energy source for industrial processes and has a significant effect on Indonesia. As noted in 2016, Indonesia's coal production of 434 million tons of total reserves is estimated at 54 million tons per year. The abundant presence of coal is directly proportional to the number of industries that use coal as a source of energy, which will continue to develop [1]. This encourages national and international researchers to utilize waste coal, fly ash (FA) on building materials and construction materials.

Previous studies [2-7] had demonstrated significant FA for the use of building materials and construction materials. However, the problems in the field may arise, since the coal quality in terms of geography, shipping process and coal combustion process in the industry make the quality of FA is very varied. This makes difficulties in previous studies to assurance the quality of binder and geopolymer concrete. In addition to FA quality issues, the main problem of binder and geopolymer concrete is the setting time. The hardening time is quite short especially FA with quite high CaO content. Therefore, it is necessary to conduct research to substitute FA with other local waste material in order to avoid dominance in quantity. This study is not only expected to give the effect of quality assurance of binder and concrete geopolymer based on FA but also increase the setting time binder and geopolymer concrete.

Bottom ash (BA) is another waste of coal combustion process. The ratio of coal waste composition between FA: BA is 1: 4. BA has potential as an alternative substance of FA-based geopolymer binder substitution; Dark gray particles, granules and porous particles, lower reactivity than FA, 10-60% grain size passes on 0.6 mm (No. 40), SiO₂, Al₂O₃ and Fe₂O₃ compounds are similar to FA. Therefore, this study further explores the potential of BA as an FA substitute material on geopolymer binders to improve setting time and compressive strength.

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2. Methodology

The methodology used in this study is laboratory experiments. The binder test object used the sample size of 2.5cm x 5cm. The main ingredients of FA and BA were used waste from PT Ipmomi Paiton (Table 1). From result of XRF test, it was known that FA used in this research was Si + Al + Fe > 70%. CaO < 10%. Thus, the fly ash used is the F type. CaO content of fly ash used in this study was 5.83%, according to ASTM [8] which has less than 10% CaO content classified into F fly ash type. Figures 1 and 2 are the description of FA and BA particles respectively. BA particle used in this research was not grinded and sieved as it was in the initial condition in field.

Table 1. Fly ash and Bottom Ash Oxide Compounds

Material	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	Na ₂ O	K ₂ O	others
Fly Ash (C)	47,1	24,25	16,07	5,83	0,645	1,64	4,465
Bottom Ash	89,91	2,93	4,71	0,73	0,0802	0,679	0,9608

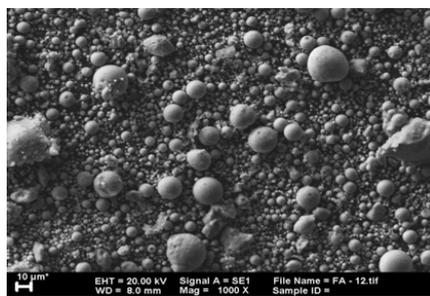


Figure 1. Scanning electron microscope *Fly Ash*

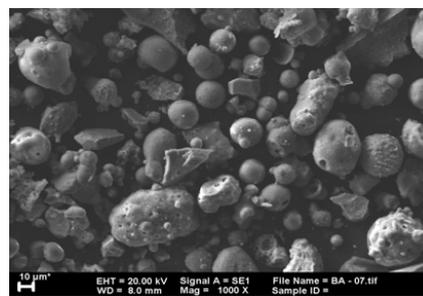


Figure 2. Scanning electron microscope *Bottom Ash*

The X-Ray Diffraction (XRD) technique was used to analyze the crystalline phases of FA and BA in the study. The representation of FA and BA patterns are shown in Figures 3 and 4.

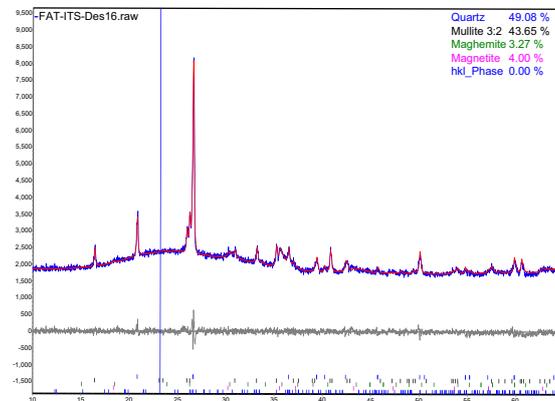


Figure 3. *Fly Ash* pattern from XRD test

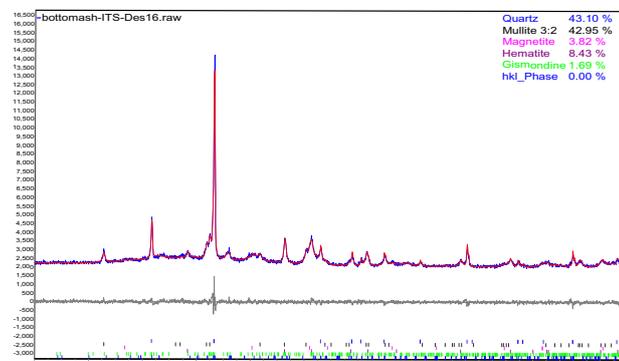


Figure 4. *Bottom Ash* pattern from XRD test

The types of activator material used were Sodium Silicate (Na_2SiO_3) and Sodium Hydroxide (NaOH) with molarity 12 M. The composition of geopolymer binder included 6 combinations which include: variation of silica alumina material composition and activator ratio variation. Details of the main composition of silica alumina material included: 100% BA, 100% FA and 50% BA + 50% FA. For the composition of 100% FA and 50% FA + 50% BA using a 74% ratio of alumina silicate material + 26% activator, 100% BA composition using 55% BA + 45% activator ratio. 2 ratios of activator material between NaOH to Na_2SiO_3 are 0.5 and 1.5. Details of the geopolymer paste composition are described in Table 2.

Table 2 Composition of Pasta Geopolymer

No	Binder code	Information
1	BA12 - 0,5	BA 100%, NaoH 12M, $\text{Na}_2\text{SiO}_3/\text{NaOH} = 0,5$
2	BA12 - 1,5	BA 100%, NaoH 12M, $\text{Na}_2\text{SiO}_3/\text{NaOH} = 1,5$
3	FA12 - 0,5	FA 100%, NaoH 12M, $\text{Na}_2\text{SiO}_3/\text{NaOH} = 0,5$
4	FA12 - 1,5	FA 100%, NaoH 12M, $\text{Na}_2\text{SiO}_3/\text{NaOH} = 1,5$
5	BF12 - 0,5	BA 50% + FA 50%, NaoH 12M, $\text{Na}_2\text{SiO}_3/\text{NaOH} = 0,5$
6	BF12 - 1,5	BA 50% + FA 50%, NaoH 12M, $\text{Na}_2\text{SiO}_3/\text{NaOH} = 1,5$

After the preparation of the tools and finished material, the next step was the manufacture of test specimens that included: mixing, printing and maintenance until the age testing reached 3, 28 and 56 days. Along with the mixing and printing process, "setting time" was tested with the standard [9] to determine the effect of BA on the lifting paste matrix to the strength compound. Implementation of the manufacture of specimens, time setting test and compressive strength test [10] were carried out in Material Laboratory and Building Structure

3. Result and Discussion

3.1. Setting time

Table 1 described the result of geopolymer binder setting time with 6 combinations and illustrated the recapitulation of the whole setting time. The longest setting time result occurred on the bottom ash 12M of the activator with 1.5 ratios where the initial binding occurred within 30 minute with a 25mm drop and the final binding took place at 85 minutes with a 3mm drop. At the fly ash composition, the longest setting time occurred on the comparison of activator 0.5 with the initial binding at 22.5 minutes with a 25mm reduction and the final binding occurred at 55 minutes with a 2mm drop. On the compositions of bottom ash and fly ash, the longest setting time result in comparison of activator 0.5 in which the initial binding occurs at 45 minutes with a 25mm drop and the final declined at 70 minutes with a 2mm drop. The result of setting time test showed that the comparison of activator 0.5 had longer binding time than 1.5.

The higher the ratio of mass ratio between NaOH and Na_2SiO_3 solution, the faster the final binding time took place. This was because the amount of Na_2SiO_3 presented in the binder mixture was greater than the amount of NaOH thus accelerated the polymerization reaction (Djwantoro 2005). The result of this setting time test also supported by the previous researcher's statement that Na_2SiO_3 were used in geopolymer paste served to speed up the polymerization reaction, therefore, if the levels were high, the crystallization process would also take place more quickly. Particle granules and BA reactivity could increase the timing of the geopolymer paste setting, compared to BA12-1,5 which had the initial setting time longer than the composition of FA12-1,5.

Table 3. Time for Binding in the beginning and end of the geopolymer paste

No	Binder code	Early binding time (min)	Last binding time (min)
1	BA12 - 0,5	26.67	75
2	BA12 - 1,5	30	85
3	FA12 - 0,5	22.5	55
4	FA12 - 1,5	12.5	40
5	BF12 - 0,5	45	70
6	BF12 - 1,5	12.5	55

3.2. Compressive strength

Figure 1 to 3 described the compressive strength of geopolymer paste using BA 100%, FA 100% and BA50% +FA50%. BA-based geopolymer paste showed the lowest compressive strength compared to the FA and FA + BA geopolymer paste. The BA12-0,5 geopolymer paste composition showed better compressive strength than BA12-1.5 at all ages. At 56 days of age the compressive strength of BA12-0.5 indicated a 300% strength of the lye press of BA12-1.5. In contrast to the compressive strength of the FA-based geopolymer paste showed FA12-1.5 was greater than FA12-0.5.

The effect of BA on the FA-based geopolymer paste could be shown in the highest compressive strength in the mixture composition of BA 50% and FA 50% with the comparison of activator 1.5 reaching 41.02 MPa at age 28 days and 49,71 at age 56 days. This result was better than the 100% FA-based geopolymer paste with a compressive strength of 34.9 MPa aged 28 days and 43.32 MPa aged 56 days.

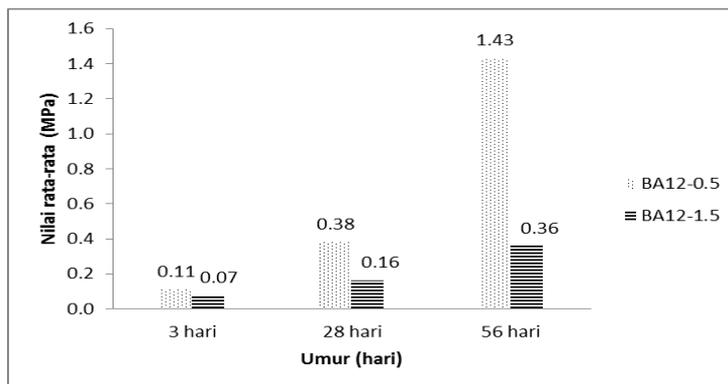


Figure 5. Compressive strength of BA geopolymer paste

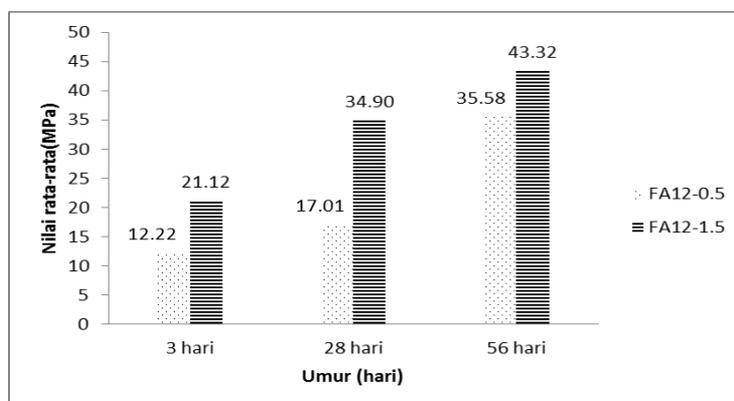


Figure 6. Compressive strength of FA geopolymer paste

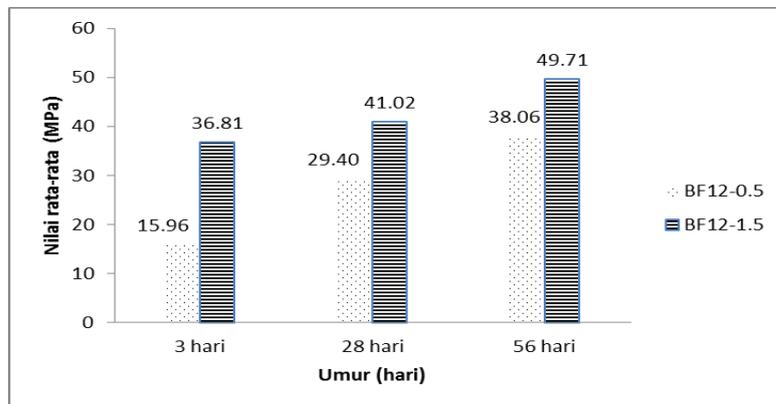


Figure 7. Compressive strenght of BF geopolymer paste

In every concrete study, BA is widely used as a filler material because of its physical and chemical properties. However, in this study, the combination of physical and chemical BA characters can show better collaboration of performance on the FA-based geopolymer paste, which slow the binding time thus it becomes one solution to solve the problem of geopolymer concrete with fast binding time due to one of the FA characters contain with quite high level of CaO and the high level ratio of Na₂SiO₃ and NaOH. The last factor is to achieve a high compressive strength target on geopolymer concrete. Strong factor that is considered from the physical character of BA, its shape is almost round and its dimension is bigger than FA. This factor proves that the increase of binding time of BA composition 100% and FA 50% + BA50% is longer than FA 100%. Of course, further research is needed, beside BA physical factors, there must be a chemical mechanism that needs to be proven in further research to strengthen BA's influence on the performance of the FA-based geopolymer paste.

To maximize the performance more of BA in the polymerization mechanism with FA, it is proposed in subsequent studies to perform a more gradual composition from the smallest percentage to the optimum composition for all aspects of geopolymer paste performance as a geopolymer concrete binder. The economical treatment of BA also needs to be proposed in subsequent research, grinding, sieving or other treatment processes to maximize its application function in geopolymer paste. In addition to setting time, BA is also able to increase the value of compressive strength of FA-based geopolymer paste by reducing 50% FA content and substituted with BA, this composition results strength similar to the FA100% geopolymer paste. This fact illustrates that BA contributes to strength despite the previous literature [11] BA reactions on hydration mechanisms are less reactive than FA. The effect of BA on fly ash geopolymer paste was tabulated in Table 2.

Table 4. The effect of bottom ash on fly ash geopolymer paste

Binder code	Performance effect			
	Setting Time		Compressive Strength	
	Poor	Good	Poor	Good
BA12 - 0,5		√	√	
BA12 - 1,5		√	√	
FA12 - 0,5	√			√
FA12 - 1,5	√			√
BF12 - 0,5		√		√
BF12 - 1,5	√			√

4. Conclusion

The best of composition ratio is found in mixture BA 50% + FA 50% with the ratio of activator 1.5 which has compressive strength reached at 49.71 MPa. The higher the mass ratio of the sodium silicate and sodium hydroxide solutions, they do not always result in a high compressive strength which is particularly occurred in bottom ash. The use of bottom ash in a binder in a particular composition can increase the value of compressive strength and tends to slow the setting time on the binder so as to provide opportunities fly ash in order not to harden quickly.

5. Acknowledgment

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6. References

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