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The Effect of Bottom Ash on the Compressive Strength and Tensile Strength of HVFA Concrete

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Abstract: This paper focuses on the effects of High Volume Fly Ash (HVFA) concrete with high content Bottom Ash (BA) as a fine aggregate. A 45 MPa with 12 ± 2 cm slump concrete was determined as a control. The tests that carried out were compressive strength at the age of 3 to 90 days ages and splitting strength at the age of 28 to 90 days ages, slump test, measurement of heat of hydration, and concrete autogeneous shrinkage. Variations in the concrete mix tested were HVFA without BA with FA content of 50% - 80%, and HVFA with 50% BA as a sand replacement. The In general, the use of high volume BA in the HVFA mixture provided an increase in strength both at the initial age and final in all variations. The internal curing effect provided by BA accelerated the hydration and solidification process at the early age, thus giving the effect of increasing the mechanical properties of concrete. However, the acceleration of solidification was accompanied by the increase in the shrinkage. BA properties which have greater absorption compared to sand also caused the workability decreased.

Keywords: *HVFA; high-volume fly ash; bottom ash; fine aggregate*

1. Introduction

The availability of coal waste in the form of fly ash (FA) and bottom ash (BA) is very abundant because the use of coal in many power plants in supporting energi supply. This encourages the creation of solutions in the mass use of FABA waste. In infrastructure applications, both of these wastes are used to mix concrete. FA can replace cement in concrete mixes, thereby creating new characteristics in concrete. FA is part of the remaining coal combustion in the form of amorphous fine particles and has pozzolanic characteristic that reacts with calcium at room temperature in aqueous media to form a binding compound. The main components of coal fly ash originating from power plants are silica (SiO2), alumina (Al_2O_3), iron oxide (Fe_2O_3), calcium oxide (CaO) and the rest are magnesium, potassium, titanium and sulfur in small amounts. Based on the composition of the constituents, FA is divided into 2 classes, namely class F and class C [1]. The use of FA and other pozzolans in concrete mixes are still limited in Indonesia to a maximum of 25% replacing cement [2-3], this shows that further studies are still needed to utilize high volume FA and BA in the concrete mixtures.

The use of BA in the cement mixture provides an internal curing effect. Internal curing can increase the hydration degree of concrete, which has a good effect on the mechanical properties of concrete [4]. BA contains silica, iron, alumina and small amounts of magnesium, calcium, sulfate, and others. BA as a substitute for fine aggregate causes a decrease in workability.

Concrete mixtures with BA resulted in more shrinkage than normal concrete [5-7]. On the other hand, concrete technology with FA as a substitute for cement in a content of 50% or more, is called high volume fly ash (HFVA) concrete. This mixture creates concrete that is resistant to extreme salt conditions. The use of HVFA concrete is suitable as a building material exposed to sea water. However, concrete with high cement reduction can cause a decrease in compressive strength growth, especially at an early age [8-10]. Therefore, studies related to HVFA are still ongoing. Some of them are the addition of additional materials in the form of calcium carbonate ($CaCO_3$) [11] and 0.03 M sodium hydroxide (NaOH) to improve the quality of concrete with high FA content [12]. Syah (2021) added $CaCO_3$ at levels of 5% and 10% to the cement paste mixture. With these additions, there is an increase in the pH of the paste was found. The pH-value causes the setting time of the paste to be faster due to the acceleration of the reaction which in turn increases the compressive strength of the paste. Pratiwi (2020) added a NaOH solution with a molarity of 0.01; 0.03; 0.05; 0.07; and 0.09 in the HVFA paste mixture (FA:Cement = 80%:20%). The experiment showed that the increase in compressive strength of the very-HVFA paste using 0.03 M NaOH as a substitute for water was a concentration that could increase the compressive strength of the paste. This is because the addition of NaOH solution with a molarity of 0.03 increases the pH-value to 12.5. Mix design with 77% fly ash with dilute-alkali FA treatment with 0.03M NaOH showed an increase in the pozzolanic reaction without causing interference with the hydration reaction of the cement. This increase in the pozzolanic reaction causes an increase in the strength of the paste.

Variation in FA levels used are 50% -80%, while variations in BA levels are used up to 50%. As a comparison, control concrete was used with a quality of 45 MPa, slump of 12 ± 2 cm, and w/c 0.3. This study can be a review of the development of the use of high volume fly ash (HVFA) technology, problems, and recommendations for the use of this technology.

2. Research Method

2.1. Materials

The cement used in this study was PCC from PT WIKA Beton, Indonesia. The fly ash used was class F fly ash from PT Petrokimia Gresik, Indonesia with the chemical composition as shown in Table 1. BA from PT Petrokimia Gresik, Indonesia is used for this study with 2.63 t/m^3 density and 10.6% water absorption. Fine aggregate in the form of sand used was also from PT WIKA Beton, Indonesia. Sand is denser and it has less absorption than BA with 2.71 t/m^3 density and 1.36% water absorption. Comparison of the characteristics between BA and fine aggregate are shown in Fig. 1 and Table 2. The coarse aggregate in the form of crushed stone used in this study was from PT WIKA Beton, Indonesia with a maximum aggregate size of 20 mm. This size was used because the specimen uses a 10 x 20 cm cylinder for the compressive and tensile tests. To ensure the targeted slump, SIKA Viscocrete 1003 is used as a superplasticizer. For additional ingredients, 0.03 M NaOH was obtained from solid NaOH mixed with water according to stoichiometry, while $CaCO_3$ was in powder form with a density of 2.68.

Table 1. FA Chemical Composition from XRF (% by mass)

Parameter	Test Result
SiO_2 (Silicon Dioxide)	44.49
Al_2O_3 (Aluminium Oxide)	24.86
Fe_2O_3 (Iron Trioxide)	17.09
CaO (Calcium Oxide)	5.70
MgO (Magnesium Oxide)	2.41
Na_2O (Sodium Oxide)	0.18
K_2O (Potassium Oxide)	1.48
TiO_2 (Titanium Oxide)	0.92
MnO_2 (Manganese Dioxide)	0.20
Cr_2O_3 (Chromium Trioxide)	0.01
P_2O_5 (Diphosphorus pentoxide)	0.46
SO_3 (Sulphur Trioxide)	1.91

Table 2. Fine Aggregate Characteristic Comparation

		BA	Sand
Density (SSD)	t/m^3	2.63	2.71
Absorption	%	10.6	1.36

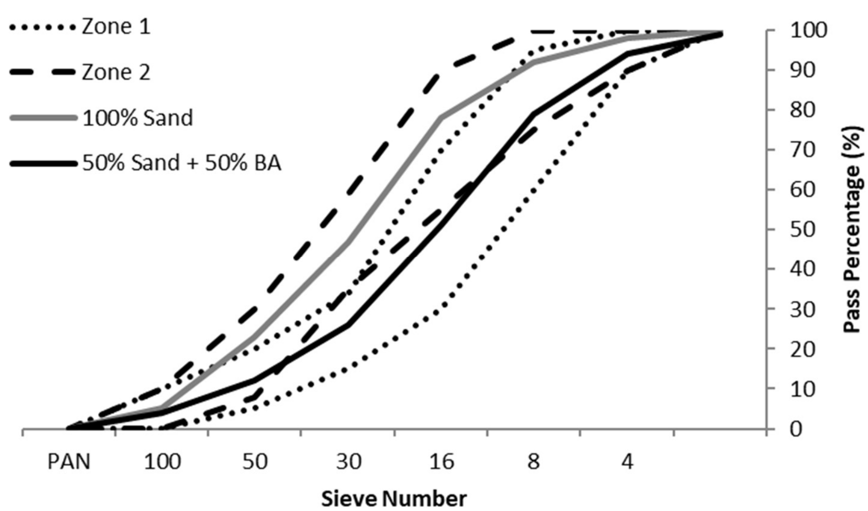

Fig. 1. Fine Aggregate Gradation

2.2. Mix design

The variation of concrete mix design that is planned to be studied consists of 2 main variations, HVFA without bottom ash (Code A) and HVFA with bottom ash (Code B). In addition to code A and code B, normal concrete with code N was used as a control. The FA content used was 50%; 60%; 70%; and 80% of the binder requirement and 0.03 M NaOH as a substitute for water according to the FA content to cement replacement. The $CaCO_3$ level was 5% of the binder requirement. The BA content in code B concrete used 50% of the volume of fine aggregate. Mix designs of all variations are presented in Table 3.

Table 3. Mix Proportion of HVFA per m^3

MAT.	PCC kg/m³	FA kg/m³	$CaCO_3$ kg/m³	BA kg/m³	Sand kg/m³	Coarse Agg. kg/m³	Wat. kg/m³	NaOH kg/m³	Air cont. %
N	600	-	-	-	431	1044	181	-	2
A50	120	480	30	-	416	1029	36	145	2
A60	180	420	30	-	416	1029	54	127	2
A70	240	360	30	-	416	1029	72	109	2
A80	300	300	30	-	416	1029	91	91	2
B50	120	480	30	208	208	1029	36	145	2
B60	180	420	30	208	208	1029	54	127	2
B70	240	360	30	208	208	1029	72	109	2
B80	300	300	30	208	208	1029	91	91	2

2.3. Concrete Mixing

Mixing of fresh concrete was carried out starting with dry mixing, where all off the dry materials, except FA, are mixed first and stirred until homogeneous. The order of the materials based on their grain size from large to small, starting from gravel, sand, BA (if any), cement, and $CaCO_3$. Once homogeneous, water and some SP are added. Meanwhile the mixing of NaOH and FA solutions was carried out separately and stirred until evenly distributed and became mud. After that, the FA mud was mixed into the concrete mixture little by little. The SP was added until it reached the targeted slump. After mixing, the fresh concrete was cast in 10 x 20 cm cylinder molds and allowed to stand for 24 hours before removing the molds. Curing is carried out in the curing room with a moist curing system according to Fig. 2

(a) (b) (c)

Fig. 2. (a) Mixer, (b) Slump Test, and (c) Moist Curing

2.4. Concrete Tests

To measure the properties of hard concrete, compressive strength and splitting tensile strength were used. Fresh concrete testing is a workability test with a slump test and mortar flow table test as seen in Fig. 3. Additional fresh concrete tests were hydration heat measurement and autogenous shrinkage measurement. The compressive strength test [13] was carried out on days 3, 7, 28, 56, and 90 for 9 variations of the mix design, and for splitting tensile strength [14] was carried out for 28 , 56, and 90 in 9 mix design variations. To measure flowability, the slump test [15] was used immediately after mixing for 9 variations of the mix design and flow table mortar test [16]. To measure the hydration heat of concrete, it is carried out by inserting fresh concrete into a 15 cm cube mold to record the temperature development of the concrete with a data logger via a thermocouple cable. The thermocouple cable was inserted to the center of the sample concrete. The temperature development was observed for 24 hours to get the highest temperature. To measure the self-shrinkage of the concrete, the fresh concrete was cast in a cylindrical mold with a diameter of 10 cm and a height of 20 cm. Teflon sheet 0.2 mm thick was placed between the concrete and the mold. Teflon sheet serves as a non-stick coating that prevents concrete from sticking to the mold. By not sticking the concrete to the mold, the concrete can shrink freely. Shrinkage measurement in concrete uses a data logger which connected to a strain gauge that has been inserted to the center point of the concrete sample. After the fresh concrete is poured into the mold, the top of the mold is closed to minimize water evaporation [17]. Heat of hydration and shrinkage were measured for 4 variations only, N, A50, A80, and B50.

(a) (b) (c)

Fig. 3. (a) Compressive Strength Test, (b) Split Test, and (c) Mortar Flow Table Test

3. Data Collection

3.1. Flowability

The results of the slump test and flow table is shown in Fig. 4 and Fig. 5. The SP used for N concrete is 0.1% by binder weight to achieve the targeted slump, whereas for variations A50, A60, A70, and A80, a higher SP content was needed than the normal concrete, which was 0.3%. Variations B50, B60, B70, and B80 are variations with the highest SP content, with 0.4%. The results of the flow table mortar for the A50 mortar variation shows a w/c requirement of 0.48 to achieve a 12 cm slump, while the B50 variation requires a w/c of 0.58 to achieve the same slump.

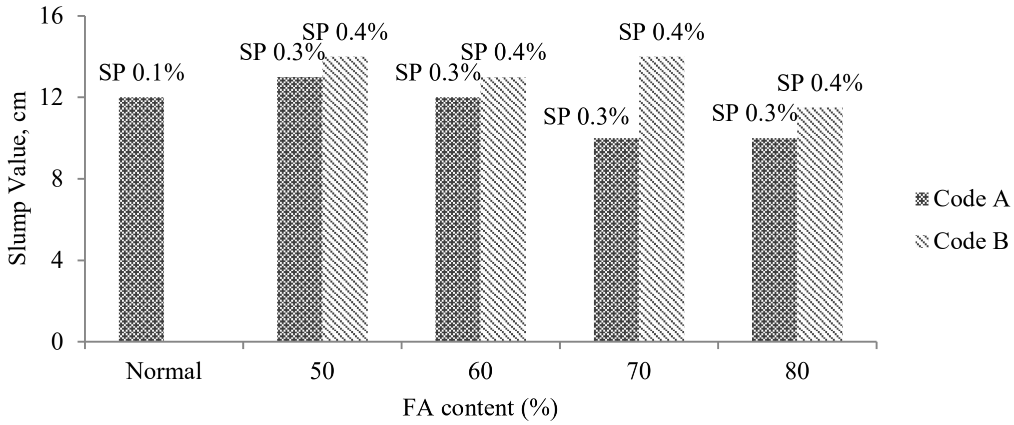

Fig. 4. Slump Test Result

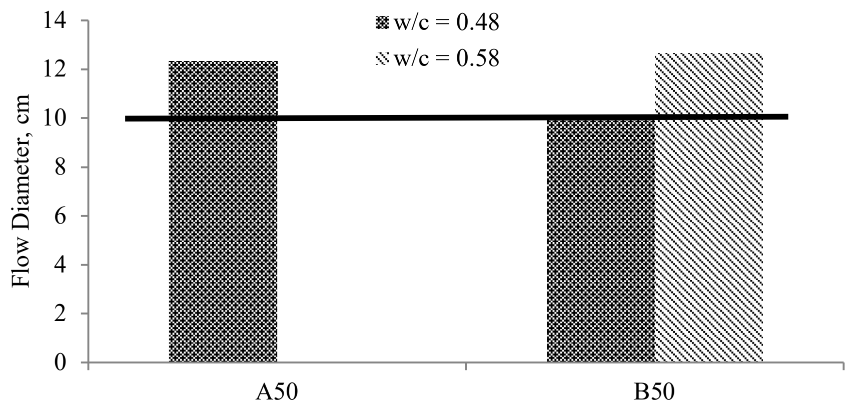

Fig. 5. Mortar Flow Table Result

3.2. Compressive Strength

The results of the compressive test can be seen in Fig. 6. Concrete N has reached the target at 28 days of age with 45.1 MPa. Concrete A50 and B50 also reached the target at the age of 28 days.

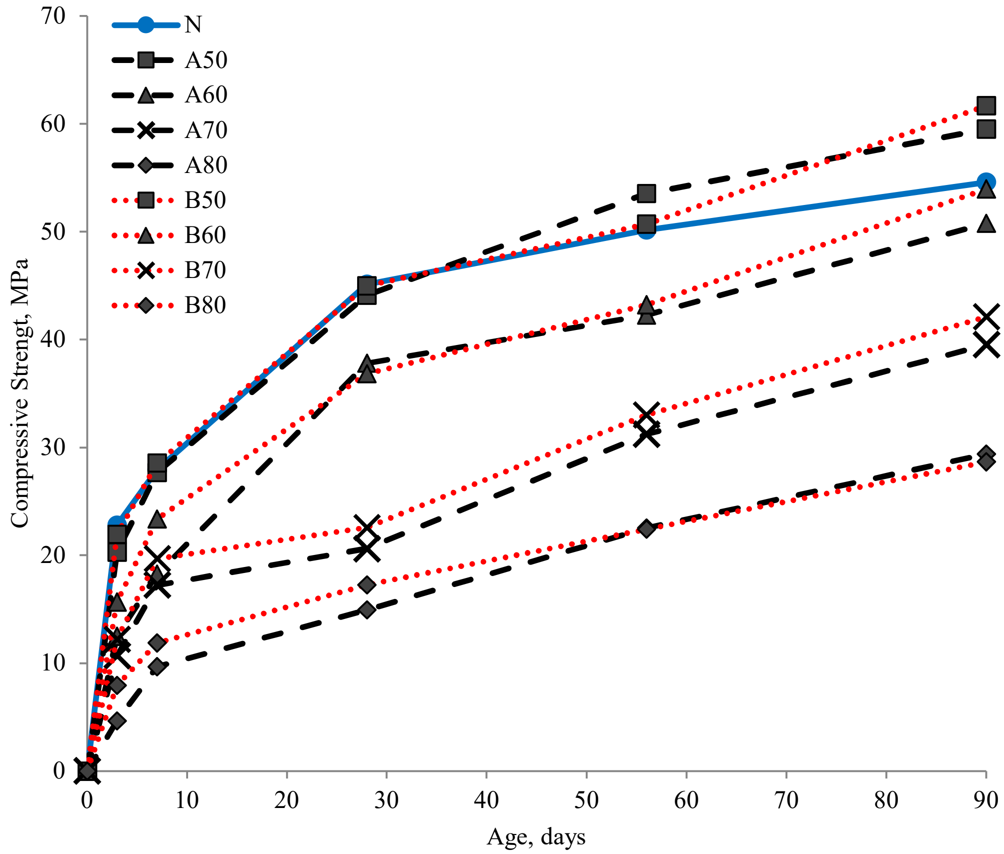

Fig. 6. Compressive Strength Result

3.3. Splitting Tensile Strength

The results of the splitting tensile test is shown in Fig. 7. The highest compressive strength results at the age of 28 days to 90 days occurred in the B50 variation with constant results over the N concrete's.

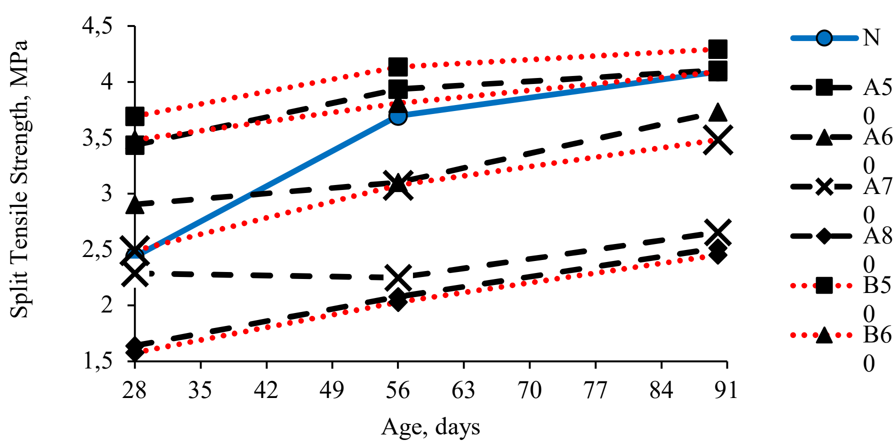

Fig. 7. Split Tensile Strength Result

3.4. Heat of Hydration

The results of hydration heat measurements is presented in Fig. 8. The highest hydration heat occurred by the N concrete, followed by B50 concrete and the lowest was A80. The results of hydration heat measurements are supported by initial setting measurements with a penetrometer shown in Table 4.

Table 4. Concrete initial Setting Time from Penetrometer

Variation	Initial Setting Time, Hour
N	2,13
A50	2,91
A80	3,57
B50	2,84

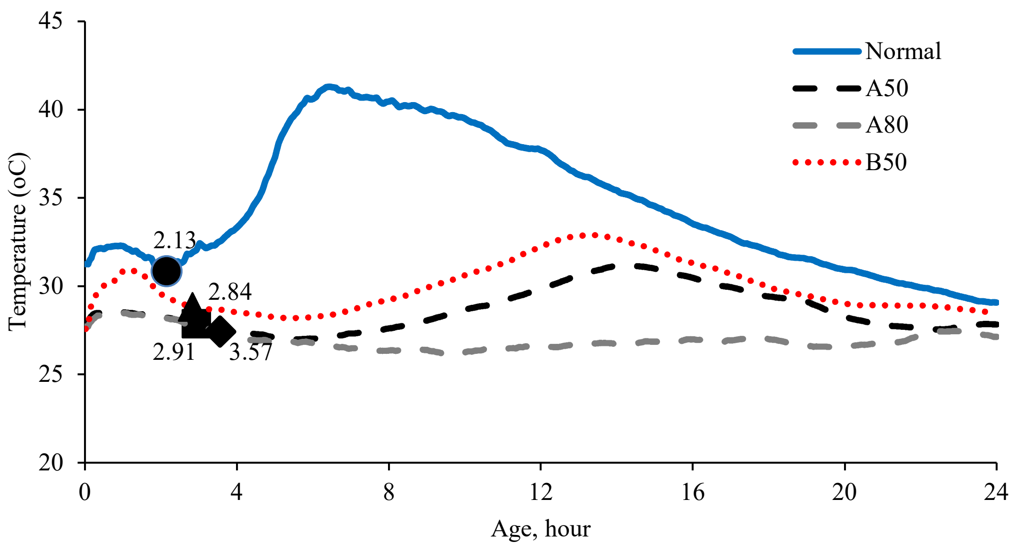

Fig. 8. Heat of Hydration Result

3.5. Autogenous Shrinkage

The results of shrinkage measurement of concrete is presented in Fig. 9. Concrete N shows the lowest shrinkage strain. Substitution of cement with FA and sand with BA has a significant effect on adding shrinkage values.

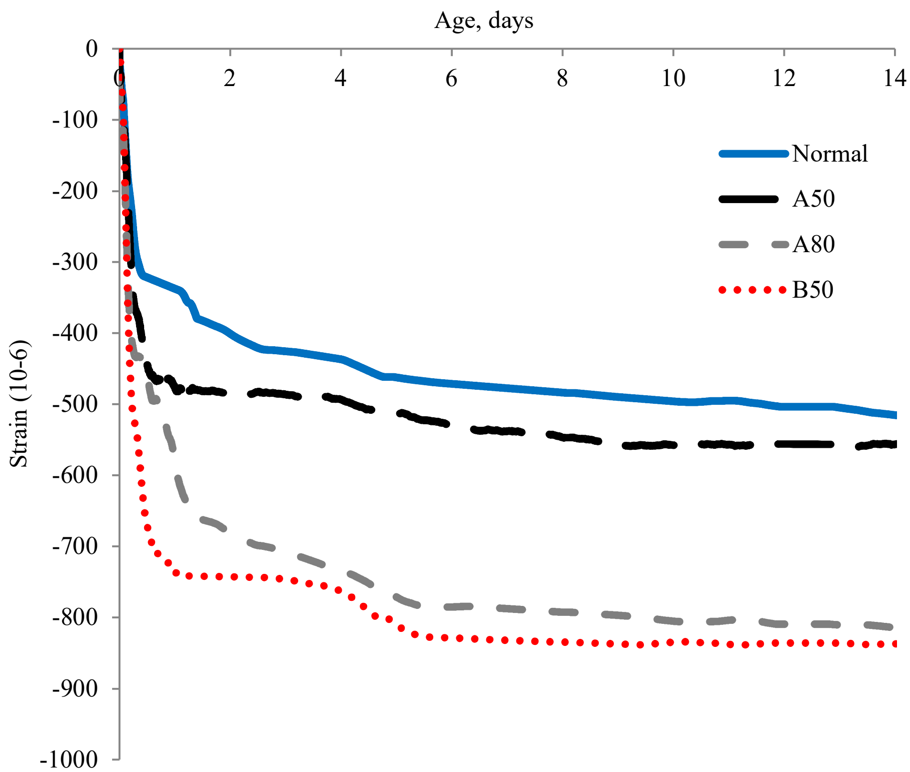

Fig. 9. Autogenous Shrinkage Result

4. Research Analysis

The use of high volume BA as a substitute for sand into HVFA concrete has the effect of changing mechanical properties. From Fig. 10, A50 concrete has decreased in hydration heat by 24.5%, while B50 concrete has decreased by 20.3%. The biggest decline occurred in the A80 variation. This shows that the increase in FA levels is inversely proportional to the increase in hydration heat temperature. The addition of BA also affects the initial setting time of the concrete. The fastest initial time occurred in the N concrete variation of 2.13 hours, followed by the B50 concrete variation with a duration of 2.84, and the slowest for setting was the A80 variation with a duration of 3.57 hours. Through penetrometer tests and hydration heat measurements. It is clear that the addition of high volume BA into HVFA concrete increases the peak temperature and accelerates setting time when compared to ordinary HVFA concrete.

The increase in the heat of hydration temperature and the rapid initial setting time is directly proportional to the results of the compressive strength and splitting tensile tests on code B concrete to code A concrete. Comparison of the results of significant compressive strength and splitting tensile can be seen in Table 5 and Table 6. The effect of using BA is proven to increase strength mechanical properties of HVFA concrete. The initial setting accelerated and hydration heat temperature increased due to BA high water absorption, so it occurs more high strength concrete mechanism due to less free water content availability on the mixture. It can be seen in Table 8, the presence of BA effectively increases the mechanical properties of concrete at an early age marked by the strength activity index (SAI) growth of B50 concrete which is higher than A50 at an early age and becomes almost the same at a later stage. Ibrahim (2015) found the same trend, where the use of BA into the mortar mixture caused an increase in compressive strength at an early age but became almost the same at more than 28 days of age [18].

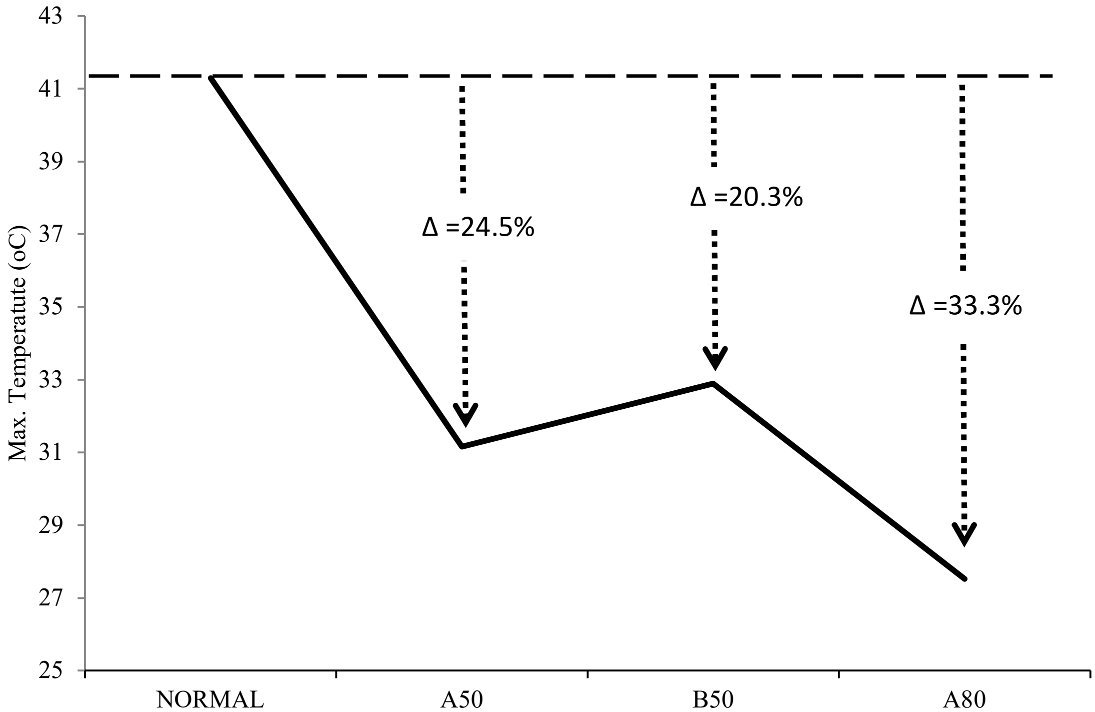

Fig. 10. Temperature differences between sample and control concrete

Table 5. Comparison of 3 days compressive strength ressult between sample A and B

Code	**3 Days Comp. Strength**		**Δ, %**
	A	**B**	
50	20.3	21.9	8%
60	12.5	15.7	26%
70	10.7	12.2	15%
80	4.7	7.9	70%

Table 6. Comparison of 56 days split tensile result between sample A and B

Code	**56 days, split tensile strength**		**Δ, %**
	A	**B**	
50	3.93	4.13	5%
60	3.10	3.81	23%
70	2.25	3.08	37%
80	2.08	2.03	-2%

Table 7. Strength activity index (SAI) of compressive strength at early age

Code	SAI (%) Age, days		
	3	7	28
Normal	100%	100%	100%
A50	89%	99%	98%
B50	96%	102%	100%

However, with the increase in compressive and splitting tensile strength, the addition of high-volume BA as a filler to replace sand also causes losses in the workability and shrinkage of concrete. In Fig. 1, there was a change in gradation and FM in the mixture with 50% BA indicating that the grain size and roughness of BA is different from sand. With the addition of 50% BA, the gradation experienced a zone change from zone 2 to zone 1 with an initial FM of 2.57 changed to 3.35. This shows that BA has a larger size and a rougher shape when compared to sand. Differences in the gradation characteristics of fine aggregate generally affect the workability of concrete. Where, the rough gradation causes the workability of the concrete to decrease due to the surface with large friction. The decrease in workability in code B concrete is due to the absorption of sand material which is much smaller when compared to BA with absorption values of 1.36% and 10.6%.

Another disadvantage of high-volume BA concrete as a substitute for sand is the increased self-shrinkage of the concrete. In Fig. 9, concrete of variation B50 has the greater strain when compared to concrete of code N, A50 and A80. The characteristics of BA which has high water absorption coupled with a large amount of FA causes the solidification process in concrete to increase. This can be seen from the faster initial setting time for B50 concrete compared to A50 concrete.

5. Conclusions

The application of high volume BA as a substitute for sand in HVFA concrete changes the characteristics of the concrete. BA has a different absorption character from sand, where BA has a much higher water absorption than sand. A mixture of BA with sand as fine aggregate changed to a coarser gradation and an increased FM when compared to pure sand. Changes in the character of the fine aggregate used in HVFA concrete have an impact on the compressive strength, splitting tensile strength, workability, hydration heat, and concrete shrinkage. In general, all variations of code B had greater compressive and splitting tensile strength than code A. In code B50, there was an 8% increase compared to A50. In code B60, there is an increase of 26% compared to A60. In code B70, there is a 15% increase compared to A70. In code B80, there is a 70% increase compared to A80. In the splitting tensile strength test, the largest average increase occurred for variations B60 compared to A60 and B70 compared to A70 at 56 days of age, with respective values of 23% and 37%. The more water absorption effect provided by BA accelerated the hydration process in early age, thus giving the effect of increasing the mechanical properties of concrete. This increase was accompanied by a faster concrete solidification process characterized by reduced initial setting time of concrete and increased concrete hydration heat when compared to ordinary HVFA. However, the fast solidification process resulted greater shrinkage. Adverse effects was shown in concrete workability. Workability of code B concrete requires more SP than code A concrete to achieve the design slump. The decreased workability was also proven by the flow table mortar test on variations A50 and B50. BA properties which have greater absorption compared to sand also caused the concrete become muddier resulted in decrease of workability.

The application of high volume BA as a substitute for sand has a good potential when combined with other additional materials which are indicated to be able to minimize the adverse effects resulting from the properties of FA & BA. Further studies are required to maximize the potential use of FABA in various concrete applications.

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