Journal of the Civil Engineering Forum, January 2023, 9(1):59-70
DOI 10.22146/jcef.3397
Available Online at: https://journal.ugm.ac.id/v3/JCEF/issue/archive

Evaluating Properties of Blended and High-Volume Fly Ash Bottom Ash (FABA) Concrete in Peat Water

Monita Olivia[1*], Alfian Kamaldi[1], Ismeddiyanto[1], Gunawan Wibisono[1], Edy Saputra[2]
[1]Department of Civil Engineering, Universitas Riau, Pekanbaru, INDONESIA
[2]Department of Chemical Engineering, Universitas Riau, Pekanbaru, INDONESIA
*Corresponding author: monita.olivia@lecturer.unri.ac.id

SUBMITTED 11 November 2021 **REVISED** 09 September 2022 **ACCEPTED** 12 September 2022

ABSTRACT FABA is a by-product of coal combustion in power plants comprising fly ash (FA) and bottom ash (BA) in ratios of 80/20. Fly ash has great potential as a mineral ingredient in concrete, while bottom ash compromises its strength and durability. However, both materials are used to improve the strength and durability of structures in sulfate, chloride, and acidic environments. This research evaluated the properties of blended and high-volume FABA concrete, such as the strength, porosity, weight loss, and sorptivity in organic acidic peat water. OPC (Ordinary Portland Cement) was compared to the blended concrete containing 25% FABA and its high-volume containing 50% and 75% FABA with target strengths of 15, 21, and 29 MPa. The compressive strength of blended and high volume FABA increased during the immersion period, while the porosity and sorptivity rates decreased. Furthermore, the strength of the OPC concrete declined at 28 days, with a gradual marginal weight loss of 5% observed in all mixes. This research suggested that blended and high-volume FABA has potential as a construction material in an acidic peatland environment.

KEYWORDS Bottom Ash; Fly Ash; Porosity; Sorptivity; Strength

1 INTRODUCTION

Several Indonesian provinces have developed coal-fired power plants to address energy shortages. Approximately 1.04 and 4.16 million tonnes of fly ash and bottom ash are generated daily as by-products from these power plants, and they have low value as construction material (Amino, 2018). Currently, most coal power plants in Indonesia use a mix of fly ash and bottom ash (FABA) at a ratio of 20 to 80. For years, coal power plants have attempted to use FABA as a profitable material, but these by-products do not produce consistent results and are still classified as hazardous materials. According to the Indonesian Environmental Impact Management Agency (1995), FABA cannot be used in any application without undergoing a solidification and stabilization process. FABA has the potential for low-strength concrete products such as paving blocks and precast concrete structural elements. In large quantities, it can be used as a cement replacement material in rigid concrete pavement materials and as a stabilizer in sub-base construction.

Fly ash is composed of light, amorphous spherical particles of micro size, and it can be used as a pozzolanic material in mortar and concrete. Typical blended concrete contains 15 to 30% fly ash by mass, and at high volume, it comprises 30-50% as a cement replacement material (Mehta, 2004). The partial substitution of fly ash for cement in the range of 10% to 20% increase the compressive, tensile, and porosity by 5%, 3%, and 7%, respectively (Reiner and Rens, 2006; Bendapudi and Saha, 2011). A research using 30% fly ash in cement increased the concrete strength by 18% and water penetration by 95% (Fládr et al., 2019). According to Hemalatha and Ramaswamy (2017), adding more than 35% fly ash to concrete will not increase its strength, but it enhances concrete durability and chemical resistance in aggressive environments containing seawater, sulphate, acid, and high temperatures (Moffatt et al., 2017; Simčič et al., 2015; Chen et al., 2017; Pacheco-Torgal and Jalali, 2009; Nadeem et al., 2014).

Figure 1. Fly ash-bottom ash (FABA) particles from West Sumatra, Indonesia

Bottom ash has darker and coarser particles than fly ash, hence, it is typically used to replace fine aggregates. Rafieizonooz et al. (2016) observed no substantial decrease in sand-replacement concrete strength at 28 days. Burhanudin et al. (2018) stated that the bottom ash can replace up to 30% of the cement by grinding it into a powder. Baco et al. (2020) reported an optimum cement replacement of 25% bottom ash despite the resulting concrete's relatively high water absorption. Therefore, concrete made from ground bottom ash has equivalent strength and mechanical qualities to fly ash-based and can be used as an alternative.

Riau Province in Indonesia has a peatland area of approximately 3.86 million hectares, and due to the high demand for infrastructure development, roads are built through the peat lands (Ritung and Wahyunto, 2012). According to Kazemian et al. (2011), peat contains a significant amount of organic matter and water as well as a low pH in the form of humic substances. Organic matter such as humic acid can impede cementing process by forming salts to delay hydration process and altering the composition and structure of the Calcium Silicate Hydrate (C-S-H) compound (Duraisamy et al., 2007). The C-S-H gel in cement paste also helps form bonds between particles with other hydration products. Furthermore, the acidic nature of this environment causes a rapid deterioration of OPC structural concrete with the easy dissolution of the cement hydration product ($Ca(OH)_2$) to form gypsum due to a low pH environment and increased acid concentrations. Following the dissolution of $Ca(OH)_2$ at low pH, other cement hydrates such as calcium silicate (C-S-H), calcium aluminate, and calcium alumino-ferrite hydrate, decompose by losing their Calcium and convert to amorphous silica, alumina, and ferric hydrogel. The loss of C-S-H and $Ca(OH)_2$ leads to concrete deterioration (Soleimani et al., 2013). Using pozzolanic and cementitious by-products as cement replacement materials could reduce waste generation and increase concrete mixture's workability, physical, and mechanical, and durability properties. Previous research has shown that using a pozzolanic binder such as blended cement can increase the resistance to deterioration in organic acid environments (Bertron et al., 2005; Dyer, 2017). Indicated that using a pozzolanic binder such as blended cement can increase the resistance to deterioration in organic acid environments. This means that the pozzolanic material, such as FABA could be included in the concrete mixture for structures in a peat environment. There is a limited scientific research available on the application of FABA as pozzolanic replacement in concrete for structures in acidic peatland.

FABA was used as a cement substitute to examine the early qualities of the concrete, such as the mechanical strength, porosity, and sorptivity following exposure to peat water. Concrete property development at 28 days is critical to ensure its re-

Table 1. Chemical composition of Ordinary Portland Cement (OPC) and fly ash bottom ash (FABA)

Chemical composition (%)	Type of material	
	Ordinary Portland Cement (OPC)*	Fly Ash Bottom Ash (FABA)
(r)1-1 Silicone Dioxide (SiO_2)	20.92	59.25
Aluminium Trioxide (Al_2O_3)	5.49	29.25
Iron Trioxide (Fe_2O_3)	3.78	5.45
Titanium Dioxide (TiO_2)	-	0.83
Calcium Oxide (C_aO)	65.21	1.54
Magnesium Oxide (M_gO)	-	0.31
Potassium Oxide (K_2O)	-	2.23
Sodium Oxide (Na_2O)	-	0.68
Phosphorus Pentoxide (P2O5)	-	0.04
Sulphur Trioxide (SO_3)	-	0.29
Manganese Dioxide (MnO_2)	-	0.01
Moisture content (%)	-	0.25
Loss On Ignition (LOI) (%)	-	18.89

sistance in this aggressive environment. This research is important because it leads to the wider use of FABA concrete in tropical peatland environments, particularly in Indonesia and other Southeast Asian countries.

2 MATERIALS AND METHODS

This research used fly ash bottom ash (FABA) particles from West Sumatra Province, as shown in Figure 1. Tamble 1 indicates the chemical composition of FABA, which according to astm 2019, is classified as Class F, with 59.25 and d18.8 percentages of SiO2 and carbon (LOI). It also indicates the chemical composition of Type 1 OPC from PT Semen Padang. The OPC was used as the primary binder for the control and FABA concrete. The specific gravities of coarse and fine aggregates from the Kampar Quarry in Riau were 2.61 and 2.76, while the fineness modulus and water absorption were 3.35% and 3.63%, respectively.

This research examined two different types of FABA-containing concrete, namely blended and high-volume, which are projected to be practical in a narrow range of applications, such as peat water. The FABA content in the blended cement concrete was 25%, with strengths of 15, 21, and 29 MPa (BLD_15, BLD_21, and BLD_29). The strength was designed using the Indonesian National Standards for low (BLD_15), medium (BLD_21), and the required concrete values in aggressive environments (BLD_29) (SNI 03-6468-2000, 2000; SNI 2847:2013, 2013). The high volume FABA concrete contains 50% (HVFA_50) and 75% (HVFA_75) FABA by volume as a cement replacement material. OPC and HVFA_25 or BLD_21 concrete were used as control mixes, with a comprehensive description shown in Table 2.

FABA specimens were prepared by combining cement, aggregates, and water with the outcome cast into 100x200 mm cylinders to determine the compressive strength, porosity, and sorptivity. For weight loss, 100x100x100 mm specimens were used, with each test prepared using the triplicate method. The samples were cured in water for 28 days before being exposed to peat for an additional 28 days. This condition was chosen to simulate precast concrete, which is typically cast and cured in a controlled environment before being exposed to an aggressive area.

Peat water was collected from Rimbo Panjang Regency, Riau, and used to submerge the samples at a ratio of 1:4 between the surface area and the volume of water, as shown in Figure 2. The samples were kept in peat water that was replaced every two weeks with the physical and chemical properties shown in Table 3. The pH of the water was

Table 2. Mixture composition of OPC and FABA concrete

Chemical composition (%)	Type of material	
	Ordinary Portland Cement (OPC)*	Fly Ash Bottom Ash (FABA)
Silicone Dioxide (SiO_2)	20.92	59.25
Aluminium Trioxide (Al_2O3)	5.49	29.25
Iron Trioxide (Fe_2O_3)	3.78	5.45
Titanium Dioxide (TiO_2)	-	0.83
Calcium Oxide (C_aO)	65.21	1.54
Magnesium Oxide (M_gO)	-	0.31
Potassium Oxide (K_2O)	-	2.23
Sodium Oxide (Na_2O)	-	0.68
Phosphorus Pentoxide (P_2O_5)	-	0.04
Sulphur Trioxide (SO_3)	-	0.29
Manganese Dioxide (MnO_2)	-	0.01
Moisture content (%)	-	0.25
Loss On Ignition (LOI) (%)	-	18.89

Table 3. Physical and chemical composition of peat water

Chemical composition (%)	Type of material	
	Ordinary Portland Cement (OPC)*	Fly Ash Bottom Ash (FABA)
Silicone Dioxide (SiO_2)	20.92	59.25
Aluminium Trioxide (Al_2O_3)	5.49	29.25
Iron Trioxide (Fe_2O_3)	3.78	5.45
Titanium Dioxide (TiO_2)	-	0.83
Calcium Oxide (C_aO)	65.21	1.54
Magnesium Oxide (M_gO)	-	0.31
Potassium Oxide (K_2O)	-	2.23
Sodium Oxide (Na_2O)	-	0.68
Phosphorus Pentoxide (P_2O_5)	-	0.04
Sulphur Trioxide (SO_3)	-	0.29
Manganese Dioxide (MnO_2)	-	0.01
Moisture content (%)	-	0.25
Loss On Ignition (LOI) (%)	-	18.89

around 5.0, and the organic content was double the permitted limit for drinking water, according to recommendations from Indonesian Ministry of Health (SNI) 1972:2008 (2008). Peat water contains organic acids such as humic (10-20%), lignin, cellulose, tannin, etc (Spedding, 1988), which are capable of delaying the hydration process by forming salts when reacted with Calcium for cement (Duraisamy et al., 2007). The continuous exposure to peat water pH could slow the cement hydration process, thereby strengthing development (Kazemian et al., 2011). In addition, the sulphate ion content was approximately five times lower than drinking water, which contained non-aggressive elements. Based on its characteristics, Rimbo Panjang peat water is unsuitable for drinking or mixing with concrete.

The slump test and compressive strength were determined using Indonesian National Standards (SNI) 1972:2008 (2008) and 1974:2011 (2011), re-

(a) (b)

Figure 2. Specimens were cured in (a) water pond and (b) peat water

Table 4. Slump and setting time of OPC, blended and HVFA concrete

Mixes	Slump (mm)	Setting time (min)	
		Initial setting	Final setting
OPC	85	59	105
BLD_15	72.5	93	210
BLD_21	67.5	73.8	135
BLD_29	62.5	47	165
HVFA_25	67.5	73.8	135
HVFA_50	62.5	95	195
HVFA_75	52.5	134	300

spectively. ASTM C642 (2013) was used to evaluate the porosity (2013), while the weight gain of the specimen was used to calculate sorptivity values at 5, 10, and 30 min, as well as 1, 2, 3, and 4-hour intervals Peek et al. (2007). The Concrete Institute of Australia defined sorptivity as water absorption rate into an unsaturated porous medium (2014). The test set-up for sorptivity is shown in Figure 3.

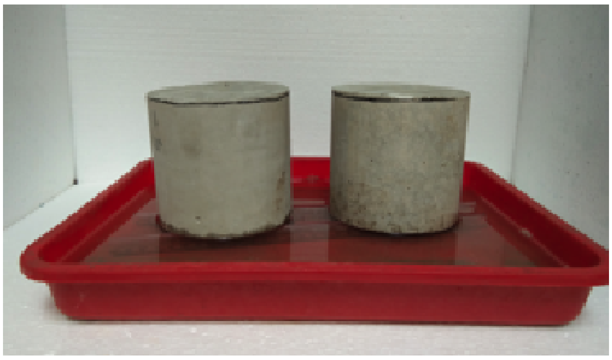


Figure 3. Sorptivity test set-up

3 RESULTS AND DISCUSSION

3.1 Slump and Setting Time

Table 4 shows the slump and setting times for various types of concrete with the mixtures designed to have approximately 80 mm slump. Workability declined from 14.7 to 26.5% and 26.5 to 38.2% for blended and high volume FABA concretes, respectively. The slump decreased with an increase in water and FABA content in the combinations. The lowest slump value was shown in high volume fly ash, indicating that an increased amount of FABA adsorbs more water in the mix, thereby reducing its workability.

The samples' initial and final setting times ranged from 59-134 and 105-300 minutes, which are useful for determining the effect of fly ash content on strength and porosity development shortly after the concrete is formed. The FABA had 55.9% and 65% longer setting times than the corresponding control OPC mix for each series because it contains a substantial amount of fine particles. Huang et al. (2013) found that concrete mixtures containing 60-80% fly ash had similar performance.

3.2 Compressive Strength

Figure 4 shows the compressive strengths of fully-cured blended FABA concrete mixtures before immersion, as well as at 7 and 28 days after immersion in peat water. The control mix of OPC and BLD_21/HVFA_25 had a compressive strength of ± 21 MPa before immersion in peat water. Although the OPC concrete met the specified strength, the BLD_21 concrete was 9.7% weaker. This is because the decreased calcium component in the combination lowers the strength gain in the blended cement more than the OPC concrete, which is beneficial for early strength development.

As shown in Figure 4, the OPC's strength decreased by 11% after 28 days of exposure to peat

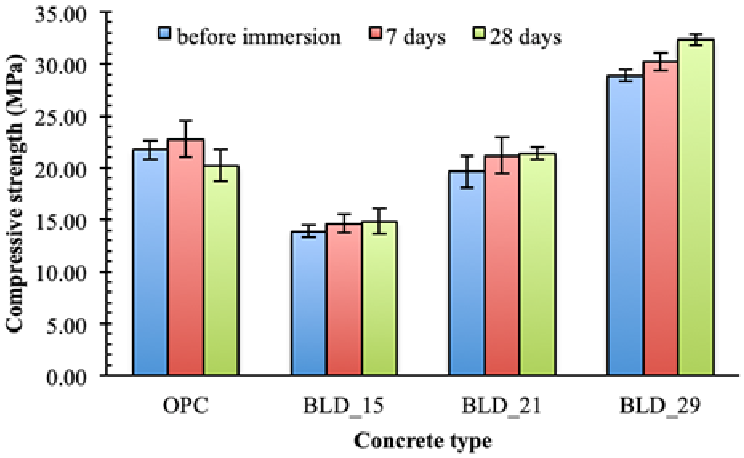


Figure 4. Compressive strength development of blended fly ash after subjected to peat water

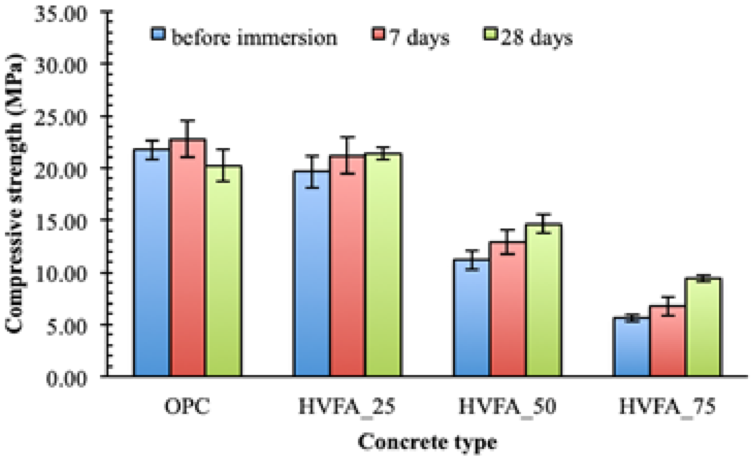


Figure 5. Compressive strength development of high volume FABA concrete after subjected to peat water

water. An abrupt decrease damaged the cement's hydration product ($Ca(OH)_2$), thereby causing an organic acid attack on the peat water, which increases the number of large pores in concrete. The organic content of peat water in this research was found to be 28.38 mgL^{-1}, which is twice the acceptable limit for drinking water. The organic content and pH affect the strength development of OPC mix in peat water. Dyer (2017) reported similar findings despite differences in the type of acid, concrete mix, and level of exposure to the organic acid environment.

In contrast, the blended FABA concrete displayed compressive strength improvements from 0 to 28 days of immersion in peat water, with better strengths obtained after 28 days. Mix BLD_15 showed the lowest compressive strength of the 3% and 6.47% strength gain, with Mix BLD_29 exhibiting a 12.01% increase before immersion. These strength gains can be explained by the formation of calcium silicate hydrate (C-S-H) in blended concrete due to the pozzolanic reaction, which increases the matrix's porosity and resistance to the acid attack in peat water. The BLD_29 mix gained strength faster than the low and medium blended concrete formulations following exposure to peat water. It also outperformed the SNI 2847:2013 (2013) for concrete durability in an aggressive environment.

Figure 5 shows that the HVFA_25 nearly reached the target strength of 21 MPa after 28 days of curing in water or before immersion. However, the HVFA_50 and HVFA_75 mixtures before immersion in peat water have lower strengths than the HVFA_25 combination, implying that the higher

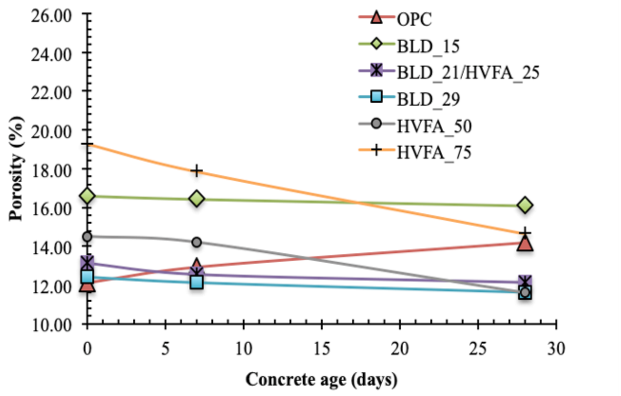


Figure 6. Change in porosity of fly ash concrete after subjected to peat water

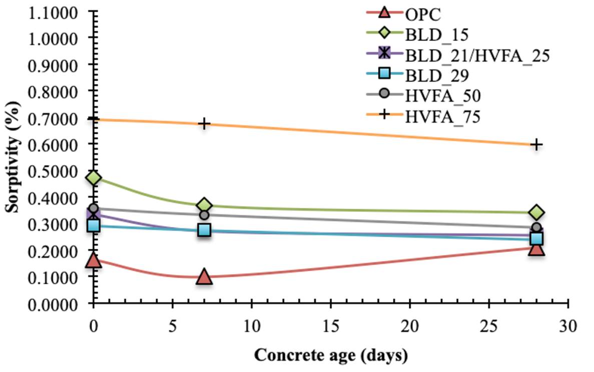


Figure 7. Change in sorptivity of fly ash concrete after subjected to peat water

proportion of FABA reduced adequate strength due to the decrease in growth of hydration products (Kim et al., 2012; Rivera et al., 2015).

Peat water improves the strengths of aging FABA concrete. According to Huang et al. (2013), large volume fly ash tends to experience significant strength gain at 7 to 28 days due to the consumption of $Ca(OH)_2$ in the pozzolanic reaction and the pore-filling effect. Berry et al. (1994) stated that only fly ash contributes to the pozzolanic reaction in a high-volume system, while the other portion stays unreacted even after a lengthy cure period because the reaction is not solely pozzolanic. Therefore, for the high volume of FABA concrete in peat water, early strength development indicates a change at the microstructural level that significantly impacts the concrete's macro mechanics.

3.3 Porosity

Figure 6 that changes in OPC and FABA concrete porosity was exposed early in peat water. For instance, the porosity of the OPC concrete increases after seven days of exposure to peat water with the ability of calcium leaching to harm the hydrated product due to the low pH environment and a degree of acid association. A similar tendency was observed in the previous research by Satya et al. (2016), where the increase in the OPC porosity of the concrete led to a rise in strength, which decreased gradually after being immersed in peat water.

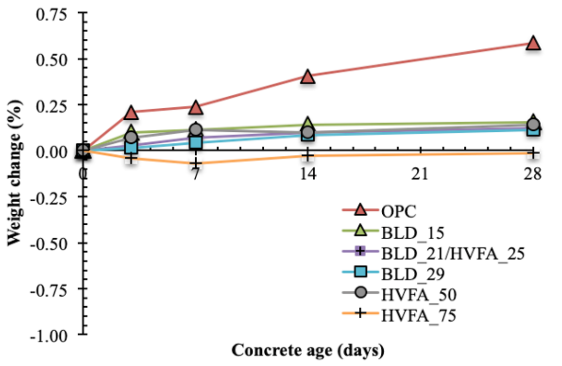


Figure 8. Weight loss of fly ash concrete after subjected to peat water

The mixtures of BLD_21 and BLD_29 showed a reduction in porosity over time with varying water content, except for mix BLD_15. The addition of pozzolanic material can improve the resistance of OPC concrete to peat water by lowering the calcium content and enhancing the pozzolanic reaction to fill the pores. The maximum strength concrete of BLD_29 has low initial porosity than other mixes. SNI 2847:2013 (2013) recommends concrete with a strength of 28 MPa in harsh environments such as peatland with a medium sulphate content of 150 to 1500 ppm.

The porosity of the HVFA_75 mix is higher than the HVFA_50 mix after 28 days of exposure to peat water due to the formation of fewer pores in HVFA_50 during the immersion time. The preliminary research by Huang et al. (2013) showed blended ash concrete has greater final strengths than high volume fly ash ones, while the area between cement paste and aggregate or transition zone has lower porosity. However, the pores in this research are larger because HVFA concrete has an insufficient pozzolanic reaction due to adequate hydration products from the OPC. HVFA_75 mix must also be considered before using this type of concrete in peatland. Due to the highly porous nature of an unstable pore network, this concrete will leach more heavy metals into the environment than other types.

3.4 Sorptivity

Sorptivity is a term that refers to the rate at which water penetrates the concrete cover by capillary action, and its value depends on the duration and velocity of water infiltration. As shown in Figure 7, the sorptivity of most concrete mixtures decreases after 7 days, which continues even after early contact with peat water. Although OPC mix has less initial sorptivity than the other concrete combination, it has roughly the same value as blended concrete after 28 days of immersion. The change in sorptivity of the OPC indicated an increase in the concrete's capillary porosity during peat water immersion.

The sorptivity of blended concrete with target strengths of 21 and 29 MPa was practically the same, although it was lower in the BLD_29 mix. Both blended concretes had a higher sorptivity than the OPC mix, showing that the capillary pores in the concrete covers absorbed water more quickly at the start of exposure to the peat environment. After early exposure to peat water, the blended concrete's sorptivity decreased and stabilized, indicating better resistance to peat water with adequate capillary pores.

HVFA_75 concrete has high porosity, very low strength, and high initial and final sorptivity, as shown in Figure 7. In comparison, HVFA_50 concrete exhibited less initial and final sorptivity. A high concentration of FABA in concrete may lower the capillary pores of the concrete and reduce sorptivity over 28 days. Although the increased proportion of fly ash in the HVFA concrete leads to a higher initial sorptivity, it reduces after initial exposure to peat water.

3.5 Weight Loss

A weight loss on the specimen indicates a porosity change in the concrete matrix after exposure to peat water due to the decrease in weight. On the other hand, weight gain is due to the result of pore refinement. Figure 8 shows that the importance of most concrete specimens decreased significantly during the immersion in peat water, with the effect more noticeable in the OPC. After 28 days, the change was approximately 0.6%, which increased with additional exposure time. Therefore, increased weight loss shows a rise in porosity following peat water exposure. Satya et al. (2016) stated that concrete used in peatland should incorporate pozzolanic material to enhance its long-term resistance.

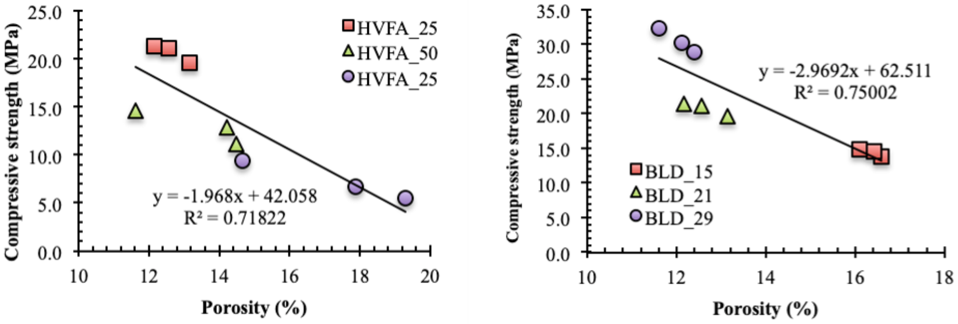
Blended concrete showed a more stable weight loss over the 28 days. The strength grade influenced the weight loss, with the BLD_29 having a minor weight loss than the BLD_21 and BLD_15, thereby demonstrating a significant change in the matrix and an influence on the porosity of the concrete. Olivia et al. (2017) stated that blended palm oil ash concrete lost less weight than OPC mix when specimens were submerged in peat water, particularly in the early days due to an initial attack by acidic peat water. The Calcium content in the OPC mix is likely to affect the concrete's resistance to peat water.

The weight loss in HVFA concretes lower than other mixes with an increase in the HVFA_75 concrete for 7 days before dropping again while approaching 28 days. Despite being exposed to peat water, HVFA_75 concrete showed a stable weight than other types and had better resistance to peat water.

3.6 Relationship between compressive strength, porosity and sorptivity

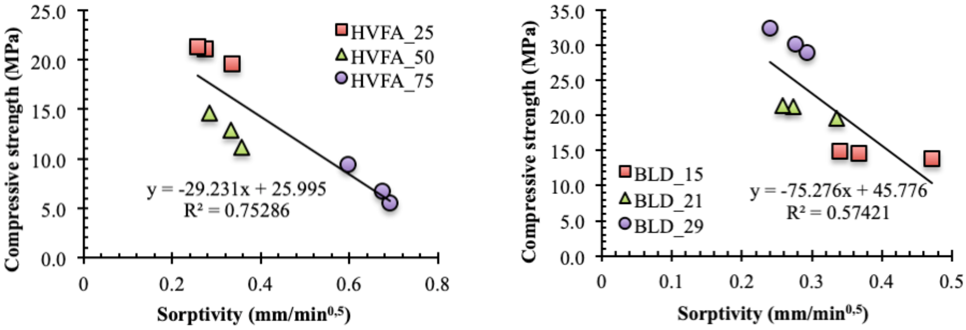
Figure 9 shows the correlation between compressive strength and porosity after 28 days, while a linear relationship between compressive strength and porosity in high-volume concrete with coefficient of correlation (R2) value of 0.71822 is illustrated in Figure 9 Based on this correlation, it can be seen that high compressive strength corresponds with low porosity of the HVFA mix. Figure 9 shows that the correlation coefficient of the blended fly ash concrete is greater than HVFA concrete, indicating a stronger correlation of porosity with the concrete's compressive strength.

Figure 10 illustrates the relationship between concrete's compressive strength and sorptivity of HVFA, which increased linearly with a decrease in strength. A moderate positive correlation of



(a) (b)

Figure 9. Compressive strength vs porosity of (a) high volume fly ash, and (b) blended fly ash concrete at 28 days



(a) (b)

Figure 10. Compressive strength vs sorptivity of (a) high volume fly ash, and (b) blended fly ash concrete at 28 days

the strength and sorptivity of HVFA concrete, with R2 of 0.75286, can be seen in Figure 10. However, a much lower R2 of 0.57421 between strength and sorptivity of blended fly ash concrete was observed in Figure 10. The sorptivity of blended FABA concrete randomly falls between 0.2410 and 0.4710 mm/min$^{0.5}$ in this Figure 10. Inconsistent relationships were observed between strength and sorptivity in the blended FABA. The trend in Figure 10 showed that substituting 25% fly ash for cement in blended fly ash concrete with different strengths had no discernible effect on the sorptivity values following early exposure to peat water.

4 CONCLUSIONS

FABA, a common by-product of coal power plants primarily disposed of in landfills, can also be used in place of cement in the production of concrete. This is possible because, after exposure to peat water for a specified duration, the strength, porosity, and sorptivity showed its potential use. According to the findings, the FABA content and strength grade were the primary determinants of early pressure gain in high volume when exposed to peat water. Meanwhile, the porosity and sorptivity values decreased as the HVFA's strength grade, and FABA content increased. This indicates the high volume FABA has a slightly greater porosity and sorptivity value than the blended fly ash at 28 days. Excess fly ash particles fill the voids and pores in the dense concrete because the higher the OPC content in the blended fly ash, the slower the porosity refinement of the FABA concrete upon early exposure to peat water. Although the resulting strength of the two types of concrete differs, the HVFA and blended FABA exhibit superior early age properties to the OPC within 28 days. This research can assist the construction industry in using FABA as a sustainable material in tropical peat environments.

ACKNOWLEDGMENTS

The authors are grateful to Sopian, Ika Nursuci Qoriah, Ramona Mardiah, Arnef Frenki for the experimental setup and data collection. The authors are also grateful to Penelitian Berbasis Kompetensi DRPM 2018 Kemenristekdikti Republic of Indonesia for supporting and funding this research through contract no. 361/UN.19.5.1.3/PP/2018.

DISCLAIMER

The authors declared no conflict of interest.

REFERENCES

ASTM C642, A. (2013), ‘Standard test method for density, absorption, and voids in hardened concrete’, *ASTM, ASTM International* .

Baco, N. S., Shahidan, S., Zuki, S. S. M., Ali, N. and Azmi, M. A. M. (2020), Strength properties of untreated coal bottom ash as cement replacement, *in* ‘Journal of the Civil Engineering Forum’, Vol. 6, pp. 13–18.

Bendapudi, S. C. K. and Saha, P. (2011), ‘Contribution of fly ash to the properties of mortar and concrete’, *International Journal of Earth Sciences and Engineering* **4**(6), 1017–1023.

Berry, E. E., Hemmings, R. T., Zhang, M.-H., Cornelius, B. J. and Golden, D. M. (1994), ‘Hydration in high-volume fly ash concrete binders’, *Materials Journal* **91**(4), 382–389.

Bertron, A., Duchesne, J. and Escadeillas, G. (2005), ‘Attack of cement pastes exposed to organic acids in manure’, *Cement and Concrete Composites* **27**(9-10), 898–909.

Burhanudin, M. K., Ibrahim, M. H. W., Sani, M., Juki, M. I., Jamaluddin, N., Jaya, R. P., Shahidan, S., Basirun, N. F. and Bosro, M. Z. M. (2018), ‘Influence of ground coal bottom ash with different grinding time as cement replacement material on the strength of concrete’, *Malaysian Construction Research Journal* **4**(2), 93–102.

Chen, F., Gao, J., Qi, B. and Shen, D. (2017), ‘Deterioration mechanism of plain and blended cement mortars partially exposed to sulfate attack’, *Construction and Building Materials* **154**, 849–856.

Duraisamy, Y., Huat, B. B. and Aziz, A. A. (2007), ‘Methods of utilizing tropical peat land for housing scheme’, *American Journal of Environmental Sciences* **3**(4), 259–264.

Dyer, T. (2017), ‘Influence of cement type on resistance to organic acids’, *Magazine of Concrete Research* **69**(4), 175–200.

Fládr, J., Bíly, P., Chylík, R. and Prošek, Z. (2019), Macroscopic and microscopic properties of high performance concrete with partial replacement of cement by fly ash, *in* ‘Solid State Phenomena’, Vol. 292, Trans Tech Publ, pp. 108–113.

Hemalatha, T. and Ramaswamy, A. (2017), ‘A review on fly ash characteristics–towards promoting high volume utilization in developing sustainable concrete’, *Journal of cleaner production* **147**, 546–559.

Huang, C.-H., Lin, S.-K., Chang, C.-S. and Chen, H.-J. (2013), ‘Mix proportions and mechanical properties of concrete containing very high-volume of class f fly ash’, *Construction and Building Materials* **46**, 71–78.

Kazemian, S., Prasad, A., Huat, B., Bolouri Bazaz, J., Mohammed, T. and Abdul Aziz, F. (2011), ‘Effect of aggressive ph media on peat treated by cement and sodium silicate grout’, *Journal of Central South University* **18**(3), 840–847.

Kim, J. H., Noemi, N. and Shah, S. P. (2012), ‘Effect of powder materials on the rheology and formwork pressure of self-consolidating concrete’, *Cement and Concrete Composites* **34**(6), 746–753.

Mehta, P. K. (2004), High-performance, high-volume fly ash concrete for sustainable development, *in* ‘Proceedings of the international workshop on sustainable development and concrete technology’, Iowa State University Ames, IA, USA, pp. 3–14.

Moffatt, E. G., Thomas, M. D. and Fahim, A. (2017), ‘Performance of high-volume fly ash concrete in marine environment’, *Cement and Concrete Research* **102**, 127–135.

Nadeem, A., Memon, S. A. and Lo, T. Y. (2014), ‘The performance of fly ash and metakaolin concrete at elevated temperatures’, *Construction and Building Materials* **62**, 67–76.

Olivia, M., Pradana, T. and Sitompul, I. R. (2017), ‘Properties of plain and blended cement concrete immersed in acidic peat water canal’, *Procedia engineering* **171**, 557–563.

Pacheco-Torgal, F. and Jalali, S. (2009), ‘Sulphuric acid resistance of plain, polymer modified, and fly ash cement concretes’, *Construction and Building Materials* **23**(12), 3485–3491.

Peek, A., Nguyen, N. and Wong, T. (2007), ‘Durability planning and compliance testing of concrete in construction projects’, *Corrosion Control* **7**.

Rafieizonooz, M., Mirza, J., Salim, M. R., Hussin, M. W. and Khankhaje, E. (2016), ‘Investigation of coal bottom ash and fly ash in concrete as replacement for sand and cement’, *Construction and Building Materials* **116**, 15–24.

Reiner, M. and Rens, K. (2006), ‘High-volume fly ash concrete: analysis and application’, *Practice periodical on structural design and construction* **11**(1), 58–64.

Ritung, S. and Wahyunto, N. K. (2012), ‘Karakteristik dan sebaran lahan gambut di sumatera, kalimantan dan papua’, *Pengelolaan Lahan Gambut Berkelanjutan. Balai Besar Litbang SDLP, Bogor* .

Rivera, F., Martínez, P., Castro, J. and López, M. (2015), ‘Massive volume fly-ash concrete: A more sustainable material with fly ash replacing cement and aggregates’, *Cement and Concrete Composites* **63**, 104–112.

Satya, Y. S. D., Saputra, E. and Olivia, M. (2016), Performance of blended fly ash (fa) and palm oil fuel ash (pofa) geopolymer mortar in acidic peat environment, *in* ‘Materials Science Forum’, Vol. 841, Trans Tech Publ, pp. 83–89.

Simčič, T., Pejovnik, S., De Schutter, G. and Bosiljkov, V. B. (2015), ‘Chloride ion penetration into fly ash modified concrete during wetting–drying cycles’, *Construction and Building Materials* **93**, 1216–1223.

Soleimani, S., Isgor, O. B. and Ormeci, B. (2013), ‘Resistance of biofilm-covered mortars to microbiologically influenced deterioration simulated by sulfuric acid exposure’, *Cement and concrete research* **53**, 229–238.

[This page is intentionally left blank]