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CHARACTERISTICS OF FLY ASH CEMENT PASTE AS AN ALTERNATIVE SUSTAINABLE MATERIAL FOR BALINESE ARCHITECTURAL ORNAMENTS

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ABSTRACT

In Bali, the demand for ornament architecture material especially natural stone is still high. The problem is the availability of material sources especially the stones is very limited. It is necessary to study alternative environmental materials that can be used as Balinese architectural ornaments. This study aims to understand the feasibility of fly ash cement paste as an alternative material based on their properties such as bulk density and compressive strength. The material composition in this research consists of cement, fly ash, fiber, superplasticizer, and water. The binder composition is a ratio of 1 cement: 2 fly ash. The water and binder ratio is fixed at 0.35. The variation in the materials was varied according to (i) fiber (0.05%, 0.025%, and 0.01%) and (ii) superplasticizer (0.1% and 0.05%). The mixture composition was determined using the absolute volume method. All samples were mixed according to ASTM C305. The mechanical strength of the material was tested according to ASTM C109 (2002) using 50 mm cube specimens. The highest compressive strength occurred when 0.1% SP and 0.025% fiber were mixed in the mixture. Based on the result, the fly ash-cement paste has a higher strength compared with other stones while having a similar bulk density. Basalt stone, a popular ornamental architectural material in Bali, has a compressive strength of 19.42 MPa, which is 44% lower than the fly ash-cement paste mixture. Andesite stone has a better compressive strength than basalt stone but a lower compressive strength by around 29% than fly ash cement paste material. Fly ash cement paste has a similar bulk density to red brick and andesite stone. Sandstone has the lowest compressive strength, about 3.87 MPa. The temple with fly ash-cement material is brownish in color. This is due to the fact that the color of fly ash dominates the proportion. When compared to other stone materials such as basalt stone, andesite stone, and red brick, fly ash cement has the highest compressive strength and the lowest price.

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1. INTRODUCTION

Ornaments or decorative motifs are works of art that originate from forms that exist in nature such as fire, water, clouds, rocks, plants, animals, humans, and other mythological creatures. The types of traditional Balinese decorative motifs include others as follows: *keketusan* (geometric) motifs, *plant* motifs (*pepatran*), and *karang* motifs. The materials used in Balinese architectural ornaments are usually stone or wood. Stones often used in making ornaments are basalt stone, andesite stone, and white sandstone (Suryada, 2011).

In Bali, the market demand for ornament architecture material especially natural stone is still high. The problem is the availability of material sources especially the stones is very limited. Besides that, the mining process of the stone greatly affects the conditions of the surrounding environment. From that problem, it is necessary to study alternative environmental materials that can be used as Balinese architectural ornaments. Pranajaya (2019) explained that creativity in the use of building materials will have a positive impact on the economic, social, cultural, and architectural fields in Bali. One of the creative developments in traditional Balinese architectural materials is the use of non-metallic materials such as fiberglass. These materials consist of resin, cobalt, catalyst, mat, aerosol, talk, acetone, mirror glass wax, gel coat, silicon rubber, silicon oil, pigments, and putty. Fiberglass material has a light-specific gravity but tends to be expensive. Besides that, Pranajaya and Eratodi (2022) also studied padas stone waste material as fine aggregate. Around 30% of padas stone waste is produced from the mining process. This material is combined with cement and water to produce Balinese architectural ornaments.

Another alternative material that can be used for Balinese ornaments is fly ash-cement paste. Fly ash is the residue from burning coal in Power Plants. Fly ash has a dominant mineral composition of quartz and a little mullite. The shape of the particle shows rounded shapes (spheres), measuring <15 µm. The size of fly ash particles ranges from 0.31 - 300.74 mm (Aziz M, N. Ardha, 2006). The application of fly ash is widely used in construction materials such as paving blocks (Nath, 2020; Santhosh & Talluri, 2015), soil treatment and stabilization (Nayak et al., 2015), wastewater treatment (Mushtaq et al., 2019) or construction material (Rivera et al., 2015; Tantermsirikul et al., 2023).

ASTM C618 (2014) classified fly ash based on their chemical composition and characteristics. Class C fly ash has a minimum of 50% accumulation of silicon dioxide (SiO2), aluminum oxide (Al2O3), and iron oxide (Fe2O3) composition while Class F fly ash has a minimum of 70%. Class F fly ash has pozzolanic properties while Class C Fly ash also has cementitious properties. Due to their properties, fly ash is usually combined with other cementitious materials to create a fly ash-cement paste material that can be used as new sustainable materials. The significance of this research is to find the optimum ratio composition from the fly ash-cement paste that can be made for a Balinese architecture ornament. The addition of fiber can affect the flexural of the materials thus the ornament can be strong enough when sculpted. Besides that, the addition of superplasticizer can longer the hardening and the workability of the materials.

2. METHODS

2.1 Materials

Ordinary Portland cement and fly ash from the Paiton power plant in East Java Indonesia was used in this study. The density and specific gravity of fly ash are 1500 kg/m3 and 2.46, respectively. The chemical composition of fly ash from the XRF test result consists of more than 70% SiO3+Fe2O3+Al2O3 and CaO more than 10% thus classified according to ASTM C 618 (2014) as class C Fly ash with pozzolanic and cementitious materials. was used in this study. Fiber Polypropylene from Sika was used with a density of 0.91 gr/cm3, 12 mm length, tensile strength of 300-440 MPa, and modulus elasticity of 6000-9000 MPa. Superplasticizer 3115N from Sika Company was used in the admixture. Figure 1 shows all the materials used in this study.

(a) (b)

(c) (d)

Figure 1. Research materials (a) fly ash, (b) cement, (c) polypropylene fiber, and (d) superplasticizer

2.2 Mixing, Casting, and Curing

The material composition for Balinese architectural ornaments in this research consists of cement, fly ash, fiber, superplasticizer, and water. The binder composition is a ratio of 1 cement: 2 fly ash. The water and binder ratio is fixed at 0.35. The variation in the materials was varied according to (i) fiber (0.05%, 0.025%, and 0.01%) and (ii) superplasticizer (0.1% and 0.05%). The mixture composition was determined using the absolute volume method in this experiment, assuming that the mixture was compact. The total component per unit volume of the admixture may be calculated from Equation 1. The mix proportions are shown in Table 1.

$$\frac{W_{fa}}{G_{fa}\cdot\gamma_w}+\frac{W_{ce}}{G_{ce}\cdot\gamma_w}+\frac{W_w}{G_w\cdot\gamma_w}=1\ m^3 \tag{1}$$

Where in 1 m^3 fly ash-cement paste, Wfa: weight of fly ash (kg); W_{ce}: Weight of cement (kg); W_w: weight of water; G_{fa}: specific gravity of fly ash; G_{ce}: specific gravity of cement; G_w: specific gravity of water; γ_w: unit weight of water: 1000 kg per m^3.

As suggested in ASTM C305 (1999), solid substances such as fly ash, cement, and fiber were mixed in the mixer for about 1 minute before pouring the water, and then mixing was maintained for 5 minutes until a consistent mixture was achieved. Finally, the superplasticizer was added to the admixture for 1 minute. The finished paste was cast into the mold. The steel cube mold with the dimension of 50x50x50 cm^3 was polished with oil before. The specimens were removed from the mold after 24 hours and maintained at room temperature and 95% relative humidity. Figure 2 shows the casting sample.

Table 1. The mix proportion of material research

Detail of variation	Materials				
	FA (kg/m^3)	Cement (kg/m^3)	Water ($lt/\ m^3$)	SP (kg/m^3)	Fiber (kg/m^3)
SP 0.1%, Fiber 0.05%	1090.22	545.11	572.36	1.10	2.21
SP 0.1%, Fiber 0.025%	1090.22	545.11	572.36	0.55	2.21
SP 0.1%, Fiber 0.01%	1090.22	545.11	572.36	0.22	2.21
SP 0.05%, Fiber 0.05%	1090.22	545.11	572.36	1.10	1.10
SP 0.05%, Fiber 0.025%	1090.22	545.11	572.36	0.55	1.10
SP 0.05%, Fiber 0.01%	1090.22	545.11	572.36	0.22	1.10

(a)

(b)

Figure 2. Sample of material (a) casting and (b) mechanical strength

2.3 Test procedure

In this study, the mechanical strength of the material was tested according to ASTM C109 (2002) using 50 mm cube specimens. The fly ash cement paste materials were cast in (50 x 50 x 50 mm^3) cube mold in the age of 7, 14, and 28 curing days. Figure 3 shows the test machine from MBT with a capacity of 500 kN. The bulk density was calculated from the weight of the cube sample divided by its volume. For each variable, three specimens were produced.

Figure 3. MBT testing machine capacity of 500 kN

3. RESULT AND DISCUSSION

3.1 The bulk density of fly ash cement materials

The results of bulk density are shown in Figure 4. Generally, the bulk density of all samples reduces along with age. Lowering the superplasticizer content from 0.1% to 0.05% in the mixture normally results in higher bulk density compared with the bulk density with 0.1% of superplasticizer. In the study by Paramitha et al., (2009), the use of a superplasticizer can increase the water-to-solid ratio of the paste, leading to a reduced bulk density of the materials. From the result, the bulk density of fly ash-cement paste ranges between 1.500 kg/m3 to 1.764 kg/m3. In this study, the fiber concentration ranged from 0.01% to 0.05%. Because of their lightweight density, fiber content has little effect on the bulk density of fly ash cement paste.

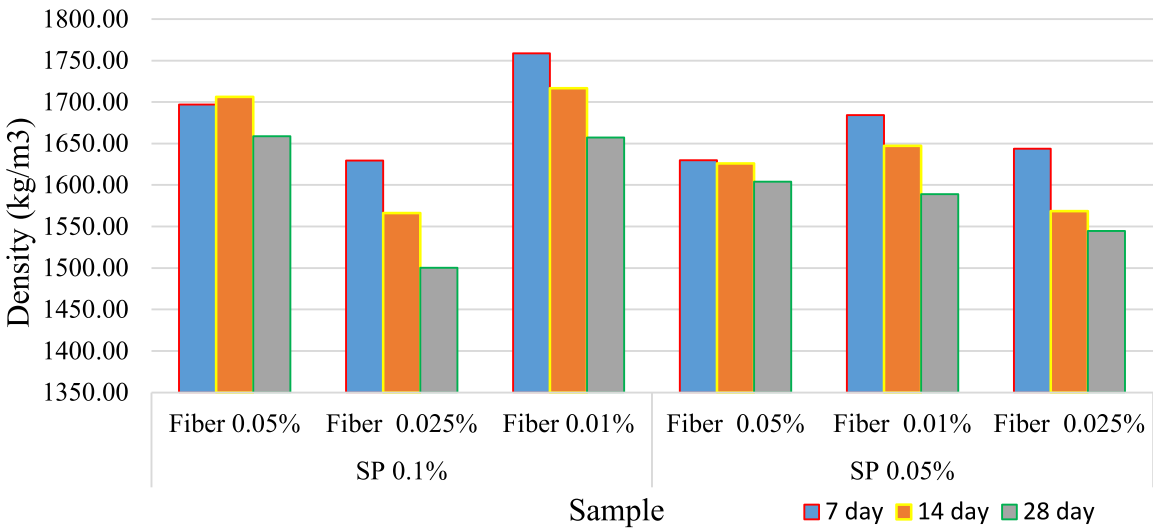

Figure 4. The bulk density of fly ash-cement paste material

3.2 The compressive strength of fly ash cement materials

The compressive strength of a fly ash-cement paste composition is shown in Figure 5. Overall, the compressive strength of fly ash cement paste increases with curing time. The test results show that the compressive strength for all the samples on 28 days exceeds 20 MPa. The highest compressive strength value in the fly ash-cement paste mixture contains 0.1% SP and 0.025% fiber. Based on the result, using 0.1% SP produces higher compressive strength values for fly ash cement paste compared with 0.05% SP. Lowering the SP content to 0.05% reduces more than 50%, 25%, and 65% of compressive strength on 28 days with the fiber content 0.05%, 0.01%, and 0.025%, respectively. According to Figure 4, the 28-day compressive strength of fly ash-cement paste contains 0.1% SP and 0.025% Fiber resulting in 35 MPa, thus this ratio was chosen as an ornament architecture material.

3.3 The comparison of fly ash-cement paste material with other stone material

3.3.1 The mechanical properties

The composition ratio used as an architectural ornament in this research is fly ash-cement paste with 0.1% SP and 0.025% fiber which has higher compressive strength. This material was compared with other stones that are usually made as an ornament architecture in Bali. A 50 x50x50 mm3 sample of red brick, andesite stone, basalt stone, and sandstone were studied for compressive strength and bulk density tests. Figure 6 shows the comparison of these materials. Based on the result, the fly ash-cement paste has a higher strength compared with other stones while having a similar bulk density. Basalt stone, a popular ornamental architectural material in Bali, has a compressive strength of 19.42 MPa, which is 44% lower than the fly ash-cement paste mixture. Andesite stone has a better compressive strength than basalt stone but a lower compressive strength by around 29% than fly ash cement paste material. Fly ash cement paste has a similar bulk density to red brick and andesite stone. The lowest compressive strength is sandstone about 3.87 MPa.

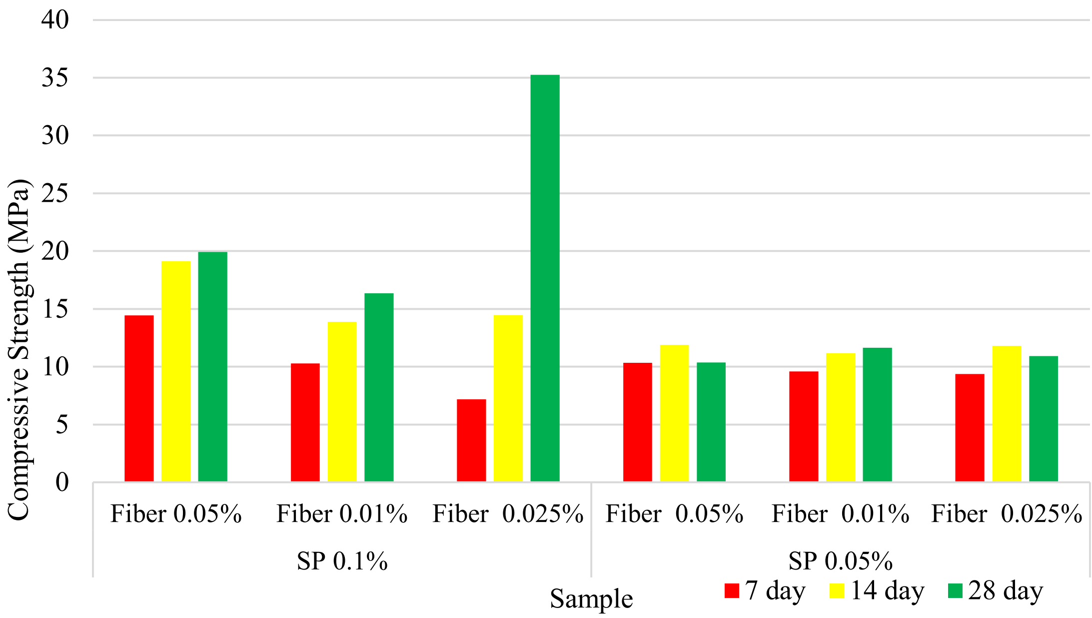

Figure 5. The compressive strength of fly ash-cement paste material

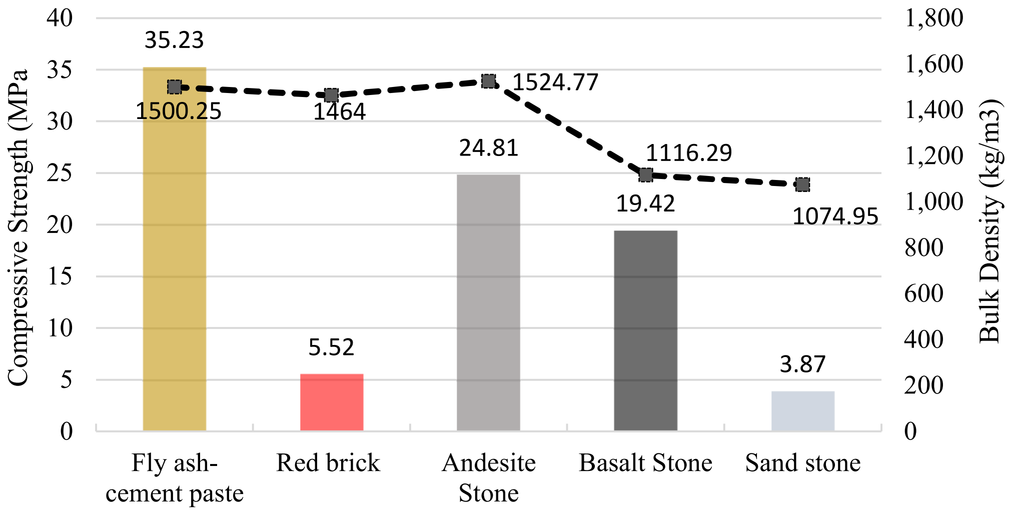

Figure 6. The bulk density and compressive strength comparison of research material and other stone materials

3.3.2 The cost comparison of Balinese temple

A prototype of a Balinese temple with dimensions of 70 x 90 cm and a height of 2 m was created to compare the cost requirement with other Balinese temple with different materials. Figure 7 shows the Balinese temple made with these research materials while Figure 8 shows another Balinese temple with different materials such as basalt stone (left) and red brick (right). The temple with fly ash-cement material is brownish. This is because the color of fly ash dominates the proportion. Table 2 displays the cost difference between this research material with other stone materials. The table shows that the cost of the temple with fly ash cement material is IDR 1.500.000. If compared to other materials, the price is significantly lower.

Table 2. The cost difference of material

No	Materials	price estimate (IDR)
1	Fly ash-cement paste	1.500.000
2	Basalt stone	8.000.000 – 10.000.000
3	Red brick	3.000.000-5.000.000
4	Sandstone	1.500.00-2.000.000

Figure 7. The Balinese temple is made from fly-ash cement material

Figure 8. The Balinese temple is made from basalt stone (left) and red brick (right)

4. CONCLUSION

In this study, the feasibility of using fly ash as a new sustainable material for Balinese architecture ornament in Bali was investigated. Six proportions were created with different ratios of fiber and superplasticizer. The highest compressive strength occurred when 0.1% SP and 0.025% fiber were mixed in the mixture. When compared to other stone materials such as basalt stone, andesite stone, and red brick, fly ash cement has the highest compressive strength and the lowest price.

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