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A Comparative Study of Plant Leaf Ash as The Replacement for Fly Ash in Breeze Blocks

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Abstract

Breeze blocks, or ventilation blocks, are made of concrete and fly ash produced from pulverised coal combustion in the power plant. However, the components of cenospheres found in fly ash can pose environmental and health hazards due to the methods used in their production and disposal. The growing recognition of environmental issues has led to a significant focus on repurposing industrial byproducts from plant fibers. These materials offer cost-effective, recyclable, biodegradable, and eco-friendly alternatives for fly ash, helping to reduce agricultural waste and lower the carbon footprint of construction projects. This study was conducted to investigate the compressive strength, water absorption, fire resistance, and workability of concrete mixes between the conventional fly ash breeze block and those reinforced with ashes from nipa palm leaf, pandan leaf, and corn leaf. The plant leaves were first burned into ashes and then sieved to a particle size range of 0.25 mm to 0.30 mm. Following that, the breeze block samples reinforced with various ashes were prepared according to the designated compositions. The fire resistance test (ASTM E119), water absorption test (ASTM C140), slump test (ASTM C143), and compressive test (ASTM C109) were conducted accordingly. Experimental results showed that the samples of nipa palm leaf ash had the best resistance to fire with 293.33s of burning time, the highest water resistance at 0.04% of water uptake after 24 hours, and excellent compressive strength at 5.97 MPa as compared to conventional fly ash breeze blocks and other samples. Nonetheless, the corn leaf ash showed the best slump head at 23.50 cm compared to the rest. Therefore, it can be concluded that the nipa leaf ash is a potential eco-friendly replacement for fly ash in the conventional breeze block industry.

Keywords: - Breeze blocks, fly ash, plant leaf ash, properties, testing

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1. Introduction

Concrete blocks made from a mixture of concrete and fly ash are called breeze blocks, cinder blocks or ventilation blocks (Fig. 1(a)). These blocks can also be made using other fillers like clinkers, sand, or gravel and are known by various names like foundation, cinder, or cement. Breeze blocks are commonly used to decorate building walls or serve as a wall itself. They are aesthetically pleasing and play an important role in Mid-Century Modern design, providing shade, ventilation, protection, and privacy. Breeze blocks are used worldwide, for their functions and decorative qualities. Breeze blocks can filter harsh sunlight while allowing ventilation and providing shade for large floor-to-ceiling windows in mid-century designs. They are often cheaper to produce locally, due to their weight and long-distance delivery costs. Local breeze block companies produce standard patterns like the typical snowflake design and unique patterns, exclusive to their factory. Today, there are around 200 different breeze block layouts (Henderson, 2019). These blocks can be constructed with various densities and weights depending on the fillers used. Lower- density blocks are often used for building garden walls and other non-structural elements, such as inexpensive shelving made by college students worldwide using concrete blocks and lengths of wood. Breeze blocks are generally lightweight and not suitable for sustaining heavy loads. Their designs make them easy to handle, as they are considerably lighter than denser blocks. The hollow sections in breeze blocks make them lighter and easier to work with, while also providing insulating properties, as the air in the spaces is an excellent insulator (McMahon, 2022).

Over the past few years, fly ash has effectively reduced the limestone and cement required in conventional fired clay bricks without compromising strength or quality. Fly ash (Fig. 1(b)) is a fine powder containing various quantities of major heavy metals and impurities with different properties. According to Dale (2023) the compound is produced by the fusion of mineral impurities in pulverised coal during combustion in power plants. During the production process, these radioactive wastes leak from the power plant and contaminate surrounding sources such as water and soil, thereby posing adverse risks to the environment and human health. Excessive production of fly ash compared to its consumption poses a significant issue, as the unused fly ash is typically disposed in the landfills or ponds, resulting in air and groundwater pollution. Several studies have demonstrated that the traditional wet dumping method of fly ash fails to safeguard the environment from the migration of heavy metals into the soil and, consequently, into the groundwater. It has the potential to risk human lungs, as it can persist in the pulmonary region for long periods. Landfilling is the most common method for disposing fly ash, despite the need for significant land and financial resources to establish a landfill site (Gupta et al., 2005; Paswan et al., 2017; Yoriya & Tepsri, 2021).

(a)

(b)

Fig. 1. (a) Breeze blocks (b) fly ash

Hence, the utilization of plant fibers as moreeco-friendly, recyclable, biodegradable and cost-effective alternatives for strengthening construction materials has received considerable interest in response to growing environmental awareness. Specialists and researchers have identified various alternative types of concrete that utilize agricultural wastes, including sugarcane bagasse, oil palm fibers, rice straw, cotton stalk, wheat straw, banana fibers, jute, flax, and so on (Ahamed et al., 2021; Agwa et al., 2020; Bheel et al., 2021; Bachtiar et al., 2019). Studies have also observed that sisal, coconut coir, and bamboo have yielded more promising results in test conditions due to their low thickness, ease of use, and biodegradability (Olatoyan et al., 2023). Thus, this study aims to investigate the compressive strength, water absorption, fire resistance, and workability of concrete mixes using ashes of pandan leaf, corn leaf, and nipa palm leaf as alternatives to traditional fly ash breeze blocks.

2. Materials

2.1 Fly Ash

Fly ash is a fine powder of 0.5 µm to 300 µm in particle size with a grey-reddish-brown appearance and constructed by 70% - 90% of solid glassy spheres such as magnetite, mullite, and quartz (Fig. 2). The chemical composition of fly ash varies depending on the coal source, the pretreatment process, and the burning operation (Yao et al., 2015). The major chemical fractions in fly ash are micro-spherical components of heavy metals such as silica, alumina, and iron oxides, as well as other harmful elements like cadmium, calcium, chromium, silver, arsenic, mercury, barium, lead, beryllium, and selenium (Gupta et al., 2005). The active silica and alumina in fly ash react chemically with calcium hydroxide at room temperature, resulting in the formation of cementitious compounds in the presence of moisture. Fly ash's morphological properties enable it to flow and blend well in mixtures, making it a suitable additive for brick production (Nordin et al., 2016). Fly ash cannot be composted or burned for disposal due to the presence of cenospheres and its non-biodegradable nature. Hence, it is crucial to consider their toxicity and environmental impact when managing and disposing of fly ash effectively (Paswan et al., 2017; Yoriya & Tepsri, 2021).

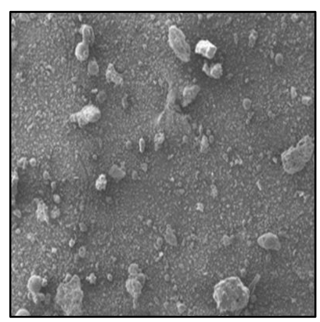


Fig. 2. Particle size of fly ash

2.2 Nipa Palm Leaf

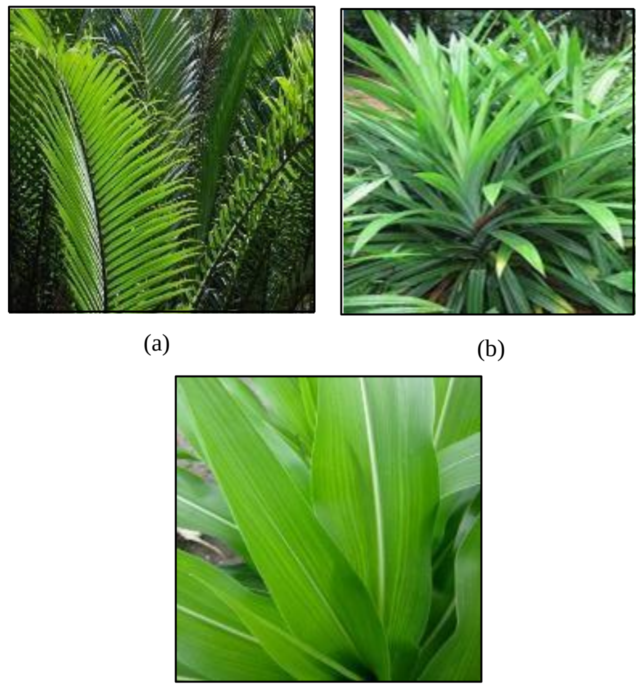
Nipa palm (or mangrove palm) is an estuary plant from Africa to South Asia, Indonesia, Malaysia, and the Western Pacific. Nipa plants can grow in water with a moderate salinity level, a little tidal activity, and soft mud that provides necessary nutrients for their growth. It can reach up to 10 metres in height, depending on the ecosystem's fertility. The nipa leaves (Fig. 3(a)) have dimensions ranging from 60 to 130 cm in length and 5 to 8 cm in width. The mature nipa leaves are green, whereas the old ones are yellow and look lustrous on the top surface. Each leaf frond contains 25 to 100 strands of leaflets (Widodo et al., 2020; Nugroho et al., 2020). The largest chemical components found in nipa leaves are lignin (19%–34% of weight), protein, starch, and extractives (2%–8%). Nipa leaf has about 5% ash content, higher than other palm ash and sugarcane bagasse ash, with 0.1% - 1.6% composition of metallic and non-metal elements such as K, Na, Cl, Mg, Ca, Al, and Si. Previously, several studies reported using nipa leaf ash as a resource for producing biofuels and improving the quality of herbal beverages and contaminated soil (Tamunaidu & Saka, 2011; Harun et al., 2020). The nipa palm leaves used in this study were taken from the recycled wrappers of local food "Otak-Otak," collected from hawker stalls around Pasir Gudang, Johor.

2.3 Pandan Leaf

The pandan plant (Pandanus amaryllifolius) has spiky-green leaves that grow in fan-shaped bunches with a range in size from 60 to 90 cm in height and 5 cm width (Fig. 3(b)). It is highly valued for its floral fragrance and adaptability in tropical and subtropical climates, particularly in the Southern India, and Southeast Asia, including Indonesia, Malaysia and Thailand. The fresh leaves are green in colour which contain chlorophyll at 24.66 mg/L. Pandan leaves are hydrophilic due to the ionic bonding of magnesium compound found in the chlorophyll. The newly reaped leaves have the most potent scent, which lingers for 1- 2 days. The distinctive fragrance of pandan leaves is attributed to the presence of a chemical compound called 2-Acetyl-1-Pyrroline (ACPY). The hydrophilic properties of the ACPY compound allow it to dissolve in water and alcohol with scent concentrations as low as 0.01 ppm (Yahya et al., 2011). Pandan leaves have a short lifespan and are easily broken due to their high-water content of 84.3%. The crude fiber content is around 3.4%, which may rise when the water decreases during the drying process. Pandan is commonly referred to as the 'vanilla of the East' and can serve as a natural aroma enhancer and green colouring for sweet and savoury cuisines (Ningrum et al., 2015; Murtini et al., 2020). The pandan leaves used in this study were freshly reaped in Pasir Gudang, Johor.

2.4 Corn Leaf

The corn leaf plant is a broadleaf evergreen that can grow up to 1.5 m tall in the tropics and warm temperate zones such as the United States, China, Brazil, and South Africa. This delicate plant has a distinct appearance and is relatively simple to recognize, as shown in Fig. 3(c). According to WorldGrain.com, 1.172 billion metric tonnes of corn are harvested in the United States from 2022 to 2023. The chemical composition of corn leaf is 43% cellulose, 22% lignin, 31% hemicelluloses, and 1.9% ash (Guru et al., 2021). However, the natural waste of corn husks causes several environmental issues, including air pollution, smoke generation, and soil moisture loss. Therefore, corn leaves are commonly recycled in a profitable and economically viable way for the farmer (Wishhart, 2014). Aswin et al. (2021) reported that 7.5% of corn leaf ash is an optimum replacement for cement, which increased the compressive strength of concrete to 9.92%, 11.34%, and 10.18% after 7, 14, and 28 days. Ahumada et al. (2021) have demonstrated the immense potential of rice husk and corn leaf ashes as pozzolanic adhesive mortars for ceramics. Kubi et al. (2021) have also concluded that corn husk ash and coconut fiber significantly contribute to concrete's compressive and impact strength. For this study, the corn leaves are collected from Zon Pengeluaran Makanan (ZPM) Labis, Johor.



(a) (b) (c)

Fig. 3. (a) *Nipa* palm leaves (b) *pandan* leaves (c) corn leaves

3. Methodology

Firstly, the nipa palm leaves, pandan leaves, and corn leaves were cut to approximately 25 - 30 cm long and washed thoroughly with water. They were then sun-dried for two days and burned to ashes (Fig. 4). Next, the resulting plant leaves ashes were sifted through a 0.25 – 0.30 mm strainer. Finally, the ashes were stored in sealed plastic containers and labelled accordingly, as shown in Fig. 5. The required amount of cement, sand, water, fly ash, nipa palm leaf ash, pandan leaf ash, and corn leaf ash were weighed according to the percentage composition, as shown in Table 1 (Abebaw et al., 2021). All the materials were mixed in a heavy- duty bucket pail using a scoop and cured for three days before being poured. Air curing is the most effective method for preventing mixed water evaporation. The temperature of the concrete determines the curing times. Hence, it is critical to monitor the transfer warmth and humidity from and into the concrete (Rohaizat & Abdullah, 2021).

Fig. 4. Preparation of plant leaf ashes

Fig. 5. Samples of fly ash and plant ashes

Table 1. Composition of materials for each sample in weight percentage (%)

Weight of Materials (%)	Types of Samples			
	Nipa Palm Leaf Ash (NPLA)	*Pandan* Leaf Ash (PLA)	Corn Leaf Ash (CLA)	Fly Ash (FA)
Ash	40	40	40	40
Cement	15	15	15	15
Sand	30	30	30	30
Water	15	15	15	15

Next, the grease was applied uniformly onto the 25 mm Polypropylene (PP) mould to prepare the water and fire-resistant test samples and onto the 50 mm x 50 mm x 50 mm ABS cube mould to prepare the compressive test samples (Fig. 6). The mixtures were then poured into the moulds and covered with plastic sheet for 24 hours to prevent air moisture or drying effects from wind and sun. Finally, the samples were removed from the moulds and cured for 28 days to increase cement hydration, strength development, and concrete durability (Abebaw et al., 2021). Samples of each ash for each test were prepared and labelled accordingly, as shown in Fig. 7.

(a) (b)

Fig. 6. (a) Polypropylene (PP) mould (b) ABS cube mould

Fig. 7. Samples of each ash for each test

4. Result and Discussion

Experimental testing was conducted on samples of breeze blocks reinforced with nipa palm leaf ash (NPLA), corn leaf ash (CLA), and pandan leaf ash (PLA) to determine compressive strength, water absorption, concrete mix workability or consistency (slump test), and fire resistance, as compared to conventional fly ash breeze block (FA).

4.1 Compressive Test (ASTM C109)

According to Mishra (2019), compressive strength is a material or structure's ability to support weights on its surface without fracturing or deflecting. The samples of the material are pressed together with a compression load between two plates. An extensometer or strain gauge is used to measure the deformation (Fig. 8). For this testing, the sample specification is a cube shape with dimensions of 50 mm x 50 mm x 50 mm in height, width, and length. The Automatic Compression Machine for Concrete Testing, manufactured by NL Scientific, was used to conduct the experiment. The one-phased machine is in

NatTest Sdn. Bhd., Johor Bahru, with a maximum capacity load of 3000 KN and 750 W power. The indications of fracture cross section for each sample are presented in Fig. 9.

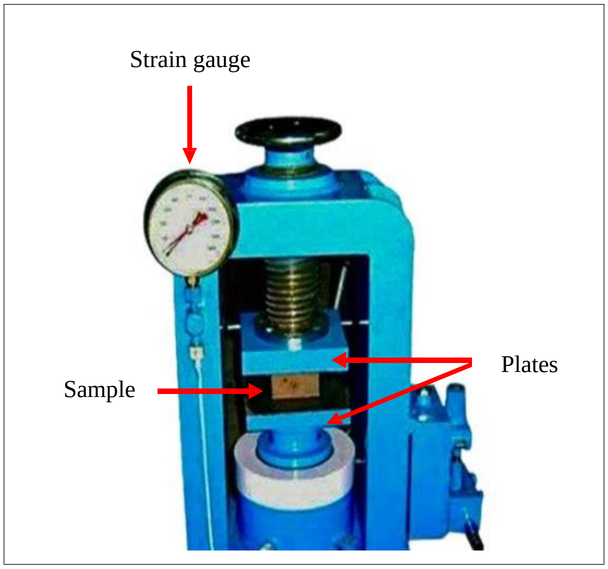


Fig. 8. Compressive test

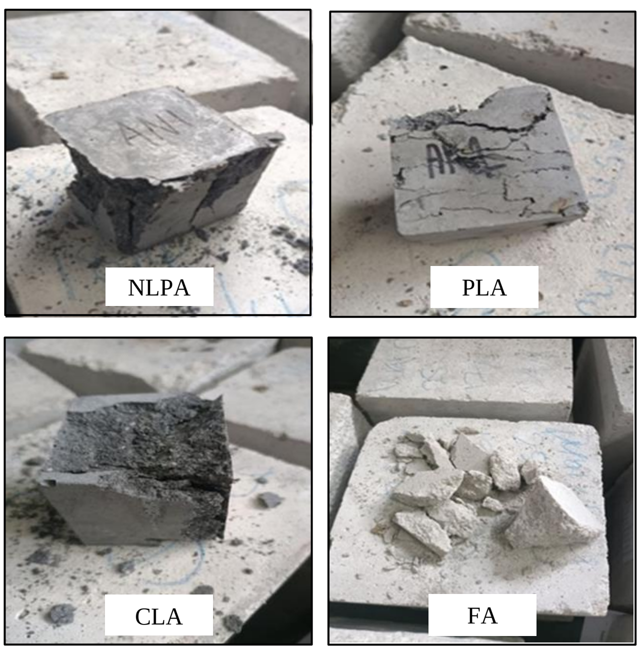


Fig. 9. Indications of fracture cross section for each sample in compressive test

The best compressive strength in this study is shown by NPLA at 5.97 MPa, followed by PLA (5.00 MPa) and CLA (4.60 MPa). Meanwhile, FA exhibited the lowest compressive strength at 4.27 MPa, as shown in Fig. 10. The high-water content of fly ash clogs the hydration and binding mechanisms between cement and water, increasing the brick's permeability and decreasing its compressive strength. Additionally, the smaller size and uniformity of the particles could expand the bonding area between ashes and cement to increase the density and strength of the brick (Nurzal et al., 2019). Nevertheless, all brick samples had a compressive strength more significant than the minimum requirement in ASTM C129-11 for non-load-bearing bricks, which is 3.45 MPa. This result was also discovered in a study by Eddy et al. (2022), which indicated that the quality of charcoal briquettes made from nipa palm leaf and fruit shells meets the minimum requirements for compressive strength in the Indonesian National Standard (SNI).

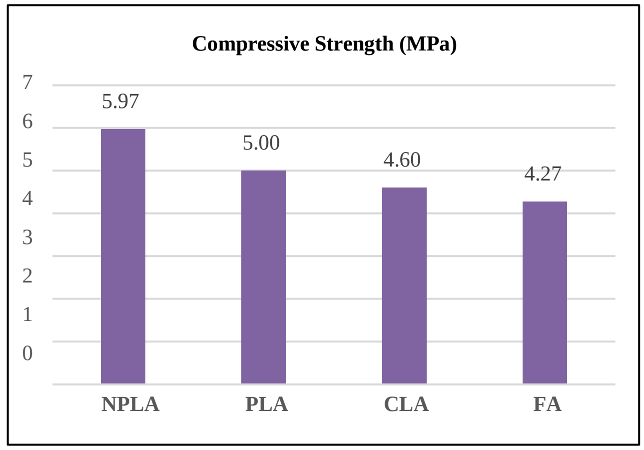


Fig. 10. Result of compressive test for each sample

4.2 Water Resistance Test (ASTM C140)

The water absorption test of concrete evaluates the volume of water that a concrete sample can absorb to indicate its performance and durability. The water resistance for concrete can be expressed by the percentage of water uptake before and after the test. The rate of water uptake (%) was calculated using the following equation:

$$Rate\ of\ water\ uptake\ (\%) = \left(\frac{wf-wi}{wi}\right)x100\% \quad (1)$$

The initial weight of samples (wi) was recorded before all the samples were immersed in water bath for 24 hours, and the final weight (wf) was taken after the procedures. The result of this testing is presented in Fig. 11. It is observable that PLA exhibits the best water resistance due to its lowest water absorption rate at 6.34%, as compared to NPLA (10.67%), CLA (12.24%), and FA (13.18%). Similarly, the high water uptake of brick reinforced with fly ash was also observed by Sun et al. (2019), who reported that the pozzolanic activity between the ash and cement in brick caused the growth in its microstructure deterioration and water absorption.

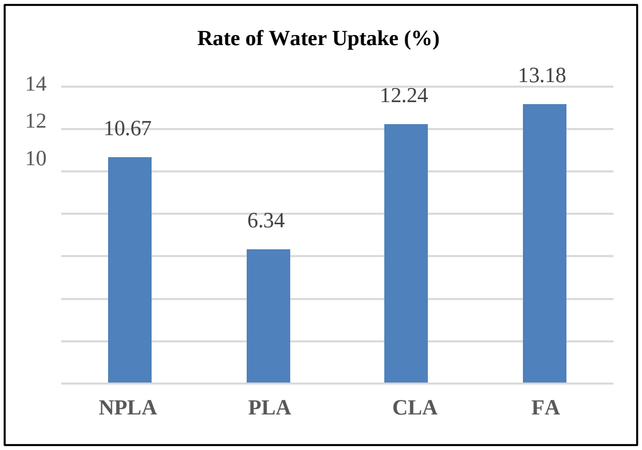


Fig. 11. Result of water resistance test for each sample

4.3 Slump Test (ASTM C143)

The slump test is the simplest method for concrete since it is inexpensive and offers rapid results. It is an empirical test used to study the level of workability and consistency of a concrete mixture by measuring its thickness (height) and viscosity. As a result, the slump test determines if the concrete mix has insufficient, excessive, or sufficient water (Bachtiar et al., 2019). 9 kg of mixture for each sample was prepared according to the composition, as shown in Table 1. The cone was filled up to 1/3 capacity with the concrete using a scoop, and the mixture was tamped 25 times with the steel tamping rod. The cone was then filled to 2/3 capacity with the mixture and tamped 25 times with the rod. The same procedure was repeated for the final layer. Then, the cone tabs were unlocked and stepped while the cone was lifted slowly in a vertical direction to clear off the sample. The cone was inverted beside the concrete sample without touching the base of the concrete sample (Fig. 12).

Fig. 12. Slump test

Finally, the slump mould base was placed on a straight edge with one end extended over the pile of concrete. A tape or ruler is used to measure the distance from the bottom of the straight line to the displaced centre of the concrete. The height of the slump was recorded and presented in Fig. 13 (Tharpe, 2021). The best slump head is shown by CLA at 23.50 cm, followed by NPLA at 20.60 cm. Meanwhile, FA exhibits the lowest head at 17.50 cm. It is important to note that a variety of factors play a role in determining the viscosity of concrete, such as material qualities, mixing procedures, dosage, admixtures including water content, cement content, aggregate form, aggregate grade, as well as other elements added (Mishra, 2020).

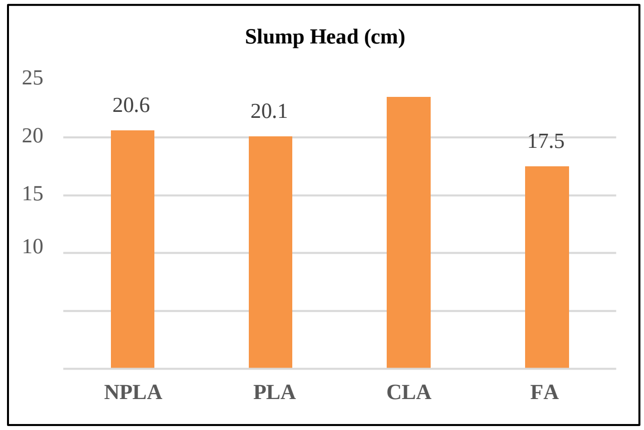


Fig. 13. Result of slump test for each sample

4.4 Fire resistance test (ASTM E119)

The test was carried out by heating the samples with flames from a torch gun, and the time it took them to endure the burning before cracking was recorded (Fig. 14). The best fire resistance is shown by NLPA at 293.33 s, as presented in Fig. 15. On the other hand, FA has recorded 210.00s of burning time, followed by PLA (143.00s) and CLA (123.00s). The various levels of ashes in the concrete can account for the number of cracks due to the tendency of the clinker substitute elements that were absorbed by cement during the pozzolanic reaction. High permeability and porous structures in ashes offer moisture escape routes during heating, leading to good fire-resistance properties (Lublóy et al., 2017; Jiang et al., 2020).

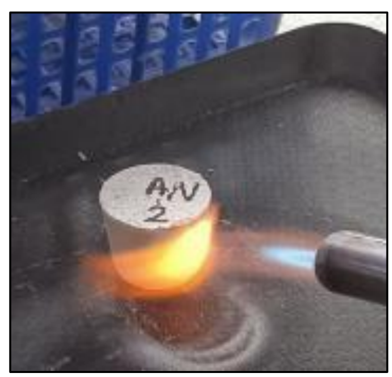


Fig. 14. Fire resistance test

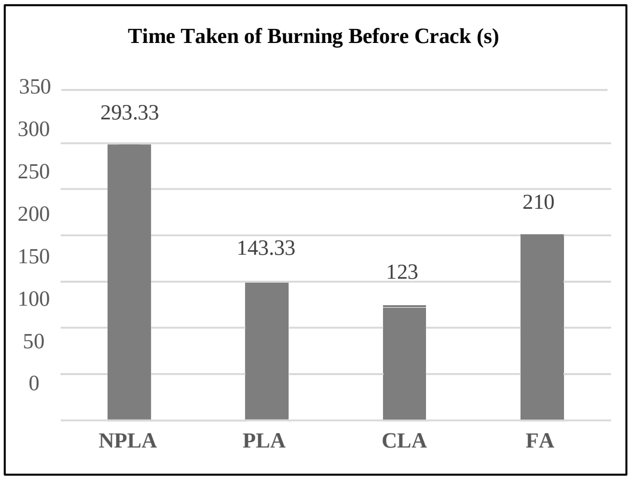


Fig. 15. Result of time taken of burning before crack for each sample

5. Conclusion

Table 2 displays the results of the tests on samples of regular fly ash breeze blocks (FA) and breeze blocks reinforced with ashes from nipa palm leaf (NPLA), pandan leaf (PLA), and corn leaf ash (CLA). The merit points are awarded based on the best results ranking, with first place receiving 3 points, second place receiving 2 points, third place receiving 1 point, and last place receiving 0 points. According to the table, NPLA has the best results with the accumulating ten merit points as compared to conventional FA and other samples. In conclusion, a breeze block reinforced with nipa palm leaf ash could be an economical alternative to the conventional fly ash breeze block in terms of cost, durability, environmental safety, and sustainability.

Table 2. Comparison of overall test results for each sample

Types of Testing	Merit points based on result ranking			
	NPLA	PLA	CLA	FA
Compressive strength (MPa)	3	2	1	0
Water absorption rate (%)	2	3	1	0
Slump head (cm)	2	1	3	0
Time taken of burning before crack (s)	3	1	0	2
Total Accumulative Points	**10**	**7**	**5**	**2**

6. Product Design

The breeze block reinforced with nipa palm leaf ash was produced using a mould made of plastic with dimensions of 300 mm × 70 mm × 300 mm in length, width, and height, as shown in Fig. 16. The product weight is 25 kg and consists of ash, cement, sand, and water at each percentage accordingly (Fig. 17).

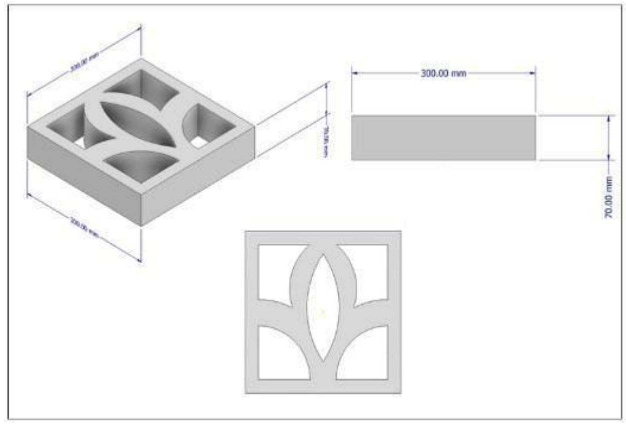


Fig. 16. Dimensions of breeze block mould

Fig. 17. Breeze block reinforced with nipa palm leaf ash

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