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UTILIZATION OF ULTRAFINE PALM OIL FUEL ASH IN INTERLOCKING COMPRESSED EARTH BRICK

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ABSTRACT: In this paper, the effect on utilization of ultrafine palm oil fuel ash (UfPOFA) on the properties of interlocking compressed earth bricks (ICEB) were investigated. The materials used to produce Interlocking Compressed Earth Brick (ICEB) includes clay soil, sand, Ordinary Portland cement (OPC), and water. OPC were replaced at 0%, 10%, 20%, 30% and 40% by mass percentage with UfPOFA. The ICEB specimens were cured at 7 and 28 days to study the bulk density, compressive strength and water absorption of the ICEB. The experimental results found that the incorporation of UfPOFA reduced the bulk density and compressive strength at both ages of the specimens as compared to the control mix. However, it was observed that their compressive strength improved with age. The compressive strength of ICEB specimen with 10% of UfPOFA showed the highest strength at 28 days amongst all mixtures containing UfPOFA with 6.53MPa, which was higher than the strength value required for loadbearing earth bricks in Malaysian Standard (MS) 76:1972. In addition, the lowest rate of water absorption was found to be 15.44% for 28-day old ICEB specimen with 10% UfPOFA, which was just slightly higher than 15% in compliance with MS 76:1972 on the rate of water absorption for earth bricks. The results thus showed UfPOFA as a potential material to be used as an OPC replacement to produce a sustainable ICEB.

Keywords: Ultrafine Palm Oil Fuel Ash, Interlocking Compressed Earth Brick, Pozzolanic Materials, Supplementary-Cementitious-Material, Sustainable Masonry

1. INTRODUCTION

Masonry brick is well known to be one of the oldest and strongest building materials. Various types of masonry bricks have been developed worldwide. These include mudbricks, fired clay bricks, concrete bricks, compressed earth bricks, and aerated bricks, among others. However, due to the economic aspect of the construction industry, the demands for fast and cost-efficient construction are dire. The conventional construction method is time-consuming and could no longer meet the construction budget given to the contractors [1]. Moreover, there is an increasing urge for environment-friendly building construction to reduce energy emissions and carbon footprint [2].

Therefore, the Interlocking Compressed Earth Brick (ICEB) system is promoted as a new building technique that may solve these related problems. ICEB system construction technique is as simple as assembling “LEGO blocks” by connecting the tongue and groove joints. ICEB uses less or minimum mortar to bind the bricks together during the assembling process [3]. Elimination of the mortar laying process speeds up the overall construction process. Furthermore, ICEB has been introduced as an alternative low carbon building material which can help to reduce the carbon footprint of building construction [4].

ICEB is made of a soil-based product that uses locally available materials and uses less mortar for bricklaying due to the interlocking shape. Its strength is increased by the age curing method. However, ICEB production using natural soil can be challenging due to the poor properties of some natural soil. Loss of strength due to weathering effects is one of a few of the challenges [5]. Therefore, a small amount of Ordinary Portland cement (OPC), which acts as a stabilizer for the soil mixture, is added to the mixture to improve the properties of ICEB [6]. Nevertheless, the usage of OPC will increase the carbon footprint of ICEB production. The contribution of OPC production worldwide to greenhouse gas emissions is estimated to be about 6% of greenhouse gas emissions [7]. Hence, the demand for supplementary cementitious material with low environmental impact has been increasing.

In this study, Palm Oil Fuel Ash (POFA) was used as an OPC replacement in the production of ICEB. POFA is one of the common pozzolans used in research studies especially in top palm oil producing countries such as Indonesia, Malaysia, and Thailand [8]. It is a waste material produced from palm oil mills, which is the final product when palm fruit residues are burnt to generate electricity after the oil extraction process [9]. Extensive research has shown that POFA can be used as an

OPC replacement in concrete production [10-12]. One factor that was found to be influencing the concrete properties is the particle size of POFA.

From the previous studies, researcher found that Ultrafine POFA (UfPOFA) has a higher specific surface area, which allows it to accelerate the pozzolanic reaction and create more calcium-silicate-hydroxide (CSH) gels. CSH gel will help to improve porosity and reduce void ratio. Because of the more significant pozzolanic reaction of UfPOFA, its inclusion in a concrete mix resulted in an increase in compressive strength [13]. Silica and aluminium oxides present in UfPOFA react with calcium hydroxide ($Ca(OH)_2$, a product of the hydration reaction between cement and water) and produce secondary hydration which consequently densifies the microstructure of concrete hence resulting in better compressive strength [14]. Recent work reported that utilization of ultrafine POFA into interlocking compressed brick (ICB) has produced ICB with good engineering properties compared to the unground POFA ICB. This paper set out to investigate the usefulness of UfPOFA in ICEB production [15].

Previous published studies have not dealt with incorporating UfPOFA in ICEB production. Kadir, Sarani, Abdullah, Perju, and Sandu [16] used unground POFA as clay soil replacement to produce fired clay bricks (FCB). Tjaronge and Caronge [17] also investigated the use of unground POFA as a clay replacement in FCB manufacturing. So far, study by Asrah, Sabana, Mirasa, Bolong, and Han [15] examined unground and ultrafine POFA in ICB. However, the formulated ICB mixture were ultrafine and unground POFA, OPC and sand only. Furthermore, the data evaluated based upon preliminary data by using 50 x 50 x 50 mm cubes. In this paper, ICEB mixture were formulated with UfPOFA, OPC, clay soil and sand. The engineering properties of ICEB were analysed using the actual ICEB size (250 x 125 x 100 mm) which are practically used in building ICEB construction.

Although there have been research outcomes on the use of UfPOFA in ICB, but the experimental data are preliminary results. Therefore, the novelty of this study is set out to assess the significance of UfPOFA as an OPC replacement to produce sustainable ICEB. The investigation was conducted on the effects of utilizing UfPOFA towards the engineering properties of ICEB in terms of bulk density, compressive strength and water absorption.

2. RESEARCH SIGNIFICANCE

The findings should make an important contribution in managing the waste productions of POFA from the palm oil mill and to reduce the dependency on OPC in ICEB production. Hence this will help to reduce the environmental damages associated with the greenhouse gas emission. In addition, it its hoped that this study will be the beginning of an ongoing body of research indicate significant potential of using POFA in the production of sustainable ICEB.

3. MATERIALS AND METHODS

3.1 Materials Preparation

The materials used in this study were clay soil, river sand, Ordinary Portland cement (OPC), and Palm Oil Fuel Ash (POFA). The clay soil was excavated from the University Malaysia Sabah land area. They were completely air-dried before being put in the crusher machine. Their basic physical properties were examined and results are shown in Table 1. Based on the Unified Soil Classification System (USCS), the clay soil can be classified as silty sand (SM). River sand was collected from a river in Tuaran, Sabah. Ordinary Portland cement used for this research were products distributed by Sabah Cement (Gajah). Waste material POFA was collected from Sawit Kinabalu Palm Oil Mill in Lumadan, Beaufort, Sabah. Collected samples of POFA were initially in wet condition.

The method of preparing UfPOFA is shown in Figure 1. All the raw materials were subjected to preliminary assessment based on the American Standard for Testing and Materials (ASTM) prior to the preparation of ICEB mixes. Physical and chemical properties of OPC and UfPOFA are shown in Table 2 and Table 3. The specific gravity of POFA was determined using the standard Le Chatelier specific gravity flask. The test was conducted based on ASTM C188 [18]. Particle size was determined using particle size analyzer Malvern Zetasizer Nano Series Instrument with water as the dispersing agent. The loss on ignition (LOI) was investigated based on ASTM C311 [19]. Epsilon X-ray fluorescence (XRF) instrument was used for the chemical analysis of POFA. The total silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and iron oxide (Fe_2O_3) of the UfPOFA sample was 64.77%. According to ASTM C618 [20], if a pozzolan has at least 50% of total $SiO_2 + Al_2O_3 + Fe_2O_3$ and a maximum of 5% SO_3, 6% LOI, and 3% moisture content, then it meets the chemical requirements for a Class C pozzolan. This class of pozzolans contains a higher calcium amount. Other than having pozzolanic properties, it also has some cementitious properties [21]. However, the used in this study did not meet all the chemical requirements due to the slightly higher percentage of LOI (8.74%) than the maximum 6%.

Table 1 Physical Properties of Soil

Parameters	Soil	Standard
Atterberg Limit Test		ASTM D2487
Liquid Limit (LL)	33.54	
Plastic Limit (PL)	19.96	
Plastic Index (PI)	13.59	
Plasticity Chart Classification	Silty-sand	
Specific Gravity		ASTM D854
Silty-sand soil	2.68	
Size distribution (%)		ASTM D422
Gravel + Sand size	84.43	
Silt + Clay size (%)	15.57	

Table 2 Physical properties of OPC and UfPOFA

Properties	OPC	UfPOFA
Particle size, D_{ave} (μm)	18.60	1.50
Specific Gravity	3.29	2.20

Table 3 Chemical composition of OPC and POFA

Oxides component		Chemical composition (%)		
		OPC	POFA	ASTM C618
Silicon dioxide	SiO_2	13.82	59.77	
Aluminum oxide	Al_2O_3	3.59	1.8	
Ferric oxide	Fe_2O_3	3.08	3.2	
Calcium oxide	CaO	70.21	10.5	
Sulfur trioxide	SO_3	5.38	0.55	5.0, max
SiO_2+Al_2O_3+Fe_2O_3		20.47	64.77	50.00, min
Loss on ignition	LOI	5.43	8.74	6.0, max
Moisture content		0.32	2.23	3.0, max

3.2 ICEB preparation

Production of ICEB starts with investigating the optimum mixture proportion for the control mixture. The research process is described in detail in Figure 2. A total of eight mixture ratios of OPC, clay soil and sand were designed to investigate the control composition of ICEB. The table of mixture proportion is shown in Table 4. Example on series C70S30, indicates clay soil (C) 70% combined with sand (S) 30%. The investigations were based on ICEB compressive strength and water absorption tests. The method for compressive strength testing was in accordance with BS EN 772-1. The ICEB unit was tested as shown in Figure 2, where both sides of each sample were capped with steel plates to ensure both faces were compressed under a flat surface. This method was selected for its reliability and validity from previous studies [22, 23]. The water absorption test was performed by following the procedures in ASTM C67 for 24-hour immersion test. The results obtained from both of the analyses are presented in Figure 3. From the data, it can be seen that series C65S35, a combination of 65% of clay soil and 35% of sand, obtained the highest compressive strength and lowest water absorption. Hence, C65S35 was used as the control

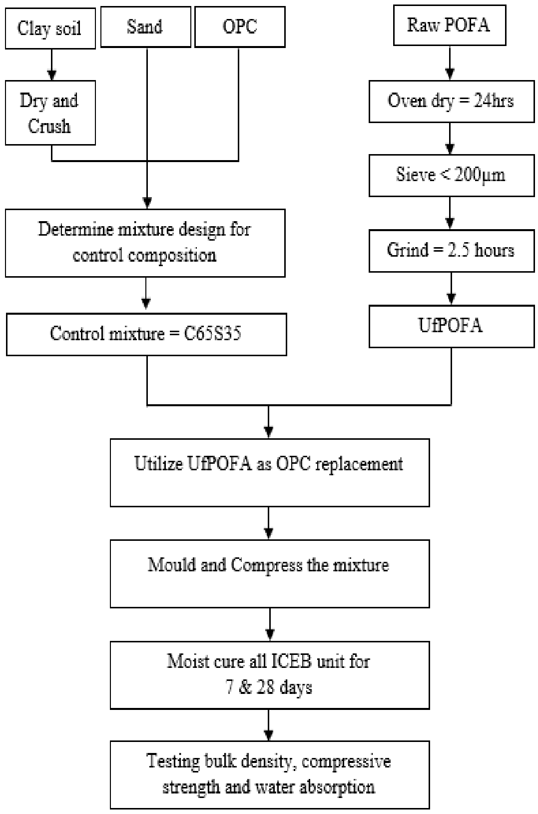

Fig. 1 Procedure to prepare ICEB

Fig. 2 Method to test compressive strength of ICEB unit

Table 4 ICEB mixture design by ratio

No	Series	OPC	Clay	Sand
1	Control	1.0	9.0	0
2	C70S30	1.0	6.5	2.5
3	C65S35	1.0	6.0	3.0
4	C60S40	1.0	5.5	3.5
5	C55S45	1.0	5.0	4.0
6	C50S50	1.0	4.5	4.5
7	C45S55	1.0	4.0	5.0
8	C40S60	1.0	3.5	5.5

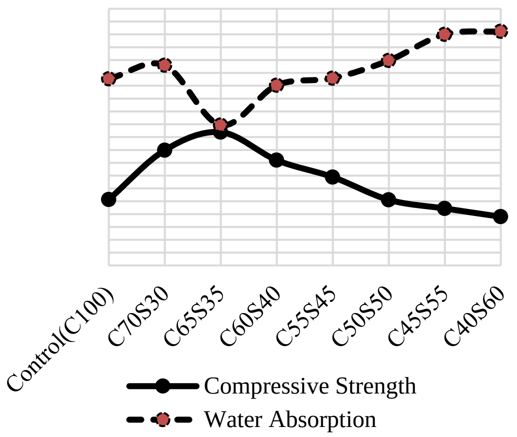

Fig. 3 Results for ICEB control mixture

mixture for further investigations of ICEB incorporated with UfPOFA.

3.3 ICEB incorporating UfPOFA

A total of five mixtures designed for ICEB were incorporated with UfPOFA to replace OPC. Table 5 shows the proposed mixture proportions. The substitutions of UfPOFA were in terms of mass percentage replacement. Five types of mixes were used to prepare ICEB specimens (250 x 125 x 100 mm) for the experiments. The ICEB was produced by mixing all the dry materials, i.e., clay soil, sand, OPC, and UfPOFA. Then water was gradually added until it reached a desired moist texture and was then put into the compressor machine to produce ICEB. The specimens were moist cured for 7 and 28 days before testing was conducted. Testing conducted on the specimens were for bulk density, compressive strength and water absorption. Water absorption is a significant durability property of ICEB because water absorption will affect the quality of the bricks, especially due to surface erosion [24]. Figure 4 shows ICEB containing UfPOFA were prepared for curing process.


Fig. 4 ICEB specimen contained UfPOFA

Table 5 Mixture of ICEB with UfPOFA by weight

Series	OPC (kg)	UfPOFA (kg)	Clay (kg)	Sand (kg)
Control	6.50	0	39.0	19.5
CP10	5.85	0.65	39.0	19.5
CP20	5.20	1.30	39.0	19.5
CP30	4.55	1.95	39.0	19.5
CP40	3.90	2.60	39.0	19.5

4. RESULTS AND DISCUSSION

4.1 Bulk Density

The bulk density is related to water absorption and durability characteristics of ICEB. The higher the bulk density, the denser the ICEB. This will usually reduce the water absorption and increase the durability of ICEB. The results for bulk density of ICEB containing 10% to 40% UfPOFA replacement (CP10-CP40) are presented in Figure 5. The results revealed that by increasing UfPOFA content in the ICEB mix, the bulk density of the specimens decreases. With 10% UfPOFA replacement, the bulk density slightly decreases as compared to the control mix. The bulk density starts to decrease further starting at 20% UfPOFA replacement. This finding is comparable with a study reported by Phonphuak, Teerakun, Srisuwan, Ruenruangrit and Saraphirom [25] where the density of brick decreasing as the pozzolan content increasing.

There are a few explanations for these reductions in ICEB bulk density. The density reduction of CP10-CP40 compared to the control might be attributed to the specific gravity of UfPOFA. In accordance with the results in Table 2, the specific gravity of UfPOFA is 2.20 while OPC is 3.29, which means that UfPOFA has a lower specific gravity than OPC.

Besides that, it might be caused by the shapes and agglomeration of UfPOFA. Figure 6 shows the scanning electron microscope (SEM) images of UfPOFA. The UfPOFA particles were seen to be agglomerated and in irregular shapes. Similar finding reported by Ranjbar, Mehrali, Alengaram, Metselaar and Jumaat [26], where POFA possesses agglomerated and irregular shapes that lead to difficulties of POFA to roll over one another. Hence more evaporable water is needed to improve the workability of the mixture. However, the additional water is also causing the increment in pores therefore reducing the density**.**

Other than that, lower bulk density at increasing replacement levels might be due to the slow pozzolanic reaction of UfPOFA. The pozzolanic reaction is lower at the early hydration stage due to the dilution effect caused by low tricalcium silicate (C_3S) content [27]. Hence it slows down the formation of hydration products and chemical interaction with other materials in ICEB. Rajak, Majid and Ismail [28] confirmed that a mixture with UfPOFA will create a desirable dense and compact microstructure at a later age.

Nevertheless, this is beneficial in terms of the improvement of the thermal behavior of ICEB structure. A further study on the thermal conductivity of ICEB should be done. Moreover, low density have the advantages in reducing the overall dead load on ICEB work, hence it will lower the transportation costs [29].

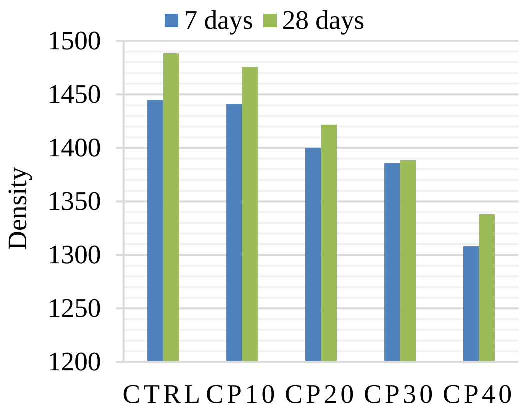

Fig. 5 Bulk density of ICEB-UfPOFA

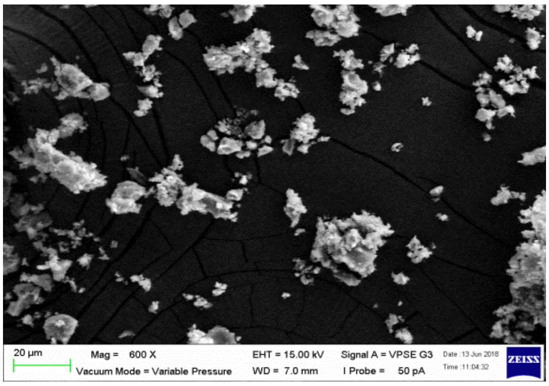

Fig. 6 SEM image of UfPOFA

4.2 Compressive Strength

The compressive strength results of the specimens are shown in Figure 7. Compressive strength was tested at 7- and 28-day curing ages. Based on the results obtained, the compressive strength increases with a longer curing time. A nearly similar pattern was obtained with the bulk density result. Specimens at 28 days were denser than specimens at 7 days. The strength gain at the age of 28 days was because the pozzolanic activity of the mixture has fully commenced, where a pozzolanic reaction between the UfPOFA, OPC, and soil forms a secondary CSH gel [30]. The strength trend shows that as the dosage of UfPOFA increases, the compressive strength of the mixture is reduced. This finding is contrary to previous studies conducted by Elahi, Shahriar and Islam [31]. The study reported that the addition of pozzolanic material is effective to increase the compressive strength of the bricks compared to the bricks with cement only.

The reduction of compressive strength caused by the reduction of ICEB density, which might be due to increase in void. Other possible explanations are the strength development is based on the reaction of calcium hydroxide (CH) from OPC with silica dioxide (SiO_2) from UfPOFA [31]. Hence the reduction in compressive strength probably due to the lack of OPC necessary for strength development. In addition, it might also be due to the interruption of the hydration process due to excess pozzolan particles surrounding the cement particles [32]. Cement not only reacts with UfPOFA particles but with clay soil and sand particles too.

The low compressive strength might also be due to the high LOI value of POFA used in this study. The high value of LOI might be indirectly due to the low burning temperature and high carbon content in POFA [33]. Chen [34] investigated the effect of LOI on the concrete properties and found that lower LOI of pozzolans will give higher compressive strength of concrete than higher LOI of pozzolans.

However, ICEB with replacement of 10% and 30% UfPOFA showed promising compressive strength, 6.53MPa and 5.27MPa respectively, although it showed lower strength compared to the control mixture. The results still achieved satisfactory compressive strength for a load-bearing wall material. In accordance with Malaysian Standard (MS) 76:1972, the minimum compressive strength requirement for a load-bearing masonry brick is 5.0MPa.

4.3 Water Absorption

The durability of ICEB is related to the water absorption. The durability of ICEB can be reduced when the brick absorbs less water [25]. Water absorption is mainly affected by the porosity of the specimens. Results shown in Figure 8 state that the water absorption increases as the percentage of UfPOFA increases. As UfPOFA content increasing, the greater the water absorption of ICEB. All modified mixtures possessed higher water absorption compared to the control mixture. The percentage of UfPOFA at 10% indicated the lowest absorption compared to the other batches. As for specimens with from 20% to 40% UfPOFA, the water absorption was further increased. This also accords with previous research, which showed that water absorption increased with the increase in content of pozzolan. All the tested brick specimen showed water absorption in the range of 15–24% [35].

The observed increase in water absorption is due to increase of porosity in ICEB which affected by the reduction in density. Other explanation could be attributed by the decrease in OPC content (due to dilution), affecting the hydration reaction to form CSH gel [35]. The pozzolanic reaction of UfPOFA and OPC forms the secondary CSH gel, which might contribute to the packing effect that helps in reducing the pores in the specimens [36]. Higher content of UfPOFA beyond 20% attributed less to the pore-filling effect. However, it might improve the water absorption at a later age due to the pore-blocking effect as an aftermath of pozzolanic reactions [37].

However, in accordance with Malaysian Standard (MS) 76:1972, the allowable water absorption of an earth brick is 15%. The water absorption of CP10 was slightly higher at 15.44%. It can be use as moderate weather resistant bricks.

5. CONCLUSIONS

This research was undertaken to investigate the engineering properties of ICEB incorporating UfPOFA. The results of this investigation has shown that UfPOFA is a potential green material that can used to produce sustainable ICEB. Utilization of UfPOFA can be effective way to dispose of the abundant waste from palm oil mill. The following conclusions can be drawn from the present study:

1. Based on the bulk density data, ICEB density reduce with inclusion of UfPOFA. ICEB with 40% UfPOFA is 10% lighter than without UfPOFA. The decrease in the weight of ICEB can be helpful in overall mass reduction of ICEB structures, which can improves the performance of structures in thermal conductivity.
2. Although the performance of ICEB in relation to compressive strength reduced with increased content of UfPOFA, however, ICEB with 10% of UfPOFA showed compressive strength of 6.5 MPa, which satisfies the minimum strength requirement of brick (5MPa) according to MS 76:1972. It can be concluded that OPC up to 10% can be effectively replaced by UfPOFA as it satisficed the minimum criteria of brick strength.
3. The study on the water absorption of ICEB indicated that with 10% of UfPOFA, it can be used as moderate weather resistant bricks. Whereas, ICEB incorporating of

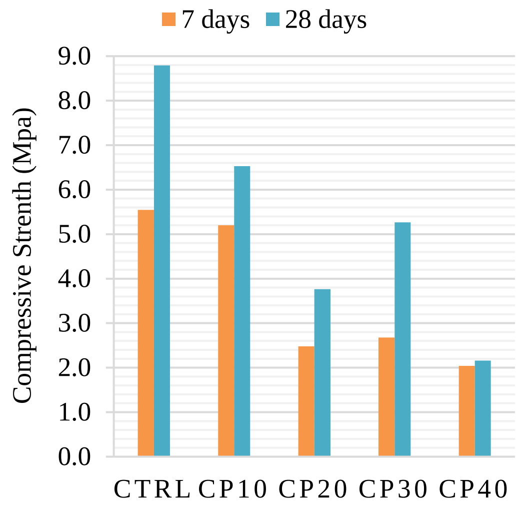

Fig. 7 Compressive strength of ICEB-UfPOFA

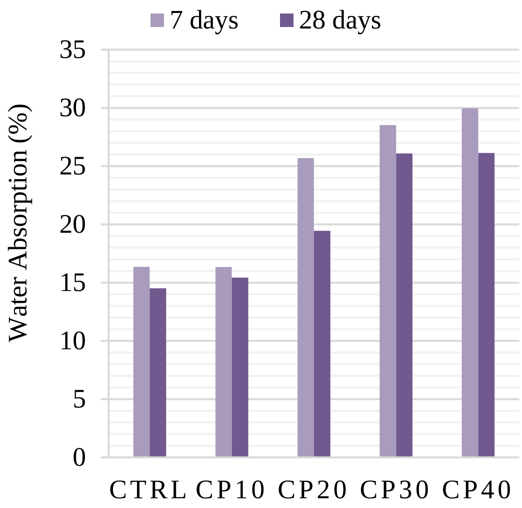

Fig. 8 Water Absorption of ICEB-UfPOFA

with 20%-40% UfPOFA can be used as normal weather resistant bricks.

4. In spite of limited results, in can concluded that ICEB with incorporation of UfPOFA up to 10% can be practically used in producing ICEB for future sustainable construction.
5. This new understanding should help to improve predictions of the impact of UfPOFA in ICEB production. Future research should identify the optimum mixture of ICEB with incorporation of UfPOFA, that will exhibit better ICEB engineering properties especially the compressive strength and water absorptions.

6. ACKNOWLEDGMENTS

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