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OPTIMIZING CLAY BRICKS WITH HDPE AND POLYETHYLENE PET AS A SUSTAINABLE CONSTRUCTION MATERIAL

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ABSTRACT: The construction industry's quest for sustainable materials drives the investigation into novel additives to enhance clay brick performance. High-Density Polyethylene (HDPE) and Polyethylene Terephthalate (PET) polymers hold promise, yet their impact on porosity and water absorption in varying grain sizes remains underexplored. They incorporated HDPE and PET polymers in diverse proportions and grain sizes into unfired clay bricks, examining the resulting changes in porosity and water absorption through bulk density measurements, microscopy, and capillary water absorption coefficient analysis. Polymer additives, particularly $\delta \leq 1$ mm PET, significantly reduce porosity, enhancing brick performance. The capillary water absorption coefficient establishes a direct link between polymer content and increased porosity. As polymer proportions rise, so does brick porosity, offering a nuanced understanding of the relationship. SEM analysis highlights PET mortar's consistent, low-porosity structure, underscoring the potential for sustainable construction materials. This study provides crucial insights for future developments in eco-friendly construction practices. In summary, the integration of HDPE and PET polymers presents a promising avenue for advancing sustainable construction materials, offering a balance between enhanced performance and environmental considerations.

Keywords: Polymer additives, HDPE & PET, Thermal, Unfired clay brick, Porosity, SEM

1. INTRODUCTION

In recent decades, the construction industry has witnessed a paradigm shift towards sustainable practices, driven by the urgent need to mitigate the environmental impacts of urbanization and infrastructure development. One such innovative approach involves the incorporation of polymer waste additives, particularly High-Density Polyethylene (HDPE) and Polyethylene Terephthalate (PET), into traditional construction materials like clay bricks. The increasing prevalence of plastic materials in our daily lives has given rise to a pressing issue, including plastic waste accumulation and its adverse effects on the environment. Indonesia, in particular, grapples with a significant plastic waste challenge. According to a report by the Ocean Conservancy, Indonesia was ranked as the second-largest contributor to marine plastic pollution, with an estimated 1.29 million metric tons of plastic waste entering the ocean each year [1]. A substantial portion of this is constituted by HDPE and PET plastic waste materials that have traditionally posed challenges for recycling and proper disposal. Indonesia's rapid economic growth, urbanization, and changing consumer habits have significantly contributed to the surge in plastic consumption, including the consumption of HDPE and PET products. HDPE is widely used in packaging, bottles, and various household items due to its durability and versatility. PET, on the other hand, is commonly employed in single-use beverage containers, food packaging, and textile fibers. However, inadequate waste management infrastructure, low recycling rates, and limited public awareness have led to the accumulation of substantial amounts of HDPE and PET waste in the country.

According to the Indonesian Ministry of Environment and Forestry, the country generated over 6.8 million tons of plastic waste in 2020 alone. Out of this staggering amount, HDPE and PET constituted a significant portion. This accumulation of plastic waste not only poses threats to terrestrial and aquatic ecosystems but also presents a challenge in terms of waste disposal and resource management [2].

The integration of HDPE and PET plastic waste into clay bricks offers a promising solution to two pressing issues: the need for sustainable construction materials and the urgent need to manage plastic waste. By incorporating these polymer waste additives into clay bricks, the construction industry has the potential to reduce the demand for virgin materials while simultaneously diverting significant amounts of plastic waste from landfills and oceans. The utilization of plastic waste like HDPE/LDPE increased density at different ages of the concrete was found between 2.09 g/cm^3 and 2.27 g/cm^{3,} which is acceptable by Rilem classification as lightweight concrete [3]. Another study using PET additive has a significant ability to improve the bonding strength and adhesion of asphalt binder to recycled concrete aggregate and reduce the stripping percentage and moisture-induced susceptibility [4]. A study about PET-blend through scanning electron microscopy (SEM) and energy dispersive x-ray analysis (EDX), showed a uniform dispersion of particles with no agglomerates on the surface [5]. Preparation of HDPE and PP plastic bricks has a compressive strength of plastic bricks, which is 14.6% higher than conventional brick [6]. Previous research proves that HDPE granules and PET flakes, for example, can be used as additives to increase the physical-mechanical properties of another building material like brick. In addition, waste polymer additives have the potential to produce lighter bricks with better thermal properties. The main impediment is the use of plastic as an additive to reduce the compressive strength of the bricks produced. Several parameters, including lower capillary water absorption coefficient, higher bulk density, and higher mechanical strength values, should be produced using plastic additives with smaller HDPE & PET grain sizes in order to produce good brick samples [7]. In fact, when compared to using the largest grain size, using a waste plastic additive with a smaller grain size increased the mechanical strength of compression and capillary water absorption coefficient by 17% and 28%, respectively. The urgency surrounding the utilization of High-Density Polyethylene (HDPE) and Polyethylene Terephthalate (PET) as additives in clay brick production is underpinned by the convergence of two critical challenges: the escalating environmental impact of plastic waste and embrace sustainable practices within the construction industry.

The aim of the study is to investigate and develop innovative methods for enhancing the sustainability of the construction industry. This research seeks to harness the potential of repurposing plastic waste, specifically High-Density Polyethylene (HDPE) and Polyethylene Terephthalate (PET), to improve the performance and eco-friendliness of traditional clay bricks.

2. RESEARCH SIGNIFICANCE

This study investigates the mechanical and thermal performance of lightweight clay bricks made without burning by incorporating polymer waste, aiming for sustainable construction materials to reduce carbon footprint. If proven effective, these bricks could significantly lower environmental impact compared to traditional alternatives, aligning with climate goals. The research's implications extend beyond bricks, potentially inspiring similar studies in other construction materials and amplifying its impact. Overall, the study contributes to sustainable construction, waste reduction, enhanced material properties, cost-effectiveness, and environmental benefits, offering practical solutions for construction professionals while addressing global plastic waste and providing practical solutions for builders professionals.

3. MATERIALS AND METHOD

3.1 Materials

The material used is clay taken from the Cot Girek area of North Aceh District, Aceh. Spectral characterization of X-ray diffraction analysis of clay sections of the earth.

3.2 Method

3.2.1 Sample preparation

Variation of the percentage of different proportions based on the weight of each type of polymer additive consisting of (0%, 5%, 10%, 15%, 20%, and 25%) with three additive grain sizes studied ($\delta \leq 1$ mm; 1 mm < $\delta \leq 3$ mm and 3 mm<$\delta \leq 6$ mm) carried out as previous research [8]. The samples are mixed and then exposed to a continuous heating process at a consistent temperature of 300°C for a duration of 15 minutes. Throughout this heating phase, the mixtures are constantly stirred at a rate of 95 revolutions per minute using an electric stirrer. This method of preparation is referred to as the melt compounding technique and is carried out in dry conditions to maximize the intensity of polymerization, as it is known to enhance the blending of clay and polymer under such circumstances. The produced mixture must be immediately cooled at 34 °C for 5 minutes. The Proctor compaction test (PCT) is then used to determine the optimal moisture content (OMC), which is 16.5% of the mass of the mixture. This mixture was then molded using a hydraulic brick press machine with a rated pressure of 6.5 MPa, yielding brick samples with dimensions of 1604040 mm. After preparation, samples were dried for 28 days at a controlled room temperature of 20°C/5°C in the finishing stage. The sample was then placed in a drying oven for 24 hours, with an initial temperature of 50°C and a 1.5°C per hour increase in temperature; the final temperature was thus recorded as 86°C. Following a 24-hour drying period, the mass of the sample is checked on a regular basis with an Ohaus lab balance. The sample's mass decreased over time, but it averaged out and stayed that way after about 24 hours, indicating that the sample had dried completely. Testing will be done after samples of the manufactured bricks have been polished to ensure that they don't contain any water.

3.2.2 Mass Density Analysis

Mass per unit volume of granules or powder when considering the material in bulk state. In the world of bulk packaging, we use the specified bulk density of a substance to find out how much of that substance we can fit in a bulk bag of a given size.

3.2.1 Compessive Srength Analysis

The ability of a brick to withstand compressive forces in every unit area of the concrete surface is expected to determine the extent to which a mixture of fine aggregate substitutes with red brick waste has compressive strength.

3.2.2 Thermal Conductivity Analysis

The thermal conductivity of brick samples as a function of the percentage and variation of grain size additives was tested using a heat flow metre HFM-100 in a steady state.

3.2.3 Porosity Analysis

The amount of fluid content that has accumulated in the reservoir rock can be described by the porosity of the rock, which is a physical characteristic of rock. The proportion of pore volume to total rock volume can be used to calculate the reservoir rock's porosity. The rock has a larger cavities the higher the porosity value.

3.2.4 Capillary Water Absorption Coefficient

The level at which water can enter or penetrate porous concrete is known as the water absorption value, and this value is typically expressed as a percentage (%).

3.2.5 Scanning Electron Microscope (SEM)

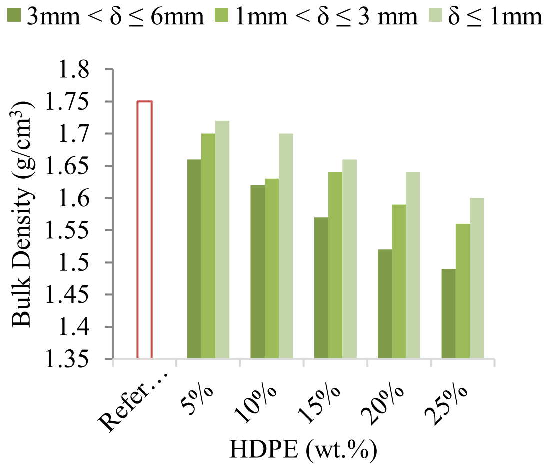
SEM is used to analyze the surface structure or morphology of a material. In theory, if the surface of a material changes, the material has changed energetically.

4 RESULTS AND DISCUSSION

4.1 Mass Density Analysis

Fig 1. represents the bulk density of the prepared brick samples. The graph depicts an increase in grain size and additive percentage, as well as a decrease in sample bulk density. In other words, there is an advantageous connection between the porosity and bulk density of the prepared samples [9].

Additionally, Fig.1 demonstrates that the bulk density will decrease as the percentage of polymer additives and grain size increase. There are several advantages to reducing the bulk density of this brick sample [10]. First off, a low clay content in the sample is indicated by a high percentage of polymer additives. Second, the resulting sample can be categorized as a lightweight brick, which is ideal for use as a tile. Its specific gravity does not exceed 1.73 g/m^3, according to the standard NM 10.1.009–2014. It should be noted that the highest bulk density recorded was 1.72 g/cm^3. The reduction in bulk density can have significant implications for the performance of clay bricks when High-Density Polyethylene (HDPE) and Polyethylene Terephthalate (PET) are used as additives.



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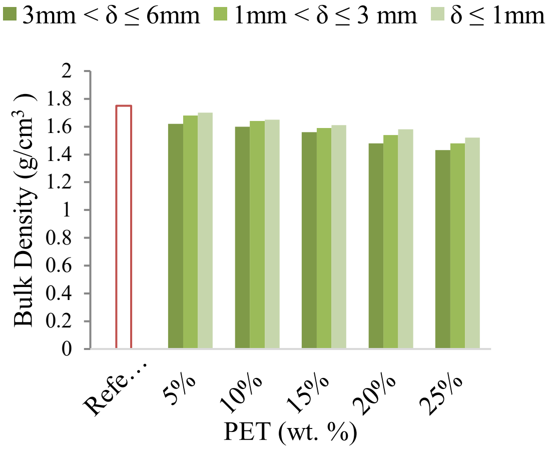


(b)

Fig. 1 Bulk density of brick samples with a) HDPE Additive (b) PET Additive

The reduction in bulk density means that there is less clay and more of the added HDPE and PET in the same volume, which can compromise the structural integrity and strength of the bricks. A lower bulk density may lead to bricks that are less robust and more prone to breakage or deformation. Bulk density can also influence the workability of the brick-making process. A lower bulk density may result in a mixture that is more challenging to mold and shape into bricks, affecting the manufacturing process.

4.2 Compressive Strength Analysis

Fig. 2 shows how changes in additive size, type, and percentage affect compressive strength. The size of the capillary channels and voids caused by porosity in the brick samples can be used to explain why this is the case [11].

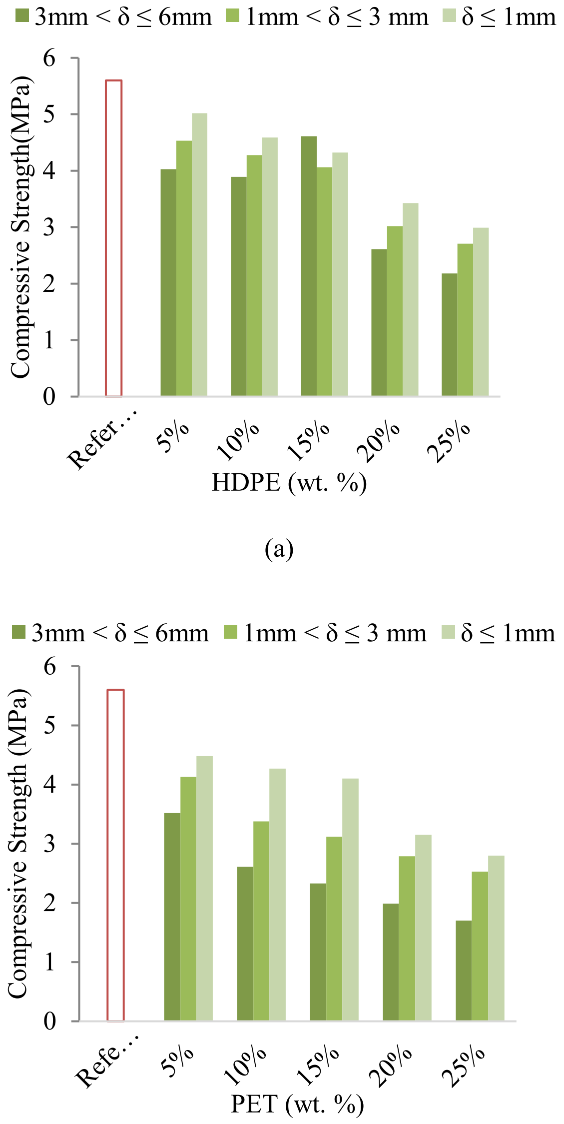
Another factor that results in a decrease in compressive strength with an increase in the percentage of additives is a decrease in the amount of clay in the brick sample [12]. When the percentage of clay is reduced, mineral crystals are reduced, weakening the sample's structure and lowering its mechanical properties.

Because there is no Indonesian standard for unfired clay bricks, the mechanical performance of the samples will be evaluated in accordance with German earthen building standards DIN 18945 (2013-08). Earth Block Class 2 (EB2) refers to brick samples with average compressive strengths ranging from 2.5 to 3.8 MPa, making them ideal for low-load construction such as huts and sheds. They can also be used as secondary structures like partitions, exterior sections, or insulation construction. Class 3 Earth Blocks (EB3), or brick samples with average compressive strengths between 3.8 and 5 MPa, are suitable for use as self-supporting, non-load-bearing walls. Finally, Class 4 (EB4) Earth Blocks are brick samples that are suitable for inner walls and load-bearing walls in low- and medium-rise buildings and have an average compressive strength value greater than 5 MPa.

The study's findings give an overview of the additives studied for HDPE and PET while for grain size ($\delta \leq 1$ mm; 1 mm$<\delta\leq$3 mm and 3 mm$<\delta\leq$6 mm) and different percentages (0%, 5%, 10%, 15%, 20%, and 25%) by weight. Examination of samples containing HDPE The use of additives resulted in interaction and flocculation, facilitated by the formation of hydrogen bonds between the oxyl groups of the polymeric additive and the mineral surface [13].

These bonds developed at the crystal's edges due to the weakening of the OH adsorption bands, leading to the formation of flocculated particles. This process enables polymer molecules to penetrate the pore spaces of the clay, ensuring long-term stability. Both the size and percentage of the polymer play a significant role in determining the pore size and distribution in the prepared brick samples. These factors, in turn, impact the thermo-physical characteristics of the bricks. Our experimental results support the initial hypothesis.

Lower polymer content means there are fewer polymer chains in the material. Smaller polymer molecules can fill gaps in the material less effectively. Larger polymer molecules can bridge voids and gaps, reducing porosity. Smaller polymer size typically leads to a higher degree of porosity because they have a harder time closing gaps and filling voids in the material This reduction in porosity improves the sample's properties by reducing capillary water absorption and increasing compressive strength. Polymer additives also influence the mechanical characteristics of the clay-polymer intercalation within the polymer matrix between the clay layers [14,15].



(a)

(b)

Fig. 2 Compressive strength of brick samples with a) HDPE Additive (b) PET Additive

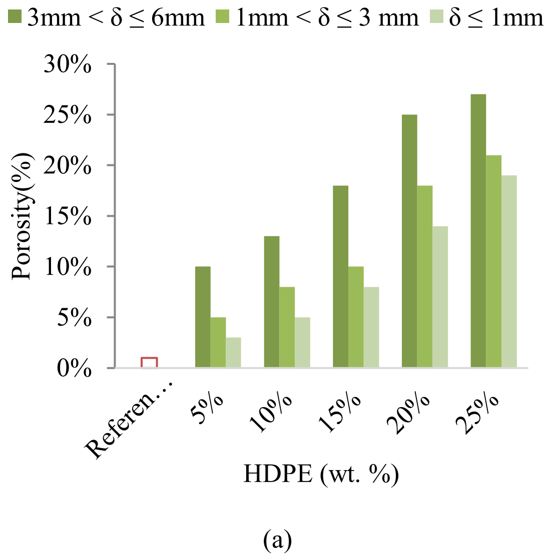
4.3 Thermal Conductivity Analysis

The thermal conductivity test was performed at a steady state with a Heat Flow Metre HFM-100. The thermal conductivity of the sample decreased in this test as the additive proportion and grain size increased [16]. The highest thermal conductivity in HDPE-based samples was 0.46 W/mK with a gain of 4%. These findings were obtained using specimens with the lowest percentage of HDPE additive (5%), and the smallest grain size, δ≤1 mm. The lowest thermal conductivity, with a gain in thermal conductivity of 10%, is 0.20 W/mK. This result was obtained using a sample that contained 25% of HDPE additives and had additive grains that were 3 mm<δ≤6 mm. The highest thermal conductivity in the PET-based samples was 0.43 W/mK, with a gain of 58%. These results were obtained when the least amount of additives and grain sizes were used, namely 1% and δ≤1 mm. The lowest thermal conductivity, on the other hand, is 0.18 W/mK, with a thermal conductivity gain of 63%.

These results were obtained when the highest percentage of PET additive was used and the largest grain size was used, namely 25% and 3 mm<δ≤6 mm. The combination of additives with large grain size and high polymer content significantly increased thermal conductivity, which improved the thermal properties of HDPE and PET samples. Previous research has found a negative relationship between thermal conductivity and the use of waste additives such as industrial sludge and agricultural wastes such as bagasse and rice husks. Previous research has also found a negative relationship between the amount of plastic additives in bricks and their thermal conductivity [17]. According to the study, bricks with a 30% plastic additive content increased thermal conductivity by approximately 34.6%.

4.4 Porosity Analysis

Fig.3 The porosity level of the samples for the investigated HDPE and PET additives, at concentrations of 5% and 25% for three-grain size polymer additives, at a microscopic scale of 70 m/cm



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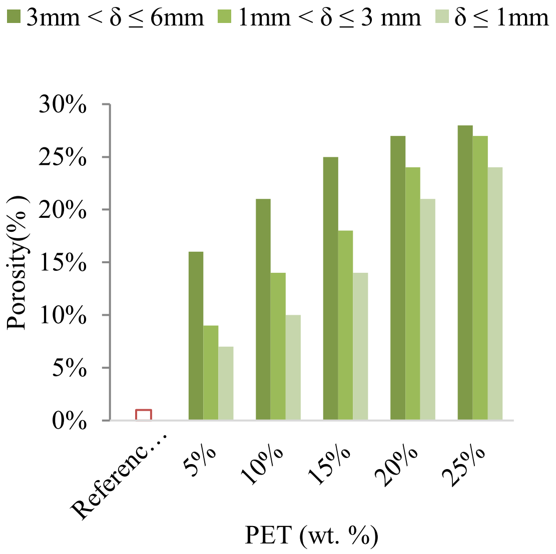

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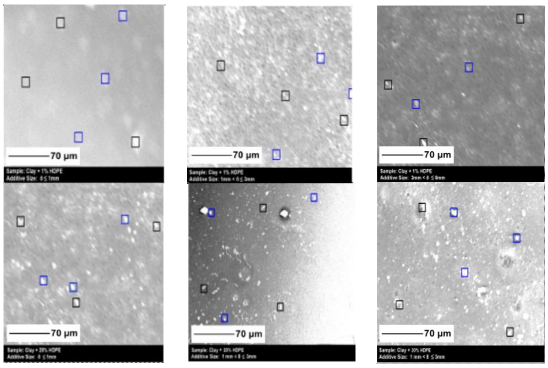
Fig.3 Brick samples with a) HDPE Additive (b) PET Additive



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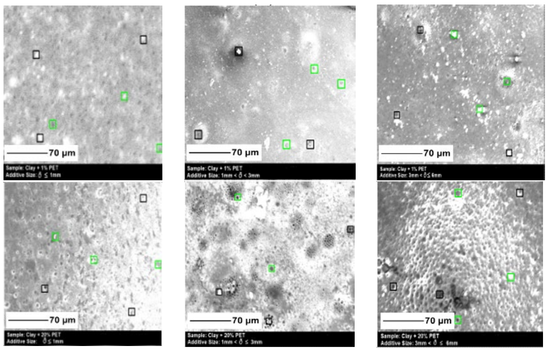


(b)

Fig.3 Microscopic snapshot illustrating the degree of porosity of brick samples with a) HDPE additive and (b) PET additive. Index: black circle – pores, blue circle – HDPE + clay mixture, green circle – PET + clay mixture.

The grey surfaces in the figure are the additives clay, HDPE, and PET, solid mixtures, with the black areas circled in blue and green, respectively. The previously mentioned microscopic image is only used as a qualitative tool to observe the behavior of the porosity distribution (maximum or minimum), not to measure it, and only to obtain the results of the actual quantity measured porosity levels with different specimens [18]. The grey surfaces in the figure are the additives clay, HDPE, and PET, solid mixtures, with the black areas circled in blue and green, respectively. The distribution of polymers and additives show different behavior. The results of the actual quantity measured porosity levels with different specimens.

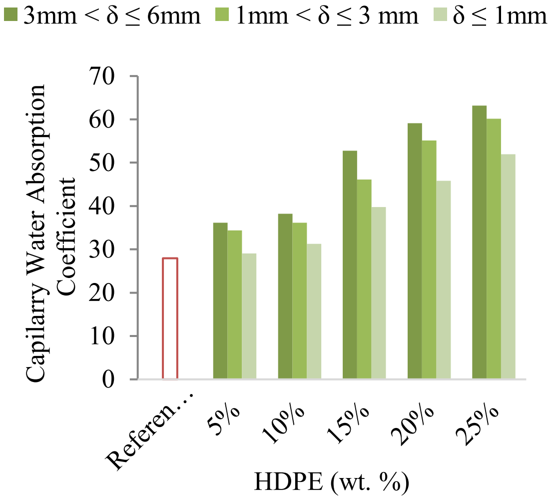
The percentage of porosity can be calculated using the following equation (1).

$$\boldsymbol{P} = \frac{\boldsymbol{W\ ssd - Wd}}{\boldsymbol{Wssd - Ww}} \qquad (1)$$

Wssd is the weight of the sample in a saturated surface dry state (SSD), WD is the dry weight after drying for 24 hours, and Ww is the weight of the sample in a water-saturated state in this formula. The microscopic images in Fig.3 qualitatively depict the increase in porosity as the size and percentage of additives increase.It was also discovered that the PET additive produced more porous brick samples than the HDPE additive in this case[19,20]. The samples with HDPE and PET additives as mention in Fig.4 of 5% and 10%, respectively, had the lowest porosity for the smallest grain size (δ≤1 mm) with 1% additive. While brick samples with HDPE and PET additives of 25% and large grain sizes (3 mm<δ≤6 mm) had the highest porosity levels, 28% and 29%, respectively.

4.5 Capillary Water Absorption Coefficient Analysis

Figure 5 depicts a close relationship between the water absorption coefficient and the degree of porosity.



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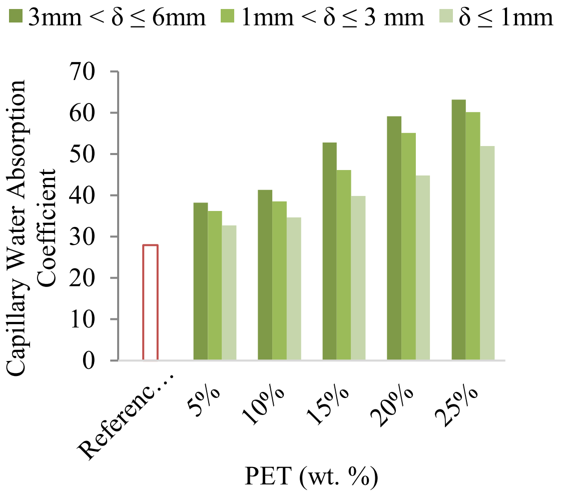

(b)

Fig.5 Capillary Water Absorption Coefficient of brick samples with : a) HDPE Additive (b) PET Additive

4.6 Scanning Electron Microscopy (SEM)

The results of the Scanning Electron Microscopy (SEM) analysis are shown in the image below. The test results are obtained using scanning electron microscopy (SEM) at a treatment distance of 400x magnification.

The microstructure of the PET mortar is depicted in Fig. 6. The mortar is consistent and has a low porosity. Clay bricks have a high water absorption capacity due to the presence of air voids in recycled clay brick powder. However, PET protects the clay brick aggregate adequately. In the interface area, there are no micro gaps [21-26].

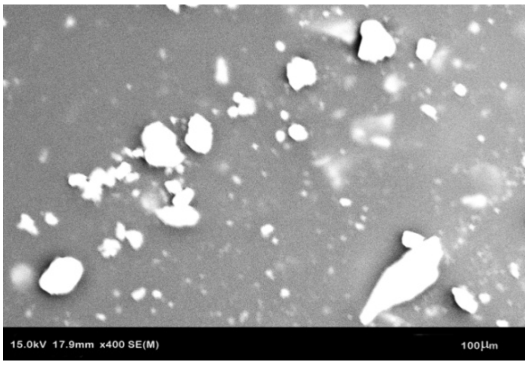

Fig. 6 Microstructure of PET and HDPE

5 CONCLUSION

This research begins with evaluating the properties of unfired clay bricks using different percentages of additives (0%, 5%, 10%, 15%, 20%, and 25%) and three different grain particle sizes ($\delta \leq 1$ mm, 1 mm$<\delta\leq$3 mm, and 3 mm$<\delta\leq$6 mm). The percentage of porosity in each brick sample is utilized to qualitatively and quantitatively evaluate porosity levels. Both tests revealed an increase in porosity along with an increase in the percentage and size of the additive. PET additives generate more porous samples compared to HDPE due to their higher Melt Flow Rate (MFR) index, which influences the properties of the polymer-clay mixture. To put it differently, samples with HDPE additives produce less flocculation than those with PET additives at the same mass, resulting in strong intercalation and improved polymer mixing. The higher the amount of additive added and the smaller the bulk particle size obtained, the lower the porosity.

Experimental compressive strength tests indicate that as the percentage of additive and particle size increases, the strength decreases. Furthermore, samples containing HDPE additives exhibit greater mechanical strength than those with PET additives. Thermal conductivity and specific heat capacity were both measured and theoretically predicted. The Pearson correlation coefficient demonstrates a strong relationship between the thermal properties of the samples and their porosity, confirming the accuracy of our experimental findings. According to the results of this study, the use of plastic waste additives with larger grain sizes enhances the thermal properties of brick samples. Additionally, samples containing 15% HDPE waste plastic additives display an optimal composition for ensuring both good mechanical durability, as required by building codes, and efficient thermal properties for effective insulation in construction materials.

6 ACKNOWLEDGEMENT

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