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RESEARCH ARTICLE

Enhancing Mortar Properties with Crushed Palm Oil Clinker as a Partial Fine Aggregate Replacement

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ABSTRACT - The study investigated the feasibility of utilizing crushed palm oil clinker, a byproduct of the palm oil industry, as a partial substitute for fine aggregate in mortar. This initiative aimed to mitigate the environmental issues arising from sand mining and excessive disposal of palm oil clinker in landfills. Five different replacement percentages (0%, 10%, 20%, 30%, and 40%) were tested, with all specimens undergoing water curing. The research outcomes revealed significant effects on mortar properties. As the proportion of crushed palm oil clinker increased, the flowability of the mortar diminished. Nevertheless, incorporating 10% crushed palm oil clinker resulted in improved compressive strength. Conversely, higher replacement percentages (20%, 30%, and 40%) led to a diminishing trend in compressive strength due to an increased porous structure and weaker bonding. Additionally, when higher replacement percentages (20%, 30%, and 40%) were employed, the water absorption of the mortar increased. In summary, employing crushed palm oil clinker as a partial substitute for fine aggregate can help reduce waste disposal while conserving natural river sand resources. This approach offers a potential solution to address both environmental concerns and the need for sustainable construction materials.

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1.0 INTRODUCTION

Malaysia is currently on a trajectory from a developing nation to achieving developed status by 2023. In this context, the construction sector stands out as a critical industry that plays a pivotal role in sustaining Malaysia's overall economic growth. It does so by providing the essential physical infrastructure needed to facilitate economic development [1]. As per the Annual Economic Statistics of 2018, the construction sector demonstrated significant growth, with a gross output value of RM204.4 billion in 2017, a notable increase from RM177.9 billion in 2015, reflecting an impressive annual growth rate of 7.2% [2]. Mortar, a fundamental construction material, is instrumental in the construction of various structures. It serves dual purposes by providing a finishing surface for walls and acting as a binding agent for holding building components like blocks or stones in place [3]. Nonetheless, the increasing demand for mortar materials within the construction industry has driven the excessive extraction of natural aggregates from local environments, with resulting adverse environmental consequences [4]. Conventional mortar comprises cement, fine aggregate (typically sand), and water, with the nature of the aggregate significantly influencing concrete properties. Unfortunately, the high demand for sand, often sourced from aquatic environments like rivers and coasts, has led to its depletion, increased costs [6][7], and significant environmental damage, affecting ecosystems, soil, water, and ecological balance [8][9]. As a result, the depletion of natural sand resources has spurred the investigation of alternative materials, including cementitious products and by-products from industrial and agricultural processes, to address environmental issues and bolster the sustainability of the concrete industry. This shift towards sustainable alternatives aims to reduce the industry's environmental footprint while ensuring its long-term viability [10]. To address the issue of waste buildup and contribute to environmental sustainability, an eco-conscious approach involves repurposing these materials, such as palm oil clinker aggregates, to create environmentally friendly construction components for sustainable concrete production [11].

Palm oil is a key player in the global oil and fats industry, carrying significant socioeconomic importance for palm oil-producing nations, particularly in the case of Malaysia [12]. Presently, Malaysia ranks second in palm oil production worldwide, contributing to 39% of the total global production. Moreover, Malaysia's palm oil exports make up approximately 44% of the global share [13]. In 2020, Malaysia, holding the position of the world's second-largest palm oil producer and exporter, produced and exported a total of 19.14 million tons of crude palm oil (CPO) and 16.22 million tons of palm oil from a source of 96.09 million tons of fresh fruit bunches (FFB) [14]. While the palm oil industry has achieved significant market success, it faces several sustainability challenges, primarily related to its environmental footprint and the release of greenhouse gases (GHGs) originating from the by-products of palm oil mills. These by-products include palm oil clinker (POC), palm oil fuel ash (POFA), and palm oil mill effluent (POME). For instance, POC, a waste by-product produced during the incineration of oil palm shells and fibers, is frequently discarded in landfills, resulting in detrimental environmental pollution [15][16]. While numerous studies have delved into the use of palm oil

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waste in the construction sector, including recycled oil palm shells (OPS), POC, and POFA, a considerable amount of palm oil waste is still being consigned to landfills. Hence, the strategy of incorporating POC as a partial fine aggregate substitute in mortar materials offers the prospect of lessening dependence on natural aggregates and concurrently mitigating the waste generated by the palm oil industry. This approach aligns with the overarching global objective of advancing sustainable development.

2.0 EXPERIMENTAL PROGRAMME

2.1 Materials

In this study, Ordinary Portland Cement (OPC), classified as Type 1 according to ASTM C150 [17], served as the primary binding material. The palm oil clinker (POC) depicted in Figure 1 was sourced from the Lepar, Kuantan Pahang palm oil mill plant. Initially, the large-sized POC chunks underwent crushing using a jaw crusher of the required size. Subsequently, the crushed material was sieved, and the particles that passed through a 600 µm sieve were utilized as a partial fine aggregate. For the fine aggregate component, oven-dried river sand was chosen. In both concrete preparation and curing, tap water was used.

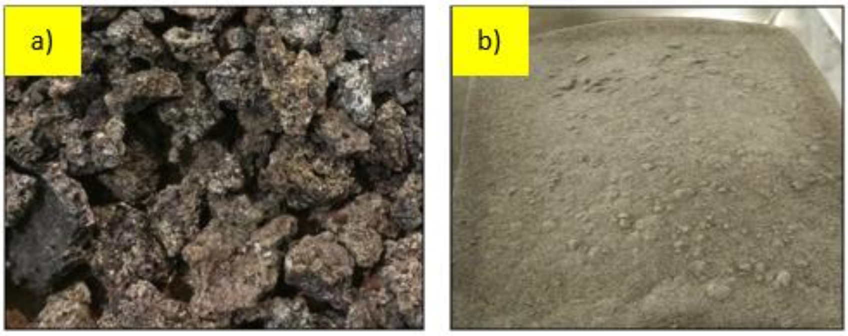

Figure 1. a) POC before crushed b) POC ready to use

2.2 Mix Proportions

The study encompassed a total of five different mixed formulations. These comprised a reference mortar sample and additional mixtures with varying proportions of POC serving as a partial substitute for fine aggregate. The reference sample was composed of mortar exclusively containing 100% fine aggregate, while the other mortar mixtures incorporated different proportions of POC (10%, 20%, 30%, and 40%) as a partial replacement for fine aggregate. A detailed listing of all the concrete mixtures can be found in Table 1. It's important to note that the water-cement ratio remained consistent at 0.66 for all five mix variations, as delineated in Table 1.

Table 1. Mix Proportion (kg/m^3)

% of POC	Cement	Water	POC	Fine Aggregate
0	675	450	0	1350
10	675	450	135	1215
20	675	450	270	1080
30	675	450	405	945
40	675	450	540	810

2.3 Testing Methods

Cement, fine aggregate, water, and the necessary amount of POC were combined to achieve a consistent mixture. Before being poured into molds measuring 50 mm x 50 mm x 50 mm, which had been thoroughly cleaned and treated with a mold release agent, the blended mortar underwent a flowability test, in accordance with ASTM C1437 [18]. The flow value of fresh mortar samples was determined by averaging four readings (expressed as percentages) obtained using calipers. Figure 2 illustrates the conducted experiment, providing a visual representation of the experimental setup. After a 24-hour period, the concrete was de-molded and submerged in a curing water tank for a duration of 28 days. Following this curing period, tests for compressive strength and water absorption were carried out. An experimental program was devised to assess mechanical properties, focusing on compressive strength, in accordance with the standards outlined in ASTM C109/C109M [19]. Furthermore, ASTM 642 [20] procedures were followed to determine the water absorption of the concrete specimens.

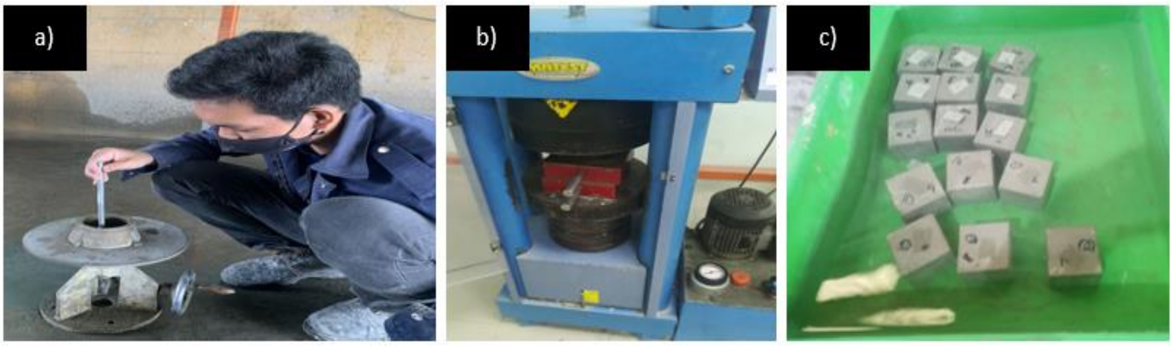

Figure 2. List of experiments a) Flowability test b) Compressive strength test c) Water absorption test

3.0 EXPERIMENTAL RESULTS

3.1 Flowability

Flow measurement served to assess the workability of the fresh mortar, as depicted in Figure 3. This figure portrays the impact of various proportions of crushed POC used as a replacement for fine aggregate on the flow percentage. Notably, mortar with 10% POC exhibited the highest flowability value, reaching 149%. However, as the quantity of POC used as a partial substitute for fine aggregate increased, the flowability of the mortar gradually decreased. The mortar mix containing 40% POC showed the lowest flowability value, registering at 140%. The decline in flowability observed with higher POC content is attributed to the increased surface area, necessitating a greater amount of water for proper mixing. It is crucial to note that the amount of water specified in Table 1 for each mix proportion was consistently maintained at 450 kg/m^3, adhering strictly to the water-cement ratio and ensuring uniformity across all mixes. These results align with the findings of Çelik & Marar [21], who observed that increased fineness led to a larger surface area, necessitating more water to achieve the desired flow. The reduction in the mortar's flow value is linked to the porous nature of the waste material, which absorbs mixing water, resulting in a decrease in the mortar's flow value, as noted by Vaishnav & Trivedi [22].

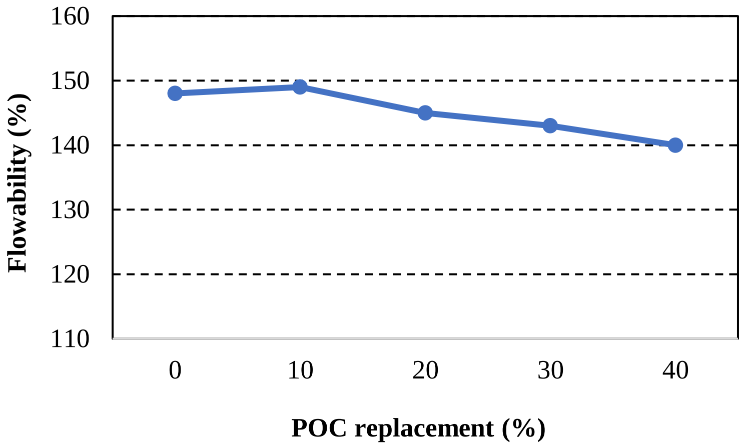

Figure 3. Flowability of mortar containing various percentages of POC

3.2 Compressive Strength

Figure 4 provides a comprehensive overview of the impact of POC replacement on compressive strength after 28 days. The control mortar mixture initially exhibited subpar performance. However, the introduction of 10% POC content into the mortar resulted in a significant boost in compressive strength, reaching 25.39 MPa. This strength enhancement can be attributed to the shape and texture of POC particles, which facilitate effective interlocking and densification of the mortar in comparison to other test samples [23]. Conversely, the compressive strength of samples with 20%, 30%, and 40% POC content exhibited a diminishing trend. The performance of the mortar was notably affected when it contained 20%, 30%, or 40% POC due to the increased presence of a porous mortar structure, weaker bonding, and higher water absorption. These results align with similar findings reported in the study conducted by Sharma & Vyas [24]. Based on Mahmoor et al. [25], the specific gravity for the palm oil clinker must be less than the normal weight aggregate which is below 2.20. A lower specific gravity for POC might contribute to a lighter material, potentially affecting the overall density and porosity of the mortar mix, thus influencing its compressive strength.

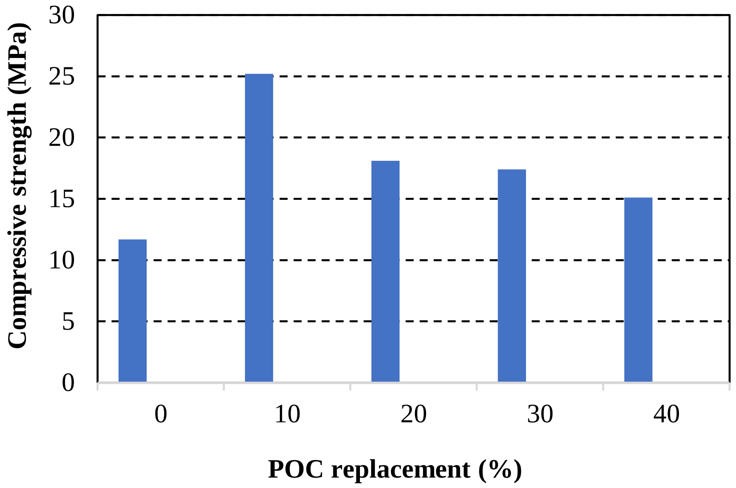

Figure 4. Compressive strength of mortar containing various percentages of POC

3.3 Water Absorption

Figure 5 provides an insight into the water absorption characteristics of mortar as it integrates varying proportions of crushed POC, functioning as a partial alternative for fine aggregate. Notably, the mortar with 10% POC displayed the least water absorption. However, as the POC content increased to 20% and beyond, a noticeable surge in water absorption within the mortar became evident. Particularly, the mortar with 40% POC as a partial replacement for fine aggregate exhibited the highest water absorption value, reaching 10.89%. This increase in water absorption can be attributed to the porous nature of POC, which promotes heightened water absorption within the mortar. These findings align with previous research, including the work of Sulaiman et al. [26].

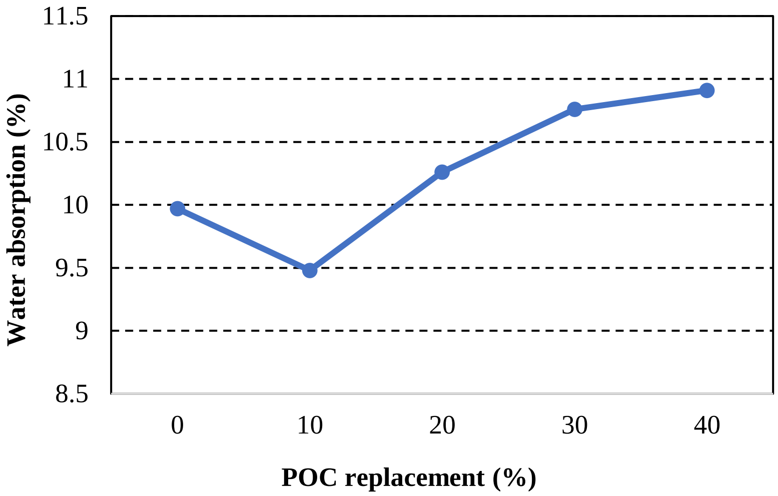

Figure 5. Water absorption in mortar with varying percentages of POC

3.4 Relations between Compressive Strength and Water Absorption

It's crucial to note that despite these observed trends, the relationship between water absorption and compressive strength, as indicated by the R-square value of 0.2607, is relatively weak as shown in Figure 6. This suggests that water absorption alone does not sufficiently explain the variation in compressive strength. Other contributing factors may influence the compressive strength of mortar with varying POC content. The observed strength enhancement in mortar with 10% POC content is attributed to the shape and texture of POC particles, facilitating effective interlocking and densification. However, it is imperative to recognize that additional contributing factors, such as curing conditions, aggregate gradation, or specific characteristics of the POC particles, may play a pivotal role in influencing compressive strength and water absorption.

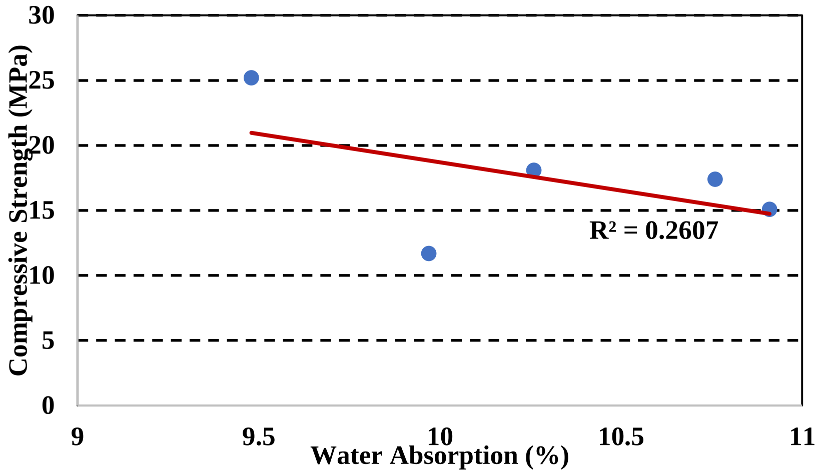

Figure 6. Relationship between compressive strength and water absorption

4.0 CONCLUSION

In conclusion, this study underscores the potential advantages of incorporating crushed palm oil clinker (POC) as a partial fine aggregate replacement in mortar. However, it's crucial to strike a balance in the percentage of POC used due to its varied effects on mortar properties. As the percentage of crushed POC used as a fine aggregate replacement increase, the flowability of the mortar mix decreases, suggesting that higher POC content may reduce workability in mortar applications. On the other hand, substituting 10% of fine aggregate with POC significantly enhances compressive strength to 25.39 MPa, credited to the unique shape and texture of POC particles that enhance mortar density. The distinctive characteristics of POC include irregular shapes and a rough texture, promoting effective interlocking and densification within the mortar matrix. The irregularities in shape facilitate enhanced mechanical interlock, while the rough texture contributes to improved bond strength between POC particles and the mortar matrix. These combined features create a more robust and densely packed mortar structure, ultimately leading to the observed increase in compressive strength. Nevertheless, using higher POC content (20%, 30%, and 40%) results in a decline in compressive strength due to increased porosity, weaker bonding, and elevated water absorption, which are characteristics of POC. Furthermore, the water absorption of the mortar rises with higher POC content, predominantly at 20%, 30%, and 40%, due to the porous nature of POC. Considering the achieved compressive strength of 25.39 MPa with 10% POC substitution, this mortar composition may find suitable applications in structural elements requiring high compressive strength, such as load-bearing walls and certain types of precast concrete components.

5.0 AUTHOR CONTRIBUTIONS

Nur Farah Aziera Jamaludin: Writing and editing

Khairunisa Muthusamy: Supervision, reviewing and editing

Mohamad Shahirudin Mohd Nasir: Experimental and data collection

Nahla Naji Hilal: Reviewing

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7.0 DATA AVAILABILITY STATEMENT

The data necessary to corroborate the findings of this study are comprehensively presented within the article.

8.0 ACKNOWLEDGEMENT

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9.0 CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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