THE EFFECT OF PALM OIL WASTE ON THE PROPERTIES OF GEOPOLYMER CONCRETE: A REVIEW

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The rapid population growth has caused an increase in energy consumption and the construction of new buildings. This has raised environmental concerns, such as the depletion of raw materials and the release of significant CO₂ emissions due to the widespread use of cement. Consequently, researchers and scientists have begun exploring alternative materials to improve sustainability and reduce the environmental impact of the construction industry. Geopolymer concrete (GPC) is a composite material made from various waste materials, utilizing alkali-activated silica (Al₂SiO₅ and Na₂SiO₃/NaOH). Compared to cement, GPC has lower CO₂ emissions and better efficiency. This review aims to examine the potential of palm oil waste, specifically palm oil clinker (POC), oil palm shell (OPS), and palm oil fuel ash (POFA), as eco-friendly materials in sustainable GPC. The properties of palm oil waste used in GPC production are presented, and their impact on GPC properties is discussed. Results indicate that palm oil waste can positively affect GPC performance, enhancing strength and reducing CO₂ emissions for a cleaner environment.

Keywords: Environment, Geopolymer, Concrete, Cement, Palm oil waste, Agriculture waste, Palm oil clinker, Oil palm shell, Palm oil fuel ash.

1 INTRODUCTION

In recent years, the increase in population has led to a rising demand for new buildings and infrastructure projects, which continues to grow over time (Thacker et al. 2019). To fulfill this demand, a large amount of concrete is produced yearly. However, using a significant amount of cement in concrete production can lead to the depletion of raw materials and the release of substantial amounts of CO₂ emissions into the atmosphere, contributing to environmental pollution (Hamada et al. 2023a). The cement industry accounts for 5 to 7% of global CO₂ emissions (Geng et al. 2019). To address this issue, researchers are exploring alternative materials as eco-friendly alternatives with lower CO₂ emissions. Geopolymer concrete (GPC) is a material developed using waste materials rich in aluminosilicates, such as those extracted from agriculture and industrial waste.

Geopolymer concrete (GPC) contains aluminosilicate materials and shares properties with cement concrete. However, GPC requires alkaline solutions such as (Na₂SO₃/K₂SO₃ and NaOH/KOH) to react and is not affected by water (Wongsa et al. 2020). GPC is a sustainable concrete material that can be produced using waste materials rich in aluminosilicates, such as agro-
industrial waste, along with alkaline solutions like potassium hydroxide (KOH) and sodium hydroxide (NaOH), and soluble silicates like gelatin silicate, under appropriate curing conditions (Aslani and Asif 2019). Although numerous studies have investigated the effect of aluminosilicates from industrial waste on GPC, few have explored agricultural waste as a primary source of aluminosilicates in GPC production. Indonesia and Malaysia are responsible for approximately 85% of global palm oil production, resulting in significant waste. Palm oil clinker (POC), oil palm shell (OPS), and palm oil fuel ash (POFA) are among the byproducts of palm oil waste. Therefore, this study aims to fill this gap by providing a comprehensive review of the effect of palm oil waste, which is rich in aluminosilicates, on the performance of GPC. Recent studies published from 2013 to 2023 were collected from Scopus journals as the main data source for this review.

2 GEOPOLYMERIZATION

2.1 Process of Geopolymerization

Guo et al. (2017) found that the composition of aluminosilicate raw materials, alkali solutions such as NaOH and KOH, and the molarity ratio of silica/alumina influences the type and structure of GPC. Formation of GPC is commonly achieved through casting and compression molding (Ren et al. 2021). Additionally, Zhang et al. (2020) reported that high curing temperatures positively affect the acceleration of polymerization and the kinetics process. The most commonly used alkali activators in the geopolymerization process are KOH or NaOH and alkali metal silicate solutions such as K$_2$SiO$_3$ or Na$_2$SiO$_3$.

2.2 Benefits of Geopolymerization

Replacing cement concrete with GPC as a construction material offers a range of benefits and advantages over traditional cement concrete. GPC can significantly reduce environmental pollution by lowering CO$_2$ emissions, making it a viable, sustainable alternative. Moreover, it promotes the conservation of raw materials for future generations while providing eco-friendly construction materials. Another significant advantage of GPC is its cost-effectiveness, as it can be made from Palm oil waste which is a costless or cheaper alternative to cement and natural aggregates. By using GPC structures, the overall construction cost can be reduced.

3 PALM OIL WASTE

3.1 Palm Oil Clinker (POC)

Palm oil clinker (POC) is a significant agro-waste produced in large quantities by the palm oil industry in tropical countries such as Indonesia, Malaysia, and Thailand (Hamada et al. 2018). The potential use of POC as a lightweight aggregate (LWA) in concrete was investigated by Hamada et al. (2019) and Hamada et al. (2023b) through experimental studies to determine its fresh and hardened properties. Furthermore, Darvish et al. (2021) studied using POC to replace fine natural aggregate in cement concrete and GPC. The results revealed that using POC as a fine aggregate reduced the density of GPC by 20% while achieving a compressive strength of up to 65 MPa under ambient conditions of 26–28°C.

3.2 Oil Palm Shell (OPS)

The OPS has a bulk density of 587 kg/m$^3$ and a particle size between 2.36 and 14 mm. Mo et al. (2015) used OPS to produce OPS concrete, as shown in Figure 1. Additionally, several studies have investigated the use of OPS as aggregates. For instance, Liu et al. (2014) used OPS as an
aggregate and combined it with POFA and fly ash as binder materials to produce foamed GPC. Kupaei et al. (2013) also conducted an experimental study to determine the potential use of OPS as an aggregate in GPC with fly ash as a binder material. They concluded that the increase in fly ash content decreased the compressive strength considerably, as the fly ash requires more water to achieve suitable workability, which negatively affected the strength of GPC.

![OPS as LWA, granite, and OPS distribution curve](image)

Figure 1. OPS as LWA, granite, and OPS distribution curve (Mo et al. 2015).

Mo et al. (2015) utilized OPS as lightweight aggregates (LWA) and examined its effect on the shear strength of GPC and cement concrete when combined with steel fibers. The study found that adding steel fibers with OPS improved the shear resistance of the GPC beams. Thus, OPS can potentially replace natural aggregates in the production of GPC, enhancing sustainability in the construction industry. Moreover, fly ash can be used as a replacement for cement and combined with OPS to achieve acceptable strength levels for the GPC produced.

### 3.3 Palm Oil Fuel Ash (POFA)

Palm oil fuel ash (POFA) is an agricultural waste byproduct produced during electricity generation in palm oil mills. Approximately 5% of palm oil waste burned is converted into POFA. As the production of palm oil increases, the production rate of POFA also increases, accumulating millions of tons in landfills and open areas (Hamada et al. 2018).

POFA has irregular porous particles with large particle size. Grinding raw POFA into smaller particle sizes can improve its reactivity. Yusuf et al. (2014) observed that using POFA to produce geopolymer concrete (GPC) can reduce the compressive strength of GPC activated with 10 M of Na₂SiO₃ and NaOH for replacement levels of POFA by GGBS greater than 20%. Alnahhal et al. (2022) investigated the effect of POFA on the compressive strength of foamed GPC. They found that the compressive strength of POFA-based foamed GPC was higher than the reference sample without POFA. However, the use of POFA in GP mortar led to a reduction in 28-day compressive strength compared to the reference mix.

### 4 DISCUSSION OF THE RESULTS

The concept of recycling is a crucial technique that not only supports the economy but also preserves raw materials for future generations while helping to reduce the accumulation of waste in landfills and promoting better waste management practices. By utilizing palm oil waste in producing Green Polymer Concrete (GPC), we can significantly contribute to enhancing the environment and promoting a circular economy. This approach involves transforming waste materials into useful and sustainable products.
Numerous studies have demonstrated the potential of palm oil waste, including the POC, OPS, and POFA, as a valuable agricultural waste source for producing green and sustainable concrete materials. In most cases, these three waste materials have been used as cement, fine, and coarse aggregates in the production of GPC.

5 CONCLUSIONS AND RECOMMENDATIONS

This review paper aims to determine the impact of eco-friendly materials, namely POC, OPS, and POFA, which are derived from palm oil waste, on the performance of GPC. The properties of palm oil waste have been presented, and the use of palm oil waste as construction materials has been explored in different sections. The following points are the major conclusions drawn from this study:

1. Palm oil waste is a significant byproduct of palm oil mills and is produced in large quantities, especially in tropical countries like Indonesia, Malaysia, and Thailand. This waste can be utilized as a material for concrete manufacturing.
2. POC, one of the palm oil waste products, has a lower specific gravity than a normal aggregate, resulting in lower density in LWA-GPC. Incorporating POC in GPC can also enhance strength due to its high pozzolanic reaction.
3. Due to its low density, OPS is used as LWA in the production of LWA-GPC. The use of OPS with POC can reduce the density up to 1955 kg/m3.
4. POFA, with its high pozzolanic reaction, especially with small particle size, can be utilized as a binder in producing GPC. The 28-day compressive strength of POFA-GP cement paste was measured to be 32 MPa.
5. Finally, this study suggests that palm oil fibers can be utilized as another palm oil waste product to improve flexural and tensile strength in GPC. Moreover, it is recommended to compare the life cycle, environmental effects, and cost valuations of using palm oil waste to traditional materials.

References


