Comprehensive Journal of Science
Volume (10), Issue (37), (NOV. 2025)
SICST2025, www.sicst.ly
ISSN: 3014-6266

مجلة العلوم الشاملة
عدد خاص بالمؤتمر الدولي الثالث للعلوم والتقنية
المجلد (10)، العدد (37)، (نوفمبر2025)
ردمد: 3014-6266

Effect of Manufacture of Industrial and Agricultural Waste By-Products on the Strength of Geopolymer Mortar

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Received: 30-09-2025; Revised: 10-10-2025; Accepted: 31-10-2025; Published: 25-11-2025

الملخص

تحولت الأبحاث الحديثة في حقل الخرسانة ومواد الأنشاء في اتجاه تصنيع بديلا للإسمنت وهو الجيوبوليمر وهو يعتبر بديلا مستخدما وصديق للبيئة .كان التركيز الأساسي لهذا العمل هو استخدام مواد النفايات الصلبة من المواد الصناعية والزراعية كمادة رابطة لكل نوع من أنواع ملاط الجيوبوليمر لدينا في هذه الدراسة ثلاثة مواد مادة من مخلفات زيت النخيل (u-POFA) والمادة الثانية الرماد المتطاير من محطات توليد الكهرباء (FA) والمادة الثالثة من خبث الافران و(GBFS) ، تم عمل مكعبات نظامية واختبار المكعبات في مدد 28,14,7,3 يوم حيث تم التحقيق في ملاط الجيوبوليمر. نلاحظ ازيد في عينات GBFSالغني بالكالسيوم عن عينات FAو u-POFA. تراوح نطاق القوة التي تم الحصول عليها للعينات من العينات علي التوالي 14.67 إلى 38.30 (نيوتن/مم²) لـu-POFA ، ومن 34.10 إلى 56.82 (نيوتن/مم²) لـFA ، ومن 66.89 إلى 83.44 (نيوتن/مم²). تم التحقق من صحة خصائص العينات من خلال تحليلات (XRD) . تُظهر النتائج أن مراحل الربط الرئيسية تتكون من بلورات سيليكات الألومنيوم وهيدرات سيليكات الكالسيوم (C–S–H) وهيدرات سيليكات الألومنيوم والكالسيوم.(C–A–S–H) .

Abstract

Recent research in the field of concrete and construction materials has shifted toward manufacturing an alternative to cement, which is geopolymer, considered an effective and environmentally friendly substitute. The primary focus of this work was to use solid waste materials from industrial and agricultural sources as a binding agent for each type of geopolymer mortar. In this study, we have three materials: palm oil waste (u-POFA), fly ash from power plants (FA), and blast furnace slag (GBFS). Standard cubes were made and tested at 3, 7, 14, and 28 days to investigate the geopolymer mortar. We observe a higher increase in the calcium-rich GBFS samples compared to the FA and u-POFA samples. The range of strength obtained for the samples was respectively from 14.67 to 38.30 (N/mm²) for u-POFA, from 34.10 to 56.82 (N/mm²) for FA, and from 66.89 to 83.44 (N/mm²). The properties of the samples were validated

thru (XRD) analyzes. The results show that the main bonding phases consist of aluminum silicate crystals, calcium silicate hydrate (C–S–H), and aluminum and calcium silicate hydrate (C–A–S–H).

Keywords: Industrial and agricultural materials Waste; Material (u-POFA), (FA), and (GGBS), Compressive Strength; X-ray diffractography (XRD).

1. INTRODUCTION

Concrete is regarded as the most essential and exceedingly utilized structural worldwide, with cement serving as its key component. However, Cement production contributes to greenhouse gas emissions in two significant ways: from through the release of CO_2 during the industrialization process, and indirectly through the energy consumption required for production. (burning of fossil fire). Currently, global yearly cement output accounts for approximately 7-8% of the world's total (CO_2) emissions into the atmosphere. (Hassan Laminu ,2021).

Researchers have minimizing the reduction of CO_2 emissions by minimizing useing Portland cement has recently been recognized as a key objective. To address this, the cement industry has made serious commitments to replace cement partially The cementitious materials include silica fume, slag, and Kaolinite, etc. Efforts are also being directed towards utilizing industrial by-products such as palm oil fuel ash.

Moveable by some of the frugal and environmental worries of cement, researchers have Concentrate on feedback as a replacement for this over the past few years. Over the past several years, researchers have focused on identifying an alternative solution. In addressing these issues collectively, significant efforts have been made to utilize materials derived from by-products or waste. This approach not only reduces the disposal of additional products at a cost but also contributes to environmental safety. Moreover, the adoption and development of blended cement are progressing swiftly within the construction industry, driven primarily by factors such as cost efficiency, energy savings, environmental sustainability, and resource conservation. The primary components of a geopolymer binder are alkali liquids and source materials

Various studies have scrupulous the use of source materials palm oil fuel ash (POFA), a byproduct of agricultural waste, as a potential substitute for cement in concrete. Research by (Sata, et al. 2004) revealed compressive strengths of 81.3(N/mm^2) , 85.9 (N/mm^2) , and 79.8 (N/mm2) at 28 days, achieved by incorporating refined POFA with a particle size of approximately 10 microns as a replacement for 10%, 20%, and 30% of cement, respectively. (Sata et al. 2004)

Geopolymer cement was produced, achieving a strength of up to 28 (N/mm^2) . Additionally, a geopolymer binder was developed using a ternary blend of slag, palm oil fuel ash (POFA), and rice husk ash. However, the binder contained a low proportion of POFA. (Karim MR, et al. 2013).

The widespread generation of Fly ash (FA), an output of coal burning, has emerged as a significant universal concern, contributing to substantial ecological damage. Data from The American Coal Ash Association (ACAA) indicates that approximately 38 million tons of fly ash were produced in 2016. Of this, around 22 million tons, or 57%, were repurposed for beneficial

applications. These uses include concrete production, flowable fill, embankments, and agriculture ACAA American Coal Ash, 2016).

On the other hand, studies have demonstrated that using precursors with high calcium content, such as GGBS, also facilitates strength development under ambient conditions (Elbasir,el,al,2019).

This research explores the use of solid waste to produce a new type of cement that's more environmentally friendly. We're testing materials such as (FA), (POFA), and (GBFS) to determine if they can serve as a binder in geopolymer mortar. It's still early, but the idea is to find a more sustainable alternative to traditional cement..

2.1. Materials

2.1.1 Palm Oil Fuel Ash (POFA)

Palm Oil Fuel Ash (POFA) was sourced from Industries Sdn. Bhd, Malaysia. Initially, the ash was desiccant in an oven at 105°C for 24 hours to eliminate any remaining moisture. Next, the POFA underwent sifting through a 300 μm sifting to separate rough tools, such as incompletely burned fibrilla and palm kernel shells. Subsequently, the (u-POFA) was milled down to an approximate particle size of 10 μm using a ball mill containing 150 steel bowls for 8 hours. The resulting ground POFA was then heated in a gas furnace maintained at 500°C for 90 minutes to remove unburnt carbon, yielding treated POFA (t-POFA). To enhance the material's fineness further, the t-POFA was subjected to an additional grinding process of 8 hours, producing fine POFA (f-POFA). Finally, for ultrafine POFA (u-POFA), the f-POFA underwent one more round of grinding for an additional 8 hours.

2.1.2. Fly ash (FA)

Fly ash (FA) for this study was sourced from Lafarge Malaysia Berhad (Associated Pan Malaysia Cement Sdn Bhd) at the Rawang Plant, 48000, Selangor Darul Ehsan. Based on the ASTM C618-12a classification, FA is categorized into two main types: low-calcium FA (Class F, with CaO content below 10%) and high-calcium FA (Class C, with CaO content exceeding 10%). In this research, low-calcium FA was utilized. Details of its chemical composition and physical properties are presented in Table 2and 3.

2.1.3 Ground slag (GBFS)

Ground slag (GBFS) was procured from the YTL Cement manufacturer in Selangor, Malaysia. Its specific gravity measures 2.89 g/cm^3, while its particular surface area is 405 m^2/kg. Characterized by an off-white appearance, GBFS is considerably lighter than Portland cement. A detailed breakdown of its chemical composition is presented in Table 2, and its physical properties are summarized in Table 3. For GBFS to meet requirements, at least two-thirds of its mass must consist of glassy slag, which includes a combination of CaO, MgO, and SiO_2 accounting for no less than two-thirds of its total mass.

2.1.4. Aggregates

The aggregate composition consisted solely of river sand as the fine aggregate (FA), characterized by a fineness modulus of 1.85. The specific gravity of the FA in a saturated surface dry (SSD) state was recorded at 2.62. Furthermore, the (FA)to-(u-POFA) ratio was kept consistent at 1.5.

2.1.5 .Alkaline activators

A commercially available sodium silicate (Na2SiO3) with an initial silica modulus (Ms = SiO_2/Na_2O) of 2.2, along with a 10 M NaOH solution, was utilized as the alkaline activator for the mixtures designated Br1 to Br21. The composition of the Na2SiO3 used was as pursue: 52.5 wt.% H2O, 32.8 wt.% SiO_2, and 14.7 wt.% Na_2O. The alkaline activator solution was prepared by combining Na2SiO3 with the 10 M NaOH solution. To create the 10 M NaOH, 404.04 g of NaOH Pellets with a 99% assay purity were resolved in one liter of water. Although the alkali activation solution can generally be formed by mixing Na2SiO3 and NaOH in ratios ranging from 0.5 to 3.0, this research used a ratio of SS/SH of 2.5.

2.2. Design of mixtures

To ensure adequate workability in the geopolymer mortar. For every mix, we made sure to add a little extra water. It came out to about 5% of the total weight of the dry materials. That way, everything stayed consistent across the board, including u-POFA, FA, GGBS, NaOH solution (10M) concentration, and Na_2SiO_3 solution. Every mixture was prepared with a weight ratio of 2.5 for Na_2SiO_3 to NaOH and a weight ratio of 0.48 for alkaline activator solutions to binder (solid material).ratio adopted from previous work. (Mijarsh et al., 2014) .. All geopolymer mortars were prepared using a sand-to-binder ratio of 1.5, deemed optimal according to previous studies (P Chindaprasirt et al., 2007). Although increasing the aggregate proportion in the mortar decreased the extent of geopolymerization, this did not significantly affect compressive strength. It has been suggested that optimizing the alkali content could further enhance compressive strength in mixtures with higher aggregate levels. Additionally, The proportions of solid materials, alkaline activators, sand, and added water in the geopolymer mortar were derived We used the absolute volume method, which is shown in Table 1. The mixtures were designed, prepared, mixed, and then cast. Table (3) details The trial blends employed in this research. The primary materials for each mix single binder included u-POFA, fly ash, and GBFS. The alkaline activator was a combination of Na_2SiO_3 and NaOH solutions. To prepare the NaOH solution, solid NaOH pellets were dissolved in distilled water to achieve concentrations of 10 M. This mixture was stirred until the pellets fully dissolved, resulting in a clear solution. Since a considerable amount of heat is generated during this process, the solution was covered and sealed for at least three hours to cool down naturally to ambient temperature (27 ± 2 °C), ensuring that heat did not influence the geopolymer reaction. Meanwhile, the Na_2SiO_3 solution was used directly without additional preparation and mixed with the NaOH solution for two minutes. After the solutions had been prepared, the raw materials were carefully scaled., Along with the NaOH and Na_2SiO_3, and H2O, were combined in preparation for the gradual addition of sand. Mixing was carried out using a Hobart N50 paddle mixer according to ASTM C305 (ASTM, 1999b) guidelines. The mixer operated at two selectable speeds: low speed (140 ± 5 rpm) and medium speed (285 ± rpm), We started by mixing the dry stuff for about half a minute on a low setting, just to make sure everything was spread out evenly. Then we poured in the activator and kept mixing slowly for another 30 seconds. After that, we added the sand bit by bit and gave it another quick mix. Once that was done, we turned the mixer up to medium speed and let it run for a minute and a half. We paused for 15 seconds to scrape down the sides and the paddle, then mixed for one more minute at the same speed. Finally, we poured the mortar into small steel molds that had been oiled, each one 50 millimeters on each side. We filled them in two layers and used a

vibrator to help settle everything in place. table on each layer for 15 seconds, ensuring proper compaction as outlined in ASTM C109/C109M (ASTM, 1999a). A final 15-second vibration facilitated further consolidation in the last step. Following their removal from the molds, the specimens were sealed in heat-resistant vinyl bags designed to prevent moisture evaporation. This was followed by a curing process for 24 h in an oven at 75 °C (Mijarsh, Johari, & Ahmad, 2015b). This procedure ensured consistent preparation and quality of the mortar samples for subsequent testing.

Table 1: Mixture proportions of geopolymer mortar

Combination	Materials	solid waste	Sand	Na_2SiO_3	NaOH	Water	Added water
		(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
A2B3C1	u-POFA	0.856	1.280	0.293	0.04	0.08	0.06
A2B3C2	FA	0.860	1.290	0.289	0.04	0.08	0.06
A3B2C2	GGBS	0.829	1.240	0.336	0.03	0.08	0.06

Table 2 Chemical compositions using XRF

Oxides (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	P_2O_5	K_2O	SO_3	TiO_2	Na_2O	LOI
u-POFA	64.59	5.85	4.73	9.29	3.13	5.19	5.21	0.47	0.21	0.05	2.5
FA	49.05	23.51	6.42	5.08	0.69	1.01	1.309	0.47	1.12	0.210	2.13
GBS	36.83	14.4	0.39	39.35	3.59	0.01	0.3761	4.20	0.40	0.059	0.60

4. The discussion of Results

4.1. Chemical c and Physical properties

The chemical composition of the raw materials, as analyzed via X-ray fluorescence, is summarized in Table 2. The primary components include SiO2, Al2O3, and CaO. Among these, the silica content was highest in all the raw materials, recorded at 64.595% for u-POFA, 49.053% for FA, and 36.83% for GGBFS. The percentages of Al2O3 were 5.851%, 23.516%, and 14.44%, respectively, while calcium oxide (CaO) levels were measured at 9.293%, 5.080%, and 39.85%. Additionally, the loss on ignition (LOI) values were 2.50%, 2.13%, and 0.60%, respectively. Table (3) presents data Of raw material

Table 3 Physical properties Materials

Colour	Blaine fineness m^2 / kg	particle size distribution, $d_{50\mu}m$)	Specific gravity	Specimen
Light grey	1.871	1.1	2.56	u-POFA
Grey	320	9.8	2.42	FA
White	485	14.2	2.89	GGBFS

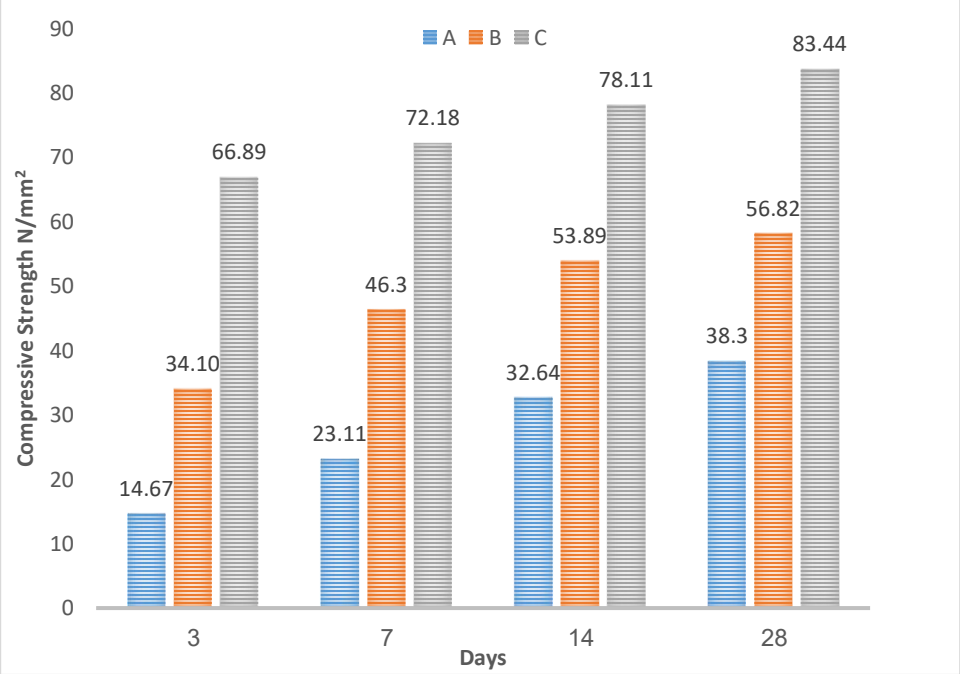

Figure 1. shows of developed compressive strength of the, geopolymer mortar at 3,7, 14, and 28 days

Fig. (1) illustrates the influence of time on specimens of geopolymer mortar by the compressive strength, which looks at how strong different types of mortar become over time, from 3 days up to 28 days. The binders we used were u-POFA, FA, and GBFS, each on its own. As the mortar aged, it kept getting stronger, which we checked at 3, 7, 14, and 28 days. The numbers varied quite a bit—u-POFA ranged from about 14.7 to 38.3 (N/mm2), FA went from around 34 to 56.82 (N/mm2), and GBFS was the strongest, hitting between 66.9 and 83.44 (N/mm2). The variation in solid waste materials appears to enhance the development of geopolymer mortars' strength. This improvement can be attributed to

changes in the levels of SiO_2, Al_2O_3, and CaO within these materials, which help optimize the compressive strength of geopolymer mortars.

4.2. XRD diffraction

Fig (2). illustrates the XRD for all specimens based on geopolymer

mortars. In the case of the u-POFA-based geopolymer mortar, the XRD pattern shows the

presence of various compounds, as shown in Fig. 2A. The primary components identified included quartz (SiO_2), calcite ($CaCO_3$), and jadeite ($NaAlSi_2O_6$).

It was reported that, jadeite ($NaAlSi_2O_6$) belongs to the family of aluminosilicates and its crystal structure contains Si which are tetrahedrally coordinated in single chain, with Al and Na in octahedral coordination (Kupwade-Patil and Allouche, 2011). The presence of calcite in the POFA might be forming because of a reaction between calcium oxide and carbon dioxide.In the case of FA, the calcite formation is generally less pronounced due to its typically lower calcium content, although trace amounts may still form through carbonation processes during storage or curing. The XRD pattern reveals the formation of various new compounds, as depicted in Figure 2B. Several prominent peaks were identified, corresponding to mullite ($3Al_2O_3{\cdot}SiO_2$), low (SiO_2), and ($CaCO_3$). Similarly, Figure 2 C illustrates the XRD for the GBFS-based geopolymer mortar. These diffractograms display several distinct peaks, representing quartz (SiO_2), portlandite ($Ca(OH)_2$), calcite ($CaCO_3$), and albite ($Na(AlSi_3O_8)$). However, previous related studies have indicated that in the pozzolanic reactions, $Ca(OH)_2$ reacted with the SiO_2 and Al_2O_3 in GGBS and formed the calcium silicate hydrate (C–S–H) and calcium aluminium silicate hydrate (C–A–S–H) crystals, which are the main materials that generate strength in hardened cementitious materials, CaO (C) reacts with H_2O (H) to form $Ca(OH)_2$, which produces C–S–H or C–A–S–H system colloids by reacting with SiO_2 (S) and Al_2O_3 (A) (Samet and Chaabouni, 2004).

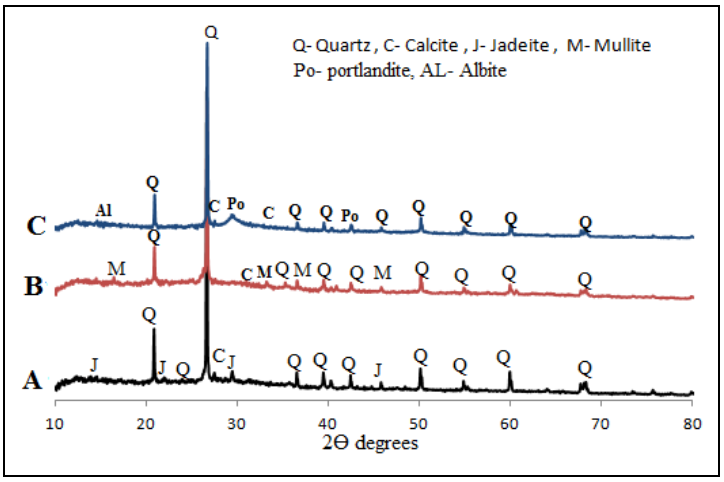

Figure 2: XRD for geopolymer mortar samples at 28 days

5. Conclusion

The results obtained from this investigation are based on. utilize solid waste materials of industrial and agricultural materials to produce geopolymer mortars as a single binder each type from solid waste materials. The results are then used to determine the effect of test factors on the compressive strength. X-ray diffraction deconvolution results of solid waste geopolymer mortars.

Based on the results of this study, the following conclusions can bedrawn: It can be concluded that the change in solid waste materials is increasing the development of compressive strength of geopolymer, because the level of SiO_2, Al_2O3, and CaO varies in these materials, during the change, optimizing the compressive strength of the geopolymer mortars. That is confirmed by X-ray diffraction. The analysis confirms thatmain phases of the reaction products, viz., N-A-S-H, C–S–H, and C–A–S–H products of geopolymer mortars. The compressive strength is shown in the reaction of the C–S–H and C–A–S–H phases, which is shown in high-strength GGBS geopolymer mortars.

7. Acknowledgments:

The writers would like to express their gratitude to the Palm Oil Industries for supplying the palm oil fuel ash used in this study. We also extend our thanks to YTL Cement Technical Center in Pulau Indah for providing the ground granulated blast furnace slag, and to Lafarge Malaysia Berhad, specifically Associated Pan Malaysia Cement Sdn. Bhd., for contributing the fly ash.

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