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EFFECT OF RUBBER SLUDGE ON THE PHYSICAL AND MECHANICAL PROPERTIES OF LOW CALCIUM FLY ASH-BASED GEOPOLYMER

In this research, experimental work has been carried out to check the feasibility of using rubber sludge (RS) to partially replace fly ash (FA) in the production of geopolymer. RS is employed in this study as disposing of RS has led to an issue and is abundant, especially in countries producing rubber products. RS is classified as hazardous waste. Improper awareness on hazardous waste handling can spread a variety of diseases. Therefore, handling of hazardous waste is not easy as competent personnel is required during the collection, transportation, treatment and final disposal. As a result, the cost of disposing the hazardous waste are relatively high. With that, FA incorporated RS geopolymer will able to solve the landfill problems and used it as building materials will save costs, preserve natural resources, and protect the environment from waste impact and hazards. In this study, the physical and mechanical properties were investigated. It was used to replace fly ash at 5 wt.%, 10 wt.%, 15 wt.%, and 20 wt.%. Water absorption, apparent porosity, bulk density, and compressive strength were tested. The test result shows that 5 wt.% of RS incorporation to fly ash-based geopolymer is optimum as it has 1752 kg/m^3 of density, 9.5% of water absorption, 19.2% of apparent porosity, and 49.9 MPa of compressive strength.

Keywords: Fly ash; Rubber sludge; Compressive strength; Apparent porosity; Water absorption

1. Introduction

The current growth in demand for construction materials due to development has necessitated an alternate method of developing or obtaining construction materials from other sources. To accommodate the rising demand, emphasis has been placed on developing sustainable construction materials. The use of enhanced construction materials in the construction sector is increasing daily, prompting an examination into their environmental effect and satisfying needed criteria when waste is employed in developing sustainable construction materials. Geopolymer is a material typically composed of an aluminosilicate that serves as a precursor. It will be mixed with an activating liquid made of sodium hydroxide and sodium silicate solution [1]. Geopolymers outperform OPC in terms of environmental effects and the use of industrial waste materials. Furthermore, this alternative binder has minimal detrimental effects from chemical attacks. As a result, lowering carbon dioxide (CO_2) emissions might be considered an ecologically beneficial cement innovation.

Fly ash, particularly low calcium fly ash, is an aluminosilicate material commonly utilised in geopolymer manufacturing. Indeed, the advantage of employing fly ash for geopolymer production is the ease of availability compared to alternative source materials [2]. One of the crucial elements influencing the behaviour of fresh and hardened geopolymer material is the content of calcium compound in the precursor. According to Chindaprasirt et al. [3], the quick hardening process is linked to the rapid production of a calcium silicate hydrate (CSH) phase. Furthermore, when the geopolymer samples were subjected to harsh treatments, they showed significant degradation [2]. It is plausible to believe that the lower calcium content of the source material is responsible for the longer setting time and able to improve resistance to chemical attack. As a result, employing low-calcium fly ash is a feasible option for creating a practical and long-lasting geopolymer binder [2-4].

Rubber glove production has increased significantly each year since the occurrence of the coronavirus in the year 2019. Hence, the sludge produced by rubber glove factories also

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increased throughout the years. Disposing of sludge waste has adverse effects on the environment and the economy since it still contains a significant amount of rubber in the sludge and it lowers the gas permeability of the soil, which kills the trees around the landfill sites [5]. Most rubber glove factories worldwide face the same issue when disposing RS due to a lack of research on treating this waste. Besides, RS is under the category of scheduled waste where special handling and disposal is required which causes extra financial burden for the rubber products manufacturers.

Researchers have sought to reuse and recycle waste to improve the sustainability of the environment. Fly ash (FA), blast furnace slag, red mud, and sewage sludge are among the wastes that have been exploited in the search for alternative sustainable building materials. Reusing or recycling such waste to create sustainable building materials has shown to be a feasible solution to disposal and environmental issues. Natural rubber latex (NRL) has also been effectively used in geopolymer and 1% of NRL was optimal for the geopolymer with higher strengths, resistance to surface abrasion, and reduced porosity [6]. According to Park et al. [7], 20% rubber crumb substitution causes a 15% loss in compressive strength. Adding recycled rubber by 10% improved the compressive strength of slag-based geopolymer concrete [8].

This research proposes to study the physical and strength properties of the effects of RS incorporation into FA-based geopolymer. It is crucial to investigate the strength of the geopolymer in order to determine whether it is suitable to be used as a construction material.

2. Experimental method

2.1. Materials

This study made use of low calcium Class F FA. The FA was obtained from Micro Dimension Concrete (MDC), Malaysia, and is in the form of fine powder with a density of 1.29 g/cm^3. Shorubber (Malaysia) Sdn. Bhd. supplied the RS. The RS is a chemical and biological treatment blend. It is placed in the oven for drying at 80°C for 24 hours. Dried sludge was pulverised by ball mill for 2 hours and sieved. Dried sludge with a density of 0.77 g/cm^3 is obtained. TABLE 1 demonstrates the chemical compositions of FA and RS as determined by an X-ray Fluorescence (XRF) spectrometer. Sodium hydroxide (NaOH) and liquid sodium silicate (Na_2SiO_3) were used as the alkali activator solution. The NaOH pellet has 99% purity with a density of 2.13 g/cm^3 supplied by Progressive Scientific Sdn. Bhd., Malaysia, whereas the liquid Na_2SiO_3 contains 60.5% of H_2O, 30.1% of SiO_2 and 9.4% of Na_2O with a density of 2.4 g/cm^3.

TABLE 1

Chemical composition of FA as determined by XRF

Compound	FA (wt.%)	RS (wt.%)
SiO_2	61.23	12.70
Al_2O_3	21.73	54.23
Fe_2O_3	5.49	2.37
CaO	3.34	3.02
MgO	1.26	1.08
P_2O_5	1.22	12.70
Na_2O	1.16	—
K_2O	1.15	—
TiO_2	1.05	1.89
SO_3	—	8.63
Cl	—	1.11
others	2.37	2.27

2.2. Sample preparation

A NaOH 16M solution was prepared by mixing NaOH pellets and distilled water in a volumetric flask, allowing it to cool for one day before use. The FA and RS were dry mixed until homogenous, then blended with an alkali activator for 5 minutes using a mechanical mixer to form a homogeneous slurry. FA was partially replaced with RS by 5 wt.%, 10 wt.%, 15 wt.% and 20 wt.%. The alkali activator (AA) ratio and the solid-to-liquid (S/L) ratio were adjusted to 2.5. The fresh geopolymer paste was then cast into plastic moulds of 50 mm × 50 mm × 50 mm. ASTM C109 was followed during the casting and compaction process. In order to eliminate entrapped air, the moulded samples were vibrated for 2 minutes on the vibration table and sealed with a thin film to prevent moisture loss. The geopolymer paste was allowed to harden for 24 hours at ambient temperature (29°C). The samples were demoulded after curing and stored at room temperature for 28 days. TABLE 2. shows the mix proportions of the geopolymer mixes.

TABLE 2

Mix proportion of FA-based geopolymers

Sample Name	Binder proportion (wt.%)		AA ratio	S/L ratio
	FA	RS		
FA	100	0	2.5	2.5
F5S	95	5	2.5	2.5
F10S	90	10	2.5	2.5
F15S	85	15	2.5	2.5
F20S	80	20	2.5	2.5

2.3. Testing and analysis

Numerous physical analyses and mechanical test will be performed in this study to evaluate the properties of geopolymer, including compressive strength, density, water absorption, and apparent porosity. These analyses and test were performed after 28 days of curing. The compressive strength test was performed according to ASTM C109-16a. The purpose of conducting the compressive strength test is to determine the maximal resistance of a sample specimen to axial force. This is crucial, especially when it comes to construction materials. The compressive strength was determined using a Universal Testing Machine

(UTM). The density of the geopolymer may be calculated using the formula in Eq. (1) below.

$$Density,\ \rho = \frac{mass\ of\ the\ sample,\ M\ (\mathrm{kg})}{volume\ of\ the\ sample,\ V\ (\mathrm{m}^3)} \quad (1)$$

Water absorption test was performed following ASTM C642-13 to determine the water absorption and apparent porosity of FA integrated RS geopolymer samples. The geopolymers were oven dried for 24 hours at 110°C. The mass of samples after drying (M_D) was determined. The samples were then submerged in water for 24 hours. The weight of the geopolymer suspended in water (M_S) was measured. The geopolymer samples were removed from the water. Their weight after immersion (M_W) was measured after the samples were pattered dry and wiped with a cloth to remove the water on the surface of the sample. The water absorption and apparent porosity of geopolymers were determined by applying Eq. (2) and Eq. (3), respectively.

$$Water\ Absorption = \frac{M_W - M_D}{M_D} \times 100 \quad (2)$$

$$Porosity\ (\%) = \frac{M_W - M_D}{M_W - M_S} \times 100 \quad (3)$$

3. Results and discussion

3.1. Bulk Density of FA Incorporated RS Geopolymer

Fig. 1 shows the bulk density of FA-based geopolymer with varying RS percentages. As the amount of RS increased, the bulk density of the geopolymer reduced considerably. When the RS content was raised from 0 wt.% to 20 wt.%, the bulk density reduced from 1848 kg/m^3 to 1620 kg/m^3, which is about 12.3%. This might be owing to the density differential between FA and RS. The density of RS (0.77 g/cm^3) is much lower than FA (1.29 g/cm^3). Therefore, with the greater RS replacement, the amount of FA will be reduced in the geopolymer system, which reduces the bulk density of the specimen. Yahya et al. [9] reported a 7.2% reduction in density when 20% crumb rubber was added as filler. Jose & Kasthurba [10] also said that the addition of natural rubber latex caused a reduction in density due to the low density of natural rubber latex added to the cement blocks. The replacement or addition of lightweight materials in geopolymer would cause a reduction of bulk density.

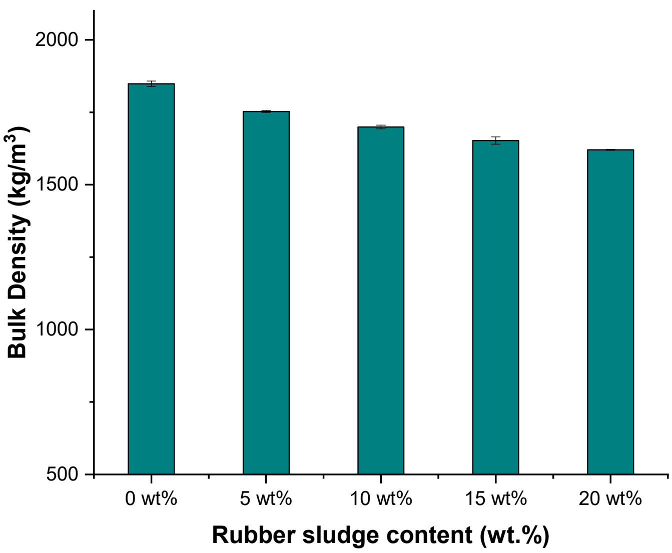

Fig. 1. Bulk density at different RS content of FA-based geopolymer

3.2. Water Absorption and Apparent Porosity of FA Incorporated RS Geopolymer

The results of water absorption and apparent porosity of FA-incorporated RS geopolymer are shown in Fig. 2. Water absorption and the pore structure of geopolymer are well recognised to be critical to the longevity of the samples. The less water penetrates the sample, the greater the durability and resilience to the natural environment [11].

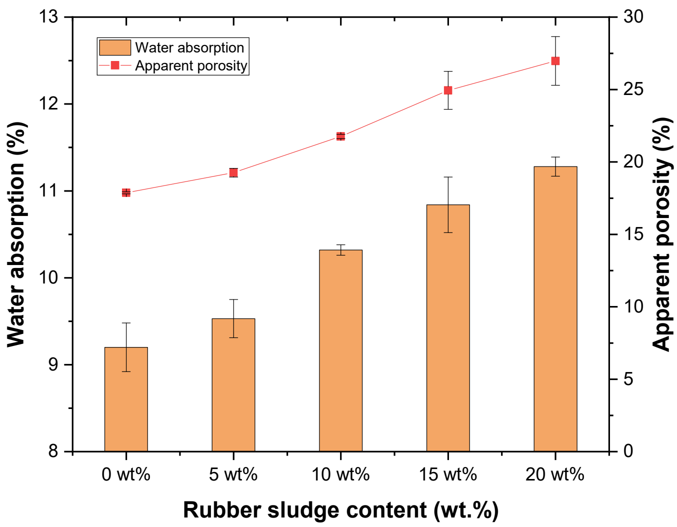

Fig. 2. The water absorption and apparent porosity of FA incorporated RS geopolymer with different RS content

The lowest water absorption was discovered in the FA geopolymer without the incorporation of RS at 9.2%, while the highest was found at FA incorporation with 20 wt.% of RS at 11.2%. The water absorption increased by increasing RS content. This is most likely owing to the nature of RS, which is hygroscopic and capable of absorbing moisture from the environment long after the incineration process has occurred.

The apparent porosity evaluates the accessible voids of the structure. Fig. 2. and Fig. 3 show that increasing the amount of RS increases the apparent porosity. The apparent porosity of the FA-incorporated RS geopolymer was 17.8% (0 wt.%) and 26.9% (20 wt.%), respectively. According to the findings, porosity affects water absorption because as porosity increases, so does the pore size [12-13]. Fig. 3 shows that as the amount of RS incorporated increases, it will promote higher unreacted

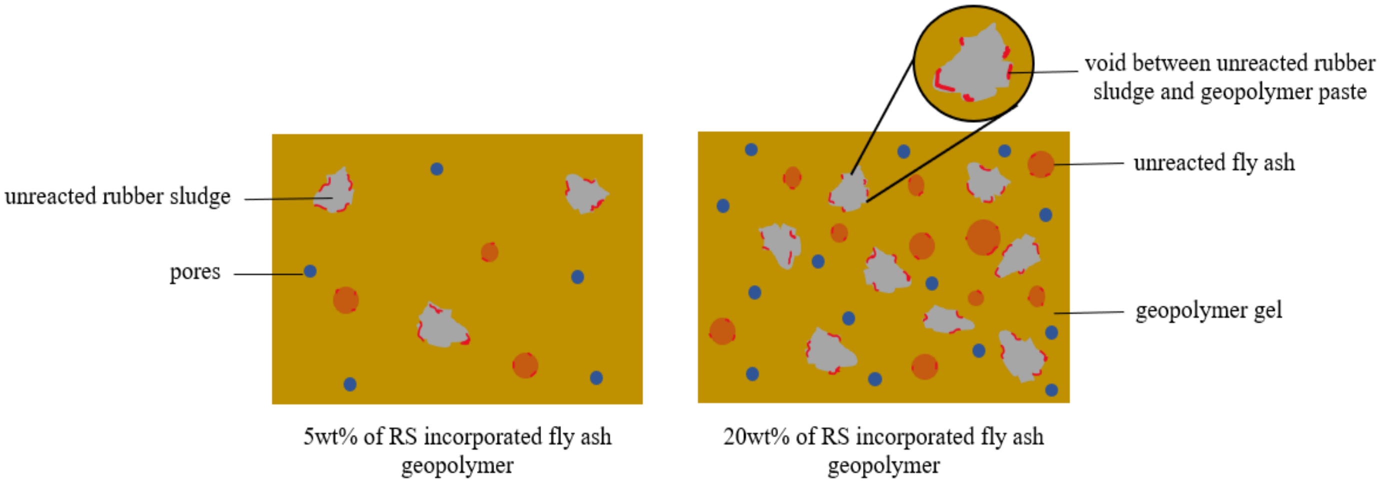

Fig. 3. Mechanism of RS in fly ash geopolymer

RS in the geopolymer matrix and lead to high chances of the void between the unreacted RS and geopolymer paste. The gap between unreacted RS and geopolymer gel caused lower bulk density and increased porosity. Besides, the poor development of the geopolymer matrix will also result in the creation of pores between the unreacted fly ash particles. Chindaprasirt & Ridtirud [6] proposed that when higher incorporation of natural latex, the water absorption and apparent porosity of high calcium FA blended geopolymer decreases due to non-homogeneity, interface, and the gap between rubber latex and paste. In a similar trend, the water absorption and porosity of geopolymer increase when crumb rubber particles are introduced. The geopolymer gel reduced as the amount of rubber was increased [14].

3.3. Compressive Strength of FA Incorporated RS Geopolymer

Fig. 4 depicts the compressive strength of FA with and without the addition of RS at various wt.%. It can be seen that introducing 5 wt.% of RS reduced compressive strength from 76.2 MPa to 49.9 MPa. When 20 wt.% RS was added to FA geopolymer, the compressive strength was lowered to 20.2 MPa, resulting in a 73.4% decrease in compressive strength compared to FA geopolymer without the addition of RS.

One of the primary factors defining the properties of the geopolymer is the chemical composition of the precursor. The primary building parts of the geopolymer structure are SiO_2 and Al_2O_3 oxides coupled with alkaline metal cations. The reduced concentration of these oxides in RS compared to FA was immediately reflected in the strength of the material [15]. Strength decreased as the weight percentage of RS increased. A similar observation was observed by Xu et al. [16] with the addition of styrene butadiene rubber (SBR) latex in geopolymer, which significantly reduces compressive strength, likely because SBR can be readily adsorbed on the surface of the geopolymer binder, which delays the geopolymerization process. The addition or replacement of low Si and Al precursors would reduce

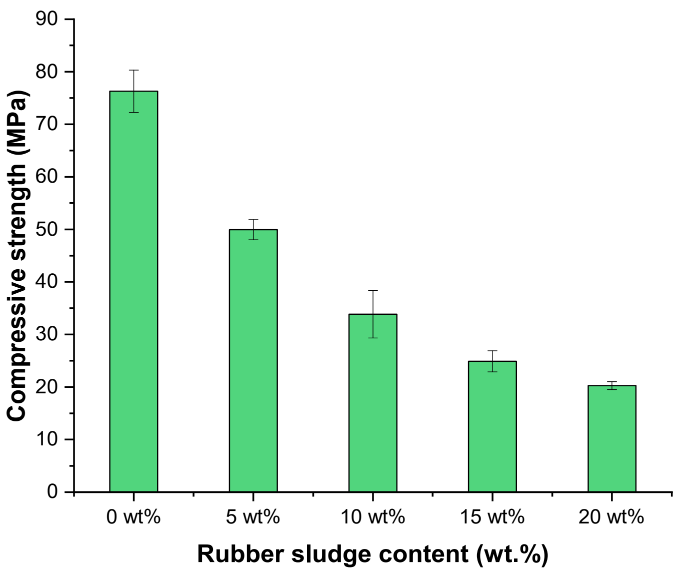

Fig. 4. The compressive strength of FA geopolymer with different RS content

the available Si and Al for the formation of geopolymer network and hence lower the mechanical strength.

Additionally, the air-entraining reaction considerably alters the pore size distribution and increases porosity, thus decreasing the compressive strength [17]. The relationship between porosity, water absorption, and compressive strength revealed that increasing porosity increases water absorption, but compressive strength is inversely proportional to water absorption and porosity. Fig. 3 shows that as the amount of RS increases in the geopolymer system, it will cause the void between the unreacted RS and geopolymer paste increases. The void will tend to become a stress concentration point and cause a reduction in compressive strength. Even though the replacement of RS deteriorates the compressive strength of the geopolymer, the FA/RS geopolymer is suited to be used as a construction material. Based on ASTM C62-99, the standard specification for building brick requires 17.2 MPa, which means that 20 wt.% RS incorporation FA geopolymer can also be used as a construction material [18].

4. Conclusion

In this study, the effect of RS replacement on the physical and mechanical properties of low calcium FA-based geopolymer was determined by bulk density, water absorption, apparent porosity and compressive strength. In general, the bulk density and compressive strength of geopolymer paste decrease as the RS content increases. In contrast, the water absorption and apparent porosity increase as the RS content increases. It is observed that 5 wt.% of RS-incorporated FA-based geopolymer is the optimum as it has 1752 kg/m^3 of density, 9.5% of water absorption, 19.2% of apparent porosity, and 49.9 MPa of compressive strength. Although the optimum mix is observed at 5 wt.%, 20 wt.% of RS incorporation in FA-based geopolymer can also be used as a construction material as the compressive strength has achieved the requirement of construction material.

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