# PROPERTIES OF COATED AND UNCOATED BIOMASS AGGREGATES AND THEIR EFFECTS ON THE STRENGTH AND WATER PERMEABILITY OF PERVIOUS GEOPOLYMER CONCRETE

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Abstract. Biomass aggregate (BA) is a by-product of biomass industries which is less dense and more porous than natural aggregate. In this two-part study, BA was mixed with fly ash and alkaline liquid, and heated in an oven at 80 °C for 24 h to produce coated biomass aggregate (CBA). The first part of this study was focused on the density, specific gravity, Los Angeles test, water absorption, aggregate impact value, and aggregate crushing value of BA, CBA, and normal aggregates (NA). The second part was focused on compressive strength and water permeability of pervious geopolymer concrete (PGC) that was produced with BA and CBA. Pervious concrete is a non-slip porous pavement concrete that allows water to slip through. In this study PGC was prepared from alkaline solution: fly ash ratio of 0:5, fly ash/coarse aggregate ratio of 1:7, Na<sub>2</sub>SiO<sub>3</sub>/NaOH ratio of 2:5, and NaOH concentration of 10 molarity. PGC was cured at 80°C for 24 h. PGC made with CBA had higher compressive strength without much effect on water permeability. It has been found that PGC made with BA and CBA are viable alternative aggregates for producing PGC.

Keywords: Geopolymer, Biomass aggregate, Pervious concrete, Compressive strength, Water permeability

# 1. INTRODUCTION

The oil palm, rubber, rice, coconut, and sugar cane industries produce approximately 80 million tons of biomass annually. The extraction of useful material from these plants generates waste material with expensive and complicated disposal strategies. These waste materials comprise ashes, grains, wastewater, and shells. Malaysia is one of the largest producers and exporters of palm oil products in the world [1,2]. All phases of palm oil processing produce by product wastes. One of these products is palm oil clinker, which is obtained from oil palm shells and from burning palm fiber. To drive steam engines for the oil extraction process, husks and fibers are used as fuel to stoke the boiler to high temperatures [3]. This process produces palm oil clinkers, which are obtained in large chunks that range in size from 400 to 100 mm. Clinkers are then crushed into smaller aggregates, called biomass aggregates (BA), with the required sizes. The internal portions of all BA are highly porous, which contribute to its lightweight nature.

Palm oil clinkers are disposed of in landfills. In addition to causing soil pollution, palm oil clinkers also contaminate groundwater. One of the ways to solve these problems is to convert these abundantly available waste products into BAs. The use of BA as substitutes for natural coarse aggregates (CAs) in the construction industry reduces environmental pollution and also provides an alternative to the diminishing sources of natural aggregates (NA) [4].

Aggregate density is an important factor that affects the properties and behavior of lightweight concrete. Incorporating BA produces lightweight concrete with a density that is less than 2000 kg/m<sup>3</sup> [5]. For example, using treated sewage sludge as an aggregate produced lightweight concrete with a density between 1400 and 1500 kg/m<sup>3</sup>, flexural strength of more than 3 MPa, and compressive strength of more than 15 MPa [6].

The use of BA as a CA has been initiated and successfully implemented. However, its practical application requires further research. BAs are mostly less dense, more porous, and heterogeneous than NA. The compressive strength of conventional concrete is decreased when NA are fully or partially replaced with BA. Compared to conventional aggregates, BAs have poor crushing and impact values, poor surface texture, excessive water absorption, and high porosity [7]. Thus, studies have been performed to improve the properties of recycled products that use agriculture waste as a component, such as concrete. Pre-soaking recycled aggregates in acidic medium (H<sub>2</sub>So<sub>4</sub>/H<sub>3</sub>Po<sub>4</sub>, HCl) has been proposed to improve the quality of recycled aggregates. However, this process may create durability problems as the acidic liquid might corrode reinforcement in concrete. The ultrasonic cleaning method has been suggested to produce higher-quality recycled aggregates and to remove loose particles from recycled aggregates [8]. After cleaning, BAs are surface-coated to improve their properties and to replace CAs in concrete. Recycled aggregates that were coated with pozzolanic powder have been used similarly [9,10]. As there are many different types of coatings on the surface of CAs, any unwanted dust particles will reduce bonding between the aggregates and cement paste, thus reduce the strength of concrete. Experiments have been conducted to identify a type of aggregate coating that will improve concrete strength [8,10].

Geopolymer, an inorganic polymer, is manufactured by reacting aluminosilicate materials with alkaline liquid [11]. Geopolymer has good resistance against acid and sulfate attacks, good performance under high temperature, and high early strength [12]. Geopolymer concrete does not use cement and reduces the emission of greenhouse gas by 44%-64%. Furthermore, certain wastes and byproducts, such as blast furnace slag and fly ash, are appropriate sources of aluminosilicate for geopolymer production. Given that geopolymers are made from byproducts, their environmental impact is lower than those of other types of concrete binders [13]. Therefore, coating BA with geopolymer paste has been proposed to improve its performance as a CA in concrete.

Compared with normal concrete, pervious or nofine aggregate concrete possesses high water permeability. PGC is an environmentally friendly material that is used in permeable pavements, water purification, thermal insulation, acoustic absorption, and other applications in architecture and civil engineering [14,15]. Typically, binder, coarse aggregate, and admixture are the main materials for PGC. Portland cement is generally used as a binding material in PGC. Considering the environmental issues, it is necessary to search alternative binding materials, such as geopolymer binders in pervious concrete. Therefore, coating biomass aggregate with geopolymer paste has been proposed to improve its performance as a CA in concrete. BAs were coated with a thin geopolymer paste and wellcured. The coated biomass aggregate (CBA) and uncoated biomass aggregate were mixed with fly ash and alkaline solution to produce pervious geopolymer concrete (PGC).

In this study, CBA and uncoated BA samples were investigated for mechanical and physical properties and their effects on PGC.

#### 2. MATERIALS USED

The raw materials for coating BA and PGC mixtures are fly ash, sodium hydroxide, sodium silicates (as alkaline solution), and three different types of CAs.

# 2.1 Fly Ash

Fly ash was collected from Sejingkat Power Corporation in Kuching, Sarawak. The chemical composition of fly ash was determined using X-ray diffraction (XRD) (SiO<sub>2</sub> = 55.7%, Al<sub>2</sub>O<sub>3</sub> = 24.22%, Fe<sub>2</sub>O<sub>3</sub> = 9.1%, K<sub>2</sub>O = 4.42%, CaO = 2.45%, MgO = 1.36%, TiO<sub>2</sub> = 1.33%, and less than 1% for P<sub>2</sub>O<sub>5</sub>, BaO, Na<sub>2</sub>O, and MnO).

# 2.2 Alkaline Solution

Sodium silicate and sodium hydroxide pellets with 98% purity were combined to produce an alkaline solution. The sodium pellets were purchased from a local chemical supplier. The sodium silicate solution (Na<sub>2</sub>O = 16.84%, SiO<sub>2</sub> = 35.01%, and water = 46.37% by mass) was used as the alkaline liquid. The sodium hydroxide solution was prepared by dissolving sodium hydroxide pellets in tap water. The alkaline liquid was prepared at least one day before use.

#### 2.3 Coarse Aggregate

Three different types of CAs (5 –10 mm) without dust were used in PGC mixtures: NA, uncoated BA, and CBA. Natural stone aggregates in dry and saturated surface conditions were used to produce PGC. Uncoated BA was produced by burning palm oil biomass. Palm oil fiber and palm oil kernel incinerated in a furnace at approximately 500°C. CBA was coated with geopolymer paste in a mixer. Fig. 1 shows the three different types of aggregates that were used in this study.



Fig.1 Different types of coarse aggregate.

#### **3. EXPERIMENTAL WORK**

Geopolymer paste was prepared by activating fly ash with sodium silicate  $Na_2SIO_3/NaOH=2.5$ ,

NaOH solution (10 M concentration), and AL/FA = 0.5. BAs were coated by geopolymer paste that contained 1:7 FA/BA. CBAs were kept in the oven for 24 h at 80 °C. The first part of experimental work focused on properties of BA, CBA, and NA such as density, specific gravity, Los Angeles test, water absorption, aggregate impact value, and aggregate crushing value of BA, CBA, and normal aggregates (NA).



Fig.2 Coating biomass aggregate

The second part was focused on compressive strength and water permeability of PGC made with BA, CBA, and NA. The prepared PGC mixtures with different types of aggregate were divided into the M1, M2, and M3 groups. Three groups of mixtures were prepared to study the influence of NA, BA, and CBA on the compressive strength and water permeability of PGC. Given that there is no standard mix design procedure for PGC, geopolymer paste trial mixes were adopted. Three different PGC mixtures with different types of aggregates were prepared by casting PGC cubes. To study the properties of different types of CAs in PGC based on compressive strength and water permeability, PGC was prepared with a FA/CA ratio of 1:7 with CA sizes 5-10 mm, AL/FA ratio of 0:5, and sodium hydroxide concentration of 10 M. The Na<sub>2</sub>SIO<sub>3</sub>/NaOH ratio was kept constant at 2:5. The PGC was mixed in a controlled room. FA was mixed with alkaline liquid for 5 min in a pan-type mixer. CA was then incorporated. The concrete was mixed for another minute. After mixing, PGC was molded in 100 mm cubes. The specimens were covered with a thin plastic sheet to reduce moisture loss before curing for 24 h at 80° C in an oven.

# 3.1 Specific Gravity and Water Absorption Test

Specific gravity is defined as the mass ratio (i.e., weight in air) of a unit volume of a material and the

mass of the same volume of water at a given temperature. In this study, the specific gravity test was conducted in accordance with ASTM C127. CBA, BA, and NA were sieved using a standard sieving apparatus. The samples were thoroughly washed, drained, and immersed in water. They were then soaked in water for no less than 15 h. Subsequently, the samples were removed from the water, towel-dried to surface-dry conditions, and then weighed in water. The samples were thoroughly dried in an oven and then weighed.

The water absorption percentages of CBA, BA, and NA indicate the proportions of water used in the concrete production process. In the present study, water absorption was utilized as an indicator of the permeability of the CBA, BA, and NA in hardened concrete. However, the water absorption percentage of aggregates can be determined in accordance with BS EN 1097-6: 2000.

# **3.2** Aggregate Crushing Value Test (ACV) and Aggregate Impact Value Test (AIV)

The aggregate crushing value (ACV) test characterizes the physical properties of CAs. ACV is used to identify aggregate crushing strength. The ACV test was conducted in accordance with BS 812: Part 110:1990. CBA, BA, and NA were passed through a 14.0-mm sieve and then through a 10.0mm sieve. Then, a measuring cylinder was filled with three layers of aggregate. Each layer was tamped 25 times with a tamping rod, and the volume was weighed to the nearest 0.1 g. A sample was taken from the measuring cylinder, placed in a test cylinder in three layers, and then tamped 25 times. The depth of the sample was roughly 100 mm. Then, the plunger was lowered onto the sample and rotated gently to the same level as the cylinder. The sample was then placed in a compressive testing machine. Load was applied at a uniform rate to obtain a force of 400 KN in 10 min and then released. The whole sample was passed through a 2.36-mm test sieve tray with the assumption that no considerable through amount passes in approximately 1 min.

The aggregate impact value (AIV) of the three different types of CA was analyzed. The AIV is the percentage loss of weight of particles that were passed through a 2.36-mm sieve with 15 blows of a standard hammer. The test was conducted in accordance with BS 812: Part 122:1990.

#### 3.3 Los Angeles Test

Aggregates that are used in highway pavement are subjected to traffic movement. When a vehicle travels on a road, its pneumatic tires will cause soil particles to abrade the road pavement. To determine the maximum abrasion value of various aggregates and to find the most suitable aggregate for use in road construction, the Los Angeles abrasion test was conducted. Indeed, this test is used to evaluate the hardness of aggregates.

# **3.4 Compressive Strength**

All specimens were cast in 100 mm cubes, molded, and tested after 24 h using a 250 KN capacity loading machine in displacement control at a rate of 1 mm/min until failure [16]. The mean value obtained from the five cubes was taken as the cube compressive strength for each PGC mix.

#### 3.5 Water Permeability

The water permeability coefficient of PGC was obtained via the constant-head method, which was performed when a steady-state flow was attained [17]. The coefficients of water permeability (k) were the three specimen averages, which were calculated by following Darcy's law as shown in the following equation:

$$K = (L \times Q) + A(L + H)$$
(1)

where:

k is the coefficient of water permeability (cm/s)

L is the thickness of the specimen (cm)

Q is the quantity of water collected (cm3) over time t (s)

A is the cross-sectional area of the specimen (cm2) H is the water head (h2-h1) (cm)

#### 4. RESULT and DISCUSSIONS

#### 4.1 Bulk Density

The densities of different types of coarse aggregate were conducted and the results are presented in Fig.3. The densities of BA, CBA, and NA are 795, 992, and 1688 Kg/m3, respectively. It can be seen that the densities of CBA and uncoated BA are lower by 41.2 % and 53%, respectively, compared with that of NA under the same conditions. Thus, these materials can be classified as lightweight aggregates. This means concrete specimens incorporation BA and CBA are considerably lighter than conventional concrete. Similar observations have been made by other researchers [5,18]. The lower specific gravity created by the void content and high porosity of BA and CBA contributed significantly to the lower density of concrete. The density of BA is lower than of the CBA, because the geopolymer paste filled and coated the pores and voids of BAs lead to increase the density. These results are similar to those obtained by other researchers that findings loose paste in recycle aggregate and porous residual coating the

circumference of recycle aggregate had contributed to weight of recycle aggregate at the same volume of NA [9,19].



Fig.3 Bulk density for NA, CBA, and BA

#### 4.2 Specific Gravity and Water Absorption Test

The specific gravities of the CBA, BA, and NA are summarized in Fig. 4, which indicate that the specific gravity values of CBA and BA are 13.7% and 25.8% lower, respectively, compared with NA under SSD conditions. Thus, CBA and BA are lighter than NA. The surface texture of BA become rough and cracked when coated by geoplymer paste and exposed to higher temperature level lead to increase specific gravity of CBA. The observation made is almost similar to findings by other researchers [4,20]. The lower specific gravity of BA than of the CBA was likely caused by the high porosity and void content of BA.



Fig.4 Specific gravity for NA, CBA, and BA

Fig. 5 shows the results of the water absorption test. It has been found that the water absorption of BA is higher than those of CBA and NA. This was likely caused by the high porosity and void content of BA. BA is characterized by its high-water absorption ratio due to high porosity and void content [20]. The water absorption of CBA is lower than those of the BA and NA, because the geopolymer paste filled and coated the pores and voids of BAs.



#### 4.3 Aggregate Impact Value (AIV)

The results of the AIV test are shown in Fig. 6. The impact value of CBA is clearly lower than those of BA and NA. Therefore, CBA is stronger than BA. Previous study conducted on lightweight aggregate confirms that the lighter ones produced a higher AIV and when the roughness of the aggregate is high, the AIV of the aggregate may decrease [18,20]. According to BS 882:1992, the maximum AIV is between 25% to 30% for heavy-duty floors and 45% for other types of concrete.



#### 4.4 Aggregate Crushing Value (ACV)

The results of the ACV test are presented in Fig. 7. The load-bearing capacity of concrete may be significantly affected given that BA is light and highly porous. The ACV is significantly related to strength-carrying capacity under load. A higher ACV generally indicates the high capability of the aggregate to sustain load, which indirectly provides good strength. BA has a higher ACV than CBA and NA, as shown in Fig. 7. This result indicates that BA is weaker than CBA because a large ACV signifies a weak material. Therefore, CBA is stronger than BA, and is a feasible replacement for NA. Kanadasan et al. [4] and Ahmad et al. [18] obtained similar result and claimed that BA has contributed to the lower strength, which is porous and can be easily broken and becoming materials that can pass through 2.36 mm sieve after applying load. Thus, when mass of crushed material passing 2.36 mm increases, it leads into high ACV and contributes to the higher value of ACV. According to Neville and Brooks [21], the value of ACV influences the compressive strength of concrete. Thus, lower ACV value with (higher strength) for CBA for present study is one of the factors that lead the CBA concrete to attain higher compressive strength than that of BA. Nevertheless, the ACV results obtained in the present study are parallel with other researchers.



Fig.7 Aggregate Crushing Value for NA, CBA, and BA

#### 4.5 Los Angeles Test

Fig. 8 illustrates the results of the Los Angeles test. The CBA and BA samples weighed 3000 g each. The NA sample weighed 5000 g. In addition, the weight of CBA and BA through 1.7 mm is 460 g and 1420 g, respectively, whereas that of NA is 1124 g. The percentage of abrasion of the CAB and BA is 14.7% and 42.3%, respectively, whereas that of NA is 24.4%. The observation made is almost similar to findings by other researchers for two lightweight aggregates with different densities [22]. Clearly, CBA has a lower percentage of abrasion than BA and NA. Therefore, CBA is more suitable for use in road construction than BA and NA.



BA

#### 4.6 Compressive Strength

Fig. 9 summarizes the compressive strength for different types of aggregate on PGC mix. The compressive strength values of BA, CBA, and NA are 8.3, 13.7, and 19.8 MPa, respectively. Apparently, their compressive strengths were within the typical strength distribution reported by ACI committee [23]. However, the compressive strength values of PGCs were slightly lower than those of normal Portland cement pervious concretes [22,24]. The relatively high strength Portland cement pervious concrete was obtained with the use of the high strength paste [25].



As shown in Fig. 9, the compressive strength of PGC containing NA was 19.8 MPa and similar to the PGC containing a slightly larger aggregate with similar alkali liquid to fly ash ratio [26]. The high strength geopolymer paste could also be obtained with the use of fine fly ash [27]. The compressive strength of CBA is 65% higher than that of BA under the same conditions. The reduction in strength of BA was due to less dense, weak ACV and AIV, poor surface texture, and high porosity and void content [18,20]. The highly porous nature of BA will more easily induce crack propagation than in dense concrete. This causes BA to fail much earlier than hardened geopolymer paste. In addition, the low and abrasion resistance of BA and CBA also contributed to the low compressive strength [4,20].

The compressive strength of PGC with BA is lower than those of CBA and NA given the previously mentioned properties of BA. CBA properties were improved by geopolymer paste coating, which helped fill the pores and voids in BA. Thus, the density and strength of PGC both increase. Previous researchers report that when the roughness of the aggregate is high, the bond strength of the interface may increase [28]. BA and CBA can reduce the density of concrete when the concrete specimens are fully replaced with BA or CBA. Compared with normal-weight PGC, concrete specimens with incorporated BA and CBA are considerably lighter. Therefore, CBA is a feasible replacement for NA.

# 4.7 Water Permeability

The effect of different types of aggregates on the water permeability of PGC is shown Fig. 10. It can be seen that the water permeability coefficients of different PGC mix were restricted to a narrow range between 1.9 cm/s and 2.3 cm/s, which resulted in high void content. It is generally understood that the water permeability coefficient of pervious concrete depends on the method of compaction and gradation of aggregates [25,28]. However, the method of compaction and gradation of aggregates were not different in this test.

Fig. 10 shows that the water permeability coefficients of PGC with NA, CBA, and BA are 2.3 cm/s, 2.1 cm/s, and 1.9 cm/s, respectively. This indicated that PGC with NA has the highest water permeability coefficient and that BA has the lowest water permeability coefficient. Although the use of BA and CBA can reduce permeability, its value was comparable and acceptable with reference to the general requirement for drainage.



Fig.10 Water permeability of PGC with different types of aggregate

PGC with CBA has a water permeability coefficient of 2.1 cm/s, which is higher than that of PGC with BA because the geopolymer paste maintained its fluidity during the forming process by coating and filling pores and voids, thus preventing the BAs from absorbing water [29]. The water permeability coefficients of PGCs with different types of aggregates and the same geopolymer paste content are not significantly different. This was also related to the pore connectivity, pore roughness, and pore size distribution that affect the permeability of pervious concrete in addition to the void content [28]. The permeability of PGC increased as void content increased, which is similar to that of conventional pervious concrete with Portland cement [30].

# **5. CONCLUSION**

Based on the overall property tests performed on BA and CBA, the variation in properties of different types of CAs is significant. CBA improves the properties of BA and had better ACV, AIV, and water absorption than BA. Therefore, coating BA with geopolymer paste improved the properties of concrete but lower compressive strength compared with PGC that used NA.

The compressive strength of CBA was 65% greater than BA under the same conditions because coating BAs prevented water absorption, which helped the geopolymer paste maintain its fluidity during the forming process. The obtained compressive strengths, which were between 8.3 and 13.7 MPa, were within the typical strength distribution. Another advantage of using CBA and BA is the decreased density of concrete. High void contents contributed to the high-water permeability values of 1.9-2.3 cm/s. The water permeability coefficient of PGC with BA and CBA and same geopolymer paste content was not significantly different from that of PGC with NA. The overall results indicated that BA and CBA can be used as CAs with a geopolymer binder to produce pervious concrete with excellent properties.

The use of BA and CBA is an environmentally friendly strategy to dispose of non-recyclable palm oil. The process of using waste materials from the agricultural industry also develops sustainability in the construction industry and contributes to a better waste management system. This study can guide upcoming research by providing enough information on the suitability and properties of BA and CBA. However, this study will provide some insight and guide to upcoming research works to further enhance the characteristics and suitability of BA and CBA to be utilized in pervious geopolymer concrete and understanding of the physical and mechanical characteristics of pervious geopolymer concrete containing BA and CBA.

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