A study on the potential of geopolymer artificial aggregate as substitute for granite and limestone aggregate

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Abstract. The aim of this research is to determine the potential of geopolymer artificial aggregate as substitute for granite and limestone aggregates. Several aggregate property test such as aggregate impact test, aggregate crushing test, specific gravity test, water absorption test and the Los Angeles Abrasion test are done on the aggregates. The fly ash-based geopolymer artificial aggregate is produced through geopolymerisation by mixing fly ash with alkaline solution. The results show that the fly ash-based geopolymer artificial aggregate is lighter than natural aggregate in term of its specific gravity. The impact value and crushing value for fly ash-based geopolymer artificial aggregate are slightly higher compared to natural aggregate while the water absorption value is much higher compared to natural aggregate. Furthermore, the fly ash-based geopolymer artificial aggregate has higher value in the Los Angeles Abrasion. Overall, the fly ash-based geopolymer artificial aggregate can be considered as one of the construction materials in the roadwork pavement and in concrete as an alternative for coarse aggregate besides natural aggregate with more lightweight properties.

1. Introduction

Nowadays, the construction industry is developing at a rapid pace and the demand for the construction material in building and infrastructure development is high. Hence, resulting in continuous usage of natural resources to produced raw materials which will eventually endangered environment. Moreover, reduction in availability of raw materials, especially the aggregates. In the construction industry, aggregate are essential material to be used, which obtained from nature through rock exploration, for producing construction material. Upon the growing issues, it is essential for identifying an alternative materials with the aid of advanced technologies to reduce environmental impact and prevent further depletion of natural resource while fulfilling the industry demand [4][6][7].
Malaysia is a fortunate country which have several distributed natural aggregate resources at almost every state. However, according to Department of Mineral and Geoscience, Malaysia, the production of aggregates has dropped by 16% from 158,744,150 tonnes in year 2015 to 133,072,882 tonnes in year 2016. The high demand of aggregate requires massive use of natural aggregates has disturbed the ecological balance. Thus, the environmental concern is a critical issues affecting the natural aggregate production nowadays [6]. Engineering activities created several environmental disturbance like change in geomorphology and conversion of land use, with association change in visual scene. This major impact may be achieved by loss of habitat, noise, dust, vibrations, chemical spills, erosion, sedimentation and dereliction of the mined site [11].

According to the 11st Malaysia Plan, the sustainability on protecting the environment has been emphasised. Hence, the “Strategic Thrust 4: Pursuing Green Growth for Sustainability and Resilience”. Prior to this, Construction Industry Transformation Plan (CITP) 2016-2020, with the aim of improving the construction industry in Malaysia had been launched by Construction Industry Development Board (CIDB), the Malaysian construction industry’s main regulating body. Four strategic thrusts, likely quality, safety and professionalism, environmental sustainability, productivity and internationalization were based on to develop CITP [2]. Therefore, research is done on fly ash-based geopolymer aggregates.

2. Material and methods

2.1. Fly ash-based geopolymer artificial aggregate

Fly ash was obtained from Manjung Power Plant, Malaysia. Fly ash geopolymer paste was formed by mixing the fly ash with the alkaline activator which was a mixture of sodium hydroxide (NaOH) and sodium silicate (Na$_2$SiO$_3$). Ready-made sodium silicate in the form of viscous liquid was used. Afterwards, the paste was then poured into a plastic container and at the same time vibration was done on the vibrating table. Next, the sample was dried and stored for about several day in order to be hardened. Then, it was cured in oven at temperature of 70°C while wrapped up with aluminium foil. Later onwards, a crushing machine was used to crush the fly ash mortar into small piece of aggregates as shown in Figure 1. Last but not least, sieving was done on this aggregate.

![Figure 1.](image)

(2.2. Granite and limestone aggregate)

The granite and limestone were supplied by the Pens Industries Sdn. Bhd. Which located at Batu Pahat, Kangar, Perlis. This aggregate was sieved and distributed into several sizes. Then, the aggregates were washed thoroughly and oven dried at temperature of 105°C for a period of 4 hours. Figure 1 shows the granite and limestone which being supplied.

2.3. Test of properties

The impact value test, crushing value test, specific gravity test, water absorption test and Los Angeles Abrasion test were performed and conducted on the fly ash-based geopolymer artificial aggregate,
granite aggregate and limestone aggregate each to determine their respective properties. Each test was done according to specification and standard as shown in Table 1.

### Table 1. Specification and Standard to Determine the Properties.

| Properties of Aggregate | Specification and Standard |
|-------------------------|-----------------------------|
| Aggregate Impact Value (AIV) | BS 812-110: 1990 |
| Aggregate Crushing Value (ACV) | BS 812-112: 1990 |
| Specific Gravity | ASTM C127 |
| Water Absorption | ASTM C127 |
| Los Angeles Abrasion | ASTM C131 |

### 3. Result and discussion

#### 3.1. Aggregate impact value (AIV)

Aggregate impact test was performed on both artificial aggregate and natural aggregate. Table 2 show the test results for the average AIV for each type of aggregates used. From the results, the AIV for the fly ash-based geopolymer artificial aggregate is 22.40% which is higher than the AIV for the both natural aggregate namely granite and limestone which are only 16.0% and 9.0% respectively. It is obviously shown that the fly ash-based geopolymer artificial aggregate which crushed more compared to the natural aggregate, had higher AIV.

### Table 2. Result for Aggregate Impact Values.

| Type of Aggregate | Weight of Aggregate, A | Weight of Aggregate Passing 2.36 mm, B | AIV = (B/A)*100% |
|-------------------|------------------------|--------------------------------------|-----------------|
| Fly Ash-based Geopolymer | 247.5 g | 55.4 g | 22.4 |
| Granite | 315.4 g | 50.4 g | 16.0 |
| Limestone | 340.5 g | 30.7 g | 9.0 |

Aggregate with lower aggregate impact value indicates that it has higher resistance to impact. Thus, both of the natural aggregate granite and limestone have lower AIV are stronger compared to the fly ash-based geopolymer artificial aggregate. This might due to the hard and low porosity of the natural aggregate. The porous structure of the fly ash-based artificial aggregate results a higher AIV which means weak and easy to be crushed.

There are several previous research show that it obtain higher AIV of fly ash artificial aggregate compared to natural aggregate [8]. Ganesh et.al (2011) with the study on the cold bond fly ash aggregate has obtained 22.70% of AIV and it is almost similar to the AIV of the fly ash-based geopolymer artificial aggregate in this study [3]. In Hamim et.al (2012), the AIV for commonly used aggregate is 10.12%. Furthermore, according to the study of Uche O. (2008), the AIV of the virgin aggregate, crushed granite is 23%. Previous study by Arafa (2018) conducted on waste produced aggregate, biomass aggregate and coated biomass aggregate with natural aggregate, the natural aggregate is 2.76% [1]. Therefore, the impact value of 22.40% for fly ash-based geopolymer artificial aggregate means that this aggregate is under strong category while for natural aggregate is exceptionally strong.

#### 3.2. Aggregate crushing value (ACV)

Aggregate crushing test was done on both the artificial aggregate and the natural aggregate. Table 3 show the test results for the average ACV for each type of aggregates used. From the results, the ACV for the fly ash-based geopolymer artificial aggregate is 37.70% which is higher than the ACV for the both natural aggregate namely granite and limestone which are only 25.40% and 19.60% respectively.
The ACV was determined by the percentage of the breakdown aggregate passing through the sieve of size 2.36 mm. It is obviously shown that the fly ash-based geopolymer artificial aggregate had been broke down more compared to the natural aggregate as its ACV is higher.

| Type of Aggregate         | Weight of Aggregate, A | Weight of Aggregate Passing 2.36 mm, B | ACV = (B/A)*100% |
|---------------------------|------------------------|----------------------------------------|------------------|
| Fly Ash-based Geopolymer  | 1910 g                 | 720 g                                  | 37.7             |
| Granite                   | 2560 g                 | 650 g                                  | 25.4             |
| Limestone                 | 2550 g                 | 500 g                                  | 19.6             |

In previous researchers study such as Hamim et.al (2012), the value of crushing test for commonly used aggregate in Malaysia road construction is 25.56%. Furthermore, the ACV of the virgin aggregates or known as natural aggregate of crushed granite is 20.0% [10]. Besides that, Arafa (2018) had obtained result of ACV for the natural aggregate which is 23.4% [1]. Aggregate with lower aggregate crushing value indicates that it has higher resistance to impact. Thus, both of the natural aggregate granite and limestone have lower ACV are stronger compared to the fly ash-based geopolymer artificial aggregate. This might due to the rigid structure of the natural aggregate. The porous structure of the fly ash-based artificial aggregate gives higher ACV which means weaker and easy to be crushed compared to the natural aggregate. However, the fly ash-based geopolymer artificial aggregate are considered to be mild tough and having resistance to crushing under traffic load. These aggregate have the stability of the pavement structure because the strength of coarse aggregate can affect the capability of the pavement to sustain.

3.3. Specific gravity (SG)

Specific gravity test was performed for both type of aggregate. Table 4 present the specific gravity value for each aggregates. From the results, the SG value for the natural aggregate is a bit higher than the SG value for the fly ash-based geopolymer artificial aggregate. Both the natural aggregate granite and limestone had SG of 2.62 and 2.71 respectively whereas the fly-ash based geopolymer artificial aggregate has SG of 2.14. The difference in SG value between the both aggregates are by 19.7%.

| Type of Aggregate | Fly Ash-based Geopolymer | Granite | Limestone |
|-------------------|--------------------------|---------|-----------|
| Bulk SG (oven dried) | 2.03                      | 2.60    | 2.70      |
| Bulk SG (SSD)     | 2.14                      | 2.62    | 2.71      |
| Apparent SG       | 2.29                      | 2.64    | 2.73      |

The SG of artificial aggregate in this study is most likely similar of other researchers work but the method of producing the artificial aggregate is different. Ganesh et.al (2011) with the study on the cold bond fly ash aggregate founded that its fly ash aggregate has SG value of 2.12 [3]. At the same time, Kockal et.al (2011) with the study on lightweight fly ash aggregate which its aggregate was also prepared through cold bonded technique, has SG value around of 1.65 [8]. Besides that, the fly ash-based geopolymer artificial aggregate in this study has almost similar value of SG value compared to study of Rafiza et.al (2013) where the geopolymer volcano ash aggregate has a SG value about 2.0.

SG of the natural aggregate is much higher compared to the fly ash artificial aggregate regardless of the processing techniques is due to the porosity of the aggregate itself. This is suggested by Kockal et.al (2011) since that almost similar value of SG for the natural aggregate was obtained compared
with this study which is around 2.70 and lower fly ash aggregate SG [8]. The porous structure with voids inside the aggregate will present air pores in which resulted in lower SG.

The SG of an aggregate particle are depending on the composition of itself and the porosity of the particle in it. For determining the required amount of asphalt, there is a need to take in account of the porosity by analysing it with three different types of specific gravity which is the oven dried bulk SG, saturated surface dry bulk SG and the apparent SG. Bulk SG includes all the pores whereas the apparent SG excludes the pores which would be filling up with water when immersed. SG is used to determine the quantity of asphalt needed in the hot mix asphalt for certain aggregate. Aggregate with more pores or void will needed extra asphalt. The aggregates that usually used in road construction have SG value range from 2.5 to 3.0.

3.4. Water absorption
Water absorption results for each aggregates were presented in Table 5. Water absorption of the fly ash-based geopolymer artificial aggregate in this study has a bit higher water absorption of 5.53% compared to the natural aggregates with lower percentage which are 0.63% and 0.36% respectively for granite and limestone. The percentage which is lower indicated that the aggregate absorb less water and have the less pores inside the aggregate itself. Water absorption which its percentage is lower in the natural aggregates was mostly due to the rigid structure and less void of the aggregates. The SG of the aggregate itself is significant as it will be affecting the water absorption properties.

| Type of Aggregate | Fly Ash-based Geopolymer | Granite | Limestone |
|-------------------|--------------------------|---------|-----------|
| Water Absorption % | 5.53                     | 0.63    | 0.36      |

From previous researchers, Kockal et.al (2011) with the study on lightweight fly ash aggregate which produced with cold bonded technique had obtained 8.9% water absorption while other two fly ash aggregates which were mixed with bentonite and glass powder as binder have water absorption of 3.3% and 2.8% respectively. In meanwhile, the natural aggregate had obtained the value which is less than 4% [8]. The difference in water absorption value of the artificial aggregate is maybe due to the method being used to produce the respective artificial aggregate. Fly ash-based geopolymer artificial aggregate may have lower porosity compared to the cold bonded fly ash artificial aggregate but higher porosity compared to the fly ash artificial aggregate with binder.

3.5. Los Angeles Abrasion (LAA)
Los Angeles Abrasion test was done for both type of aggregates according to ASTM C 131. The sample used for this test is designed under grade B. Under grading designation of B, 11 steel balls are used. The steel balls then place in the test machine and rotated for revolution number of 500 at a rotation speed of 30 per minute. The LAA value for both artificial and natural aggregates were shown in Table 6. From the result, it can be seen that the LAA value for the fly ash- based geopolymer artificial aggregate is 27.40% which is higher compared to the LAA value of the natural aggregate granite and limestone which are 24.80% and 17.60% respectively.

| Type of Aggregate | Fly Ash-based Geopolymer | Granite | Limestone |
|-------------------|--------------------------|---------|-----------|
| Weight of Aggregate before test, A | 5000 g | 5000 g | 5000 g |
| Weight of Aggregate after test, B | 3630 g | 3760 g | 4120 g |
| Loss, X = A-B | 1370 g | 1240 g | 880 g |
| % Loss = (X/A)*100% | 27.4 | 24.8 | 17.6 |
The fly ash-based geopolymer artificial aggregate particles are assumed to have less hardness which resulting more amount of small size aggregate and dust content. The hardness of the composition that formed the aggregate particles in which the individual grains are interlocked manipulating the aggregate to resist the abrasion and degradation. But, the weight of sample is not near to half of the total weight of aggregate tested it is not consider as weak in resistance. The LAA value obtained for common used coarse aggregate for Malaysia hot-mix asphalt is 21.4% [5]. Besides that, the percentage of abrasion for both the biomass aggregate and coated biomass aggregate are 42.30% in the study of (Arafa, 2018) whereas natural aggregate in this study is 24.80%. Hence, the LAA value of fly ash-based geopolymer artificial aggregate is also higher than the natural aggregate mentioned by the previous study. In meanwhile, by considering to the LAA value of biomass aggregate produced by waste products which is higher shows that the fly ash-based geopolymer aggregate is better. Furthermore, the coated biomass aggregate with the same product but coated with geopolymer paste also proven that the geopolymer product can withstand abrasion resistance.

4. Conclusion
Fly ash-based geopolymer artificial aggregate is comparable to the natural aggregates in term of its properties as it can be a substitute for granite and limestone in roadwork and a new material as lightweight aggregate with thermal insulation. From the compatibility analysis, the results of the study show that geopolymer artificial aggregate had properties which is good enough and not bad at all when referring to standard specification. It presented a higher water absorptions but lesser resistance to abrasion. Therefore, it may be considered as lacking features depending on the purpose of usage. However, it has a comparable resistance to impact and crushing which can be seen as significantly good feature especially in building construction. Furthermore, it has lower specific gravity which gives a new feature for producing lightweight material that can serve much of benefits in nowadays industry. Nevertheless, there are also a few present study show that the geopolymer artificial aggregates having potential to be utilized in road pavement construction. Based on the study, following conclusion are arrived at the artificial aggregate can be one of the alternative aggregate for natural aggregate be utilized as sustainable aggregate materials.

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