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The Effect of Different Crumb Rubber Loading on the Properties of Fly Ash-Based Geopolymer Concrete

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Abstract: This study aims at viability study the effects of addition of crumb rubber loading in fly ash-based geopolymer concrete for its properties. Crumb rubber is the recycled rubber from automotive scrap tires which can reduce scrap into uniform granules shapes that can absorb stress that reduces the reflective cracking because of its elastic properties. Geopolymer concrete includes an alternate material i.e Fly ash in replacement of cement, as a binding material. Mortar cubes of size 50mm x 50mm x 50mm were casted and curing at room temperature. X-Ray Fluorescence (XRF) and Scanning Electron Microscopy (SEM) were used to analyze the chemical composition of fly ash and the microstructure of the concrete. Moreover, compressive strength, water absorption capacity, and density of concrete are inter-related. Compression test, water absorption capacity test and density test were performed in hardened state, for different proportions of replacing the aggregate with crumb rubber i.e. 5%, 10%, 15%, 20%. Compressive strength test was performed at 7, 14 and 28 days. Results were obtained and compared. Decrease in strength was observed at 7, 14 and 28 days.

1. Introduction

The huge amount of waste tire becomes an emphasis topic that causes several environmental problems such as landfill pollution. An escalation in waste management problems was experienced in many countries [1]. To reduce the presence of non-biodegradable disposal materials in our surrounding, people can recycle disposal rubber tires by making use of pelletized cut rubber tire particles as a displacement of aggregates in a concrete mix. At the same time, it also helps to improve the supply demanding of coarse aggregates in low-strength concrete mixes as good strength building materials [2].

Environmental durability and sustainability characteristic is very important for a geopolymer material. A by-product of one industry use as source materials for other industrial application is a sustainable practice for industrial ecology demands. Geopolymer concrete is produced without the presence of Portland cement as a binder.



Fly ash which is rich in Silicon (Si) and Aluminium (Al) can be activated by an alkaline solution use as a binder in the concrete mixture instead of cement [3]. Low calcium fly ash is used as the major material in the mixture. The fly ash reacts with an alkaline solution to produce aluminosilicate gel that binds the aggregate to produce a geopolymer concrete.

The development of fly ash-based geopolymer concrete is an attempt to answer the challenge to produce more environmentally friendly concrete. The use of by-product material such as fly ash, as a base material for the concrete binder to exactly replace the use of Portland cement through a geopolymerisation process, has been attracting a lot of attention globally.

2. Experimental

2.1. Raw Materials

In this experiment, crumb rubber from tires used as a replacement of fine aggregates. Crumb rubber has a lower unit weight in between all the typically mineral aggregates. However, the addition of crumb rubber to the geopolymer concrete mixture can result a large reduction of unit weight of specimen. The addition of crumb rubber loading in the mixture by mass are 5%, 10%, 15% and 20%.

This study was using fly ash as the raw materials as cement replacement in concrete as geopolymer concrete. Fly ash was also gone through the XRF to analyze its chemical composition. Fly ash as the industrial by-product found that it can affect the mechanical properties of the concrete if the optimum amount of fly ash was used.

2.2. Mixing Method

The 400g of NaOH was dissolved in 1 L distilled water to produce 10M of sodium hydroxide solution. The hydroxide solution was left for one day prior. The alkaline activator was prepared by combining of a required amount of NaOH and sodium silicate solution, Na_2SiO_3 . The ratio of Na_2SiO_3 to NaOH was kept constant at 2.0 for all mixing design. It must be one day prior to use.

Different loading of crumb rubber aggregate was first mixed by using hand mixer and fly ash was added to it in a dry state and mix for about 4 minutes. The ratio of fly ash to alkaline activator was fixed at 2.5. The alkaline activator solution was shaken properly before poured in the hand mixer. Then, continue stir for about 10 minutes until homogenous. In this way, the different loading of crumb rubber in the fly ash based geopolymer concrete mix was prepared.

2.3. Mix Design

In this study, the specimen cube is cast by using cube mold with dimension 50mm x 50mm x 50mm. Five different types of fly ash based geopolymer concrete mixtures sample were produced and five specimens for each type sample mixture. The mortar specimens were prepared with five different mix designs as shown in Table 1.

2.4. Casting and Curing

The mixing of fly ash and crumb rubber were mixed well with the alkaline activator solution for 15 minutes. The mixture was mix until homogenous mixture form by using a hand mixer. The geopolymer paste with addition of crumb rubber was poured into 50mmx 50mmx50mm cube molds. It was then compacted on a vibration table for few minutes. This step was accordance to ASTM C109 standard. The samples were sealed or covered with a thin plastic film to prevent contaminants and moisture loss. Then, the cube specimens left cured at room temperature.

Table 1: Mix proportion for the specimen.

Materials		Mix Proportion					
		0%	5%	10%	15%	20%	0%
Crumb Rubber Aggregate (w %)		2.0	2.0	2.0	2.0	2.0	2.0
Ratio of Na ₂ SiO ₃ to NaOH		2.5	2.5	2.5	2.5	2.5	2.5
Ratio of fly ash to alkaline activator							

2.5. Testing

2.5.1. Compressive Properties Test

According to ASTM C 109/C, the compressive strength test of geopolymer cube specimens were performed using a GoTech Universal testing Machine. According to BS 1881: Part 116: 1983, the force applied on the cube was continuously increased with a nominal rate within the range of 0.2 to 0.4 N/mm².s until no greater force can be sustained and the maximum force applied to the cube that was recorded as compressive strength.

2.5.2. Water Absorption Test

The water absorption test was carried out after the cubes were cured for 1, 7 and 28 days. The concrete cubes were left to dry for 24 hours. The weights of the dried cubes were measured before immersed in water for another 24 hours. The percentage increase in weight which is the result of the water absorption is then calculated by using the equation (1):

$$\text{Water absorption \%} = [(W_0 - W_i) / W_0] \times 100\% \tag{1}$$

Where W₀ is the weight of the specimen at the absorbing equilibrium and W_i is the initial dry weight of the specimen.

2.5.3. Density Measurement

To determine the density of the fresh mixed geopolymer concrete, it gives formulas for calculating the unit weight, yield, and air content of the concrete. Yield means the volume of the concrete produced from a mixture of known quantities of the component materials. The density of the concrete cube was calculated by equation (2).

$$\text{Density} = \frac{\text{mass of the concrete cube after dried (kg)}}{\text{Volume of the concrete cube}} \tag{2}$$

2.5.4. Morphology Test

The SEM was used to carry out the morphology study in accordance with ASTM B748. The microscopic images of the fly ash based geopolymer concrete were captured using SEM on the surface of the geopolymer concrete after tested under the compression test. Then, the image was used to analyze the stress distribution and failure mechanism of the geopolymer concrete samples after the compression test.

2.5.5. Composition Test

XRF was used to analyze the composition of raw materials which such as fly ash before producing concrete cubes. Panalytical XRF was used in this study and the scan range used was 10° to 100° with a scan rate of 2° per minutes.

3. Result And Discussion

3.1. Compressive Strength

Based on figure 1, it shows that the average compressive strength for all five different mixes of mortar specimens cured for 7, 14 and 28 days under room temperature. These five specimens contain different loading of crumb rubber in fly ash-based geopolymer concrete. The control mix sample only contains fly ash without the addition of crumb rubber. The crumb rubber aggregate was used to replace sand aggregate in the fly ash geopolymer mortar at a replacement level of 5%, 10% 15% and 20% respectively by weight of the binder.

The compressive strength of the rubberized geopolymer mortar will increase with curing time for all different mixes. The longer the curing age resulted in higher compressive strength for the rubberized mortar. This might because longer curing time is required for optimum activation of pozzolanic reaction [4]. To produce a concrete with optimum potential performance, sufficient curing age is essential [5]. The curing is the most important step for concrete as it maintains the moisture content during its early stage in order to develop its properties like strength, porosity, shrinkage and durability of the concrete [6].

From the overall, the compressive strength of the geopolymer mortar reducing with addition crumb rubber loading. The increasing of crumb rubber loading in rubberized geopolymer mortar will gradually weakened its compressive strength. , the failure of the rubberized mortar specimens occur attributed to the more elastically deformable of crumb rubber than the matrix. The cracks begin at the softest areas when the mortar specimens were loaded. The site of the inclusion of rubber is where these sites appear [7]. In other words, the inclusion of crumb rubber implies defects in the internal structure of the concrete which resulting in a reduction in strength. This behaviour can be profitable when some ductility of the material is required [8].

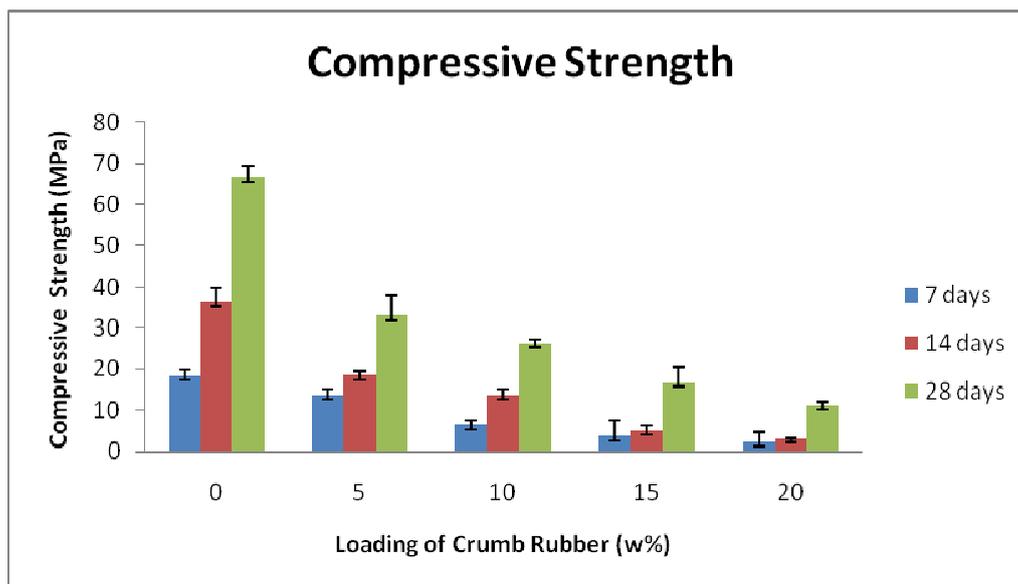


Figure 1. The compressive strength of the mortar specimens with different loading of crumb rubber for 7, 14 and 28 days of curing time.

3.2. Water Absorption Properties

Figure 2 showed the water absorption capacity of five different mixes of rubberized geopolymer mortar at three different curing periods. The water absorption test is correlation with the density test.

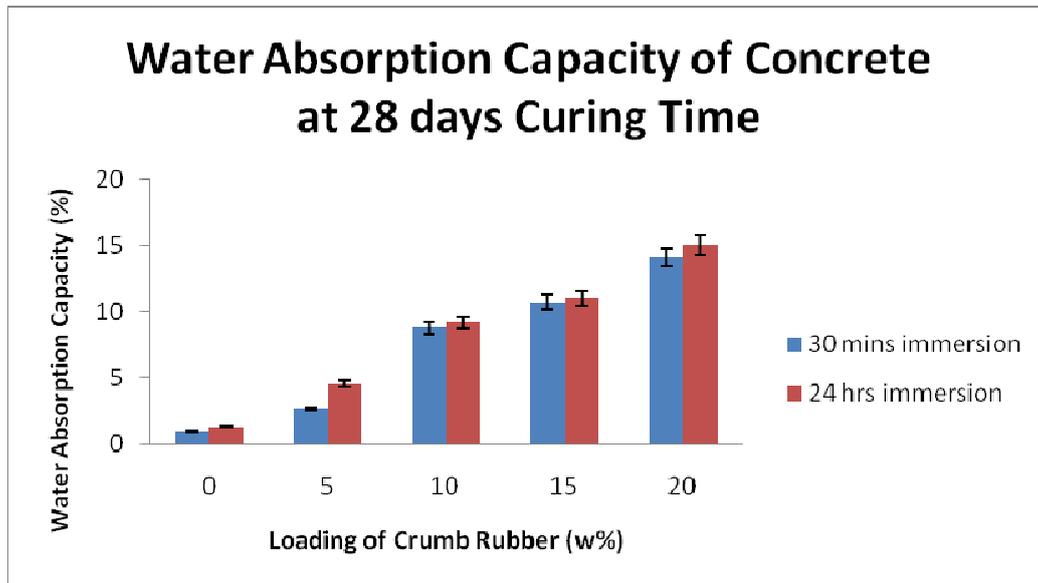


Figure 2. Effect of different loading of crumb rubber content on the water absorption capacity of rubberized geopolymer mortar at 28 days curing time with 30 minutes and 24 hours of immersion.

It can be concluded that the higher the water absorption capacity of the mortar, the lower density of the concrete. This is because of the presence of the amount of the voids in the mortar will decrease its unit weight.

Based on the data obtained from figure 2, the water absorption capacity of the rubberized geopolymer mortar shows an increasing trend as the crumb rubber content increases. The higher in water absorption capacity means that the density of the mortar is lower. This is because the amount of voids presence in the concrete is more than expected. It shows lowest water absorption capacity for plain geopolymer mortar among the five different mixes of rubberized geopolymer mortar, which means it has the best hydration characteristic. Hence, the low water absorption capacity and good hydration characteristic in plain geopolymer mortar results in highest compressive strength among all concrete mixes.

3.3. Density

Figure 3 shows the density of different mixes of hardened rubberized geopolymer concrete of curing day for 7, 14 and 28 days. The resulted obviously showed that the density of the rubberized geopolymer mortar reduce during the curing period from 7 to 28 days. This is because the rubberized mortars will loss of water during the curing period which contributes to a lower density. The loss of water may attribute to improper sealed of mortar specimens during the curing period [9]. But the loss of water do not contributed to a reduction of compressive strength on rubberized geopolymer mortar. This is because the main reaction product of the alkali activation of fly ash causes a zeolite-type phase [10].

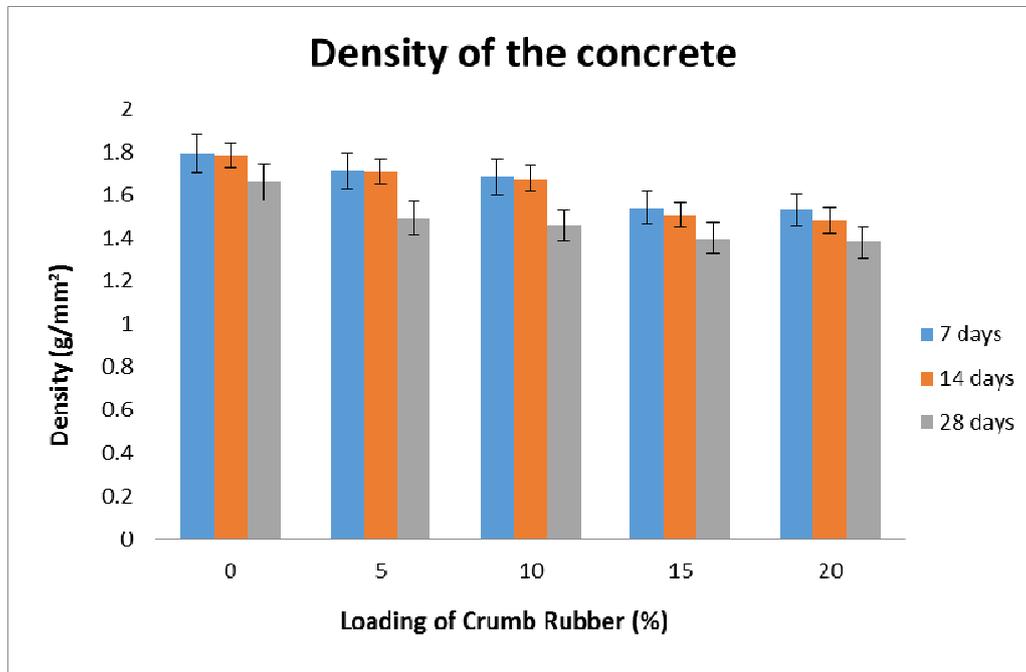


Figure 3. Effect of different crumb rubber content on the density of rubberized geopolymer mortar for 7, 14 and 28 days of curing time.

The density of rubberized concrete was found comparatively less than plain geopolymer concrete. With the increase in the percentage of rubber in concrete the density of it decreases [11]. From the results obtained the unit weight of the rubberized geopolymer concretes ranged from 2.243 to 1.722 kg which depend on the crumb rubber contents. With the increasing crumb rubber loading, the unit weight of the rubberized geopolymer concrete was reduced which results into a lighter concretes [12]. The results reveal that rubberized geopolymer concrete mixtures showed lower unit weight compared to plain concrete was due to the low specific gravity of crumb rubber [13].

3.4. Scanning Electron Microscope (SEM)

The SEM micrograph for different loading of crumb rubber loading in the rubberized geopolymer mortar were compare under magnification of 200x as shown in figure 4.

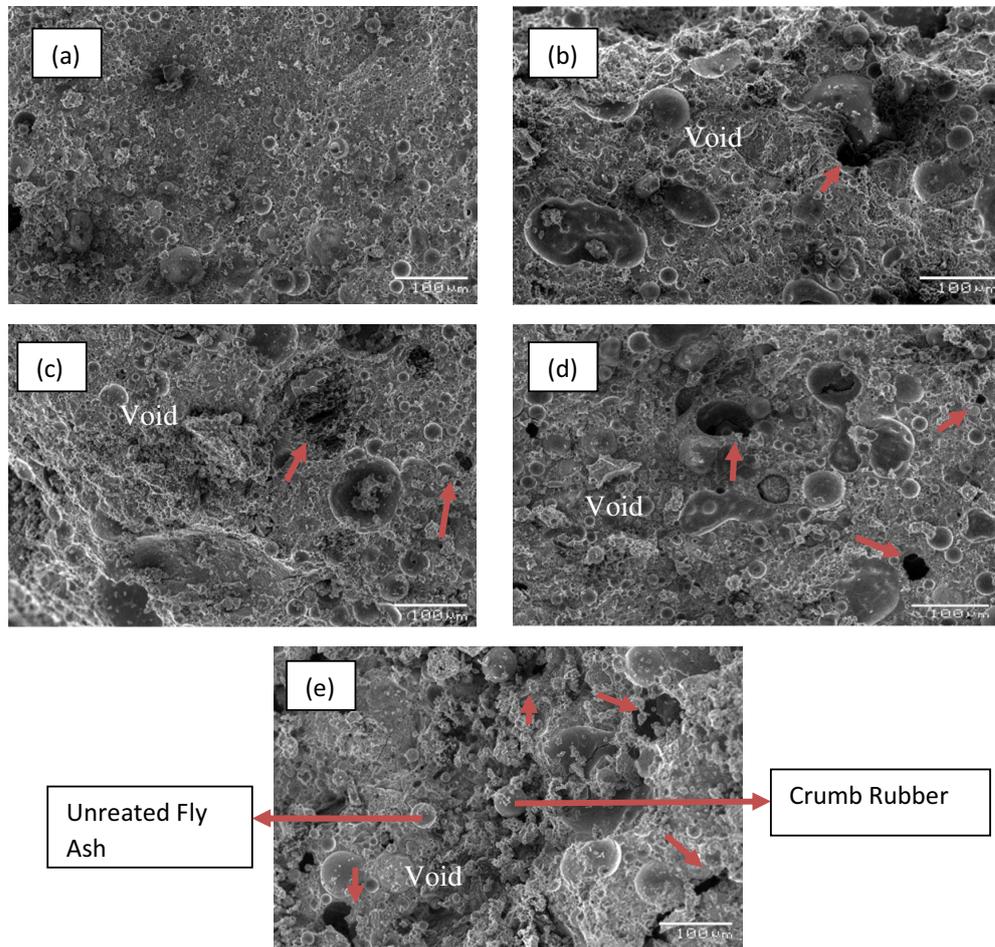


Figure 4. SEM micrographs of (a) Plain geopolymer mortar, (b) 5% of crumb rubber content, (c) 10% of crumb rubber content, (d) 15% of crumb rubber content, and (e) 20% of crumb rubber content under magnification of 200x.

These pictures can indicate the crumb rubber–mortar interfaces in all the rubberized geopolymer mortar specimens. In plain geopolymer mortar as shown in (a), the matrix has possess into a highly compacted paste. The non-reacted fly ash particles are embedded into the matrix, which bears the semispherical imprints of some of the grains that did. They are embedded into the sodium aluminosilicate gel produced during the reaction process. For the 5% crumb rubber content of rubberized geopolymer mortar as in (b), the interfacial zones are less dense with little micro-cracks. For the 10% crumb rubber content of rubberized geopolymer mortar as in (c), the interfacial zones become denser with increasing of micro-cracks. As the crumb rubber content up to 15% and 20% as in (d) and (e), the microstructure of the mortar shows the matrix appeared a lot of larger porosity and result in a relatively poor adhesion between the crumb rubbers and cement paste. These weak interfacial zones may have many serious influence on a range of properties of mortar.

The poor adhesion between the crumb rubber and the cement paste is very clear in these images. It was also observed that some rubber grains were buried in cement the matrix. Moreover, from SEM micrograph showed the porosity or void formed around the crumb rubber as a fine aggregate in the microstructure. These voids are susceptible to cracking when subjected to the influences of

compressive stress caused by the differential movements between hydrated cement paste and aggregate. Such movement can occur either during curing or drying of concrete. Furthermore, concrete can have microcracks in the interfacial transition zone even before a structure is loaded. This can be attributed to the content of rubber crumb loading present in the sample, which encourages poor bonding within the concrete structure. As a result, the application of compressive force puts a lot of pressure on the weak bonds. Hence, the mortar will be easy disintegration, which will lead to the large cracks in the sample.

3.5. Elemental Analysis

XRF analysis is used to determine the chemical composition of fly ash used in this study. For the use of fly ash in concrete, it can be classified into two categories, which are Class F and Class C [14]. In order to classify the fly ash as Class F, the sum of SiO_2 , Al_2O_3 , and Fe_2O_3 , is not less than 70% and very low in CaO which lower than 10%, while Class C, the total of these constituent is not less than 70% and high content CaO which is more than 20% [15].

Therefore, based on the XRF results in table 2 obtained that the fly ash used in was belong to low calcium Class F- acidic ashes. This is because the sum of the main constituent such as SiO_2 , Al_2O_3 , and Fe_2O_3 was not less than 70% with less than 10% of CaO content. The summation of these three chemical constituents was 90.32% and the content of CaO is 5.06%, which is classified as Class F – acidic ashes according to the ASTM C-618 standard with McCarthy amendment [16]. According to the international system of classification of fly ash, the fly ash used in this study is belonging to aluminosilicate ashes. The due to the $\text{SiO}_2/\text{Al}_2\text{O}_3$ was more than 2 and content of CaO less than 15% [17].

Table 2. Chemical composition of fly ash

Chemical Constituents	% Mass of Chemical Constituents (%)
Al_2O_3	23.40
SiO_2	50.00
SO_3	0.08
K_2O	1.41
CaO	5.06
TiO_2	1.60
MnO	0.22
Fe_2O_3	16.92
BaO	0.37
$\text{SiO}_2/\text{Al}_2\text{O}_3$	2.1368
$\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$	90.32

4. Conclusions

From this study, it is concluded that the fine aggregate in geopolymer concrete was replaced by the addition different loading of crumb rubber with 0%, 5%, 10%, 15% and 20%. The different loading of crumb rubber content in the rubberized geopolymer concrete is highly influence the results of compressive strength, density, water absorption capacity and different SEM micrograph. From the

overall of this research demonstrated that crumb rubber can be easily mixed in geopolymer paste without any difficulties. Potential use of crumb rubber cannot be used for the increasing compressive strength for concrete. This may be due to the improper bonding of crumb rubber with the mix and also due to the presence of voids in the concrete. The compressive strength of the rubberized geopolymer mortar reduces about 60% with 10% crumb rubber loading in the mixture. For large amount of crumb rubber in the mixture, the compressive strength gain rate is lower than plain concrete. Although the addition of crumb rubber in the mixture of rubberized geopolymer concrete does not show a significant improvement in the strength but these concrete still can be take advantage of many others engineering applications.

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