

Development of geopolymer mortar made from bagasse ash with waste aluminum

Kitti Onmak*¹, Songrit Puttala², Chaicharn Chotetanorma¹, Sahalaph Homwuttiwong¹

¹ Faculty of Engineering, Mahasarakham University, Mahasarakham, 44150 Thailand

² Department of Civil and Architecture, Faculty of Industrial Technology, Sakon Nakhon Rajabhat University, Sakon Nakhon, 47000 Thailand

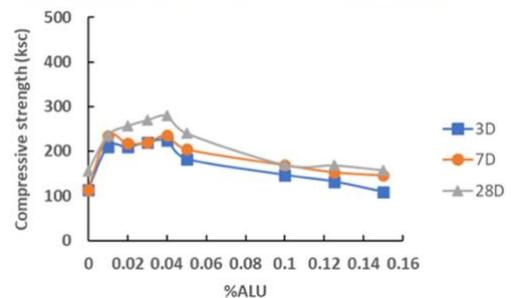
*Corresponding Author: kit.ti.001@hotmail.com

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Abstract

Geopolymer concrete is a type of concrete that is produced using industrial waste materials such as fly ash, slag, and other similar materials instead of traditional Portland cement. This research studied the variables affecting geopolymer mortar from bagasse ash mixed with aluminum scraps. The waste materials, bagasse ash (BA) and aluminium scrap (AL) were crushed to reduce the particles by grinding. An amount of ALU 0.01 – 0.15 wt% bagasse (BA) ash was added to the mixture. The alkaline solutions (AS) used to leach silicon oxide and aluminium oxide from BA were sodium hydroxide (NH) and sodium silicate (NS). The concentration of NH solution was varied between 7.5 – 15 molar. The ratio of alkaline solution to bagasse ash (AS/BA) was controlled at 0.50. Mortar samples were cast and cured at 60 80 and 100 °C for 48 hours. The results showed that the 10-molar sodium hydroxide solution tended to support the higher compressive strength. The highest compressive strength of geopolymer was found when using 0.04% aluminum scrap and curing at 80 °C. The additional water improved the workability of the fresh mortar, but the lower strength of the geopolymers was archived.



Keywords: Bagasse ash; Aluminum scrap; Geopolymer Mortar; Compressive strength; Waste materials

1. Introduction

In the production of Portland cement, a lot of energy is consumed to heat the raw materials to temperatures around 1400 – 1600 °C. Carbon dioxide (CO₂) is released into the atmosphere. And this energy consumption is very high. It is one of the causes of global warming due to the greenhouse effect. It is said that the production

of 1 ton of cement emits about 0.96 tons of carbon dioxide (CO₂) [1]. This is a problem that has a huge impact on the environment. Therefore, this research gives importance to the above problems and focuses on recycling waste materials to develop new materials that can replace Portland cement. In 2022, Portland cement production in Thailand amounted to

39.5 million tons and increased annually [2]. The waste material used instead of cement must have the properties of pozzolan. The known waste materials are byproducts of industrial plants, such as fly ash, rice husk ash, blast furnace slag, etc. Bagasse ash was recently studied as pozzolanic material and reported [3, 4].

In the past, fly ash and calcined kaolin (metakaolin) were most commonly used as source materials for the production of geopolymer concrete. However, bagasse ash is not sufficiently used as a pozzolanic material due to the poor properties of geopolymers. Bagasse ash is classified as type N pozzolanic material according to ASTM C618 [5]. Bagasse ash has a high chemical composition of SiO_2 , but a low content of Al_2O_3 . [6,7] Therefore, there is a demand for Al_2O_3 because of its suitability for the production of geopolymers.

It was found that the construction industry generates about 360 tons of aluminium waste each year [8]. The aluminium in construction is used as a decorative material for buildings. In Thailand, the demand for aluminum has continued to increase. And there are many other industries, such as construction, electricity, packaging, and automotive, that also produce aluminium waste. Each year, more than 280,000 tons of aluminium metal must be imported from abroad, a value of nearly 18,200 million baht [9]. This means that there will be more aluminum waste than initially estimated.

The geopolymer was introduced by the materials scientist Joseph Davidovits [10]. Geopolymer is a type of cementitious material that is in amorphous form. The main chemical components of the material are SiO_2 and Al_2O_3 . If a strong alkaline solution is used to react with alkali, it will lead to decomposition or separation from each other, such as NaOH or KOH solutions. Then curing with heat to form the hardening state and it has the ability to obtain a good compressive strength as concrete. However, the crystalline structure of

geopolymer has different characteristics from the use of cement as a binder [11].

In recent years, there have been research reports using bagasse ash as a source material for the production of geopolymers. Their compressive strength is at a level that can be used [12]. Therefore, this research aims to develop the strength of geopolymers by using bagasse ash and aluminum scrap. It is the use of waste materials, that reduces disposal costs and environmental impacts.

The aim of this article is to develop and utilize waste materials as building materials. By adding aluminum scrap to the geopolymer mixer, the ratio of silica to alumina of source materials will be adjusted. This will have an impact on the development of the compressive strength and properties of bagasse-ash geopolymers.

2. Materials and Methods

Materials; Bagasse ash (BA) from the sugar mill industry in Kalasin province was ground to improve the fineness. The remaining particles of BA on sieve No. 325 were controlled to less than 5%. Aluminum scrap (AL) was also improved so that all their particles passed through a sieve No. 40. The alkali solution (AS) consisted of sodium hydroxide (NH) at a concentration between 7.5 – 15.0 molar and sodium silicate (NS). Natural sand with a fineness modulus (F.M.) of 2.55 was used as fine aggregate.

Sample preparation; To prepare the geopolymer mortar samples, aluminum scraps were dissolved with sodium hydroxide solution at room temperature for 15 – 30 minutes. Then bagasse ash was added to the mixture and mixed until the components were uniform. Then sand and sodium silicate solution were added accordingly. Finally, 5 wt% of fresh water was added to the mixture. The preparation of the mixture is shown in Fig. 1(a). In Fig. 1(b), the samples were cast in 50x50x50 mm mold according to ASTM C192 [13] standard.

The mold was left in the laboratory for 1 hour, then the sample was cured at 60, 80 and 100 °C in an electric oven for 48 hours. The specimens were then removed from the mold and cured at room temperature until they reached the test age. The compressive strength was determined using the universal testing machine (UTM). The 3 – 5 of the samples were tested at each age according to the ASTM C109 standard [14]. The compressive strength of the geopolymer samples was calculated as follow,

$$\frac{P}{A} \dots\dots\dots (1)$$

where,

P = Force from UTM (kg)
 A = Area of sample (cm²)

The mixing ratios of the geopolymer mortar are shown in **Table 1**.



Fig. 1 (a) Mixing the geopolymer (b) Casting the samples of 50x50x50 mm

Table 1 Mixed proportions of geopolymer mortar made from bagasse ash and aluminum scraps

| No. | Mixture | AS/B | ALU (g) | BA (g) | NH (g) | NS (g) | Sand (g) | Water (g) |
|-----|------------------|------|------------|-----------|-----------|-----------|-------------|--------------|
| 1 | 7.5M0.5ALU0.125 | 0.5 | 87.5 | 700 | 175 | 175 | 1890 | 35 |
| 2 | 10M0.5ALU0.125 | 0.5 | 87.5 | 700 | 175 | 175 | 1890 | 35 |
| 3 | 12.5M0.5ALU0.125 | 0.5 | 87.5 | 700 | 175 | 175 | 1890 | 35 |
| 4 | 15M0.5ALU0.125 | 0.5 | 87.5 | 700 | 175 | 175 | 1890 | 35 |
| 5 | 12.5M0.5ALU0.125 | 0.5 | 87.5 | 700 | 175 | 175 | 1890 | 42 |
| 6 | 12.5M0.5ALU0.125 | 0.5 | 87.5 | 700 | 175 | 175 | 1890 | 49 |
| 7 | 12.5M0.5ALU0.125 | 0.5 | 87.5 | 700 | 175 | 175 | 1890 | 56 |
| 8 | 15M0.5ALU0.125 | 0.5 | 87.5 | 700 | 175 | 175 | 1890 | 42 |
| 9 | 15M0.5ALU0.125 | 0.5 | 87.5 | 700 | 175 | 175 | 1890 | 49 |
| 10 | 15M0.5ALU0.125 | 0.5 | 87.5 | 700 | 175 | 175 | 1890 | 56 |
| 11 | 10M0.5ALU0 | 0.5 | 0 | 700 | 175 | 175 | 1890 | 35 |
| 12 | 10M0.5ALU0.01 | 0.5 | 7 | 700 | 175 | 175 | 1890 | 35 |
| 13 | 10M0.5ALU0.02 | 0.5 | 14 | 700 | 175 | 175 | 1890 | 35 |
| 14 | 10M0.5ALU0.03 | 0.5 | 21 | 700 | 175 | 175 | 1890 | 35 |
| 15 | 10M0.5ALU0.04 | 0.5 | 28 | 700 | 175 | 175 | 1890 | 35 |
| 16 | 10M0.5ALU0.05 | 0.5 | 35 | 700 | 175 | 175 | 1890 | 35 |
| 17 | 10M0.5ALU0.10 | 0.5 | 70 | 700 | 175 | 175 | 1890 | 35 |
| 18 | 10M0.5ALU0.125 | 0.5 | 87.5 | 700 | 175 | 175 | 1890 | 35 |
| 19 | 10M0.5ALU0.150 | 0.5 | 105 | 700 | 175 | 175 | 1890 | 35 |
| 20 | T60M0.5ALU0 | 0.5 | 28 | 700 | 175 | 175 | 1890 | 35 |
| 21 | T60M0.5ALU0.04 | 0.5 | 28 | 700 | 175 | 175 | 1890 | 35 |
| 22 | T80M0.5ALU0.04 | 0.5 | 28 | 700 | 175 | 175 | 1890 | 35 |
| 23 | T100M0.5ALU0.04 | 0.5 | 28 | 700 | 175 | 175 | 1890 | 35 |

proportions of geopolymer mortar made from bagasse ash and aluminum scraps

AS/B = The ratio of alkaline solution to bagasse ash, ALU = Aluminum scrap, BA = Bagasse, ash, NH = Sodium hydroxide, NS = sodium silicate, M = Molar of solution

3. Results and Discussion

Influence of the concentration of sodium hydroxide solution on the compressive strength; In this research, the concentration of NH solution was used in the range of 7.5 – 15M. Fig. 2 show the effect of NaOH concentration on compressive strength of geopolymer bagasse ash mortar mixed with 0.125% aluminum scrap. The result reveals that the compressive strength, of geopolymer bagasse ash mortar mixed with 0.125% aluminum scrap. The result reveals that the compressive strength of the samples tended to increase with curing period. At the early stage, the mixture with a 7.5 M NH solution was found to have the higher compressive strength than the other mixtures.

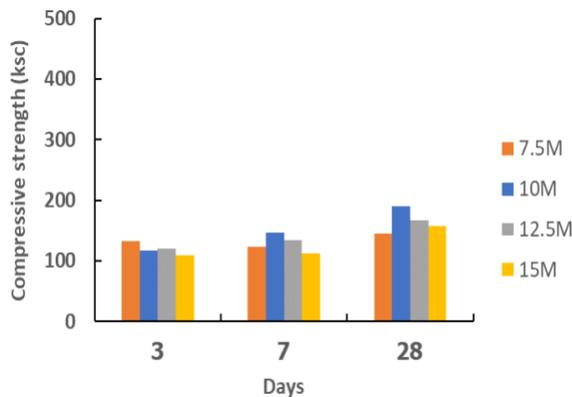


Fig. 2 Effect of NaOH concentration on the compressive strength.

In the mixture with a concentration of 7.5 M, the compressive strength was higher after 3 days than after 7 days, which is due to the low concentration of the solution. As a result, silicon and aluminium oxide are poorly leached from the source materials. In addition, the test was carried out after only one day of 48 hour curing at high temperature. The sample was still in a dry state. However, when the samples were kept in the laboratory for 7 days, they absorbed moisture from the environment. This caused them to expand and small cracks would appear. As a result, the compressive strength decreased after 7 days. Other researchers have also found

a reduction in the strength of geopolymers in their investigations. Wongpa *et al.* [15] investigated the inorganic geopolymer concrete and assumed that the reduction in compressive strength was caused by cracking due to shrinkage. In addition, Zuhua *et al.* [16] reported that the volume of the geopolymer changed when the samples were cured in air.

Otherwise, the samples with 10 M NH exhibited a higher strength at both 7 and 28 days. For the samples mixed with 12.5M and 15 M of NH, even though the compressive strength increased with age, but it was still lower than that of the mixture using 10M of NH. This result agrees with previous studies [17, 18].

The influence of aluminium content on the compressive strength; Fig. 3 shows the relationship between the amount of aluminum powder and the compressive strength of the geopolymer mortar using 10M NH and curing at 60 °C. The amount of aluminum used was in the range of 0 – 0.15 wt% of the bagasse ash. It was found that the use of aluminum in the mixture made the compressive strength of the geopolymer mortar higher than that of the control geopolymer or the mixture without aluminum addition. The controlled geopolymer had a compressive strength of 155 ksc at 28 days of age. The addition of 0.04% aluminum to the mix resulted in the highest compressive strength of 280 ksc, or 1.8 times that of the control mixture. However, as the amount of aluminum increased, the compressive strength decreased. The compressive strength rapidly reduced when the amount of aluminum was increased to 0.08%, 0.12% and 0.16%. This indicates that the amount of aluminum scrap that contributes to adequately adjust the oxide content of Al₂O₃ in the amount of bagasse ash geopolymer is in the range of about 0.04% by weight of bagasse ash.

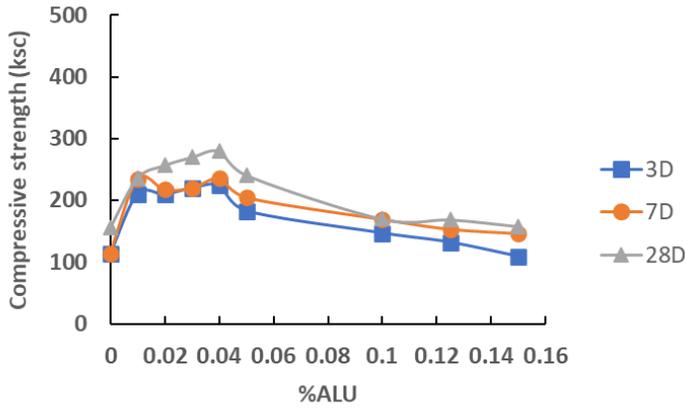


Fig. 3 Effect of aluminum scrap content on the compressive strength.

The results of curing the geopolymer mortar at room temperature, 60, 80 and 100 °C are shown in Fig. 4. The results show that the compressive strength of the geopolymers at all ages improves with increasing curing temperature. When cured at room temperature (control), the 3 day compressive strength of the geopolymer sample was 105 ksc. Thereafter, it slowly increased to 121 ksc. and 155 ksc. after 7 and 28 days, respectively. The compressive strength of geopolymers improved when cured at higher temperatures. Curing at a temperature of 60 °C tended to increase the compressive strength with the age of the specimens tested. and has a higher compressive strength than the control geopolymer mortar. The curing temperature was 80 °C. It was found that the initial compressive strength was significantly higher than when cured at 60 °C, but decreased after 7 days. Thereafter, however, the compressive strength tended to increase again until it reached 450 ksc at 28 days of age. The evolution of the compressive strength after curing at 100 °C showed a similar trend to that of curing at 80 °C, but the value was slightly lower.

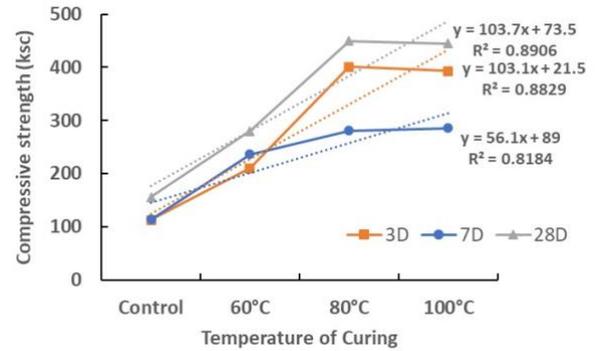


Fig. 4 Effect of curing temperature on the compressive strength.

The maximum compressive strength after curing at 100 °C was 393 ksc. Many researchers dealt with geopolymers and reported that the temperature of 80°C has the highest compressive strength [19 – 20].

Another conclusion is that the compressive strength of the geopolymer mortar cured at low or not very high temperatures tended to increase with the age of the sample [18]. Since the sample with low heat curing still contained some moisture in the microstructure, the geopolymerization reaction could be continued. Due to the densely matured geopolymer gel [21]. However, when cured at high temperatures, the compressive strength obtained may vary, especially during the test period of 7 days. Curing at high temperatures can destroy the granular structure of the geopolymer, leading to dehydration and excessive shrinkage and ultimately to a reduction in strength [22].

The drop in strength is significant in accordance with previous reports [15, 23]. The decrease in strength of geopolymers at 7 days may be due to the stage of pore refinement that the materials have reached. After heat curing, the polycondensation reactions were still in progress and not completed [24] and some water from the environment was absorbed and coalesced with the residual water in the matrix

[25]. In the first few days after heat curing, this effect is not yet recognizable. The subsequent evaporation over the following 7 days created large pores, which limited the strength of the material. At a later age, the microstructure developed further and led to a higher strength after 28 days.

The influence of extra water on the compressive strength; The geopolymer mixture obtained in this research was quite sticky and had relatively low workability. Therefore, extra water was added to the mixture and the effect on the compressive strength of geopolymer mortar was studied. The compressive strength of geopolymer mortar prepared with 12.5 and 15 M of NH are shown in Fig. 5. It was found that the mixture becomes less viscous when additional water is added to the mixture. The workability depends better on the amount of water added. It was found that the addition of water at any stage of the test resulted in a decrease in the compressive strength of the geopolymer [26 – 28]. The decrease in compressive strength is directly proportional to the amount of water added to the mixture. When comparing the geopolymer mortar mixes with NH concentrations of 12.5 M and 15.0 M, it was found that both mixes showed a similar tendency in the reduction of compressive strength. This could be due to the fact that the addition of water decreases the concentration of the solution, which affects the leaching rate of silica and alumina to perform polymerization reactions. However, the addition of water will reduce the compressive strength of the geopolymer. But when the workability and compaction of the mixture in the mold are considered together, there are no pores or voids. The reduced performance may be within acceptable limits.

In addition, the compressive strength of geopolymers mixed with 12.5 M and 15 M solution was lower than that of 10 M and tended to decrease with increasing concentration. This result also agrees with that of Pudasaini *et al.*

[21], who reported that the 10 M solution has higher compressive strength than the 12 M and 14 M solution, which is also confirmed by Zhang *et al.* (2023) [29]. An optimum alkalinity (Na concentration) was influenced by the NaOH solution. However, when a high NaOH concentration was used, the system contained only Na⁺ but very few dissolved ions and hydration products in comparison, which was reflected in lower compressive strength [30].

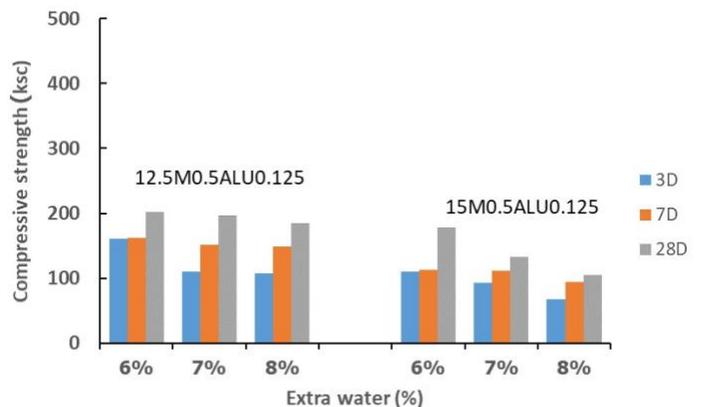


Fig. 5 Effect of Extra water on the compressive strength.

4. Conclusion

From the experimental results of the development of geopolymer mortar from bagasse ash with aluminum waste, a summary can be written as follows.

A concentration of sodium hydroxide (NaOH) solution of 10 M resulted in the compressive strength of the geopolymer mortar being the highest. The evolution of the strength depends on the age of the specimens.

The optimum ratio of the addition of aluminum scrap in the production of geopolymers from bagasse ash is approximately 0.04 percent by weight of the bagasse ash.

The compressive strength of geopolymers prepared from bagasse ash mixed with aluminum scrap increases with increasing curing temperature. The highest compressive strength is obtained at a curing temperature of 80 °C.

The amount of excess water added to the geopolymer mortar slightly increases workability. However, it reduces the compressive strength of the geopolymer.

5. Suggestions

This research focused on studying the compressive strength of geopolymer mixed with aluminum scraps. It is primary because it is a vital default property of concrete. In the subsequent study, the researcher will study mechanical properties, such as flexural strength and durability, to understand the factors of adding aluminum scraps.

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