Graduate Students, Science and Engineering

Development of Sustainable Eco-friendly Geopolymer Composites for Construction Applications

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Abstract

Geopolymerization is a process where silica and alumina rich source materials turns into excellent binding materials by the aid of alkali solutions. Materials such as fly ash are by-products in energy power plants. Fly ash is classified based on its constituent materials. Fly ash class F mainly consists of alumina and silica. Compressive strength of class F fly ash geopolymer mortar is influenced by many factors such as the molarity of sodium hydroxide solution, fluid to binder ratio, Na2SiO3/NaOH ratio, curing duration and curing temperatures. The present study investigates the effect of these factors on the compressive strength of geopolymer mortar. For each combination, three cubes with dimensions of 50 x 50 x 50 mm were casted. After heat curing in the laboratory oven, the samples were tested on a universal testing machine for the compressive strength.

The results showed very high early compressive strength of 63.9 MPa for samples cured at 80 °C and for a duration of 24 hr.

Aims and Objectives

The aim of this study is to investigate the factors influencing the mechanical properties of geopolymer mortar (GPM), and what are the best practices and optimum conditions.

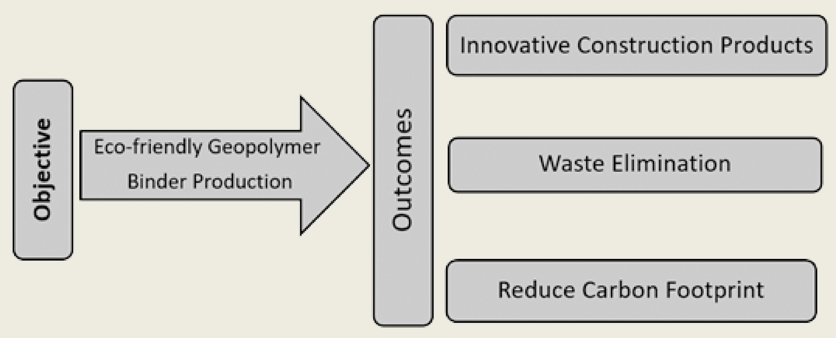

Figure 1. Goal and outcomes of the research

Significance

This research of high significance as it will:

- Allow for establishing methods for production of high strength geopolymer mortar that can be used in civil engineering applications.
- Reducing the environmental impact of the construction industry due to the use of traditional construction material and using source materials to produce binding materials with outstanding mechanical properties.

Research Motivation

Cement production processes requires immense amount of energy and is accountable for 7% carbon dioxide emissions to the atmosphere. It is estimated that production of one ton of cement is equivalent to one ton of CO2 (Alnahhal et al. 2017; Ng et al. 2018; Singh et al. 2015). There has been an increasing demand to develop a new binding material that can partially or fully replace cement in mortar and concrete. Geopolymerization is a process where three-dimensional polymeric chain rings consisting of Si-O-Al-O are formed by alkali activating the source material that are rich with silica and alumina (Rattanasak and Chindaprasirt 2009). The geopolymerization process is summarized in Figure 3.

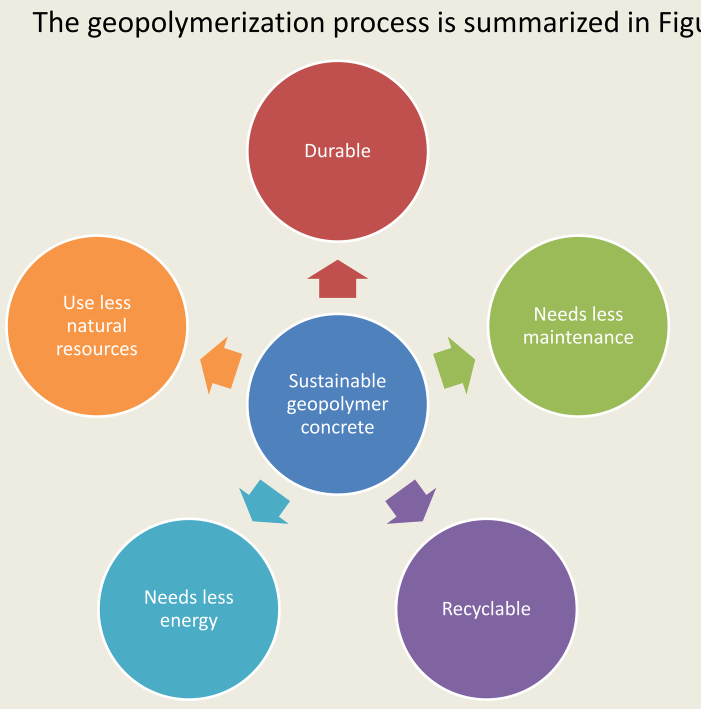

Figure 2. Research Motivation

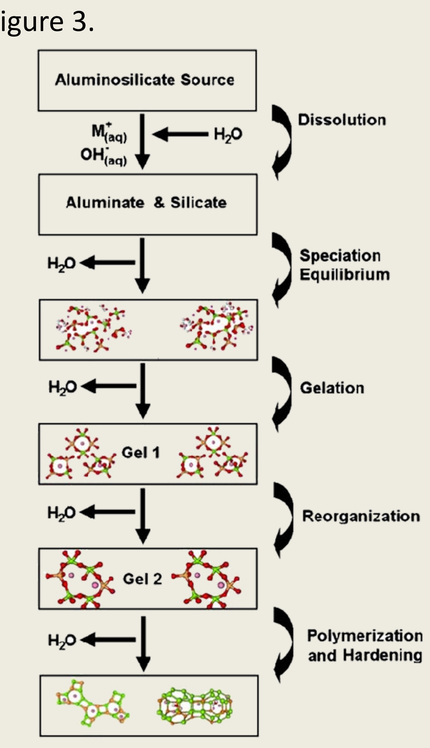

Figure 3. Geopolymerization Process

Methods and Materials

Materials:

- Sand
- Fly Ash class F
- Activator Solution:
  - Sodium hydroxide 12, 14 and 16 M
  - Sodium Silicate (Na_2SiO_3 40%)

Figure 4. Source materials

Methods:

- Casting Procedure were performed according to ASTM C109 standards

Figure 5. Casting procedure

Curing conditions:

- Temperatures of 40, 60 and 80 °C **(T)**
- Duration of 24, 48 and 72 hrs. **(D)**
- Age of mortar 0,3,7 and 28 days

Mix designs:

- Molarities of NaOH are 12, 14 and 16 M **(M)**
- Fluid to binder ratios of 0.60, 0.65 and 0.70 **(F)**
- Sodium silicate/Sodium hydroxide ratios of 1, 1.5, 2 and 2.5 **(N)**

Results

Effect of fluid to binder ratio, Sodium Hydroxide molarity, and Sodium Silicates to Sodium Hydroxide ratios on the compressive strength of geopolymer mortar are shown in Figures 6, 7 and 8.

Effect of molarity (M) of NaOH solution and Na_2SiO_3/NaOH ratios (N):

Fluid to binder ratio (F) = 0.60 :

- GPM activated with 16 M exhibited the highest compressive strength of more than 60 MPa for all sodium silicate to sodium hydroxide ratios of 1, 1.5, 2 and 2.5.
- Minimum Compressive strength of 33.4 MPa for GPM activated with 12 M NaOH and with Na_2SiO_3/NaOH ratio of 1 .

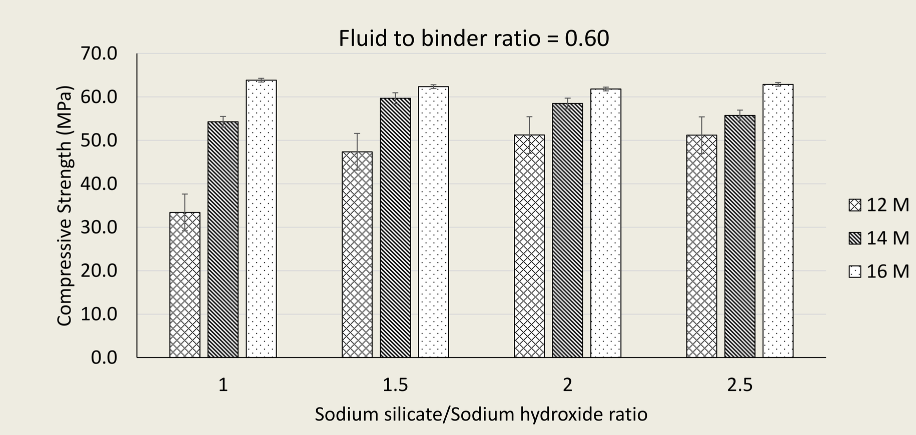

Figure 6. Effect of Na_2SiO_3/NaOH ratio at different molarities at Fluid to binder ratio (F) = 0.60

Effect of molarity (M) of NaOH solution and Na_2SiO_3/NaOH ratios (N):

Fluid to binder ratio (F) = 0.65 :

- GPM mix designs with 0.65 fluid to binder ratio and with Na2SiO3/NaOH ratio of 1 and 1.5 had little variations in the compressive strength.
- Minimum Compressive strength of 45.1 MPa for GPM activated with 14 M NaOH and with Na2SiO3/NaOH ratio of 1.
- GPM mix designs with Na2SiO3/NaOH ratio of 2.5 showed increasing trend for the compressive strength as the molarity increased.

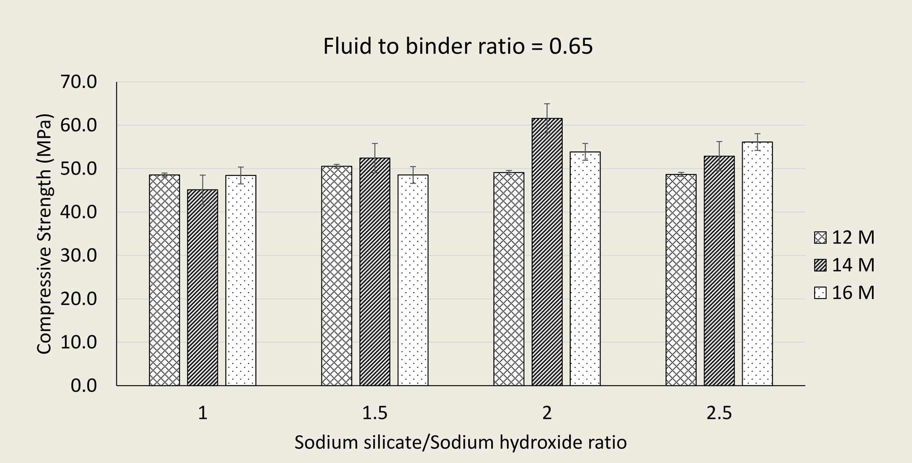

Figure 7. Effect of Na_2SiO_3/NaOH ratio at different molarities at Fluid to binder ratio (F) = 0.65

Effect of molarity (M) of NaOH solution and Na_2SiO_3/NaOH ratios (N):

Fluid to binder ratio (F) = 0.7

- Fluid to binder ratio of 0.70 attained the lowest compressive strength.

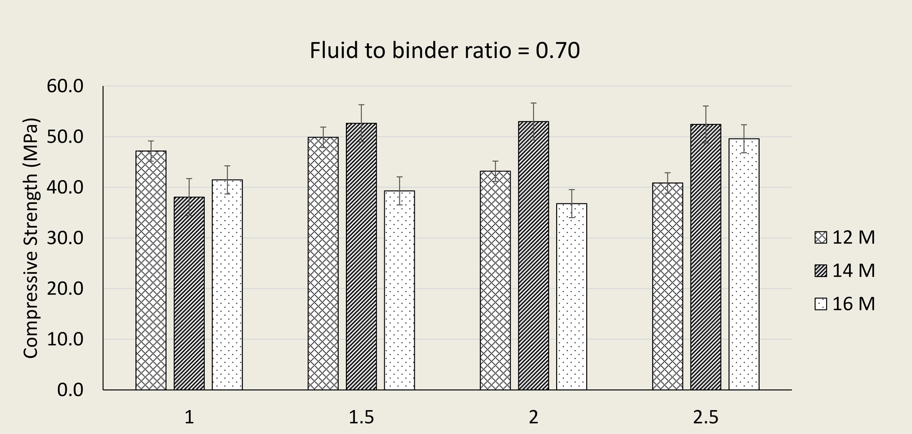

Figure 8. Effect of Na_2SiO_3/NaOH ratio at different molarities at Fluid to binder ratio (F) = 0.7

Effect of Curing conditions (T and D):

- Optimum curing temperature of 80 °C.
- Optimum curing duration is 24 hours.
- Curing temperature at 120 °C adversely affects the compressive strength.

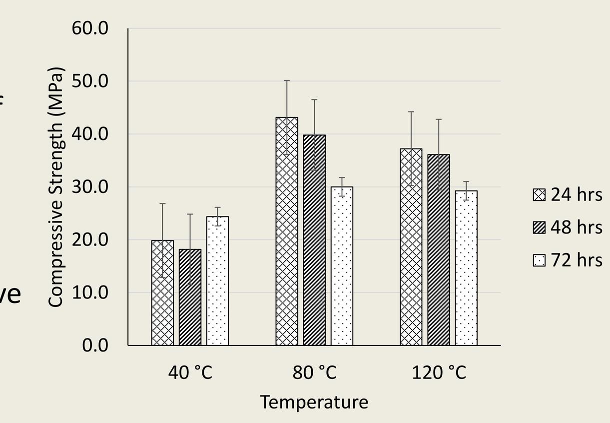

Figure 9. Effect of curing conditions

Effect of Age:

Early strength development depends on the curing temperature.

- At 28 days the strength development were:
- Increase of 30% in the compressive strength for Heat curing.
- Increase of 400% for Ambient cured GPM Specimens

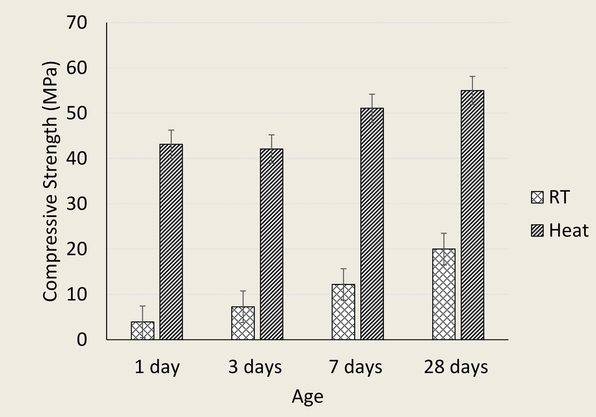

Figure 10. Effect of Age on GPM

Scanning Electron Microscopy (SEM)

The effect of the molarity of the NaOH solution has been clearly observed through the SEM images.

The higher the molarity the better the microstructure of the GPM as the amount of reacted FA particles increased, and the less pores in the matrix observed as shown in Figure 11.

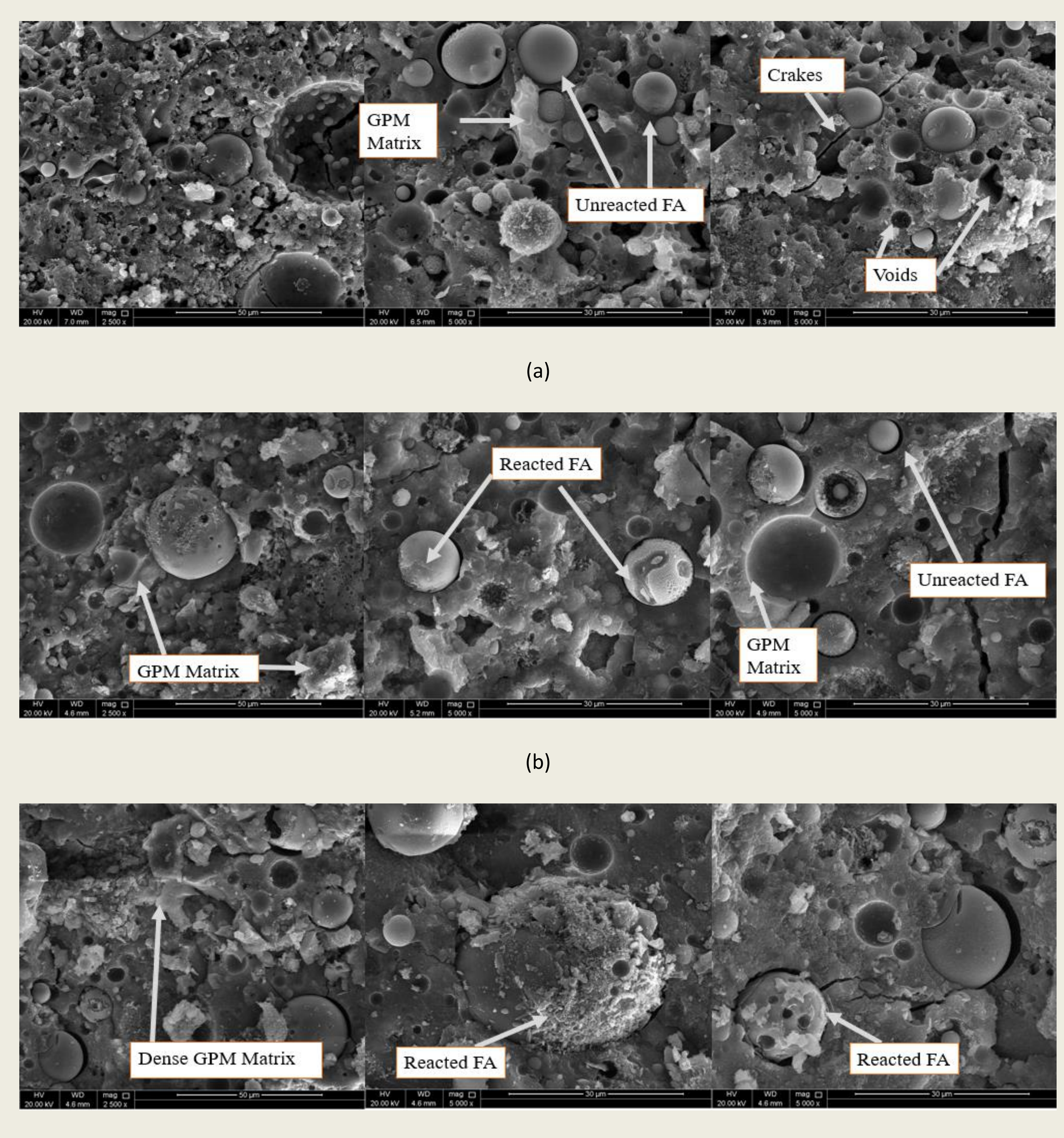

Figure 11. SEM Images of GPM specimens casted with (a) M1F1N1 (b) M2F1N1 (c) M3F1N1

Conclusion

This study proves the efficacy of using Geopolymer mortar to replace the cement mortar in civil engineering applications, and the main findings are summarized below:

- The Molarity of the sodium hydroxide solution affects the compressive strength of GPM.
- The effect of fluid to binder ratio is a major contributor to the mechanical properties of GPM.
- Maximum early compressive strength of 63.9 MPa was achieved by M3F1N1 fluid to binder ratio of 0.60 and Na_2SiO_3/NaOH of 1 and 16 M NaOH solution.
- Heat curing is preferable to achieve early compressive strength for GPM.
- GPM gains strength with age for both heat curing and room temperature curing.
- Fly ash made of Sodium hydroxide only has very low compressive strength compared to this made of both sodium hydroxide and sodium silicate, which is confirmed by SEM results.
- GPM produced by fly ash shows very promising results that will ultimately be used in construction and building materials replacing OPC.

Acknowledgement

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