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Strength Evaluation of Red Mud based Geopolymer Mortar Incorporating Industrial Waste: Comparative Study

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Abstract: This study investigates the strength performance of a geopolymer mortar made from red mud and combined with industrial waste. In the creation of geopolymer mortar, red mud, a result of the aluminium refining process, is mixed with various industrial waste products as a precursor. The investigation's main goal is to evaluate the compressive strength of various formulations and additives in order to get knowledge about how effective they are as strengthening agents. Strength development and material structure are related by microstructural investigation, which uses SEM and XRD methods. The comparative nature of the study reveals the best mixtures of red mud and industrial waste for raising the compressive strength of geopolymer mortar. These results highlight the potential for eco-friendly geopolymer materials to replace traditional cement-based systems.

Keywords: Geopolymer, Red mud, Industrial waste, Compressive strength

I. INTRODUCTION

The pursuit of environmentally responsible and structurally effective solutions has been sparked by the push for sustainable building materials. A possible option is geopolymer technology, which is well known for its potential to lower carbon emissions and conserve natural resources. This work presents a thorough inquiry aimed at assessing the durability of a geopolymer mortar based on red mud and enhanced with a variety of industrial waste materials using a rigorous comparative analysis. Red mud, a byproduct of the aluminium extraction process, poses environmental problems because of its alkaline composition and large quantities produced. Diverse industries simultaneously produce industrial waste products that need effective management techniques. In order to transform red mud and industrial waste into useful construction resources, this research investigates the incorporation of these materials as precursors in the formulation of geopolymer mortar. The study places a strong emphasis on evaluating compressive strength—a fundamental mechanical property—across various compositions of geopolymer mortar made from red mud and adding diverse industrial waste additions. The study aims to determine the possible efficacy of these waste materials in improving mortar strength through rigorous investigation and comparison of compressive strength results. SEM and X-ray diffraction (XRD) are two microstructural analysis methods that are used to decipher complex bonding mechanisms and phase evolution inside the geopolymer matrix. This method makes it easier to comprehend how observed strength development and microstructural changes interact. The goal of this extensive comparison study is to pinpoint the ideal ratios of red mud and industrial waste components that boost the compressive strength of geopolymer mortar. By investigating the potential of waste-incorporated geopolymer materials as environmentally responsible substitutes for traditional cement-based systems, the findings ultimately aim to enhance sustainable construction methods.

Red mud and its properties:

Red mud, commonly referred to as bauxite residue, is a byproduct of the process used to extract alumina from bauxite ore, the main raw material used to make aluminium. Red mud is a fine-grained, reddish-brown substance that is made up of a variety of different chemicals and minerals. The source of the bauxite, the method of extraction, and other elements can affect its qualities. Along with traces of other elements, red mud largely consists of oxides of aluminium, iron, silicon, and titanium. Although the chemical composition can vary greatly, the main ingredients are usually alumina (Al_2O_3), iron oxide (Fe_2O_3), and silica (SiO_2). Red mud particles typically range in size from submicron to a few micrometres and have a fine particle size dispersion. The fine texture and capacity for surface area reactivity are both influenced by the small particle size. Due to the presence of sodium hydroxide (NaOH) and other alkalis employed in the Bayer process for alumina extraction, red mud has a high alkalinity, which is one of its standout characteristics. Safe handling and disposal of the alkalinity may be difficult. Iron molecules, particularly iron oxide (Fe_2O_3), are responsible for red mud's distinctive red hue. Depending on the iron amount and oxidation state, its colouring can change. The naturally occurring radioactive elements uranium and thorium, which are contained in bauxite ore, can occasionally be found in trace amounts in red

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mud. The amounts of radioactivity are normally modest, though, and are thought to be within legal bounds for safe handling and disposal. Red mud's chemical make-up, alkalinity, and surface area all affect how reactive it is. When employed as a filler in various applications or as a precursor in geopolymer systems, it may react with other substances. Red mud is typically a dense, highly compactable material with a granular to clay-like consistency. It can exhibit poor drainage and low permeability due to its fine particle size. While red mud has potential applications in various industries, including construction, ceramics, and environmental remediation, its high alkalinity and potential trace contaminants have posed challenges in finding sustainable and safe uses.

II. LITERATURE REVIEW

Available literatures on geopolymer are summarised and discussed below. Saloma et al (2016) studied on using fly ash as an alternative to cement. Alkaline activator in the form of sodium silicate (Na2SiO3) or potassium silicate (K2SiO3) and sodium hydroxide (NaOH) or potassium hydroxide (KOH) must be added to fly ash as a binder. To determine the value of compressive strength, the effect of activator liquid concentration on geopolymer mortar properties was examined. According to the experimental findings of a new mortar, the molarity of NaOH affects the flow of the slump and the time it takes for it to set. The greater the concentration of NaOH, the smaller the slump value and the quicker the setting time. According to the density experiment's findings, the specific gravity as NaOH molarity. Smitha Singh et al (2017) investigated on to conduct synthesis and performance experiments on both heat-cured and ambient-cured mortar is the goal of this inquiry. Hardened mortar's compressive strength is a crucial component. The tensile strength, modulus of elasticity, and compressive strength of mortar have also been covered. While ambient cured mortar has superior strength at lower molarities, thermally cured mortar's strength increased with molarity. All mortars that had 30% red mud were at their strongest.

The ambiently cured mortar that had 30% red mud and a 6M molarity had the highest strength, which was 11.8 MPa. The pattern of the tensile strength was identical to that of the compressive strength. Thermally cured mortars were found to be less rigid than ambient-cured mortars. Mohamed G. Khalil et al (2020) studied on application of green concrete as a replacement for conventional concrete has gained popularity all over the world. Waste materials are one of the components that can be used to create the inventive green concrete. As a result, research into the characteristics of both fresh and hardened geopolymer has significantly increased in recent years. The ideal activator modulus is attained, producing the highest compressive strength with tolerable workability. Industrial byproducts like Metakaolin (MK) and Ground Granulated Blast Furnace Slag (GGBS) were used to combine nine different mixes. As an activator, sodium hydroxide and sodium silicate were utilized. Utilizing the flow table test and compressive strength test, respectively, the attributes of the fresh and hardened materials were evaluated. Ning Lu et al (2022) investigated on Possibility of producing ambient-cured geopolymers by partially substituting municipal solid waste incinerator fly ash (MSWIFA) for pulverized fly ash (PFA).

The MSWIFA dosage, the ratio of sodium silicate to sodium hydroxide (SS/SH), the liquid to solid (L/S) alkaline activator ratio, and the ratio of SH molar were the examined parameters. The pretreatment procedure for MSWIFA was chosen to be a water immersion approach. Category four masonry mortars were created to replace varying percentages of natural sand with fine recycled glasses based on the ideal paste combination. The qualities of the mortars complied with the limits up to a 30% replacement ratio. A combination of calcium silicate hydrate gel and aluminosilicate gel was found to be the primary reaction product, according to microstructural investigation.

III. MATERIALS AND METHODOLOGY

The red mud used in the present study is collected from the source. For the experiment, particles passing through 75 micron is considered as red mud. Class F Fly ash and GGBS were collected from Jindal steel and power plant, Odisha, India. Fly ash of specific gravity 2.08 was used. Standard Sand Confirming IS 650: 1991 is used for preparation of Geopolymer mortar Specimen. Specific gravity and fineness modulus of fine aggregate were 2.65 and 2.73 respectively. The raw materials are dried under the sun and thoroughly mixed to obtain homogeneity of sample. Alkaline solution used in the study is the combination of Sodium Silicate (Na_2SiO_3) or Potassium Silicate (Na_2SiO_3) and Sodium Hydroxide (NaOH) or Potassium Hydroxide (KOH). For example, Sodium Hydroxide (NaOH) of 1M Molarity is prepared by mixing 240g of caustic soda pellets in one litre of total solution and stirring continuously for two minutes and slowly mixing Sodium Silicate solution into it.

The Alkaline Solution is kept for 24hrs. After which it is suitable for use. Hence the solution is needed to be prepared a day before experiment. It gives best results when used hot. NaOH solution of range 6M-15M was used with the ratio of Na_2SiO_3 / NaOH of range 1-2.5 was used. The specimen of this research was cube shaped of size 70.6 x 70.6 x 70.6 mm.

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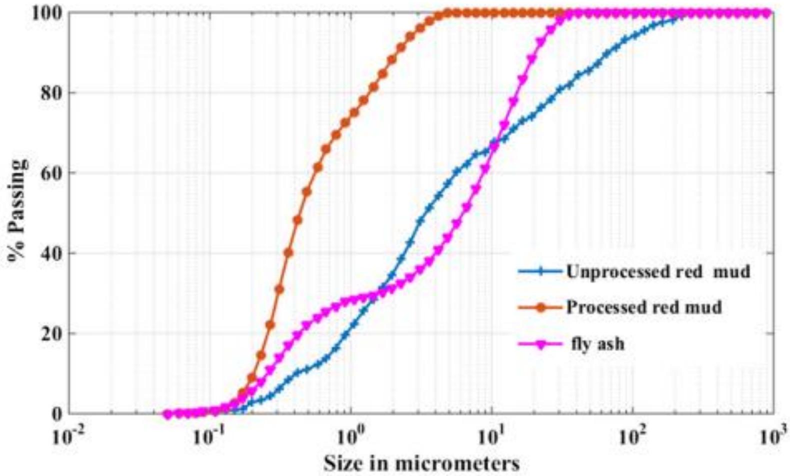

Fig. 1. Particle size distribution of red mud and fly ash [14]

IV. EXPERIMENTAL PROGRAM

Vicat's apparatus was used to determine the typical consistency and setting times of fresh geopolymer paste in accordance with IS: 4031 (Part 4)-1988 (1988) and IS: 4031 (Part 5)-1988 (1988), respectively. According to IS: 4031 (Part 3)-1988 (1988), soundness was obtained. According to IS: 4031 (Part 10)-1988 (1988), the drying shrinkage value of FA and GGBS-based mortar specimens activated with various concentrations of NaOH is determined. The flow of freshly mixed geopolymer mortar is calculated using a flow table in accordance with IS: 5512-1983 (1983). According to IS: 4031 (Part 6)-1988 (1988), the compressive strength of geopolymer mortar samples at ages 3, 7, and 28 days is assessed. In order to prepare the mortar specimen, one part of binder was combined with three parts of Indian standard sand.

The initial and final setting phases of NaOH activated fly ash and slag pastes' reaction products, chemical bonding, and microstructure are examined using X-ray diffraction (XRD), Fourier transform infrared (FTIR), and scanning electron microscopy (SEM) analysis, respectively. These typical samples were homogenized after being finely mashed with a mortar and pestle to a size less than 75 m. Utilizing a Rigaku Japan/Ultima-IV model diffractometer with Cu K radiation at 40 kV and 40 mA across a range of 5° to 70° 2 at a scanning rate of 5°/min with a step size of 0.05°, the mineralogical examination (XRD analysis) is carried out. The peaks were located with the use of X'Pert High Score software. The molecular fingerprint acquired from the FTIR spectrums using PerkinElmer Spectrum version 10.4.00 and a LiTa03 detector for the frequency range served as the basis for the secondary analysis.

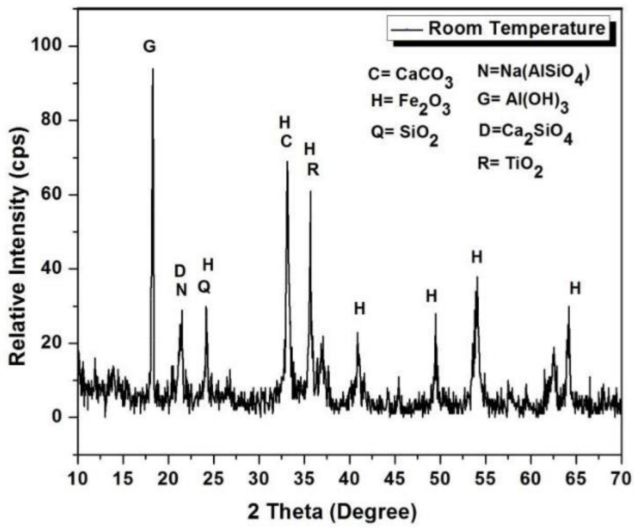

Fig. 2. XRD Pattern of Red Mud [15]

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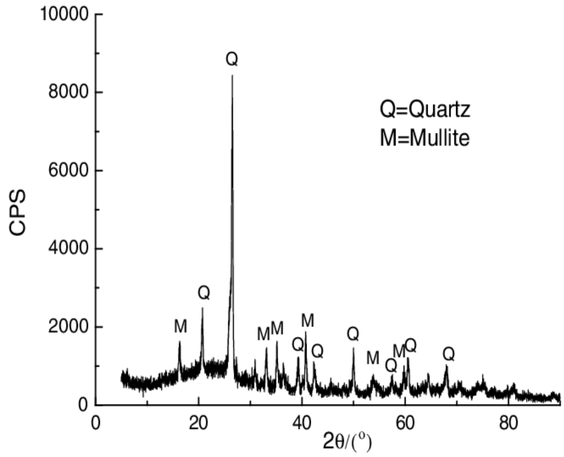

Fig. 3. XRD Pattern of Fly ash [16]

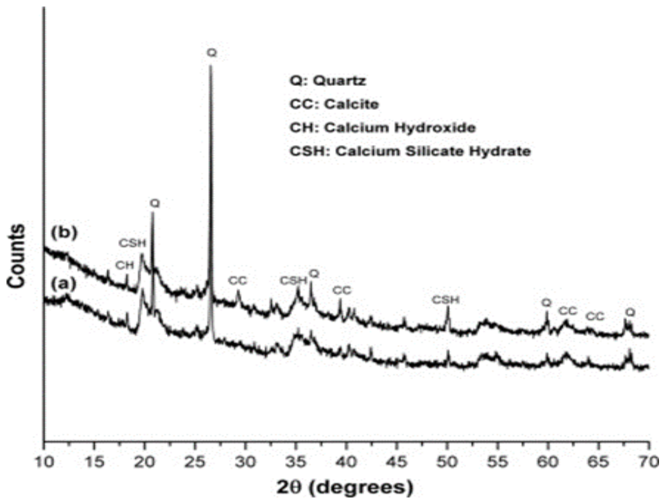

Fig. 4. XRD Pattern of GGBS [17]

XRD patterns of raw materials determines the chemical composition of minerals present in it. Chemical composition of materials is summarised in Table 1.

Table 1: Chemical Composition of (wt.%) raw materials

Components	Na_20	Al_20_3	SiO_2	CaO	TiO_2	Fe_2O_3	MgO	P_2O_5	SO_3	K_2O	N_20
Portland Cement	-	5.6	21.28	64.64	-	3.36	2.06	-	2.14	-	0.05
Red Mud	7.15	16.52	3.03	0.54	2.02	70.75	-	-	-	-	-
flyash	0.01	33.4	47.5	2.09	2.04	10.1	0.1	0.95	-	1.6	-
GGBS	-	18.82	29.58	45.71	1.36	0.97	-	-	1.71	0.91	-

Malvern Instruments' Master Sizer, a laser particle size analyzer with a size range of 0.05 m to 900 m, was used to assess the particle sizes of red mud. Red mud particles have a rustic color, are incredibly fine and cohesive, and 90% of them are less than 75 m. The fineness of the raw red mud was 33650 m2/kg, whereas the pulverized red mud had a fineness of 39400 m2/kg. For heat curing, micro silica and unprocessed red mud were employed, whereas for ambient curing, GGBS was combined with processed fly ash and red mud. To prepare mortar, natural sand has been used as a fine aggregate. Water was replaced with the alkaline activators sodium hydroxide (NaOH) solution and sodium silicate (Na2SiO3). The ratio of Na2SiO3/NaOH/ was kept as 2.5.

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Fly ash, red mud, and micro silica/GGBS, the basic components for the binder, were first combined in a dry state. Following that, fine aggregate was blended in various ratios according to plan. The homogeneous dry constituents were

then given an addition of alkaline solution and well mixed. The mortar was cast into several molds based on the type to determine the workability of the conducted test. The mold used for the compression test was a 70.6 mm cube. The heat drying process was place at 60°C for 24 hours. Molds were covered, held at room temperature, and exposed to unrestricted humidity for ambient curing for a week. With a binder: fine aggregate ratio of 1:3, the molarity used for ambient cured mortar was 6M, 8M, and 10M for 30% and 50% red mud.

The fly ash-red mud binder was pre-pared using an alkaline activator in the first stage of the experiment. First, a control batch was cast using 100% fly ash, and then the fly ash was combined with the red mud. A 10% interval separates the range of red dirt content, which ranges from 10 to 50%. For the creation of Geopolymer Paste Binder, numerous trials and tests were conducted, and their compressive strength was assessed. Standard cubes measuring 7.06 cm 7.06 cm x 7.06 cm were cast, and their compressive strength was tested after 3, 7, 14, and 28 days. The cubes were maintained at a temperature of 35°C until the testing day after being oven-cured at 60°C for 48 hours. In the following findings and discussion, the geopolymer paste made solely of fly ash is referred to as FA- geopolymer, whereas the geopolymer made by replacing 10% of the fly ash with red mud is referred to as FA-RM-geopolymer.

All of the samples were removed from the oven after 24 hours of oven curing, demolded, and then retained for another 24 hours in order to achieve uniform heat curing on all of the cubes' surfaces. The compressive strength test was conducted on a Heico compressive strength testing equipment with a force of 29 kN/s until the sample cube failed after 48 hours of oven curing for all the cubes at a temperature of 35 C. According to Indian standard testing procedures (IS:4031: 1988 (Reaffirmed, 2019); (Part 6) Determination of Compressive Strength of Hydraulic Cement & IS:516 (Part 1): 2018; Determination of Strength of Concrete), three cubes were tested at various ages, and the average was taken as the compressive strength and the strength of the cubes was determined after 3, 7, 14, and 28 days.

V. RESULTS AND DISCUSSION

The 28-day strength of ambient-cured red mud-based geopolymer mortar decreases with increasing molarity. At 6M itself, the amount of silica and alumina leached reaches optimum. Further increasing the molarity hampers the geopolymerization process because there are too many OH- ions present. The heat-cured mortar that uses unprocessed red mud has a different outcome because of the effect of curing methods on the characteristics of red mud-based geopolymer mortar mud. For unprocessed red mud and fly ash, a higher molarity of NaOH solution is required for the ideal amount of silica and alumina to be leached. Additionally, 30% red mud (GRM30) exhibited greater strength than 50% red mud (GRM50) in the binder mix. For GRM30, the highest strength of 11.8 Mpa is attained at 6M.

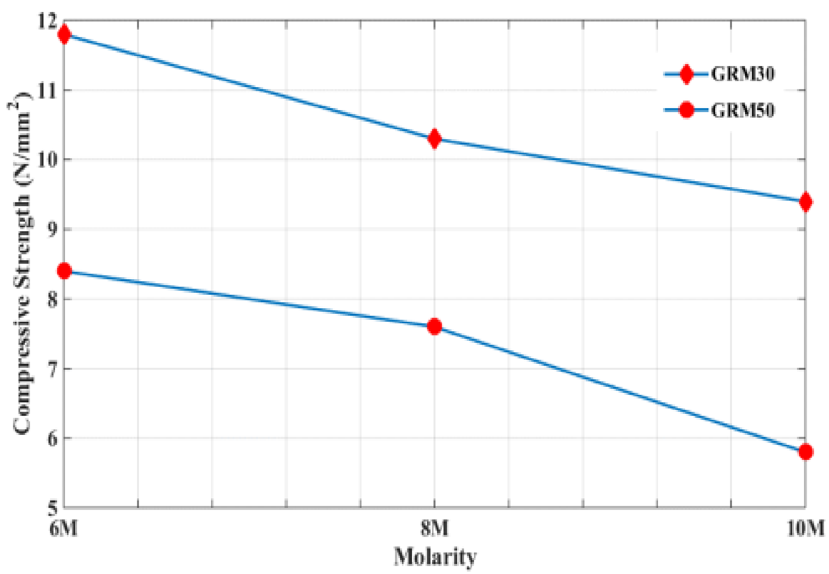

Fig. 5. Variation of compressive strength of ambient cured mortar [13]

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Table 1 displays the chemical composition of the red mud and fly ash samples. According to the literature, FA contains considerable amounts of iron oxide in addition to silica and alumina, whereas RM also contains alumina, the mechanical testing was performed on the geopolymer. The 7.06 x 7.06 x 7.06 cm^3 mortar cubes underwent a 24-hour oven cure at 60 °C before being demolded for 3, 7, and 28 days of ambient curing. Then, these cubes were tested for compressive strength using a HEICO machine with 2.9 kN/s load values that were reported in MPa. Three cubes were tested for each experiment, and the average result has been published. The UCS of the binder material created for combining red mud with fly ash at various weight percentages are noted. As can be observed, adding 10 weight percent of fly ash to red mud produced a binder with a higher UCS. It's probable that the 10% red mud and fly ash addition increased the alkalinity, which in turn sped up the polymerization reaction as well as improved the dissolution of aluminosilicates.

The compressive strength increased as a result. However, as the red mud concentration is increased further, its strength decreases, which may be caused by the red mud's high pH and higher calcium concentration. Both the calcium concentration and pH are higher in red dirt. The construction of a 3D aluminosilicate network is not supported by the presence of excessive calcium. The addition of 20% more fly ash may raise the alkalinity, which may facilitate the creation of anions such $HSiO_4$, which are known to not readily occur in nature. Al-O-Si connections are created when M. Mudgal et al. complex with the aluminate species (Engelhardt et al., 1987). The formation of zeolite may be the cause of the loss in compressive strength that occurs as red mud's weight percentage is increased further. As noted by Sanjay et al. (2015), the compressive strength of the geopolymer reduced as the weight percentage of red mud was increased past 15%. This decrease was attributed to the red mud's assistance in the geopolymer's zeolite's creation. This may also be a contributing factor in the current investigations. The RM-geopolymer and FA-RM-geopolymer (where 10 wt% red mud was combined with the fly ash) were the subjects of additional research.

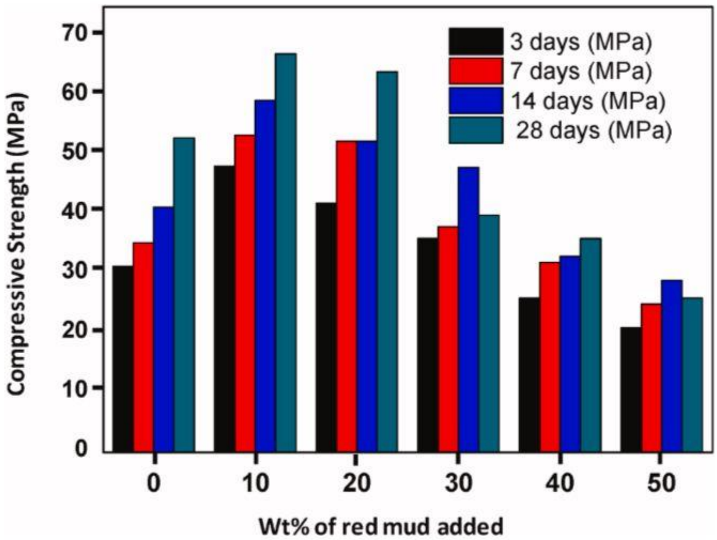

Fig. 6. Compressive strength variation with replacement of known weight percentage of fly ash by red mud [2]

VI. CONCLUSION

Slag-fly ash mixed geopolymers consistency, flow, setting, shrinkage, soundness, and compressive strength parameters are examined. Physical and mechanical qualities are connected with changes in microstructure and chemical composition. The following conclusions are made in light of experimental findings:

- Addition of 30% red mud in the geopolymer mortar enhanced its strength for all binder: aggregate ratio.
- Ambient cured mortar exhibited greater stiffness and better compressive and tensile strength than the thermally cured mortar.
- Red mud and fly ash both have the potential to be utilised in geopolymer applications. The geopolymer's performance improved with the addition of 10 weight percent of fly ash to the red mud. The XRD analyses showed that the addition of the red dirt did not significantly alter phase formation or composition. The SEM images demonstrated that red mud's presence caused the production of tightly packed geopolymer gel, with red mud possibly serving as additional filler. Understanding the chemical fate of various components in FA- geopolymer and RM-FA-geopolymer was a goal.

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