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# Impact on Mechanical and Durable Properties of Rubber and Copper Slag-based Geo-polymer Mortar using Various Sodium Hydroxide Molarities and Proportions of Alkali Activator Solutions

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## Abstract

The efficiency of geo-polymer mortar is analyzed by replacing fine aggregates with different ratios of copper slag and crumb rubber. Properties such as flow value, setting time, strengthening properties, density, and water absorption are studied for different factors, i.e. molarities of sodium hydroxide (8, 10, and 12 M), various ratios of alkali-activator solution (1, 2, and 3), and the effect of pre-treating rubber. The results indicate that the increase in molarity increases the compressive strength, setting time, and flow value of mortar. It is observed that NaOH of 12 M and an alkali activator ratio of 2 show high compressive strength, which is 71.79 N/mm<sup>2</sup>. The rubber treated with alkali improves the bonding between the binder and the rubber, which leads to an increase in the material's strength by 7% for 1 hour and 10% for 24 hours, and density by about 1.5%. It is suggested that the optimum mix with 50% copper slag, 10% rubber with pre-treatment for a period of 1 hour, 12 M NaOH, and alkali activator ratio 2 provide excellent results among all mixes. In conclusion, the findings indicate that the produced mortar contributes to economic and ecological improvement.

## 1. Introduction

The construction industry stretched its limitations to a modern level in the 21<sup>st</sup> century by building skyscrapers, underground tunnels, tailings, deep-aquatic structures, and tall buildings [1]. The use of natural resources such as aggregates leads to natural imbalances all over the world due to the huge demand for materials in civil engineering [2]. To achieve sustainability, lots of waste materials are used as replacements for natural resources. A massive amount of industrial waste is produced daily globally, and disposing of this waste material is a difficult task due to limited storage [3]. The concrete tends to deteriorate due to various factors such as de-icing salt, weathering conditions, and an increase in live loads [4]. Renovation and reintegration should be carried out on deteriorated concrete globally to increase its life span [5]. Generally, cement-based materials are used as repair materials, but recent studies show

that the use of geo-polymer mortar has beneficial factors as it has better properties than conventional concrete [6]. The repairs should be done quickly, improve the structure's performance, make it stronger and stiffer, make the concrete's surface look better, seal it against water, and make it last longer [7].

The combination of cement, water, and aggregate is known as composite. Most recent research work is focused on reducing the use of naturally occurring resources like cement, sand, and gravel, substituting them with waste materials, and improving composite performance [8]. The geo-polymer technology offers a fresh, eco-friendly approach to using waste materials, mitigating its detrimental effects on ecological and environmental issues. The term "geopolymer" was originally coined in the late 1970s by Davidovits, where aluminosilicate materials were stimulated

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with an alkali activator [9]. The synthesized inorganic polymer is formed by the reaction of an alkali-activator with aluminosilicate materials, which allows the effective usage of C&D waste and results in the development of polymeric chains and ring structures containing Si-O-Al-O bonds. The most commonly used waste materials are fly ash, GGBS, and different slags [10]. Si and alkali activator solutions play a significant role in the polymerization of Si and Al oxides. Thus geopolymer is formed by processing strong alkaline substances such as sodium hydroxide (SH) or potassium hydroxide (NaOH or KOH) along with sodium silicate (SS) or potassium silicate in aluminosilicate materials [11]. The use of concentrated NaOH influences both the disintegration process and the bonding of solid materials in the structural system of the aqueous phase of the geo-polymeric system [12]. NaOH has a better reaction capability and compressive strength with fly ash than other activators when used with a sodium silicate solution. It is due to increasing reaction products whose silica content is higher [13]. The use of sodium hydroxide with sodium silicate shows better results when compared to its isolated application. Sodium silicate in liquid form shows better strength than in powder form [14].

Fly ash is generally obtained from coal-fired power plants; the solid residue typically consists of fine particles expelled from the furnace along with flue gases using electrostatic precipitators [15]. The elements in fly ash vary considerably depending on the source of the coal being consumed. Typically, fly ash consists of  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{CaO}$ , and  $\text{Fe}_2\text{O}_3$ , which exist as amorphous and crystalline oxides or as diverse minerals. Fly ash may contain four to ten times more toxic trace elements than coal, which results in hazardous effects on the environment [16]. Increasing efforts have been made in recent decades to use fly ash in an efficient and environmentally friendly manner. The increase in Si/Al ratios caused by the activation of fly ash with the help of activators leads to higher compressive strength than OPC due to its compact structure. Additionally, the calcium in fly ash is favourable for materializing the amorphous C-S-H gel and C-A-S-H gel, which decrease the porosity, and improve the compressive strength of geo-polymers [17].

Sand is one major constituent used in composites as fine aggregate, which is usually obtained from riverbeds and beaches. The requirement for sand has skyrocketed to around 4 billion metric tons at present. The mining of sand leads to various effects

on the environment such as water table reduction, degradation of soil, and effects on flora and fauna. To overcome the need for sand alternatives such as copper slag and manufactured sand, various ashes are used. Previous studies show that the use of copper slag as a replacement for sand helps improve compressive strength [18- 21]. This study also shows that the replacement of copper slag with up to 50% sand shows better mechanical and durability properties in both conventional and geopolymer concrete. Due to rapid urbanization, a lot of automobiles lead to the accumulation of huge tire waste. Due to its non-biodegradable nature, it becomes a problem to dispose of tire waste effectively. To overcome this, crumb rubber can be used as an alternative to sand, which helps enhance the thermal and sound properties of composites. Previous studies suggest that the use of rubber helps achieve the flexural properties of composites by about 15–30% but causes a considerable decline in compressive strength by 0–50% [22, 23].

Recently, a lot of studies have been conducted on geo-polymer materials. The utilization of NaOH of molarities 8, 12, and 16 M in addition to an alkali-activator solution (SS/SH) ratio of 1, 2.5, and 4 on fly ash-based concrete suggests that the use of NaOH of 12 M and an SS/SH ratio of 2.5 shows influential characteristics of both the physical and strengthening properties of geopolymer mortar [24]. Moreover, an increase in molarity as well as an increase in curing temperature also enhance strength [25]. However, the use of 12 M NaOH shows better compressive strength when compared with 18 M NaOH [9]. The mechanical strength of slag-based mortars that are alkali-activated is influenced by the concentration of the activator, and the optimal proportion of  $\text{Na}_2\text{O}$  for these mortars ranges from 3 to 5.55% of the total mass of the slag. According to the findings of those authors, raising the quantity of alkaline activator used in conjunction with silica modulus from 1 to 1.5 results in greater mechanical strengths. In addition to this, they found that utilizing powdered water glass resulted in a performance that was inferior to that of the liquid version [26]. Further investigation of the activation of metakaolin by the use of NaOH and sodium silicate after seeing that the decrement of the molar ratio of sodium oxide to silica oxide increases the material's mechanical strength [27]. Increasing the quantity of  $\text{Na}_2\text{SiO}_3$  causes an increase in the cohesiveness and quick hardening of the mixes by decreasing the flowability and setting time of the mixtures. It affects the workability of mortar. On the other hand, it does not have a substantial impact on either compressive

or flexural strength. It would be beneficial to use a lesser quantity of  $\text{Na}_2\text{SiO}_3$  to achieve acceptable workability and workable time. Additionally, the drying shrinkage effect in the mortar is amplified by an increase in the quantity of  $\text{Na}_2\text{SiO}_3$  to a significant degree [28]. Based on low-calcium fly ash geo-polymer concrete with a 10 M NaOH concentration and copper slag as a limited alternative to natural river sand, it has a compressive strength of  $71.2 \text{ N/mm}^2$  and a split tensile strength of  $4.95 \text{ N/mm}^2$  while cured at ambient temperature. Because copper slag contains a greater proportion of silica than sand does, it can be used in place of sand to boost the strength of concrete. This may be because copper slag contains more silica than sand does. The use of copper slag in geo-polymer concrete could potentially increase the positive effects on the environment by lowering the demand for sand mining [29]. In mortars, natural sand of size 0–4 mm was partially substituted with shredded unusable tires of size 0–4 mm for percentages of 10, 20, and 30%, respectively, by volume. For a 28-day curing period, the compressive strength decreased by 57% and the tensile strength decreased by 79% depending on whether 20 or 30% of rubber sand was added. Meanwhile, the drop in tensile strength was 40 for 20% and 70 for the 30% addition of rubber. There was a drop of 38 and 59% in the elastic modulus. On the other hand, there was a reduction of 47.25 and 77.59% in the tensile elastic modulus [30].

The purpose of this study is to determine the optimum mix for replacing the fine aggregate with copper slag and rubber aggregates by using various proportions of alkali activator solutions, which earlier research couldn't provide. The earlier research used 100% replacement of copper slag, which has a negative impact such as corrosion on mortar [60]. The fabrication of geo-polymers including Class F fly ash, copper slag, and crumb rubber, as well as the key components of the synthesis technique that influence their mechanical characteristics, in particular the influence of NaOH concentrations and the  $\text{Na}_2\text{SiO}_3/\text{NaOH}$  ratio in the aqueous form of the geo-polymeric structure on the fresh properties and compressive strength of the geo-polymers, are studied. According to the results of the current study, a mix of the most important factors in the geo-polymerization of fly ash, which is being studied, could produce a material with a compressive strength of more than 40 MPa.

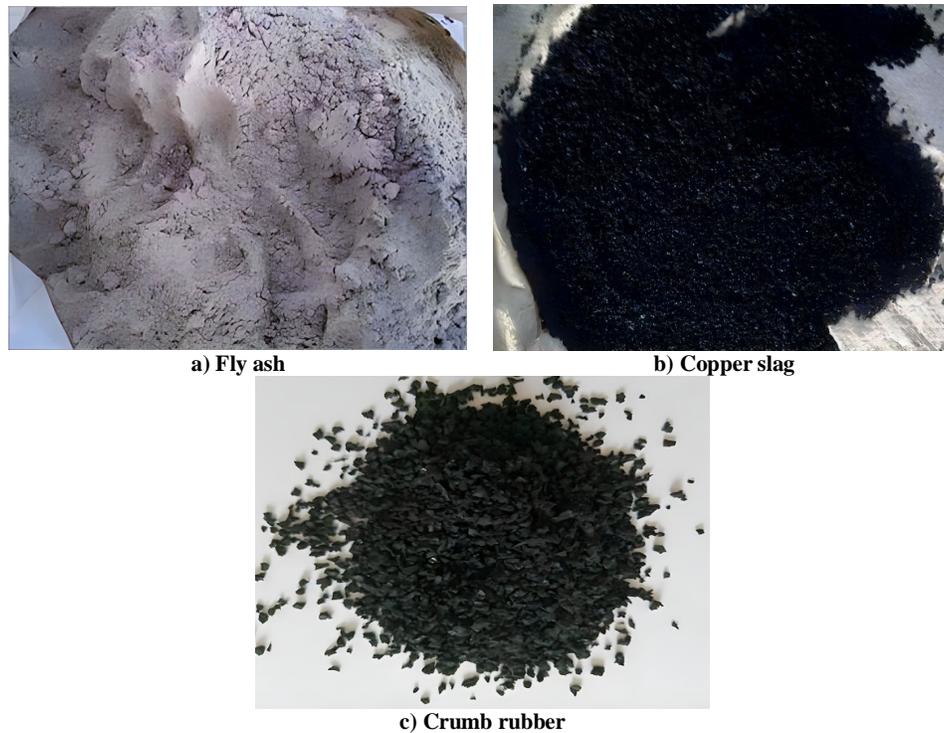
## 2. Materials and Mixes

The class F fly ash obtained from the Rayalaseema Thermal Power Plant, India, is used as the main component material. The fineness and specific gravity of the fly ash used are  $325 \text{ m}^2/\text{kg}$  and 2.20, respectively. The chemical characteristics of the material were defined by using X-ray fluorescence, which is presented in Table 1, and the classification of fly ash was defined according to IS 3812. The fly ash was then blended with an alkali activator solution, which is a mixture of both NaOH and  $\text{Na}_2\text{SiO}_3$ , resulting in the formation of the binder material. The alkali-activated solution is prepared by first dissolving 320, 400, and 480 grams of NaOH pellets in 1000 ml of distilled water to produce NaOH with molarities of 8, 10, and 12 M, respectively, which are kept at ambient temperature for 24 hours to cool off. The alkali-activator solution is made by mixing the solution of NaOH that is left over with a solution of  $\text{Na}_2\text{SiO}_3$  in a ratio of 1, 2, and 3.

**Table 1. Chemical composition of class F-Fly ash and copper slag.**

Component	% Fly ash	% Copper slag
$\text{SiO}_2$	49.52	35.00
$\text{Al}_2\text{O}_3$	29.83	3.01
$\text{Fe}_2\text{O}_3$	10.76	55.00
CaO	3.58	0.20
MgO	1.6	0.90
$\text{Na}_2\text{O}$	0.32	0.95
$\text{TiO}_2$	1.89	0.60
$\text{P}_2\text{O}_5$	0.48	-
$\text{Mn}_2\text{O}_3$	0.2	-
$\text{SO}_3$	0.35	-
$\text{K}_2\text{O}$	-	1.02
Cu	-	0.42
LOI	1.5	-

Copper slag obtained from Kalyan Industries, located in Bhavnagar, India, was used as a partial replacement for sand. The chemical composition of copper slag is provided by the manufacturer, which shows a high amount of iron, silica, and calcium. The crumb rubber utilized in this research work was obtained from the local rubber recycling plant in Jalandhar, India, which was generated by crushing discarded tire rubber. To obtain the desired rubber size, the crumb rubber is then passed through a sieve of 4.75 mm.



**Figure 1. Materials for making rubberised copper slag based geo-polymer mortar.**

### 3. Pre-treatment of crumb rubber with NaOH

Crumb rubber was treated with a NaOH solution of molarity 10 M for a period of 1 and 24 hrs, respectively, as suggested by previous studies [31]. Firstly, the rubber is washed thoroughly under pressure to remove the dirt and any foreign material, which leads to better bondage with the rubber. Secondly, the rubber is immersed in a NaOH solution with a pH value of 13 for the treatment period. Finally, the rubber is removed from the alkaline solution and washed with normal water to reduce the pH level to a neutral level and reduce the adverse effect of the excess alkaline solution on the properties of the mortar. The pre-treatment leads to the removal of dirt and contamination from the exterior surface of the rubber, which leads to the opening of surface pores. The fresh binder paste can fill these pores, which results in better bondage and improved friction with the rubber material. The rubber's exposure to a concentric NaOH solution for a longer duration leads to the removal of the surface, which acts as a barrier between rubber and binder, improving the bonding of the aggregates and binder.

### 4. Mix design

In the present study, the copper slag and crumb rubber were partially replaced with natural sand for

a different treatment period of the crumb rubber to improve the performance of the mortar mix. Copper slag along with crumbed rubber was partially replaced with 0, 10, 20, 30, 40, and 50% and 5, 10, and 15%, respectively. Various studies suggest that the use of rubber beyond 15% replacement leads to stiff and unworkable mortar, which can't achieve amicable strength according to structural application. The pre-treatment of rubber for periods of 1 and 24 hours was chosen because there is no significant difference in performance in mortar observed when treated under a 1 hour period, and extending the period over 24 hours leads to a negative effect on the bond as it increases the porosity of rubber aggregates. Therefore, here we consider three categories of crumb rubber: untreated, treated for a period of 1 hour, and 24 hours. A total of various mixes were prepared with various molarities of NaOH. Various SS/SH ratios were determined to achieve the desired flowability and setting time. Table 2 shows the mix proportions of geo-polymer mortar per m<sup>3</sup>.

**Table 2: Mix proportions of geo-polymer mortar per m<sup>3</sup>.**

Materials	Quantity (kg/m <sup>3</sup> )
Fly ash	735
Sand	1165
Alkaline activator solution	300

Firstly, in the mechanical mixer, fly ash is mixed with fine aggregates of sand, copper slag, and rubber in the dry state for 2 minutes, and then alkali activator solution is added to the mixer along with excess water needed for the mix and thoroughly mixed for 5 minutes. After obtaining a homogenous mix, the mortar is transferred to moulds and properly compacted. The specimens

are demoulded after one day and placed for curing under ambient conditions for a desired period. Previous research shows that heat curing results in high performance in geo-polymer specimens but ambient curing is preferred because of less shrinkage, energy efficiency, and fewer surface cracks.



**Figure 2.** Rubberised copper slag based geo-polymer mortar.

## 5. Tests

### 5.1. Flow value test

According to ASTM C1437 [32], a flow table test was conducted to determine how easy the fresh mortar was to work with. A freshly prepared mortar is poured into a cone-shaped mould that is set on the flow table. Then the mould is lifted to allow the flow of mortar to continue its own. The flow table is raised to a height of 13 mm and then dropped 25 times in a span of 15 seconds. The spread mortar diameter (d) is the mean of two fully spread mortar diameters at right angles to one another. The flow value is just the diameter (d) minus the base diameter of the cone.

### 5.2. Initial and final setting time

By ASTM C191 [33], the configuration was modified so that it could be used to measure the setting time using a Vicat needle. The diameter of the needle that was utilized was  $1.00 \pm 0.05$  mm.

### 5.3. Density

According to ASTM C642 [34], density is measured for a curing period of 28 days by oven drying the sample for a period of 1 day at a temperature of  $110 \pm 5$  °C and measuring the weight after cooling down.

### 5.4. Water absorption

To determine the mortar sample's durability, both the initial and final water absorption are assessed. After a curing period of 28 days, the water absorption is measured following ASTM C642 [34] by submerging the specimen in water for 0.5 and 48 hours, respectively.

### 5.6. Mechanical Properties

The compressive strength of geo-polymer mortars (GPMs) was determined using cube-shaped molds with a size of 50 mm and measured using the Compressive testing machine (CTM) according to ASTM C109/109M [35]. The compressive testing machine (CTM) used for this research has the capacity of 3000 KN and compression speed of 10 KN/sec. The control mortar strengths were used to evaluate and analyze the strengths of the GPM sample. The compressive strength of the sample was tested for 7, 28, and 90 days. The findings are presented after calculating three separate averages for the samples.

### 5.7. Results and Discussion

The compressive strength, density, flow value, setting time, and absorption capacity of the mortar sample are evaluated in this study. Below are the results of rubberized slag-based geo-polymer mortar with different amounts of NaOH, SS/SH ratios, and curing periods.

### 5.8. Setting time

The setting time test was performed at ambient temperature. Figures 1 and 2 show how the amount of sodium hydroxide affects the time it takes for slag-based geo-polymer mortar to set. From these figures, it is observed that the initial and final setting times for slag-based geo-polymer mortar increase as the molarity of the NaOH solution rises. For example, if the molarity of NaOH goes from 8 M to 12 M, the initial setting time goes from 165 to 285 minutes, and the final setting time goes from

226 to 442 minutes. This could be because when the molarity of the NaOH solution is low, there are more calcium ions available to react with water to form the CS-H and C-A-H gels, while when the molarity is high, there are more Na<sup>+</sup> and OH<sup>-</sup> ions, which makes it easier for the aluminosilicate precursors to dissolve and makes it harder for the calcium ions to leach out [36]. On the other hand, reactions with higher molarity are linked to geopolymerization processes, which are slower than the hydration reactions of calcium ions. Higher molarities increase setting time, and this trend fits with what has been found in the past [37, 38].

Figures 1 and 2 show how the alkaline solution ratio (SS/SH) influences the initial and final setting times of slag-based geo-polymer mortar. From this graph, we can see that the initial and final setting times for slag-based geo-polymer mortar mixes decrease as the number of alkaline solutions increases. For example, increasing the ratio from 1 to 2 decreases the initial setting time from 165 minutes to 123 minutes, and increasing this ratio

from 2 to 3 decreases the initial setting time from 123 minutes to 59 minutes. However, increasing this ratio from 1 to 2 decreases the final setting time from 226 minutes to 135 minutes, and increasing the ratio from 2 to 3 decreases the final setting time from 135 minutes to 118. This shows that the geo-polymer binder with an SS/SH ratio of 3 creates polymerization bonds at the fastest rate. When there are fewer SS/SH ratios in a mixture, the polymerization process takes longer because it needs more time to bind. When sodium silicate is added, Si is produced, which is then used as a monomer for the Si-O monomer chain in geopolymer. Sodium silicate plays an important role in the polymerization process, and it can speed up the polymerization reaction [39]. Also the time it takes to bind can be reduced by increasing the ratio of sodium silicate to sodium hydroxide [40]. When there is more copper slag, it takes longer for the mortar to set. For example, the initial setting time for 0–50% copper slag is 165–210 minutes, and the final setting time is 226–311 minutes.

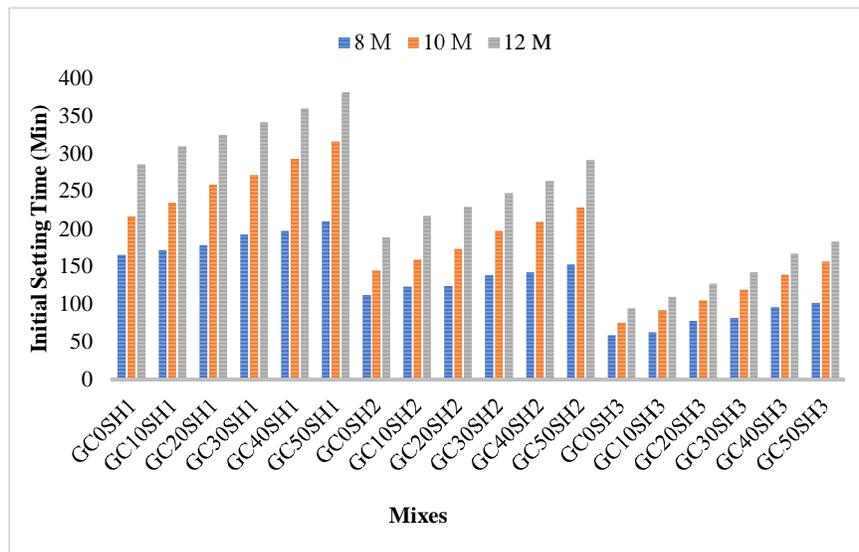


Figure 3. Initial setting time.

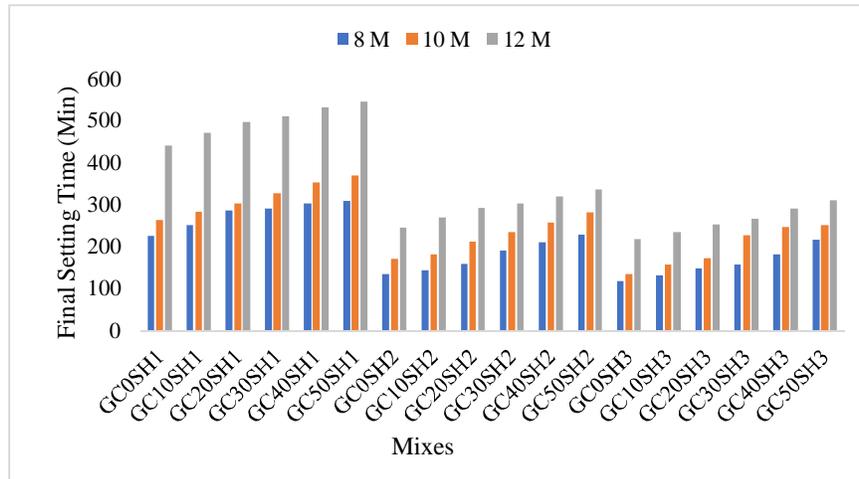


Figure 4. Final setting time.

## 6. Flow value

The effect of sodium hydroxide molarity on slag-based geo-polymer mortar flow value shows an increment with an increase in molarity. As a case in point, with the increment in flow value from 130 to 132 for 8 M to 10 M and 132 to 142 for 10 M to 12 M, because of the gradual rise in NaOH molarity concentration, the viscosity of the solution gradually improved, which led to the leaching of alumina and silica from the fly ash. After that, the procedure of dissolving the aluminosilicates of the slag-based geo-polymer mortar and the alkali activator solution turns out to be more viscous because of the increasing amount of NaOH concentration. It has been demonstrated that a greater flow can be expected if a larger concentration of alkali solution is used. The combination of the lubricating effect of the alkaline activator solution and a lower molarity concentration of NaOH results in a lower flow value. This is because the alkaline activator solution is less concentrated. Because of the high molarity of the concentrated alkaline solution, the cohesiveness of the pore liquid is reduced, which in turn limits the flow. As a result, the flow value of the paste is increased.

The effect of the ratio of sodium silicate to sodium hydroxide ( $\text{Na}_2\text{SiO}_3$ ) on the flow value of fresh geo-polymer mortar is shown in Figure 5. It has been observed that an increase in the ratio of SS to SH results in a reduction in the flow value of mortar. For example, the flow value for SS/SH ratios 1 to 3 demonstrates a decrease from 135 to 95 and from 95 to 81, respectively. The change in the ratio between the various alkaline solutions

influenced the consistency of the geo-polymer mortar. The higher the ratio between SS and SH, the greater the viscosity of the geo-polymer mortar, which in turn restricts its flow [41]. The fresh mortar's flow was negatively affected because of the partial replacement of fine aggregate with copper slag crumb rubber, as can be seen in Figure 5. For instance, the flow rate was reduced by 15, 24, and 42%, respectively, when compared to that of the control mix. The greater flow resistance seen in rubberized mixes compared to mixes without rubber may be caused by the surface abrasiveness of crumb rubber. The presence of contaminants on the surface of the crumb rubber aggregate is another factor that could be causing the decreased workability. Previous studies have shown that employing fine aggregate containing 5–30% crumb rubber can minimize the flow of fresh mortar by anywhere between 30–80% [42, 43]. These outcomes lend authority to those conclusions. The flow was also further decreased as a result of surface-treating the crumb rubber with a NaOH solution, and the reduction in flow intensity increased as the pre-treatment time was prolonged. For instance, pre-treating crumb rubber for 1 hour and 24 hours reduced the flow at a replacement ratio of 15% by 10–20% and 20–30%, respectively, in comparison to the untreated mix, as shown in Figure 6. In comparison to the flow of the untreated mix, this was assessed. It's conceivable that this is the result of rubber particles being exposed to a NaOH solution, which prompts chemical reactions at the surface of the particles and, in turn, makes the particles scraggly. Due to the enhanced adhesion between the rubber and the paste, the fresh mortar now has a higher flow resistance.

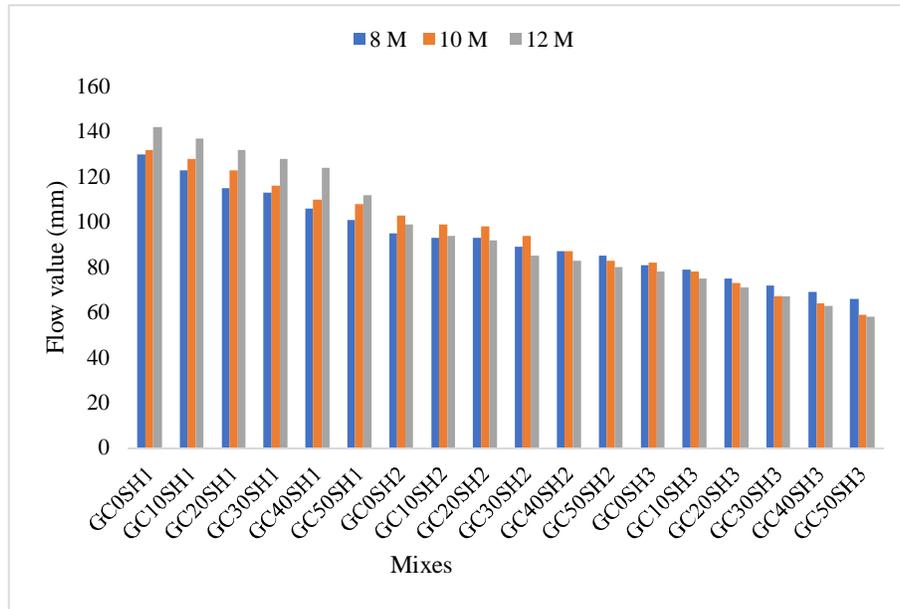


Figure 5. Flow value of copper slag-based geo-polymer mortar.

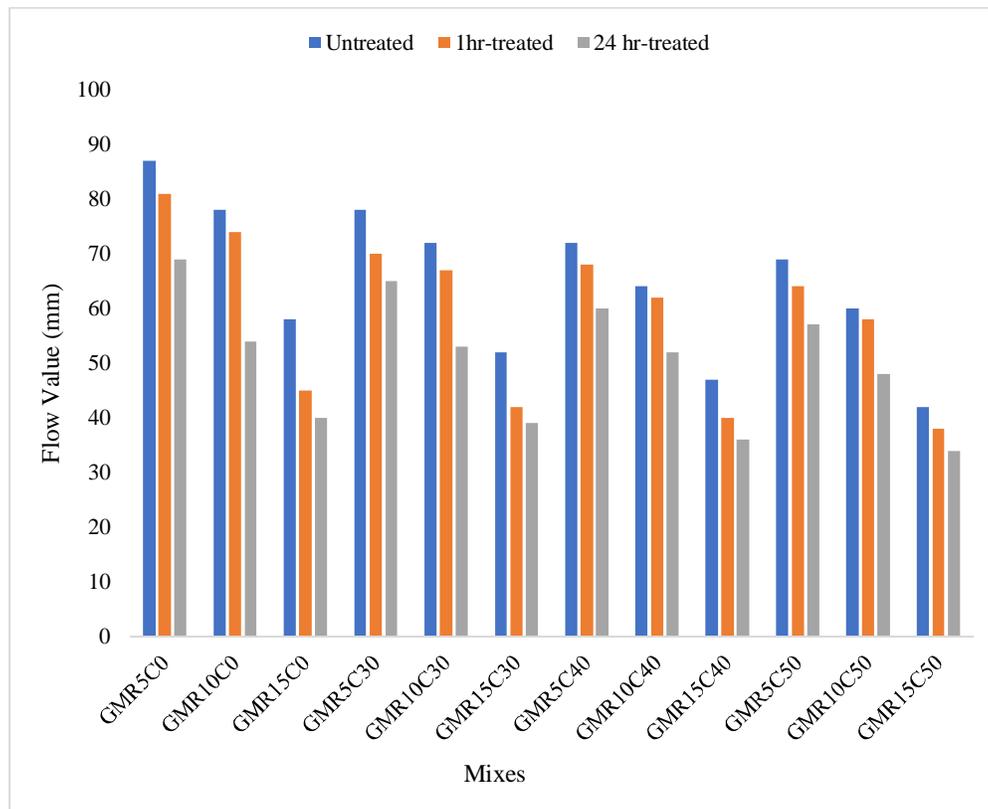


Figure 6. Flow value of rubberized slag-based geo-polymer mortar.

**7. Density**

The density of the mortar samples is considered after a curing period of 28 days, where the density of the samples lies between 2400 and 2750 kg/m<sup>3</sup>. The density of slag-based geo-polymer mortar is

around 2800 kg/m<sup>3</sup>. It is due to the heavy weight of copper slag content compared to fine aggregate. The incorporation of crumb rubber leads to a decrease in density of 5, 12, and 15% when compared to slag-based mortar. Even though the density is decreasing, the decrement brings the

density down to the level of the normal weight of mortar from the heavyweight that was suggested by ACI Committee 213 [44]. The pre-treatment of crumb rubber did not significantly affect density, and only a slight increase in density was obtained compared to the non-treated crumb rubber specimens. In contrast to the density of the equivalent mixes with untreated crumb rubber, an hour-long alkali treatment of crumb rubber increased the density of the mixtures by 1.6, 3.2,

and 1.5%, respectively, for blends containing 5, 10, and 15% of the material, as shown in Figure 7. Similarly, pre-treating the material for 24 hours increased its density by up to 2.6, 4.5, and 1.6%, respectively, of the crumb rubber replacement ratio. Both the alkali-silica reaction of the silica in rubber and the reaction between NaOH and the isoprene present in rubber, which can result in a low degree of densification in the ITZ, may be to blame for the slight increase in density [45, 46].

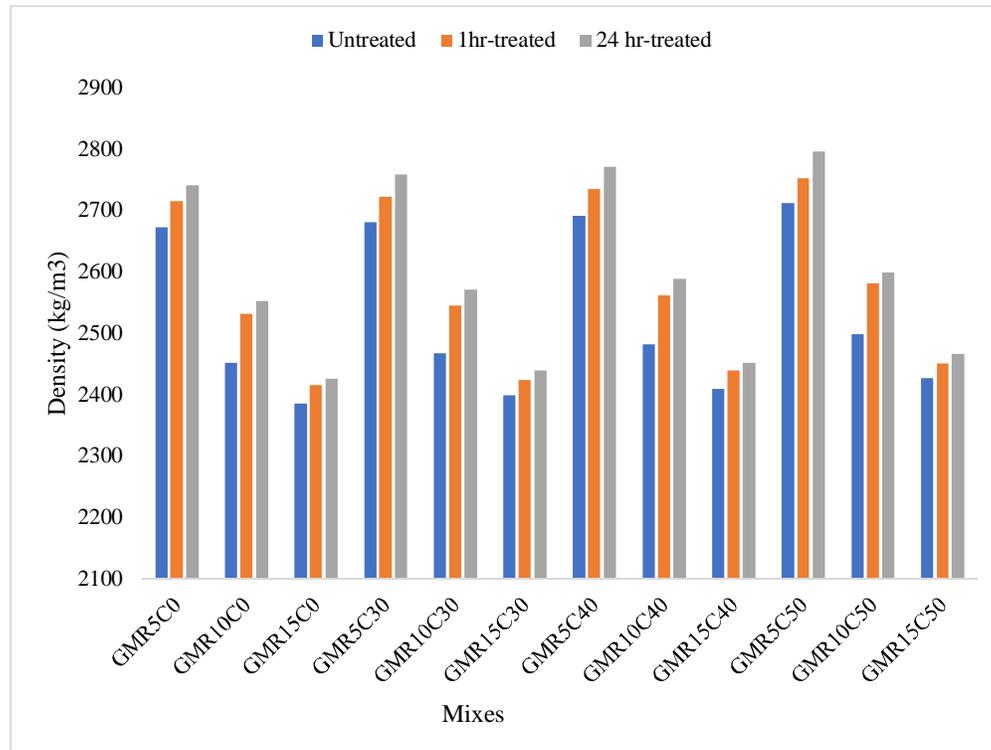


Figure 7. Density of rubberized slag-based geo-polymer mortar.

## 8. Water absorption

The water absorption of mixtures at both their initial and final levels was assessed to analyze the effects of the crumb rubber replacement ratio and alkali treatment period on the parameters related to durability. Figure 8 shows that as the percentage of crumb rubber increased, there was a clear downward trend in the amount of water that the material absorbed. For instance, the initial and final water absorption of mixes that contained 5, 10, and 15% crumb rubber rose by 24, 36, and 47% and by 9, 12, and 16%, respectively, over that of the slag-based mortar, where the initial and final water absorption are 2.39 and 3.53, respectively. The

higher water absorption capacity of crumb rubber in comparison to CS and the increased porosity of rubberized mixes because of the non-polar nature of crumb rubber may be the causes of the increased water absorption. [47, 48]. Additionally, due to the crumb rubber's low density, there is a higher chance that it will migrate to the specimen's top surface during compacting. This kind of migration might cause the crumb rubber aggregate to clump together, which would increase the porosity and the number of micro-cracks in the mix. In addition, the weak adhesion that exists between the binder and the rubber has contributed to the rise in the amount of water that is absorbed by expanding the channels that are permeable to water [49].

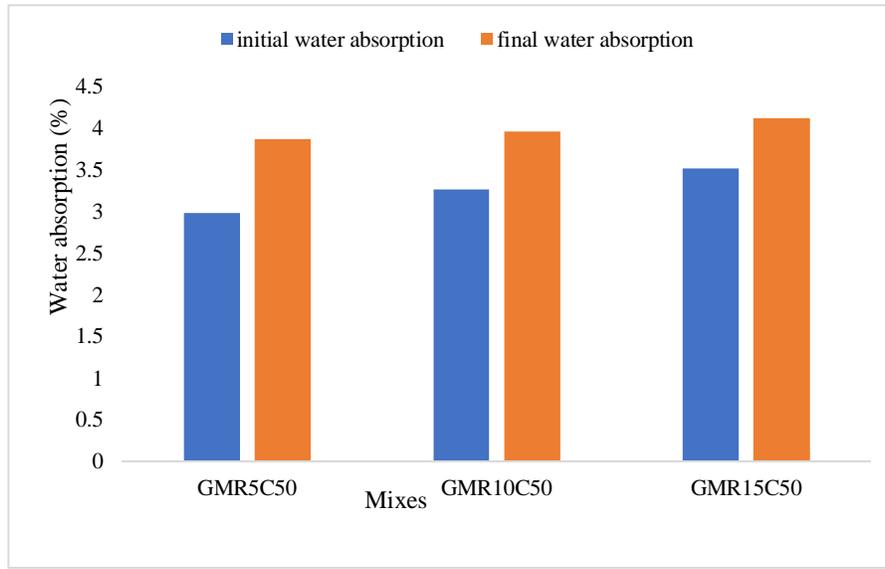


Figure 8. Water absorption capacity of rubberized slag-based geo-polymer mortar.

### 9. Compressive strength

It is utilized as an indicator of the other mechanical properties because of the high degree of correlation that exists between the compressive strength and the other properties. The results of the compressive strength of various geo-polymer mixes are given in Table 3.

### 10. Effect of copper slag

Fly ash geo-polymeric formulations where fine aggregate is replaced with copper slag in 10, 20, 30, 40, and 50% were designed to create mortar samples with the appropriate compressive strength for our investigation. The following sections contain a discussion of the findings that were received from the many kinds of testing that were carried out.

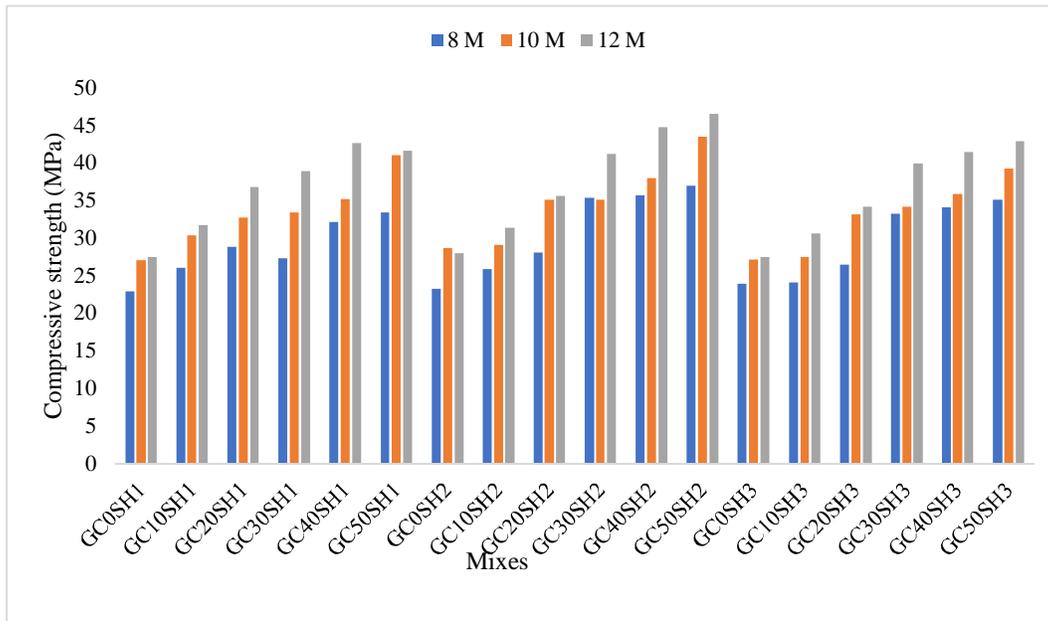


Figure 9. Compressive strength of slag based geo-polymer mortar for 7 days.

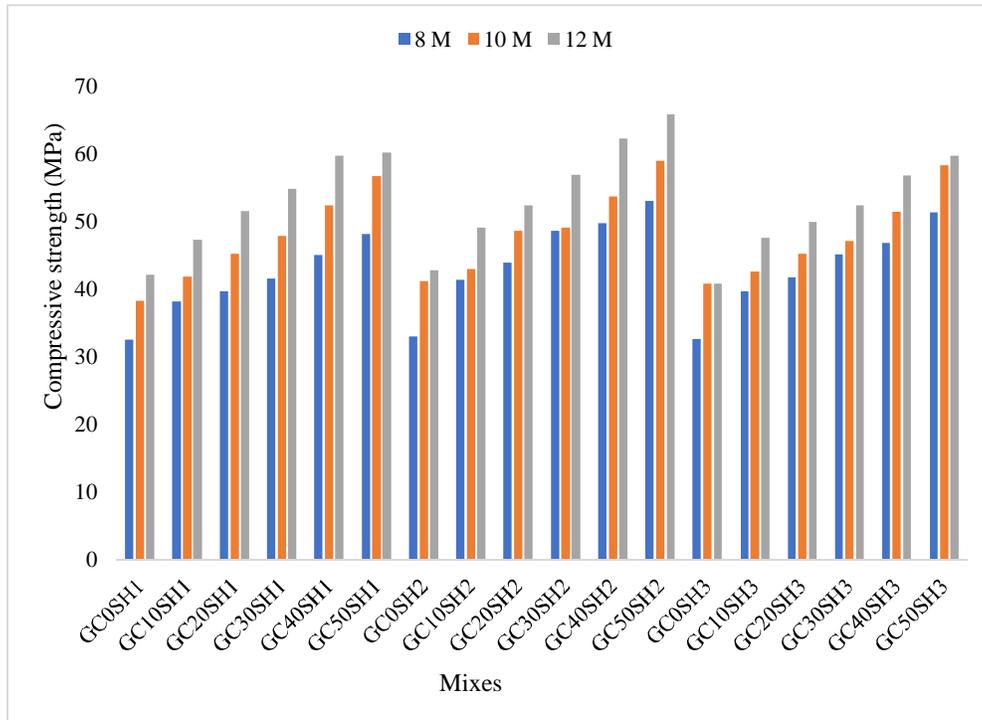


Figure 10. Compressive strength of Slag based geo-polymer mortar for 28 days.

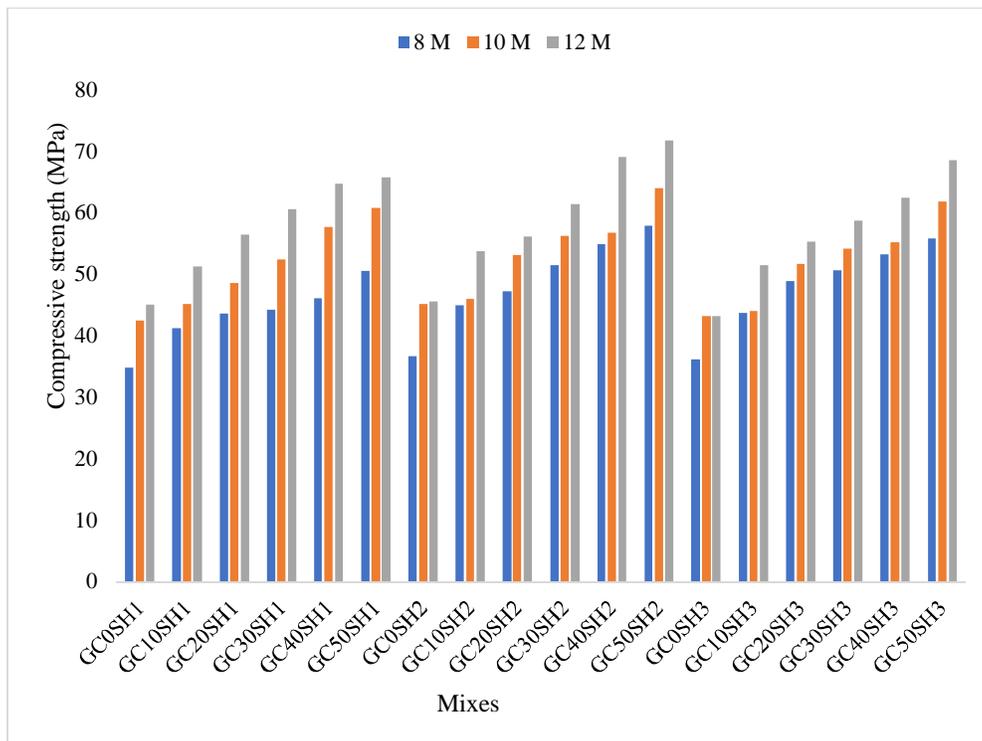


Figure 11. Compressive strength of slag-based geo-polymer mortar for 90 days.

**Table 3. Compressive strength (MPa) of slag-based geo-polymer mortar.**

Mixes	NaOH 8 M			NaOH 10 M			NaOH 12 M		
	7 days	28 days	90 days	7 days	28 days	90 days	7 days	28 days	90 days
GC0SH1	22.98	32.60	34.83	27.07	38.40	42.43	27.47	42.20	45.09
GC10SH1	26.05	38.20	41.30	30.34	41.90	45.15	31.66	47.40	51.24
GC20SH1	28.82	39.80	43.54	32.75	45.30	48.50	36.74	51.60	56.46
GC30SH1	27.33	41.60	44.23	33.43	47.90	52.41	38.92	54.90	60.60
GC40SH1	32.20	45.10	46.11	35.16	52.40	57.65	42.64	59.80	64.72
GC50SH1	33.45	48.20	50.58	40.95	56.80	60.81	41.66	60.20	65.72
GC0SH2	23.29	33.10	36.66	28.70	41.30	45.19	28.07	42.92	45.56
GC10SH2	25.85	41.50	44.91	29.05	43.10	46.05	31.34	49.20	53.83
GC20SH2	28.14	43.90	47.15	35.11	48.70	53.11	35.58	52.40	56.10
GC30SH2	35.31	48.70	51.43	35.13	49.20	56.20	41.14	56.90	61.38
GC40SH2	35.66	49.80	54.91	37.98	53.80	56.75	44.73	62.30	69.07
GC50SH2	36.90	53.10	57.84	43.44	59.10	63.96	46.53	65.90	71.79
GC0SH3	23.92	32.70	36.20	27.14	40.87	43.21	27.51	40.89	43.21
GC10SH3	24.10	39.70	43.71	27.48	42.58	44.12	30.58	47.65	51.47
GC20SH3	26.42	41.80	48.89	33.12	45.28	51.70	34.12	49.97	55.26
GC30SH3	33.21	45.17	50.70	34.17	47.20	54.20	39.87	52.47	58.72
GC40SH3	34.10	46.82	53.21	35.85	51.47	55.12	41.50	56.82	62.47
GC50SH3	35.12	51.40	55.80	39.25	58.40	61.74	42.87	59.74	68.59

When compared to cement mortar, the early strength of geo-polymer mortar is nearly 1.5 times higher [50]. Such initial strength development can prove to be very advantageous in the construction industry, primarily because of the physical and chemical characteristics of the binder that is formed in those mixes. Early formwork removal and quicker work advancement are two of the main advantages that can come from such a development in initial strength from a cost-effectiveness perspective. Table 3 shows the compressive strength of copper slag-based GPM for NaOH molarities of 8, 10, and 12 M and SS/SH ratios of 1, 2, and 3 for curing periods of 7, 28, and 90 days. The addition of copper slag increases the compressive strength of geo-polymer mortar by 12, 21, 25, 29, and 40% when compared with conventional mortar due to an increase in free water content in the mix, as shown in Figure 9 [51]. The strength of geo-polymer mortar is enhanced with the addition of NaOH and curing periods. There is an increment in strength of 5–20% for a molarity increment of 8 M to 10 M, whereas 15–30% for a molarity increment of 10 M to 12 M. Previous research showed similar findings, albeit with a focus on different characteristics [52, 53]. Because of the increase in hydration degree, which is caused by a greater concentration of OH<sup>-</sup> in the alkali activator solution, the conclusion can be attributed to the fact that a higher OH<sup>-</sup> concentration results in a higher compressive strength value [54]. The compressive strength for various SS/SH ratios from 1 to 3 at 7, 28, and 90

days. The SS/SH ratios up to 2 were observed to increase in the samples we tested, as shown in Figure 10. For instance, for 7 days of NaOH 12 M and 50 % copper slag replacement in the sand, the compressive strengths for SS/SH ratios of 1, 2, and 3 are 41.65, 46.52, and 42.87 MPa. This could be because there is sufficient sodium silicate present for the development of geo-polymeric gel, which results in an accelerated geo-polymerization reaction [55]. The addition of sodium silicate does not result in an increase in strength beyond a certain point. When the ratio of SS to SH was increased even further to 3, a weakening effect was noticed, as shown in Figure 11. Because of this ratio, the geo-polymerization reaction is inhibited, and as a result, the Al-Si phase precipitate inhibits reactive materials and activating solutions from connecting [56]. Additionally, a high porosity results from the less workable nature of the mixture. However, the strength may be significantly impacted when it is used more than the optimal value. Due to the rapid polymerization process, geopolymer pastes gain more strength at younger ages, but this rise is not accompanied by a significant increase in variance as the pastes continue to age. When there is less NaOH present, the effect of age becomes more apparent.

### 11. Effect of untreated and treated rubber

With more crumb rubber present, the compressive strength trended downward, as shown in Figures 12 and 11. The compressive strength for

7 and 28 days was decreased when added with 5, 10, and 15% crumb rubber as a partial replacement of fine aggregate for 12 M NaOH and SS/SH ratio 2. For 30% replaced copper slag 15, 25, and 54% and 18, 44, and 54%; 40% replaced copper slag 15, 25, and 49% and 15, 40, and 53%; and 50% replaced copper slag 15, 24, and 49% and 17, 38, and 50%, respectively, for untreated rubber. Other

researchers also said that adding 15% crumb rubber as fine aggregate made the compressive strength of OPC concrete mixes drop by about 50%. Thus replacing copper slag with crumb rubber in geo-polymer mortars has the same effect on the mix's microstructure, and the bond between the rubber and the binder is the same as in similar OPC systems [57, 58].

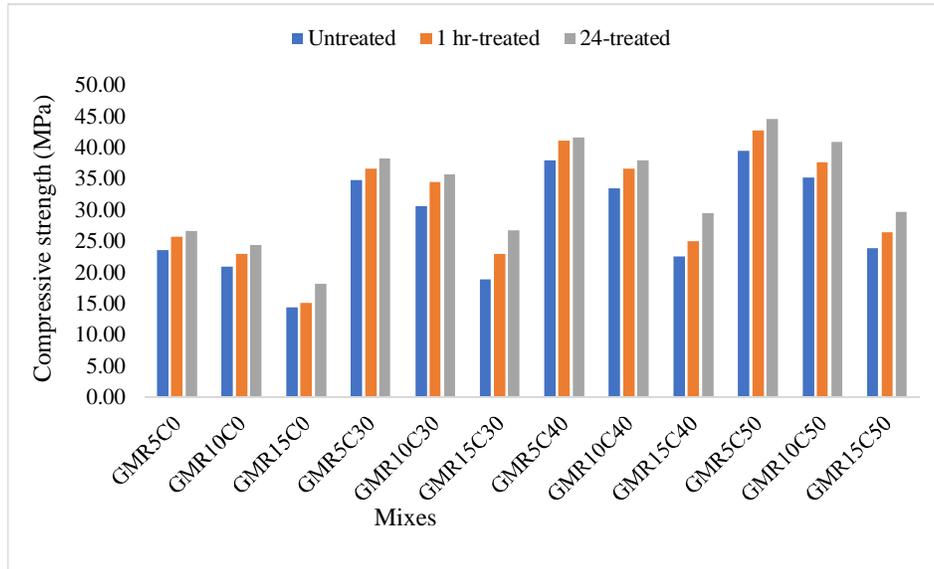


Figure 12. Compressive strength of rubberized slag-based geo-polymer mortar for 7 days.

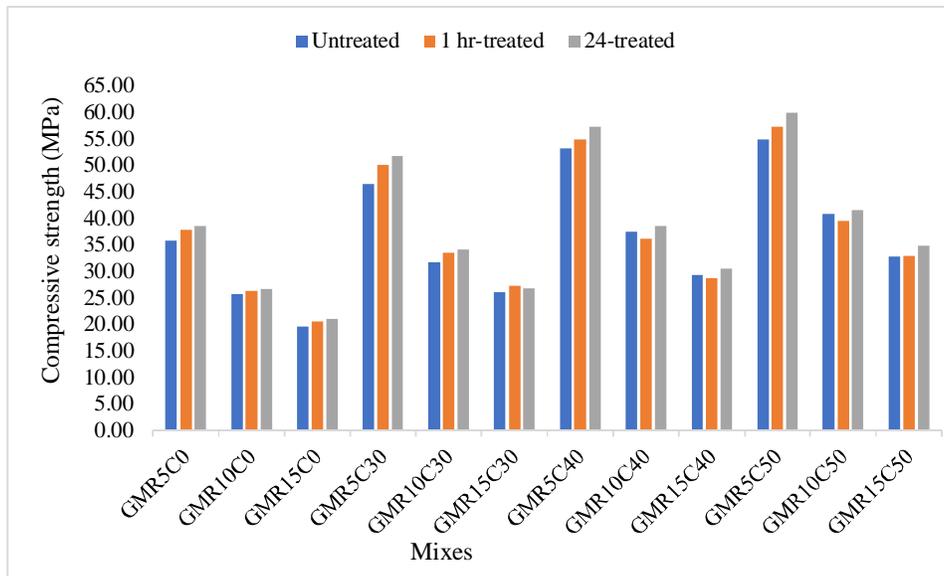


Figure 13. Compressive strength of rubberized slag-based geo-polymer mortar for 28 days.

**Table 4. Compressive strength (MPa) of rubberized slag-based geo-polymer mortar.**

Mixes	Untreated		Treated-1 hr		Treated- 24 hr	
	7 days	28 days	7 days	28 days	7 days	28 days
<b>GMR5C0</b>	23.57	35.79	25.82	37.77	26.67	38.63
<b>GMR10C0</b>	20.99	25.75	23.02	26.32	24.42	26.61
<b>GMR15C0</b>	14.39	19.64	15.16	20.60	18.25	21.03
<b>GMR5C30</b>	34.84	46.47	36.61	50.07	38.26	51.78
<b>GMR10C30</b>	30.68	31.73	34.56	33.57	35.79	34.14
<b>GMR15C30</b>	18.92	26.07	23.04	27.31	26.74	26.74
<b>GMR5C40</b>	37.97	53.15	41.15	54.82	41.60	57.32
<b>GMR10C40</b>	33.47	37.52	36.68	36.13	38.02	38.63
<b>GMR15C40</b>	22.62	29.39	25.05	28.66	29.52	30.53
<b>GMR5C50</b>	39.54	54.86	42.80	57.33	44.66	59.97
<b>GMR10C50</b>	35.36	40.81	37.69	39.54	40.94	41.52
<b>GMR15C50</b>	23.90	32.78	26.52	32.95	29.78	34.93

There is a probability that the decrease in strength is mainly due to the incompatibility between the strain capacity of crumb rubber and paste [59]. In addition, the incorporation of crumb rubber increases the amount of air that is trapped within the ITZ, leading to an increase in the mix's porosity, which in turn increases the thickness of the ITZ [60]. Comparing crumb rubber to natural aggregates, the strength is lower. Additionally, applying a NaOH solution to the crumb rubber's surface could help to regain some of the lost strength. The results showed that, in comparison to specimens that had not received any pre-treatment, rubberized specimens that had crumb rubber pre-treated for either an hour or 24 hours displayed significantly increased strength. The pre-treatment of crumb rubber for a period of 1 hour shows increases in strength over 5-18% for 7 days and 1-7% for 28 days, whereas the pre-treatment for 24 hour shows 9-29% for 7 days and 2-10% for 28 days over untreated rubber, as shown in Table 4. This is primarily due to the surface of the crumb rubber being modified. In addition, treatment with NaOH improved the adhesion between the crumb rubber and the other ingredients, which ultimately resulted in the formation of a dense matrix [61]. After being treated with NaOH, rubber became more hydrophilic, and the porosity at the interface between the rubber and the other ingredients shrank, which led to an improvement in the material's mechanical properties [49]. In general applications, the increase in strength from alkali treatment for 1 hour is the same as that from alkali treatment for 24 hours after 28 days. Additionally, the mortar created using crumb rubber that had been alkali-treated for 24 hours was difficult to work with, indicating that an hour of alkali treatment is more effective and efficient and is therefore better for actual use.

## 12. Conclusions

This paper concludes the effect of sodium hydroxide concentration and alkali activator solution on the fresh properties, mechanical properties, and durability properties of rubberized slag-based geo-polymer mortar. From the study, it is observed that with an increase in sodium hydroxide concentration, the properties of the mortar progressed, whereas with an increase in the alkali activator solution ratio, the properties of the mortar enhanced. For a ratio of 2, further increase leads to a decrement in the compressive strength of the mortar. The use of copper slag up to 50% doesn't have any adverse effects on mechanical properties; it increases the compressive strength of mortar, but there is a decrement in setting time and flow value. The incorporation of crumb rubber as a substitute material for natural sand shows a decline in mechanical properties but is better than a conventional mix. Treatment of rubber with an alkaline solution enhances its properties, but the treated period plays an important role. The rubber treated for 1 and 24 hr periods shows that there is an increment in strength, but there is no significant strength increment for the 24 hour period over the 1 hr period. Therefore, the optimum mix for rubberized slag-based geo-polymer mortar is replacing the fine aggregate with 50% copper slag along with 10% crumb rubber pre-treated for 1 hr, NaOH of 10 M, and an alkali activator ratio of 2.

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## تأثیر بر خواص مکانیکی و بادوام ملات ژئوپلیمری بر پایه سرباره کائوچو و مس با استفاده از مولارینته‌های مختلف هیدروکسید سدیم و نسبت محلول‌های فعال کننده قلیایی

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### چکیده:

کارایی ملات ژئوپلیمری با جایگزینی سنگدانه‌های ریز با نسبت‌های مختلف سرباره مس و خرده کائوچو تجزیه و تحلیل می‌شود. خواصی مانند مقدار جریان، زمان گیرش، خواص تقویتی، چگالی و جذب آب برای عوامل مختلفی از جمله مولارینته‌های هیدروکسید سدیم (8، 10 و 12 مولار)، نسبت‌های مختلف محلول فعال کننده قلیایی (1، 2، و 3) و اثر کائوچو قبل از درمان مورد بررسی قرار گرفت. نتایج نشان می‌دهد که افزایش مولارینته باعث افزایش مقاومت فشاری، زمان گیرش و مقدار جریان ملات می‌شود. مشاهده شده است که 12 مولار NaOH و نسبت فعال کننده قلیایی 2 استحکام فشاری بالایی دارد که  $71,79 \text{ N/mm}^2$  است. کائوچوی قلیایی شده پیوند بین بایندر و کائوچو را بهبود می‌بخشد که منجر به افزایش استحکام ماده به میزان 7 درصد برای 1 ساعت و 10 درصد برای 24 ساعت و تراکم آن تا حدود 1,5 درصد می‌شود. پیشنهاد می‌شود که مخلوط بهینه با 50 درصد سرباره مس، 10 درصد کائوچو با پیش تصفیه برای مدت 1 ساعت، 12 مولار NaOH و نسبت فعال کننده قلیایی 2 نتایج عالی را در بین همه مخلوط‌ها ارائه دهد. در نتیجه، یافته‌ها نشان می‌دهد که ملات تولید شده به بهبود اقتصادی و اکولوژیکی کمک می‌کند.

**کلمات کلیدی:** سرباره مس، خرده کائوچو، خواص تراکم تازه، ملات ژئوپلیمر، خواص مقاومتی.