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Performance of eco-friendly mortar mixes against aggressive environments

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Abstract. Past research efforts already established geopolymer as an environment-friendly alternative binder system for ordinary Portland cement (OPC) and recycled aggregate is also one of the promising alternative for natural aggregates. In this study, an effort was made to produce eco-friendly mortar mixes using geopolymer as binder and recycled fine aggregate (RFA) partially and study the resistance ability of these mortar mixes against the aggressive environments. To form the geopolymer binder, 70% fly ash, 30% ground granulated blast furnace slag (GGBS) and alkaline solution comprising of sodium silicate solution and 14M sodium hydroxide solution with a ratio of 1.5 were used. The ratio of alkaline liquid to binder (AL/B) was also considered as 0.4 and 0.6. In order to determine the resistance ability against aggressive environmental conditions, acid attack test, sulphate attack test and rapid chloride permeability test were conducted. Change in mass, change in compressive strength of the specimens after the immersion in acid/sulphate solution for a period of 28, 56, 90 and 120 days has been presented and discussed in this study. Results indicated that the incorporation of RFA leads to the reduction in compressive strength. Even though strength reduction was observed, eco-friendly mortar mixes containing geopolymer as binder and RFA as fine aggregate performed better when it was produced with AL/B ratio of 0.6.

Keywords: fly ash; ground granulated blast furnace slag; geopolymer; recycled fine aggregate; eco-friendly mortar; compressive strength; durability

1. Introduction

Continuous research investigations are present throughout the world to find effective and environment-friendly alternative binder materials for Ordinary Portland Cement (OPC) as it is the most used construction material to produce the concrete. The huge demand for concrete using OPC results in high volume of carbon dioxide (CO_2) emission, leads to environmental problems continuously and results huge depletion of natural resources. In 1970's, Prof. Davidovatis coined the material, "Geopolymer", which is resulted from the reaction between materials, which are rich in Si or Al (e.g., fly ash, slag etc.) and alkali solutions (e.g., hydroxide and sodium silicate). Researchers are trying to establish geopolymer as the most effective replacement of OPC throughout the world. From the chemical reaction between the source materials and alkaline solution, sialate structures (-Si-O-Al-O) is produced, which is basically the governing factor to attain the strength. Based on the Si/Al ratio, different types of sialate structures can be formed (Davidovatis 1991, 2002). The schematic formation of geopolymer is shown in the following Eqs. (1) & (2).

$$(Si_2O_5.Al_2O_2)_n + H_2O + OH^- \rightarrow Si(OH)_4 + Al(OH)^{4-} \quad (1)$$

$$Si(OH)_4 + Al(OH)^{4-} \rightarrow (-\underset{O}{\underset{|}{\overset{|}{Si}}}-O-Al-\underset{O}{\underset{|}{\overset{|}{O}}}-)_n + 4H_2O \quad (2)$$

Numerous research on the utilization of geopolymer as an alternative binder material to produce concrete/mortar mixes with desired properties exist presently. In our earlier studies, fly ash (Saha and Rajasekaran 2019) and GGBS (Saha and Rajasekaran 2017) were used as source materials to produce geopolymer paste. Higher compressive strength of those pastes was observed for the mixes produced with the consideration of the alkaline solution having 14M sodium hydroxide solution and sodium silicate solution as a ratio of 1.5 to the amount of sodium hydroxide solution. But it was found that fly ash based geopolymer paste requires significantly more time whereas GGBS based geopolymer paste set very quickly. These setting time problems of fly ash based geopolymer had been addressed by introducing GGBS into the mixes in our previous work (Saha and Rajasekaran 2017). Pattanapong *et al*. (2015) observed higher compressive strength, tensile strength and bond strength for the geopolymer concrete mixes than that of OPC based concrete. Rahim *et al*. (2014) investigated the properties of fly ash based geopolymer varying the solid to liquid ratio without using silicate solution. Rahmiati *et al*. (2014) studied and characterized the properties of fly ash based geopolymer and found the ratio of solid to liquid is one of the most important factors. Gorhan and Kurklu (2014) found compressive strength of geopolymer mortar mixes increasing with the curing time and the increase in the concentration of sodium hydroxide. Chindaprasirt *et al*.

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(2012) used class C type of fly ash for the production of geopolymer paste and investigated the effect of SiO_2 and Al_2O_3 on the properties of the geopolymer.

To make concrete more environment-friendly, utilization of industry by-product materials is increasing day by day and these studies on the utilization of industry by-product materials are also getting established well. These by-product materials are indicated to be used as supplementary cementitious materials, alternative for aggregates etc. in the concrete production. Saha and Rajasekaran (2020) used concrete waste as recycled fine aggregate in the production of fly ash based geopolymer mortar mixes at level of 10%, 20%, 30%, 40% and 50% and investigated the volume change properties of the mixes. Praveen Kumar and Ravi Prasad (2019) conducted a study on strength and durability of concrete mixes produced with fly ash, silica fume and lime sludge as replacement of cement. Lim *et al*. (2018) found ceramic waste in the form of Al_2O_3-SiO_2 nano-particles as feasible replacement of OPC upto 40% to produce mortar mixes. Mohammadhosseini *et al*. (2018) observed the improvement in log-term compressive and tensile strength of the concrete mixes containing 16% POFA in lieu of OPC and 0.5% polypropylene waste carpet fibres. Mohammadhosseini and Md. Tahir (2018) concluded that incorporation waste metalized plastic fibres and palm oil fuel ash as substitution of OPC lead to produce durable concrete. Kagadgar *et al*. (2017) used fly ash and alccofine as supplementary cementitious material to develop better durable concrete mixes to be used in marine environment. Mohammadhosseini *et al*. (2017) utilized waste polypropylene carpet fibres and palm oil fuel fly ash to produce a green and durable concrete. Chore and Joshi (2015) tried to use fly ash and GGBS in replace of OPC and evaluated strength properties of concrete. They concluded that fly ash and GGBS can be used as the replacement of OPC to produce sustainable concrete.

Saha *et al*. (2019) investigated to utilize used foundry sand as fine aggregate to produce concrete. Mohammadhosseini *et al*. (2019) concluded from their experimental observations that ceramic waste powder as supplementary cementitious material and ceramic particle as fine aggregates are feasible to use to produce sustainable mortar mixes. Saha *et al*. (2019) also used recycled fine aggregate as alternative of natural fine aggregate for the production of concrete and found that recycled fine aggregate can be used effectively. Patra and Mukharjee (2018) used granulated blast furnace slag as the alternative of sand to generate mortar mix. Thomas *et al*. (2018) used copper slag and ferrous slag as the replacement of fine aggregates to produce concrete in the view of protecting natural fine aggregate and environment. Sunil *et al*. (2017) conducted experimental investigations to improve the durability properties of concrete by replacing fine aggregate by tailing material partially and OPC by fly ash partially. They found higher durability characteristics for the concrete mix with 35% tailing material in place of river sand and 20% fly ash in lieu of OPC. Deepa and Bhoopesh (2017) conducted experimental investigations to determine the optimum content of recycled aggregates (RA) by replacing 20%, 30%, 40%, 50% and 60% of coarse aggregates by RA to produce recycled aggregate geopolymer concrete and found slight reduction in its strength and ductility with the incorporation of RA in concrete mixes. Thete *et al*. (2017) investigated the feasibility of using quarry dust as fine aggregate to produce self-compacting concrete with desired properties. Shaikh *et al*. (2016) investigated the influence of the micro-silica on the mechanical and durability properties of concrete. 50% class F fly ash and 35% recycled coarse aggregate were also used to produce the concrete mixes. They found concrete with 5% micro-silica content to exhibit the best performance for all mechanical properties and whereas the lowest sorptivity and drying shrinkage at all ages were observed for concrete mixes with 10% and 5% micro-silica content respectively. With the increase of micro-silica content, chloride ion-permeability was found to be decreased in their study. Mukharjee and Barai (2015) used recycled concrete aggregates and nano-silica to evaluate strength of the produced concrete mixes. They concluded from their experimental studies that the incorporation of 3% Nano-Silica compensated the loss of the properties of concrete mixes with recycled concrete aggregates. Past studies (Saha and Rajasekaran 2016, Apoorva *et al*. 2016, Saha *et al*. 2015;) conducted experimental investigation to use recycled aggregate in the production of fresh concrete and found recycled aggregate as the one of the feasible alternative for natural aggregates.

In this paper, an attempt has been made to produce eco-friendly mortar mixes utilizing fly ash, GGBS, alkaline liquid having sodium silicate solution and sodium hydroxide solution and recycled fine aggregate as the replacement of natural fine aggregate. For the production of the geopolymer mortar mixes, 70% fly ash, 30% GGBS, alkali solution having sodium silicate solution and 14M sodium hydroxide solution in a ratio of 1.5 and 25% recycled fine aggregate were used. The long-term properties of the produced environment-friendly mortar exposed to the aggressive environments were investigated and reported.

2. Materials

In order to determine the mechanical and durability properties of geopolymer mortar mixes, fly ash, GGBS, locally available sand, alkali solution (combination of sodium hydroxide solution and sodium silicate solution), distilled water, sulphuric acid, nitric acid, and magnesium sulphate were used for the preparation of specimens and to conduct the different tests.

2.1 Fly ash

For this research work, locally procured class F type of fly ash was used as the main binder source material for the production of geopolymer. Specific gravity of fly ash was found to be 2.3.

2.2 Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag (GGBS), by-product material of steel and iron production industries resulting from the quenching of molten iron slag in water or steam, was procured from JSW Cement Ltd. GGBS was

Table 1 Properties of fine aggregates

Properties		Observed Values	
		RFA	Sand
Specific Gravity		2.27	2.36
Bulk Density (kg/m^3)	Loose	1.315	1.445
	Compacted	1.523	1.666
Water Absorption		7.14%	2%
Zone		I	I

used to eliminate the setting problem of geopolymer produced with fly ash only. In this work, specific gravity of GGBS was observed to be 2.9.

2.3 Fine aggregate

Aggregate passing through 4.75 mm IS sieve and retained on 150-micron IS sieve is defined as fine aggregates. In this experimental work, locally available sand and recycled fine aggregate were used as fine aggregate to produce geopolymer mortar mixes.

2.3.1 Sand (S)

Locally available sand was procured to use in the production of geopolymer mortar mixes. It conformed to grading zone I (IS: 383-1970). Table 1 represents the properties of sand and particle size distribution of sand has been shown in Fig. 1.

2.3.2 Recycled Fine Aggregate (RFA)

Recycled fine aggregate was generated by crushing the tested concrete specimens, which were collected from the laboratory dumping yards. The crushed material, passing through 4.75 mm sieve and retained on 150-micron sieve, was considered to use as recycled fine aggregate. The generated RFA conformed to zone I according to the guidelines given by IS: 383-1970. The properties of RFA were determined as per IS: 2386-1963 and have been represented in Table 1. The particle size distribution curve for sand, RFA and combination of sand and RFA are represented by the Fig. 1.

2.4 Alkali solution

Sodium silicate solution and sodium hydroxide solution of 14M concentration were mixed properly, and the mixed solution was chosen as the alkali solution to produce the geopolymer mortar mixes. The sodium silicate (Na_2SiO_3) is available commercially in solution form. Table 2 shows the chemical composition of sodium silicate solution (percentage by mass) given by the supplier. The sodium hydroxide (NaOH) is available commercially in flakes or pellets form. For the present study, NaOH flakes with 98% purity were used for the preparation of 14M sodium hydroxide solution. In this study, ratio of sodium silicate solution to sodium hydroxide solution was kept constant at 1.5 to prepare the alkali solution. First sodium hydroxide solution was prepared and cooled down. Then, the required quantity of sodium silicate solution was added to the cooled down sodium hydroxide solution and mixed well. Alkali solution, i.e., the mixture of sodium silicate and sodium hydroxide solution was prepared before 24 hours prior to use in mixes.

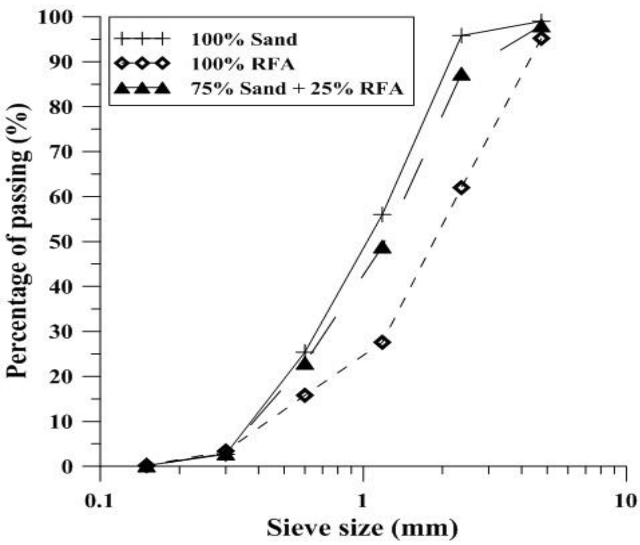

Fig. 1 Particle size distribution of sand, RFA and combined RFA & sand

Table 2 Chemical composition of sodium silicate solution (% by mass)

Na_2O	SiO_2	Water
8.5	28.0	63.5

2.5 Water

In the present investigation, distilled water was used for the preparation of sodium hydroxide solution. Normal tap water was used to prepare the desired acid and alkaline solutions to conduct durability tests.

2.6 Sulphuric acid

10% sulphuric acid solution was used for the durability studies (acid attack test) on the geopolymer mortar cubes. For the preparation of the desired acid solution, sulphuric acid of 98 percent purity was diluted.

2.7 Nitric acid

Locally procured nitric acid of 98 percent purity was used for the preparation of 10% nitric acid solution, which was used for the acid attack test on the geopolymer mortar cubes.

2.8 Magnesium sulphate

To check the resistance against alkaline environment by the produced geopolymer mortar mixes, 5% magnesium sulphate solution was used. Locally procured magnesium sulphate solids were used to prepare the magnesium sulphate solution with the desired concentration.

3. Methodologies

Preparation of the geopolymer mortar mixes, casting of the specimens, curing of the specimens and the procedures of the different tests (compressive strength, acid attack test, alkali attack test, and rapid chloride penetration test) have been explained in details in the following sections.

3.1 Preparation of the specimens

To produce the geopolymer mortar mixes containing recycled fine aggregate, the ratio of total binder to the total fine aggregate was considered as 1:3. All the materials were weighed as required. First, fly ash (70% of total binder), GGBS (30% of total binder), sand (75% of total fine aggregate) and RFA (25% of total aggregate) were taken and mixed in dry condition properly for 3-5 minutes. Then, the required quantity of alkali solution was added and mixed thoroughly for 2-5 minutes. Then the mortar mix was poured into the moulds to prepare the test specimens. Cubical specimens having 50 cm^2 surface area were used to determine the compressive strength and to conduct the durability test of the produced geopolymer mortar mixes.

3.2 Compressive strength

In order to determine the compressive strength of geopolymer mortar, cubes having surface area of 50 cm^2 were cast. After de-moulding, mortar cubes were kept at room temperature for curing. Cast specimens were tested after 3, 7, 28 and 56 days of curing at ambient temperature. Tests to determine compressive strength were conducted according to the guidelines given by IS- 4031 (part 6)-1988.

3.3 Durability study

In order to determine the ability of resistance against aggressive environment conditions, durability tests on the cast specimens of the produced geopolymer mortar mixes, namely acid attack and sulphate attack test were conducted. The detailed procedures of acid attack test and alkali attack test have been explained in the following sections.

3.3.1 Acid attack test

10% sulphuric acid and 10% nitric acid were chosen to conduct the acid attack test on the cast cubical specimens to find the resistance ability of the produced geopolymer mortar mixes against the acidic environment. Cast cubical specimens were cured for 28 days at ambient temperature before keeping into the 10% sulphuric acid solution and 10% nitric acid solution for a different duration. After the exposure into different acid solutions of 28, 56, 90 and 120 days, change in mass and change in compressive strength of the specimens were observed and analysed. The average observations of three specimens at a particular exposure period have been reported for both change in mass and change in compressive strength.

<u>Change in Mass</u>

Change in mass of specimens was measured after the various exposure period. The weight of each specimen was measured before immersion into the solution. After the desired exposure period into the solution, the specimens were taken out and made the specimen's surface dry. Then the weight of the specimens was noted down and change in mass was calculated. Change in mass of the specimens has been calculated using Eq. (3) and expressed as percentage. Positive percentage values indicate the gain of the mass and negative percentage values indicate the loss of the mass.

$$Change\ in\ mass\ (\%) = \frac{(\boldsymbol{M_f} - \boldsymbol{M_i})}{\boldsymbol{M_i}} \times \mathbf{100\%} \tag{3}$$

Where M_i=mass of the specimens before keeping into the solution and M_f=mass of the specimens after a desired period of exposure in the solution (surface dry condition).

<u>Change in Compressive Strength</u>

After 28, 56, 90, 120 days of exposure into the solutions, the specimens at saturated surface dry conditions were tested under compression test to determine the compressive strength at a particular exposure duration. Change in compressive strength of the specimens has been expressed by relative strength factor. Relative strength factor has been calculated according to the Eq. (4). Relative strength factor values less than 1 indicate the loss of the strength of the mix.

$$Relative\ strength\ factor = \frac{\boldsymbol{S_f}}{\boldsymbol{S_{28}}} \tag{4}$$

Where S_{28}=compressive strength of the mix at 28 days (without keeping into the solution) and S_f=compressive strength of the mix after a desired period of exposure in the solution (surface dry condition).

3.3.2 Sulphate attack test

In order to determine the resistance ability of the produced geopolymer mortar mix against the aggressive alkaline environment, 5% magnesium sulphate solution was used in this work. Cast cubical specimens cured for 28 days at ambient temperature were kept fully immersed into the desired solution for different duration. Both change in mass and change in compressive strength of the mixes after the exposure in sulphate solution for the desired duration have been analysed using Eq. (3) and Eq. (4) respectively.

3.3.3 Rapid Chloride Permeability Test (RCPT)

Rapid Chloride Permeability Test (RCPT) was performed to evaluate the chloride permeability through the specimens having dimension 50 mm height and 100 mm in diameter, cast with the geopolymer mortar mixes containing recycled fine aggregate. Specimens were cured at ambient temperature for 28 days and then RCPT was conducted according to the guidelines given by ASTM C 1202. Based on the cumulative charge that passed through the specimens, a qualitative rating for chloride permeability has been made for the mortar mixes.

4. Results and discussion

4.1 Compressive strength

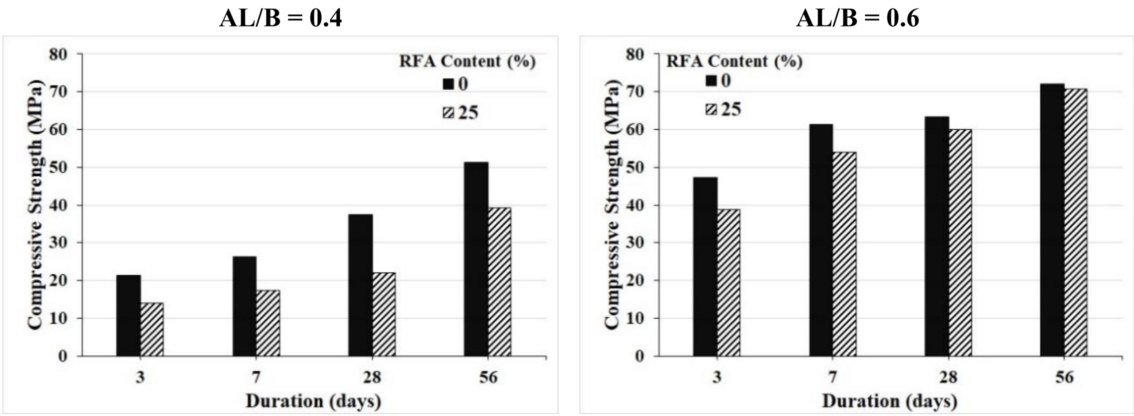

Fig. 2 Compressive strength of geopolymer mortar mixes

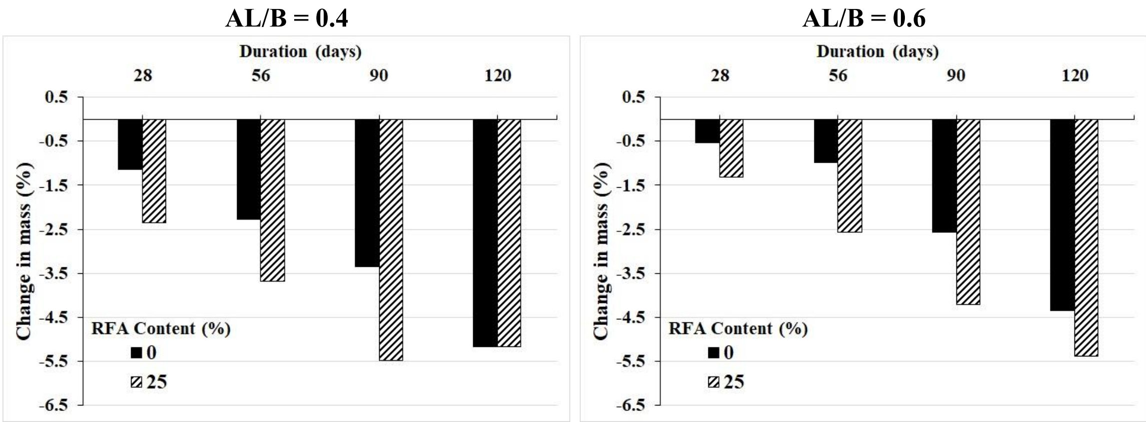

Fig. 3 Change in mass of specimens after the immersion into sulphuric acid

Fig. 2 represents the compressive strength of the geopolymer mortar mixes at different duration for both AL/B. From the obtained results, it is clear that higher compressive strength was observed for the geopolymer mortar mixes produced with the consideration of AL/B ratio of 0.6. Compressive strength at 28 days was observed around 1.5-2 times higher for the geopolymer mortar mixes produced with the consideration of AL/B ratio of 0.6 than that for the mortar mixes produced with AL/B ratio of 0.4. When higher AL/B ratio is considered to produce the geopolymer mortar mixes, formation of the main strength attributing geopolymeric structure from the reaction between the binder and AL is higher due to the presence of higher AL in mixes.

Incorporation of RFA into the mixes resulted in the reduction of compressive strength for the geopolymer mortar mixes produced with the consideration of both AL/B. Presence of RFA in the mortar mixes may disturb the alkaline liquid due to its higher water absorption capacity. As results, formation of geopolymeric structure is getting disturbed and gaining less strength. Saha and Rajasekaran (2020, 2019) stated that the RFA present in the mix disturbed the reaction between the source materials and alkali solution due to its higher water absorption capacity. As results, strength decrement was observed. Compared to the compressive strength of the mixes with no RFA at 28 days, 41.06% and 5.26% less compressive strength of the mortar mixes containing 25% RFA was found when AL/B was considered as 0.4 and 0.6 respectively.

4.2 Acid attack test

4.2.1 Change in mass

Fig. 3 shows the variation profile of the change of mass of the specimens cast with geopolymer mortar mix containing RFA partially at different ages. From the figure, it is evident that specimens cast with geopolymer mortar mixes produced with the consideration AL/B ratio of 0.6 was less affected by the acidic solution. It is due to the better geopolymeric structure formation for the mixes produced with AL/B ratio of 0.6 than that of the mortar mixes produced with AL/B=0.4. Loss of mass of the cast specimens was found to be more for the geopolymer mortar mixes containing RFA partially. Due to RFA's porousness nature, acidic solution can penetrate easily inside the specimens and deteriorate the specimens. As results, more loss in mass was observed for the specimens, which were cast with the mixes having RFA.

When the specimens were immersed into nitric acid solution in order to check the resistance ability of the produced mortar mixes against the acidic environment, a similar types of observations were noticed. Specimens cast with higher AL/B ratio were observed less loss in mass. RFA incorporation leads to the higher loss of mass at different ages. Change in mass of the specimens immersed into nitric acid solution is represented by Fig. 4.

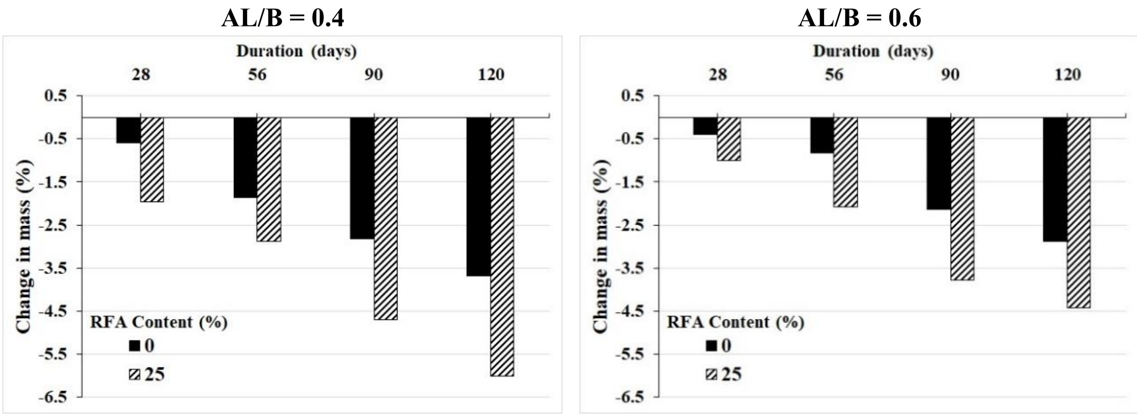

Fig. 4 Change in mass of specimens after the immersion into nitric acid

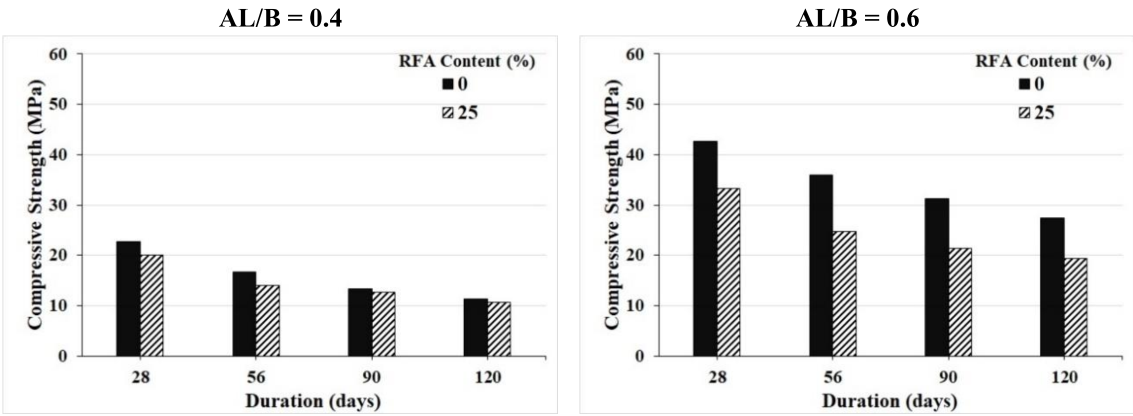

Fig. 5 Compressive strength of specimens after the immersion into sulphuric acid

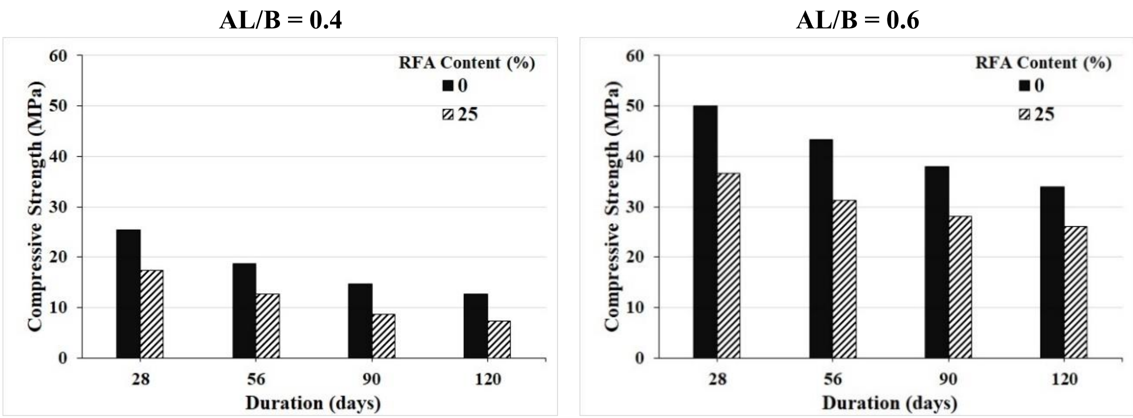

Fig. 6 Compressive strength of specimens after the immersion into nitric acid

4.2.2 Change in compressive strength

Fig. 5 represents the observed compressive strength of the geopolymer mortar mixes exposed to sulphuric acid solution for a particular duration. Decrement of compressive strength of the mortar mixes was observed with the duration of exposure to sulphuric acid solution. Acidic solution penetrates into the specimens and disturbs the equilibrium of system. As a result, formation of geopolymeric structure, which is mainly responsible for gaining strength, also gets disturbed. Thus, strength was observed to be decreasing with the exposure time to acidic environment. After 120 days' exposure to sulphuric acid solution, geopolymer mortar mix containing RFA partially gained 19.33 MPa as minimum strength when AL/B ratio was considered as 0.6 whereas this value was observed as 10.67 MPa when AL/B ratio was considered as 0.4.

When the specimens were immersed into nitric acid solution for a particular duration, the variations of compressive strength of the mixes were in similar trend like the specimens kept into sulphuric acid solution. After the exposure of 120 days to nitric solution, minimum compressive strength of 7.33 MPa was observed for the mixes containing RFA partially produced with consideration of AL/B ratio of 0.4 whereas it was found as 26 MPa when

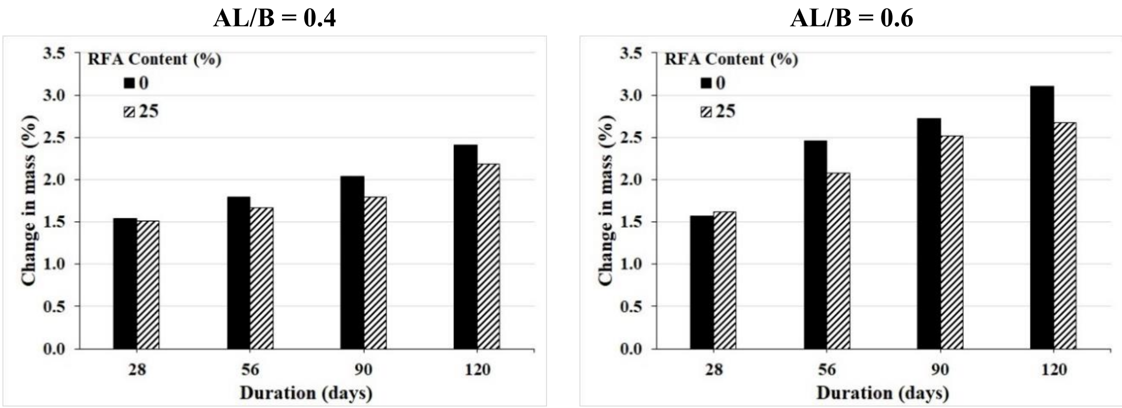

Fig. **7** Change in mass of specimens after the immersion into magnesium sulphate solution

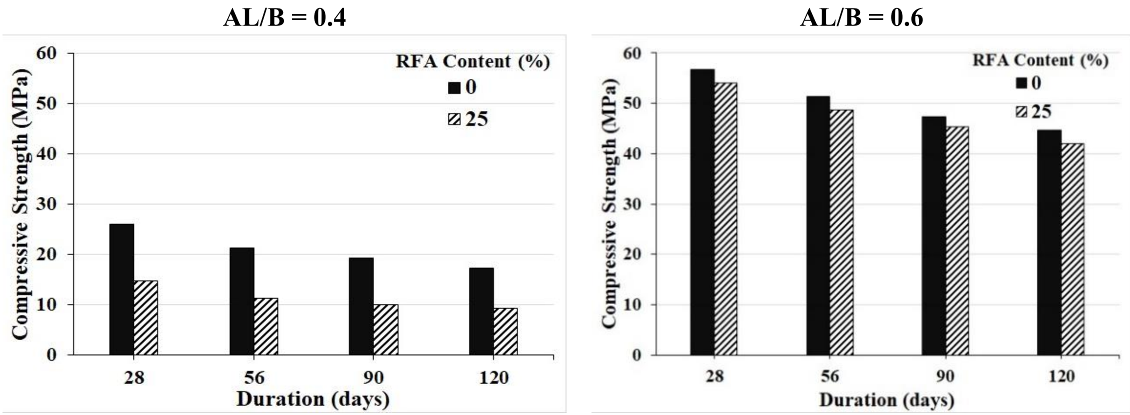

Fig. 8 Compressive strength of specimens after the immersion into magnesium sulphate solution

Table 3 Relative strength factor of geopolymer mortar mixes

Solution	Sulphuric Acid				Nitric Acid				Magnesium sulphate			
AL/B	0.4		0.6		0.4		0.6		0.4		0.6	
RFA	0%	25%	0%	25%	0%	25%	0%	25%	0%	25%	0%	25%
28 days	0.61	0.91	0.67	0.56	0.68	0.79	0.79	0.61	0.70	0.67	0.89	0.90
56 days	0.45	0.64	0.57	0.41	0.50	0.58	0.68	0.52	0.57	0.52	0.81	0.81
90 days	0.36	0.58	0.49	0.36	0.39	0.39	0.60	0.47	0.52	0.45	0.75	0.76
120 days	0.30	0.48	0.43	0.32	0.34	0.33	0.54	0.43	0.46	0.42	0.71	0.70

AL/B was adopted 0.6. Fig. 6 shows the compressive strength of the specimens after the exposure to the nitric acid for different durations.

From the observation, it has been seen clearly that geoploymer mortar mixes with or without RFA, which was produced with the consideration of AL/B as 0.6 perform better than that of AL/B=0.4 against the acidic environment. Table 3 represents the values of relative strength factor for all mixes exposed to the different solutions.

4.3 Sulphate attack test

4.3.1 Change in mass

Fig. 7 shows the variation profile of the mass change of the specimens exposed to alkaline solution, i.e., magnesium sulphate solution for different time periods. It has been observed that all the mixes gain more weight. It signifies that sulphate solution does not have any negative effects on the specimens. Hence, no deterioration was found for the specimens. Therefore, it can be said that produced geopolymer mortar mixes containing recycled fine aggregate partially can withstand the aggressive alkaline environment without any deterioration, i.e., any loss of mass.

4.3.2 Change in compressive strength

The observed compressive strength after the particular durations of the immersion to magnesium sulphate solution has been shown in Fig. 8. From the observations, it is clear that the geopolymer mortar mixes lost its compressive strength as the passage of immersion time to the magnesium sulphate solution. Minimum compressive strength of 9.33 MPa for the mortar mixes containing RFA produced with AL/B ratio 0.4 was observed after the 120 days' immersion into magnesium sulphate solution. For the mortar mixes produced with AL/B ratio of 0.6, it was observed 42 MPa. It is clearly seen that geopolymer mortar mixes perform better under alkaline environment than the acidic environment. Table 3 gives the relative strength factor of the mixes immersed into the magnesium sulphate solution.

4.4 Rapid chloride permeability test (RCPT)

Rapid chloride penetration test (RCPT) was conducted to get knowledge about the chloride permeability of the

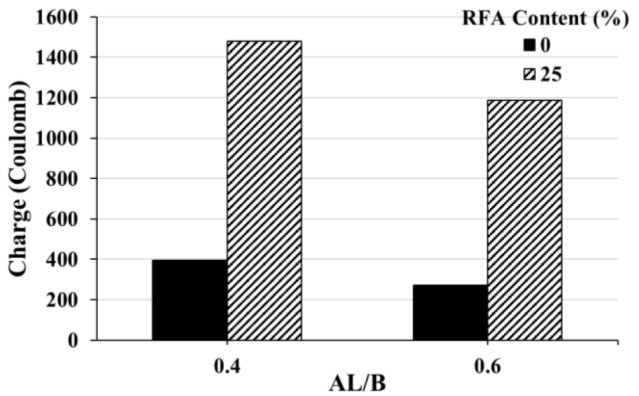

Fig. 9 Cumulative charge passed through mortar specimens in RCPT

geopolymer mortar mixes containing RFA partially in terms of cumulative charge passed through the specimens. Fig. 9 shows the cumulative charge passed through the specimens cast with different mortar mixes. It is clearly observed that geopolymer mortar mixes produced with AL/B ratio of 0.6 showed better resistance to the penetration of chloride ions than that of the mixes produced with AL/B ratio of 0.4. Saha and Rajasekaran (2019) also found less charge passed through the geopolymer mortar mixes when AL/B ratio was adopted 0.6. Geopolymer mortar mixes with RFA were observed to be less resistant to the penetration of chloride ions as current passed more through the specimens. According to the specified categorization given in ASTM C1202, geopolymer mortar mixes with RFA can be designated as low-permeable to chloride ions and mortar mixes without RFA can be designated as very low permeable to chloride ions.

5. Conclusions

In order to find out the resistance ability against aggressive environmental conditions, experimental investigations on the durability properties of geopolymer mortar mixes has been presented and discussed. From the observations, it is clear that consideration of AL/B ratio of 0.6 to produce geopolymer mortar mixes provides better mixes. Incorporation of RFA leads to the reduction of compressive strength of the mortar mixes. But, even after immersion to aggressive environmental conditions up to 120 days, based on the compressive strength, most of the mixes can be categorized as MM7.5 grade of masonry mortar as per the guidelines of IS: 2250-1981. From this study, it can be concluded that geopolymer mortar mixes containing RFA partially perform better against the aggressive alkaline environment than that of acidic aggressive environment. Utilization of RFA as fine aggregate and geopolymer as binder makes the final product geopolymer mortar mixes more environment-friendly. Further studies on the produced geopolymer mortar mix having RFA can be conducted for several applications in real practices effectively.

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