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Geo-polymer sea sand cubes filled gabions

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ABSTRACT

A gabion is derived from the Old Italian term "large cage." Caged riprap is utilized for erosion prevention while building foundations or dams. Gabions are commonly used in civil engineering and landscaping projects as they provide a cost-effective erosion control and soil retention solution. They are also known for their flexibility and durability in various weather conditions. The present investigation aims to replace stones or cement mortar elements used in the gabions with the geo-polymer mortar cubes manufactured using the sea sand readily available at the construction site. The mortar cube specimens were prepared using industrial wastes such as ground-granulated blast-furnace slag (GGBS), fly ash (FA), polymerized in the presence of sodium hydroxide (NaOH) solution used as an alkali catalytic liquid and by sea sand as fine aggregate. The mortar cubes of three different mixes with the varied trial mixes of fly ash and GGBS along with the solution of NaOH with different molarities were cast. The cubes were air cured for 7 and 28 days, and the hardened properties were studied. The maximum 28-day compressive strength was found for 30% replacement of fly ash at 10 M solution, i.e., 16.13 MPa A model gabion of 0.5mX0.3mX0.3 m is prepared using a 'Netlon' mesh of geo-synthetic material to indicate the actual application in sea erosion control. The sea sand cubes are filled in the box to obtain a typical gabion filler.

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1. Introduction

Sea erosion is a severe problem prevailing in coastal regions through wave action, tidal currents, drainage, or strong winds; it is the wearing down of the ground and the removal or redistribution of beach or dune deposits. Waves produced by storms, the wind, or fast-moving watercraft led to coastal erosion, resulting in long-term sediment losses or a brief redistribution of the coastal silt. Therefore, the prevention of sea erosion is necessary as erosion causes damage to houses, lives and livelihoods of the people in the coastal regions. The environmental and financial aspects of producing, transporting and using sea erosion control measures are becoming essential. One of the erosion control methods is using gabions filled with stone blocks. The work describes replacing stones or OPC cement mortar elements in the gabions with the geo-polymer mortar cubes prepared using the sea sand readily available at the construction site. A combination of unwashed sea sand, typical ground-granulated blast-furnace slag (GGBS), fly ash (FA) and sodium hydroxide solution (NaOH) was adopted to prepare the mortar cubes of sufficient strength. Approximately 75 years ago, Italy's river projects introduced gabions. They are used nowadays for many applications, including breakwaters, flexible aprons, retaining walls, and embankments.

The call for the day is reducing the gabions' production and transportation costs by using cost-effective filler material. The practical measures used in our country to control sea erosion are the gabions and tetrapod. Gabions are used to protect Swami Narayan Temple near the seashore in Gujrath. Tetrapods protect the marine drive in Mumbai and Uppunda sea shore near Kundapura, Udupi District of Karnataka (Fig. 1). This paper describes replacing stones or cement mortar elements in the gabions with geo-polymerized mortar cubes prepared using sea sand, readily available at the construction site. A combination of unwashed sea sand, typical ground-granulated blast-furnace slag (GGBS), fly ash (FA), and sodium hydroxide solution (NaOH) was adopted to prepare mortar cubes. By efficiently using sea sand when producing mortar components in a region where river sand is not commonly available, such as isolated islands and coastal areas, this method not only lowers the cost of production of the gabions but also lowers

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Fig. 1. Tetrapod at Uppunda shore and Non-Destructive Testing by using Rebound hammer.

the material transportation expense and minimizes the CO_2 emissions from construction activities.

2. Objectives of the investigation

This investigation aims to propose an alternative cost-effective, green filler material in the gabions produced by using unwashed sea sand, which is readily available at the site to be used as fine aggregate in obtaining alternative filler material. The present investigation has the following specific objectives.

- To study the effect of re-placement of the gabions' angular stones and concrete blocks by geo-polymerized mortar elements.
- To study the effect of use of sea sand as fine aggregate to produce geo-polymerized elements as filler materials for gabions.
- To study the effect of the alkaline solution's molarity on the geo-polymerized element's physical properties.
- To study the structural behaviour of geo-polymerized mortar under the impact of vertical and axial forces to reach the design strength for using them in gabions as elements of construction

3. Literature review

The Department of production engineering, Obayashi Corporation, Japan, successfully used sea sand in Japan. Srilanka also detailed studies on using sea sand for construction works. For the past many years,alkali activated concretes and geopolymers and polymerization have been extensively researched for many applications [17–22]. Using ground blast furnace slag, a latent hydraulic cementitious component, the setting time is sped up, and the compressive and flexural strengths are markedly increased, according to [1] research and [2]. Their study on fly ash and kaolinite mixtures showed how the changes significantly influence the final characteristics of the geo-polymeric material in the reactivity of the source materials employed during the synthesis of waste-based geo-polymers. The definitive characteristics of the geo-polymer are greatly influenced by its water content, fly ash/kaolinite ratio, and metal silicate type. According to [3], fly ash has greater activation energy than slag, making heat treatment more crucial for fly ash activation. Even after one day of curing at room temperature, the geo-polymeric pastes under study showed no signs of hardening. According to the micrograph analysis, the components are heterogeneous and comprise a significant amount of unreacted fly ash. The influence of the inclusion of ground granulated blast furnace slag (GGBS) on the microstructure and mechanical characteristics of meta kaolin (MK) based geo-polymers have been explored by [4]. The investigation on fly ash with an 8 M NaOH solution by [5] showed that the reactive silica concentration, the vitreous phase content, and the particle size distribution are three essential variables influencing the potential reactivity of the fly ashes. According to [6], the alkaline nature of the catalytic liquid may relatively more readily break the covalent bonds of Al, Si, and Ca found in blast furnace slag. A higher temperature and more alkaline atmosphere were often needed to break fly ash's glassy surface. [7] concluded that although there are several ways to prevent riverbank erosion, gabion structures are frequently preferred because of their affordable production, flexibility, durability, stability, and sustainability. It has been proven that PVC-coated and galvanized (Zn-coated) wires are more durable and have better tensile strengths than regular steel wire. The wires' tensile strength (Mpa) depends on the applicable specifications.[8] Concretes prepared using DMS in place of fine sand (0–2 mm) had mechanical parameters (compressive strength, elastic modulus, tensile strength with Barcelona-Test, and flexural tensile strength) comparable to those in the control concrete.[9] demonstrated that dredged marine sand might be used effectively as a fine aggregate for making concrete. This is supported by the fact that DMS-made concrete has comparable mechanical and physical qualities to standard concrete. It was established that using DMS instead of raw sand either preserved or decreased the number of accessible pores, absorptivity, and water penetration depth under pressure [10]. Even if seawater and sea sand are utilized entirely in place of freshwater and river sand, C-A-S-H gel remains the primary hydration product for the four forms of ASC. The four varieties of ASC have strengths that are comparable to one another.

Therefore, the summary of the literature review revealed that the reactivity of fly ashes can be increased by increasing the reactive silica concentration, vitreous phase content, particle size distribution, increase in temperature and alkaline atmosphere. This increased reactivity can improve the performance of concrete, waste utilization, and soil remediation applications. DMS may be used effectively as a fine aggregate for making concrete. This concrete has comparable mechanical qualities of standard concrete. The pores, absorptivity, and water penetration depth under pressure are preserved or decreased using DMS instead of conventional sand. This finding is significant because it provides a sustainable alternative to traditional sand mining, which can have negative environmental impacts.

Additionally, using DMS in concrete production could reduce costs and increase the availability of construction materials and addresses the global shortage of construction sand. Thus, it can be considered the combination of partial replacement of fly ash as a binder and replacement of marine sand in place of river sand for the preparation of a type of geopolymer concrete thereby yielding a sustainability in construction in preventing sea erosion.

4. Site visit and non-destructive testing using rebound hammer

As the present work is related to the control of sea erosion, a site visit was made to study the laying of tetrapods on the Uppunda shores near Kundapura, which is one of the measures of construction of breakwater (Fig. 1). Tetrapods are a four-limbed structure having an angle of $120^{\circ}30'$ between each limb. The limbs of these tetrapods are arranged so that three of the four limbs will rest on the ground, and the other one will be directed upwards, perpendicular to the ground surface. This shape gives it a better interlocking ability when laid. The voids created by these tetrapod helps dissipate the wave energy and helps in reducing the erosion caused by it.

Maravanthe, a beach around 12 km from Kundapur city, is a place where a fishing port has been proposed, which requires a quiet and wave-free water surface; this can be satisfied by having a breakwater. Two artificial breakwaters are under construction, wherein a tetrapod is used in the outer layers and angular stones in the inner layer to form the breakwater. Angular rocks have been dumped, and the tetrapod of three different sizes has been placed on top of these to interlock the tetrapod properly. Smaller ones have been placed at the bottom and larger ones on the top. Non-destructive tests were conducted to assess the strength of the tetrapod laid on the Maravanthe shore. Compressive strength was found by using a Rebound hammer at different specimens of different sizes, and the average compressive strength was around 25 MPa. The Rebound hammer test was carried out to know the power of the tetrapod required at that particular region. Accordingly, curate the mix design for the gabions to obtain that strength. This is considered as the gabions will be used in the same area for a similar purpose.

5. Experimental methodology

5.1. Materials

The raw material for the current experiment was low-calcium fly ash (ASTM Class F), purchased from Udupi Power Corporation Ltd (UPCL), Padubidri. Fly ash has a specific surface area that ranges from 290 to 350 m^2/Kg, a specific gravity of1.85, and a greyish-white hue. According to the chemical examination of the fly ash sample, the main constituents are 42.89% silica (SiO_2) and 24.51% alumina (Al_2O_3). Jindal Steel Works (JSW), Thoranagallu, Bellary District, provided the Ground Granulated Blast Furnace Slag (GGBS) required for the proposed study. According to the examination of GGBS, it has a specific gravity of 2.80 and a fineness of 400–600 m^2/Kg. According to the chemical evaluation of the GGBS sample, the main constituents were calcium oxide (CaO), which made up 41% of the sample, silica (SiO_2), which made up 36%; and alumina (Al_2O_3), which made up 10%. Fine aggregates used were sea sand which was procured from Padubidri beach. Sea sand was collected from the coast and utilized directly without being washed with water to remove the salt. The sieve analysis, chloride content, and sulphate content tests were conducted on the procured sea sand. The chloride content in the sea sand was found to be 4.97 g/l. The use of potable water that complied with (IS: 456–2000) criteria was made for producing mortar. It uses sodium hydroxide flakes (NaOH) with a purity of 97–98% acquired from commercial sources. The sodium hydroxide solution was initially made by dissolving the required quantity of NaOH flakes in water. Alkali activator is NaOH's primary function. The alkali content of the activator is essential for strengthening and boosting the mechanical properties of fly ash.

The mix design was developed for the three different NaOH trial molarities in the current study—10 M, 12 M, and 14 M. The geogrid mats used to prepare the Gabions for the present investigation were obtained from Jyothi Traders, Surathkal. The gabions come in different sizes thanks to the sausages created of PP twisted strands and skillfully braided using a unique technology. Gabions are often sold in a prefabricated, collapsible shape with a bottom, four sides, and a flip-open top lid customarily kept together by the suitable binding. The body rope measures 10 mm × 8 mm × 6 mm, while the border rope is 10 mm × 12 mm in size. The sizes are chosen based on the seriousness of the issue and the implementation strategy to be used. Polymeric gabions provide the following benefits: Resistance to both alkaline and acidic environments; resistance to decay and marine organisms; flexibility and quick adapts to the curvature of the river bed; no rusting or harm to the fish; No water effect; non-biodegradable; good thermal stability, strong abrasion resistance, and high tensile strength; immunity to UV deterioration; able to be raised by cranes; capable of supporting undersea installation. The typical gabion is shown in Fig. 2.

Fig. 2. Gabions.

5.2. Material Testing

The following material tests were performed.

- A specific gravity test on fly ash by the Le-Chatelier flask [12] was found to be 1.85.
- The specific gravity test on fine aggregate (IS 2386-1963 Part 3) was 2.62.
- Sieve analysis test on fine aggregate (IS2386–Part I, 1963) showed that the fine aggregate belongs to zone IV as per IS 383:2016.
- Chloride ion is determined by Argentometric method titration with standard silver nitrate solution, and the chloride content is found to be 4.99 mg/l
- The sulphate test and the concentration of sulphate were found to be 323.59 mg/l.

5.3. Mix design calculations

The mix design for the study was obtained based on literature [15], from which the water to binder ratio was maintained at 0.30, and Fine aggregates to binder ratio were kept constant at 3.0, where the fly ash and GGBS together form the binder material. In addition, three trial molarities of the NaOH were used to prepare an alkaline activator solution. The three mix designs of fly ash (FA) and GGBS are used. These are FA: GGBS:80:20, FA: GGBS:70:30 and FA: GGBS:60:40. The mix proportions used for the investigation based on the above details are tabulated in Table 1.

5.4. Preparation, casting and curing of test specimens

The source materials were weighed, batched as per mix design and hand mixed. An appropriate quantity of NaOH solution is added. The moulds of 70.5 mm × 70.5 mm × 70.5 mm size were cleaned and assembled firmly, ensuring no gaps. To stop the mortar from sticking, a thin layer of oil was added to the interior surface of the moulds. Three mixture layers are filled, each being tamped 25 times using a tamping rod. The moulds are then kept at room temperature and de-moulded after three days. Fig. 3 shows the cast samples kept for air curing. The sand cubes are left to air-cure for 7 and 28 days at room temperature before being evaluated. After the air curing, compressive strength and water absorption tests were performed. The requisite methodology on the material procurement, prep aration of sample, and other details carried out following the relevant Indian Standard guidelinesINS> [11,13,14].

6. Results and discussion

Table 2 displays the specimens' compressive strength findings after 7 and 28 days. The results of the water absorption test are

Table 1
Items of three variables.

Mix	Molarity (M)	FA (kg/m^3)	GGBS (kg/m^3)	Fine Agg (kg/m^3)	NaOH (kg/m^3)
60/40	10	338.8	225.9	1694.5	101.7
60/40	12	338.8	225.9	1694.5	122.0
60/40	14	338.8	225.9	1694.5	132.2
70/30	10	375.3	169.5	1694.5	101.7
70/30	12	375.3	169.5	1694.5	122.0
70/30	14	375.3	169.5	1694.5	132.2
80/20	10	451.8	112.9	1694.5	101.7
80/20	12	451.8	112.9	1694.5	122.0
80/20	14	451.8	112.9	1694.5	132.2

Fig. 3. Prepared Specimens filled in Gabion.

Table 2
Compressive Strength Test Results.

Mix	Molarity (M)	7 days (MPa)	28 days (MPa)
60/40	10	8.33	13.02
60/40	12	7.03	9.22
60/40	14	5.42	8.83
70/30	10	8.63	16.13
70/30	12	8.00	11.54
70/30	14	6.51	10.8
80/20	10	7.7	13.4
80/20	12	7.37	10.4
80/20	14	4.62	8.28

shown in Table 3, which shows that the water absorption is nearly constant for varying ratios of fly ash and GGBS with ten molarity.

The maximum strength is attained for each mix made for 10 M catalytic liquid, as shown in Table 2. Thus 10 M NaOH can be considered optimum to produce geo-polymer sand cubes. Figs. 4–6 illustrate how compressive strength varies for various molarities and experimental mixtures.

The maximum compressive strength obtained for a 70/30 mix with 10 molarity is 16 MPa, 36% less than 25 MPa, as found from the field test on tripods. This indicates that the strength of geo-polymer mortar cubes is to be increased by considering other suitable materials, which can be determined from further investigations.

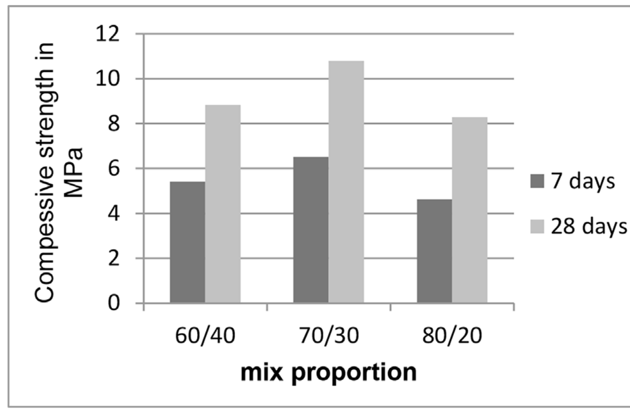

Fig. 4. Compressive strength of 10 M mix.

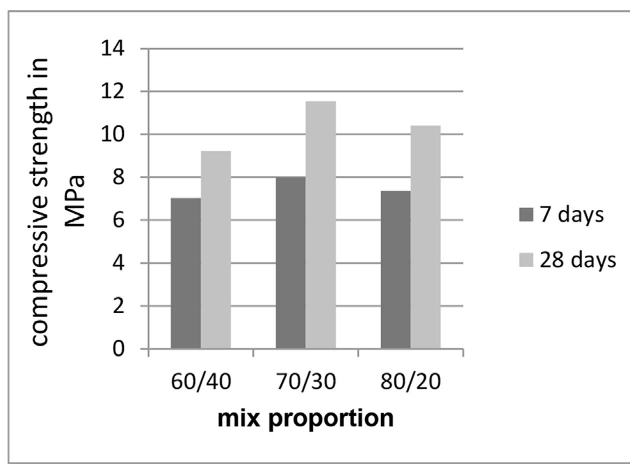

Fig. 5. Compressive strength of 12 M mix.

Table 3
Water Absorption Test Results.

Mix	Molarity (M)	Average Water absorption (%)
60/40	10	14.48
70/30	10	14.54
80/20	10	13.89
60/40	12	11.39
70/30	12	12.69
80/20	12	11.65
60/40	14	15.86
70/30	14	10.25
80/20	14	11.70

7. Conclusions

In this study, an effort has been made to look into using gabions filled with geopolymer mortar cubes generated from industrial wastes like fly ash and GGBS. The experimental study's findings have been deemed satisfactory; the mortar cubes that were produced may be utilized to fill gabions that will be used to safeguard the coast.

Within the scope of limited experiments conducted during the present investigation, their results and observation, the following conclusions are drawn:

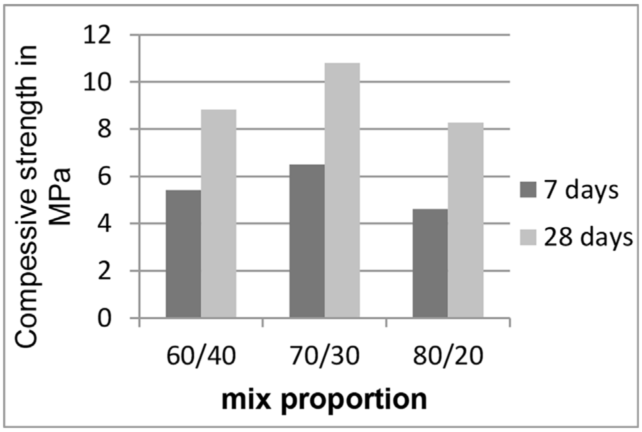

Fig. 6. Compressive strength of 14 M mix.

- The sea sand may be used as fine aggregate for the geo-polymer mortar cubes despite having a 4.97 g/lit chloride level. This finding is significant as it suggests that sea sand can be a viable alternative to river sand, which is becoming scarce in many parts of the world. However, further research is needed to determine the long-term durability and strength of the geo-polymer mortar cubes made with sea sand.
- Since geopolymer mortar cubes have sufficient compressive strength, they can replace the angular stones and cement concrete blocks in the gabions. This makes them a more sustainable and eco-friendly option for erosion control and retaining walls. Also, geopolymer materials have a lower carbon footprint than traditional cement-based materials.
- As the stones and cement concrete blocks are successively replaced by the geo-polymer sea sand elements, resulting in economic construction and time-saving as transportation cost is eliminated by using sea sand on the beach itself.
- The strength of the mortar cubes reduces with the increase in the molarity of the alkaline solution. This decrease in strength is due to the reaction between the alkaline solution and the binder material in the mortar, which leads to the formation of calcium hydroxide and a weaker bond between the aggregates.
- As this technique does not require water curing, it needs water only for the preparation of an alkaline solution, which reduces the manual work of curing the cubes, causing a reduction in the cost of the cubes. It also has the potential to significantly reduce the environmental impact of concrete production by minimizing water usage and energy consumption[11,13,14]

CRediT authorship contribution statement

Shriram Marathe: Writing – original draft, Writing – review & editing, Resources, Visualization, Validation. **S. Akhila:** Investigation, Methodology, Formal analysis. **I.R. Mithanthaya:** Supervision, Conceptualization, Validation. **N. Bhavani Shankar Rao:** Supervision, Conceptualization, Validation.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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