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Laboratory Study of High-Resistance Laterite-Based Geopolymer Bricks

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Abstract: A high amount of energy is required to produce different types of clay and sand-lime bricks, and a huge amount of carbon dioxide is released into the atmosphere. Also, brick waste from the destruction of dilapidated buildings pollutes the environment. The application of pozzolanic sources containing aluminosilicate and alkaline activators can be beneficial in the production of Geopolymer bricks, which do not need to be baked in a furnace and can be recycled for industrial and port facilities. A laterite-based Geopolymer brick mix design was introduced in this study as an environmental-friendly material. This type of brick is produced using available and cheap raw materials without the need for high furnace heat. The raw materials included laterite soil as aluminosilicate, laterite aggregate filler passed through sieve no. 8, and an alkaline activating solution with different concentrations. The effect of sieve size for laterite soil screening on the compressive strength of these brick samples was investigated. The results showed that the compressive strength of the prepared bricks here was much higher than the recommended standards for construction bricks and was similar to those of high-resistance bricks. The size of laterite soil sieves had a significant effect on the compressive strength of Geopolymer brick samples. The percentage of water absorption of the bricks with different concentrations of alkali activating solution was also within the recommended range for construction bricks.

Keywords: Geopolymer bricks, laterite soil, aluminosilicate, compressive strength, water

1. Introduction

High energy is required to produce different types of building bricks in the furnace, and a considerable amount of greenhouse gases are released into the atmosphere. Also, brick waste caused by the destruction of buildings is often unusable and causes environmental pollution worldwide. In this regard, using the pozzolanic sources containing aluminosilicate and alkaline activators in geopolymer bricks, which do not need to be baked in the furnace and can be recycled, is very useful in achieving the goals of sustainable development. A geopolymer mortar is obtained by reacting between aluminosilicate solids and alkaline activating solutions such as high concentration sodium hydroxide and sodium silicate. This mortar can be used to make a variety of environmentally friendly building materials. High mechanical strength, low shrinkage, high durability, high resistance in fire, and severe environmental conditions, as well as low thermal conductivity, are other advantages of geopolymer materials [1]-[3]. Laterite as an iron-rich aluminosilicate material can be a suitable choice for an aluminosilicate base component used in the geopolymer construction materials. Various studies have been conducted on the behavioral characteristics of different types of laterite-based geopolymer mortar and concrete [4]-[8]. Udawattha and Halwatura [9] used fly ash in the construction of concrete blocks containing mud. They utilized alkaline solutions of sodium hydroxide and sodium chloride at different concentrations and investigated the resulting geopolymer reactions under an electron microscope. Youssef et al. [10] used a new alkaline activator called Minealithe to make geopolymer bricks that did not require heat for curing and had the same compressive strength as conventional bricks. Kamseu et al. [11] showed that the presence of amorphous silica helped low temperatures polymerization of the laterite. They proposed a new method for brick producing [11]. Singh [12] compared the compressive strength and water absorption of laterite building bricks with local building materials. He also used percentages of fly ash and lubricant in his mix design and achieved acceptable strengths for masonry bricks [12]. Azeko et al. [13] investigated the physical and mechanical properties of laterite bricks reinforced with polyethylene waste. Shimol et al. [14] presented light and economic geopolymer bricks using fly ash and bentonite, which its other raw materials were made of waste materials except for the alkaline activating solution. The production of bricks and other building materials following the indicators of sustainable development in Africa was reviewed by

Oyelami and Van-Rooy [15], and successful laterite soil application in the manufacturing of load-bearing and non-load-bearing bricks was reported. Outage and Oladunmoye [16] tested water absorption properties of laterite bricks containing cement and wood ash. They showed that optimal ratios of wood ash and cement could effectively reduce the water absorption of bricks [16]. Tarighat and Moazzenchi [17] investigated the effects of different variables such as type of alkaline solution, presence of micro-silica, curing temperature (higher than 100 °C), and the laterite content in the mixture of laterite-based bricks. They achieved a water absorption range of 9-14% and maximum compressive strength of 21 MPa [17].

According to the review of previous studies in this field, it is necessary to perform the feasibility study of making geopolymer bricks using raw materials that are quickly and cheaply available in our neighborhood. In the present study, the application of laterite-based polymeric materials in producing the high-resistance bricks at a low curing temperature (85 °C) without the need for pressing was investigated. An alkaline solution containing sodium hydroxide as well as the industrial sodium silicate were utilized, and the effect of laterite soil particle size (passing through sieves No. 30 and 100), as well as the concentration of the alkaline solution on the compressive strength and water absorption of the bricks, have been evaluated. In the introduced design mix ratios here, an attempt was made to use cheap and available raw materials and a simple process for molding and curing the bricks. The main goals here were achieving high compressive strength and reasonable water absorption.

2. Materials and Methods

The aluminosilicate material used to make the geopolymer bricks in this study is the laterite soil, collected from "Qaryaghdi" laterite quarry in Miandoab town, East Azerbaijan. Based on the results of X-ray Fluorescence (XRF) analysis, the chemical composition of the laterite soil (table 1) indicates its rich sources of iron oxide aluminosilicate. Sodium silicate with a ratio of 2:4 and sodium hydroxide (99% caustic soda flakes) was used to prepare the alkaline activating solution. The alkaline solution of sodium hydroxide was made of drinking water. The tools and equipment used in this research include a pan mixer, a 5×20×10 cm wooden mold, an oven, and a compressive strength testing machine, available at the soil mechanics laboratory of the Department of Civil Engineering, Faculty of Engineering, University of Bonab. The X-ray diffraction analysis (XRD) test results related to the laterite soil sample are demonstrated in Fig. 1. According to Fig. 1, the laterite is composed of kaolinite (Aluminum Hydroxide Silicate), hematite (Iron Oxide), and cristobalite (Silicon Oxide) minerals.

Table 1 - Chemical content of laterite soil (weight percentage) with XRF analysis

SO3	P2O5	CaO	MgO	TiO2	Fe_2O_3	SiO_2	Al_2O_3
0.1	0.1	0.54	1.87	3.29	37.37	19.03	37.03

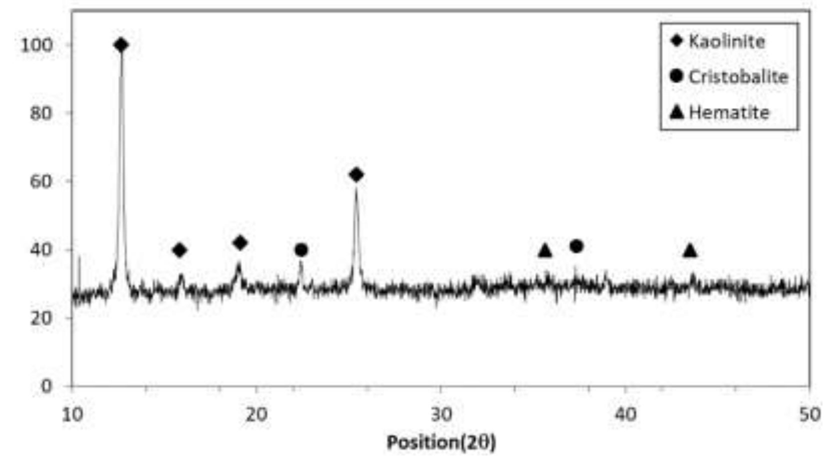


Fig. 1 - XRD analysis of laterite soil used here

Sodium hydroxide solution with a concentration of 8, 10, 14, and 18 M was used to make geopolymer brick samples. The mass ratios of sodium silicate to sodium hydroxide equal to 1 and 2 were selected to prepare the alkaline activating solutions. For example, the sample naming "G14-2" of geopolymer mortar indicates the use of 14 M sodium hydroxide solution and a mass ratio of sodium silicate to sodium hydroxide solution of 2. The laterite soil passed through sieves No. 30 and 100, and the laterite aggregate filler remaining on sieve No. 8 was selected as the aluminosilicate base material and the filler aggregates, respectively. Then, the laterite powder and the laterite aggregates were poured into a plastic container, and the alkaline activator was gently added and mixed. Then, the mixture was poured into a pan mixer and after 5 minutes of complete mixing, cast into the wooden molds having a size of 10×20×5 cm and vibrated on a vibrating device. Also, similar to the mix proportions in table 2, several perforated brick samples were prepared and tested. Pictures of raw materials and molded brick samples are given in Fig. 2.

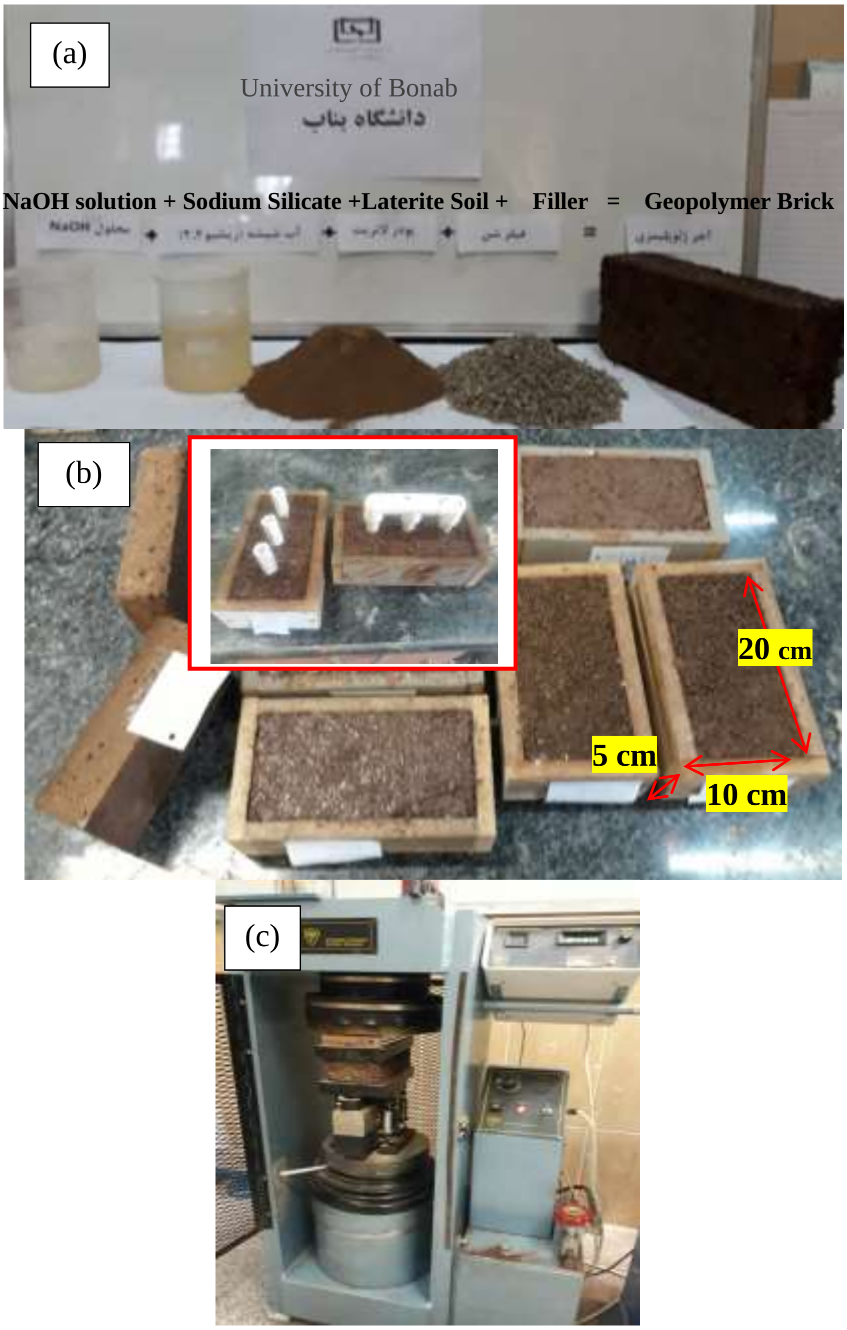


Fig. 2 - Samples of (a) Raw materials; (b) Molding ordinary and perforated samples; (c) Compressive strength testing machine

The molded brick samples here were oven drying at a relatively low temperature (85 °C) for three days, and compressive strength was measured 7 and 28 days after leaving the oven. The average compressive strength of every three samples of each design mix ratio was calculated. The water absorption percentage of each design mix with specific molarity was also determined at 7- and 28-days ages. To measure the water absorption percentage, requirements of ASTM-C67–03a standard [18] (under Iranian National Standard ISIRI-7 [19]) for the method of boiling for 5 hours at a temperature range of 110-115 °C was used. The water absorption capacity of the brick is then obtained by Eq. 1.

$$\text{Water absorption (\%)} = 100(W_2 - W_1)/W_1 \qquad (1)$$

Where W_1 is dry weight, and W_2 is the wet weight of the sample.

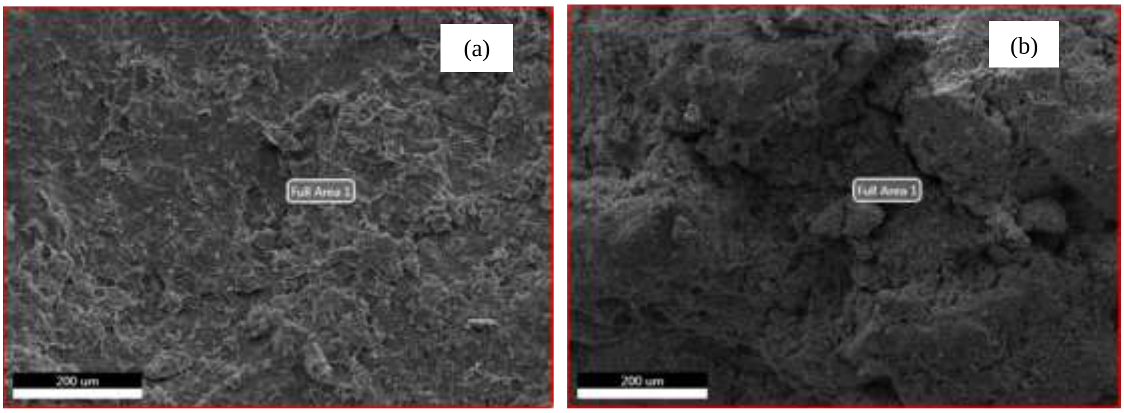
The testing program and mix proportion of geopolymer brick samples are according to table 2. Several conventional clay bricks were also purchased from the market and have been subjected to compressive strength tests, and measurement of water absorption (mixing: clay, silica sand, and water with baking in a kiln at 1000 °C temperature). It should be noted that from each sample row in table 2, 6 perforated brick samples were also prepared and subjected to compressive strength tests at the ages of 7 and 28 days.

Table 1 - An example of a table

No.	Composition	Activator/Pozzolan ratio	Laterite Soil (gr)	Laterite aggregate filler (gr)	NaOH solution (ml)	Na_2SiO_3 (ml)	Number of samples
1	G-F 8-1	0.33	900	900	148.5	148.5	4×3
2	G-F 8-2	0.33	900	900	99	198	4×3
3	G-F 10-1	0.33	900	900	148.5	148.5	4×3
4	G-F 10-2	0.33	900	900	99	198	4×3
5	G-F 14-1	0.33	900	900	148.5	148.5	4×3
6	G-F 14-2	0.33	900	900	99	198	4×3
7	G-F 18-1	0.33	900	900	148.5	148.5	4×3
8	G-F 18-2	0.33	900	900	99	198	4×3

3. Results and Discussion

The specific weight of traditional clay bricks in Iran is about 1700 kg/m3, and the weight of each brick is about 2 kg that gives several approximately 450-500 bricks per ton weight. The laterite-based geopolymer bricks introduced in this study had similar weight characteristics, and the perforated samples were about 300 g lighter than normal samples. In this study, some of the geopolymer brick samples with different molarity were selected for electron scanning by an SEM device to investigate their microstructural aspects. The results of SEM imaging, along with energy-dispersive X-ray spectroscopy EDAX analysis on the laterite and 10 M laterite-based geopolymer samples containing laterite aggregates are presented in Fig. 3. The increase in sodium-ion peak in the geopolymer sample indicates the chemical reactions between the activating solution (containing sodium hydroxide and sodium silicate) and the laterite powder as an aluminosilicate source.



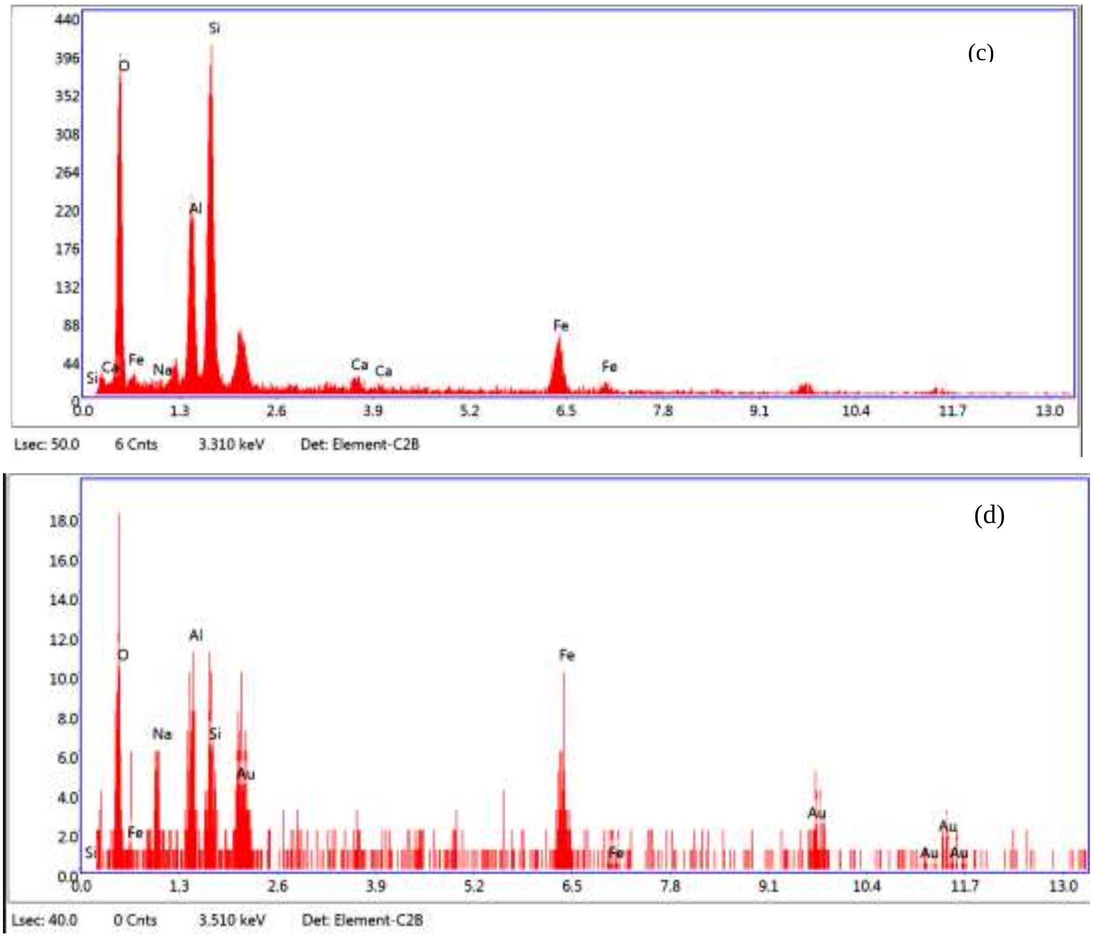


Fig. 3 - SEM images and AEDX spectra of: (a) and (c) laterite particle; (b) and (d) 10 M geopolymer samples

In the following, the introduced bricks were tested in terms of mechanical properties (compressive strength and water absorption), and the results are presented here.

3.1 Compressive Strength Test

The average compressive strength of the geopolymer brick samples at 7 and 28 days are presented in Fig.s 4 and 5 for bricks made of laterite soil passing through sieve No. 30 and 100, respectively. The composition named “A-Shahid” in the following diagrams refers to the control clay bricks. It can be seen that the compressive strength at 7 and 28 days of all samples cured in the oven is higher than 23 MPa, which is much higher than the resistance of traditional clay brick samples, and it is near to the expected strength of engineering (high-resistance) bricks. It is noteworthy that this high strength is achieved even at an early age. Also, the highest resistance was obtained in the concentration of 14 M sodium hydroxide solution and the mass ratio of sodium silicate to sodium hydroxide solution of 1 (37.5 MPa) for the case of No. 30 sieve screening of the laterite soil. And, for this case, the lowest resistance was obtained in the concentration of 8 M sodium hydroxide solution (24.5 MPa). For the case of using a sieve No. 100, similarly, the highest compressive strength (45 MPa) was obtained at a concentration of 14 M sodium hydroxide solution and a mass ratio of sodium silicate to sodium hydroxide solution of 1 and the lowest compressive strength (30.8 MPa) at the sodium hydroxide solution concentration of 8 M. Compressive strength of bricks made with an alkaline solution containing 10 M sodium hydroxide is not significantly different from bricks made with an alkaline solution containing 8 M sodium hydroxide. Therefore, to produce bricks with a lower cost and adequate compressive strength, it is recommended to use an alkaline solution containing 8 M sodium hydroxide, and a mass ratio of sodium silicate to sodium hydroxide solution of 1.

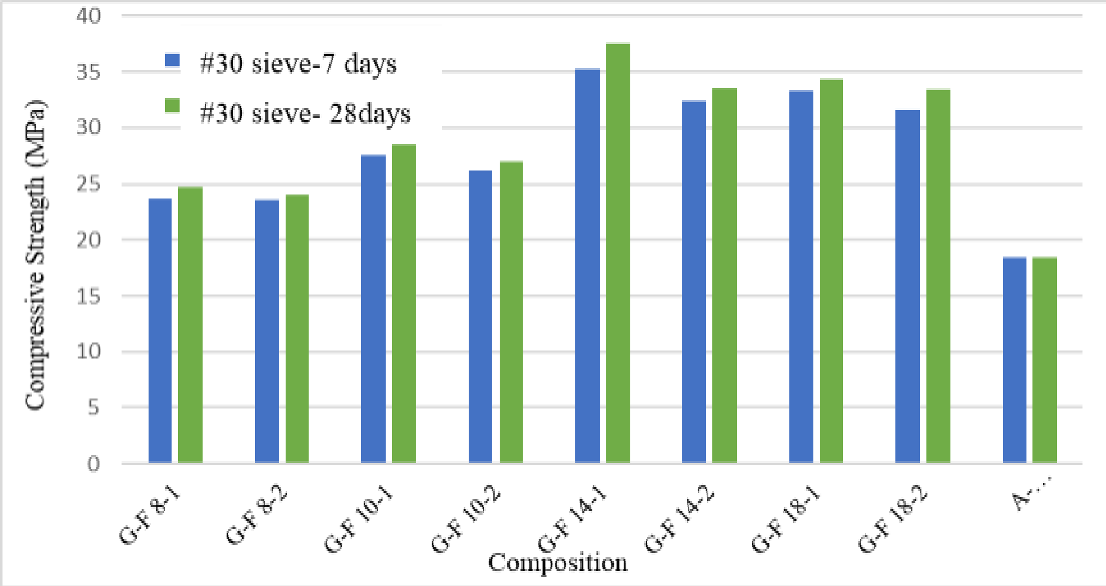


Fig. 4 - Average compressive strength of the laterite-based geopolymer bricks at 7 and 28 d (sieve No. 30) containing laterite aggregates as filler

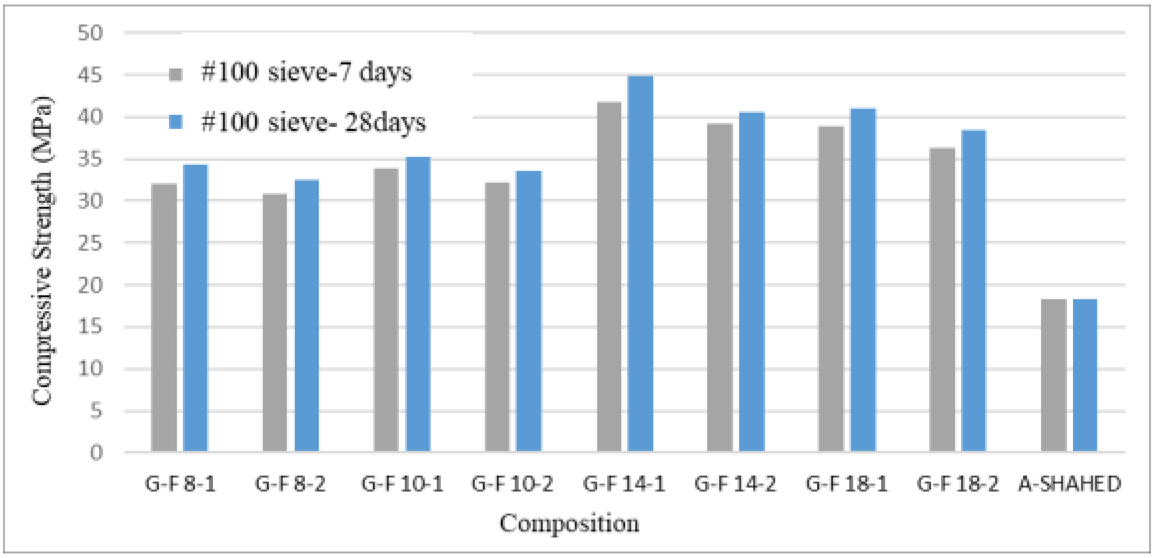


Fig. 5 - Average compressive strength of the laterite-based geopolymer brick samples at 7 and 28 d (sieve No. 100) containing laterite aggregate filler

From the above-mentioned results, it is clear that the obtained strengths are comparable to the minimum standards for high-strength engineering clay bricks proposed by the Iranian and international standards [19],[20] and are far higher than the strength of common construction bricks in the market. The similarity of the 3-day resistance to those of 28-day indicates that most of the polymerization reactions took place at a very early age.

To better investigate the sieve size effects, the compressive strength of all samples at 7 and 28 days is shown in Fig.s 6 and 7, respectively. It can be seen that in the case of using laterite soil passing through a sieve No. 100, the compressive strength of the brick is generally higher than in the case of using sieve No. 30 (14-39% differences). This phenomenon is due to the smaller size of the laterite powder grains and their higher specific surface area, which improves the geopolymerization reactions.

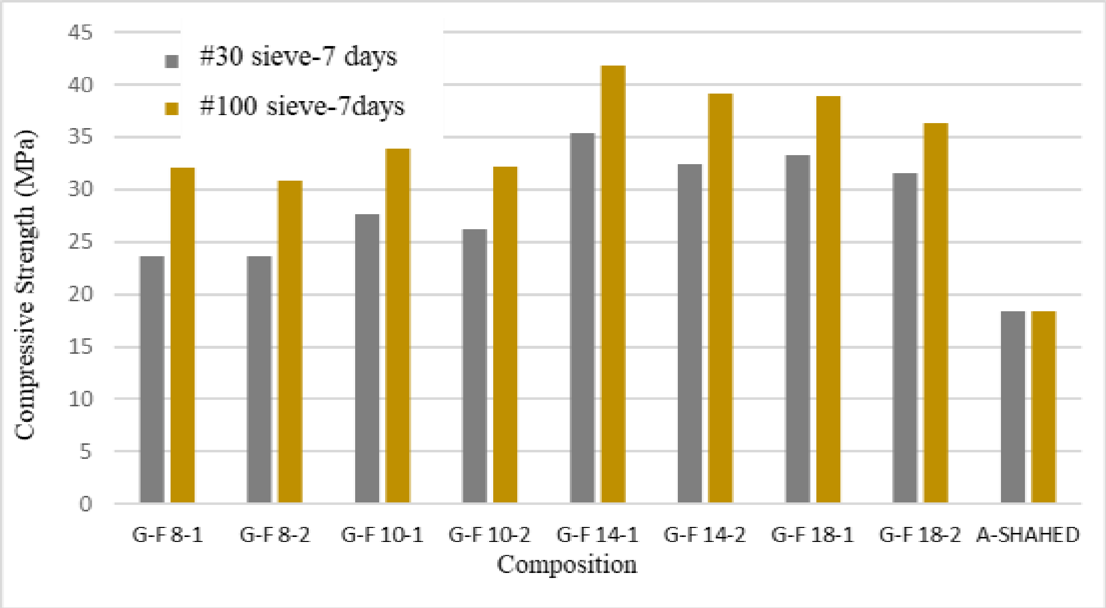


Fig. 6 - Average compressive strength of the geopolymer brick samples at 7 d with laterite screened through sieve No. 30 and 100

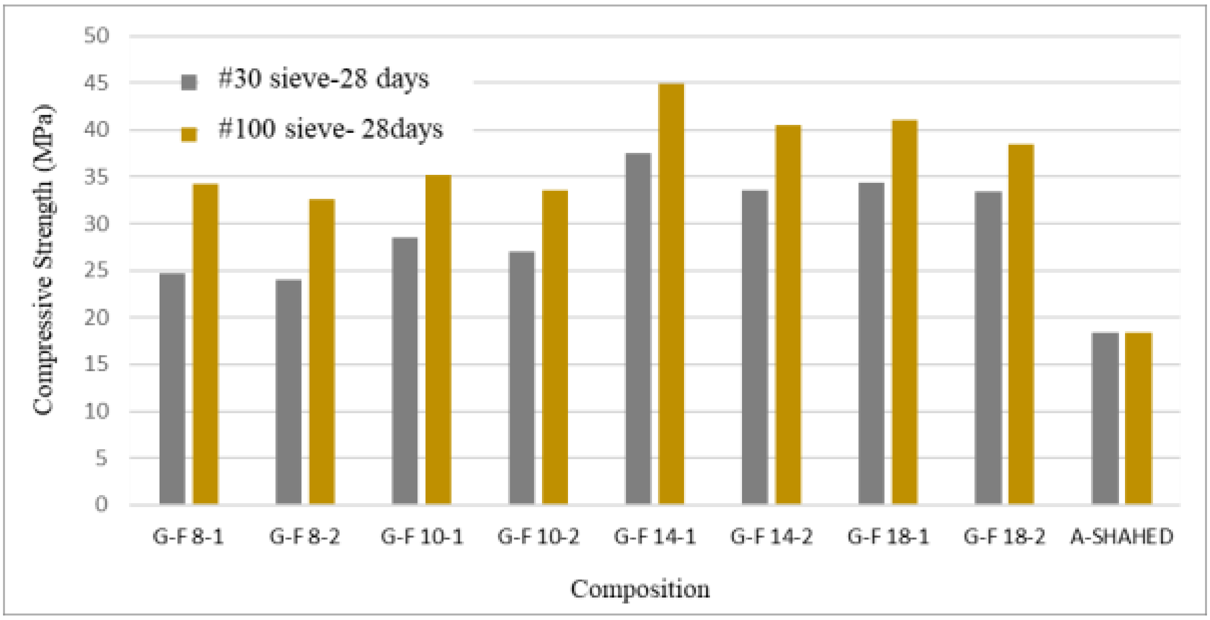


Fig. 7 - Average compressive strength of the geopolymer brick samples at 28 d with laterite screened through sieve No. 30 and 100

The average compressive strength of the geopolymer perforated brick samples at 7 and 28 days are presented in Fig.s 8 and 9 for bricks made of laterite soil passing through sieves No. 100 and 30, respectively. It can be seen that despite the lower mass of perforated bricks compared to normal ones, the compressive strength of all perforated brick samples at 7 and 28 days is still in a high range and does not decrease significantly (more than 28 MPa and 22 MPa for sieves No. 100 and 30, respectively).

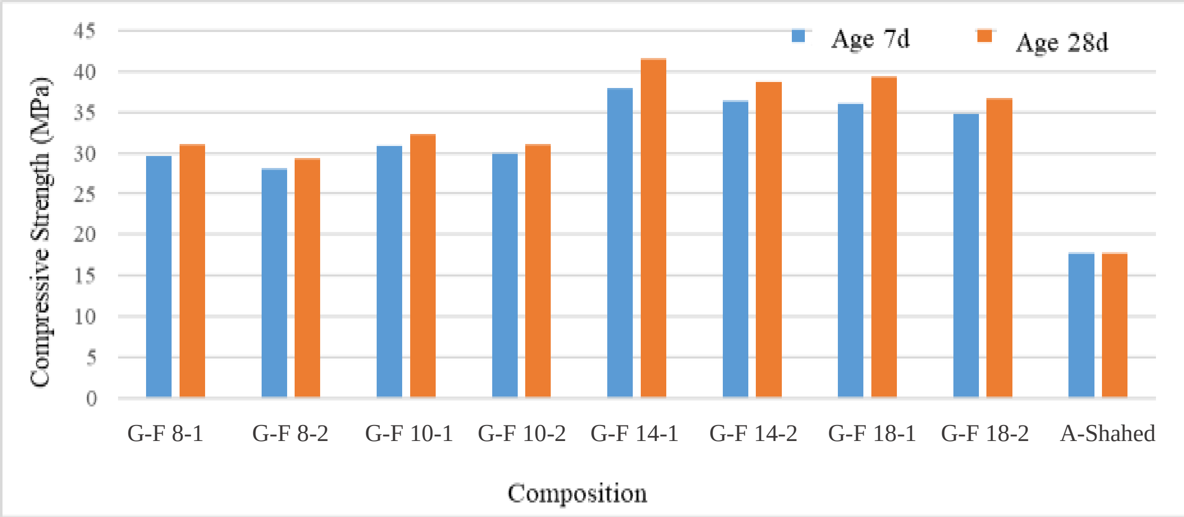


Fig. 8 - Average compressive strength of the perforated geopolymer bricks at 7 and 28 d with laterite (passing sieve No. 100) and laterite aggregate filler

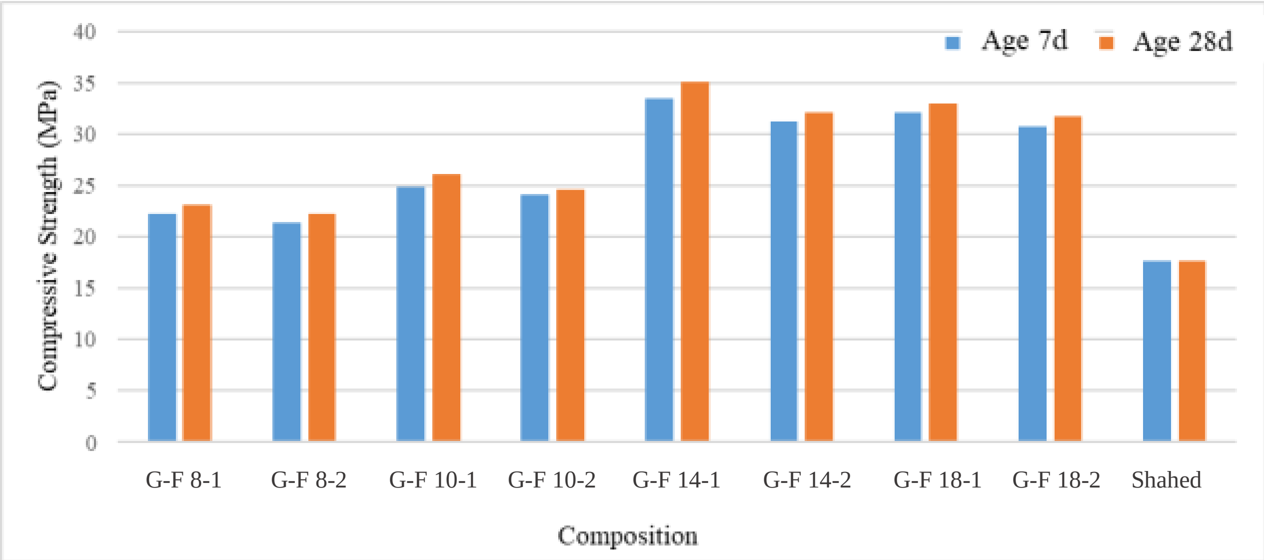


Fig. 9 - Average compressive strength of the perforated geopolymer bricks at 7 and 28 d with laterite (passing sieve No. 30) and laterite aggregate filler

3.2 Water Absorption Test

Fig. 10 shows the water absorption capacity of the samples. It can be seen that with increasing the sodium hydroxide solution content and the mass ratio of sodium silicate to sodium hydroxide solution, the water absorption of geopolymer bricks has also increased. In general, the water absorption of geopolymer bricks introduced here is 17 to 51% lower than conventional control clay bricks. At the same time, it provides the requirements for the minimum water absorption necessary for adhesion to the mortar.

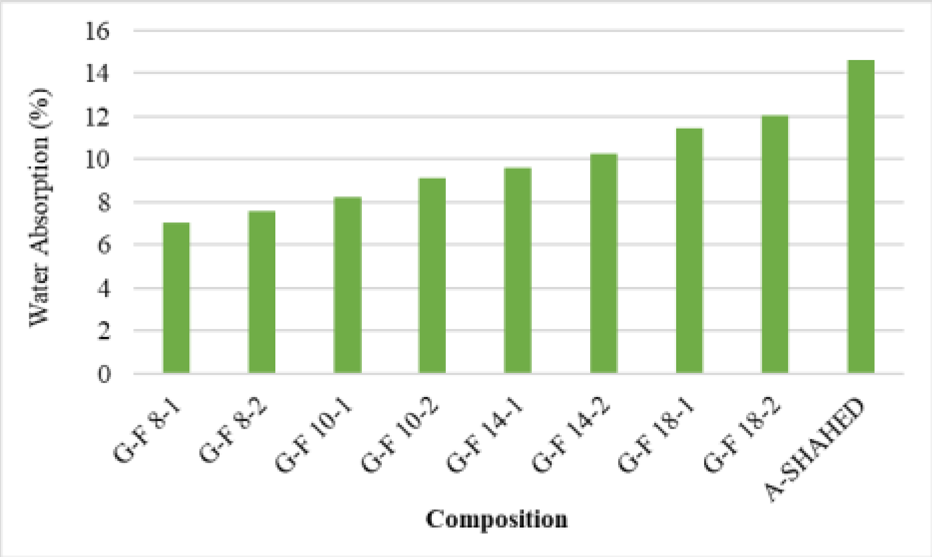


Fig. 10 - Water absorption capacity of geopolymer brick samples with laterite aggregate filler

The range of water absorption of laterite bricks introduced here (in most samples) is within limits recommended in Iranian National Standard No. 7 [19] and Part 5 of the Iranian national building code [21]. Table 3 lists the required specifications of bricks for severe, moderate, and mild weathering conditions (S, M, and N, respectively) according to the ASTM-C standard. C-62 series clay bricks are suitable for construction work, and C-902 series bricks are desired for pavement applications under light traffic conditions. The requirements of clay bricks according to the Iranian national building code (Part 5) are shown in table 4. Considering tables 3 and 4, it can be inferred that in terms of resistance properties and water absorption, most samples made and tested in this study are in the range of high-strength (engineering) load-bearing bricks and can even be used in pavement applications.

Table 3 - Standard specifications of clay bricks according to ASTM-C [20],[22]

Brick Class		**Minimum Compressive Strength psi (MPa)**		**Maximum Cold-Water Absorption, %**	
		Average of 5 brick	Individual	Average of 5 brick	Individual
C 62 Grade	SW	3000 (20.7)	2500 (17.2)	-	-
	MW	2500 (17.2)	2200 (15.2)	-	-
	NW	1500 (10.3)	1250 (8.6)	-	-
C 902 Class	SX	4000 (27.6)	3500 (24.1)	16.0	18.0
	MX	3000 (20.7)	2500 (17.2)	14.0	17.0
	NX	3000 (20.7)	2500 (17.2)	No limit	No limit

Table 4 - Performance specifications of clay bricks according to Iranian national building code- Part 5 [21]

Brick Class		**Minimum Compressive Strength, (MPa)**		**Maximum Water Absorption*, %**	
		Average	Individual	Average	Individual
Engineering brick	Class-1	35	30	12	15
	Class-2	25	20		
Facing brick	Class-1	14	11	18	20
	Class-2	12	9		
Building brick	Load-bearing	8	6	-	-
	Non-loadbearing	4	3		

* Minimum Water Absorption: 8%

4. Conclusion

In this paper, a mixed design for recyclable and eco-friendly geopolymer bricks for industrial and port buildings was presented. Laterite soil was utilized here as a pozzolanic solid component with a laterite aggregate filler in combination with an alkaline activating solution of sodium silicate and NaOH. These bricks are cured in the oven at a temperature below 100 °C and gained high compressive strength at an early age. The bricks introduced here were molded without the need for pressing force and in a simple curing process. The compressive strength of the introduced bricks was much higher compared to the conventional clay bricks, and their water absorption capacity was in a reasonable range. Therefore, laterite-based geopolymer bricks introduced here can be very suitable construction materials for load-bearing applications (with a minimum compressive strength of 24 MPa). Also, the results showed that in the case of using laterite powder passing through a sieve No. 100, the compressive strength of the bricks was always higher than the case of using laterite passing the sieve No. 30. From the economic point of view, the production of perforated geopolymer bricks using an alkaline solution containing 8 M sodium hydroxide solution was more cost-effective than other samples and had adequate mechanical strength.

Initial price analysis in this study showed approximately 5,000 Rials (about 0.2 $) were required for each laterite-based geopolymer brick sample under the laboratory conditions, which can compete with conventional building bricks in the market. It should be noted that in a practical factory environment, due to the existence of mass production facilities, these costs can be reduced significantly. As a result, these bricks will be an excellent alternative to conventional clay bricks, which is also very desirable in savings clay consumption (which is essential for agricultural applications).

We can also recommend the high-strength bricks introduced here for façade and pavement applications. Therefore, to continue the studies, abrasion, and durability tests against freeze-thaw cycles should be implemented. According to the experience of the authors, the laterite-based geopolymer bricks introduced here will show high resistance to fire, freezing, and thawing, and abrasion. Also, it is predicted that if the curing temperature increases, the strength of the resulting bricks would increase significantly. So that by further increasing the compressive strength of the laterite bricks, it is possible to produce the bricks for paving purposes that meet the requirements of the Iranian National Standard ISIRI-20185 [23].

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