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THE INFLUENCE OF BASALT MINERALS AS CEMENT SUBSTITUTION MATERIALS IN MORTAR

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Abstract. This study was conducted to determine the effect of the concentration of basalt as a cement substitution material in mortar. Basalt was analysed by XRD and XRF. From the XRD results, the diffractogram shows the dominant phases, such as anorthite, augite, forsterite, and quartz or silicon oxide. SiO_2, Al_2O_3, Fe_2O_3 are the main components in basalt, as can be seen from the XRF. With the concentration at 5 % of the basalt before the calcination, the optimum compressive strength of the OPC and PCC cement mortar was obtained. The highest compressive strength of the OPC cement mortar was 24.97 MPa with a porosity of 2.4 % and absorption of 1.29 %. Furthermore, the highest compressive strength of the PCC cement mortar was 22.55 MPa with a porosity of 4.8 % and absorption of 2.52 %. This result indicates that the substitution of composite cement with a basalt with a concentration of 5 % can increase the compressive strength of the mortar.

Keywords: Basalt, OPC, PCC, mortar, compressive strength.

1. Introduction

Indonesia is a country that has abundant metallic and non-metallic mineral resources. One of the non-metallic mineral resources is basalt rock. Based on the data from the Ministry of Energy and Mineral Resources Center in 2014, Indonesia has 6,282,661,980 tons of non-metallic basalt mineral resources. Meanwhile, according to the Lampung Mining and Energy Department, there are 318,480,000 tons of basal rock reserves [1].

Basalt is a one type of igneous rock formed by freezing magma on the surface of the earth, alkaline and grey in colour [2, 3]. The composition of basalts, with materials such as SiO_2, Al_2O_3 and Fe_2O_3 comprising more than 70 %, makes basalt a potential material that can be promoted into a cement or pozzolan substitution [4]. Pozzolan is a material that does not have properties like cement, but compounds, such as silica or silica-alumina, can react with $Ca(OH)_2$ and form compounds that have properties similar to cement (CSH) [5]. Generally, Pozzolan was used as a substitute of cement in mortars and concrete. The use of pozzolan as a cement substitute material can increase the porosity of the paste in the mixture of mortar consisting of cement, sand, water and other additives [6].

Dobiszewska et al., [7] used basalt powder with different variations as a substitution in materials. It was shown that 8 % of the weight concentration is optimal with respect to compressive and flexural strength. Abdelaziz et al., [8] used basalt powder and limestone in a mortar as a substitute of Portland cement and it exhibited the greatest compressive strength at a concentration of 12 %. Basalt powder can be used as a cement replacement material that is measured in accordance with specifications related to natural pozzolan based on ASTM C618 requirements, such as chemical components and physical properties [9]. Pourkhorshidi et al., [10] stated that the minimum concentration of $SiO_2+Al_2O_3+Fe_2O_3$ is 70 % for the pozzolan activity, fineness retained in filter no. 325 (45 μm) (wet sieved at 45 μm sieves) maximum 34 % and pozzolanic activity index at least 75 %.

In this research, basalt powder before and after the calcination was used as a cement substitution material in a mortar. It was tested for compressive strength, porosity, and absorption after 28-days.

2. Materials and methods

2.1. Materials

Basalt stone was obtained from Mataram Baru, East Lampung, Sumatera. Portland cement type I (Ordinary Portland Cement) from Semen Padang Indonesia. Portland Cement Composite (PCC) type I from Holcim, Indonesia, and sand beach from Maringgai, East Lampung.

2.2. Basalt preparation

Basalt stone was crushed by jaw crusher and grinded in the ball mill for 4 h. Then, the basalt powder was sifted using mesh no. 325. Basalt powder was calcined using electric furnace panels at 900 °C for 1 h.

2.3. Mortar preparation

The production process of mortars begins with mixing all materials having different compositions. The composition weight ratio of cement:sand was 1:2.75 and the weight concentration of the basalt powder was 0, 5, 10, 15, and 20 %. The water to cement ratio was equal to $0.4 - 0.50$. After that, the mixture was stirred until it was homogenous and put into a $5 \times 5 \times 5$ cm cube mould and dried for 24 h. Then, the mortar was soaked for 28 days and samples were tested for compressive strength and physical properties.

2.4. Sample characterization

The crystallinity and phase of basalt stone were measured by X-Ray Diffraction (XRD: Panalytical Xpert 3 Powder XRD) with a Cu-Kα as a source of X-ray operating at 40 kV and 30 mA. Samples were scanned in the range 2θ of 0-80°. The chemical composition of basalt stone was characterized by X-Ray Fluorescence (XRF Epsilon 4 XRF Spectrometer from Malvern Panalytical) operating at 50 kV and 3 mA. The compressive strength testing of OPC, PCC, and mortar was analysed by the Farrance Wykeham Machine (Model 55104 with capacity 1500 kN). The testing of beach sand, such as water content, gradation, specific gravity, sludge levels, and absorption, was conducted to characterize the used material properly. The water content was tested with ASTM D-2216 and the gradation with ASTM C-33. For testing the specific gravity, a pycnometer, according to ASTM D-854, was used. The sludge levels were tested with SNI 03-2461-2002, the absorption with SNI 1970-2008.

3. Results and discussion

3.1. The characterization of basalt stone

The composition of basalt stone from Mataram Baru, East Lampung, Sumatera is presented in Table 1. Table 1 shows the basalt before and after the calcination, which has a total content of SiO_2+Al_2O_3+Fe_2O_3 of 82.155 % and 82.190 %. Based on ASTM C618, basalt fulfills chemical requirements as a cement or pozzolan substitution. Generally, the content of pozzolan with a percentage of total gravity of SiO_2, Al_2O_3, and Fe_2O_3 of 50 % produces good pozzolanic materials and it can be used as a cement substitution material [11].

The XRD patterns of basalt before and after the calcination are presented in Figure 1. In Figure 1a, the diffractogram of the basalt before the calcination is dominated by peaks of anorthite, augite, forsterite, quartz. After the calcination in Figure 1b, the peaks of anorthite, augite, forsterite, and silicon oxide dominated. Generally, this phase consists of compounds, such as calcium, silica, alumina, iron oxide and magnesium. In addition, the calcination does not significantly influence the phase formed in the sample. The results of the analysis of sand beach are presented in Table 2. The results showed that the standard is sufficient as a fine aggregate in the mortar.

3.2. The effect of basalt as cement substitution material in mortar

The compressive strength testing was carried out on mortar specimens with dimensions of $5 \times 5 \times 5$ cm. The purpose of this test was to get the value of the mortar's compressive strength and determine the quality of the mortar. The results of the compressive strength testing are shown in Figure 2 and Figure 3. The compressive strength of Ordinary Portland Cement (OPC) was 19.50 MPa. In Figure 2, the values of the compressive strength of the OPC at concentrations of 5, 15, and 20 % with basalt powder before the calcination are 24.97, 21.03, and 22.37 MPa, respectively, while the value of the compressive strength at a concentration of 10 % reached 17.89 MPa. This is because the index of the pozzolan from basalt is still low compared to a standard value. With the basalt powder, after calcination, the value of the compressive strength of the OPC at concentrations of 5 and 20 % are 20.85 and 24.16 MPa, respectively. In addition, with concentrations of 10 and 15 %, the strength only reached 15.83 and 15.92 MPa, respectively. This result indicates that the heavy concentration of basalt powder after calcination can negatively affect the compressive strength of the mortar.

The standard compressive strength of Portland Cement Composite (PCC) was 13.95 MPa. In Figure 3, the values of the compressive strength of the PCC at concentrations of 5 and 10 % with basalt powder before the calcination are 22.55 and 19.15 MPa, respectively. In addition, with concentrations of 15 and 20 %, it only reached 11.98 MPa and 9.02 MPa, respectively. With basalt powder after calcination at concentrations of 5, 10, 15, and 20 %, the value of the compressive strength of the PCC were 21.11, 17.62, 10.36, and 9.92 MPa, respectively. This result indicates that the substitution of cement with basalt concentration of 5 % can increase the strength due to a reduction of the cement content in the mortar [12, 13].

The value of the compressive strength is influenced by the density of the mortar. The addition of the basalt into the mortar increases the compressive strength as a consequence of the density increment. As shown in Table 3, the cement matrix such as pozzolan (based on ASTM C618) consists of SiO_2+Al_2O_3+Fe_2O_3 by more than 70 %, in our case, the amount before and after the calcination was 82.155 % and 82.190 %, respectively [14]. Furthermore, the mortar with the basalt after the calcination showed a lower compressive strength than before the calcination. This is because high temperatures in pozzolan materials can affect the pore volume in the mixture so that the compressive strength decreases [15]. The water to cement ratio is very influential on the level of dryness of the mortar. If the ratio is higher, the

No	Sand (gr)	Water (mL)	OPC cement (gr)	Basalt powder	
				Before calcination	After calcination
1.	688	121	250	-	-
2.	688	121	237.5	12.5	-
3.	688	121	225	25	-
4.	688	121	212.5	37.5	-
5.	688	121	200	50	-
6.	688	121	237.5	-	12.5
7.	688	121	225	-	25
8.	688	121	212.5	-	37.5
9.	688	121	200	-	50

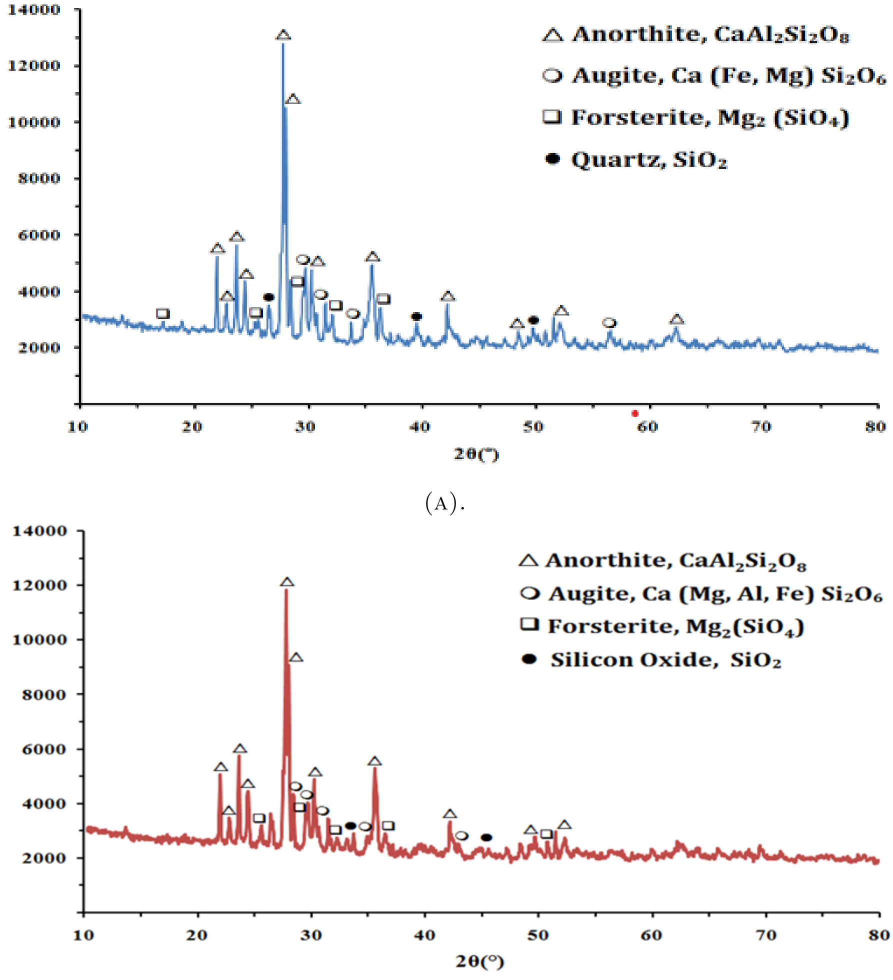
Table 1. Mortar mixture proportions (gr) with OPC cement.

No	Sand (gr)	Water (mL)	PCC cement (gr)	Basalt powder	
				Before calcination	After calcination
1.	688	121	250	-	-
2.	688	121	237.5	12.5	-
3.	688	121	225	25	-
4.	688	121	212.5	37.5	-
5.	688	121	200	50	-
6.	688	121	237.5	-	12.5
7.	688	121	225	-	25
8.	688	121	212.5	-	37.5
9.	688	121	200	-	50

Table 2. Mortar mixture proportions (gr) with PCC cement.

Compounds	Percentage (%)	
	Before calcination	After calcination
SiO_2	50.729	50.303
Al_2O_3	19.337	19.417
Fe_2O_3	12.109	12.470
CaO	10.358	10.300
MgO	4.387	4.418
TiO_2	1.378	1.368
K_2O	0.654	0.676
P_2O_5	0.529	0.519
MnO	0.202	0.213
$SiO_2 + Al_2O_3 + Fe_2O_3$	82.175	82.19

Table 3. The composition of basalt stone.



(a).

(b).

Figure 1. XRD diffractogram pattern of basalt samples before and after calcination.

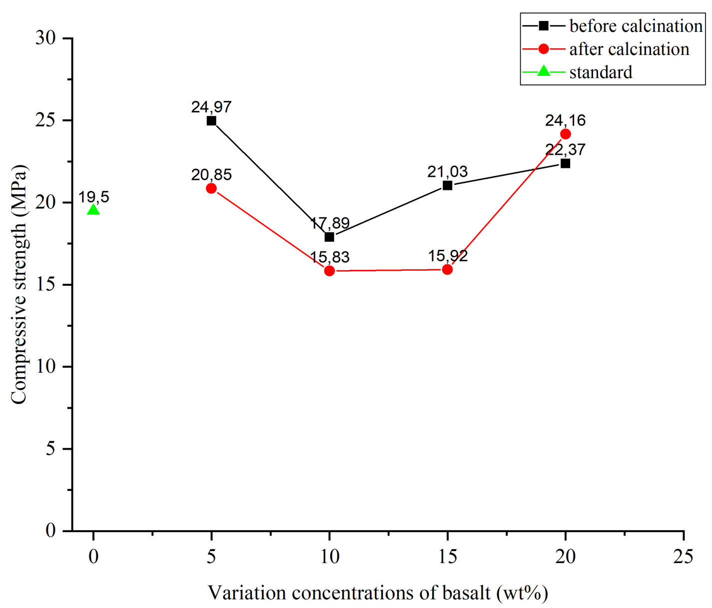


Figure 2. Compressive strength of OPC cement mortar with variations concentration.

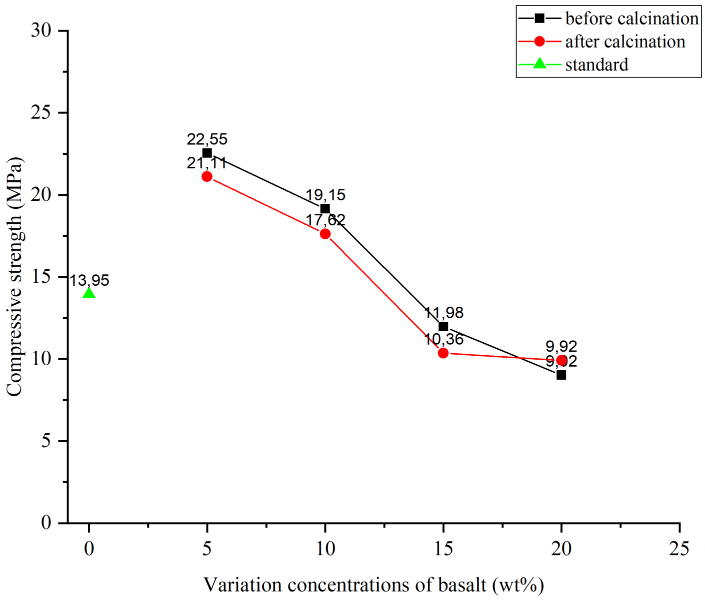


Figure 3. Compressive strength of OPC cement mortar with variations concentration.

mortar is more dilute and dries for longer, therefore, it affects the compressive strength of the mortar.

The compressive strength of the mortar with the substitution of the basalt has a higher compressive strength due to a good pozzolan reaction. When the silica-containing pozzolan material is added during the hydration of Portland cement, it reacts with calcium hydroxide $Ca(OH)_2$ to provide additional Calcium Silicate Hydrate (CSH), which is a major component in the cement hydration. Gradually, the addition of calcium silicate hydrate formed binds and fills the space and thus provides a better impermeability, durability and strength [16]. The pozzolanic reaction that occurs during hydration is:

$$Ca(OH)_2 + SiO_2 \longrightarrow C - S - H \tag{1}$$

Basalt can react with $Ca(OH)_2$ during the hydration reaction and form calcium silicate hydrate (CSH). It reduces the pores of the product and makes the microstructure of the material more uniform, increases density, compressive strength, and durability [9]. In addition, the size of the basalt powder (45 μm) causes a larger surface area, which increases the reactivity of pozzolan. The smaller size causes the basalt to be dispersed into the mixture of cement in the mortar and makes the cement more homogeneous. This powder will fill the voids that exist and make the structure more solid and thus increases the compressive strength [17].

3.3. Porosity and absorption properties of OPC and PCC cement mortar

Porosity and absorption properties of the OPC and PCC cement mortar with various concentrations of basalt are shown in Figure 4. The porosity and absorption of the OPC cement mortar are 3.2 and 1.73 %, respectively. In Figure 4a, the concentrations of basalt, before the calcination, of 5, 10, 15 and 20 % are shown, having a porosity of 2.4, 4.0, 3.2 and 2.4 %, with an absorption of 1.29, 2.13, 1.69 and 1.29 %, respectively. In Figure 4b, the concentrations of basalt, after the calcination, of 5, 10, 15 and 20 %, having a porosity of 3.2, 4.8, 4.8 and 2.4 %, with an absorption of 1.70, 2.58, 2.54 and 1.30 %, respectively. The porosity and absorption of the PCC cement mortar are 8.0 and 4.24 %, respectively. In Figure 4c, the concentrations of basalt, before the calcination, of 5, 10, 15 and 20 %, having a porosity of 4.8, 4.8, 8.8 and 11.2, with an absorption of 2.52, 2.56, 4.85 and 5.98 %, respectively. In Figure 4d, the concentrations of basalt, after the calcination, of 5, 10, 15 and 20 %, having a porosity of 4.8, 5.6, 8.8 and 10.4 %, with an absorption of 2.50, 3.06, 4.93 and 5.58 %, respectively.

Porosity is reduced because large pores in the mortar are filled up with basalt. This result improved mechanical properties of mortar [18]. Furthermore, the reduction of porosity is due to the fewer pores that are connected so that compressive strength will be higher and the absorption of water will be smaller [19]. These results indicate that basalt can reduce the porosity and absorption of the PCC and OPC cement mortar. The secondary reaction formation of calcium silicate hydrate (CSH) produced from the pozzolan reaction between the basalt and cement in the mortar can increase the bond between the paste and aggregate so it can reduce the porosity and capillaries in the mortar. The decrease in porosity and capillary shows that the

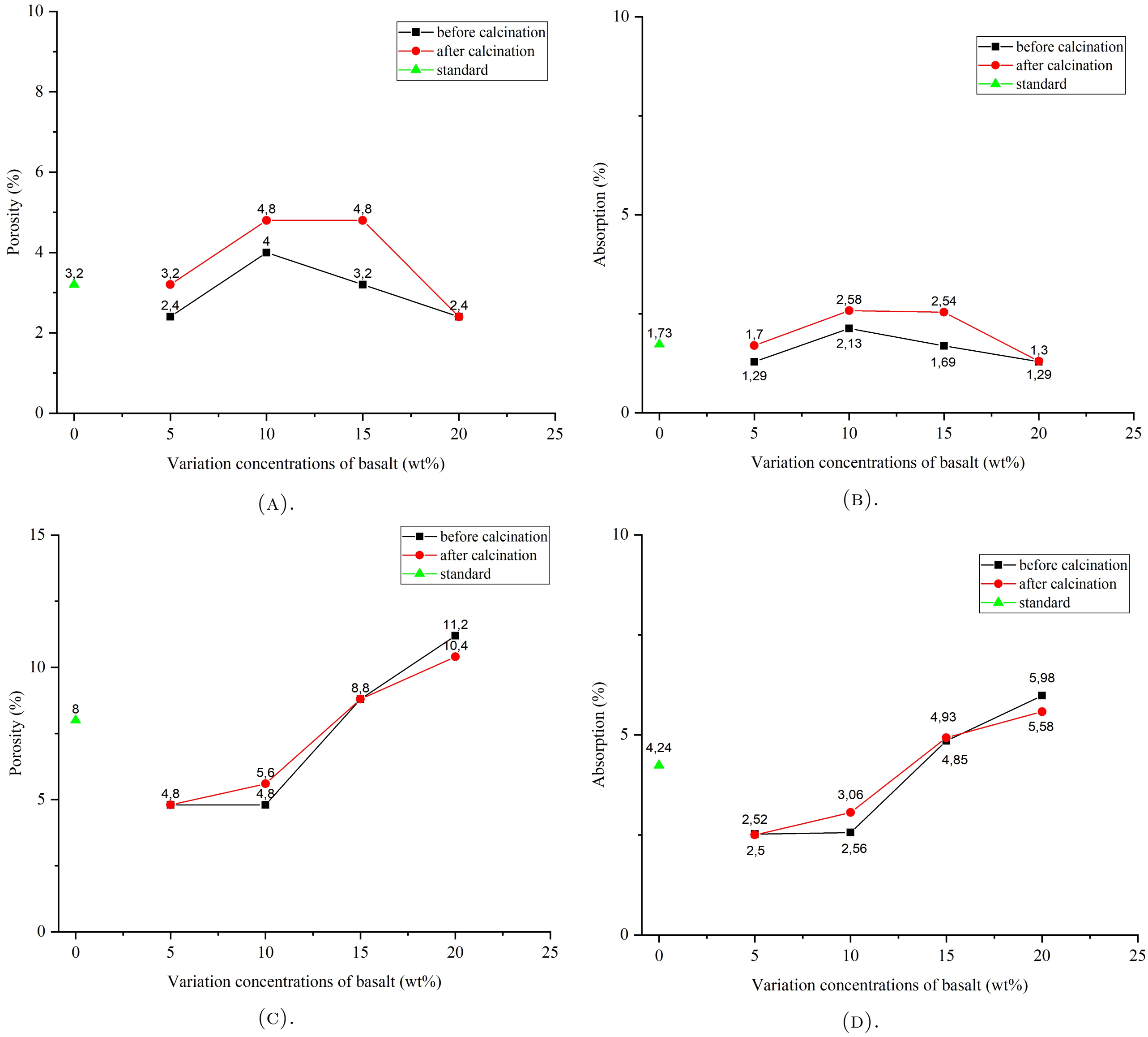


Figure 4. The porosity and absorption properties of OPC cement mortar (a and b) and PCC cement mortar (c and d) with variation concentration of basalt.

No.	Testing	Results	Standard	Information
1.	Water content	0.3 %	-	According to humidity
2.	Gradation	2.3	2.2 – 3.2	Qualify
3.	Specific gravity	2.55 gr/cm^3	2.4 - 2.9	Qualify
4.	Sludge levels	1.3 %	$\leq$ 5 %	Qualify
5.	Absorption	3.1 %	$\leq$ 13.27 %	Qualify

Table 4. The results of analysis of sand testing.

smaller pores are responsible for the good mechanical performance [20].

4. Conclusions

This paper has demonstrated the potential of using basalt from Mataram Baru, East Lampung, Sumatera. It was found that the compressive strength of the OPC cement mortar and the PCC cement mortar with basalt at a concentration of 5 % before a calcination was 24.97 and 22.55 MPa, respectively. Furthermore, the mortar with the basalt showed a lower compressive strength after the calcination than before the it. This is because high temperatures in pozzolan materials can affect the pore volume in the mixture so that the compressive strength decreases.

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