# STEEL FIBER EFFECT IN BENDING AND COMPRESSIVE STRENGTH ENHANCEMENT OF GEOPOLYMER COMPOSITE

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## Abstract

*Geopolymer composites are good substitute (alternative) for traditional concrete and their essential material are plant toxic byproducts or inexpensive and abundant nature materials like pozzolans. In this study NaOH and $Na_2SiO_3$ was used for pumice activation that extracted from Hasankale resource located east of Turkey to produce geopolymer and the effects of the steel fibers on the compressive and bending strength of geopolymer composites has been studied. The unique chemical structure of geopolymer ingredients leads to superior properties and while bending and compressive strength of geopolymer enhanced with steel fiber a reinforced geopolymer concrete is produced and with regard to the effect of the geopolymer composites in reducing greenhouse gas, environment $CO_2$ content and amount of energy needed to produce ordinary cement, using of geopolymer composites instead of ordinary concrete is recommended.*

## 1 Introduction

The environmental impact of ordinary Portland cement is significant because its production emit large amount of $CO_2$. In recent year's research about geopolymer as a good substitute material to enhance cementitious material greenness and concrete durability has been increased. Geopolymer can be classified as an inorganic material with a chemical composition similar to zeolites and normally have an amorphous texture [1]. The geopolymer terms describe a family of mineral binders that they have polymeric silicon-oxygen-aluminum framework structures [2]. In other words geopolymer cement are a group of alkali activated materials that exhibit superior engineering properties compared to Portland cement [3,4,5] and geopolymers can be produced when alumino-silicate and alkali poly-sialate react in a highly alkaline conditions.

The alumino silicate used for the production of geopolymer cement must contain Al which is readily soluble with an overall molar ratio of $Al_2O_3/SiO_2$ between 1/3.3-1/6.5 [6].

In this study the possibility of geopolymer production from Hasankale natural pumice and the effect of fiber steel in bending and compression strength improvement have been investigated.

## 2 Materials

*2.1 Pumice*

Natural pumice used in present study has been obtained from Hasankale region near Erzurum located in the east of Turkey. The pozzolan firstly has been characterized for its chemical composition. The chemical composition has been shown in Figure 1, Table 1 and Table 2. X-ray diffractogram for the ground pumice showed very amorphous phase in sample textures.

All of the powdered pumice was finer than 200 µm and 93.8% is finer than 90 µm. Blaine's specific surface was 2980cm$^2$/g and the density of ground pumice is 2.38. The used pumice is grounded in FRITSCH mill made in Germany (Figure 2).

Particle size distribution has a very important effect in geopolymer cement specification and the particle size distribution for ground pumice has been illustrated in Figure 3.

| $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $K_2O+Na_2O$ | Others | LOI |
|---|---|---|---|---|---|---|---|
| 67.08 | 14.06 | 1.91 | 0.87 | 0.25 | 0.11 | 15.72 | 3.94 |

**Table 1.** Chemical composition of Hasankale pumice.

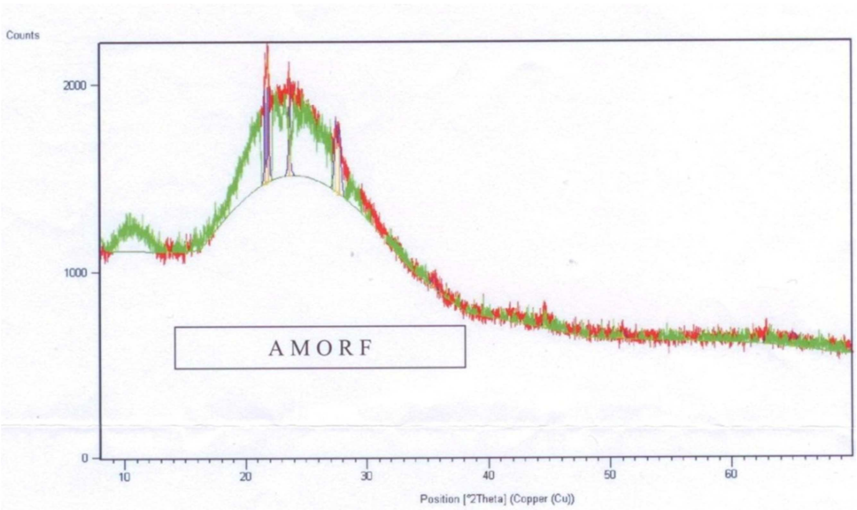


**Figure 1.** X-ray diffraction pattern of Hasankale pumice.

**Figure 2.** FRITSCH mill used for grinding the pumice.

In the non-crystalline state, diffraction of X-Rays results in a broad diffuse halo rather than sharp diffraction peaks.

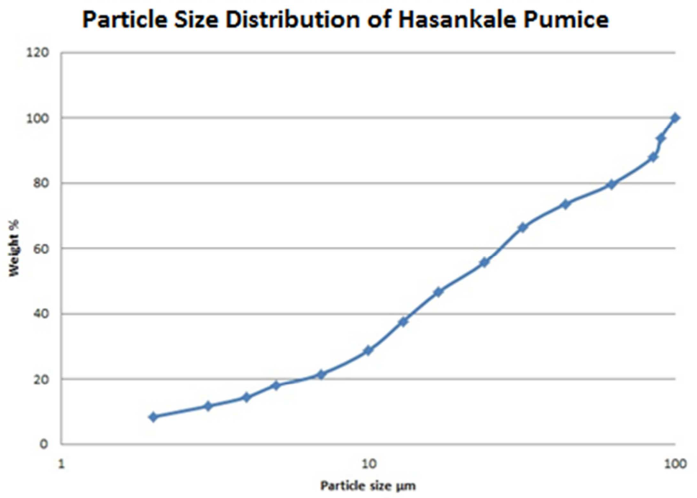


**Figure 3.** Particle size distribution of ground Hasankale pumice.

| No | Mineral Name | Framework Formula |
|---|---|---|
| 1 | Cristobalit, High | $SiO_2$ |
| 2 | Silicium Dioxide | $SiO_2$ |
| 3 | Labrodorit | $(Na_{0.4}Ca_{0.6})Al_{1.6}Si_{2.4}O_8$ |
| 4 | Cristobalit, Low | $SiO_2$ |
| 5 | Albit, High, Sodium-Tectosilicate | $Na(AlSi_3O_8)$ |

**Table 2.** Some of determined materials in the Hasankale pumice from XRD.

*2.2 Sodium hydroxide*

Commonly the sodium hydroxides are available in solid state by means of pellets and flakes [7]. In this study the liquid sodium hydroxide was used and its physical and chemical properties are given by the manufacturer has been shown in Table 3.

| Chemical Formula | $NaOH*H_2O$ |
|---|---|
| NaOH | 32-33 |
| $H_2O$ | 67-68 |
| Appearance | Gel |
| Specific Gravity ($20^0C$) | 1.35 |

**Table 3.** Physical and chemical properties of sodium hydroxide.

*2.3 Sodium silicate*

Sodium silicate is known as water glass and available in gel form. In this study ratio between $SiO_2$ to $Na_2O$ is 1.95-2.3 chemical specifications and the physical properties for used sodium silicate have been shown in Table 4. The production has been purchased from MERCK company.

| Chemical Formula | $Na_2O*SiO_2$ Colour Less |
|---|---|
| $SiO_2$ | 22-24 |
| $Na_2O$ | 11-12 |
| $H_2O$ | 64-67 |

| | |
|---|---|
| Appearance | Gel |
| Specific Gravity(20$^0$C) | 1.38-1.397 |

**Table 4.** Physical and chemical properties of sodium silicate.

*2.4 Steel fibers*

Used steel fiber properties for matrix enhancement has been shown in Table 5.

| | |
|---|---|
| Name | Dramix OL6/16 |
| Diameter, d (mm) | 0.16 |
| Length, l (mm) | 6 |
| Aspect Ratio (l/d) | 37.5 |
| Density (g/cm$^3$) | 7.17 |
| Tensile Strength (MPa) | 2250 |
| Cover | Brass |

**Table 5.** Mechanical properties of steel fibers.

## 3 Sample preparation and experimental techniques

In order to determine the Hasankale pumice activation and steel fibers effect in the compressive and bending strength of samples a mix design has been selected from previous works that has been shown in Table 6. Resulting paste from Table 7 [3] mix design was blended with blender (Bench-mounting Mixer made by ELE company-Germany) for about 3 minute then the paste transferred to steel moulds and has been vibrated for 2 minute with ELE 34-6220/01 vibrating table. Then specimens were left standing for 48 hour at 65$^0$C in curing chamber. Demoulding was done at 48 hours and then specimens left in curing chamber with relative humidity about 50% and 30$^0$C and 28 days after casting the samples ready for bending (ASTM C348-86) and compressive testing (ASTM C109-90). It is remarkable that alkaline liquids are prepared by mixing of the sodium hydroxide solution and sodium silicate at the room temperature. When the solution mixed polymerization takes place and it liberate large amount of heat so it is recommended to leave it for about 24 hours thus the alkaline liquid is get ready as binding agent.

In this study three mixtures has been used. In first mixture only geopolymer has been used but in others the weight ratio for steel fiber to pumice is 2% and 4% orderly. For each mixture five 50*50*50mm cube moulds for compressive strength and five 40*40*160mm prismatic moulds for bending strength has been used.

| No | Pumice (gr) | NaOH Solution (gr) | $Na_2SiO_3$ Solution (gr) | $H_2O$ (gr) | Super Plasticizer (gr) | Steel Fiber (gr) |
|---|---|---|---|---|---|---|
| 1 | 1600 | 456 | 456 | 196 | 16 | 0 |
| 2 | 1600 | 456 | 456 | 196 | 16 | 320 |
| 3 | 1600 | 456 | 456 | 196 | 16 | 640 |
| *These mix proportions are for 1mix batch i.e. 1548 cc geopolymer cement paste. | | | | | | |

**Table 6.** Mix proportions for Hasankale reinforced pumice-based geopolymers.

## 4 Results and discussions

In the present work, to determine the effect of steel fiber on compressive strength and bending strength in geopolymer cements, samples were tested after 28 days. The results are given in Table 7 and Figures 4, 5 for the three percentage of steel fiber (0, 2%, and 4%).

| Type | Load (N) | Area ($mm^2$) | Compressive Strength (MPa) |
|---|---|---|---|
| Without fiber | 22340 | 50*50 | 8.94 |
| With 2% steel fiber | 41923 | 50*50 | 16.77 |
| With 4% steel fiber | 42414 | 50*50 | 16.97 |

**Table 7.** Average of compressive strength for 5 samples of geopolymer composites after 28 days.

| Type | Length (cm) | Load (N) | Bending Moment (N.cm) | Bending Area ($mm^2$) | Bending Strength (MPa) |
|---|---|---|---|---|---|
| Without fiber | 16 | 275.76 | 1103.04 | 40*40 | 1.03 |
| With 2% steel fiber | 16 | 372.65 | 1490.60 | 40*40 | 1.40 |
| With 4% steel fiber | 16 | 410.60 | 1642.40 | 40*40 | 1.54 |

**Table 8.** Average of bending strength for 5 samples of geopolymer composites after 28 days.

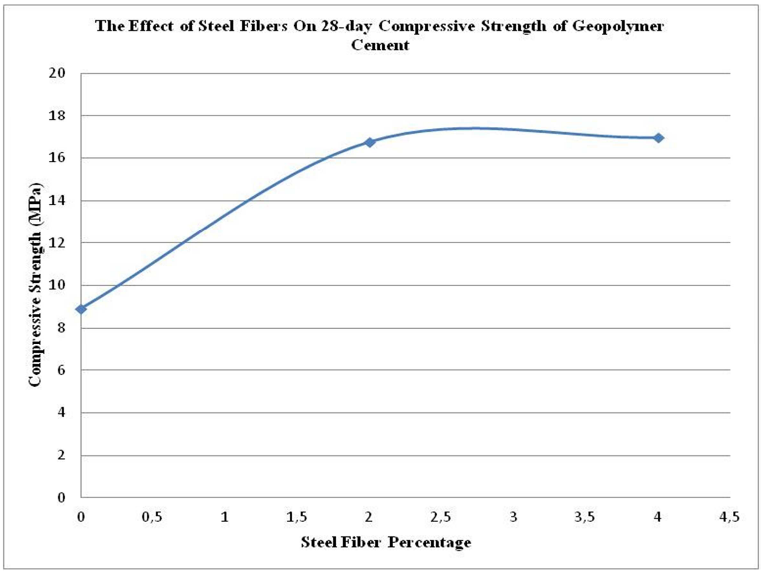


**Figure 4.** The effect of steel fibers on 28-day compressive strength of geopolymer cement.

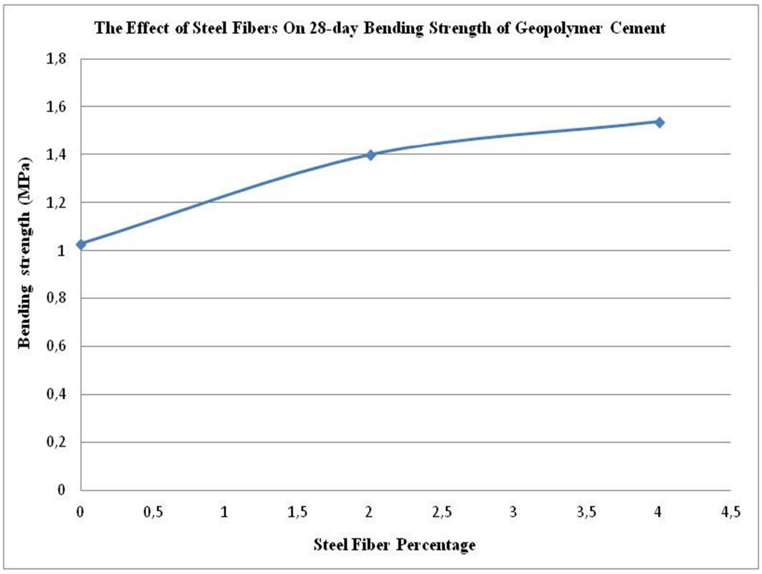


**Figure 5.** The effect of steel fibers on 28-day bending strength of geopolymer cement.

## 5 Conclusions

- Hasankale pumice can be activated and condensed in alkaline environment with sodium silicate and sodium hydroxide and can be generate geopolymeric material with a low environmental impact.
- Relatively 28-day compressive and bending strength without steel fiber are 8.94 MPa, 1.03 MPa orderly and relatively 28-day compressive and bending strength with steel fibers are 16.77 MPa, 1.40 MPa and 16.97 MPa, 1.54 MPa for 2% and 4% steel fibers orderly.
- We can use steel fibers for geopolymer cement enhancement.

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