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Investigation of Mechanical Properties of Geopolymer Concrete and Its Application in Beam-Column Joint

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ABSTRACT: In this study, the effects of sodium hydroxide solution concentration and sodium hydroxide to sodium silicate weight ratio on compressive strength, tensile strength, and elastic modulus of slag-based geopolymer concrete are investigated. The results of the experiments show that by reducing the ratio of sodium hydroxide to sodium silicate and increasing the concentration of sodium hydroxide, the compressive strength and tensile strength of concrete increase. In addition, by increasing the concentration of sodium hydroxide and reducing the ratio of sodium hydroxide to sodium silicate, the modulus of elasticity decreases, and no clear relationship is observed between compressive strength and modulus of elasticity of geopolymer concrete. Therefore, a mix design with a ratio of sodium hydroxide to sodium silicate equal to 0.4 and a concentration of 6 molarity sodium hydroxide with the highest compressive strength was selected to be used for the second step of the research. The performance of beam-column joints in past earthquakes shows their importance in the performance of concrete moment-resisting frames. Therefore, in the second step of this research, an experimental study is done for two beam-column joints with geopolymer concrete and ordinary concrete. In order to investigate the cyclic behavior of the joint, the experiment is performed according to the loading protocol of ACI 374.1-05. The results of the experiment show that the geopolymer concrete beam-column joint has the acceptance criteria of ACI 374.1-05 regulations, and also, its seismic performance assures that the plastic hinge is generated in the beam properly.

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1- Introduction

Geopolymer concrete can be used as a scientific and practical solution and is a suitable alternative for concrete containing Portland cement. Production of geopolymer cement requires less energy consumption and Carbon dioxide emissions are reduced by 22 to 72 percent compared to Portland cement production. Hence, one of the ways to produce environmentally friendly concrete is to use pozzolanic and quasi-cement adhesives and reduce the consumption of Portland cement [1].

In a concrete beam-column joint, the strong-column weak-beam concept enforces that the beams should fail or have plastic hinges prior to the columns. In addition, the panel zone of the connection should perform perfectly to cause a proper performance of the beam and the column. Otherwise, the expected performance of the beam and the column will not be achieved. Therefore design criteria should be formulated in such a way that this mechanism does not occur in a concrete beam-column joint. Deepa Raj et al. [2] investigated the performance of geopolymer concrete beam-column joint constructed with fly ash under a cyclic load. Datta and Premkumar [3] studied beam-column joint using geopolymer concrete based on a mixture of fly ash and slag and with and without steel fibers.

The application of geopolymer concrete in non-structural elements has been developed in many countries. However, the application of this concrete in structural components has been studied less. Also, since in most countries, fly ash is mostly found as a by-product of factories, studies on geopolymer concrete are also mostly based on fly ash. The need to study the behavior of beam-column joint using slag-based geopolymer concrete, which is a by-product of factories in Iran and is found at a reasonable price, is clear. It should be noted that so far, no similar study has been conducted in Iran for the application of geopolymer concrete in structural members.

2- Materials and Methods

In this paper, first, six mixing designs of geopolymer concrete have been prepared. Then compressive strength, tensile strength and modulus of elasticity tests were performed on their cylindrical specimens. The composition of the six mixing designs is shown in Table 1. The results of the tests of compressive strength, tensile strength and modulus of

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Table 1. Selected mixing designs

Design name	1	2	3	4	5	6
Sodium hydroxide solution concentration (Molarity)	4	4	4	6	6	6
Weight ratio of sodium hydroxide solution to sodium silicate	3	1	0.4	3	1	0.4
Slag (kg/m^3)	3888.3	375.5	365	380	371	364
Sodium hydroxide solution (kg/m^3)	131.5	84.5	47.5	128	83.5	47.3
Sodium silicate (kg/m^3)	43.8	84.5	117	42.7	83.5	116.5
Added water (kg/m^3)	36.9	55.5	71.6	48	62.3	72.8
Polycarboxylate lubricant (kg/m^3)	3.8	3.7	3.6	3.8	3.7	3.6

Table 2. Results of the tests of compressive strength, tensile strength and modulus of elasticity

Design name	1	2	3	4	5	6
7-day compressive strength (MPa)	24.2	21.3	19.5	25.3	23.7	24.6
28-day compressive strength (MPa)	37.2	40.6	35.8	39.6	43.5	48.3
90-day compressive strength (MPa)	39.9	44.2	47.7	42.2	46.3	56.7
28-day tensile strength (MPa)	3.1	3.35	2.9	3.3	3.7	4
28-day Modulus of elasticity (GPa)	23	20	19	21	18	16

elasticity are shown in Table 2.

According to the experimental observations of the six mixing designs, the sixth design, having more sodium silicate, had the highest compressive strength of 28 and 90 days and the highest tensile strength. Also, based on the observations during the construction of the specimens, this design maintained its workability for a longer period of time. In addition, due to the lower amount of sodium hydroxide in it, a later initial setting time occurred in it. Therefore the sixth design was selected as the optimal design.

In order to investigate the application of geopolymer concrete in the beam-column joint, it is necessary to test the specimen under cyclic load. Figure 1 shows the sample connection dimensions and the reinforcement details of the specimen. A connection specimen was also made using ordinary concrete. How to configure the experiment is shown in Figure 2.

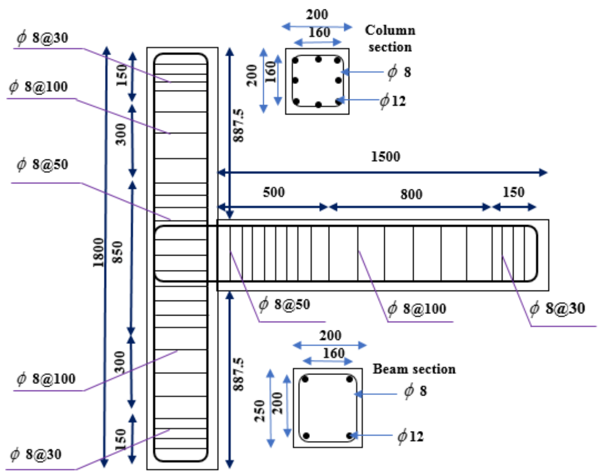


Fig. 1. Geometric specifications and reinforcement details of the connection sample (all dimensions are in millimeters)

3- Results and Discussion

According to the hysteresis curve (Figure 3), beam-column joint using geopolymer concrete had a complete elastic behavior until lateral drift of 0.75%, but in beam-column joint using ordinary concrete, this behavior is found until 0.5% lateral drift. Figure 3 indicates the proper absorption of energy in the specimen with geopolymer concrete and its similar performance to the joint constructed with ordinary concrete.

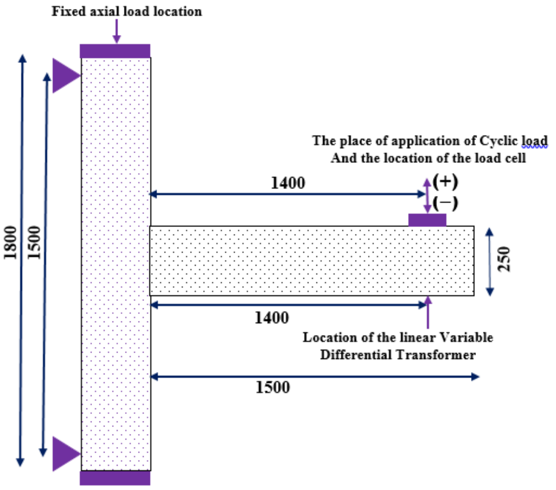
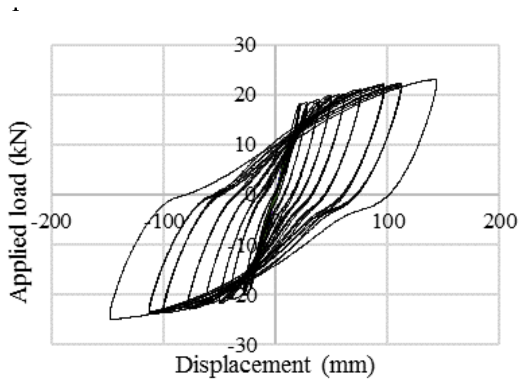
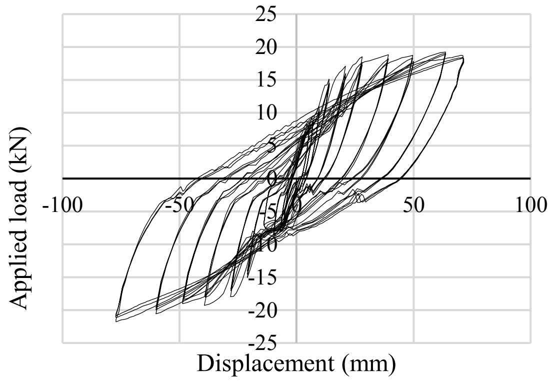


Fig. 2. Schematic view of the test configuration (all dimensions are in millimeters)



(A)



(B)

Fig. 3. Hysteresis curve (Applied load vs. Beam tip displacement) of A- Specimen using geopolymer concrete B- Specimen using ordinary concrete

4- Conclusions

By increasing the concentration of sodium hydroxide, the compressive strength of concrete increases. By reducing the ratio of sodium hydroxide to sodium silicate, which increases the amount of sodium silicate in geopolymer concrete, the compressive strength of concrete increases. The reason for this is the formation of more C-A-S-H gel in concrete.

The beam-column joint using geopolymer concrete passes the criteria of the ACI 374.1-05 regulations and its appropriate behavior and satisfactory seismic performance allow the formation of a plastic hinge in the beam.

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