Experimental study on early strength of polymer concrete reinforced by basalt fiber content and age

GaoJie Liu¹, ErLei Bai¹, Jinyu Xu¹², Tengjiao Wang¹ and Sen Chang¹
¹College of aeronautical engineering, Air Force Engineering University, 710038 Xi’an, China
²College of mechanics and civil architecture, Northwest polytechnical University, 710072 Xi’an, China

Abstract. In order to study the modification effect of basalt fiber in the address polymer concrete, three groups of basalt fiber reinforced geopolymer concrete (BFRGC) with volume content of 0.1%, 0.2% and 0.3% respectively were selected, for its early mechanical properties test. The test adopts HYY series hydraulic servo test system, and the test piece is tested for quasi-static mechanical properties by standard curing to 3 d, 7 d, and 28 d. The test results show that the addition of basalt fiber in the enhanced geologic concrete can effectively improve its early quasi-static mechanical properties. The early compressive strength, flexural strength and tensile strength of basalt fiber reinforced geopolymer concrete were greatly improved, and the degree of improvement was positively correlated with the curing time of the test piece, which was 1.67 times higher than that of 3.3 d for 7 d and 28 d. For each strength, the compressive strength is the most improved, the tensile strength is the smallest, and the flexural strength is moderate. At the same time, in the concrete with the basalt fiber, the addition of the enhanced geopolymer can further improve the concrete mechanics. Performance, and the optimal blend of basalt fiber is 0.1%.

1. Introduction
Geopolymer is a new type of cementitious material that can replace Portland cement. Because of its special inorganic polycondensation three-dimensional oxide network structure, its durability and mechanical properties are significantly better than Portland cement, stable at high temperature. Performance and interface strength characteristics are particularly outstanding. As a new type of concrete toughening material, basalt fiber[1-3] is made of pure natural volcanic rock (including basalt) ore. It is a typical silicate fiber with natural compatibility and superiority. Mechanical properties.[1-2] Therefore, it is foreseeable that the organic combination of high-performance basalt fiber and GC will produce a more outstanding basalt fiber reinforced geopolymeric concrete (GC).

Brazilian scholars Dias and Zielinski studied the effects of basalt fiber content on fracture toughness and strength of basalt fiber reinforced inorganic polymer cement concrete, and compared it with basalt fiber reinforced Portland cement concrete. The results show that: Basalt fiber reinforced inorganic polymer cement concrete has superior fracture resistance. Xin Luo and Jinyu Xu studied the effect of basalt fiber and carbon fiber on the early impact mechanical properties of geopolymer concrete. The results show that the early impact mechanical properties of fiber reinforced geopolymer concrete have significant strain rate correlation, while basalt fiber reinforced geology. The early dynamic strength properties and impact toughness of polymer concrete are superior to those of carbon fiber reinforced geopolymer concrete.
Basalt fiber reinforced geopolymer concrete (BFRGC) with volumetric content of 0.1%, 0.2%, and 0.3%, respectively, was prepared. BFRGC (BG3, standard maintenance for 3, 7, and 28 d) was studied using HYY series hydraulic servo test system. The quasi-static mechanical properties of BG7 and BG28 were analyzed. The effects of basalt fiber volume and curing age on the mechanical properties of BFRGC were analyzed and compared with the quasi-static mechanical properties of basalt fiber reinforced ordinary Portland cement concrete (BFROPCC). Comparative study analyzed the strengthening and toughening effects of basalt fiber on different cementitious materials.

2. Test scheme

2.1. Preparation of raw materials and test pieces

Raw materials: water quenched blast furnace slag of Hancheng Longmen Iron and Steel Co., Ltd. (specific surface area is 491.6 m²/kg, 28 d activity index ≥95%), first-grade fly ash produced by Hancheng No. 2 Power Plant; Jingyang County Limestone gravel (5-10 mm, ~15%; 10-20 mm, ~85%); medium sand (fineness modulus 2.8); chemically pure NaOH flake solid (purity ≥97%); A liquid sodium silicate produced by an inorganic chemical plant (ie, water glass, modulus 3.1-3.4, SiO₂ content ≥26.0%, Na₂O content ≥8.2%); Hengdian Group Shanghai Russian gold basalt fiber limited. The main performance indexes of the basalt fiber produced by the company are shown in Table 1. The GC fit is shown in Table 2.

| Fiber material | Basalt fiber |
|----------------|--------------|
| Monofilament diameter (m) | 15 |
| Chopped length (mm) | 18 |
| Density (kg/m³) | 2650 |
| Young’s modulus (GPa) | 93-110 |
| Tensile strength (MPa) | 4150-4800 |
| Ultimate elongation (%) | 3.1 |

| Mix ratio | kg/m³ |
|-----------|-------|
| Slag      | 300   |
| Fly ash   | 100   |
| Sand      | 629   |
| Limestone gravel | 968 |
| Water     | 125   |
| Liquid sodium silicate | 125 |
| NaOH      | 30    |

Preparation of test piece: test piece: FRGC mixture was loaded into the test mold and molded. After exposure for 24 h at room temperature, the mold was removed and the standard curing was carried out immediately (T=20±2 °C, relative humidity RH>95%); according to research needs After 3, 7 and 28 days, respectively, it is taken out for cutting and water grinding to ensure that the flatness, smoothness and verticality of the test piece are within the standard range. The preparation of the BFRGC test piece is shown in Figure 1.
2.2. Test equipment

In this paper, the HYY electro-hydraulic servo material test system is used. The main components of the system are: hydraulic test machine, hydraulic source, data acquisition system and computer. The maximum load is 2000 KN.

3. Results and discussion

3.1. Standard maintenance of quasi-static mechanical properties of BFRGC for 3 d

The test results of 3bg cube compression, flexural and splitting tensile strength are listed in Table 3. The quasi-static mechanical properties of 3bg of different basalt fiber content are shown in Figure 2.

| Basalt fiber volume $V_{BF}$ (%) | Compressive strength $f_{c,s}$ (MPa) | Flexural strength $f_{f}$ (MPa) | Splitting tensile strength $f_{s,t}$ (MPa) |
|----------------------------------|--------------------------------------|---------------------------------|----------------------------------|
| 0                               | 14.3                                 | 2.4                             | 1.55                             |
| 0.1                             | 16.5                                 | 2.8                             | 1.65                             |
| 0.2                             | 18.2                                 | 2.6                             | 1.60                             |
| 0.3                             | 19.7                                 | 2.5                             | 1.58                             |

Figure 1. Preparation of bfrgc test piece

Table 3. 3bg quasi-static mechanical properties
Figure 2. Quasi-static mechanical properties of 3bg of different basalt fiber content

It can be seen from Figure 2 that: (1) The quasi-static mechanical properties of 3BG with basalt fiber volume of 0.1%, 0.2% and 0.3% respectively are higher than that of the matrix, and the compressive strength is increased by 15.4%, 27.3%, 37.8%, respectively. The flexural strength increased by 16.7%, 8.3%, and 4.2%, respectively, and the tensile strength increased by 6.5%, 3.2%, and 1.9%, respectively. (2) The basalt fiber was used for standard curing 3 d GC (abbreviated as 3GC) compressive strength. The most significant improvement is the second, the increase of flexural strength is second, and the increase of tensile strength is relatively small, indicating that the incorporation of basalt fiber can significantly improve the quasi-static mechanical properties of the matrix. The basalt fiber volume is 0.1% when the volume is 0.1%. excellent.

3.2. Quasi-static mechanical properties of BFRGC for standard curing 7 d
The results of the cubic compression, flexural and splitting tensile strength tests of BFRGC (abbreviated as 7BG) for 7 d of standard maintenance are shown in Table 4. The quasi-static mechanical properties of 7BG with different basalt fiber content are shown in Figure 3.

| Basalt fiber volume $V_{bf}$ (%) | Compressive strength $f_c$(MPa) | Flexural strength $f_f$(MPa) | Splitting tensile strength $f_s$(MPa) |
|---------------------------------|-------------------------------|-----------------------------|----------------------------------|
| 0                              | 22.4                          | 3.7                         | 2.38                             |
| 0.1                            | 25.3                          | 4.3                         | 2.55                             |
| 0.2                            | 27.8                          | 3.8                         | 2.42                             |
| 0.3                            | 30.2                          | 3.9                         | 2.40                             |

Table 4. 7bg quasi-static mechanical properties
It can be seen from Figure 3 that: (1) The quasi-static mechanical properties of 7BG with basalt fiber volume of 0.1%, 0.2% and 0.3% respectively are higher than that of the matrix GC, and the compressive strength is increased by 12.9%, 24.1% and 34.8%, respectively. The flexural strength increased by 16.2%, 2.7%, and 5.4%, respectively, and the tensile strength increased by 7.1%, 1.7%, and 0.8%, respectively. (2) The basalt fiber was used for standard curing 7 d GC (abbreviated as 7GC) tensile strength. The increase of flexural strength and compressive strength gradually increased, indicating that the incorporation of basalt fiber has a certain effect on the quasi-static mechanical properties of 7GC. The volume of basalt fiber is relatively significant at 0.1%.

3.3. Quasi-static mechanical properties of BFRGC with standard curing for 28 d
The standard results of the BFRGC (abbreviated as 28BG) cube compression, flexural and split tensile strength tests for 28 d are shown in Table 5. The quasi-static mechanical properties of 28BG with different basalt fiber content are shown in Figure 4.

| Basalt fiber volume $V_{BF}$ (%) | Compressive strength $f_{c,s}$ (MPa) | Flexural strength $f_f$ (MPa) | Splitting tensile strength $f_{st}$ (MPa) |
|---------------------------------|-------------------------------------|-------------------------------|-------------------------------------|
| 0                              | 44.1                                | 7.2                           | 4.73                                |
| 0.1                            | 48.9                                | 8.8                           | 5.21                                |
| 0.2                            | 55.7                                | 7.5                           | 4.83                                |
| 0.3                            | 58.0                                | 7.8                           | 4.79                                |
Figure 4. Quasi-static mechanical properties of 28bg of different basalt fiber content

It can be seen from Figure 4 that: (1) The quasi-static mechanical properties of 28BG with basalt fiber volume of 0.1%, 0.2% and 0.3% respectively are higher than that of the matrix, and the compressive strength is increased by 10.9%, 26.3%, 31.5%, respectively. The flexural strength increased by 22.2%, 4.2%, and 8.3%, respectively, and the tensile strength increased by 10.1%, 2.1%, and 1.3%, respectively. (2) The basalt fiber was used for the standard curing of 28 d GC (abbreviated as 28 GC) compressive strength. The increase is the largest, followed by the flexural strength, and the increase of tensile strength is relatively small, indicating that the basalt fiber has a significant effect on the quasi-static mechanical properties of 28GC. The improvement effect of basalt fiber volume is 0.1%.

3.4. Comparison of quasi-static mechanical properties between BFRGC and BFROPCC

In view of the need of comparative studies, we tested the mechanical properties of basalt fiber reinforced ordinary Portland cement concrete (BFROPCC) with a static compressive strength of 44.6 MPa (comparable to BFRGC's matrix strength of 44.1 MPa). After that, the mechanical properties of BFRGC and BFROPCC were compared at 7 and 28 days, respectively.

Figure 3.16 shows the comparison of quasi-static mechanical properties between 7 d and 28 d (in the figure, 7BP indicates BFROPCC for 7 days of conservation, the same below). As can be seen from Figure 3.16, the quasi-static mechanical properties of BFRGC are significantly better than BFROPCC.
Figure 5. Comparison of quasi-static mechanical properties of bfrgc and bfropcc

The quasi-static mechanical properties of BFRGC are significantly better than BFROPCC, and the improvement effect of basalt fiber on GC dynamic mechanical properties is better than that on OPCC. The mechanism can be explained as follows: there are two basic units of silicon oxide tetrahedron and aluminum oxygen tetrahedron in geopolymer concrete. The structure is a continuous three-dimensional network framework composed of cyclic chains with certain crystal morphology. The molecule is composed entirely of Si, Al, O and other links through covalent bonds, wherein the Si-O bond energy is 535 kJ/mol, which is higher than the CC bond energy of the organic polymer of 360 kJ/mol, and Si-O bond and the Al-O bond are directional and are not easily rotated. Therefore, the geopolymer concrete has better integrity and structural stability than the ordinary Portland cement concrete, and the bonding state with the fiber is better. In addition, in the process of coagulation hardening of geopolymer concrete, Ca(OH)₂ is not produced, and the weak links in the concrete are relatively small, and the compactness is high, which contributes to the bonding with the fibers.

4. Conclusion
In this paper, the quasi-static mechanical properties of BFRGC for standard curing for 3 d, 7 d, and 28 d were studied by HYY series hydraulic servo test system. The main conclusions are as follows:

1. Basalt fiber can effectively improve the quasi-static mechanical properties of GC, in which the increase of the compressive strength is the largest, followed by the flexural strength, and finally the tensile strength;

2. BFRGC has good early quasi-static mechanical properties. The quasi-static compressive, flexural and tensile strength of BFRGC increased with the increase of curing age. The strength of 3 d and 7 d was about 1/3 and 1/2 of the strength of 28 d, respectively.

3. The quasi-static mechanical properties of bfrgc are significantly better than bfropce. For bfrgc, the relative optimum volume of basalt fiber is 0.1%.

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