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Effect of Temperature on Basalt Fiber Reinforced Polymer Bars in Moist Geopolymer Concrete

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Abstract **-** This research aims to study the effect of temperature on basalt fiber reinforced polymer (BFRP) bars embedded in moist geopolymer concrete. The conditioning temperature varied among 20, 40, and 60°C. The geopolymer concrete was designed with a nominal cylindrical compressive strength of 40 MPa with a slag-to-fly ash mass ratio of 1:3. The samples were conditioned for a duration of 3 months. The tensile strength, moisture uptake, and matrix retention of BFRP bars were measured. Test results highlighted a 30% decrease in the tensile strength, 47% increase in the moisture uptake, and 33% decrease in the matrix retention when the temperature increased from 20 to 40°C. Meanwhile, limited changes to the durability performance of BFRP bars was noted as the conditioning temperature further increased to 60°C.

Keywords**:** Basalt Fiber Reinforced Polymer, Geopolymer Concrete, Tensile Strength, Durability.

1. Introduction

Reinforcement corrosion in concrete structures is one of the main reasons for low its durability performance. Corrosion occurs due to carbonation of concrete, presence of chloride ions, and acid rain attack through the penetration of corrosive ions into the concrete [1]-[3]. As a result, steel bars oxidate with the surrounding environment, resulting in the deterioration of structures and the loss of bond between steel bars and concrete [4]. Such structure deterioration plays a major role in decreasing its service life, costing billions of dollars for repair annually [5, 6].

As an alternate solution, fiber-reinforced polymer bars (FRP) are amongst the best replacement for conventional steel bars. FRP bars have been used since the 1980s in concrete [7, 8]. The most commonly used types of FRP include glass fiber-reinforced polymer (GFRP), carbon fiber-reinforced polymer (CFRP), and basalt fiber-reinforced polymer (BFRP). BFRP has been especially studied in the last few years due to its high resistance to severe environmental conditions, high stability, zero-toxic material, and low cost [9]. Yet, BFRP do not exhibit impressive ductility when embedded in concrete. Having such a brittle behavior might lead into a sudden failure of the structure [10].

Numerous research studies had investigated the performance of BFRP composite in concrete, highlighting its performance in different conditions. Yang et al. [11] evaluated the flexural and compressive performance of BFRP embedded in geopolymer sea-sand concrete (GSSC). Results showed that the ultimate load capacity of BFRP in beams and columns was greater than that in conventional steel-reinforced concrete [11]. Al-Hamrani and Alnahhal assessed the durability of BFRP immersed in seawater at 50°C for durations of 3, 6 and 9 months. It was found that the BFRP embedded concrete experienced a higher retained bond strength in conventional concrete than in seawater [12]. Lu et al. [13] evaluated the durability of BFRP embedded in conventional and geopolymer concrete for 6 months at 60°C. The results showed that the strength retention for the BFRP bars in geopolymer concrete was 11% higher than that of counterparts in conventional concrete [13]. Furthermore, Elgabbas et al. [14] reported that BFRP bars had poor resistance towards alkaline solution, which resulted in decreasing the mechanical properties of the bars. On the other hand, exposing BFRP bars to deionized water had a higher strength retention than conditioning in alkaline solution [15]. According to Mingchao et al. [16], the flexural strength of BFRP bars was found to be more sensitive than the flexural modulus to alkaline solution exposure.

This study aims to evaluate the durability performance of BFRP bars upon embedment into slag-fly ash blended geopolymer concrete. The tensile strength is determined after 3 months of conditioning in saturated geopolymer concrete at temperatures of 20, 40, and 60°C. The deterioration in the bars was characterized by their moisture uptake and matrix composition.

2. Experimental Program

2.1 Materials

Sand-coated BFRP rebars, made of basalt fibers impregnated in epoxy resin with a nominal diameter size of 12 mm, were used in this experiment. The cross-sectional area was found to be 121 mm^2, based on the procedure of ACI 440.3R [17]. The basalt fiber content by mass was calculated by matrix digestion using nitric acid HNO_3 in accordance with ASTM D3171 [18]. It was found to be 74.5% The void content was determined as 0.24%, per ASTM D3171 and D2734 [18, 19].

The geopolymer concrete was made with a blended binder comprising a slag-to-fly ash ratio of 3:1. The coarse aggregates were in the form of crushed dolomitic limestone, with a nominal maximum size of 10 mm. Meanwhile, the fine aggregates were desert dune sand. The alkaline activator solution was made of sodium silicate and sodium hydroxide (14 M) at a ratio of 1.5:1. The concrete mix was designed to attain a 40-MPa nominal concrete cylinder strength. The dry components comprised 337.5 kg/m^3 of slag, 112.5 kg/m^3 of fly ash, 600 kg/m^3 of desert dune sand, 1100 kg/m^3 of coarse aggregates. At the same time, the wet ingredients included 11.25 kg/m^3 of superplasticizer, 25 kg/m^3 of additional water, and 225 kg/m^3 of the alkaline activator solution. After mixing, casting, and compacting, the concrete specimens were tested for bulk electrical resistivity, ultra-sonic pulse velocity (UPV), split tensile strength, and water absorption. Table 1 summarizes the values from each test.

Table1 : Concrete tests measurements

Test	Value	Standard
Bulk electrical resistivity	1110 Ω.cm	ASTM C1876-23 [20]
UPV	4.7 km/s	ASTM C597-22 [21]
Split tensile strength	3.09 MPa	ASTM C496 [22]
Water absorption	3.36 %	ASTM C642-21 [23]

2.2 Preparation of specimens

The BFRP bars had a total length of 1280 mm. A length of 480 mm was embedded in the geopolymer concrete, while 360 mm extended from each side to install the steel grips for tensile strength testing. The concrete prism length was selected such that it was 40 times the diameter of the BFRP (40 x 12 mm= 480 mm). The BFRP geopolymer concrete prisms (50 x 50 x 480 mm) were conditioned in a moist environment for 3 months at 20, 40, and 60°C. A total of 3 isolated high resistance tanks were used. To control the conditioning temperature, a high-quality thermostat was inserted into each tank. Addition of water and thermostat replacement was carried out regularly. Furthermore, PVC pipes, with a total length of 360 mm, were installed on both sides of the BFRP bars. To effectively isolate the bars in the conditioned tanks, a universal multi foam material was used in the pipes and subsequently sealed with impermeable plastic covers.

2.3 Performance evaluation

BFRP specimens were tested to longitudinal tensile strength as per ACI 440.3R-04 [17]. By the end of the conditioning period, the geopolymer concrete was removed from all the BFRP bars. Specially designed steel grips were installed to perform the tensile strength test. Steel-grips were designed to have 50 mm outer diameter with a length of 400 mm and thickness of 1.5 mm to be able to transfer load from testing machine to BFRP bars safely. To ensure strong connection between the steel-grips and BFRP bars, epoxy was used and kept for 24 hours for hardening purposes. Also, the inner surface of the steel-grips was roughened to enhance the bonding of the epoxy through the entire 400 mm length. After setting up specimens, uniaxial tension load was applied on the BFRP specimens until failure with a displacement control of 1.5 mm/min. Load data measurements were taken to get the tensile strength by dividing the maximum tensile strength by the surface area of the BFRP bar.

The moisture uptake of BFRP specimens was taken at the end of the 3 months for the 3 different temperatures, i.e., 20, 40 and 60°C. The test was carried out following the procedure in ASTM D570 [24]. For more accurate measurements, the mass loss was taken into consideration by drying the conditioned BFRP specimens in oven for 24 hours at a temperature of 100°C.

To determine the mechanism of degradation, the fiber and matrix contents of the BFRP specimens were found using the matrix digestion. This test was performed according to ASTM D3171 [18] using nitric acid. It was conducted by mixing an amount of 0.5-1.5 g of BFRP material with 50 mL of 70% aqueous nitric Acid. The combined mixture was exposed to a temperature of 80°C in a heat preserved tank for 6 hours. The main aim of having the mixture of the two materials exposed to temperature was to dissolve the epoxy resin from the BFRP due to the chemical reaction occurred. Finally, distilled water was used to wash the mixture before drying it in oven at 100°C for 1 hour.

3. Experimental Results

3.1 Tensile strength

Figure 1 shows the tensile strength of the control bar and those conditioned for 3 months at 20°C. Compared to the control sample, the strengths of conditioned bars for 3 months at 20, 40, and 60°C decreased by 31%, 52% and 47%, respectively. Results from the uniaxial tensile load test on BFRP bars indicate that, of the exposed bars, the specimen conditioned at 20°C exhibited the highest strength, measuring 879 MPa. However, a subsequent increase in temperature to 40°C resulted in a 30% reduction in strength, reaching 614 MPa. Yet, at 60°C, the tensile strength did not further deteriorate. Meanwhile, a slightly higher tensile strength was recorded at 60°C than the one at 40°C. The strength loss with temperature was due to the acceleration of the hydrolysis degradation reaction at a high water diffusion rate [25].

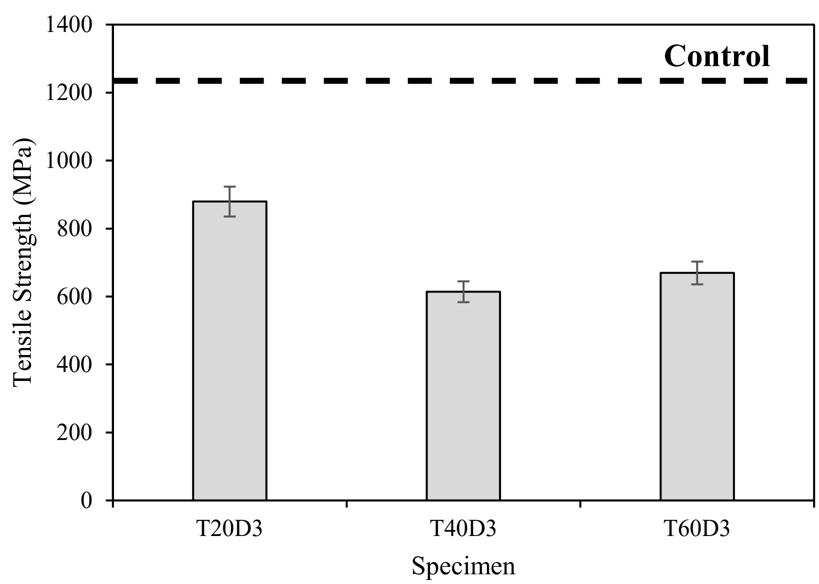

Figure 1: Tensile strength analysis of the conditioned specimens

3.2 Moisture uptake

Table 2 shows the moisture uptake of the control and conditions BFRP bars. Submerging specimens in a moist environment leads to water penetration into the concrete through the microcracks. Through the 3-month conditioning period, the average moisture uptake for the 3 temperatures was lower than 1%. The moisture uptake for the 20ºC specimen was found to be 0.43%. This percentage increased to 0.63% when bars were exposed to 40ºC. Thus, it can be noticed that increasing the conditioning temperature contributes to a significant increase in water absorption by BFRP fiber, with a nearly 47% rise from 20°C to 40°C. Higher temperature led to higher diffusion rate as well as a larger crack widths [26].

Table 2: Matrix digestion & moisture uptake proportions

Specimen Designation	Conditioning temperature (ºC)	Content (%)		Matrix retention (%)*	Matrix loss (%)	Moisture uptake (%)
		Fiber	Matrix			
T20D3	20	79.3	20.6	81.0	19.0	0.43
T40D3	40	86.3	13.7	54.0	46.0	0.63
T60D3	60	82.4	17.6	69.0	31.0	0.59

*The matrix retention is calculated with respect to the control mix.

3.3 Matrix Digestion Analysis

Results of the matrix digestion are shown in Table 2. The matrix mass and fiber contents of the specimens conditioned at 20ºC were 20.7% and 79.3%, respectively. BFRP specimens experienced a higher deterioration in matrix content at both of 40ºC and 60ºC, with matrix contents of 13.8% and 17.6%, respectively. Due to the matrix proneness to deteriorate, the increase in temperature led to dissolution of the matrix attached to the fibers. It was found that BFRP specimen exposed to 40ºC had higher tendency of losing matrix than the other temperatures. Similar findings have been reported in other work on GFRP bars conditioned in moist seawater-contaminated concrete [26]. The Fiber content of the specimen exposed to this specific temperature was found to be the highest compared to the other temperatures. Having high fiber content might be due to the degradation of the interface between the fiber and polymer matrix. The matrix retention for each conditioning regime was also compared and calculated based on the control value of matrix content of 25.5% [27].

4. Conclusions

This paper evaluated the performance of basalt fiber reinforced polymer (BFRP) bars at a total duration of 3 months under three temperatures (20, 40, and 60ºC) in moist geopolymer concrete. The conditioned specimens were submerged in water tanks. Based on the test results, the following conclusions were obtained:

- The tensile strengths decreased by 31%, 52% and 47%, respectively, compared to the control sample. BFRP bars conditioned at 20°C exhibited the highest strength, with further strength loss at elevated temperatures of 40 and 60°C.
- Increasing the temperature of the moist geopolymer environment contributed to a significant increase in the water absorption by BFRP fibers, with nearly a 47% increase as the temperature increased from 20°C to 40°C.
- The effect of increasing temperature from 20°C to 40°C caused a higher dissolution of resins and a lower matrix retention.

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