British Journal of Multidisciplinary and Advanced Studies:
Engineering and Technology, 4(3),14-20, 2023
Print ISSN: 2517-276X
Online ISSN: 2517-2778
https://bjmas.org/index.php/bjmas/index
Published by the European Centre for Research Training and Development UK

Investigating the Flexural Performance of Basalt Fiber Reinforced Polymer (BFRP) Bars at Elevated Temperatures

Ahmad Sadq Aween
Civil Engineering Department, Gaziantep University, Iraq

Sarwar Hasan Mohmmad
Technical College of Engineering, Sulaimani Polytechnic University, Sulaymaniyah, Iraq

doi: https://doi.org/10.37745/bjmas.2022.0192 Published: May 15, 2023

Citation: Aween A.S. and Mohmmad S.H. (2023) Investigating the Flexural Performance of Basalt Fiber Reinforced Polymer (BFRP) Bars at Elevated Temperatures, *British Journal of Multidisciplinary and Advanced Studies*: Engineering and Technology, 4(3),14-20

ABSTRACT: *The FRP-reinforced concrete constructions may be subjected to elevated temperatures, which may compromise the structural integrity of the bars and, finally, the whole structure. As a result, the thermal stability of the FRP bars needs to be properly examined before they can be completely used in the construction field. Flexural strength testing has been utilized as a standard approach for determining the uniaxial tensile strength of brittle materials since it is less costly and easier to perform than the direct tension test. While the findings achieved were not absolute tensile data, they can offer a prediction of the relative tensile strength of the FRP bars. The flexural behavior of basalt fiber-reinforced polymer (BFRP) bars with different nominal diameters (8.0 mm, 10.0 mm, 12.0 mm, and 14.0 mm) exposed to increased temperatures (up to 150 °C) was examined in this research. According to the findings, when the temperature rises, the stiffness and flexural strength of the BFRP bars reduce. As the temperature approached the glass transition temperature (Tg) of the bars, a significant decrease in stiffness and strength was noted. These outcomes were also seen in other studies' pure tension tests of FRP bars. At higher temperatures, bigger nominal diameter bars are superior to smaller nominal diameter bars in terms of flexural strength decaying resistance. Although a comparable flexural stiffness degradation was noted as temperature increased.*

KEYWORD*:* FRP bar, thermal stability, flexural strength, tensile strength, glass transition temperature.

INTRODUCTION

Reinforced concrete (RC) structures, particularly those situated in harsh environments like mining and marine areas, are prone to premature failure and shortened service life due to the corrosion of steel bars. However, the usage of fiber reinforced polymer (FRP) bars can be a promising solution. These bars are not only corrosion-resistant but also possess high, electromagnetic, strength-to-weight ratio, and durability resistance. In the past, FRP bars have been successfully utilized as internal reinforcement for concrete in the construction of bridges and roads. Now, researchers and engineers are exploring their use in constructing multi-storey and industrial buildings. However, for widespread acceptance and application of FRP reinforced concrete (FRP-RC) structures, data regarding their fire resistance performance needs to be gathered (e.g., the duration for which the structures are capable of withstanding elevated temperatures and also fire exposures; the temperature at which the stiffness, strength, and bond between the materials decreased).

The fire resistance of FRP-RC constructions is strongly dependent on the materials employed, specifically the concrete and FRP bars. However, at elevated temperatures, the latter is more vulnerable to deterioration. As the temperature approaches its "glass transition temperature (Tg)," the polymer's stiffness and strength decline dramatically, resulting in a diminished composite action between the fibers and the polymer. As a result, the width of the crack in the concrete increases and the structural part deflects more.

As a result, it is critical to conduct detailed research on the tensile behavior of the FRP bar at higher temperatures. Past studies, including those by Kumahara et al(1993),Abbasi and Hogg (2005), Wang et al. (2007), and Kashwani and Al-Tamimi (2014), have examined the tensile performance of FRP bars at varying temperatures using a pure tension test. However, this test has several limitations, including the need for longer test specimens, extended test duration, high costs of specimen fabrication and testing, and difficulties of gripping. To address these limitations, a bending test can be employed to roughly investigate the tensile performance of FRP bars. Flexural strength testing has been a reliable method for measuring the uniaxial tensile strength of brittle materials, such as ceramics and glasses, for a considerable time (Quinn et al., 2009). This test is relatively easy to perform and cost-effective when compared to direct tension tests (Whitney & Knight, 1980). Moreover, the tensile stress achieved from flexure tests of FRP bars is generally higher than that attained from pure tension tests (Tripathi, 2003; Whitney & Knight, 1980). This study focuses on the investigation of the tensile performance of deformed basalt fiber-reinforced polymer (BFRP) bars at higher temperatures, using three-point bending tests. The obtained experimental results offer a rough interpretation of the tensile behavior of the bars at high temperatures, and can be utilized to establish a correlation between the flexural strength and tensile strength of BFRP bars at high temperatures. This approach can lead to the back-calculation of the tensile response from the bending behavior, resulting in a statistically significant database in a more cost-effective and convenient manner. The results of this study have practical implications in designing fire-resistant FRP-reinforced concrete (FRP-RC) structures that can withstand high temperatures, and also in developing better fire-resistant construction materials.

EXPERIMENTAL PROGRAM

BFRP Bars

In this study, four deformed basalt fiber reinforced polymer (BFRP) bars with diameters of 8.0 mm, 10.0 mm, 12.0 mm, and 14.0 mm were selected and are illustrated in Figure 1. For each bar diameter, three specimens were fabricated. The BFRP bars were sourced from Hebei Jiubai Technology Co., Ltd and were manufactured via the pultrusion process, utilizing vinylester resins impregnated with continuous basalt fibers. The basalt fiber content of the BFRP bars, as determined by the Burn-out test based on ISO 1172:1996(E), was found to be 84.05%.

Differential Scanning Calorimetry (DSC) Analysis

“Differential scanning calorimetry (DSC)” is a valuable technique used to study the thermal characteristics of polymer materials and composites. In particular, it can provide crucial information about the curing process and the glass transition temperature (T_g). In this study, the T_g of the deformed BFRP bars was determined using a TA Instruments Q100 DSC machine in accordance with ASTM D3418-12 standard (2012). To carry out the analysis, unconditioned samples weighing approximately 30-40 mg were taken from the reference bars and placed in sealed aluminum pans, as depicted in Figure 2. Two scans were conducted for each BFRP type with the samples being heated from 25 °C to 150 °C at a rate of 3 °C/min for an hour. The mean T_g of the bars (125 °C), as determined by the DSC analysis, was found to be consistent with the range of T_g for a vinyl ester matrix system (110 °C to 120 °C) as reported by Robert et al. (2009).

Flexural Test

Flexural testing is an important quality control tool for evaluating the performance of materials. However, the flexural properties can be influenced by factors such as the specimen diameter, temperature, weather conditions, and straining rates. To conduct the three-point bending test on BFRP bars, full bars were used instead of half bars, and the test was carried out according to (for Testing et al., 2011)standard(2012). The specimens were simply supported, with a clear span of 180 mm, and were loaded at midspan at a rate of 10 mm/min using the MTS testing machine with a capacity of 500 kN. The specimens were placed on two circular supports, which allowed the specimens to bend. To ensure a steady-state temperature regime, the specimens were subjected to temperatures ranging from 25°C to 150 °C in an oven chamber. The temperature was raised to the desired level, and the bars were placed inside the chamber for 30 minutes before testing to ensure that the temperature at the core of the bars had reached the desired temperature. The load and displacement were recorded using a data logger, and each specimen was labeled with its nominal diameter (8.0 mm, 10.0 mm, 12.0 mm, or 14.0 mm) and the temperature it was subjected to (25°C to 150°C). Figure 3 shows the three-point bending test, while the data obtained from the test were recorded in Table 1.

Figure 1. BFRP bars

Figure 2. Sample T_g

Figure 3. Three-point

RESULTS AND DISCUSSION

The experimental results of the three-point loading test conducted on BFRP specimens are presented in Table 1. The test evaluated the flexural load (P), flexural strength (f_b), flexural modulus of elasticity (E_b), and midspan deflection of the specimens. The flexural strength was determined using Equation (1), while the flexural modulus of elasticity was calculated using equation (2). The slope of the linear component of the load-deflection curves shown in Figure 4 was used to calculate the ratio (F/Δ). The results indicate that as the diameter of the BFRP bars increases, there is a reduction in both their strength and stiffness

$$f_b = \frac{8PL}{\pi d_b^3} \qquad (1)$$

$$E_b = \frac{P}{\Delta}\frac{4L^3}{3\pi d_b^4} \qquad (2)$$

Where f_b is the flexural strength (N/mm^2), P is the failure load (N), L is the clear span (mm), E_b is the flexural modulus of elasticity in bending (N/mm^2), and Y is the mid-span deflection at load P (mm), and L, d_b, and Δ are the clear span(mm), the nominal diameter(mm), and the midspan deflection(mm), respectively.

Load and Midspan Deflection Relationship at Elevated Temperatures

The behavior of BFRP bars subjected to elevated temperatures can be characterized by their load-deflection relationship, as demonstrated in Figure 4 using 12.0 mm BFRP bars as an example. The results indicate that the load increases linearly with deflection up to the point of failure across all temperatures tested, ranging from 25 °C to 85 °C. However, the bars

tended to fail in a brittle manner, as the simultaneous crushing of resin and fibers in the compression zone was observed, as depicted in Figure 5. Furthermore, larger diameter bars showed interlaminar shear failure in the tension zone, as demonstrated in Figure 6. Conversely, Figures 7 and 8 indicate that the mode of failure for 12.0 mm and 14.0 mm BFRP bars was dominated by fiber rupture and interlaminar shear failure in the tension zone. These findings provide insight into the behavior of BFRP bars under varying conditions, aiding in the development of more reliable and durable composite materials. A similar behavior for OC has been reported by Maranan et al.(2014).

When BFRP bars were subjected to high temperatures ranging from 105°C to 150°C, their behavior became non-linear and exhibited stiffness degradation before reaching the maximum load. This phenomenon was caused by the glass transition temperature (T_g) of the polymer, which falls within this temperature range. At these elevated temperatures, the polymer behaves like a rubbery material and the bars exhibit a ductile behavior. Figure 8 illustrates a typical crushing failure of the BFRP bars exposed to these temperatures, with white powder resins formed as a result. Additionally, at a temperature of 150°C, interlaminar shear failure was observed in the tension zone of the bars with larger diameter. The bars with larger diameter experienced more severe failure than those with smaller diameter.

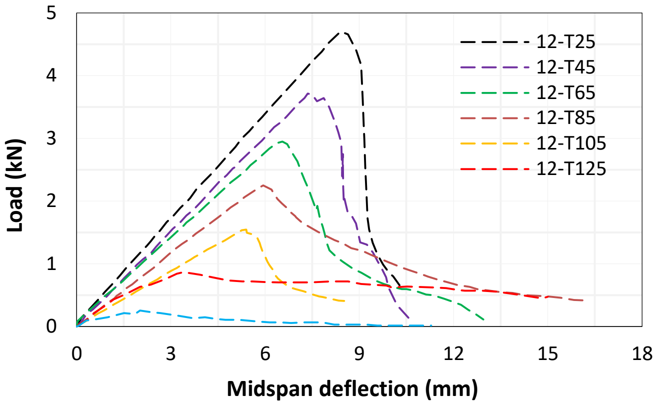

Figure 4. Typical load and midspan deflection relationships of the BFRP bars at elevated temperatures

Table 1. Flexural load, strength, and stiffness of the BFRP bars at elevated temperatures

specimen	$P_{max.}$ (kN)	F_b (MPa)	Deflection (mm)	E_b (GPa)	f_b/f_{RT} %	E_b/E_{bRT} %
8.0-T25	3.30	2.95	5.17	385.56	100.0	100.0
8.0-T45	2.41	2.16	4.41	370.14	73.03	96.00
8.0-T65	2.26	2.02	4.21	362.43	68.35	94.00
8.0-T85	1.80	1.61	3.58	354.72	54.55	92.00
8.0-T105	1.25	1.12	3.11	335.44	37.79	87.00
8.0-T125	0.50	0.45	1.87	192.78	15.29	50.00
8.0-T150	0.09	0.08	1.01	100.25	2.73	26.00
10.0-T25	3.84	1.76	6.54	145.43	100.0	100.0
10.0-T45	3.04	1.39	5.63	143.97	79.08	99.00
10.0-T65	2.76	1.27	5.57	142.52	71.93	98.00
10.0-T85	2.22	1.02	4.16	139.61	57.75	96.00
10.0-T105	1.63	0.75	3.60	132.34	42.40	91.00
10.0-T125	0.69	0.31	2.63	68.35	17.88	47.00
10.0-T150	0.19	0.09	1.52	34.10	5.01	23.45
12.0-T25	4.70	1.25	8.40	66.76	100.0	100.0
12.0-T45	3.71	0.98	7.35	64.09	78.94	96.00
12.0-T65	3.01	0.80	6.55	62.09	63.83	93.00
12.0-T85	2.30	0.61	5.90	60.09	48.94	90.00
12.0-T105	1.55	0.41	5.40	56.08	32.98	84.00
12.0-T125	0.87	0.23	3.40	36.72	18.51	55.00
12.0-T150	0.25	0.07	2.02	14.02	5.32	21.00
14.0-T25	5.15	0.86	10.67	31.10	100.00	100.0
14.0-T45	4.60	0.77	8.48	31.10	89.30	100.0
14.0-T65	4.16	0.70	8.10	29.85	80.84	96.00
14.0-T85	3.28	0.55	6.20	29.54	63.68	95.00
14.0-T105	2.33	0.39	5.05	27.05	45.31	87.00
14.0-T125	1.12	0.19	4.08	13.99	21.74	45.00
14.0-T150	0.45	0.08	3.84	6.22	8.74	20.00

T = temperature; RT= room temperature; Fb = flexural strength; and E_b= the flexural stiffness

Figure 5. Crushing of the resin and fibre of BFRP bars (25 °C to 85 °C)

Figure 6. Interlaminar shear failure of BFRP bars (25 °C to 85 °C)

Figure 7. Interlaminar shear failure of the 12.0 mm and 14.0mm BFRP bars (25 °C to 85 °C)

Figure 8. Crushing of the resin and fibers of BFRP bars (105°C to 150°C)

Effect of Temperature on the Flexural Strength of the BFRP Bars

Figure 9 illustrates the impact of temperature on the flexural strength of BFRP bars, presented as normalized flexural stress values. To calculate these values, the flexural stress at the given temperature (f_{bt}) was divided by the flexural stress at room temperature (f_{bRT}). As expected, the flexural strength of the bars decreased with increasing temperature, primarily due to the decomposition of the resin. This trend aligns with previous studies, such as those conducted by Abbasi and Hogg (2005), Wang et al. (2007), and Robert and Benmokrane (2010), which reported similar findings in pure tension tests of FRP bars.

Notably, when the temperature approached the T_g of the bars, a significant decrease in flexural strength occurred. This is because the polymer softens, which impairs its ability to hold the glass fibres together and to distribute stresses effectively. Interestingly, larger-diameter bars demonstrated better flexural performance at higher temperatures than smaller-diameter bars. This suggests that variations in nominal diameter (i.e., size effect) should be taken into account when assessing the thermal stability of FRP bars.

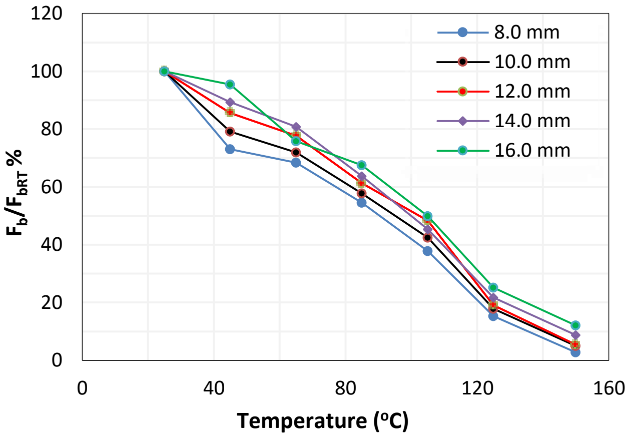

Figure 9. Effect of Temperature on Flexural strength of BFRP Bars

Effect of Temperature on the Flexural Stiffness of the GFRP Bars

Figure 10 depicts the relationship between the normalized flexural stiffness and temperature for BFRP bars. The normalized values were calculated by dividing the flexural stiffness at the given temperature, E_{bT}, by the flexural stiffness at room temperature (25 °C), E_{bRT}. Similar to the trend observed for flexural strength, the flexural stiffness of the BFRP bars decreases as temperature increases. However, the rate of deterioration of flexural stiffness is slower than that of flexural strength in the temperature range from 25 °C to 105 °C. As the temperature approaches the Tg of the bars, a significant decrease in flexural stiffness is observed for the same reason as that for flexural strength. The composite action between the fibers and the polymer diminishes, resulting in lower flexural stiffness (and strength) of the BFRP bars. Notably, comparable rates of degradation of flexural stiffness are observed for BFRP bars of varying diameters at increasing temperatures.

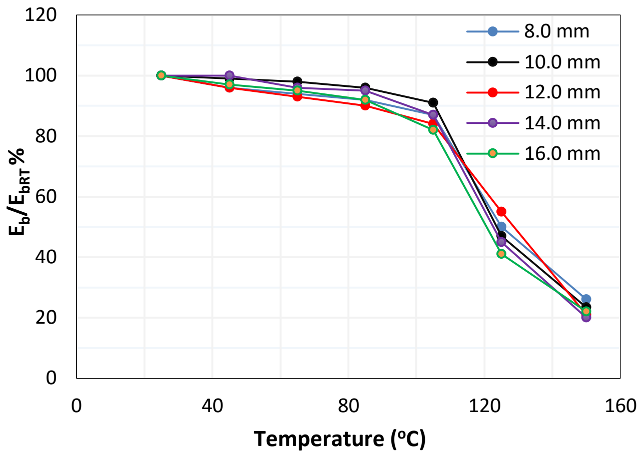

Figure 10. Effect of Temperature on Flexural Stiffness of BFRP Bars

CONCLUSIONS

The experimental results of the three-point bending test conducted on BFRP bars subjected to elevated temperatures led to several noteworthy conclusions. Firstly, it was observed that the flexural strength and stiffness of the BFRP bars generally decreased as the temperature increased. This decrease was more pronounced as the temperature approached the Tg of the bars. At this point, the polymer undergoes a transition from a glassy to a rubbery material, losing its ability to hold the fibers together and transfer stresses between them, resulting in a drastic reduction in flexural strength and stiffness.

Moreover, the bars with a larger nominal diameter exhibited better resistance to decay of flexural strength at elevated temperatures than those with a smaller nominal diameter. However, the rate of degradation of the flexural stiffness of BFRP bars with varying diameters was comparable to each other at increasing temperatures.In light of these findings, further studies are needed to establish a relationship that can predict the tensile response of the BFRP bars from the bending response at elevated temperatures. This would provide additional information that can be used to design and optimize the use of BFRP bars in high-temperature applications.

REFERENCES

Abbasi, A., & Hogg, P. J. (2005). Temperature and environmental effects on glass fibre rebar: modulus, strength and interfacial bond strength with concrete. *Composites Part B: Engineering*, *36*(5), 394–404.

for Testing, A. S., on Concrete, M. C. C.-9, & Aggregates, C. (2011). *Standard test method for splitting tensile strength of cylindrical concrete specimens*. ASTM International.

International, A. (2012). *Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry^1*. ASTM International.

Kashwani, G. A., & Al-Tamimi, A. K. (2014). Evaluation of FRP bars performance under high temperature. *Physics Procedia*, *55*, 296–300.

Kumahara, S., Masuda, Y., Tanano, H., & Shimizu, A. (1993). Tensile strength of continuous fiber bar under high temperature. *Special Publication*, *138*, 731–742.

Maranan, G. B., Manalo, A. C., Karunasena, W., Benmokrane, B., & Lutze, D. (2014). Flexural behaviour of glass fibre reinforced polymer (GFRP) bars subjected to elevated temperature. *Proceedings of the 23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23)*, *1*, 187–192.

Quinn, G. D., Sparenberg, B. T., Koshy, P., Ives, L. K., Jahanmir, S., & Arola, D. D. (2009). Flexural strength of ceramic and glass rods. *Journal of Testing and Evaluation*, *37*(3), 1.

Robert, M., & Benmokrane, B. (2010). Behavior of GFRP reinforcing bars subjected to extreme temperatures. *Journal of Composites for Construction*, *14*(4), 353–360.

Robert, M., Cousin, P., & Benmokrane, B. (2009). Durability of GFRP reinforcing bars embedded in moist concrete. *Journal of Composites for Construction*, *13*(2), 66–73.

Tripathi, V. K. (2003). *Standardization of test methods for property evaluation of FRP bars*. West Virginia University.

Wang, Y. C., Wong, P. M. H., & Kodur, V. (2007). An experimental study of the mechanical properties of fibre reinforced polymer (FRP) and steel reinforcing bars at elevated temperatures. *Composite Structures*, *80*(1), 131–140.

Whitney, J. M., & Knight, M. (1980). *The Relationship between Tensile Strength and Flexure Strength in Fiber Reinforced Composites.*