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Performance of Basalt Fiber Reinforced Continuous Beams with Basalt FRP Bars

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Abstract. The state of Qatar is suffering from a harsh environment and coastal conditions which stand for most of the year. As a result, steel-reinforced concrete (RC) structures are subjected to rapid corrosion and deterioration. Therefore, there is a necessity to replace the conventional steel reinforcement by fiber-reinforced polymers (FRP) composites. Apart from FRP corrosion resistance property, their strength to weight ratio is higher than steel reinforcement which made them a viable alternative to steel reinforcement. This study aims to investigate the flexural behavior of basalt fiber reinforced concrete continuous beams reinforced with basalt FRP (BFRP) bars. Two RC continuous beams with a size of 200 x 300 x 4000 mm were prepared and cured for 28 days. Then, the beams were tested up to failure under five-point loading. The volume fraction of basalt macro-fibers (BMF) was the only investigated parameter in this study. Test results have shown that the addition of BMF in volume fractions of 0.75% improved the crack widths, cracking loads, failure mode, strains and displacements of the beams.

1. Introduction

Corrosion in steel reinforcement has been identified as one of the most challenging problems in the construction industry. In recent decades, a huge amount of money has been spent to improve the steel reinforcement corrosion resistance in reinforced concrete (RC) structures [1]. However, corrosion was not fully eliminated. For that, acquiring an alternative reinforcement material is needed to overcome the steel corrosion-related problems.

Recently, fiber reinforcement polymers (FRP) composites have been used as an alternative to steel reinforcement to overcome the steel corrosion-related problems. FRP composites have several applications such as internal reinforcements in new RC members, strengthening and retrofitting of existing or failure RC members and chopped fibers in concrete mixtures [2, 3]. Apart from its corrosion resistance, FRP bars have much less weight compared to steel reinforcements [4].

With the development of FRP composites, basalt FRP (BFRP) has been added to the FRP family. BFRP is made by melting the igneous rock at 1400 ^{o}C. On the one hand, it is a non-toxic and environmentally safe material. In addition, it can be available in different forms such as reinforcing bars, mesh and chopped fibers. On the other hand, BFRP has linear-elastic behavior with brittle failure, lower strain at failure and lower modulus of elasticity [2, 5].

Indeterminate RC members such as continuous beams are the most widely used members in real life. A number of studies have investigated the flexural behavior of basalt FRP-RC beams [6-11]. For example, Habeeb and Ashour [11] studied the flexural performance of Glass FRP-RC continuous beams. It was found that the maximum applied load increased with increasing the bottom reinforcement ratio at an increasing rate. It was also observed that crack widths of FRP-RC beams were wider than steel-RC beams. Other researchers found that concrete shortcoming properties such as low tensile strength, brittle failure and wider cracks can be mitigated by mixing chopped fibers randomly in concrete mixtures [12-14].

Although many studies investigated the flexural behavior of BFRP-RC simply supported beams and slabs, still further studies are needed to understand the flexural performance of BFRP-RC continuous beams and to establish its design code and guideline. This study was therefore needed to investigate the flexural behavior in terms of cracking loads, strains and displacements of BFRP-RC continuous beams mixed with basalt macro-fibers (BMF).

2. Experimental program

The study consisted of two continuous RC beams measured 4000 mm long and a cross-section of 200 × 300 mm as presented in Figure 1. The first beam was made with plain concrete and the second with basalt fiber reinforced concrete. The beams were loaded until failure under five-point loading using a 1500 kN universal testing machine (UTM). The beams were reinforced with similar longitudinal and transverse reinforcement, but with a different volume fraction of BMF. Volume fraction of BMF of 0.75 was selected in this study based on the findings of a pilot study. Cracking loads, strains and displacements of the tested beams were investigated in this study. The displacement values at each midspan were recorded using a linear variable differential transformer (LVDT) installed at the center of each midspan. The reinforcement details of the test beams are provided in Table 1.

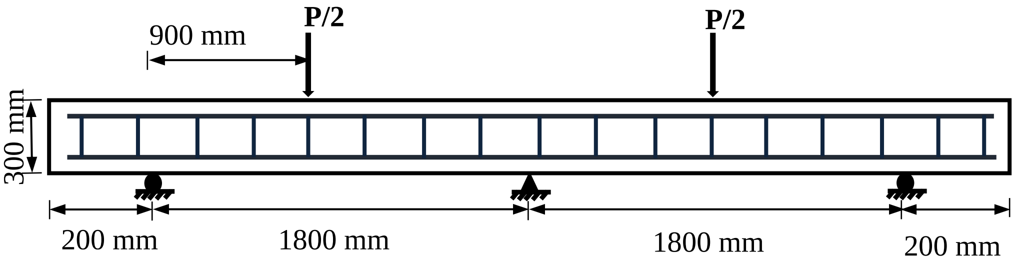

Figure 1. Geometry and details of the tested beams.

Table 1. Reinforcement details of the tested beams.

	Volume fraction of BMF	Bottom reinforcement	Top reinforcement
B1	0.00%	6 ϕ 10	4 ϕ 10
B2	0.75%	6 ϕ 10	4 ϕ 10

3. Results and discussions

3.1. Failure mode and cracking pattern

Table 2 lists the cracking load and the failure mode of beams B1 and B2. It was noticed in beam B1 that as the load increased, the cracks were propagated toward the compression side and became wider until the failure in beam B1. As a result, these cracks caused beam B1 to fail in shear failure mode. By contrast, in beam B2, these cracks were restrained when the volume fraction of BMF of 0.75% was added. The added BMF had prevented the shear failure and caused it to fail in concrete crushing mode. Additionally, it was noticed that the cracking load has increased by 10% in beam B2. The change in the failure mode and the increase in the cracking load are attributed to the bridging effect of the BMF, which had reduced the crack widths. The findings are matching with the findings of Alnahhal and Aljidda [14], who showed that RC beams with BMF experienced less number of cracks.

Table 2. Failure mode, cracking load and crack width of the tested beams.

	Failure mode	Cracking load (kN)
B1	Shear	80.0
B2	Concrete crushing	89.0

3.2. Load-displacement behavior

Figure 2 illustrates the load-displacement curves of beams B1 and B2. The results revealed that both curves were bilinear regardless of the volume fraction of BMF. Both beams demonstrated small displacements before cracking. However, the displacements were significantly increased after cracking. As expected, beam B2 showed better performance in terms of its load-displacement behavior compared to beam B1. However, both beams had approximately similar failure load, but the deflection in beam B2 was lower than beam B1. For example, at the load of P = 150 kN, the measured deflections of beams B1 and B2 were 6.80 and 4.80 mm, respectively. The result of Alnahhal and Aljidda [14] also confirmed that adding the BMF in RC beams increased the ultimate flexural capacity of the beams.

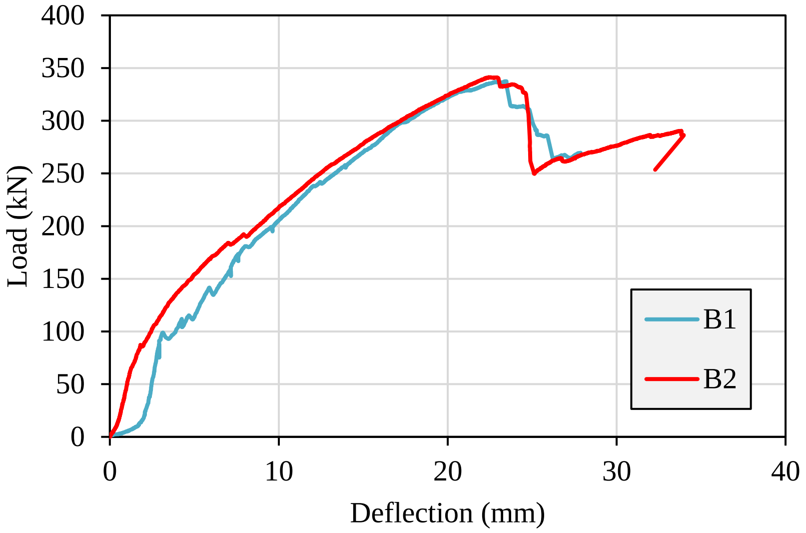

Figure 2. Load-displacement relationship of the tested beams.

3.3. BFRP tensile strain

The variation of the measured strains in BFRP bars between beams B1 and B2 is presented in Figure 3. It is worth noticing that regardless of the BMF, the BFRP tensile strains for both beams increased linearly up to the cracking stage. After that, the strains increased significantly and nonlinearly. At the same load of P = 150 kN, beam B2 had approximately 34% less BFRP strain than beam B1. The reduction in BFRP strains in beam B2 is attributed to the reduced crack widths by the bridging effect as presented in Section 3.2 which, in turn, has controlled the tensile strains in the BFRP bars.

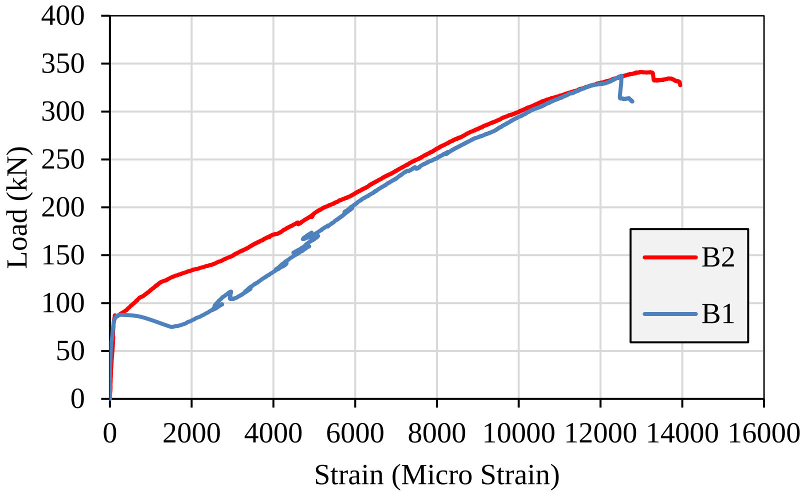

Figure 3. BFRP tensile strain variation against the applied load.

4. Conclusions

This study evaluated the effect of reinforcing continuous RC beams with BFRP and BMF on their failure mode, cracking loads, load-displacement and load-strain relationships. The following conclusions can be drawn from this study:

- The addition of BMF resulted in an improvement in the ultimate flexural capacity, compared with the controlled beam with no BMF.
- The ultimate deflection corresponding to the beam with BMF is lower than the beam with no BMF.
- The cracking pattern and the failure mode were significantly affected by the BMF.
- The BMF significantly improved the tensile strains of the BFRP bars.

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