The Effect of Surface Treatment of Basalt FRP Bars on the Shear Capacity of Oneway High-Strength Concrete Slabs

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Abstract

Corrosion is a common condition encountered by steel reinforcing bars which has a considerable negative impact on the structural integrity of concrete structures. Nowadays, applying anti-corrosive composite materials such as fiber-reinforced polymer (FRP) bars as reinforcing bars instead of steel bars is a major area of interest among researchers. The current study presents an investigation on the influence of surface treatment of the basalt (B) FRP reinforcing bars on the shear strength ofone-way high-strength concrete slabs. Two types of BFRP bars were tested, one with a sand-coated surface and the other with a ribbed surface.The testing results showed that the ribbed BFRP bars resulted in a slightly higher shear strength than the slab reinforced with sand-coated bars. The ultimate shear capacity in the ribbed bars reinforced slab was recorded as 95.65 kN, whereas it was recorded as 90.08 kN in the sand-coated bars reinforced slab. Moreover, in comparison to the slab with sand-coated bars, the first flexural crack was delayedin the slab with ribbed bars.Also, reinforcing the one-way slab with ribbed BFRP bars has shown higher stiffness represented by lower midspan deflection at all loading stages compared to the sand-coated bars. As a result, this has induced lower stresses on the ribbed bars, which caused lower midspan strain values in the ribbed bars than the sand-coated bars.

Keywords: Shear strength; Ribbed; Sand-coated; BFRP bars; One-way slab

1 Introduction

Despite the distinct mechanical characteristics of steel reinforcement, corrosion is still recognized as one of the main reasons that deteriorates and shortens the lifespan of many concrete structures worldwide such as parking garages and bridge decks (El-Sayed et al., 2005a). To tackle this problem, there is a growing body of literature investigating the structural performance of concrete structures that are reinforced with an anti-corrosive material known as fiber-reinforced polymers (FRP) Al-Hamrani & Alnahhal (2021); Al-Hamrani & Alnahhal (2022); (Balaguru et al., 2009); (El-Refai et al., 2022); (Zoghi, 2013). However, special care must be given to the concrete members designed with FRP bars due to the distinct difference in the mechanical properties between the FRP and the steel bars. The most critical difference is the low modulus of elasticity of the FRP bar compared to the steel bar, which leads to increased deflection and crack depth and width Abushanab et al., (2021); Attia et al., (2020); El-Sayed set al., (2005b); (El-Sayed et al., 2007); (Razaqpur et al., 2004). This in turn will reduce the depth of the uncracked compression zone and the aggregate interlock along the shear crack surface, which both are responsible for reducing the ultimate shear capacity.

It is customary when conducting a study on the one-way slabs to consider the flexural behavior as done by several studies Attia et al., (2019); Benmokrane et al., (2005); Chang et al., (2012); (Michaluk et al., 1998); (Zheng et al., 2019). However, because of the brittle nature of both the FRP bars and concrete and the low elastic modulus of the FRP bars, it is also recommended to investigate the shear behavior of one-way slabs reinforced with FRP bars.

Recently, few studies have been published on the shear behavior of one-way slabs reinforced with FRP bars Abdul-Salam et al., (2013); (Abdul-Salam et al., 2016); (El-Sayed et al., 2005a). These studies have used the GFRP and the CFRP as the main reinforcing bars, while the BFRP bars are still not investigated. In addition,previous studies have concentrated on the effect of reinforcement ratio, concrete compressive strength, span-to-depth ratio, and depth of the slabs, but the effect of surface treatment of the bar on the shear behavior was not studied. Therefore, the present study was designed to determine the effect of the surface treatment of BFRP bars on the ultimate shear capacity of a one-way high-strength concrete slab. The effect of two surface treatments will be investigated herein, namely the ribbed and the sand-coated surfaces.

2 Materials

2.1 BFRP Bars

All the used BFRP bars were of 12 mm diameter with two different surface treatments. The first type of bars was manufactured with a sand-coated layer on the outer surface, while the second type of bars was manufactured with ribs on the outer surface as can be seen in Figure 1. The mechanical as provided by the manufacturer's data sheet were as follows: the ultimate tensile strength, the elastic modulus, and the ultimate strain values were 1177 MPa, 49.48GPa, and 2.55% for the sand-coated bars; whereas for the ribbed bars, these values were 1100 MPa, 50GPa, and 2.20%, respectively.

Fig. 1: The Used BFRP Bars

2.2 Concrete

In this study, a concrete mix with the proportions listed in Table 1 was prepared.To measure the concrete strength of each mix, three concrete cylinders of 200 mm height and ×100 mm diameter were cast, cured in water for 28 days, and tested according to ASTM C39. The obtained average compressive strength was 55.12 MPa.

Table 1: Concrete Mix Proportions

Concrete ingredients					
Cement (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Gabbro coarse aggregate, 10 mm (kg/m^3)	Gabbrocoarse aggregate, 20 mm (kg/m^3)	Superplasticizer (kg/m^3)
500	165	700	105	945	0.35

3 Test Set-Up

As shown in Figure 2, the testing set-up with the dimensions of the tested one-way slabs in mmis illustrated in Figure 2. The experimental work includes two one-way slabs with the following dimensions: 600 mm width × 150 mm height × 2550 mm length. The first slab was reinforced longitudinally with 8ϕ12mm sand-coated bars, while the second slab was longitudinally reinforced with 8ϕ12mm ribbed bars. The reinforcement ratio of the tested slabs was specified as 1.27%, which is equivalent to 3.62 times greater than the balanced reinforcement ratio. The slabs were loaded until failure with two symmetrical point loads located at the middle of the slab with a loading span of 1350 mm. The loading rate was specified to be 1 mm/min. At the midspan, two linear variable differential transformers (LVDTs) and two strain gauges were fixed to record the deflection of the slabs and the strain values in the longitudinal BFRP bars, respectively.

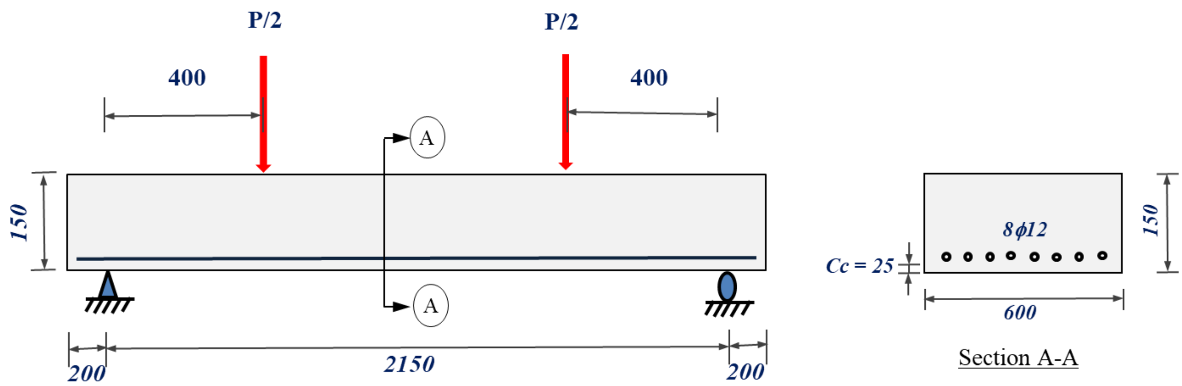

Fig. 2: Testing Set-Up. All Dimensions are in Mm

4 Testing Results

In this section, the obtained experimental results will be discussed in terms of the load versus midspan deflection and the load versus BFRP bar's strain behaviors that are shown in Figure 3 and Figure 4, respectively. Further details listed in Table 2 will be discussed, including the ultimate load and the corresponding midspan deflection, the BFRP bar's strain at the ultimate load, the onset of flexural crack, and the failure mode. Overall, when loaded, both slabs experienced a linear increase in the applied load with a small increment in the deflection as the slabs were utilizing their full moment of inertia before the onset of the first flexural crack as can be seen in Figure 3. At this stage, the stiffness of the ribbed bars reinforced slab was higher than the sand-coated bars reinforced slab. Moreover, as reported in Table 2, the load at the first flexural crack was recorded at 27.5 kN in the slab reinforced with ribbed bars, whereas it was recorded at 22.5 kN. Beyond this stage, the stiffness of both slabs was reduced progressively, then the loads continued to increase linearly with a higher increment in the midspan deflection. Similar to the pre-cracking stage, in the post-cracking stage, the slab reinforced with ribbed bars exhibited higher stiffness than that reinforced with sand-coated bars in all loading stages. To clarify this, the midspan deflection at 100 kNreached 10.34 mm in the former slab, however, a higher midspan deflection of 15.26 mm was reached in the latter slab. Similarly, the midspan deflection corresponding to the ultimate loading capacity was 27.86 mm in the slab with ribbed bars, while the midspan deflection was 35.52 mm in the slab with sand-coated bars. This could be due to the difference in the surface treatment of the used bars. According to Fahmy et al., (2021), the difference in the surface treatment can lead to different bonding characteristics. Therefore, they reported a significantly higher bond strength in the helically ribbed FRP barsthan in the sand-coated bars. This observation might also justify the higher shear capacity of 95.65 kN that was attained by the slab reinforced with ribbed BFRP bars when compared to the shear capacity of 90.08 kN attained by the slab reinforced with sand-coated bars.

It is expected that the higher deflection in the slab will induce higher stresses in the bottom reinforcing bars. As a result, it can be observed in Figure 4 that the strain values in the ribbed BFRP bars were notably lower than the sand-coated ones in all loading stages after cracking load. For instance, the strain in the ribbed BFRP bars corresponding to the ultimate load was 0.0062, but the sand-coated bars demonstrated higher strain with a value of 0.0081 despite the failure of the latter at a lower loading level. As can be seen in Figure 5, both slabs have failed under diagonal tension failure.

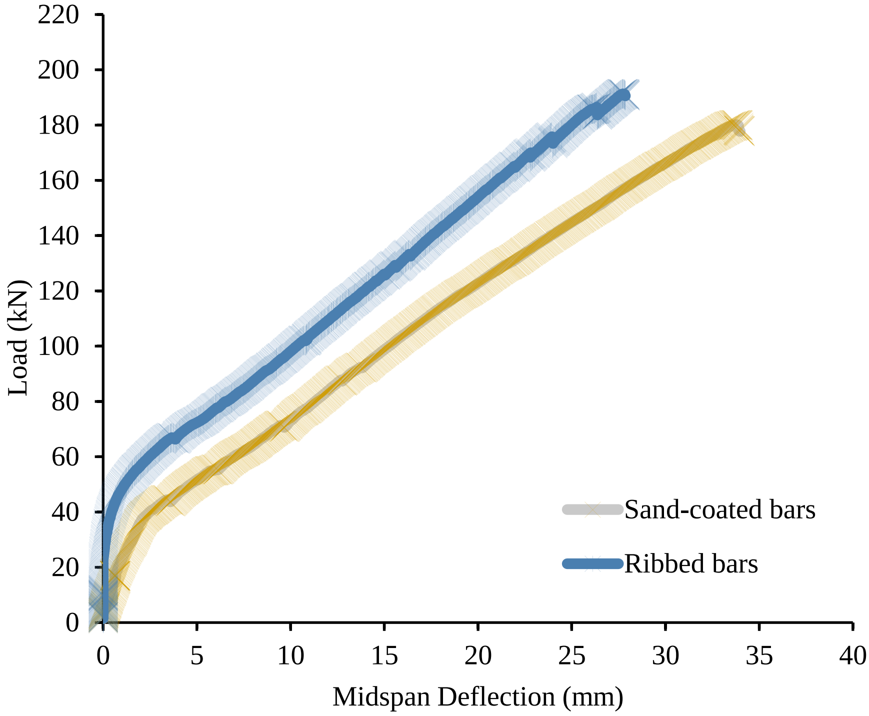

Fig. 3: Load vs Midspan Deflection relationship

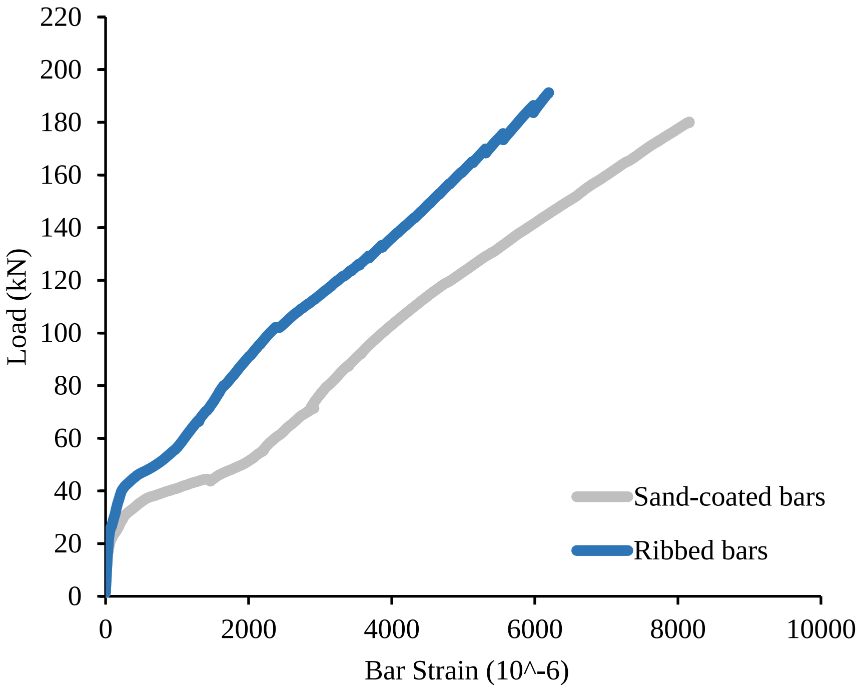

Fig. 4: Load Vs BFRP Bar Strain at Midspan

Table 2: Detailed Test Results

	Slab with sand-coated bars	Slab with ribbed bars
Ultimate load (P/2)	90.08 kN	95.65 kN
Midspan deflection at ultimate load	35.52 mm	27.86 mm
BFRP strain at ultimate load	0.0081	0.0062
Load at the first flexural crack	22.5 kN	27.5 kN
Failure mode	Diagonal tension	Diagonal tension

Slab with sand-coated bars

Slab with ribbed bars

Fig. 5: Failure Modes of the Tested Slabs

5 Conclusion

This study has assessed the effect of two surface treatments, namely ribbed and sand-coated surfaces on the shear behavior of one-way high-strength concrete slabs. The main outcomes obtained from the current study are as follows:

1. The slab reinforced with ribbed bars resulted in a higher stiffness and lower midspan deflection than the slab reinforced with sand-coated bars in all loading stages.
2. The load at the initial flexural crack in the concrete slab with ribbed bars was increased by 22.4% over the counterpart slab with sand-coated bars.
3. After cracking, the developed strain in the ribbed BFRP bars was notably lower than that in the sand-coated bars up to the ultimate stage.
4. Both slabs failed under shear, however, the shear capacity of the ribbed bars reinforced slab was higher than the sand-coated bars reinforced slab by 6%.

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