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Effect of Prestressing on the Flexural Response of Thin-flat Textile Reinforced Concrete Slabs

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ABSTRACT

Textile Reinforced Concrete (TRC) composites possess excellent mechanical properties and a pseudo-ductile response. Yet, they are prone to cracking and deformation under service loads. Prestressing the textiles before casting can address this problem. While prestressing has long been used to create thinner structural members and control deflection, its application to TRCs has only received limited attention. As a result, several aspects in the field of prestressed Textile reinforced concrete (PTRC) require further investigation to be utilised. To expand the existing knowledge, this paper presents an experimental activity on the flexural load-bearing capacity of PTRCs. The obtained results are presented and discussed concerning the design implications.

KEYWORDS

Textile Reinforced Concrete, Prestressing, Thin-walled structural components, Flexural Behaviour.

INTRODUCTION

Recently, advanced materials such as textile reinforcement have been widely investigated. When combined with concrete, Non-corrosive properties, high strength-to-weight ratio and flexibility of such material make it suitable to produce and optimise new thin products with different geometries(K & Sambath, 2020). Thin structural members, particularly those made of textile reinforcement are usually associated with high curvatures and cracks under service loads. To fully utilize the potential of such structures, prestressing can be used for optimising its serviceability limit state, load-bearing capacity, and cracking behaviour. Additionally, prestressing can enhance bond strength and stiffness (Schmidt et al., 2012; Zdanowicz et al., 2019).

The application of this technology to TRC has only recently received attention. The few existing studies show very promising results. A Study made by (Reinhardt et al., 2003) on AR glass and coated carbon fibre reported that prestressing improved the flexural behaviour of the tested specimens by reducing the ultimate deflection and increasing the ultimate load, while dry carbon fibres exhibited the opposite. Moreover, prestress can delay the generation of cracks and improve the post-cracking stage flexural stiffness (Meyer & Vilkner, 2003). Despite these positive findings, there are limitations to the use of certain materials such as carbon fibre, which are not economically feasible. Moreover, the durability of AR glass is questionable due to chloride ingress under sustained loads. As a result, researchers have turned their attention to a more economical, durable, and fire-resistant alternative: basalt textile reinforcement. Recent studies have shown promising results when basalt textile reinforcement is subjected to prestressing (Du et al., 2018).

Basalt textile is considered a relatively new material in the field, and wide aspects of its structural behaviour are yet to be investigated. In this research, the flexural performance of thin flat slabs reinforced with basalt textile will be investigated through 4-point bending tests. The experimental investigation will include prestressing the basalt reinforcement at three different prestressing levels (13%, 25% and 35%), expressed as a percentage of the ultimate tensile strength of the used textile. The mechanical properties of the used matrix and textile material were also determined through compressive and tensile tests, respectively.

EXPERIMENTAL STUDY

The work presented in this paper is part of a larger experimental program, to study the flexural and bond performance of prestressed TRC. The work presented here consists of evaluating the role of prestressing level on the flexural response of basalt-based mortars.

Materials

Textile reinforcement

One type of textile reinforcement was used in this study, made of basalt material. Fabricated as a unidirectional textile mesh with a spacing of 25 x 25 mm, with polymer coating. The mechanical properties of the basalt reinforcement according to the manufacturer's data sheet are listed in Table 1. The ultimate tensile strength of the used textile is 1350 MPa, determined experimentally by direct tensile tests on 410mm long non-standard bare textile coupons using an Instron machine under a constant displacement rate of 0.005 mm/sec. The applied load was recorded with an internal load cell and the strain of the material was measured by using a video gauge over a 200 mm gauge length.

Table 1: Mechanical Characteristics of basalt reinforcement

Material	Coating	Mesh size	Modulus of elasticity	Weight	Density	Nominal thickness
		[mm]	[GPa]	[g/m^2]	[g/cm^3]	[mm]
Basalt	Polymer	25x25	89	220	2.67	0.037

Concrete matrix

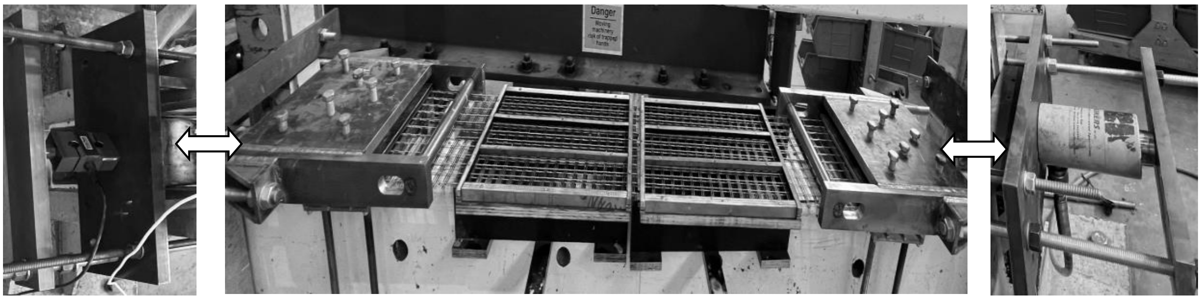
In the current study, the mix consisted of rapid-hardening Portland cement (52.5R, CEMI), Fly ash and silica fume as binding materials. Sand with a maximum particle size of 1mm was used as an aggregate. A mix with sufficient flowability, and high initial strength was designed (Table 2). The slump of the produced mix was estimated by using the mini-slump method, and the average value was 280mm. The compressive strength of the produced mortar was determined according to ASTM C109 (ASTM C109 / C109M-16a, 2016), with six samples of size 50 x 50 mm. The compressive strength of the hardened concrete at 24hrs was 29MPa with a coefficient of variation (COV) of 5.7, and 113 MPa at 28 days with a 5.1 coefficient of variation (COV).

Table 2: Mix proportions of the matrix.

Material	Cement (52.5 R)	Fly Ash	Silica Fume	Sand (0.6-1.0 mm)	Water	Superplasticiser
[Kg/m^3]	589.2	189.0	50.3	1121.6	259.2	13.2

Specimens Preparation and Testing

Prestressed samples were produced by using a prestressing rig (Figure 1). Specifically developed to apply uniform tensile load over the textile material, through mechanical clamping. Once the textile material is attached to the sliding clamps, the load is applied through a hydraulic jack at one end and controlled by a load cell on the other end. Once the desired load is achieved, the casting moulds are then placed in between the clamps with the textile reinforcement positioned inside it. The concrete mix is then cast and set to cure for 24 hrs, covered with a plastic sheet before the pretension is released. After that, the samples were demoulded and cured in water up to 7 days from casting, and then stored in a temperature-controlled room until the day of testing. Non-prestressed samples were prepared in the same regime but without the application of any prestressing load.



a) Load cell b) Samples before casting c) Hydraulic jack

Figure 1: Developed prestressing rig.

The influence of prestressing on the fabric–cement composites' flexural properties were determined by four-point loading at a span of 300 mm. The load was applied using a ZwickRoell machine under displacement control with a rate of 1mm/min. Load and deflection were recorded using an internal load cell and video gauge, to calculate the toughness (energy dissipation) of the composite. The toughness values were found by calculating the area under the load-deflection curve up to a 10 mm deflection, for ease of comparison between samples. The test results are an average of at least 5 specimens. The tested specimens had a dimension of 410 mm in length, 90 mm in width and 20 mm in thickness(see Figure 2), and these values fall above the minimum values that were recommended in RILEM TC 232-TDT(Brameshuber et al., 2016).

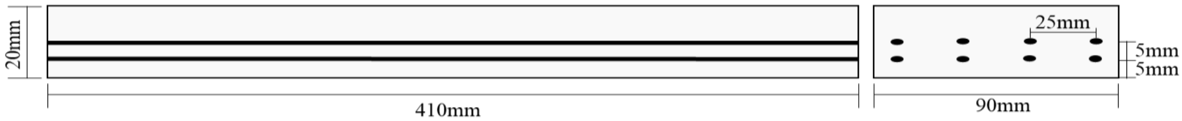


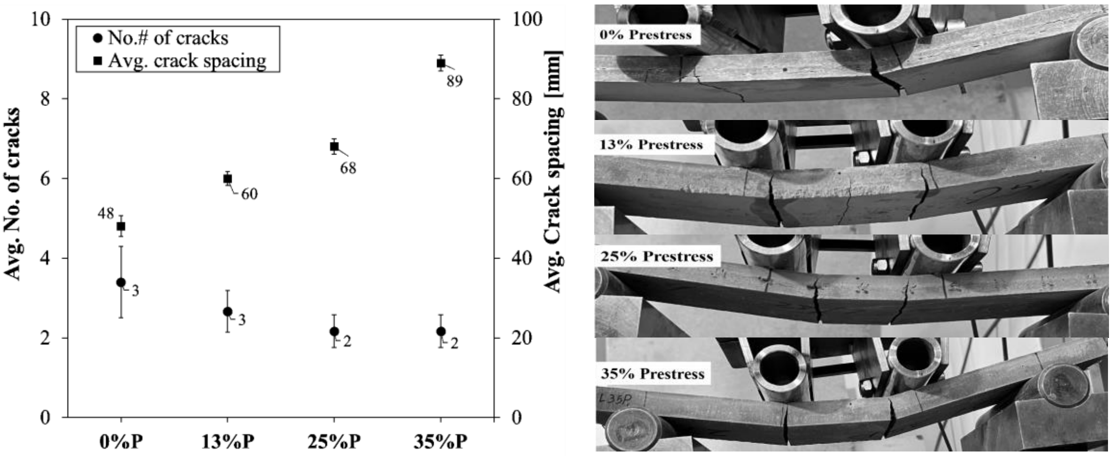
Figure 2: Specimen geometry.

EXPERIMENTAL RESULTS AND DISCUSSION

Crack pattern and failure mechanism

Figure 3 shows the change in crack pattern and failure mechanism observed in the tested specimens. In the non-prestressed specimens (Figure 3a), an average of three cracks was observed, primarily located at the edge of the pure bending zone. One of these cracks widened significantly at the point of failure (Figure 3b).
At a prestress level of 13%, the samples had a comparable crack pattern and spacing with non-prestressed samples. However, as the prestress level increased to 25% and beyond, there was a slight reduction in the number of cracks observed, accompanied by an increase in their average spacing. Additionally, the distribution of cracks shifted slightly towards the pure bending zone due to the influence of prestressing. The effect of prestressing on improving stress transfer between the fibres and the matrix became more evident, leading to a more uniform widening of the cracks.

No delamination was observed among the samples, and the main failure modes were either concrete crushing at the tip of the sample or fibre rupture. In the non-prestressed samples, a combination of concrete crushing and partial fibre rupture was observed as the main failure mechanism. The effect of prestressing exhibited variation at different prestress levels. At low prestress levels (e.g., 13% and 25%), the samples failed primarily due to the rupture of the yarns. However, in the 35% prestressed samples, a combination of fibre slippage followed by concrete crushing was observed. This can be attributed to the differences in bonding characteristics at various prestress levels.



a) Cracks number and spacing. b) Failure mechanism.

Figure 3: Cracking and failure behaviour.

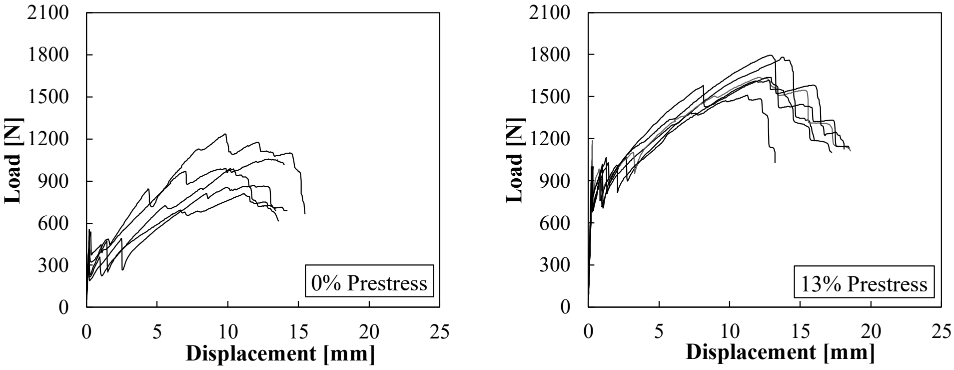
Flexural Response

The test results of the conducted 4-point bending test are summarised in (Table 3). Including various parameters such as the variation in first crack load and initial stiffness, ultimate load, corresponding deflection of each load level, toughness at 10mm and the cracking behaviour. Figure 4visually depicts the typical load-displacement behaviour of the tested PTRC specimens. The positive influence of prestressing is evident in increasing the cracking load of the specimens and their ability to resist cracking at higher loads. The load-bearing capacity of the samples was also enhanced by the application of prestressing. Additionally, it is observed that prestressing leads to an increase in the deflection at the ultimate load, indicating enhanced ductility.

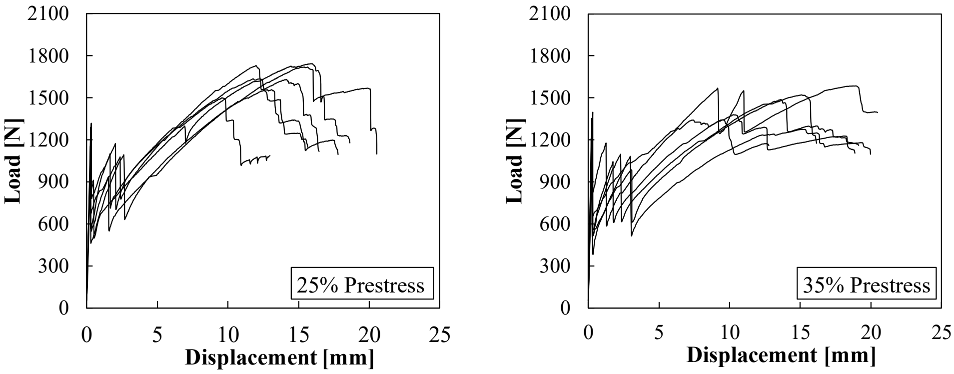
Table 3: Summary of the testing results

Prestress Level	n	First crack						Post cracking						Cracking Behaviour				
		Cracking Load (F_{cr})		Displacement (δ_{cr})		Initial Stiffness		Ultimate Load (F_{fu})		Displacement (δ_{ult})		Toughness @ δ=10mm		No. of cracks		Crack spacing		Failure Mechanism
		kN	COV [%]	mm	COV [%]	kN/mm	COV	kN	COV [%]	mm	COV [%]	kN.mm	COV [%]	-	COV [%]	mm	COV [%]	
0%	5	0.470	19.5	0.20	17.9	2.32	11.8	0.993	17.0	11.1	11.7	7.40	22.5	3.00	26.3	48.0	54.6	C.C/F.R.
13%	6	1.038	7.81	0.30	10.8	3.81	11.9	1.664	6.50	12.6	6.6	12.0	3.40	3.00	19.4	60.0	28.5	F.R.
25%	6	1.192	9.20	0.30	7.80	3.83	7.53	1.649	6.20	13.0	17.9	10.9	6.90	2.00	18.8	68.0	28.5	F.R.
35%	6	1.298	7.80	0.30	14.2	4.63	12.1	1.441	7.40	13.8	25.1	10.1	10.7	2.00	18.8	89.0	21.8	C.C

n: Sample size; COV: Coefficient of variation; C.C.: Concrete Crushing; F.R.: Fabric Rupture; C.C/F.R.: Combined concrete crushing and fabric rupture.



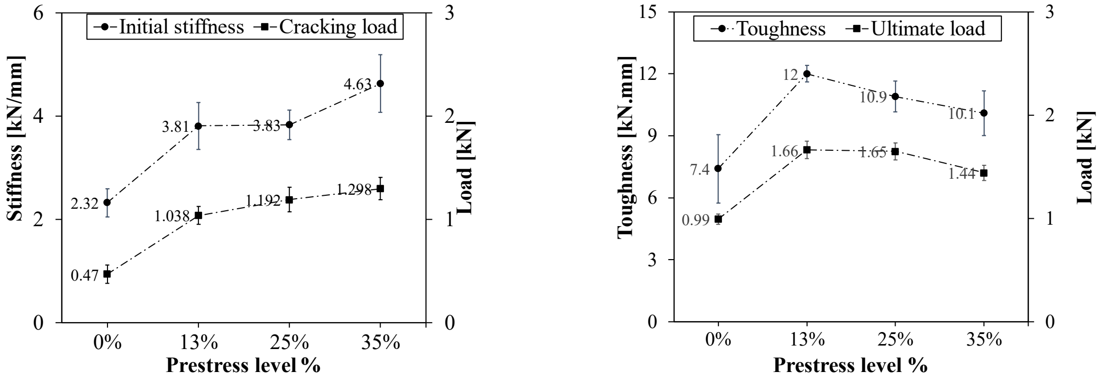
a) 0% Prestressed specimens b) 13% Prestressed specimens



c) 25% Prestressed specimens d) 35% Prestressed specimens

Figure 4: Load-Displacement graphs

The cracking load and initial stiffness of the samples prior to cracking increased proportionally with the increase of prestress level (Figure 5a). A considerable enhancement in cracking strength, ranging from 120% to 180%, was observed at prestress levels of 13% and 35% respectively. Furthermore, the rigidity of prestressed specimens improved significantly, as the prestressed specimens demonstrated a twofold increase in stiffness before crack initiation when compared to their control specimens. The influence of the prestressing level on the ultimate load and toughness values, measured at 10 mm deflection, had a variant effect (Figure 5b). At lower prestress levels (i.e., 13%), a substantial increase in both ultimate load and toughness, by approximately 65%, was observed. However, this increment showed a slight decline as the prestress levels increased. Specimens prestressed at 25% and beyond exhibited lower ultimate load and toughness values compared to the 13% prestressed samples yet these values remained at least 40% higher than those of the control samples, indicating that even at higher prestress levels, the specimens still outperformed the non-prestressed counterparts in terms of load-bearing capacity and energy absorption.



a) Initial stiffness and cracking Load b) Toughness at 10mm and ultimate load.

Figure 5: Summary of the testing results.

CONCLUSION

In this paper, an experimental study was conducted to examine the role of prestressing on the flexural behaviour of basalt textile reinforcement. Based on the obtained results, the following conclusions can be drawn:

1- The utilization of polymer-coated basalt textile reinforcement demonstrates promising suitability for prestressing applications. The cracking strength and initial stiffness exhibit a proportional increase in response to the prestress level. This indicates that higher prestress levels contribute to enhanced resistance against cracking and increased structural rigidity.

2- The load-bearing capacity of PTRC specimens improved with prestressing. The ultimate Load and toughness increased with the prestress level up to a certain level. However, at higher prestress levels, the rate of improvement begins to reduce.

3- The application of prestressing has a slight influence on the cracking behaviour of the specimens. It led to a reduction in the number of cracks accompanied by an increase in their spacing. It also influences failure modes, including fibre rupture, slippage, and concrete crushing, which vary with prestress levels.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest associated with the work presented in this paper.

DATA AVAILABILITY

Data on which this paper is based is available from the authors upon reasonable request.

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