FLEXURAL BEHAVIOR OF CARBON FIBER TEXTILE REINFORCED CONCRETE SLAB ELEMENTS

Offri Rashti, Ben Guion University of the Negev and SCE – Shamoon College of Engineering, Beer Sheva, Israel
Rami Eid, Braude College of Engineering, Karmiel, Israel (Formerly of SCE – Shamoon College of Engineering), Corresponding author, ramie@braude.ac.il
Alva Peled, Ben Guion University of the Negev, Beer Sheva, Israel
Erez Gal, Ben Guion University of the Negev, Beer Sheva, Israel

ABSTRACT
Textile reinforced concrete (TRC) can have a great advantage over conventional steel-reinforced concrete especially with respect to corrosion prevention. This paper deals with the flexural behavior of thin slab panel elements reinforced with coated and uncoated carbon fiber textile. The uncoated textiles were examined due to their enhanced mechanical behavior under fire conditions. Bending tests were performed on large scale TRC specimens. Overall structural behavior, crack development and failure mechanism of preliminary tested specimens were recorded and analyzed. The test results reveal the main structural behavior characteristics of the coated and the uncoated textile reinforced concrete thin slab panel elements.

KEYWORDS
Textile reinforced concrete – TRC, Concrete slab, Precast panels, Flexural behavior, Reinforced concrete

INTRODUCTION
Textile Reinforced Concrete (TRC) has emerged as a promising alternative to conventional reinforced concrete, offering enhanced performance and durability in various applications. TRC is a composite material that combines cementitious matrices with high-performance textile reinforcements, leading to an innovative construction material with unique properties (Peled et al., 2017). This scientific article aims to test TRC under flexural loading both coated and uncoated, focusing on its mechanical properties, durability, and potential applications in the construction industry.

The mechanical performance of TRC surpasses that of traditional reinforced concrete in several aspects, notably in tensile strength, ductility, and crack resistance. Fibers made of materials such as glass, carbon, or basalt, demonstrate exceptional tensile strength and stiffness, making them excellent candidates as concrete reinforcement (Peled et al. 2017). The nature of concrete is that it is a brittle material. This brittleness can lead to sudden failure and poor resistance to cracking under tension. Cracks, once formed, can influence durability issues including the corrosion of reinforcement, penetration of fluids and hazardous ions, which compromise the structural integrity (Peled et al., 2017; Boulekbache et al., 2016; Beglarigale and Yazıcı, 2015; Nahum et al., 2020; Mobasher, 2011)

The strategic utilization of TRC for structural elements can potentially reduce the concrete cover, facilitating the production of thin elements. This property broadens TRC's application range to include slabs, wall panels, precast panels, and structural building façade elements (Krüger, 2004; Peled et al., 1999). The present study is devoted to exploring the flexural behavior of thin slab panel elements reinforced with both coated and uncoated carbon fiber textile (CFT). Due to its high stiffness and strength, CFT is an ideal reinforcement for structural concrete elements (Peled et al., 2017; Schladitz et al., 2012; Park et al., 2020).

Uncoated textiles were also used in this study due to their superior mechanical behavior under fire conditions compared to the coated textiles. Three-point bending tests were conducted on large scale TRC specimens, with the variables being slab thickness, concrete cover, the number of textile layers, and type of textiles. Preliminary results are presented in the paper showing the overall structural behavior, crack development, and failure mechanism of the tested specimens. The findings shed light on the main structural behavior characteristics of both the coated and uncoated textile-reinforced structural concrete thin slab panel elements (Du et al., 2018; Schladitz et al., 2012; Park et al., 2020).

EXPERIMENTAL PROGRAM

The flexural tests were designed to measure the resistance of concrete plates reinforced with fabrics under bending loading. Three-point bending test configuration was implemented. During the experiment, the force and midspan deflection of the specimen were measured using load cell and linear variable differential transformer (LVDT) with a 100 mm testing range in one direction. The test was terminated when the sample reached complete failure, indicated by a load reduction greater than 80%.

Materials

Concrete

The compressive and tensile strengths of the concrete were investigated. Three sets of standard cylinders (150 mm diameter x 300 mm height) were used to determine the compression strength and 3 additional sets of concrete cubes 100x100x100 mm were prepared at the "Ackerstein Industries Ltd". The tensile strength was determined based on the splitting test, which can experimentally determine the tensile strength of brittle and tension-sensitive materials. The concrete modulus of elasticity was obtained by testing 3 standard cylinders prepared during the casting stage. Details are presented in Table 1.

Table1 - Concrete mechanical properties

Property	[MPa]
Splitting tensile strength	3.1
Compressive strength – cylinder 150x300 mm	66.2
Compressive strength 100x100x100 mm cubes	83.2
Modulus of Elasticity	40,000

Carbon fiber textile - CFT

Both coated and uncoated carbon fabrics were examined aiming to study their influence on the element structural behavior, as well as their effect on tensile resistance, crack development, and failure mode. Uniaxial tensile tests on carbon fabric specimens were conducted. The axial deformation and the applied force were measured, and stress-strain curves were plotted accordingly.

It was observed that the tensile strength of a single uncoated transverse fiber (1507 N) was significantly smaller compared to that of a single uncoated longitudinal fiber (2359 N) as shown in Figure 1. This was likely due to the presence of an additional set of loops, which leads to friction between the fibers and causes them to work together, unlike the transverse fiber (Figure 2). Nevertheless, it still accounts for approximately 40% of the load capacity of a coated fabric (Figure 1, Figure 3, and Table 2). These findings should be considered when calculating the load resistance of the structural element. This comprehensive analysis of the material properties allows for a more informed understanding of the performance of carbon fabrics in different configurations and coating conditions. In addition, the tensile strength of the coated mesh fibers is higher compared to that of uncoated ones due to the fact that the epoxy penetrates the carbon fibers and allows them to work together. As a result, the strength of coated fabrics is about 2.3 times higher than uncoated ones.

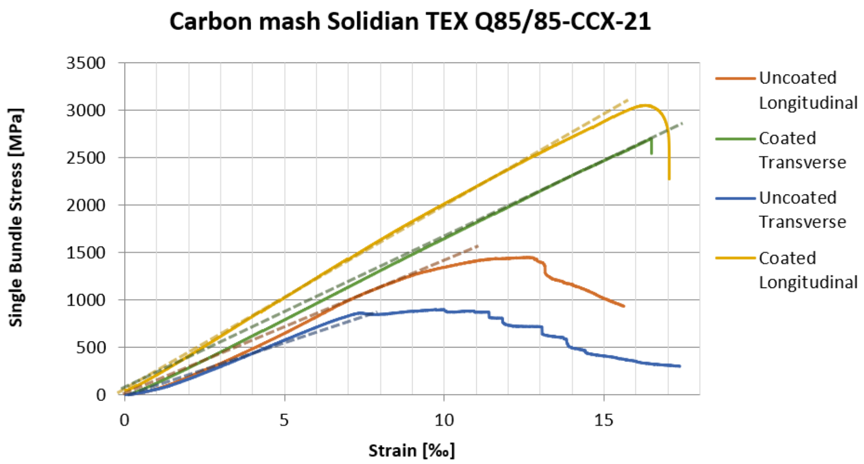


Figure 1 – Typical stress-strain curves of coated and uncoated textile fibers – longitudinal and transverse

Figure 2- Uncoated textile

Figure 3- Coated Textile

Table2 - Textile tensile strength properties

Textile		Carbon Mesh Solidian TEX Q85/85-CCX-21 (Uncoated) *Averaged lab results	Carbon Mesh Solidian GRID Q85/85-CCE-21 (Coated) *Reported by manufacturer
Mesh opening size		21x21 [mm]	21x21 [mm]
Tensile Strength	Longitudinal	1304 [MPa]	3000 [MPa]
	Transverse	833 [MPa]	2300 [MPa]
Fiber Cross Section	Longitudinal	1.81 [mm^2]	1.81 [mm^2]
	Transverse	1.81 [mm^2]	1.81 [mm^2]

Test Setup

Each tested TRC plate specimen had a length of 1.8 m and a width of 0.4 m, with varying heights of 50-75 mm. The plates were placed on two supports such that the span of each plate was 1.6 m (see Table 3 and Figure 4). The TRC specimens were tested for flexure in a 3-point bending test. The load was applied by an MTS actuator with a displacement control capability. The displacement rate for all the tested specimens was of 0.01 mm per second. The load frame was connected to a data acquisition system (can record up to 100 readings per second). Test setup is shown in Figure 5(a).

Table 3- TRC plate specimens' details

Series #	Series name	Span [mm]	Weight [mm]	Height [mm]	Number of Layers	Cover Thickness [mm]
1	NC-1L-05	1600	400	50	1	5
2	NC-1L-15				1	15
3	C-1L-05				1	5
4	C-1L-15				1	15

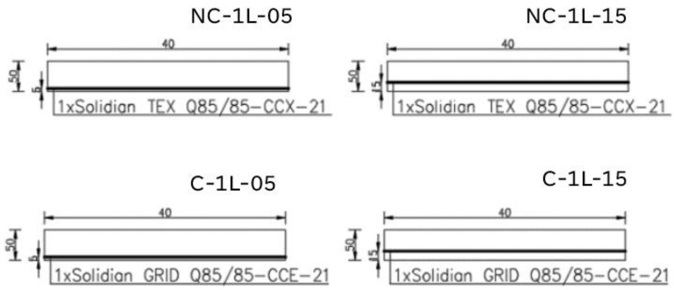


Figure 4 - TRC specimens' sections

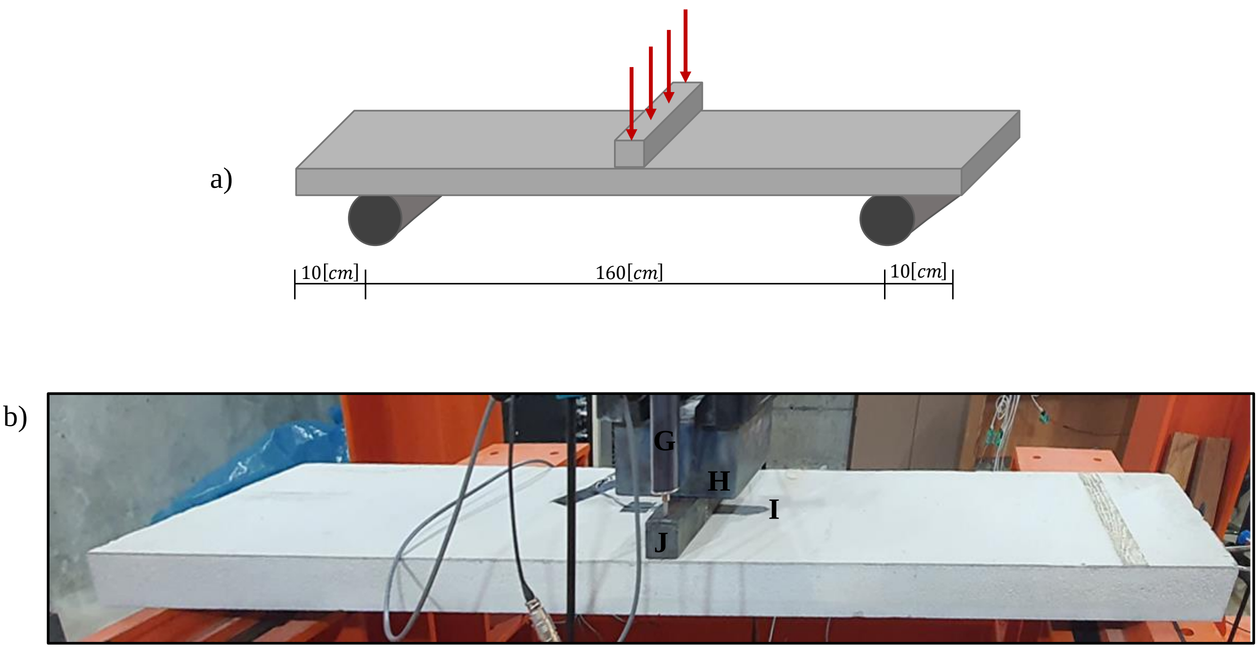


Figure 5: Test setup: (a) Dimensions of specimens (b) setup before testing. In the figure the following symbols are used: "G" = axial LVDT, "H" = actuator head plate, "J" = force distribution bar, "I" = strain gauge

Strain gauges were attached at the midspan of all specimens. A gauge was located at the bottom of the specimen to measure the tensile strains that occur during testing. An additional gauge was located on the top side of the section to measure the compressive strains of the concrete. To obtain a better image of the strains in the tension zone, an additional LVDT displacement sensor was placed horizontally to record horizontal readings for comparison with the strain gauge. Two additional LVDTs were placed on both sides of the plate center.

TEST RESULTS AND DISCUSSION

Initially, it was observed that the reinforcement influence is negligible, and the element resistance was controlled solely by the concrete until reaching the first crack (reaching the uncracked capacity). This behavior is believed to be due to the non-uniform stress profile across the filament bundle in non-coated fabrics and the fact that these fabrics were placed stress-free (relaxed) before casting. At this point, the reinforcement started to contribute to the overall resistance, resulting in a composite cross-section behavior of the plate. The midspan load-deflection behavior of the two uncoated specimens, NC-1L-05 and NC-1L-15, is presented in Figures 6 and 7. Comparison of the behavior of the two specimens revealed nearly identical cracking moments, primarily determined by the concrete's properties. The main distinction between these specimens lies in the position of the reinforcement within the composite section. As observed, TRC plates with a cover thickness of 15 mm showed a more gradual applied force decrease. On the other hand, the plate with a cover thickness of 5 mm reached higher load capacity compared to the one with 15 mm cover thickness (about 2.2 kN for NC-1L-05 and 1.5 kN for NC-1L-15). It should be noted that both specimens reached a high deflection at the end of testing (higher than 40 mm). The tests of were terminated after reaching second peak load and concrete crushing in compression.

The midspan load-deflection behavior of the specimens reinforced with coated textile mesh, C-1L-05 and C-1L-15, is illustrated in Figures 8 and 9. The figures present the results of coated TRC sections with different cover thicknesses. Specimen C-1L-05 features a cover thickness of 5 mm, while C-1L-15 has a cover thickness of 15 mm. Both sections demonstrated the ability to reach maximum loads about 2 times higher than those achieved by similar uncoated TRC elements. This result aligns with the expectation, as the strength ratio between coated and uncoated fabrics is also about 2 times. During the loading process, small cracks formed in the coated TRC sections, which resulted in sudden drops in the applied force as shown in Figures 8-9. The observed behavior underlines the significant impact of cover thickness and fabric coating on the performance of TRC sections, with potential implications for enhancing the durability and load-bearing capacity of such structural elements in various applications. In comparison to NC-1L-05 and NC-1L-15, the maximum deflection was similar (higher than 40 mm). The specimen with a cover thickness of 5 mm reached higher load capacity compared to that of a cover thickness of 15 mm (about 6.7 kN for C-1L-05 and 5.3 kN for C-1L-15)

The comparison between C-1L-05 and C-1L-15 highlights the influence of fabric positioning on the performance of textile-reinforced concrete (TRC) sections. C-1L-05 outperformed C-1L-15 in terms of achieving greater loads. This finding reveals that even for a very small concrete cover of 5 mm the composite cross section structural behavior was not affected. Thus, the behavior of the TRC structural elements can be increased by optimizing fabric placement within TRC sections. This should be done while keeping in mind the fire resistance of these elements.

Figures 10-11 show both uncoated and coated specimens before, during and at the end of testing. Figure 10a displays an uncoated section before loading, while Figure 10b captures the first crack that develops in the plate, which is a relatively wide crack that fails to meet the design standards regarding crack width. As the crack expands, the concrete eventually crushes in compression, as depicted in Figure 10c. Conversely, Figure 11a presents a coated textile reinforced concrete specimen before loading. In Figure 11b, a cracked coated textile reinforced concrete specimen is shown, revealing the development of very small cracks compared to the uncoated section. As a result, the coated section exhibits smaller deflections and behaves similarly to steel-reinforced concrete, which is capable of withstanding normal service loads. Figure 11c shows the sudden brittle failure of the coated TRC plate element.

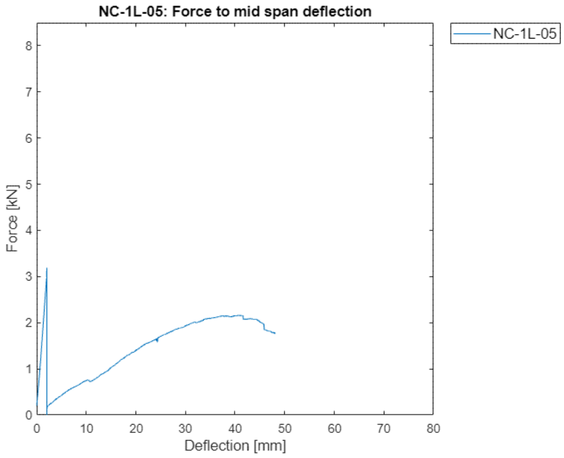


Figure 6: Load-deflection curve of specimen NC-1L-05 with 1 uncoated CFT layer and 5 mm cover thickness

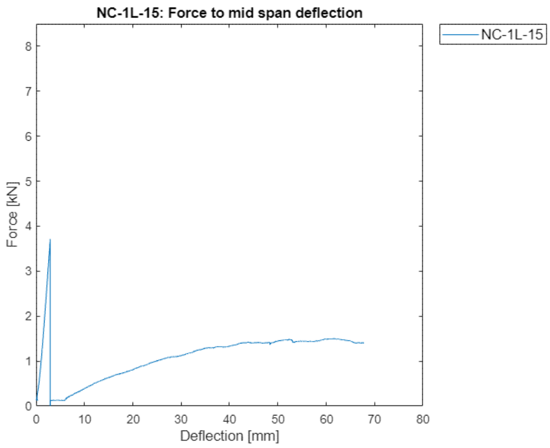


Figure 7: Load-deflection curve of specimen NC-1L-15 with 1 uncoated CFT layer and 15 mm cover thickness

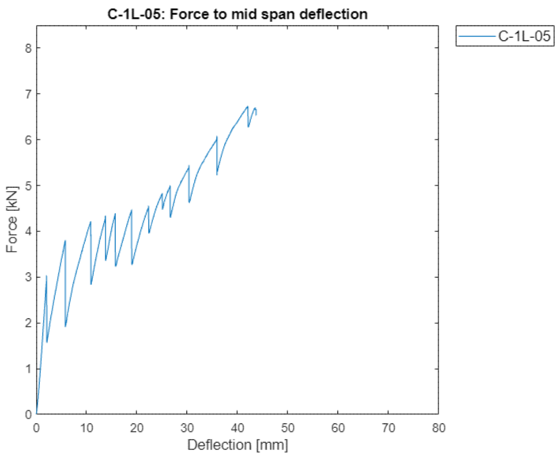


Figure 8: Load-deflection curve of specimen C-1L-05 with 1 coated CFT layer and 5 mm cover thickness

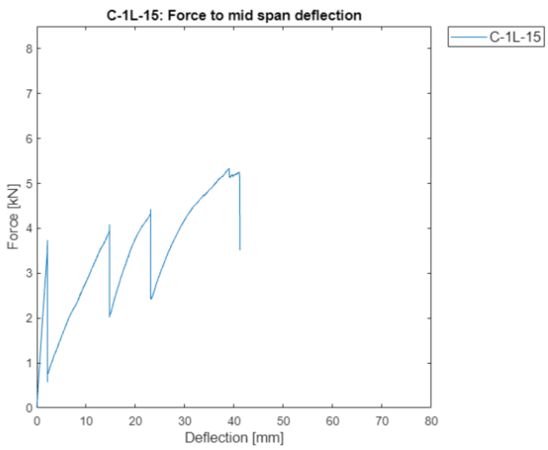
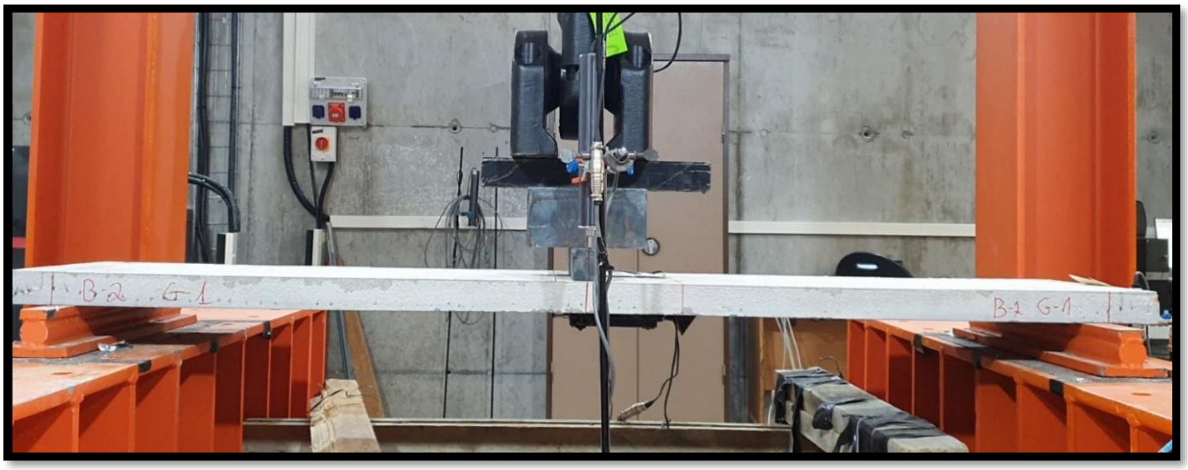
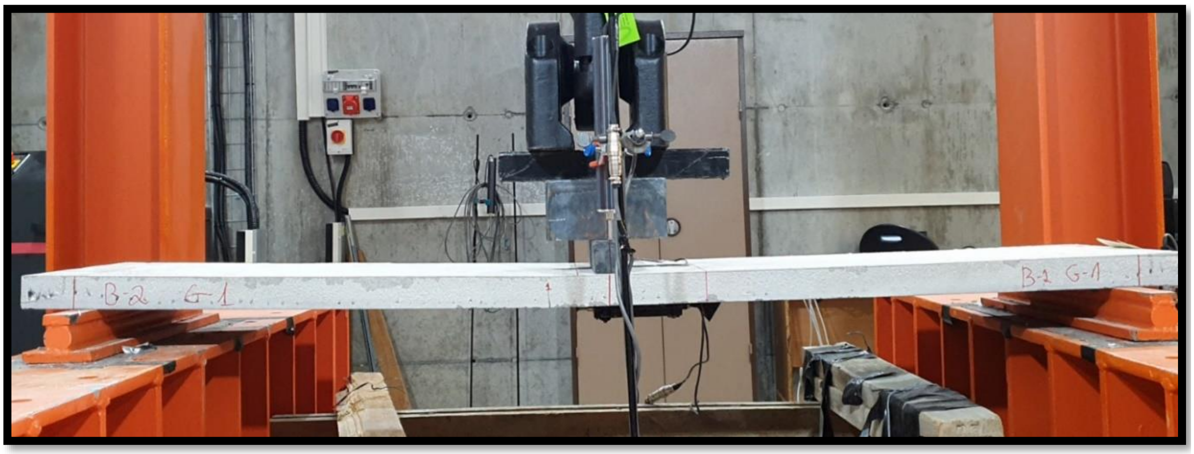


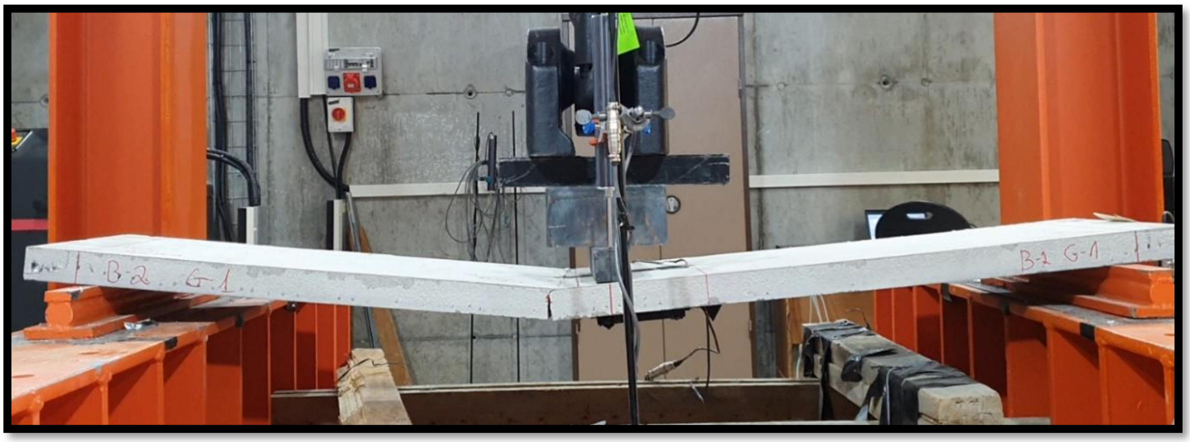
Figure 9: Load-deflection curve of specimen C-1L-15 with 1 coated CFT layer and 15 mm cover thickness



(a)



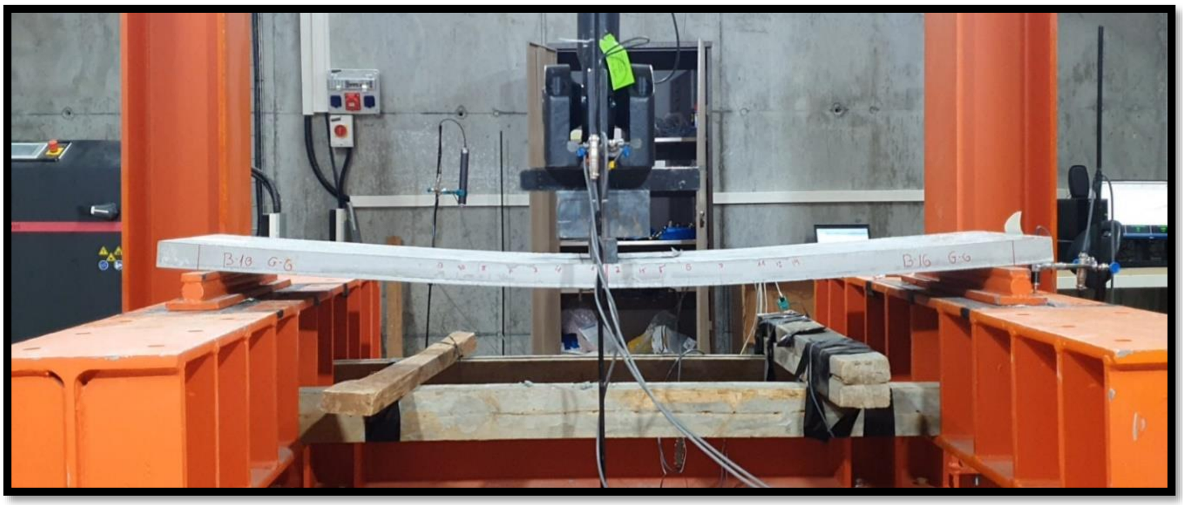
(b)



(c)

Figure 10 – Uncoated TRC specimen (NC-1L-05): (a) before load application, (b) cracking during loading, and (c) at failure

(a)



(b)

(c)

Figure 11 – Coated TRC specimen (C-1L-05): (a) before load application, (b) cracking during loading, and (c) at failure

CONCLUSIONS

This study presents preliminary results of the flexural behavior of thin slab panel elements reinforced with coated and uncoated carbon fiber textiles (CFT). This study shows that the structural behavior of the textile reinforced concrete (TRC) specimens is not influenced by the reinforcement up to the development of the first crack. The results show that specimens with a very small cover thickness of 5 mm can provide higher load capacity than those with 15 mm. Coated TRC specimens achieve significantly higher maximum loads compared to uncoated ones. Visual observations reveal differences in crack development and failure between coated and uncoated sections. The coated TRC plates exhibited smaller deflections and performed more similarly to steel-reinforced concrete in terms of crack pattern development, whereas the uncoated sections displayed fewer and wider cracks and a brittle failure. This research provides an insight into optimizing TRC elements for enhanced structural behavior while recognizing their advantages over conventional steel-reinforced concrete, particularly in terms of corrosion prevention and the ability to manufacture thin elements.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to Mr. Adam Shochen from "Ackerstein Industries Ltd" for his invaluable help in handling the models, and for his expertise in operating the casting. The technical assistance of Mrs. Victoria Elkenbard, Mr. Haim Dahan, Mr. Haim Forman and Mr. Yossi Gesua is gratefully acknowledged.

REFERENCES

A. Peled, A. Bentur, B. Mobasher, Textile Reinforced Concrete, 2017.

B. Boulekbache, M. Hamrat, M. Chemrouk, S. Amziane, Flexural behaviour of steel fibre reinforced concrete under cyclic loading, Constr. Build. Mater.

A. Beglarigale, H. Yazıcı, Pull-out behavior of steel fiber embedded in flowable RPC and ordinary mortar, Constr. Build. Mater. 75 2015.

Nahum Lior, Peled Alva, Gal Erez. The flexural performance of structural concrete beams reinforced with carbon textile fabric 2020.

B. Mobasher, Mechanics of fiber and textile reinforced cement composites, 2011.

Hegger J, Voss S Investigations on the bearing behaviour and application potential of textile reinforced concrete Engineering structure 2008.

Krüger M Vorgespannter textilbewehrter Beton (Prestressed textile reinforced concrete). Dissertation, University of Stuttgart 2004.

Peled A, Bentur A, Yankelevsky D Flexural performance of cementitious composites reinforced with woven fabrics Journal of materials in civil engineering 1999.

Schladitz F, Frenzel M, Ehlig D, Curbach M Bending load capacity of reinforced concrete slabs strengthened with textile reinforced concrete Engineering structures 2012.

Du Y, Zhang X, Liu L, Zhou F, Zhu D, Pan W. Flexural Behaviour of Carbon Textile-Reinforced Concrete with Prestress and Steel Fibres.

Park J, Park S, Hong S. Experimental Study of Flexural Behaviour of Reinforced Concrete Beam Strengthened with Prestressed Textile-Reinforced Mortar. Materials.

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.