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EXPERIMENTAL INVESTIGATION ON THE TENSILE STRENGTH DEGRADATION IN CURVED REINFORCEMENT OF TEXTILE REINFORCED CONCRETE

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Abstract. Recently, textile reinforced concrete (TRC) has become a new approach for strengthening the existing reinforced concrete and masonry structures. When TRC wraps around the structural members, the direction of textile reinforcements changes according to the curvature radius of the structural corner. This paper presents an experimental investigation into the tensile strength degradation in curved glass and carbon reinforcement of TRC specimens. The results show that the ultimate tensile load decreases as the diameter of the semi-circle parts reduce. At the same diameter, the carbon TRC specimens have a higher tensile load-bearing capacity than glass textile-reinforced concrete. The failure modes of all the experiment cases are the fracture of the textile reinforcement in the middle of the semi-circle parts or at the transition region of the straight and curved region. The tensile strength degradation of both glass and carbon textile reinforcement has a linear relationship with the diameter of the semi-circle parts of the TRC specimens. The value only reaches up to 41% and 60% tensile strength of the individual filaments for glass and carbon fiber, respectively.

Keywords: Textile reinforced concrete, tensile strength degradation, glass textile, carbon textile, curvature radius.

1. INTRODUCTION

After a long time under service, the existing reinforced concrete and masonry structures have been damaged because of the external load and effect of the surrounding environment. Several methods are commonly used for structure repair, retrofit, and rehabilitation such as fiber-reinforced polymers (FRPs), external post-tensioning, or sectional enlargement. Besides these traditional approaches, textile reinforced concrete (TRC) recently has emerged as a viable solution for structural strengthening [1-7]. Although there is one guideline for designing and constructing the externally bond TRC for repair and strengthening the existing structures [8], further investigation into the mechanical properties of this strengthened material is required for enabling its wide application in the practical field.

In literature, many researchers have found that it is difficult to determine the exact tensile strength of textile reinforcement, especially when it impregnates with fine-grain concrete (FGC). The study of Curbach [9] showed that the maximum tensile strength of textile roving is smaller than the individual filament. The work pointed out that the unequal loading among textile filaments is the reason for the reduction of the tensile strength. Papanicolaou [10] found that the bond behaviour between the reinforcement and FGC, the damage of the textile roving at the crack location, and the textile coating influence the tensile strength of textile reinforcement. The authors provided the respective coefficients related to these factors of both glass and carbon materials. Hegger [11] stated that the concrete cracks damage the textile and reduce the tensile strength of the textile reinforcement. The authors also recommended an effective ratio for tensile strength reduction of the textile material according to the angle between the tensile load and the roving direction.

When TRC wraps around the beams or columns of existing structures, the textile roving is bent according to the curvature radius of the members' corner. Many studies proved that the changes in reinforcement direction cause a reduction in the tensile strength of the textile fiber. The experimental work of Curbach [12] and Meßerer et al. [13] found that the tensile strength of single yarn and textile mesh depends on the fillet radius of the steel roller in the tensile testing system. The authors suggested that the tensile strength degradation of the carbon textile reinforcement is influenced by the crack at the concrete matrix and the transverse pressure on the curved TRC specimens. Ngo et al. [3] investigated the compression behaviour of RC columns with TRC wrapping. The experimental and modeling results also showed that the tensile strength of textile reinforcement at the column's corners reduces to 50% as compared with the values of the individual filament in the uniaxial test result. The aforementioned researches found the effect of curvature radius on the tensile strength of textile fiber, however, the investigation into the tensile strength reduction ratio of different types of textile with respect to different diameters of curved TRC is not yet considered. This paper conducted an experimental study on the tensile strength degradation in curved reinforcement of glass and carbon textile-reinforced concrete. The special testing system was designed for the measurement of tensile strength. The textile reinforcement was bent along the curvature diameters of the cured TRC specimens. Then the experiments were implemented by a tensile machine until the failure happens in the specimens to get the tensile strength of the textile fiber.

2. EXPERIMENTAL PROGRAM

2.1. Design of test specimens

This study investigates the tensile strength degradation in curved reinforcement of textile reinforced concrete from a uniaxial tensile test. To obtain the tensile strength of curved textile roving impregnated by FGC, the hollow shape TRC specimens with 70 mm width and 12 mm thickness were prepared (Fig. 1). Each specimen includes a 300 mm length of the straight part and two semi-circles at two ends. The diameters of the semi-circle parts are 22, 60, 90, and 120 mm which were chosen based on the work of Ortlepp et al. [14] and Meßerer et al. [13]. For each curved diameter, four glass and carbon TRC specimens were prepared. The letters G and C in the specimen label stand for glass and carbon textile reinforcement. The number after the letter indicates the diameter of the semi-circle. In this experiment, a total of 32 specimens were prepared to investigate the tensile strength of curved textile reinforcement.

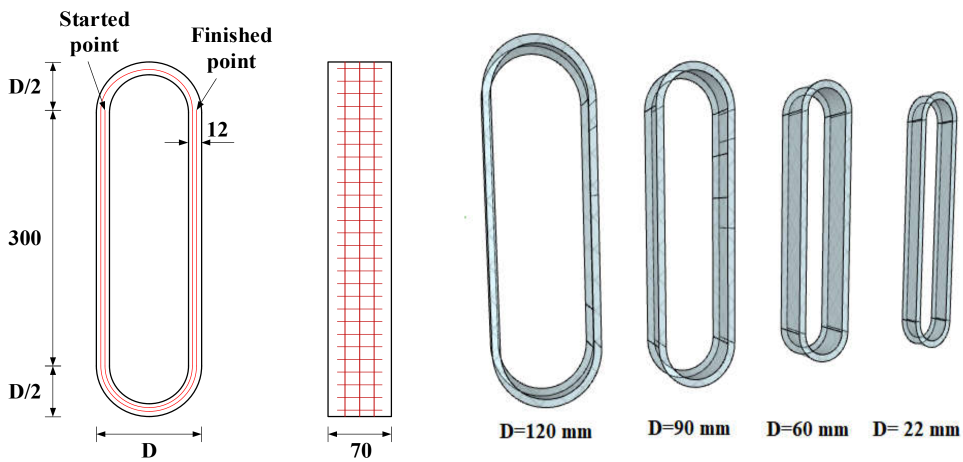
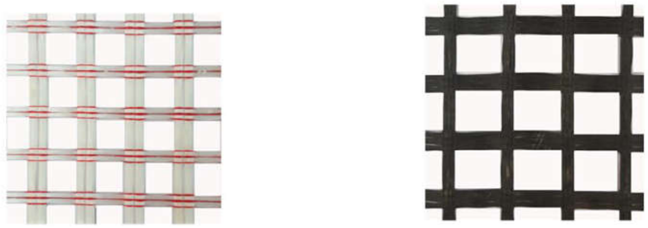


Figure 1. Dimension of test specimens (in mm).

2.2. Material properties

All TRC specimens were made from fine-grained concrete and textile reinforcement in the laboratory. The maximum size of FGC in the concrete mixture is 6 millimetres. According to RILEM [15] and TCVN 6016-2011 [16], the mechanical properties of FGC were determined by testing 6 samples of 40 x 40 x 160 mm prisms. The obtained flexural and compressive strength of the concrete at a testing age of 28 days are 6.95 and 47.5 MPa, respectively. High-strength plasticizer and fly ash were used to ensure the workable and proper penetration of concrete among textile fabric. This study used the glass textile SITgrid200KE and carbon fabrics SITgrid017 for reinforcement (Fig. 2). The glass and carbon fiber yarns were processed in two-dimensional wrap knit at 0°/90° direction with a distance of 17.1 and 12.7 mm, respectively. Table 1 presents the geometry and the mechanical properties of glass and carbon textiles used in the experiment [17].



(a) Glass textile (b) Carbon textile

Figure 2. Glass and Carbon textiles.

Table 1. Geometry and mechanical properties of carbon and glass textiles.

Textile	Geometry		Mechanical properties	
	Roving spacing (mm)	Roving area (mm^2)	Tensile strength (MPa)	Elastic modulus (GPa)
Carbon	12.7	1.8	2890	185
Glass	17.5	1.8	1890	120

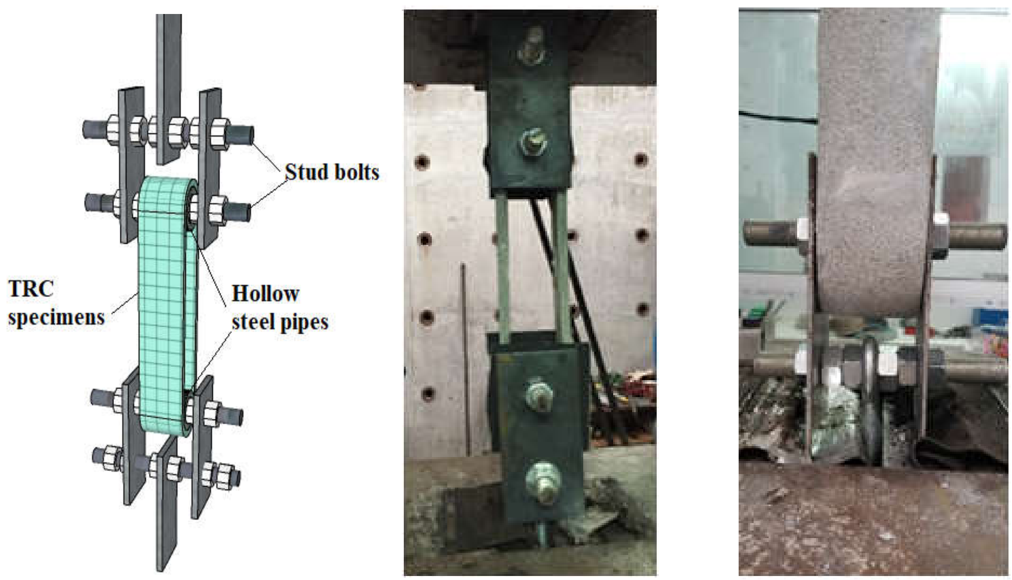
2.3. Instrumentation and test setup

The fabrication process of TRC specimens includes the following steps. Firstly, a 4 mm thick layer of FGC was prepared on the bottom surface of the specimen's mold. Then the textile roving was pressed lightly until it was immersed into the FGC layer. The same process was repeated for the second fine grain concrete and textile layer to anchor the textile reinforcement in the specimens. Finally, another layer of FGC was applied on the top of the fiber meshes to complete the production of the TRC specimens. In this experiment, there are different molds concerning semi-circle diameters of 22, 60, 90, and 120 mm for curved specimens. All the TRC specimens were cured indoors for at least 7 days to reach the strength before testing. The stages of TRC production in this study are illustrated in Fig. 3.

(a) Textile mesh (b) 1st FGC layer (c) Finished specimens (d) Cured TRC specimens

Figure 3. Fabrication of the TRC specimens.

The experiment on determining the tensile strength of carbon and glass textiles on FGC was implemented according to the idea of Meßerer's study [13]. To investigate the degradation of tensile strength of curved carbon and glass reinforcement on TRC specimens, a reusable tensile test system was designed as shown in Fig. 4. The two ends of the specimens were gripped by the steel plates via the steel bolts. The thickness of the steel plates is 5 millimetres. To transfer the uniform tensile force on the curved area of the TRC samples, the hollow steel pipes wrapping outside the 25 mm diameter stud bolts were used in the semi-circle parts. The diameter of the pipe changes from 22, 60, 90, and 120 mm with respect to different curved TRC specimens. The system then connected with the 3000 kN tensile force machine via the second stud bolt across the steel plates for testing. The tensile loading was applied based on displacement control with a loading rate of 5 mm/min. The tensile load data were recorded and stored in an analysis computer during the experiment.



(a) Testing system components (b) Tensile test system (c) Zoom in tensile testing system

Figure 4. Tensile test system.

3. RESULTS AND DISCUSSIONS

3.1. Ultimate tensile load and failure modes

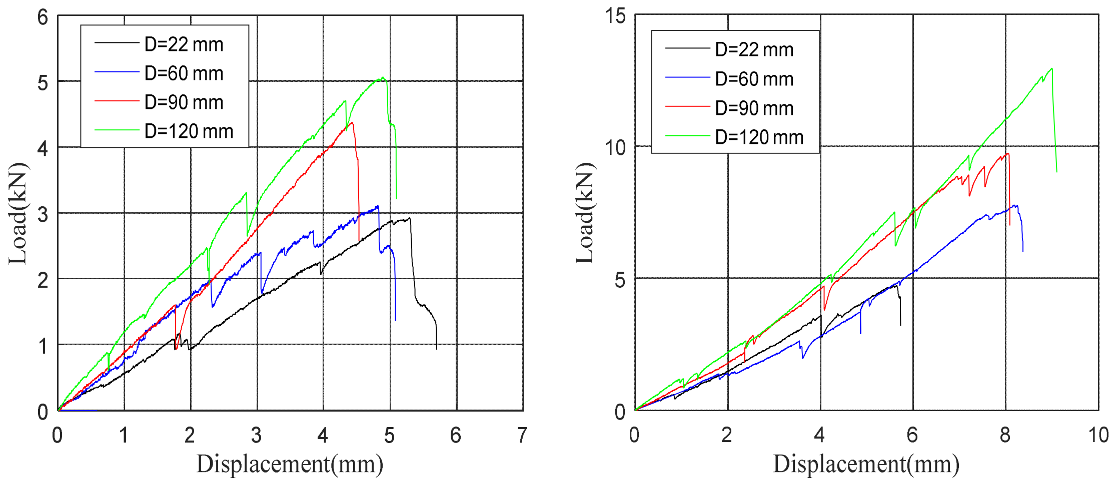
The ultimate tensile load and the respective failure modes of glass and carbon TRC specimens for different curved diameters are presented in Table 2. The load value was recorded in the analysis computer connected to the tensile machine during the test. In both types of textile mesh, the ultimate load goes up with the curvature diameter. At the 22 mm diameter, the tensile load is almost the same for glass and carbon textile reinforcement. As the diameters increase, the ultimate tensile load capacity of carbon TRC is always higher than that of glass TRC specimens.

Table 2. Ultimate tensile load and failure mode of TRC specimens in the experiment.

Textile	Diameter (mm)	Specimen	Load (kN)	Failure mode
Glass	22	G22_1	2.93	Type I
		G22_2	2.52	
		G22_3	2.93	
		G22_4	2.73	
	60	G60_1	3.06	Type I/II
		G60_2	3.99	
		G60_3	2.97	
		G60_4	3.55	
	90	G90_1	3.83	Type I/II
		G90_2	4.38	
		G90_3	3.13	
		G90_4	4.37	
	120	G120_1	4.35	Type II
		G120_2	3.59	
		G120_3	5.06	
		G120_4	4.71	
Carbon	22	C22_1	2.67	Type I/II
		C22_2	3.13	
		C22_3	4.72	
		C22_4	2.79	
	60	C60_1	6.29	Type II
		C60_2	8.43	
		C60_3	7.77	
		C60_4	8.76	
	90	C90_1	9.72	Type II
		C90_2	6.79	
		C90_3	9.25	
		C90_4	8.10	
	120	C120_1	6.64	Type I/II
		C120_2	12.9	
		C120_3	9.50	
		C120_4	8.50	

Fig. 5 shows some typical load-displacement curves of glass and carbon TRC specimens in the experiment. Noted that the tensile behaviour of the specimens is significantly influenced by the hollow steel pipe, steel plates, and stud bolts of the tensile testing system, the curves illustrated the behaviour of the whole testing system rather than only the TRC specimen itself. As compared to the uniaxial tensile test of straight TRC specimens, there is no clear crack development stage in the curved TRC specimens. The displacement increases with the tensile load until the test specimens failed at a fracture manner in the semi-circle region.

The failure modes of the specimens are the fracture of textile reinforcement in the middle of the curved arc (Type I) or at the transition region between the semi-circle and straight area (Type II), respectively. Fig. 6 showed the failure modes of the glass and carbon TRC specimens in the tensile testing. The crack development in the curved TRC specimens in the experiment can be described as follows. Firstly, the crack appears at the transition parts of the straight and curved region. It is because, in these locations, fiber meshes start to bend around the member's corner, and the direction between the textile reinforcement and the tensile load changes from zero to a certain angle. As the load increases, other cracks also appear, but only on the semi-circle parts. The results showed that in both types of textile reinforcement, the failure modes of 22 mm diameter specimens happened in the middle of the curved region (Type I). For a larger radius, the textile reinforced concrete failed at the fracture manner from the cracks at the transition part (Type II). It can be seen that in all experiment cases, the failure modes always happened in the curvature region of TRC specimens.



(a) Glass TRC (b) Carbon TRC

Figure 5. The load-displacement curves of glass and carbon TRC specimens in the experiment.

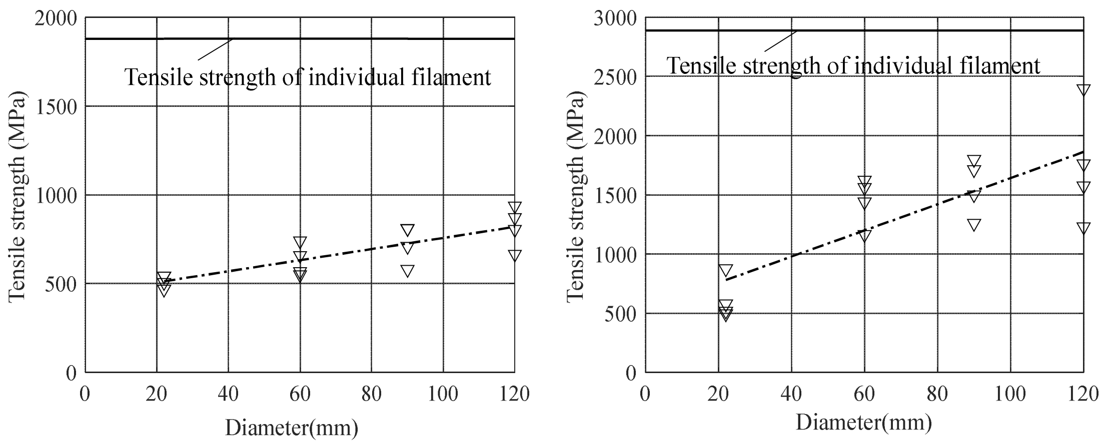
(a) Glass-Type I (b) Glass-Type II (c) Carbon- Type I (d) Carbon-Type II

Figure 6. Failure modes of curved glass and carbon TRC specimens.

3.2. The reduction of tensile strength

In this study, the tensile strength of the glass and carbon textile is derived by dividing the ultimate tensile load by the area of the textile reinforcement. The individual data points of tensile strength of glass and carbon TRC for each curved diameter are depicted in Figs. 7(a) and (b). It can be seen that the tensile strength of curved textile reinforcement is significantly reduced in all TRC specimens. The measured strength goes up as the diameter of the semi-circle increases. In both types of TRC specimens, the built-in trend line shows the linear relationship between the diameter and the tensile strength of the glass and carbon textiles in TRC.

Table 3 presents the mean and COV of tensile strength of curved carbon and glass textile reinforcement in TRC specimens. The results show that the mean tensile strength of glass and carbon textile reinforcement could reach 819.73 MPa and 1740.66 MPa in 120 mm diameter curved specimens, respectively. Although the measured strength can vary with approximate COV of 13% and 25% in glass and carbon textiles, the strength values of all experiment cases are smaller than that of the individual filament. In both types of materials, the tensile strength is significantly reduced in 22 mm diameter curved TRC specimens.



(a) Glass textile (b) Carbon textile

Figure 7. Tensile strength of glass and carbon textiles in TRC specimens at different diameters.

Table 3. Mean and COV of the tensile strength of glass and carbon textiles in the experiment.

Diameter (mm)	**Glass textile**		**Carbon textile**	
	Mean (MPa)	**COV (%)**	**Mean (MPa)**	**COV (%)**
22	514.31	5.98%	616.02	24.78%
60	628.45	12.16%	1446.83	12.16%
90	727.41	12.97%	1567.71	13.35%
120	819.73	12.29%	1740.66	24.39%

Table 4 provides the mean reduction ratio of tensile strength of curved textile reinforcement in different TRC specimens. The results show that the tensile strength ranges from 27 % to 41% and 21% to 60% of the theoretical strength of the glass and carbon textile filament, respectively. It can be found that the degradation of tensile strength of the reinforcement immersed into the FGC depends on the curved diameter of the TRC specimens. The ratio becomes smaller as the diameter of the semi-circle reduces from 120 mm to 22 mm in both glass and carbon textiles. As mentioned by Meßerer et al. [13], the local transverse pressures on cracks opening are the reasons for the appearance of the concentrated stress on the edge of the textile fiber. As the curvature diameters of the TRC specimens reduce, the built-in stress increases. Therefore, the fractures of the textile reinforcement happen earlier in the smaller diameters of curved TRC specimens. The results from Table 4 also show that the reduction of tensile strength depends on the type of textile fiber. Between two reinforcement materials, the tensile strength degradation of glass textile is higher than that of carbon textile.

Table 4. Mean reduction ratio of tensile strength of textile reinforcement in different curved diameters.

Diameter (mm)	Glass textile	Carbon textile
22	0.27	0.21
60	0.33	0.50
90	0.39	0.54
120	0.41	0.60

4. CONCLUSIONS

This paper investigates the reduction of tensile strength in curved glass and carbon reinforcement of textile reinforced concrete. The conclusions of this study are summarized below:

- The ultimate tensile load of curved glass and carbon textile reinforced concrete specimens increases with the diameter of the semi-circle parts. At the same diameter, the tensile load-bearing capacity of carbon TRC is always higher than that of glass TRC.
- The failure modes of both glass and carbon TRC specimens are the rupture in textile reinforcement in the curved region. The failure modes could happen in the middle of the curved arc (Type I) or at the transition region between the semi-circle and straight area (Type II).
- The measured tensile strength of glass and carbon reinforcement in curved TRC specimens only reaches 27 % to 41% and 21% to 60% of the theoretical strength of textile filament, respectively. A linear relationship between the degradation of tensile strength and the diameter of semi-circle parts is found. The reduction ratio of tensile strength of glass reinforcement is higher than that of carbon textile.

The results of this study confirmed that the tensile strength of both glass and carbon textile reinforcement is degraded in curved TRC. The reduction ratios of the strength with respect to each curvature radius and textile material could be used as the reference values for designing and constructing of TRC system. In this paper, the test specimens were examined under the tensile load. In practical applications, external TRC jackets for concrete columns are normally under both tensile and compression loading. A further experimental study is required to investigate the effect of the combined loading and different corner radius on the tensile strength of the textile reinforcement in TRC.

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