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The Usage of Carbon-Based Filament Yarns in Different Forms in the Design of Textile Reinforced Concrete Structures

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ABSTRACT

Textile reinforced concrete (TRC) is an innovative building material that has been used in recent years and consist of textile components with high tensile strength and concrete produced from fine-grained aggregates. Textile components can be used in the form of raw yarn, coated with various polymers, and recently, in the form of hybrid yarn. There are many hybrid yarn production methods used in the textile industry, and in this study, the braiding technique, which is suitable for the material used, is emphasized. In the study, samples were produced by positioning two different textile surfaces produced from three different yarn structures with carbon roving in three different positions in the concrete. Compared to the raw filament use, it was observed that the flexural strength increased by 23% with the use of hybrid yarn, while it increased by 167% with the use of epoxy coated filament.

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Buildtech, hybrid yarn, braiding yarn, epoxy resin, textile reinforced concrete (TRC), flexural behavior

1. INTRODUCTION

Various materials such as straw, clay, stone, and wood have been used in the production of buildings since the first periods of history for accommodation, which is one of the basic needs of human beings. Building materials have changed with the developments throughout history. Concrete is one of them, and with the discovery of cement in the 1800s, the use of concrete increased and it has become one of the most widely used construction materials today. The reason for this is that high compressive strength concrete is low cost and abundant. However, besides these advantages of concrete, it also has some disadvantages. For example, concrete with high compressive strength has high shrinkage and cracking and gives low tensile and bending strength. In addition, the weak toughness, high fragility and low impact strength of concrete led researchers to new searches for concrete [1-2].

Due to these disadvantages of concrete, which is widely used today because there is no alternative, studies have been carried out on its reinforcement with various materials, as was done in the first periods of concrete history. In particular, studies on composite structures created by combining concrete mortar and textile structures have gained intensity in the last quarter-century. These materials, called textile reinforced concrete (TRC), are composite materials that have been used as building material recently. TRC is known as innovative building materials with various uses such as sandwich panels, roofs, and outdoor furniture [3-4]. TRC is a composite material and consists of fine-grained concrete and textile materials with high tensile and alkali resistance such as alkali-resistant glass, basalt, and carbon filament. These high-strength materials are transformed into different textile structure forms to transfer their technical properties to concrete. The textile structures with a hollow structure that such as leno woven fabrics, knitted fabrics with bidirectional or multidirectional warp, or sandwich knitted fabrics can be used to allow the passage of the prepared concrete mortar [4-7]. Technical textile materials used in concrete reinforcement consist of materials that do not have the risk of corrosion. For

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this reason, it is not necessary to create thick structures in order to prevent rusting as in classical reinforced concrete production. Thanks to these structures, thin, high-strength, and long-lasting structures that do not carry the risk of corrosion can be obtained [4, 8].

Concrete mortar has a high alkaline environment and this environment affects the strength of textile fibers to be used in concrete reinforcement [9]. Despite alkaline-resistant filaments are mostly used as a textile component, and coating these filaments with various materials in order to further increase their alkali and tensile strength is one of the common methods used recently [10]. Due to the high cost of the coating materials used and the complex process steps of the coating process, alternative methods have been sought in the composite industry. With this quest, intensive studies have been carried out on hybrid yarn production technologies in which the main reinforcement component and thermoplastic material are combined. Thermoplastic composites are preferred because they can be processed at low pressure with temperature. In addition, it provides the possibility of production suitable for automation according to thermoset composites. However, there are problems in the impregnation process due to the high viscosity of the thermoplastic material in the melt. Therefore, the necessity of close contact between the reinforcement component and the thermoplastic component arises [11]. Hybrid yarn production technologies can provide this desired close contact. There are different hybrid yarn production techniques available and these methods aim to reduce the damage applied to the reinforcement component during the process [12].

Based on this, an alternative to the textile structures commonly used in concrete reinforcement was sought. Despite the disadvantages of the coating process applied in TRC production, the use of hybrid yarn production technologies is becoming widespread.

Halvaei et al. 2020, used carbon woven textiles for TRC production. These textile structures have gaps to allow concrete flowing. These gaps' sizes are changing from 0 to 20 mm. Since the reinforcement components contribute to the flexural direction, the performance of the samples was examined with the four-point flexural test. When the textile gap size was reduced, the samples gave higher flexural load and toughness. When the gap size was chosen as 2 mm instead of 20 mm, the flexural strength increased approximately 4 times, the toughness increased 8 times. It is thought that the more textile volume percentages causes this. When the gap size is zero, the infiltration of the concrete matrix into the textile material decreases in the samples and therefore shows a weaker performance. As a result of the study, it was found that the gap size of the textile structure is an important component in the flexural behavior of TRC [13].

Kravaev et al. 2009, developed and produced hybrid yarn with commingling technique. Thanks to this yarn, TRC was able to carry more loads. It was used AR-Glass fibers and water-soluble PVA yarns to produce hybrid yarn. At the end of production, the strength of hybrid yarns is 30% lower than conventional roving. Despite this, the hybrid structures is still twice as much as the strength of the composite structure that its sterngth is 500 N/mm² [14].

Merter et al. 2016, their study have showed the influences of hybrid yarn preparation method and fiber sizing type on the mechanical properties of composites that consist of glass and PP fibre. The air-jet and direct twist method were selected to produce composite material from hybrid yarn. When they produced fabrics with the air-jet hybrid yarn preparation method, they achieved the best glass fiber orientation. The tensile strength test was applied to investigate to the influences of production parameters on the mechanical properties of composites. Composite panels with similar fiber volume ratios were produced with both hybrid yarn production methods and their mechanical properties were compared. The best mechanical properties were obtained with the usage of air-jet hybrid yarn. PP resin and PES resin were used as sizing agents. It has been observed that the PP resin sizing agent contributes more to the bending and shear properties [15].

Hengstermann et al. 2016, have produced the hybrid spun yarns with reinforcement and thermoplastic component. They have used staple CF (Carbon fibre) as a reinforcement component and PA6 fibre as a thermoplastic component. Two different fibre length have used as a 40 mm and 60 mm. The length of used fibers, their mixing ratio, and their orientation in the card web are crucial factors in the carding process. Fibers with a length of 60 mm provide better carding effect and therefore better orientation. Consequently, if 60 mm fibers have used, the sliver quality has found to be better owing to the excellent orientation of fibers. In order to increase the strength of hybrid yarns, 60 mm fiber should be used as fiber length, yarn twist and CF ratio should be increased [16].

Funke et al. 2013, created a new superior-performance hybrid material for construction applications. For this, they combined textile reinforced concrete (TRC) and glass fiber reinforced plastic (GFRP). When TRC has high strength and durability, GFRC has high strength and design flexibility. The advantage of these two materials is combined in the hybrid material obtained. In comparison, while the tensile strength of fiber reinforced concretes is 12 MPa, ultra-high performance concretes 15 MPa, and textile reinforced concretes 44 MPa, the designed hybrid material has 165 MPa tensile strength. The test results showed that the usage of this hybrid structure as a building material is possible. The high tensile strength, low density and high design flexibility of the hybrid material increase the usage of the material in the construction industry [17].

Kurban and Babaarslan 2020, produced hybrid yarns to use at TRC production. AR-Glass and PP filament were combined with the commingling technique. They utilized the Taguchi orthogonal design to optimize the parameters of commingling yarn production. When the effect of hybrid yarn production parameters on breaking strength was examined, it was determined that the machine speed with 62.6%, air pressure with 15.4%, and the amount of feed with 9.6% had the effect [18].

The braiding technique, which is one of the hybrid yarn production techniques, has been used in textile production for about two centuries. A structure is formed by braiding three or more threads crosswise over each other [19-20]. In the braiding machines, which have two main types as a fixed and variable cross-section, only three-dimensional braiding machines allow the production of products with variable cross-sections [20]. With the technological developments in braiding machines, the usage areas of the products have expanded and their usage in technical applications has increased [21].

Kurban et al. 2017, in their study, alkali-resistant glass filament yarn was used for concrete reinforcement such as raw roving, epoxy resin coated, and hybrid yarn that was produced with the braiding technique. The yarns were not converted to the surface but placed in the concrete in the direction of bending. As a result of the study, samples produced from epoxy coated yarn contributed 78% to flexural strength compared to samples using raw filament yarn, while samples produced using hybrid yarn contributed 12% [22].

In this study, it is focused on whether the braiding technique, which has different applications in the textile industry but has not been studied in concrete reinforcement, can be used to create a textile structure for concrete reinforcement.

2. MATERIAL AND METHOD

2.1 Material

Carbon roving fibers are used as reinforcement materials in this study. Three different patterns of these materials were used in this investigation: (i) raw yarn, (ii) epoxy resin coated yarn, and (iii) hybrid yarn. Carbon fiber roving (DowAksa) was used as raw yarn for the first pattern. For the second pattern, carbon fiber roving was coated with epoxy resin (SR 8500/ SD 8605 from Sicomin). For the last pattern, carbon fiber roving for reinforcement material and polypropylene (PP) filament yarn (Aker Textile Yarn) for thermoplastic matrix material were combined to obtain hybrid yarn. Braiding technique, which has different application areas, such as shoelaces and ship rope, was chosen to obtain hybrid yarn. Hybrid yarns were produced by combining reinforcement and matrix components on a tubular braiding machine consisting of 16 spindles (Figure 1). The obtained hybrid yarn is a compact yarn structure in which the reinforcement and thermopastic component is combined into a single yarn. In order to obtain hybrid yarn with braiding technique, continuous carbon filament was placed in the center where braiding is performed, and PP filaments were placed in the 16 sindles around the center. In the hybrid yarn production process, while the continuous carbon filament moves, the PP filamentsi the spndles, rotate around the carbon filament, and thermoplastic component are braided on the reinforcement component. Properties of carbon roving and PP filament yarn were shown in Table 1.

Figure 1. Braiding machine

2.2 Method

Three different yarns were transformed into two different textile structures. Each textile structures have 10x40 yarns or 10x8 yarns (Figure 2). The first pattern (raw carbon roving) is winded to a special mold with noches getting textile surface (Figure 3).

Table 1. Properties of hybrid yarn materials

	Linear density (tex)	Density (g/cm^3)	Tensile strength (MPa)	Young's modulus (GPa)
Carbon	1600	1,78	4200	240
PP	66,6	0,9	550	3,5

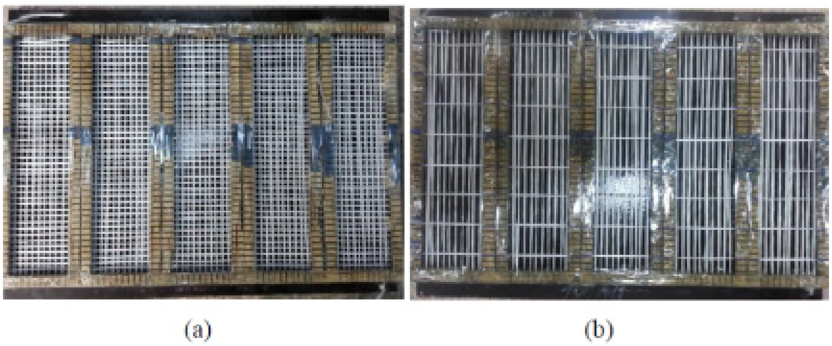

(a) (b)

Figure 2. Textile forms using raw roving: (a) 10x40, (b) 10x8

Raw carbon rovings are winded in the mold to form textile structures in two different forms.

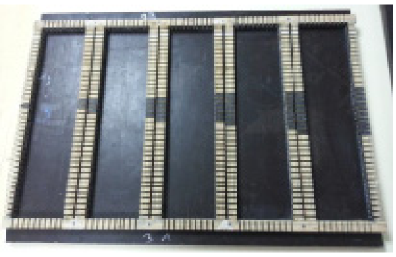


Figure 3. Special molds with notches

For the second pattern, carbon roving coated epoxy resin and they were winded to a frame getting a textile structure. After coated carbon rovings were formed textile strucures, all textile structres were put the oven for curing epoxy resin. The epoxy resin coated textile structures were pre-heated and fixed at the appropriate temperature and time as specified in the technical data sheet (TDS).

For the last pattern, hybrid yarns are winded in a frame to form a textile structure (Figure 4). Next, these structures were put in a hot compression device. Matrix fibers (PP filament) melted between hot compression molders. Then the molten thermoplastic component covers the reinforcement component which is the carbon roving. After hot compression, textile structures with hybrid yarns were obtained (Figure 5).

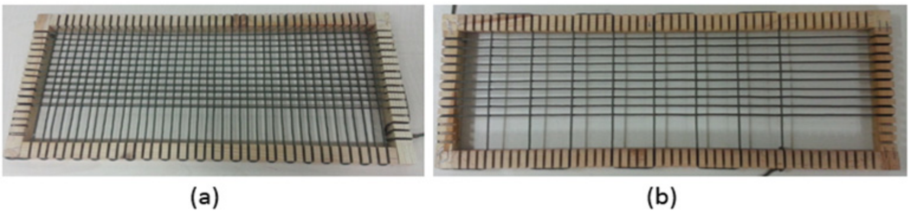
Contrary to molds in which raw carbon filaments are winded, textile surfaces obtained from the epoxy resin coated filament or hybrid yarn are put in different molds (Figure 6). These molds have holes and the strands to be used to fix the structures are passed through these holes. After the concrete pouring process, the structure fixing strands are removed. The textile structures were placed at three different distances from the bottom of the sample: (a) 3 mm, (b) 5 mm, and (c) 10 mm.

TRC is produced from high workability concrete. In order to meet this requirement, fine-grained concrete was chosen as the matrix in the study. Aggregates with a maximum particle size of 0.5 mm were used to obtain fine-grained concrete. In this way, it is ensured that the concrete matrix passes easily through the gaps of the textile structures and settles in the mold homogeneously. After all textile components were prepared, concrete was prepared as shown mix proportions in Table 2.

After the prepared concrete mortar was poured into the lubricated molds, a vibrator was used to better settle the concrete in the mold and to reduce the number of air bubbles. The dried samples were removed from the mold after 1 day and placed in the pool in the curing chamber to be cured according to the TS EN 12390-2 standard [23].

The prepared fine-grained concrete mixture is poured into molds of 150x150x150 mm and 400x100x20 mm. While 150x150x150 mm cubes are used for the compression test, 400x100x20 mm beams were used for the four-point flexural test. According to TS EN 12390-3 standard [24], the compression tests were carried on the 150x150x150mm cubes out in UTEST compression test machine (Type UTC-5750) (Figure 7, a). The loading rate was chosen at 4 kN/sec. The average compressive strength of a cube specimen was measured as 52,3 MPa. According to TS EN 12390-5 standard [25], the four-point flexural tests were carried on the 400x100x20mm beams out in ELE flexural test machine (Model 37-6330) (Figure 7, b). The loading rate was chosen at 0,05 kN/sec.

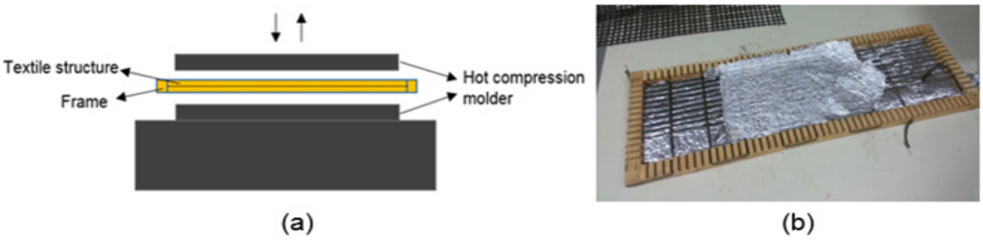
A comparator was attached in the mid-span (Figure 7b). During the test, when the deflection was measured from the comparator, the load was measured by the load cell in the test machine, too. The placement of the sample in the flexural test machine is seen in Figure 8.



(a)

(b)

Figure 4. Frames to form textile structures from hybrid yarns: (a) 10x40, (b) 10x8



(a)

(b)

Figure 5. (a) Hot compression device, (b) Textile structure after hot compression

Figure 6. Special molds with holes for structure production from epoxy resin coated filament or hybrid yarn

Table 2. Fine-grained concrete matrix composition

Material	Cement CEM I 42,5 R	Fly ash	Siliceous fines (0–0.3 mm)	Siliceous sand (0.2–0.5 mm)	Superplasticiser	Water
Content (kg/m^3)	480	240	642	503	10,8	284

(a) (b)

Figure 7. (a) Compression test machine (b) Flexural strength test machine

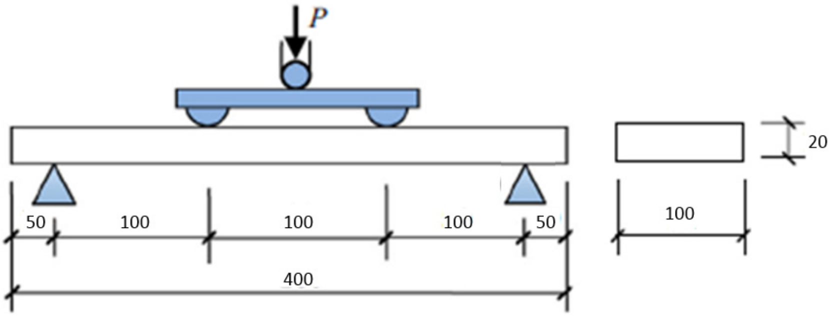


Figure 8. Four-point bending test setup and sample sizes

The flexural behavior of the different test specimens were compared according to TS EN 12390-5. According to the test standard, the deflection and flexural stress was expressed [25]. The results of the experiment are described as flexural strength and load-deflection curves. The flexural strength is calculated by Equation (1).

$$\sigma = \frac{(P\,l)}{(b\,h^2)} \tag{1}$$

Where σ is the flexural strength, P is the load, l is the span of the specimen, b is the width of the cross-section, and h is the height of the cross-section.

The area under the load-deflection curve gives the flexural toughness. The evaluation of the flexural toughness of the TRC specimens was carried out by adopting the energy method. The energy absorption is calculated by Equation (2).

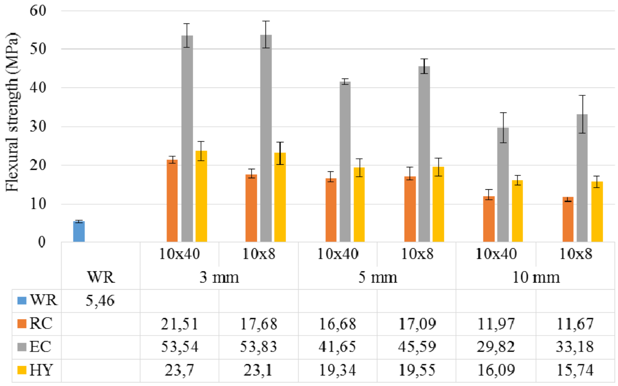
$$W = \int_0^{\delta} F\,d\delta \tag{2}$$

W is the energy absorbed by the specimen, N mm; δ is the mid-span deflection, mm; F is the load, N.

3. RESULTS AND DISCUSSION

3.1 Flexural strength

The flexural strength of samples are shown in Figure 9. The use of carbon roving as a reinforcement component contributed to the flexural strength for each reinforcement type, on both textile structures and at all distances. There are different parameters in the study such as reinforcement type, reinforcement location, and textile structure type. The effect of these parameters were explained in the next sections. The unreinforced concrete sample was coded as WR (without reinforced). The samples with raw carbon roving were coded as RC. The samples with epoxy resin coated carbon roving were coded as EC. The samples with hybrid yarn were coded as HY.



		3 mm		5 mm		10 mm	
	WR	10x40	10x8	10x40	10x8	10x40	10x8
WR	5,46						
RC		21,51	17,68	16,68	17,09	11,97	11,67
EC		53,54	53,83	41,65	45,59	29,82	33,18
HY		23,7	23,1	19,34	19,55	16,09	15,74

Figure 9. Flexural strength of TRC samples

3.1.1 Effect of reinforcement type

The flexural strength of all samples with reinforcement is higher than that of without reinforcement. As seen in Figure 9, the greatest contribution to the flexural strength was obtained in the samples where epoxy-coated textile structures were used. The lowest contribution was obtained in the samples using raw carbon filament. Based on the highest mean flexural strength values, the reinforced samples showed an increase in flexural strength of approximately 9.8 times with epoxy resin coated carbon roving, 4.3 times with hybrid yarn, and 3.6 times with raw carbon roving compared to the unreinforced sample. Even at its lowest flexural strength values, epoxy resin coated carbon roving contributed 446%, hybrid yarn 188%, and raw carbon roving 114% according to the unreinforced sample. Each reinforcement component contributed to the flexural strength thanks to its mechanical properties. With the contribution of the thermoplastic structure in the hybrid yarn structure, the flexural strength increased compared to the raw filament samples. In the use of epoxy resin, a high flexural strength has been obtained due to the superior mechanical properties of the material. For example, when the 10x8 reinforcement component is used at 3 mm, hybrid yarn contributed 30.7% and epoxy coated contributed 204.4% according to the raw carbon roving.

3.1.2 Effect of reinforcement location

As seen in Figure 9, flexural strength increases as the textile structure get closer to the sample base. As the textile reinforcement structures approached the sample bottom, they contributed more to the flexural strength as more stress was created in the sample bottom during bending. In the 10x40 textile structures, for raw carbon roving, when the textile structures are placed 5 mm, it gives 39,3% better flexural strength than 10 mm, when the textile structures are placed 3 mm, it gives 29% better flexural strength than 5 mm. For epoxy resin coated carbon roving when the textile structures are placed 5 mm, it gives 39,7% better flexural strength than 10 mm, when the textile structures are placed 3 mm, it gives 28,5% better flexural strength than 5 mm. For hybrid yarn, when the textile structures are placed 5 mm, it gives 20.2% better flexural strength than 10 mm, when the textile structures are placed 3 mm, it gives 22.5% better flexural strength than 5 mm. In the 10x8 textile structures, for raw carbon roving, when the textile structures are placed 5 mm, it gives 46,4% better flexural strength than 10 mm, when the textile structures are placed 3 mm, it gives 3,5% better flexural strength than 5 mm. For epoxy resin coated carbon roving when the textile structures are placed 5 mm, it gives 37,4% better flexural strength than 10 mm, when the textile structures are placed 3 mm, it gives 18,1% better flexural strength than 5 mm. For hybrid yarn, when the textile structures are placed 5 mm, it gives 24,2% better flexural strength than 10 mm, when the textile structures are placed 3 mm, it gives 18,2% better flexural strength than 5 mm.

3.1.3 Effect of textile structure type

In this study, two different textile structures such as 10x40 and 10x8 were used. While the number of yarns in the bending direction was kept constant, the number of yarns in the other direction was changed. In the use of epoxy resin coated carbon roving, the flexural strength of 10x8 textile structures is higher than 10x40 textile structures. The flexural strength of samples with 10x8 textile structure placed at 3 mm, 5 mm, and 10 mm increased by approximately 1%, 9,5%, and 11,3%, respectively, compared to samples with 10x40 textile structure. In the raw carbon roving and hybrid yarn, the flexural strength of both textile structures is similar, except raw carbon roving at 3 mm. In the raw carbon roving at 3 mm, 10x40 textile structure contributed 21,6% according to the 10x8 textile structure.

3.2 Load-deflection curve

In order to explain the flexural strength of textile reinforced concrete, the bending state of composite structures should be examined. The bending behavior of textile reinforced concrete under load can be modeled as the load-deflection curve shown in Figure 10. The load-deflection curve technically consists of two main regions and is defined as Case I: Uncracked concrete and Case II: Crack stabilization [5, 26].

State I corresponds to the elastic state of the textile-reinforced concrete element without cracks, where the stiffness is purely a function of the concrete matrix. It consists of a linear slope in this region. The first cracking occurs when the tensile strength of the concrete is reached, and then the stress in the crack area initiates the stresses in the textile component used as reinforcement. At the end of crack formation it stabilizes in State II, where stress reinforcement of the concrete is said to be effective. In this region, it consists of a linear but lower slope than in State I. Finally, in the end of State II, when the reinforcement component in the textile-reinforced concrete reaches its final limit load, the test sample breaks when the filament breaks or the filament is pulled out [5, 26].

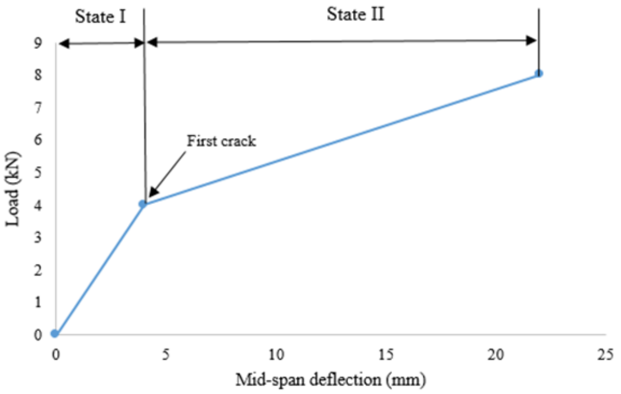


Figure 10. Load versus mid-span deflection for TRC under four-point bending, with indicated stages

The load-deflection curves of the samples produced from different reinforcement types are shown in Figure 11. In order to observe the effect of the reinforcement type, the load-deflection curves of the samples with 10x40 or 10x8 textile structures which give the highest load value, are placed at 3 mm, were examined. To compare the load-deflection curves, the load and direction axis values are kept constant. All curves were plotted up to the maximum load. As seen in Figure 11, all samples showed similar behavior up to the part where the first crack occurred. After the first crack formation, the slope of the load-deflection curve decreases. However, samples with raw filament and hybrid yarn have a similar and low slope, while epoxy resin coated samples have a greater slope. Hybrid yarn samples gave greater load and deflection value according to samples with raw carbon roving. It is thought that the thermoplastic reinforcement in the hybrid yarn protects the reinforcement filament and contributes more to the flexural strength, causing an increase in load and deflection. For example, in the use of 10x40 textile structure at 3 mm, for 2 kN load, a deflection value of 3,2 mm was obtained by raw filament, while a deflection value of approximately 4,3 mm was obtained in the use of hybrid yarn.

The load-deflection curves of the samples obtained when the textile structures are placed at different distances are shown in Figure 12. In order to observe the effect of the reinforcement location, the load-deflection curves of the epoxy resin coated samples with 10x40 or 10x8 textile structures were examined. In order to compare the load-deflection curves, the load and direction axis values are kept constant. All curves were plotted up to the maximum load. Since the highest flexural strengths were obtained in epoxy resin coated samples, the effect of reinforcement location was investigated in these samples. As can be seen in Figure 12, the first crack formation in all samples took place a bit later than in the unreinforced sample. After the first crack formation, the slope of the load-deflection curve increases from 10 mm to 3 mm. A greater load is required to achieve the same deflection value as the reinforcement component approaches the bottom of the sample. For example, in the use of 10x8 textile structure, for 4 mm deflection, a load value of 6 kN was obtained at 3 mm, a load value of 4,5 kN was obtained at 5 mm, and a load value of 3,5 kN was obtained at 10 mm. Textile reinforcement components should be placed close to the sample bottom in order to obtain greater flexural strength for a constant deflection value. In addition, when Figure 12 is analyzed, it is seen that 10x8 textile structures give higher load and deflection values than 10x40 textile structures. It is thought that the reason for this is that the 10x8 textile structures allow the concrete to flow more due to the hollow structure and the concrete matrix-textile reinforcement bonding is more.

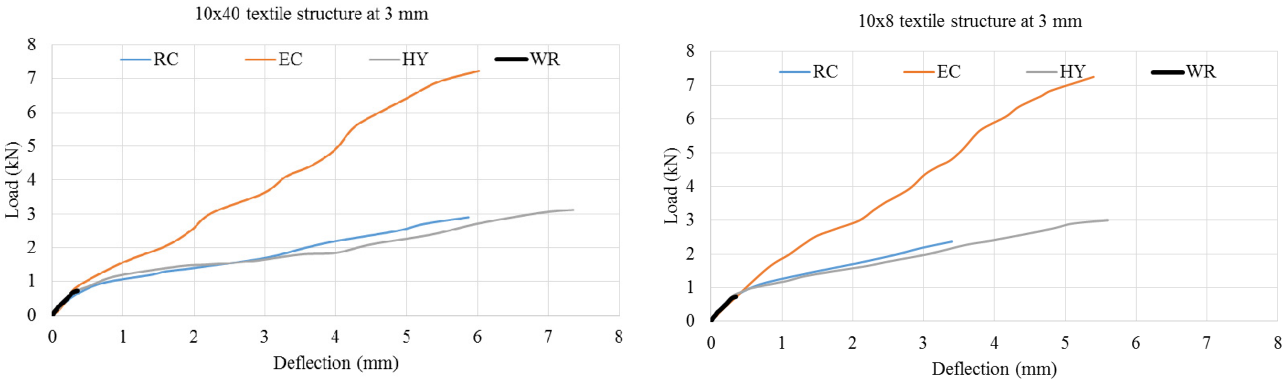


Figure 11. Load-deflection curves of the samples with 10x40 and 10x8 textile structure at 3 mm

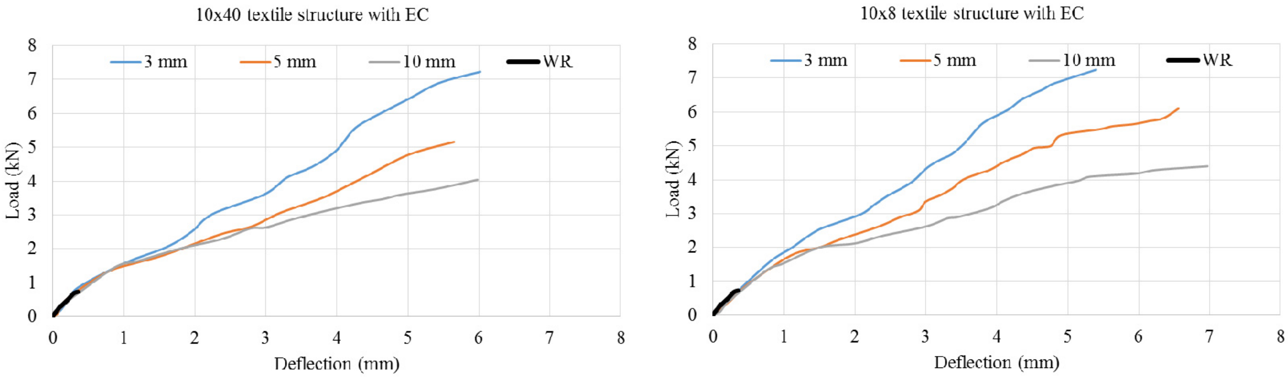


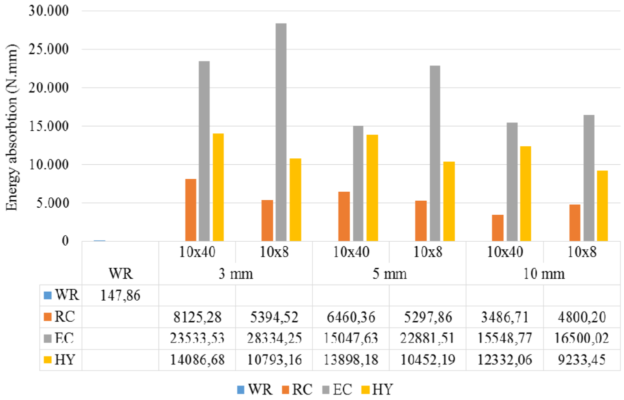
Figure 12. Load-deflection curves of the epoxy resin coated samples with 10x40 and 10x8 textile structure

3.3 Flexural Toughness

The energy absorptions of samples are shown in Figure 13. The effect of reinforcement types, reinforcement location, and textile structure type on energy absorption is seen in Figure 13.

The use of epoxy resin coated or hybrid yarn as a reinforcement component contributed to the energy absorption for each textile structure and at all distances according to samples with raw carbon roving. In the use of epoxy resin coated yarn, the energy absorption of 10x8 textile structures is higher than that of 10x40 textile structures. This is a similar result to that of the flexural strength graph.

When the energy absorption and flexural strength graphs are examined, it is seen that they are similar to each other. While samples with epoxy resin coated to give the highest values, samples with raw filament give the lowest values. For 10x40 textile structures, while the flexural strength of samples with hybrid yarn textile structures placed at 3 mm, 5 mm, and 10 mm increased by approximately 10,2%, 16%, and 34,4% respectively, compared to samples with raw filaments, the energy absorption of samples with hybrid yarn textile structures placed at 3 mm, 5 mm, and 10 mm increased by approximately 73,4%, 115.1%, and 253,6% respectively. For 10x8 textile structures, while the flexural strength of samples with hybrid yarn textile structures placed at 3 mm, 5 mm, and 10 mm increased by approximately 30,7%, 14,4%, and 34,9% respectively, compared to samples with raw filaments, the energy absorption of samples with hybrid yarn textile structures placed at 3 mm, 5 mm, and 10 mm increased by approximately 100%, 97,3%, and 92,4% respectively. The use of hybrid yarn instead of raw filament made a greater contribution to energy absorption according to flexural strength. The reason for this is that the thermoplastic structure in the hybrid yarn contributes more to the deflection as well as the increase in flexural strength.



		3 mm		5 mm		10 mm	
	WR	10x40	10x8	10x40	10x8	10x40	10x8
WR	147,86						
RC		8125,28	5394,52	6460,36	5297,86	3486,71	4800,20
EC		23533,53	28334,25	15047,63	22881,51	15548,77	16500,02
HY		14086,68	10793,16	13898,18	10452,19	12332,06	9233,45

Figure 13. Energy absorbtion of samples

3.4 Failure Modes

In this section, crack images of the samples after the flexural test are given in Figure 14. The fracture images of raw, epoxy resin-coated and hybrid-fiber carbon filament reinforced samples placed at a distance of 3 mm from the base after the flexural test are given. When Figure 14 is examined, it has been observed that fractures occur in the vertical and diagonal directions to the bending axis in the samples where raw filament structures are used. In the samples where epoxy resin coated and hybrid yarn structures were used, fractures occurred along the bending axis and in the diagonal direction. Fracture formations show that the bond between the textile structure and the concrete is good or moderate in samples where raw filament textile surfaces are used. The fractures in the samples where epoxy resin coated and hybrid yarn structures are used show that

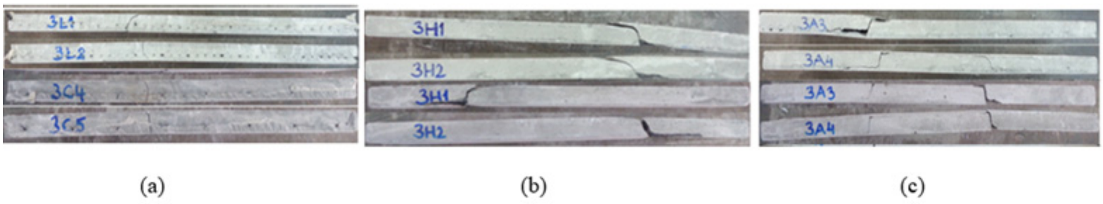


Figure 14. Failure modes of specimens with different materials (a) RC, (b) EC, (c) HY

the connection between the textile structure and the concrete is moderate or weak. While covering the raw filament with epoxy resin or using it in the form of hybrid yarn increases the flexural strength of the structure, it reduces the textile structure-concrete bond.

4. CONCLUSION

This article has shown the effect of the reinforcement types, reinforcement location, and textile structures on the flexural behavior of TRC by analyzing the results of four-point flexural tests. The main conclusions are as follows:

- All reinforcements contributed to the flexural strength according to unreinforcement sample. While epoxy resin coated samples provided the highest contribution, the lowest contribution was obtained in raw roving samples.
- The textile reinforcement structures contributed more to the flexural strength as they approached the sample bottom, as it better accommodated the stress on the sample bottom during bending.
- When 10x40 textile structures were placed at 3 mm for all reinforcement types, it gave more deflection than 10x8 textile structures. When the flexural strengths are examined, 10x40 textile structures in the use of raw carbon roving and hybrid yarn have higher values at other usage distances except 5 mm. In the use of epoxy resin coated yarn, 10x8 textile structures showed better flexural strength than 10x8 textile structures.
- The toughness distribution is similar to the flexural strength distribution of the samples. However, since the melted thermoplastic structure increased the deflection in the hybrid yarn samples, its contribution to the toughness was more.
- While the textile structure-concrete connection is good and moderate in raw filament samples, the connection is moderate and weak in epoxy resin and hybrid yarn samples.
- Although the hybrid yarn samples did not show sufficient flexural strength compared to the epoxy coated samples, it contributed to the flexural strength compared to the raw filament use. It has been observed that hybrid yarn structures have the potential to be used in concrete reinforcement.

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