Transport and Communications Science Journal, Vol. 72, Issue 1 (01/2021), 127-142

Transport and Communications Science Journal

A STATE-OF-THE ART REVIEW OF TENSILE BEHAVIOR OF THE TEXTILE-REINFORCED CONCRETE COMPOSITE

Tran Manh Tien[1]*, Do Ngoc Tu[1], Vu Xuan Hong[2]

[1]Department of Mechanisms of Materials, Hanoi University of Mining and Geology (HUMG), no.18, Pho Vien street, Duc Thang ward, Bac Tu Liem district, Ha Noi city, Vietnam

[2]Université de Lyon, Université Claude Bernard LYON 1; Laboratoire des Matériaux Composites pour la Construction LMC2, France

ARTICLE INFO

TYPE: Research Article
Received: 21/10/2020
Revised: 16/11/2020
Accepted: 18/11/2020

https://doi.org/10.47869/tcsj.72.1.14
**Corresponding author*
Email: tranmanhtien@humg.edu.vn; Tel: 0973094737

Abstract. Over the past two decades, textile-reinforced concrete (TRC) materials have been increasingly and widely used for the strengthening/reinforcement of civil engineering works. Thanks to their many advantages as the durability, considerable bond strength with the reinforced concrete (RC) members, best recycling conditions, the TRC materials are considered as an optimal alternative solution to substitute the traditional strengthening and reinforcing materials FRP (Fiber-Reinforced Polymer). The mechanical behavior of TRC composite has been characterized in previous experimental studies. This paper presents a state-of-the-art review of the mechanical behavior of TRC composite under tensile loading. By inheriting from previous review studies, this paper updates the experimental studies on the tensile behavior of TRC composite in the last decade. The review addresses, firstly the mechanical properties of constituent materials in TRC as reinforcement textile, cementitious matrix, and textile/matrix interface. Secondly, it addresses the tensile behavior of TRC composite, including the characterization methods as well as analyses of its strain-hardening behavior with different phases. The paper then discusses the main factors which influence the mechanical behavior of TRC materials in the available experimental studies. Finally, the conclusion of this review terminates this paper.

Keywords: textile-reinforced concrete (TRC), reinforcement textile, cementitious matrix, strain-hardening behavior, cracking stress, ultimate strength.

1. INTRODUCTION

In the field of civil engineering, the textile-reinforced concrete (TRC) composite was extensively researched in the early 1990s [1,2]. This new material has then been used for the different application in the civil engineering field, as strengthening or reinforcing of existing and old structures of infrastructure works, protective linings, bridges and also lightweight structures. It can also be used as a bearing structure in new buildings (thin-walled elements, façade elements)[3]. The TRC material is a combination of a cementitious matrix and a reinforcement of industrial textiles in different natures (carbon fiber, glass fiber, basalt fiber). The cementitious matrix contributes a role as a protective layer against the environmental impacts as well as a transmission layer to transfer and distribute the internal force from the structural element to the reinforcement textiles. On the other hand, the high mechanical strength of the reinforcement textiles ensures the bearing capacity of the TRC under the loading. In comparison with the FRP (Fiber-Reinforced Polymer) composite materials, the TRC material presents its advantages as the durability, considerable bond strength with the reinforced concrete (RC) members, best recycling conditions, etc. In special environmental conditions such as corrosion or at high temperatures, TRC materials also present an improvement in strength compared to FRP composite [4,5].

Until now, there were several experimental studies on the mechanical behavior of TRC composite under tensile or flexural loading. All experimental results showed the stress-strain relationships with different phases, depending on several factors belonging from reinforcement textiles, cementitious matrix, or environmental conditions [6,7]. The characterization of tensile behavior and the identification of the mechanical properties of TRC composites are necessary for the design. Depending on the application case, the designer has a good choice for used materials. Furthermore, a better understanding of this TRC material could allow discovering its new applications.

In Vietnam, this TRC material is not yet widely used. For strengthening or reinforcing old structures of infrastructure works, the FRP composite was used and presented many disadvantages with the humidity and temperature in this country. With the advantages mentioned above in comparison with FRP, the use of the TRC composite is necessary for Vietnam. Hence, to contribute additionally to the knowledge for a better understanding of TRC materials, this paper presents a state-of-the-art review of its mechanical behavior under tensile loading. By inheriting from previous review studies, this paper updates the experimental studies on the tensile behavior of TRC composite in the last decade [8,9,10]. It begins by discussing the mechanical behavior of the constituent materials itself in TRC as a cementitious matrix, reinforcement textile, and textile/matrix interface. Available experimental studies on TRC materials were reviewed and discussed on several aspects as characterization methods, stress-strain relationships, ultimate strength, or failure modes. By summarizing available results, several factors that influence on the mechanical behavior of TRC materials under tensile loading were highlighted and discussed.

2. CHARACTERIZATION METHODS

2.1. Materials used for TRC composite

For the materials used, the reinforcement textiles and cementitious matrices were generally commercial products or in development for application in the civil engineering field.

2.1.1. Reinforcement textiles.

The choice of reinforcement textile was generally based on the nature of the fiber and was dependent on several factors such as mechanical, thermal, physicochemical properties. Furthermore, it needs to correspond with the compatible, physicochemical, and geometrical characteristics of the types of matrix used. In considering the criteria of sustainable development, the choice of reinforcement textile ensures the proportion, availability, cost requirement, sustainability criteria. In terms of mechanical behavior, Young's modulus of the fiber, as well as the textile-matrix bond strength could lead either to a sufficiently stiff response to control the crack opening and to contributjikm to the stiffness of the composite, or flexible to follow in deformation without suffering cracking damage. So, the carbon, glass, and basalt fibers were better choices for the manufacturing of composite. Among them, despite a high cost, carbon textiles were fluently used for strengthening or reinforcing the structures of old civil engineering works because of more interesting mechanical performance associated with a low density [7].

In general, the reinforcement textiles exhibited an elastic quasi-linear behavior until their rupture. Regarding the capacity of industrial fiber, carbon fiber has the best mechanical strength of about 3000 – 5000 MPa and Young’s modulus about 200 – 250 GPa while glass fiber has the capacity less than about three times related to that of carbon fiber (see Table 1). The basalt and aramid fibers have considerable mechanical properties, higher than glass fiber, and lower than carbon fiber. Their mechanical strength is about 1800 MPa and 3000 Mpa, corresponding to basalt and aramid fibers (see Table 1). Concerning the mechanical properties of reinforcement textiles, it could be influenced by the treatment product in different natures (resin, sand powder, or mix) that will ensure the joint working between thousand monofilaments. A reasonable treatment could cause better values of the mechanical properties of the reinforcement textile. The experimental results in [11] showed that the pre-impregnation with an epoxy resin product could improve the tensile capacities of carbon textiles (ultimate stress and Young’s modulus) 2 times related to that in case of treatment with amorphous silica. The improvement of the tensile performance of reinforcement textile by pre-impregnation with resin products was also highlighted in some research of literature [6,9,10,11].

Table 1. Mechanical properties of different types of fibers [4].

Types of fibers	Strength in tensile (MPa)	Young’s modulus (GPa)	Elongation (%)	Poisson’s coefficient	Density (g/cm3)	Diameter min – max (µm)
Carbon	3000 - 5000	200-250	1,8	0,3	1,8	5-8
E-Glass	1100-1550	72-73	1,8	0,22	2,6	5-24
AR-Glass	1100-1750	74-76	1,8	0,25	2,7	9-27
Basalt	1800	85	2,1	0,25	3,0	9-13
Aramid	3000	60-130	1,8-2,3	0,35	1,8	5-15

2.1.2. Cementitious matrix

Depending on the nature of the cement, the cementitious matrix could be divided into four main groups often used for TRC composites: matrices based on Portland cement, matrices based on phosphatic cement, matrices based on aluminate calcium cement (or aluminous) and cementitious matrices loaded with polymer [4,6]. Each type of cementitious matrix has advantages as well as disadvantages for the manufacturing of TRC materials. For example, the Portland cement-based matrix widely used for reinforced concrete structure, however, it could not combine with E glass fibers because of the creation of an alkaline medium during molding, leading to the degradation of ordinary glass fibers [7,12]. The calcium aluminate cement-based matrix was considered a matrix alternative for specific applications such as rapid curing, chemical resistance, and heat transfer [4,13,14]. For the phosphatic cement-based one, the curing of this matrix occurs spontaneously and then creates a neutral medium (limitation of the alkali-reaction) which allows it to adapt with several types of fibers (E glass fibers, AR glass fibers, aramid fibers, natural fibers) [4,7].

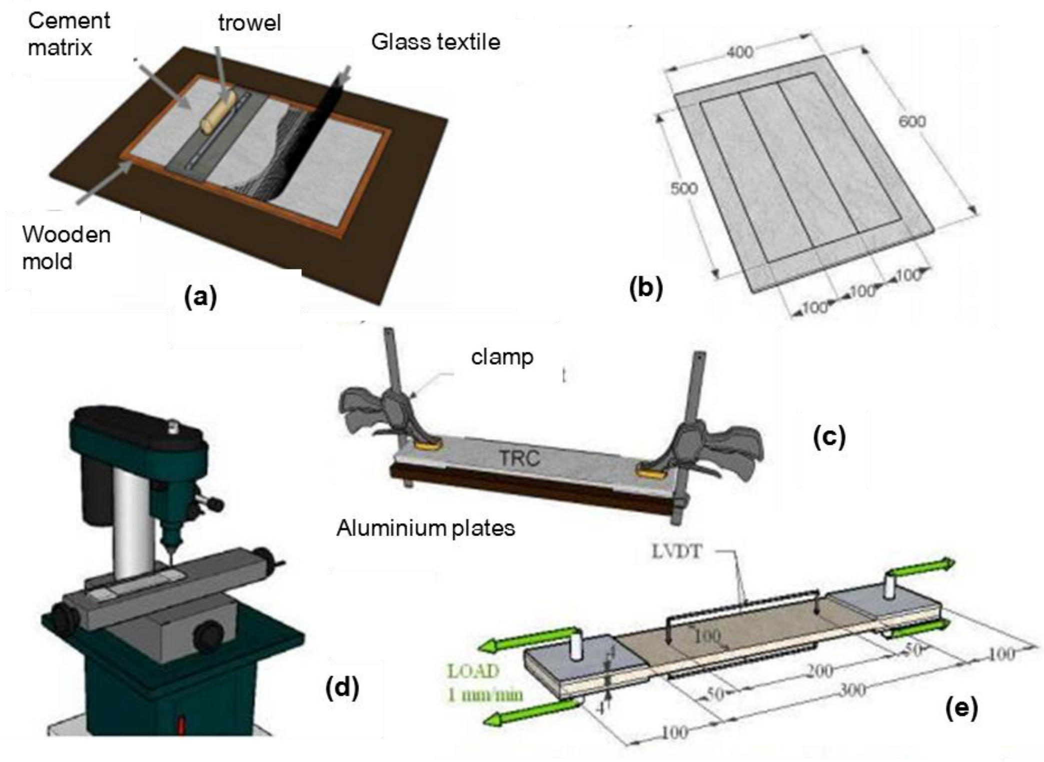


Figure 1. Procedure of specimen preparation of TRC composite in [6] (a) Hand lay-up technique, (b) Cutting to TRC specimens, (c) Bonding with aluminum plates at two ends, (d) Creating a hole to apply the tensile force, (e) Specimen for test.

2.1.3. Textile / matrix interface

The bond strength of the textile/matrix interface is the main factor that strongly affects the mechanical behavior of TRC composite, particularly in the phase of joint working between both components mentioned above [15,16]. Thanks to the textile/matrix bond, the retransmission of loading between the textile yarns themselves as well as with the cementitious matrix occur efficiently. It increases the matrix contribution in the overall mechanical behavior of the TRC composite. On the other hand, the weakness of bond strength between both components leads to the mechanical behavior of TRC like that of the reinforcement textile [4].

2.2. Specimen preparation

In previous studies, the procedure of specimen preparation was carried out in laboratory conditions with the hand lay-up technique. In this process, it needs to avoid factors that could affect the experimental results such as the dissymmetry of the reinforcement textile or the warping of the TRC plate after being cured [6,17]. Figure 1 presents steps of the procedure of TRC specimen preparation in [6], including the hand lay-up technique, the cutting of TRC plate to test specimens, the bonding with aluminium plates at two ends, the creating a hole to apply the tensile force, and finally the labelling specimen for test.

2.3. Test setup

Available experimental tests carried out with the tensile test machine were generally controlled by the control system that could record all experimental data. Moreover, it was also connected with measurement equipment to identify the axial deformation when the TRC specimen subjected to a tensile force. It needs to understand several techniques to obtain the best results. Firstly, the loading rate must be in the limited range, not be too fast to avoid the effect of dynamic phenomena, but not be to slow to not damage by the fatigue. The tensile force is applied by the movement of the traverse of the test machine with the predetermined loading rate. This value was generally from 0.1mm/min to 1mm/min, depending on the properties of TRC specimen (the type of reinforcement fiber, reinforcement ratio) [4,6,18]. Secondly, it needs to reduce the effects of the additional efforts (bending, compression, or torsion efforts) due to geometric imperfections of the TRC specimens that could cause the early cracking of the cementitious matrix. The ball-joint loading heads were usually used in this case to maintain and transmit the load from the test machine to the tested TRC specimen [19,20]. One thing else must be careful was the stress concentration at two ends of TRC specimens. It could lead some phenomena such as the non-uniform displacement field across the specimen width, the generation of compression effort transmitted by the talon, or the failure in shear of TRC specimens with the high reinforcement ratio [6]. So, it needs to reinforce two ends of TRC specimens by bonding with the metal plates (aluminium plates) to reduce the effects of this phenomenon and present a damage section in the middle of the TRC specimen.

2.4. Measurement methods

For the measurement of the axial deformation of TRC composite, several measurement instruments were used and presented good results (see Figure 2). These instruments based on contact measurement methods such as strain gauges [21,22,23] and LVDTs (Linear Variable Differential Transformer) [24,25], or non-contact measurement method such as laser sensor [26,27,28], and DIC (Digital Image Correlation) [17,29]. Moreover, several authors used the high-technique methods as acoustic emission [33] or optical fiber [17,22] to study mechanical behavior as well as the axial deformation of material components in TRC composite. Each measurement method has certain limitations to give reasonable results for the axial strain measurement.

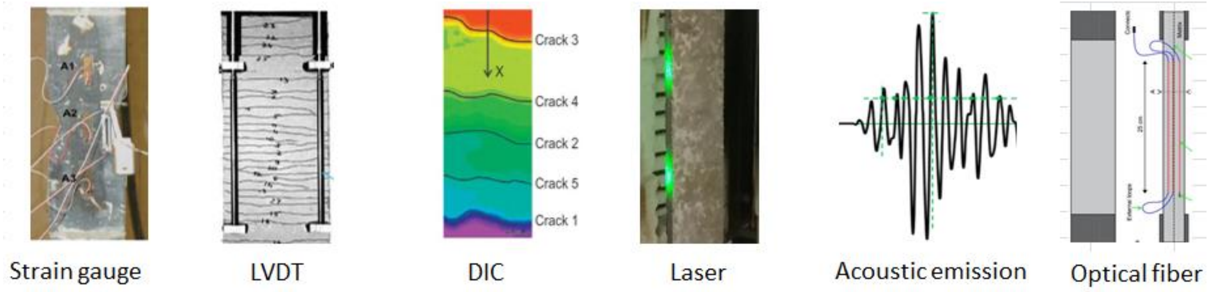
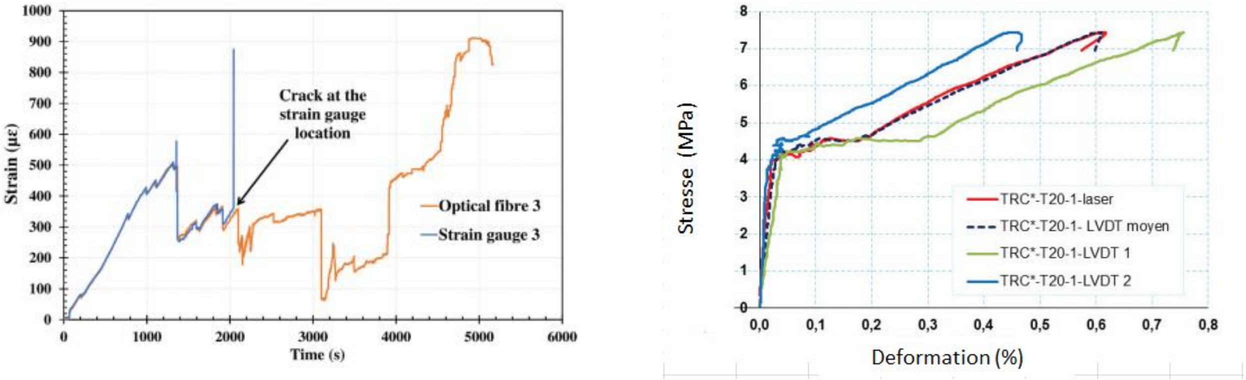


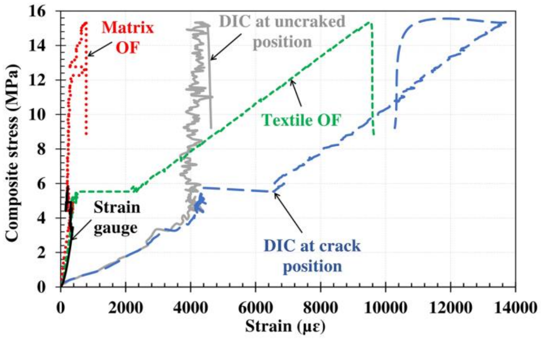
Figure 2. Methods for measurement of axial deformation of TRC composite.

In comparison between the measurement methods themselves, it could be found the disadvantage of each measurement method. The strain gauge presented good results in the elastic phase, however, these results were not exact anymore at all when the crack occurred in the cementitious matrix at the strain gauge location (see Figure 3a) [25]. The LVDTs generally provided a reliable strain result, but they could not be used in some cases of difficulty as too small specimens or at the elevated temperature. In these cases, the non-contact measurement method (DIC and laser sensor) have been efficiently used for axial deformation measurement of TRC composites [26,27,29]. Recently, the optical fiber becomes the better choice for the measurement of strain and stress of all points in the measurement zone of the TRC specimen. It leads to a better understanding of the internal behavior and allows analyzing their micromechanical mechanisms and the load transfer between both components [25]. Figure 3 presents the comparison of strain results between different measurement methods in previous research of the literature.



(a) Strain gauge versus optical fiber [25]

(b) Laser sensor versus LVDT [34]



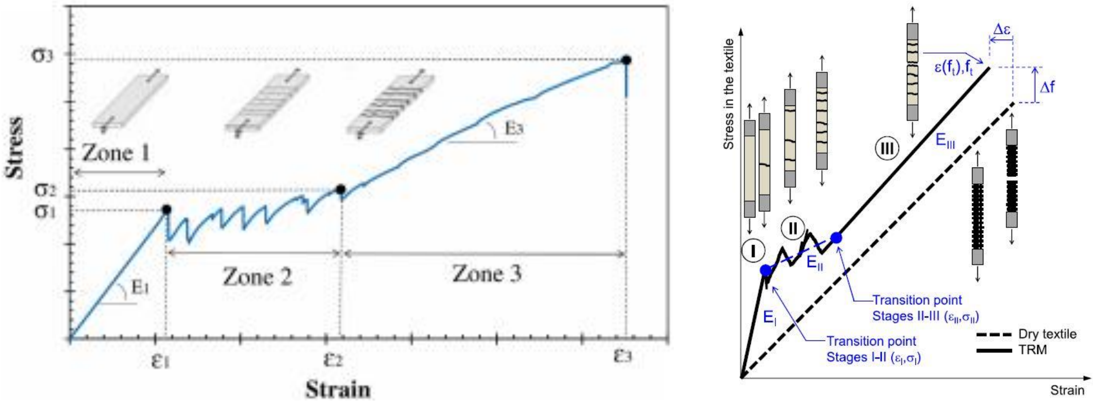
(c) Optical fiber versus DIC [21]

Figure 3. Comparison of strain results between different measurement methods.

3. TENSILE BEHAVIOR OF TRC COMPOSITE

3.1. Strain-hardening curves

As experimental results in the literature, the TRC specimens presented a strain-hardening behavior with different phases. This behavior depends on several factors belonging from reinforcement textile as nature of the fiber, treatment product, reinforcement ratio, or from the cementitious matrix as its nature, aging condition, and water content. [6], showed that, with the reinforcement ratio higher than the critical value (V_f), TRC composite provided a mechanical behavior with three distinguishable phases (zone 1, 2, 3 as in Figure 4). For the identification of TRC's mechanical properties, an idealization of the axial stress-strain curve was usually used with the definitions of typical points. These points were related to the beginning (zone 1) and the end of the cracking (zone 2), and the failure of the specimen (zone 3). Figure 4 shows several ways to identify the mechanical behavior of TRC or TRM (Textile-Reinforced Mortar) composite by using the notations for the exploitation of experimental results. The following paragraphs present the description of three phases, including the identification, mechanical properties, and failure mode of TRC specimens.



(a) Result in [35] (Construction and Building Materials Journal)

(b) Result in [36] (Composites Part B Journal)

Figure 4. Identification of mechanical behaviour of TRC or TRM composite.

3.2. Mechanical properties of TRC composite

In the first phase, the TRC specimen exhibits a quasi-linear behavior, from the beginning point of the stress-strain curve into that of the beginning of the cracking [27,32]. This phase also presents the perfect working together (perfect interface) between both material components. It means that the mechanical behavior of TRC composite completely follows the mixture law of composite materials. The initial stiffness (E_1), the stress (σ_1 or σ_{cr}) and strain (ε_1 or ε_{cr}) corresponding to the point of the beginning of the cracking are three mechanical properties of TRC composite. Generally, these values depend on that of the cementitious matrix. However, with a reasonable choice of reinforcement textile (mechanical performance, mesh geometry, treatment product), the weakness in the tensile strength of the cementitious matrix is significantly improved. The mesoscale experimental results in [30], showed that this improvement is about 1.25 times at room temperature and decreases with elevated temperature. This result could be explained by the effect of temperature on the bond strength of the textile/matrix interface.

The appearance of the first crack defines the beginning of the second phase of the tensile behavior. After that, there is a redistribution of the internal force between both material components (from the reinforcement textile to the cementitious matrix) at the cross-sections next to the first crack position [28,32]. That leads to the increase of stress and strain in the cementitious matrix and the shear stress at the textile/matrix interface in a distance from the crack called the load transfer length (δ_0). The redistribution of the internal force occurs until the cementitious matrix reaches the limit state in tensile. That explains the occurrence of the second crack, and so on. Corresponding with each of its appearances, the drops in stress were observed in the stress-strain curve of TRC's behavior. Noted that the behavior of the textile or matrix strongly depends on the position of the studied point. Saidi and Gabor [21], have compared the experimental results obtained from the optical fiber in the matrix and textile at the cracked and uncracked regions (see Figure 5). This finding also was studied by using the 3-D numerical model for the mechanical behavior of TRC composite [31].

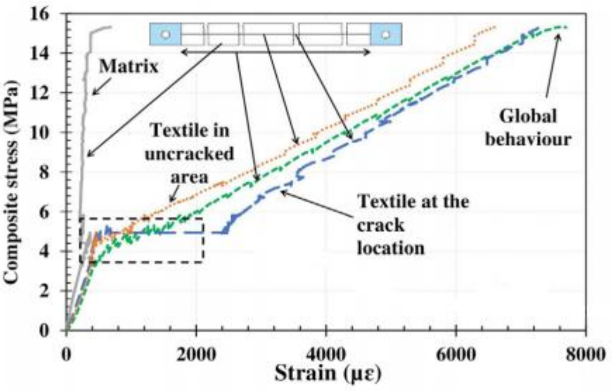


Figure 5. Experimental results obtained from optical fiber in textile, matrix at different positions; [35].

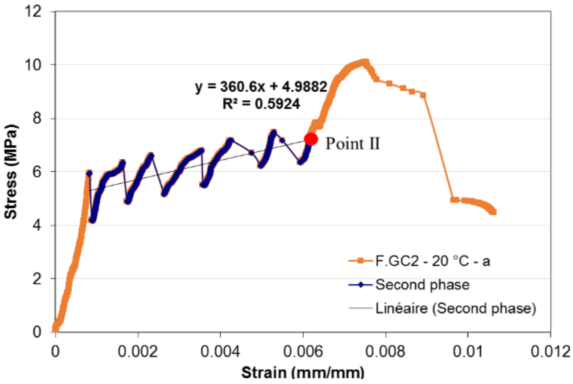


Figure 6. Identification of the point 2 for mechanical behavior of F.GC2 composite [30].

To identify the mechanical properties of TRC composite in this second phase, it needs to determine the point corresponding with the end of the cracking (point 2 or transition point Stages II-III). In the literature, a useful way for identification of this point was the intersection between the linear regression line of the second phase (cracking phase) and the response curve of the posted-cracked one [27,33] (see Figure 6). The stress and strain relating to this point (σ_2 and ε_2) and stiffness defined as the average slope of the second phase of the stress-strain curve (E_2) are three principle properties for the characterization of TRC's behavior.

The point 2 (or transition point Stages II-III) mentioned above (as point corresponding with the end of the cracking) defines the beginning of the third phase. In this phase of the mechanical behavior of TRC composite in tensile, the reinforcement textile almost supports all applied force, while the cementitious matrix already has cracked and has no contribution in the tensile performance of TRC specimen. Therefore, TRC specimens generally present a quasi-linear behavior into its failure (see Figure 4), and the point corresponding to this rupture is called the UTS (Ultimate Tensile Strength) point. The stress and strain regarding this point in the stress-strain curve of TRC behavior define the ultimate properties of TRC specimen (σ_{UTS}, ε_{UTS}). Concerning the stiffness of the TRC composite in this phase (E_3), the results of Kok [37] showed that its value is lower about 10-30% than the real stiffness of the textile. This result could be explained by the rupture of a part of the textile warps during the cracking phase of the TRC behavior [7]. After being reached the UTS point, the TRC specimen provides a post-peak behavior which is presented by a pull-out response of the reinforcement textile from the cementitious matrix coupling with the rupture of the textile located at a crack location. According to [38] and [39], post-peak behavior can be observed, whereas this is rarely the case in other studies such as [27] or [40]. Unlike the behavior of a steel frame structure, the textile reinforcement does not exhibit plastic behavior. The rupture of the TRC composite is therefore fragile [7].

In comparison with the FRP composite or steel-reinforced concrete, the mechanical performance of TRC composite is not the best. The application of this material for reinforcement or strengthening of RC members could improve the ultimate strength of the structures, however, not too much. On the other hand, it significantly improved the ductile of the reinforced structures. So, in terms of the reinforcement efficiency of the material, TRC composite presented stability in strength with the environmental conditions as seismic, corrosion, or at elevated temperature [9,10].

3.3. Failure mode

In general, all TRC specimens present a failure mode with the multi-cracks on their surface. However, depending on the properties of reinforcement textile as the reinforcement ratio, mesh geometry, pre-impregnation, treatment products, they lead the different aspects of failure mode. Figure 7 presents the mechanical behavior and failure mode of basalt TRC composite corresponding with variable values of reinforcement ratios [41]. As a result, the density of cracks increased with the number of basalt fabric layers from one to five layers. It means that with a higher number of basalt fabric, the internal efforts were equally distributed on a cross-section of TRC specimen as well as along its length.

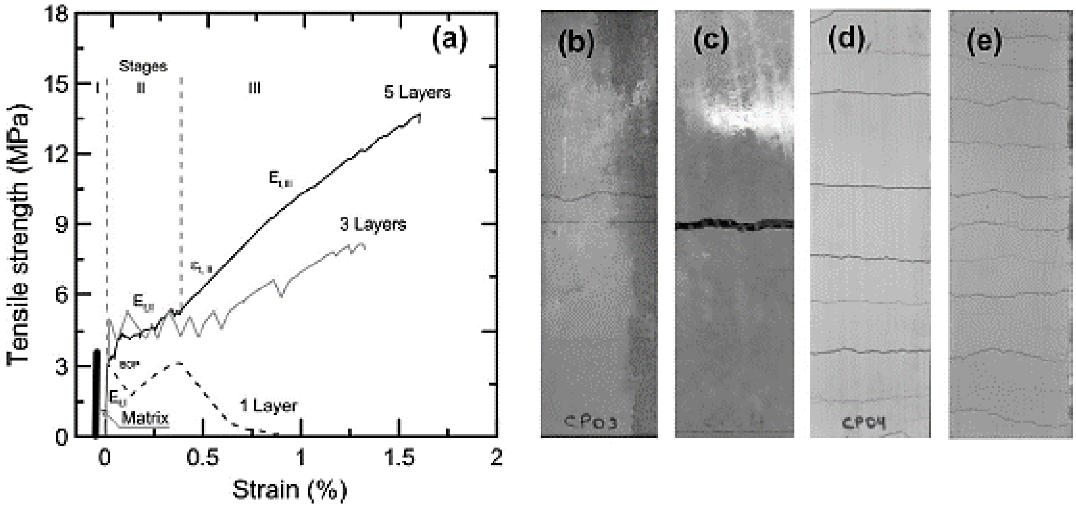
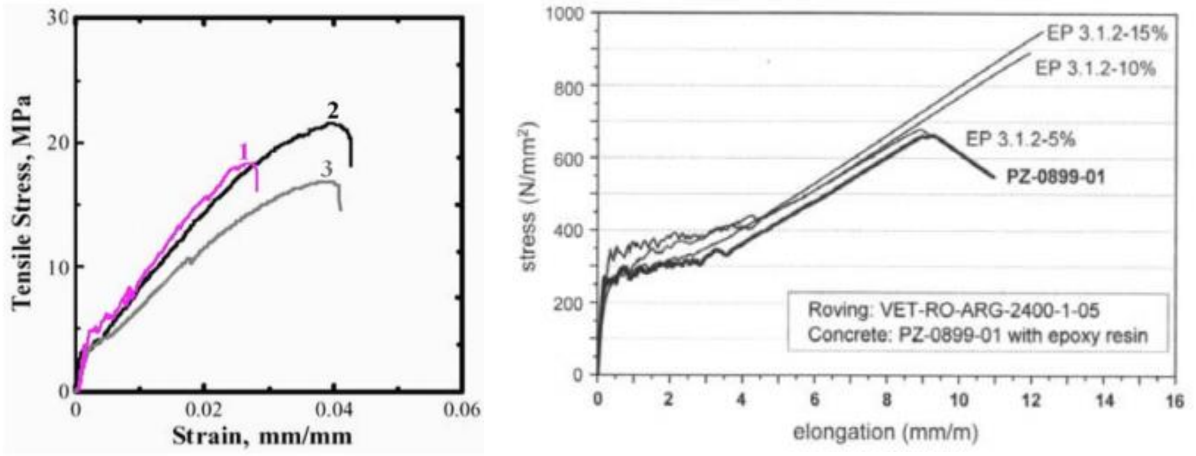


Figure 7. Effect of the reinforcement ratio on the tensile behavior and failure mode of basalt TRC composite: (a) Stress-strain relationship; Failure mode (b) without reinforcement; (c) with a layer of fabric; (d) with three layers of fabric and; (e) with five layers of fabric [41].

4. DISCUSSION

This section focuses on the discussion concerning the effects of several factors on the mechanical behavior and failure mode of TRC composite. These factors belonging from the reinforcement textile, cementitious matrix, or the reinforcement ratio.

4.1 Effect of nature of cementitious matrix



(a) Modification by super-plasticizer and silica fume ratios [45]

(b) Modification by epoxy/binder ratio of 5, 10, and 15% [14]

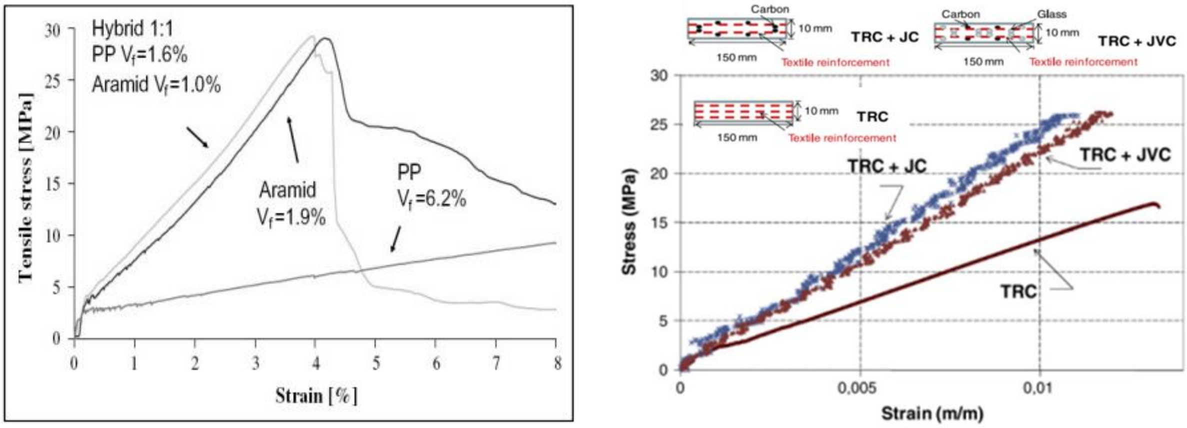
Figure 8. Effect of the nature of cementitious matrix on the mechanical behavior and properties of TRC composite.

In the literature, few studies focused on the effect of the cementitious matrix nature on the mechanical behavior of TRC composite [6,39,40,41]. In theory, the nature of the matrix influence the mechanical behavior of the TRC in the elastic phase as well as the impregnation of the reinforcement textile in the matrix, which dominates the bond strength of the interface between both components [7]. However, [45] showed that the nature of the cementitious matrix could also significantly influence the third phase (post-crack phase) of the stress-strain curves, as well as the ultimate strength and strain of the TRC composite. In their study, the influence of two constitutive parameters (the super-plasticizer and the silica fume ratio) in the cementitious matrix on the global behavior of TRC was analyzed. The ratio in volume for silica fume and super-plasticizer was respectively 5% and 0.1% in specimen No.1, 5% and 0.2% in specimen No.2, and 10% and 0.4% in specimen No.3. The results showed that this modification in the ratio of the two additive products leads to the change in the workability of the matrix, which improves the impregnation rate of the filaments in the cementitious matrix. Furthermore, the use of silica fume could minimize the pores inside the matrix and make them denser, especially at the interfacial transition zones (ITZ). The improvement in the ITZ could enhance the bonding between textile and cement composites, hence, improving the strength of the TRC. It explains the improvement of the mechanical characteristics of the TRC composite in tension (ultimate strength and strain) (see Figure 8a).

Similarly, the mechanical properties of TRC composite were significantly improved by using the epoxy polymer as a component in the mixture composition of the matrix. The influence of the modification of a cementitious matrix with an epoxy/binder ratio of 5, 10, and 15% on the global tensile behavior of TRC has been studied in [14]. The results showed that beyond 5% by weight of the binder, including in the case of the very fluid matrix, the epoxy added makes it possible to significantly improve the ultimate strength of the TRC composite about 40-45 % for an amount of epoxy of 10-15% (see Figure 8b). This improvement could be explained by the significant modification of the impregnation of the filament in the cementitious matrix.

4.2 Effect of nature of fiber

The nature of fiber influences the mechanical behavior of TRC composite in the post-cracking phase because there is only the loading support of reinforcement textiles after the complete cracking of the cementitious matrix. Furthermore, the nature of fiber is also an appreciated factor for the adhesion between the reinforcement textile and the cementitious matrix. This factor slightly affects to TRC behavior at first and second phases through by them together working between both components. In literature, several types of fibers have been used and tested for TRC's application [35,43], however, no author suggests a parametric study on the effect of variable fibers on TRC's behavior. Besides, the quantity or quality of these different variables does not allow the authors to conclude about the influence of the nature of the fiber.



(a) Aramid fiber versus PP fiber [38]

(b) Glass fiber versus carbon fiber [46]

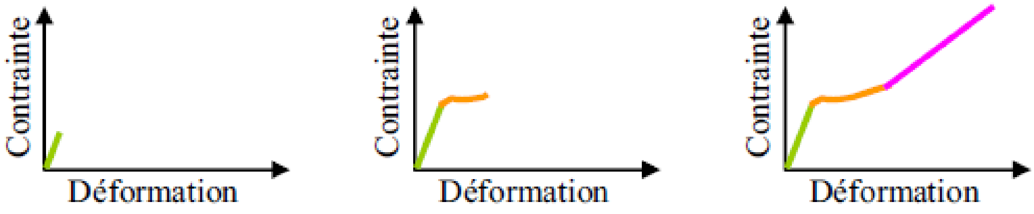
Figure 9. Effect of the nature of fiber on the mechanical behavior of TRC composite.

Peled et al. [38], provided attractive results concerning knitted textiles, with a warp configuration in which different natures of filaments were used. Two configurations of textiles were tested. The first was the one where the warps are made entirely of aramid filaments. The second one was identical to the first except that half of the aramid filaments were replaced by polypropylene (PP) filaments of weak characteristics mechanical and low cost (hybrid wire). The ultimate stress of the two TRC composites was almost identical. However, the TRC composite with hybrid reinforcement presented slightly lower rigidity, and its post-peak behavior was significantly more fragile (see Figure 9a). In the experimental study [46], the reinforcement by AR glass textile was modified with hybrid solutions of 2 layers of reinforcement associated either with carbon rods (TRC + JC (Jointe avec Carbone - in French)) or with a combination of carbon and glass rods (TRC + JVC (Jointe avec Verre et Carbone – in French)). The surface of the rods has been the subject of adapted surface treatment (surface strewn with silica) intended to improve its roughness. For the TRCs of hybrid reinforcements, their linear behavior was conditioned by those of the rods. The very significant increase in overall stiffness compared to the reference TRC was mainly the result of the better interaction (by friction) between the mortar and the rods (see Figure 9b).

4.3 Effect of reinforcement ratio

With a similar thickness of the TRC specimen, an increase in the reinforcement ratio can lead to a decrease in the spacing between the textile layers, which can influence the textile-matrix adhesion. However, several results show that this effect of the spacing between the textile layers is less than the effectiveness of the reinforcement ratio [6,25,41,44]. In the work of Rambo et al. [41], the basalt TRC composites with different reinforcement ratios by 1, 3, and 5 layers of basalt textile, presented different mechanical behaviors as well as the ultimate strength. With the reinforcement by 1, 3, and 5 layers of basalt textile, the mechanical performance in tensile increased respectively 1.01, 1.2, and 2.6 times compared to that of the unreinforced matrix. The improvement of ultimate strength was observed in other experimental studies on TRC composite [25,34]. However, the evolution of this mechanical property as a function of the reinforcement ratio is not linear because this depends on the work efficiency coefficient between the textile layers.

Generally, the influence of the reinforcement ratio on the performance of the TRC composite depends basically on two factors. The first one is the interaction between the reinforcement textile layers that can lead to a reduction in the textile-matrix bond strength. The second is the thickness of the matrix presenting between the textile layers that makes it possible to correctly transfer the internal force between the textiles in the TRC composite [7]. So, the reinforcement ratio strongly affects the shape of the stress-strain curve as well as the failure mode. Contamine [6] has illustrated the stress-strain qualitative behavior as a function of the reinforcement ratio, as presented in Figure 10. Two critical values of the reinforcement ratio defined for the estimation of the mechanical behavior of TRC composite. The experimental results in [41], showed a hardening behavior for the reinforcement of 3 and 5 basalt textile layers and a softening behavior for that of one layer of basalt textile (see Figure 7a). The observation of TRC specimens presented a failure mode with the increase of density of crack when the reinforcement ratio raises from one layer to 5 layers of basalt textile (see Figure 7 b,c,d).



(a) Reinforcement ratio smaller critical 1

(b) Reinforcement ratio smaller critical 2

(c) Reinforcement ratio higher critical 2

Figure 10. Illustration of the stress-strain qualitative behavior as a function of the reinforcement ratio [6].

5. CONCLUSION

The TRC composite has been used for different applications in the civil engineering field, as strengthening or reinforcing of existing structures, protective linings, thin-walled and façade elements, and lightweight structures. For a better understanding of this material, this paper has presented a detailed review of the state-of-the-art on the tensile mechanical behavior of TRC composites, showing that during the last decade, considerable progress has been made in terms of available experimental data. With the technology development, the new measurement methods allow us to study the mechanical behavior and displacement of a point inside the TRC specimen (reinforcement textile, cementitious matrix, textile/matrix interface). It also allows us to understand their behavior in several studied cases of environmental conditions, such as in the corrosion environment, aging, and elevated temperature.

This paper presented the material components of the TRC composite and their characteristics, mechanical performances, notes for an application in civil engineering. This review has noted that the choice of material components was generally dependent on several factors such as mechanical, thermal, physicochemical properties, the compatible, physicochemical, and geometrical characteristics between themselves, as well as the proportion, availability, cost requirement, sustainability criteria.

For the characterization of the mechanical behavior of TRC composites, this review has shown the noted points of experimental works as preparation procedure of TRC specimens, test setup, and the measurement methods for the axial deformation of TRC. These scientific points could influence differently and affect to the convergence of experimental results.

This review has shown that the TRC composite presented a strain-hardening behavior with different phases depending on several factors belonging from reinforcement textile, cementitious matrix, and textile/matrix interface. With a reinforcement ratio higher than the critical value (critical 2), TRC's mechanical behavior could be divided into three phases as pre-cracking, cracking, and post-cracking. The aspect and mechanical properties of these phases defined from the stress-strain curve. The pre-cracking and post-cracking phase were described by the law of mixtures of TRC composite while it's hard to draw by an equation for the cracking one because of the random occurrence of cracks in the cementitious matrix.

Finally, the discussion of this paper focuses on the effects of several factors on the mechanical behavior and properties of TRC composites. This review has shown that the reinforcement ratio greatly influenced the shape of the stress-strain curve as well as the mechanical performance of TRC composites. The critical values of the reinforcement ratio depend on the correlation in strength between reinforcement textiles and the cementitious matrix. For the effect of environmental conditions, the decrease of the mechanical performance of TRC composite was noted when the temperature increases.

ACKNOWLEDGMENT

This research is funded by Hanoi University of Mining and Geology (HUMG) under the project code T19-34.

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