Textile Reinforced Concrete: A Review

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Abstract. In order to solve a problem in reinforced concrete, which is the corrosion of the steel bars, Textile Reinforced Concrete (TRC) appears as an interesting new innovative building material. Unlike the concrete with fibers dispersed in the cement matrix, this type of reinforcement uses non-corrosive fibers meshes positioned in the direction of the tensile stresses, allowing to reduce the thickness of the concrete elements with high tensile strength, increasing its effectiveness. In addition to having high durability, Textile Reinforced Concrete is very easy to handle, to execute and to transport. Furthermore, it is also possible to produce concrete pieces with a better surface finish and in different architectural designs. Research on this new building material takes place mainly in Germany. In this way, we seek to further disseminate the knowledge of the TRC, so that more research is carried out, that more information gaps are explained and for more people to know their advantages and disadvantages. In this paper we want to make a brief review of the available literature on this subject, presenting the history of the TRC, its main characteristics and properties, seeking to arouse interest in this material so that it can be further developed and applied.

Keywords. Textile reinforced concrete; TRC; textile reinforcement; fibers.

1. Introduction

It is common knowledge that, since Roman times, concrete has been used in construction and there are several reports of adding reinforcements to these materials to make them more efficient composites because concrete is a relatively brittle material with a low tensile strength [1]. Over the centuries, advances in building materials and constructions methods have established reinforced concrete as a great building material. However, there is a big problem: the possibility of corrosion of the reinforcement steel [1]. Concrete is a highly alkaline material and, with a small thickness of this material, the steel bars must be protected against the entrance of aggressive agents that can reduce the alkalinity over time, leaving the reinforcement prone to corrosion. Resulting in performance and structural problems [2]. In addition, reinforced concrete allows a few ranges of architectural designs and requires care in terms of appearance [3].

In order to solve these problems in conventional reinforced concrete, the use of non-corrosive reinforcement materials, as is the case of alkali-resistant fibers arranged in mesh, becomes an interesting and promising material. This non-metallic reinforcement allows the construction of concrete structures with higher durability, in addition to lightweight elements and thicknesses [4]. Also has the advantage of being molded into different architectural designs.

Combining a cement matrix with aggregates of low maximum dimension with a textile grid, the textile reinforced concrete (TRC) is formed. These materials are mainly applied to the facades of buildings, but their use in bearing structures with minor vertical load is growing [4].

2. Textile Reinforced Concrete (TRC)

As an alternative to conventional reinforced concrete, textile reinforced concrete (TRC) is a promising material because there is the replacement of steel bars for textiles, nomenclature linked to the structural similarity to the fabrics. Reinforced concrete is reinforced with steel bars positioned in specific places in order to absorb the acting stresses. Fiber-reinforced concrete, on the other hand, has the replacement of steel bars with fibers that are dispersed in the cement matrix with the main objective of controlling cracking. Due to the different positions and orientations of fibers within the structure, their use for the purpose of resisting tensile strength would not be very effective. In this way, two problems can be determined: the possibility of corrosion of steel bars (conventional reinforced concrete) and poor orientation of dispersed fibers for tensile strength (concrete with fibers). Thereby, the TRC emerges as new technology to solve these problems, because meshes of non-corrosive fibers are used, positioned in the direction of the stresses of traction, increasing its effectiveness [5]. Such concrete reinforcements can be seen in Figure 1.

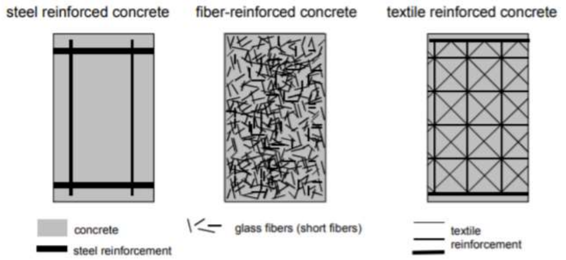

Fig. 1 – Concrete reinforcement systems: a) Conventional reinforced concrete; b) Concrete fiber reinforces; c) Textile reinforced concrete. Source: [5].

The TRC combines the advantages of Glassfiber Reinforced Concrete (GRC), which has been used for many years in non-structural or complex-shaped elements, with the capacity to support the structural load in previously defined directions of the tensile forces, also not needing a concrete cover to protect the reinforcement [3] [4]. The textiles are polymeric continuous fibers, non-corrosive and with a high tensile strength that can be used incorporated into the cement matrix of fine granulometry customized as 2D or 3D and are mainly made of materials such as glass, carbon and aramid [1].

2.1 History

From the 1960s onwards, materials such as textiles and fabrics made from high-quality polymer fibers such as carbon, Kevlar and Spectra were already available to the aerospace industry. But it was not until the 1980s that studies began to be carried out on the use of these materials in cement matrices in order to replace the steel bars with fibers [6]. This replacement tries to solve one of the greatest problems of the reinforced concrete, which is the possibility of corrosion of the reinforcement due to the entrance of aggressive agents. During this period, between the end of the 1980s and the beginning of 1990, the first research started in Germany, in Chemnitz and Dresden, as well as the first textile reinforced concrete patents. The initial project investigated the use of 2D (Figure 2 – a) and 3D (Figure 2 – b and c) format textiles and their efficiency in use in reinforced lightweight concrete or gypsum elements [1].

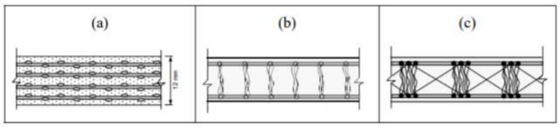

Fig. 2 – Sections of TRC: a) layers of 2D textiles reinforcements; b) and c) one layer of 3D textiles reinforcements. Source: [6].

In order to progress in the study and in the use of textile reinforced concrete, researchers from two German universities, Dresden and Aachen, have worked in the development of several projects in the area. Some researches carried out in Germany in 1990 were: aramid textile reinforcements, textile concrete and the use of meshes close to the surface to minimize cracks in the concrete [1]. After a first recognition of the potential of the material in 1990 at the *TechTextil Conference*, in 1996 a group of students from the Technical University of Dresden developed and won a competition from the *Deutscher Betonverein* (German Concrete Association) due to the construction of two boat in TRC (Figure 3). One of the boats was reinforced by alkali-resistant glass textiles and the other by carbon textiles. This demonstrates the great potential of textile reinforced concrete and a lot of information was gathered in reports and research intensified [1].

Fig. 3 – TRC boats in 1996. Source: [1].

Other countries such as Israel, Japan and the United Kingdom also carried out research, respectively, on the influence on the mechanical properties of the textile structure in the cement matrix; use of fibers of various materials (carbon, glass or aramid) with resins; propylene fiber meshes and the bond between the fibers and the matrix and the absorption of internal fiber forces [1]. According to [1], the activities of an international scope did not exceed the research carried out by two Collaborative Research Centers (*Sonderforschungsbereich* - SFB), founded in 1999 and active until 2011 by the German Research Foundation (DFG), who research both the combination of textiles and concrete, as well as the textile reinforcement of masonry and wooden structures. Thus, from the 1990s onwards, the first prototypes were made and the first applications in structures began, some examples are shown in Figure 4 to Figure 7.

Fig. 4 – TRC applications - façade RWTH Aachen University (Germany). Source: [1].

Fig. 5 – TRC applications - bridge in Kempten (Germany). Source: [7].

Fig. 6 – TRC applications - bridge in Albstadt-Lautlingen (Germany). Source: Innovation in Textiles by Groz-Beckert KG.

Fig. 7 – TRC applications - pavilion at TU Chemnitz (Germany). Source: [8].

Since 2001, six technical conferences have been held in Aachen and Dresden with national and international participation and, from 2009, the first "user conference" on textile reinforced concrete, which in 2016 reached its seventh edition. In addition, there have been several publications on textile concrete such as the report RILEM (RILEM State-of-the-Art Report) in 2006 and in other German magazines. Still, in 2007, the German Textile Concrete Center was established with the objective of transferring knowledge between science and industry in parallel with research [1].

Research on this material is expanding in several countries such as those already mentioned in Germany, Japan, Israel and the United Kingdom, but also in France, Italy, Spain, Sweden, China, the United States and Brazil. In 2014 a line of research was formed, called CONTEXT, at the Federal University of Rio Grande do Sul, which wanted to study high-performance textile concrete and enable the construction of the first structure of this type in America [9]. Yet, according to [9], until 2010 it was intended to know the composite material and its properties of strength and durability. Since then, more studies have been carried out on the applicability of the material in new building elements and as structural reinforcements.

2.2 Characteristics

Textile reinforced concrete is made of alkali-resistant textiles, preferably with high rigidity and resistance and with concrete of fine aggregates, with dimensions between 1 and 7 mm to allow adequate penetration between the mesh opening spaces. Textiles are a set of hundreds of fibers in filaments with, approximately, 5 and 30 μm, processed into yarn format which, with the use of textiles machines, are manufactured in different geometries depending on the type of use [2]. As can be seen in Figure 8, there are microscopic hollow spaces between the fibers and, because of that, the cementitious material does not manage to reach the core filaments (red part in Figure 8), which would result in the load absorption only by the outermost fibers (blue part in Figure 8) [2].

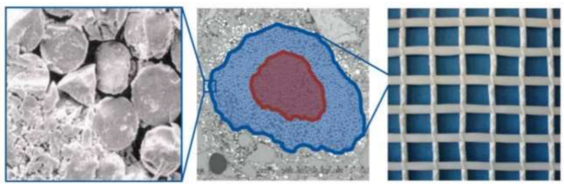

Fig. 8 – Carbon fibers present in the yarn of a textile: if there is no impregnation, the fibers in red are not actually used, only the outermost ones in blue. Source [2].

That is why, for textiles to be efficient, they are impregnated with a coating much thinner than concrete such as epoxy resin or polymer such as rubber styrene-butadiene. So that it can penetrate these spaces between fibers and increase the bond between the innermost and outermost fibers, as well as increase the bond between the fibers and cement matrix [2] [7]. Such adhesion between the fibers and the cement matrix is extremely important to allow an adequate mechanical behavior.

Thus, the characteristics and properties of textiles can differ according to the following parameters: fiber material, yarn density, thickness, number of filaments, bond length, final shape-geometry and production process.

2.3 Properties

The main advantage of textile reinforced concrete compared to conventional reinforced concrete is its non-corrosive characteristic and smaller dimensions, as said earlier. According to [2], only 10 to 15 mm are needed for good adhesion between the concrete and the textile, which results in slim pieces with approximately 20 to 30 mm, which considerably reduces the cost of materials, saving up to 80% of concrete and resulting in lightweight structural elements. Due to these lightweight and smaller dimensions, it is also easier to transport and to install prefabricated parts, in addition to the ease of molding the elements.

With this reduction in the use of materials such as cement, the cost of concrete is reduced, however, the cost of fiber-reinforced polymer textiles has a high value compared to steel mesh, but the material has advantages because can be produced according to the intended use, they are lightweight, malleable and easily adjusted and cut, which can make textiles increasingly competitive economically [9].

The malleability of textiles, as mentioned earlier, is an important characteristic and can be influenced by some parameters such as material fiber, mesh dimensions and pattern of stitches between the yarns of the textile [10]. Because the textiles are low thickness and because they include meshes that adapt to different positions, it is possible to form parts and architectural elements with different geometries, including curved elements, being a very versatile concrete. And, because they are composed of fine concrete, also allow a high-quality appearance.

In addition, textiles have a high loading capacity. Depending on the fiber and the impregnation carried out, it is possible to reach more than 3000 MPa (according to Figure 9), which is five times higher than steel reinforcement; the stiffness depends, mainly, on the characteristics of the fiber used [2].

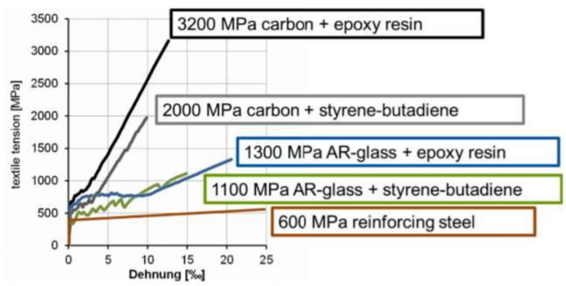

Fig. 9 – Effect of different impregnations on different fibers. Source [2].

The cement matrix is formed by high rates of binders, fine aggregates, additions of fines such as fly ash, silica fume and additives such as superplasticizers and water reducers (Figure 10 shows an example of the composition, in volume, of a fine-grained textile concrete). Due to more various textile geometries and its reduced mesh opening size, characteristics such as fluidity and workability are very important to allow the complete filling of the structure with concrete without the presence of voids. As a result, the composition of the concrete must be adjusted according to the application and according to the properties of the fibers and textiles used [12]. Also, due to the use of fine-grained materials in the mixture of concrete, besides from the addition of pozzolanic materials, the porosity of the textile concrete is reduced, as there is higher closure of the pores, preventing the entry of aggressive agents that can deteriorate the concrete, presenting, therefore, higher durability.

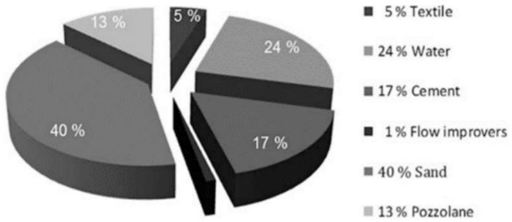

Fig. 10 – Composition, by volume, of a fine-grained TRC. Source [11].

Regarding the resistance of concrete to aggressive environments, [9] and [2] comment on the possibility of using the material in environments with exposure to chlorides and the marine environment. Also, according to [13], who carried out research to determine the strength of textile concrete in an aggressive environment using accelerated testing of durability, the resistance of the concrete increases with the rate of reinforcement applied. However, there is a lack of data comprehensive literature on the subject, also commented on by [14].

Another unfavorable point is the existence of few studies to characterize the behavior of textile concrete in the face of high temperatures, which, due to the fine thickness, can be an important factor in fire protection [9]. According to [15], one of the most important parameters of the textile that affect the behavior at a high temperature is the textile finishing, while the fiber material does not significantly change the result. Still, uncoated textiles showed, in general, the best performance at high temperatures. However, more studies should be carried out on the subject; is recommended to analyze the advantages of different textiles according to the environmental conditions.

From all the characteristics presented, it is possible to say that textile reinforced concrete brings many advantages over conventional reinforced concrete, as allows the construction of thinner, lighter elements in the most diverse architectural designs. With this, it also enables the reduction of the consumption of materials and, together with the lower porosity of the material, resulting from the fines of the concrete and the pozzolanic additions, has higher durability, allowing to reduce the emission of CO_2 due to the conservation of energy and materials, especially with regard to the cement [11] and also increases the life cycle of structures.

The dosage of concrete is a point that deserves care, as it must be ensured adequate concreting, with a mixture that allows fluidity and workability suitable and compatible with the characteristics of the textiles and fibers used, uniformly filling the entire structure. Although the initial cost of the fibers is higher, there is great ease of storage, handling, transport and execution of textile concrete. Thus, with higher dissemination, knowledge and application of this concrete technology, textile concrete can be more attractive and this value can be more competitive.

3. Conclusion

Considering the growing concern with the sustainability of structures throughout their life cycle, it becomes essential to adopt materials that promote lower energy consumption for production and maintenance, in addition to higher durability. In this way, the use of innovative technologies such as textile reinforced concrete tends to become more and more present. Still, the possibility of more thin elements and with more complex geometries ends up increasing the aesthetic appeal of this material, indicating strong development potential for this alternative to reinforced concrete

However, the lack of regulations regulating the situation of this technology, currently, reduces the speed of advance of TRC, and the lack of advanced studies about fire protection and durability in harsh environments can generate some insecurity in the application of this material. Furthermore, due to the tendency to compose slimmer structures, and by reducing the maximum size of the aggregates, the textile reinforced concrete tends to present higher deformability compared to conventional concrete, a factor that can impact the global analysis of the structure.

Yet, despite the high costs of textile components and the need to control the concrete that end up increasing the final price considerably, compared to conventional concrete, this financial difference becomes less evident when evaluating together lifetime maintenance costs, labor and the sustainable appeal that TRC presents.

Thus, the biggest barrier to the development of structures of textile concrete is precisely the scarcity of technical information (on the part of engineers) and regulatory support, in addition to its short time working in real cases. As it is relatively emerging, this technology has not yet been validated in the market, its current use is limited mainly to the region of Germany. However, by presenting this set of advantages such as durability and higher architectural potential, concrete reinforced by textile materials has great potential and it is a great alternative to conventional reinforced concrete, in addition to being an increasingly competitive alternative in terms of production costs.

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