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Compare the Mechanical Properties of Fiber-Reinforced Polymer (FRP) and Textile-Reinforced Concrete (TRC) as A Composite Material

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مقارنة الخواص الميكانيكية للبوليمرات المسلحة بالألياف (FRP) والخرسانة المسلحة بالمنسوجات (TRC) كمواد مركبة

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الملخص:
تستعرض هذه الورقة البحثية نظامين بديلين للتسليح، هما **الخرسانة المسلحة بالمنسوجات (TRC)** و**البوليمر المقوى بالألياف (FRP)**، مع مقارنتهما بالتسليح التقليدي باستخدام الفولاذ. وقد حظيت كلتا المادتين باهتمام كبير نظرًا لإمكاناتهما في معالجة مشكلات مثل التآكل، وتقليل الوزن، وتحسين المتانة.
تتكون الخرسانة المسلحة بالمنسوجات (TRC) من مصفوفة إسمنتية مدعمة بألياف نسيجية منسوجة، وتتميز بمطيلية جيدة، وقدرة فعالة على التحكم في التشققات، وتوافق ممتاز مع الركائز الخرسانية. ومع ذلك، فإن استخدامها لا يزال مقيدًا بانخفاض مقاومة الشد نسبيًا مقارنة بالبوليمرات المقواة بألياف الكربون(CFRP) ، بالإضافة إلى الحاجة إلى مزيد من الدراسات والتجارب واسعة النطاق للتحقق من أدائها. أما البوليمر المقوى بالألياف(FRP) ، والذي يتكون من ألياف مستمرة مدمجة داخل مصفوفة بوليمرية، فيتميز بمقاومة عالية جدًا للشد والانحناء، إلى جانب نسبة مرتفعة بين المقاومة والوزن. إلا أنه يعاني من سلوك انهيار هش، إضافة إلى تأثر خواصه بالعوامل البيئية مثل الأشعة فوق البنفسجية ودرجات الحرارة المرتفعة. وأكدت نتائج الفحص باستخدام **المجهر الإلكتروني الماسح(SEM)** ، إلى جانب المقارنات المستخلصة من الدراسات المنشورة، أن كلاً من نظامي **TRC**و **FRP**يمتلك مزايا وقيودًا تختلف باختلاف طبيعة التطبيق. وتخلص هذه المراجعة إلى أن أيًا من النظامين لا يُعد بديلاً كاملاً للتسليح الفولاذي التقليدي، إلا أنهما يمثلان حلولًا فعالة في تطبيقات محددة تكون فيها الخصائص الميكانيكية، والمتانة، والظروف البيئية من العوامل الأساسية في عملية التصميم الهندسي.

الكلمات الدالة: الخرسانة المسلحة بالمنسوجات، البوليمر المقوى بالألياف، المجهر الإلكتروني الماسح ، الخواص الميكانيكية، المتانة.

Abstract:
This review paper examines two alternative reinforcement systems—Textile Reinforced Concrete (TRC) and Fiber Reinforced Polymer (FRP)—in comparison to conventional steel reinforcement. Both materials have attracted significant attention due to their potential to address issues such as corrosion, weight reduction, and improved durability. TRC, which combines a cementitious matrix with woven textile fibers, provides good ductility, crack control, and compatibility with concrete substrates, though it remains limited by relatively lower tensile capacity compared to carbon-based FRP and the need for further large-scale validation. FRP, consisting of continuous fibers embedded in a polymeric matrix, offers very high tensile and flexural strength with a superior strength-to-weight ratio, but suffers from brittle failure and environmental sensitivity (UV degradation, temperature effects). Scanning Electron Microscope (SEM) observations and literature comparisons confirm that both TRC and FRP demonstrate distinct advantages and limitations depending on the application. The review highlights that neither system fully replaces steel reinforcement, but both serve as viable alternatives in specific contexts where mechanical performance, durability, and environmental conditions are critical design factors.

Keywords: TRC, FRP, SEM, Mechanical properties, Durability.

Introduction

The ingenious composite materials Textile-Reinforced Concrete (TRC) and Fiber-Reinforced Polymer (FRP) have garnered considerable attention in the construction field thanks to their distinctive features and benefits.[1] TRC, marrying a cementitious matrix with industrial textiles like carbon fiber, glass fiber, or basalt fiber, provides superior durability and bond strength with reinforced concrete in comparison to FRP. The mechanical behavior of TRC under tensile or flexural loading has been extensively studied, revealing varied stress-strain relationships influenced by factors such as reinforcement textiles, cementitious matrix, and environmental conditions.[2] In contrast, FRP has found widespread application in fortifying existing structures due to its impressive strength-to-weight ratio, resistance to corrosion, and ease of use. Nonetheless, issues like high cost and subpar performance in elevated temperatures have prompted researchers to investigate alternative solutions like TRC. [1] [2]

The bonding mechanisms in TRC resemble those in steel-reinforced concrete but on a smaller scale, affected by parameters like fiber volume ratio, yarn type, impregnation composition, and textile geometry.[3] On the whole, both TRC and FRP offer distinct advantages in the construction realm. While TRC delivers enhanced durability and bond strength with improved mechanical properties under specific environmental conditions when compared to FRP, the latter presents a high strength-to-weight ratio and simplified application process. Understanding the attributes and performance of these composite materials is essential for choosing the most appropriate material for particular construction tasks. [1] [2] [3] [4] Note that those values can vary based on specific material formulations and manufacturing processes.

2 Textile reinforced concrete (TRC)

2.1 Composition of TRC

TRC is a composite material that integrates high-performance textiles (carbon, glass, or basalt fibers) within a cementitious matrix. The textiles provide mechanical strength, while the matrix ensures load distribution and environmental protection. [3] [5] The various properties of TRC have been studied by many researchers since the early 1990s, and due to its better durability and stronger bonding with the concrete members, TRC has several advantages over FRP composites. [2] [5] [6] In addition, recyclability is possible in the case of TRC. TRC is stronger under severe environmental conditions like corrosion at high temperature compared to FRP. [3] [5]

The industrial fabrics of TRC are usually woven into particular mesh patterns using premium fibers in order to maximize performances. For example, basalt textiles possess astonishing strength and Young's modulus and alkali-resistant glass textiles are made in order to bear moisture and alkaline conditions. [2] [5] [6] These textiles, once imbedded into the concrete, in case of cracking will internally reinforce the concrete in order to control the tensile pressures. [3] [5] Among others, properties of bond between concrete and textile reinforced are fundamental to ensuring structural safety, include the performance of the overall system.

Methods for improving the bond strength between the textile and fine-grained concrete include treatments with bonding sand and with impregnation by epoxy resin. Testing has shown that the materials in TRC possess very beneficial mechanical properties-high values of tensile strength combined with flexural rigidity-caused by the very good bonding of the cementitious matrix with high-performance textiles. use TRC in a broad range of construction activities, not only its composition but also its behavior has to be understood, especially when developing environmentally close, durable, and lightweight materials. [3] [2] [5] [6].

2.2 Properties of TRC

Examples of high-valued textiles in use in TRC include basalt and AR-glass, among others. All of them possess different specific qualities: density, elongation at failure, modulus of elasticity, and tensile strength. These properties highly affect the strength, hardness, and ductility of TRC. Its composition, a variety of textile textiles can considerably influence mechanical performances of TRC. Reinforcement by the number of layers and orthogonal orientation of the rovings can also affect overall performance of TRC. More important, manufacturing of TRC elements to different applications will make other factors such as mesh size, filament diameter, weight per unit area, and ultimate strain necessary as well. **Fig. 1** shows textile reinforcement with Concrete as a composite material. Characteristics of TRC are very essential in making it effective during the construction of building projects. Based on the unique properties of various textile materials that include basalt and AR-glass, engineers can modify the TRC parts in meeting specific structural needs. Some of the variables that result in overall effectiveness include the following: density, elongation at failure, modulus of elasticity, and tensile strength in many applications. [5] [7] [8].

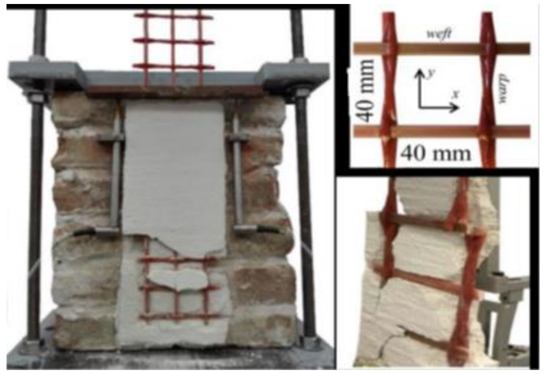


Fig. 1. 2D textile of Carbon fibres renforcement concerte [8].

3 Fiber Reinforced Polymer (FRP)

3.1 Composition of FRP

Fiber Reinforced Polymer, FRP is a composite material that becomes more popular in the building sector because of its surprising qualities. Continuous unidirectional fibers combined in a polymeric matrix create the considerable improvement in the mechanical characteristics of FRP along the longitudinal axis. The performance of FRP depends mainly on the type of polymer matrix, which controls its mechanical behavior and compliance with design standards. Polymer dispersions provide the added benefit of flexibility in transit owing to the less rigid cured state and are used in 2D and 3D types. In light of this, different fibers in various combinations, such as carbon, basalt, aramid, and alkali-resistant glass, are combined in preparation for FRP component manufacturing. The combination gives a high specific tensile strength and excellent corrosion resistance compared to the usual steel reinforcement. Due to these properties, FRP is particularly suitable for buildings with such extreme weather conditions. Unlike the ductile failure that usually characterizes the conventional steel reinforcement, FRP deforms in a linear-elastic way up to brittle failure. That is the difference and requires great care in the structural design, especially in seismic zones where ductility is important for safety. However, with the continuous development in the science and production techniques of this material, FRP is turning out to be one competitive alternative for conventional steel reinforcement in most building applications [9] [10].

3.2 Properties of FRP

FRP Composites are highly attractive alternatives to the conventional building material due to its many advantages. Their superior specific tensile strength compared to conventional reinforcing steel allows a reduction in the thickness of the concrete cover-one of the most salient advantages. Due to this, it is expected that the structural elements will be lighter and last longer, especially for the cases of parking structures and bridges where chloride ions abound. Various composite combinations may be included in FRP. Among the most available common fiber materials, one can name AR glass, carbon, basalt, and aramid, among others. Usually, the matrixes are one of the following: epoxy resin, water-dispersed rubber-based systems, including styrene-butadiene, or acrylate-based systems. The detailed mechanical behavior of FRP depends on a specific mix of fibers and matrix incorporated. Due to the properties of anisotropy, FRP shows linear-elastic material behavior and fails brittlely rather than ductility, in opposition to normal steel reinforcement. Compared to conventional steel reinforcement, the FRP reinforcement elements are GFRP, AFRP, and BFRP, which have a higher tensile strength and low stiffness in general. Carbon fiber-reinforced polymer normally has much higher tensile strength than that of steel and a similar or slightly lower rigidity. In general, FRP composite can be introduced as one of the most promising materials for many applications in construction, which require high strength and low weight, resistance to corrosion, and design flexibility [9] .

Fig. 2 shows fiber polymer with Concrete as a composite material.

4 Microstructure assessment

4.1 Scanning Electron Microscope (SEM)

Examining the microstructural characteristics of the TRC-concrete interface under chloride assault was the aim of the SEM tests carried out for the study. The researchers observed and evaluated the bonding effectiveness between TRC reinforcement layers and the pre-existing concrete surfaces using a scanning electron microscope. The tests for these variables were conducted experimentally by changing the content of sodium chloride, frequency of the dry and wet cycles, time for which the reinforcement layer was bonded, and types of reinforcement material that were used. From the test results obtained from the SEM test, it can be obtained that with the increasing concentration of sodium chloride; the degradations at the interface became more critical. The microstructure degradations were also seen to increase considerably when higher levels of salting chloride were used and the numbers of wet and dry cycles were increased. However, as the length of bonding increased along with increasing reinforcement such as by using cast-in-place, the performance enhancement at bond interface took place, [6]. Fig. 3 appears that SEM testing provided the most vital information regarding the adhesion between the TRC and the concrete surfaces under chloride attack conditions. In bringing to the fore three typical types of interface failure, the results emphasize the importance of appropriate bonding in improving the effectiveness of the reinforcement. Using the SEM analysis while investigating the microstructural features helped the researchers to understand clearly how many factors affect the binding qualities between TRC and concrete. [6] [9].

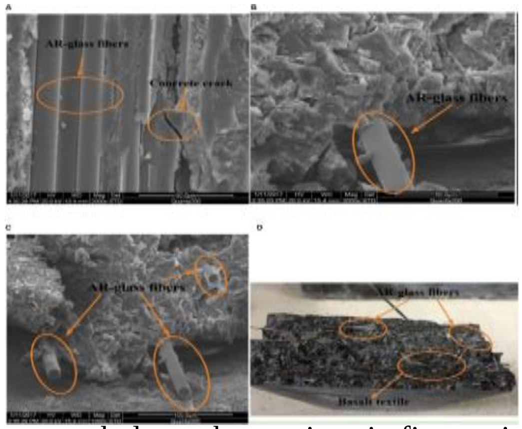


Fig. 3: Textile and short fiber morphology observations in fine-grained concrete. (A) The ability of short fibers to withstand cracking; (B) their ability to bridge gaps; (C) their uniform distribution; and (D) their ability to recombine with textiles, [11].

4.2 Fiber-concrete analysis at micro-level

The research into the behavioral and performance analysis of a composite material, like Textile Reinforced Concrete and Fiber Reinforced Polymer, generally relies on proper understanding at a micro-level in respect to fiber-concrete connection. The overall strength and durability are significantly related to the interaction between fibers and the concrete matrix.

The additional reinforcement is given to the BTRC sheets with the incorporation of continuous basalt fiber textiles and discontinuous AR-glass fibers because their short fibers function as connectors and fracture arresters which increase the delay in damage due to distribution of stress over the inner voids and cracks as reported in the SEM analysis conducted. [11] The overall strength of continuous fiber fabrics increases due to the absorption of a part of the mechanical stresses which enhances their macro-flexural performance. On the other hand, TRC possesses some desirable bonding properties with rigid contacts. It was shown that resin composition, textile design, and additives are the most influencing factors on the relationship of FRP textiles and concrete matrices in TRC. In this respect, the reinforcement effects will be fully achieved in TRC structures if substantial knowledge about the bonding properties exists.

All these factors act on the nature of adhesion between carbon fibers and concrete matrices, including but not limited to cement types, chemical treatments, and time-dependent behaviors. Bond-slip diagrams provide an understand of the interaction between concrete and reinforced fabric and explain how important the quality of bond between them is with respect to maintaining the safety of a structure under stress.

In general, SEM tests give insight into the fiber-concrete bond in the microscale level and demonstrate different natures of fibers that interact with the concrete matrix for improvement in mechanical performance. These add to our knowledge regarding TRC and FRP composites and their functional mechanism in construction applications based on the properties of bonding, [12] [13].

5 Mechanical Properties

5.1 Tensile strength

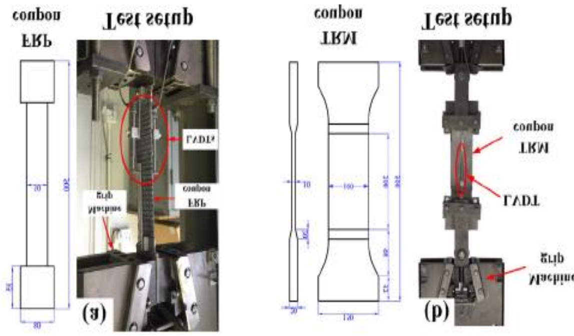
There is an interest in the strength of composite materials: common concrete, FRP, and TRC. In essence, tensile tests have to be conducted on any material in order to understand its ability to withstand pull without failure. Research studies indicate that the tensile strength of TRC may vary between 1000-1700 MPa depending on density and spacing of AR-Glass fiber fabrics. [14] It is also seen that FRP materials normally have tensile strengths from the order of 1019-1415 MPa depending on their composition and reinforcement[8]. Compare TRC and FRP tensile strength findings are indicated in **Table. 1**.

The tensile test determines the maximum stress a material can undergo before rupture, and it is a method in which samples are subjected to controlled pulling pressures until failure. [14] It is from the results of such tests that engineers decide whether the mechanical properties of the material are right for a particular application, [8]. **Fig. 4** shows the tensile test setup for TRC and FRP.

When a particular structure needs more strength and resistance to degradation, TRC and FRP are far superior to conventional concrete in terms of tensile strength. Much greater values constitute their tensile strength. The superior tensile behavior displayed by TRC and FRP is simply because of the reinforcement therein, inclusive of the fibers which enhance the mechanical behavior, [14]. In other words, tensile strength tests demonstrate that TRC and FRP outperform traditional concrete in terms of resistance because of their composite nature and additional reinforcement. This will then be indicative of the derived potential benefits from the employment of composite materials such as TRC and FRP in any building project, especially when the tensile strength is to be high, [2] [8] [14].

Table. 1: TRC and FRP's tensile strengths.

Material	**Tensile Strength (MPa)**	**Advantages**	**Disadvantages**	**Notes**	**Reference**
TRC (AR-Glass)	1000-1700	Good resistance to tensile forces, enhanced crack control	Slightly lower tensile strength than basalt or carbon FRP	Dependent on textile density and fiber spacing	[2] [8] [14]
TRC (Basalt)	1190-1680	Good performance under harsh conditions (corrosion, heat)	Slightly lower than carbon FRP but better environmental resistance	Best used in high-temperature and aggressive environments	[15] [16] [17]
FRP (Carbon)	2936 ± 31.5	Extremely high tensile strength, excellent for high-load structures	Brittle failure, sensitive to temperature extremes	Offers the best tensile strength but is expensive	[16]
FRP (Basalt)	1501-1950	Good tensile strength, eco-friendly option	Lower performance compared to carbon FRP in high-stress applications	Ideal for medium-load and eco-sensitive projects	[10] [16]
FRP (Glass)	1019-1415	Affordable, good resistance to corrosion	Lower tensile strength compared to carbon and basalt	Suitable for less demanding tensile applications	[10] [16]



5.2 Ductility of TRC, FRP, and NC

The obtained ductility values of both the steel- and textile-reinforced slabs were compared, showing that the addition of textile
reinforcement allowed for higher values than traditional reinforcement with steel.[18] Also, embedding a layer of mortar between the textile reinforcement and steel increased the strength of the binding, thus allowing a positive influence on the ductility. That is in agreement with other studies dealing with changes in the reinforcement type regarding the ductile behavior of concrete elements [18] [19]. **Table. 2** examine TRC and FRP mechanical characteristics and ductility.

Considering all the aspects, the type of reinforcing material applied can seriously affect the ductility in the concrete buildings. Even though in many practical applications conventional steel reinforcement is adequate for ductility performance, there are several conditions in which adding FRP or textile reinforcements provides more advantages. For the purpose of optimization in design and performance, a fundamental understanding of the performance of different types of materials under various loading conditions is required for composite structures, [19].

Table. 2: TRC and FRP mechanical characteristics ductility.

Material	Ductility (Ratio/Behavior)	Advantages	Disadvantages	Notes	Reference
TRC (AR-Glass)	High ductility, gradual failure	Excellent deformation capacity before failure	Slightly less ductile than carbon or basalt composites	Best for structures requiring energy absorption and flexibility	
TRC (Basalt)	High ductility, energy absorption	High deformation before failure, good for high-temperature environments	Slightly lower ductility than carbon FRP but still excellent	Ideal for coastal and industrial environments where flexibility is key	
FRP (Carbon)	Low, brittle failure	High strength-to-weight ratio	Brittle failure, lacks warning before failure	Requires careful structural design to accommodate brittle behavior	[18] [19]
FRP (Basalt)	Moderate ductility, more flexible than carbon	Better ductility than carbon FRP, handles moderate deformations	Less ductile than TRC, needs specific applications	Good for applications needing a balance of strength and ductility	
FRP (Glass)	Low ductility, brittle behavior	Affordable solution for non-critical applications	Very low ductility, brittle failure	Best for low-risk applications with minimal dynamic load demands	

5.3 Flexural strength

It is an important property in tests made on composite materials such as conventional concrete, FRP, and TRC. It can be determined with four-point bending exams amongst others. In tests with 2D reinforcements, it was found that the mechanical performance of these configurations was somewhat superior to the 3D, according to the research on TRC made with uncoated woven basalt fabrics [16]. Because mismatched textile orientation affects the load-bearing performance, especially in the tiny cross-sections and low fiber volume fractions, warp direction reinforcement displayed notably higher failure loads and displacements compared to the weft direction reinforcement.

Another investigation was conducted using a cement-based binder and positive results were reported on the warp knitted cloth reinforced concrete. Tested beams had two, three, four, and six layers of basalt cloth that showed significant strength gains compared to the control beams. The beams bonded with four-layer basalt textiles showed greater ultimate strength and deflection enhancements compared to the unstrengthened beam. That is to say, during the rise in the number of textile layers, the impregnated binder gained strength and supported the outer layers; hence, the strength came into the composite, [5]. TRC and FRP's flexural strengths showing in **Table. 3**.

The experimental comparison between strengthening of RC beams with TRC and FRP in bending also highlighted advantages that the reinforcement can ensure. Retrofitted beams, either by TRC or FRP, showed noticeable bending stiffening from the reference beams during the pre-cracking, cracking, and post-yielding phases, [16]. Such an increase was found to be dependent upon the strengthening method, thickness of the used layers, type of fiber, and global design. Overall performances, driven both by reinforcement schemes and material qualities, are compared with comparisons in bending strength between TRC and FRP and conventional concrete. The conditions of the material property of the bending strength would make a marked understanding towards the load-carrying and structural integrity of the composite materials for application in construction. **Fig. 5** shows the flexural test setup for TRC and FRP [16] [20].

Table. 3: TRC and FRP's flexural strengths.

Material	**Flexural Strength (MPa)**	**Advantages**	**Disadvantages**	**Notes**	**Reference**
TRC (AR-Glass)	36.8-62.2	Good flexural performance with multiple textile layers	Lower flexural strength compared to carbon FRP	Performance improves with additional layers (4-6 layers)	[21] [16]
TRC (Basalt)	38.5	Exceptional toughness and deflection with basalt textiles	Slightly lower than carbon-based composites	Flexural strength increases with more textile layers	[5]
FRP (Carbon)	60.4-83.7	High stiffness and flexural capacity, ideal for reinforced structures	Brittle failure, requires careful design	Carbon FRP shows superior flexural capacity	[16]
FRP (Basalt)	54.2	Good flexural	Performance	Best for eco-	[21]

		performance, especially in aggressive environments	slightly lower than carbon FRP	friendly and medium-strength applications	
FRP (Glass)	41.5-48.2	Cost-effective solution for flexural reinforcement	Lower stiffness and flexural strength compared to carbon and basalt	Suitable for less demanding flexural requirements	[16]

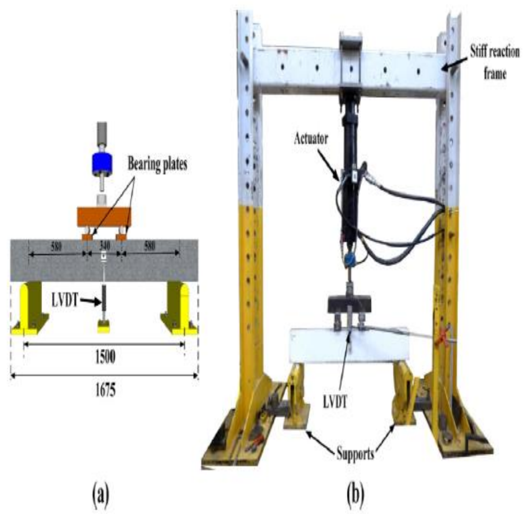


Fig. 5: Flexural test setup: TRC and FRP [21]

5.4 Durability

5.4.1 Factors influencing composite materials' durability

In general, composite materials may be apt to many determining factors that impact their durability, depending on the material type being employed. For instance, FRP bars may have a tendency to deteriorate in mechanical performance due to extreme loading and environmental conditions. This in turn, may relate to several factors including, but not limited to, the type of reinforcement, resin, and diameter of the bar. FRP may also deteriorate owing to several other exposure conditions such as water, sea water, and alkaline solution. Wet-dry and freeze-thaw cycles have also been reported as some of the most aggressive factors affecting FRP bar durability. Less delicately said, FRP bar durability is grossly influenced by the interaction of loads, concrete wrappings, temperatures, and exposure conditions. Enhancement of the durability of FRP bars for infrastructure applications will require a firm understanding of these degradation processes, [9].

A number of models have, however been developed which forecast the long-term durability of FRP bars to assess their performances. The incorporation of variables like exposure condition as well as environmental stress, presents what is expected from FRP bars under given conditions. Assessment of the variables and prediction models leads to informed decisions on employment of FRP bars during building by the researcher.

Durability is a very complicated issue related to composite materials such as FRP because of variables such as the type of reinforcement, resin properties, bar size, and several aspects of the exposure conditions. In building applications, the sustainability of composite materials also depends upon the discernment of some issues related to type of reinforcement, properties of resin, size variations in bars, and several other aspects of exposure conditions [9] [22].

5.4.2 Durability of TRC & FRP

These tests being done to find out the durability of FRP and TRC could therefore yield valuable information with respect to the performance of these materials under extreme conditions. Most of the studies regarding FRP bars put forth a very important understanding of the degradation process of these materials when an adverse environment is concerned. Some significant variables which have been studied affecting the mechanical properties of FRP bars, especially under an alkaline solution, concern reinforcement, resin type, and diameter of the bar. Wet-dry and freeze-thaw cycles shall be considered in the test analysis for the degrading of FRP bars in different environmental conditions, [9]. Moreover, the tests shall be extended in order to establish the FRP rebar performance prediction model for a long period to enhance the effectiveness of its practical use. **Table. 4** displays all of the TRC and FRP durability test results. On the other hand, the ability of TRC to strengthen the concrete in place is acutely sensitive to the question of its bond. Those studies that address the issues of sodium chloride concentration, cycling between dry and wet, bond length, and reinforcement type with a view to determining the chloride-exposure behavior of TRC utilize double-sided shear tests and sophisticated micro-testing techniques like XRD and SEM. Increasing the bond length, another means of improving the effectiveness of TRC bonding to existing concrete structures is by using cast-in-place reinforcement. It has been shown in comparing FRP and TRC under such hostile conditions as being immersed in alkaline, salty, and acidic solution that proper selection of reinforcing textiles can make a difference in enhancing the durability of TRC. Tensile behavior is assessed on the submergence of specimens in a controlled temperature for 1000 hr in order to calculate for the following: ultimate strength, elongation, energy dissipation at failure, and environmental conversion factors.[23] This comparative analysis will try to find out their response, FRP versus TRC, against various hostile situations. Worldwide, these investigations introduce new basic information on the resistance of TRC and FRP composites, while putting into evidence that the knowledge of composite behavior under aggressive agents is an avoidless step toward their application optimisation to structural works, [6] [22].

Table. 4: Compare durability test findings of TRC and FRP.

Material	Durability	Advantages	Disadvantages	Notes	Reference
TRC (AR-Glass)	Excellent resistance to corrosion and alkaline environments	Long-lasting in harsh environments, good for outdoor applications	Less durable in high-temperature conditions	AR-glass fibers are specifically designed for alkali resistance	[6] [9] [22] [23]
TRC (Basalt)	Excellent, especially under extreme conditions	Eco-friendly, high resistance to corrosion and temperature	May degrade over very long periods in certain extreme conditions	Best used in coastal or industrial environments	
FRP (Carbon)	Good resistance to corrosion but sensitive to UV and high temperatures	Very durable in moderate climates	High sensitivity to UV exposure and temperature fluctuations	Requires protective coatings in extreme climates	
FRP (Basalt)	Excellent resistance to corrosion, moderate resistance to UV and	Good balance of durability and environmental	Slightly less durable than carbon in extreme conditions	Suitable for most outdoor applications	

	temperatures	friendliness			
FRP (Glass)	Moderate, good in non-alkaline and non-corrosive environments	Cost-effective durability solution	Low durability in alkaline and aggressive environments	Suitable for light structural applications in stable conditions	

5.5 Applications for construction

5.5.1 Present-day TRC and FRP applications in the building sector

Textile-reinforced mortars,

abbreviated as TRC or textile-reinforced concrete, or even as fabric-reinforced cementitious matrix, have received much attention in construction due to their potential to act as substitutes for fiber-reinforced polymer materials in the reinforcement of concrete structures. TRC is a composite material comprising high-performance mortar as the matrix and a textile as reinforcement; hence, it presents excellent crack-limiting ability, high tensile strength, resistance to corrosion, and compatibility with concrete. The applications of TRC are quite wide in various construction projects, especially in the realm of permanent formwork. These formworks can be perfectly integrated with the cast-in-place concrete and hence provide structural stability, reducing crack formation and enhancing durability. Permanent formwork systems made from TRC have shown a lot of improvement in bearing and deformation capacities compared to conventionally cast-in-place concrete structures. In addition, TRC has also been used for the strengthening of the masonry walls, in which its inorganic cement-based matrix shows much better compatibility with masonry substrates compared to FRP composites. The increased interfacial bond between TRC and masonry substrate the overall mechanical behavior of the strengthened structure would rise considerably. Compatibility, excellent mechanical properties, and durability make TRC feasible material under various applications in buildings. From panel elements up to load-carrying components, the ingenuity turns out to be a solution to the problems of contemporary building, [24] [25] [26].

5.5.2 Future applications based on requirements for mechanical performance

There are considerably a lot of promising applications of both TRC and FRP composites in the civil engineering industry as far as satisfaction for the modern needs of structural requirements is concerned. Recognized with very high tensile strength, resistance to corrosion, and effective crack-limiting properties, TRC-or FRCM-has been identified as a competitive alternative to FRP in retrofitting and strengthening concrete structures. Textile reinforcements may become even more competitive when compared to traditional steel meshes, since recent studies have demonstrated potential advanced 3D textiles for both thin and large-scale applications. Another route toward eventually more cost-effective solutions improving mechanical qualities will include the use of lightweight matrices combined with FRP meshes or textiles. The overall performance and durability of TRC materials are also expected to be improved by the development of hybrid 3D textiles that blend FRP fibers with steel wires or strands. For structural reinforcement in difficult conditions, novel techniques like self-stressing composites that make use of shape memory materials with deformation recovery capabilities are being investigated. The creation of high-performance composite materials with excellent mechanical properties may result from the combination of textiles with ultra-high performance cementitious (UHPC) matrices. The major building applications for which TRC and FRP composites are envisaged in the near future include seismic retrofitting solutions, lightweight structures, protective linings, and facade components. TRC and FRP composites are able to fully innovate the various conventional reinforcing and strengthening techniques due to their innovative design techniques and development of material technology, [1] [6] [24].

6 Conclusion

Both Fiber-Reinforced Polymer (FRP) and Textile-Reinforced Concrete (TRC) present promising alternatives to traditional steel reinforcement, each with unique mechanical and durability characteristics. FRP, particularly carbon-based types, exhibits extremely high tensile strength and an exceptional strength-to-weight ratio, making it ideal for lightweight and high-strength applications such as bridges and marine structures. However, its brittle failure behavior and sensitivity to UV radiation and temperature variations demand careful design and protective measures.

TRC, on the other hand, provides significant ductility, progressive failure mechanisms, and strong bond performance between textiles and cement matrices. These features enhance crack control and energy dissipation, making TRC suitable for retrofitting, formwork systems, and improving structural longevity. TRC's superior resistance to corrosion and alkaline environments also makes it highly suitable for coastal and industrial settings.

Ongoing innovations—such as hybrid 3D textiles, self-stressing composites, and advanced resin systems—aim to enhance both materials' performance and expand their applications. The choice between FRP and TRC ultimately depends on project requirements, including desired mechanical performance, environmental exposure, and cost. While FRP leads in tensile strength and lightweight performance, TRC excels in compatibility with concrete and environmental durability.

Future research should emphasize large-scale field validation, hybrid reinforcement systems combining FRP and TRC, and long-term cost–benefit analysis to optimize their use in sustainable and resilient infrastructure.

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