RESEARCH ARTICLE OPEN ACCESS

Flexural Behavior of a New Dune Sand-Based Textile Reinforced Concrete

Fatma Bouzeboudja *,**, Chafika Ali ahmed *,**, Fatma Kheloui*,**, Souad Ait Taleb*,**

* Laboratory L2MSGC, Faculty of Construction Engineering, University Mouloud Mammeri of Tizi Ouzou, 15000 Tizi-ouzou, Algeria

** Civil Engineering Department, Faculty of Construction Engineering, University Mouloud Mammeri of Tizi Ouzou, 15000 Tizi-ouzou, Algeria

Corresponding author: Fatma.bouzeboudja@ummto.dz

--************************----------------------------------

Abstract:

Over the last few decades, textile-reinforced concrete (TRC) has established as a promising construction material, with a wide range of applications in innovative structures such as thin walls, complex design structures, and outdoor furniture. TRC is characterized by a fine-grained concrete matrix combined with high-performance multi-filament yarn grids, known in particular for their lightness and exceptional corrosion resistance. The worldwide scarcity of river sand resources requires further research into alternative materials more abundant and more environmental friendly. In this context, this experimental work focused on the study of mechanical properties of a new low-cost TRC using Tougourt dune sand as a substitute of river sand in the matrix; for the reinforcement, an alkali-resistant glass textile was used. An experimental campaign involving compression tests on 50x50x50 mm^3 cubes and four-point bending tests on 400x100x20 mm^3 plates was carried out, at the age of 28 days. The results showed that, compared to river sand, the fine grain size of dune sand significantly improved the compactness of the matrix, increasing its compressive strength. The quality of the reinforcement-matrix interface was also significantly improved, through better infiltration of the fine dune sand particles between textile filaments; this has enhanced the four-point bending performance of the TRC, a gain of in terms of 6, 29 % in flexural strength, and 40% in term of ultimate deflection

Keywords — **Textile-reinforced concrete, Dune sand, Compression, Bending, Glass textile**.

--************************----------------------------------

I. INTRODUCTION

Textile Reinforced Concrete (TRC) is a composite material consisting of a fine-grained matrix combined with textile materials such as alkali-resistant glass, carbon, basalt, or polymer fibers. The matrix can be a cementitious paste or a mortar with a fine grain size to allow continuity through the textile reinforcement [1].

TRCs have enjoyed huge success in civil engineering thanks to their improved mechanical and chemical properties compared to traditional construction materials [2]. TRC's ability to offer increased strength while allowing design flexibility and a significant reduction in the weight of structures makes them the preferred solutions for many applications [3].TRCs have a wide range of applications in the construction sector, used as internal reinforcement for new structures,they are also used as external reinforcement for the reinforcement of existing structures (rehabilitation), mainly used in the form of contact-molded fabrics, bringing substantial improvements in strength and lightness to the reinforced elements [4].

Internal reinforcement is used to create thin walls and complex architectural structures (as an alternative to conventional reinforcement) [5]. This new concept offers important advantages such as corrosion resistance, and allows for thinner and lighter structures compared to traditional reinforced concrete structures. These materials optimize structural performance while offering increased durability [6], [7]. At the Museum of the Future (figure 1.a), TRC enables the creation of its iconic, column-free, and organic shapes, enhancing both structural integrity and aesthetic appeal. This innovative material allows for intricate designs that reflect the museum's focus on forward-thinking concepts. Similarly, the National Museum of Qatar (figure 1.b) TRC is used to form fluid, organic shapes that resonate with the region's natural landscape, embodying its cultural heritage. By integrating TRC, both museums exemplify how advanced materials can redefine architectural possibilities and contribute to sustainable construction practices.

a) b)

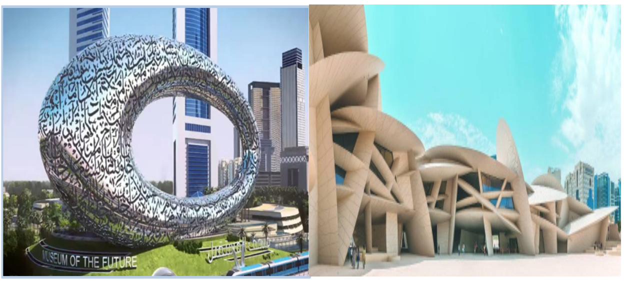

Fig. 1 TRC constructions: a) Museum of the future (Dubai), b) National museum (Qatar)

Yarns generally used in TRC reinforcement textiles, are made up of 400 to 7,000 filaments with diameters ranging from 5 to 30 µm. Textile impregnation in TRC composites depends on the nature of the textile and the nature and fluidity of the matrix. The tighter the weave, the more difficult it is for the matrix to penetrate between the filaments. However, even in the densest fabrics, a gap remains between each filament. This space, generally of the order of the filament's diameter, allows the matrix to infiltrate and partially coat the filaments. Studies have shown that the outer filaments of the yarn are the most impregnated. This is because they are in direct contact with the matrix over a larger surface area. As one approaches the center of the yarn, the area in contact with the matrix decreases. The core filaments, as shown in figure 2, are generally not impregnated by the matrix [8].

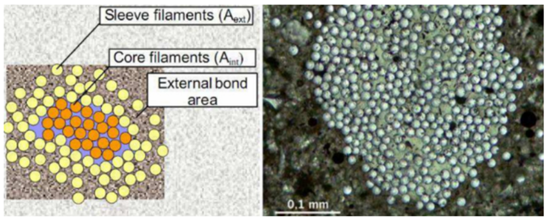

Fig. 2 A filament embedded in its matrix. Visualization of the inner unimpregnated and outer impregnated filaments [10].

The impregnation of the textile reinforcement, dominates the adhesion between the textile reinforcement and the matrix. Researches have shown that the nature of the matrix can have a significant influence on the behavior of the elastic phase, the crack stability phase of the stress-strain curve, as well as on the strength and ultimate deformation of the composite TRC. The sand used in textile-reinforced concrete (TRC), mainly extracted from quarries or rivers, must meet several essential criteria to guarantee the composite's performance. It is siliceous sand characterized by a fine grain size, often less than 2 mm, a rounded grain shape favoring good penetration between the filaments, which provides optimum adhesion to the textile fibers [9], [10], [11] .

The over-exploitation of river and quarries sands has led to a number of negative effects, both on the environment and on human society, such as the depletion of water tables, hydrological imbalances, and the destruction of bridges [13].To remedy this situation, the use of alternative materials has become essential [14], [15]. The desert, with its abundant sand reserves, offers a viable alternative. Promoting more sustainable and environmentally friendly construction practices [16], [17].

In this context, the main objective of the present work is to valorise the dune sand available in inexhaustible quantities around the world, using it as an alternative to overexploited river sand in a fine aggregate textile-reinforced concrete (TRC). With its fine grains size, well-rounded shape and cleanliness, making it ideal for TRCs. An experimental investigation focused on the effect of the use of dune sand in the matrix of an AR glass textile reinforced fine aggregates concrete. Cubic specimens were confectioned and subjected to compressive test; Plate specimens were made and subjected to four-point flexural test. The obtained results concluded that the substitution of river sand by dune sand improves notably the flexural behavior of the TRC. Which can make it a very good alternative to overexploited sands.

II. EXPERIMENTAL METHODS AND MATERIAL

A. Experimental program

A total of 18 specimens divided into 2 sets were manufactured. 6 cubes of 50x50x50 mm^3 dimensions subjected to compression, and 12 plates of 400x100x20 mm^3 dimensions subjected to four-point bending test. Tables 2 and 3 illustrate the samples designation and composition according to the type of used sand. It is significant to notice that three identical specimens were confectioned for each sample set. The experimental campaign defined in the below section contains, the experiments, and reinforcement procedure as well as the testing instrumentation.

B. Materials

The whole of used raw materials for the manufacturing of the samples reinforcement and matrix is respectively shown in Fig. 3 and Fig. 4. Indeed, river and dune sand based fine aggregate matrix, and AR-glass textile reinforcement constitute the main materials of the investigated TRC specimens. Furthermore, a mechanical and physical characterization was performed to assess their main intrinsic properties.

C. AR glass reinforcement

Glass fibers are made from silica and other metal oxides, fused and drawn into fine fibers. They offer an interesting combination of properties such as high mechanical strength, good rigidity, low density and good resistance to chemicals and high temperatures. These characteristics make glass fibers the material of choice for many construction applications.

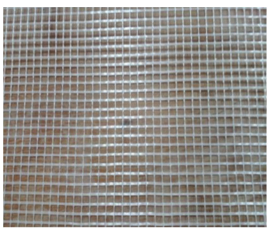

Fig 3. AR Glass Textile reinforcement

Fiber glass offers high strength for its weight, improving structural performance without significantly increasing mass [6]. Non-corrosive and resistant to many chemicals, it is durable and suitable for a variety of industrial environments. What's more, its low coefficient of thermal expansion minimizes the risk of cracking and warping under temperature variations [7]. Table 1 presents the mechanical properties of monofilament fibers of used textile.

TABLE 1. MECHANICAL PROPERTIES OF MONOFILAMENT FIBERS OF USED TEXTILE [6-7]

Parameter	Glass fiber
Tensile strength (MPa)	3100
8Young's modulus (GPa)	72
Elongation at failure (%)	4.5

D. Sand

Sand is the constituent of the granular skeleton that has the greatest impact on concrete and mortar. It plays a vital role in reducing volume variations. It must be clean and free from harmful chemical elements. As dune sand is available in vast quantities, we decided to use river sand instead of dune sand in the manufacture of our fine aggregate concrete. In this study we used two types as shown in fig .2 of sand with the same maximum grain diameter of 1.25 mm. The first is a local river sand (RS), and the second is a siliceous dune sand from the Touggourt region (DS).

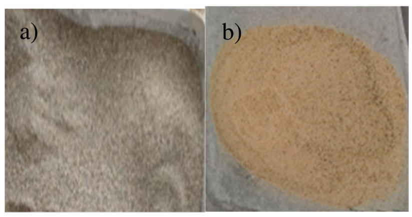

Fig. 4 Used sands and slag: a) River sand,b) Tougourt dune sand .

E. Matrix composition

The composition and the mix design of the used matrix are shown in **Error! Reference source not found.**2. To evaluate the impact of the matrix composition on the global and local performances of TRC, the amount of the river sand was totally or partially substituted with an equivalent amount of dune sand. The fine concrete matrix was mixed with slag, superplasticizer, and cement referred to as NA 442-CEM II /B-L 42.5 N. Two types of sand with a maximum grain size of 1,25mm were used, as shown in **Error! Reference source not found.**4: a local river sand (RS), and a fine siliceous dune sand (DS) issued from the Touggourt region (Southern Algeria). To reduce the amount of cement in the matrix, the sand /binder ratio used in this work is 2, 15, and the water/binder ratio is 0, 4.

TABLE 2. THE MIX DESIGN PROPORTIONS OF USED FINE AGGREGATE MATRIX

Material	Cement	slag	Sand	Water	Super plasticizer	w/b
Amount (kg/m3)	605	35	1380	262	8	0,4

TABLE 3. DESIGNATION OF ALL MANUFACTURED AND TESTED SPECIMENS

Designation	River sand (%)	Dune sand (%)	Glass textile
RS	100	-	-
DS	-	100	-
RSG	100	-	2
DSG	100	-	2

F. Methods and design

The mixing procedure was as follows: first, the dry materials were introduced in a double-speed mortar mixer (fig. 5), which possesses a blade rotating in a planetary motion. The mixer was then started at low speed for 60 seconds for dry pre-blending. After this,the water was added, and mixing continued for 2 minutes at high speed. A 15-second pause was taken to quickly scrape the matrix and re-center it in the middle of the tank. Finally, the superplasticizer was added along, and the mixer was set to high speed for the final mixing. Cubic specimens were filled and vibrated.

As for the plate specimens, part of the matrix was distributed at the bottom of the prismatic mold (5 mm high), followed by a layer of resin-coated textile of glass fiber. Another layer of 5mm of matrix was then distributed over the textile; the second textile layer has been applied. A final layer of matrix was then spread to a thickness of 20 mm. After casting, the specimens were vibrated.

After 24 hours, the test specimens were removed from the molds and stored in water at room temperature until the day before testing to prevent shrinkage and ensure proper cement hydration. After 28 days, the test specimens were removed from the water and placed in the open air (in the laboratory) to achieve their normal moisture content.

Fig. 5 Samples production and manufacturing

G. Tests instrumentations

The bending characteristics of the designed samples were determined using four-point bending tests, as depicted in Fig. 6. The experiments were carried out on TRC members with 400 x 100 x 20 mm3 dimensions under controlled displacement. According to ASTM standards (ASTM C1609 2012) The effective span of the samples was 300 mm, and the distance between the support ensuring the four-point bending was 100 mm (fig. 6. a and fig.6. b) . The load and deflection were automatically measured at the application area of the load using the software integrated in the used ZWICK/ROELL Z250 machine. The samples were loaded with a constant loading speed rate of 0,5 mm/min. The curves were obtained by direct record of displacement using the machine software controlled by a computer with data acquisition, as used by [1], [2], [8] when global behavior of samples was focused.

The loads are applied in order to create a zone of maximum bending at the center of the specimen. This configuration generates a maximum bending moment in the middle of the span between the two loads. The results of the four-point bending test provide information on the material's ability to resist bending. It is an important measure of structural strength, often used to assess the quality and durability of building materials such as concrete in a variety of applications.

The same machine was used to carry out compression tests on cubic specimens, with a loading speed of 2.5 KN/s as shown in figure 7.

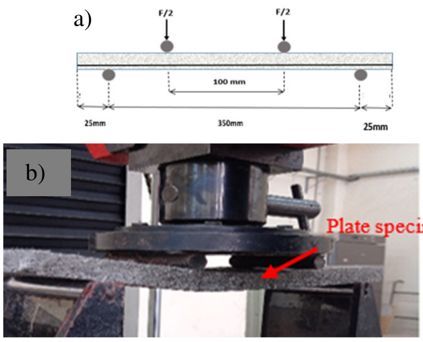

Fig 6. Four-point bending test setup: a) Schematic of the test setup, b) specimen under the test machine

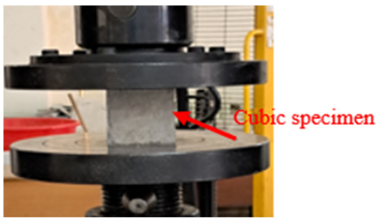

Fig. 7 Compression test setup

III. RESULTS AND DISCUSSION

Table 4 presents the obtained results in terms of First crack, and Maximum load with their corresponding deflections, as well as the flexural and compression strengths for the different specimens. rupture modes are present in fig.12

A. *Compression test*

Compression tests are commonly used to evaluate the mechanical properties of materials. This essential characteristic corresponds to the maximum load obtained in the compression test, where the specimen is subjected to a continuous axial force until it breaks. In this work, the load is applied at a load speed of 2 KN/s, guaranteeing constant, even load progression for reliable results.

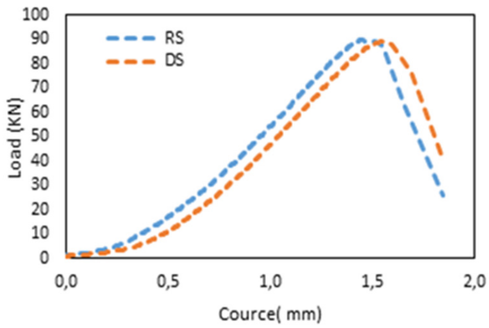

Fig 8. Load curves for compression tests

Fig. 8 shows the compressive load-displacement curves for the fine aggregate matrix RS based on river sand, and DS based on dune sand. From this comparison, we can see that the two sands offer very similar compressive strengths, whereas better ductility has been achieved with dune sand (DS).

TABLE 4. RESULTS OF FLEXURAL AND COMPRESSION TESTS

Specimen	Initial crack load (KN)	Initial crack deflection (mm)	Ultimate load (KN)	Ultimate load deflection (mm)	Ultimate deflection (mm)
RS	1,43	0,40	1,43	0,40	0,4
DS	1,45	0,47	1,44	0,47	0,47
RSG	1,52	0,92	1,62	1,45	2
DSG	1,52	0,51	1,69	1,80	2,80

B. Four-point bending test

The four-point bending test offers a significant advantage over the three-point test: it avoids stress concentration at the central support, which can induce premature defects and distort results. The main failure mode in a three-point test is shear, while the four-point test favors tensile failure, better representing the material's real behavior.

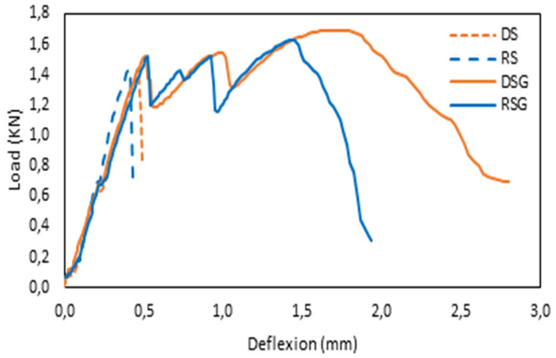

Fig 9. Flexural load versus midspan deflection curves of tested TRC samples.

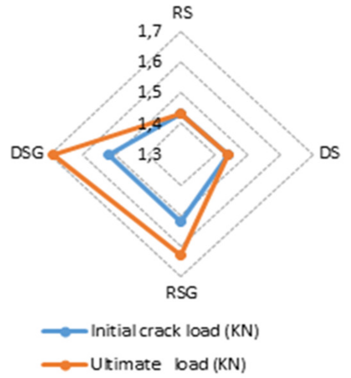

Fig. 10. Radar of loads comparison of tested TRC samples

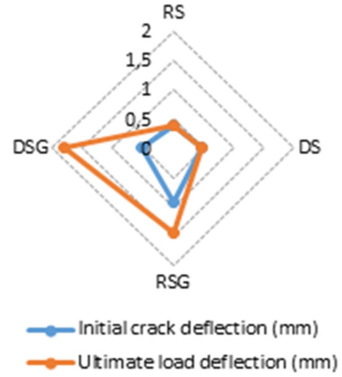

Fig. 11 Radar of deflections comparison of tested TRC samples

Fig. 9 shows the flexural load versus midspan deflection curves of tested samples with textile reinforcement DSG and RSG, compared to samples designed without reinforcement RS and DS. In the case of the comparison between the RS and DS specimens without reinforcement, fragile behavior with a low deflection level is observed for the two simples, with the same load of 1.52 KN, but higher ductility for dune sand (DS) with a gain of 80.39%.

In the case of the comparison of the textile-reinforced specimens (DSG and RSG) to the specimens without reinforcement. The textile ensures the resumption of loading and the passage from a ductile behavior combined with an increased ultimate load. Accordingly, the gain of the DSG and RSG specimens was 252,94% and 57,61% in ductility (see table 4 and figure 11); 56,82 % and 13,29% in ultimate load (see table 4 and fig. 10) , respectively compared to the DS and RS ones.

In the case of the comparison between textile-reinforced specimens based on the two sands, the use of dune sand (DSG) offers to the TRC significantly better ductility than river sand (RSG) (see table 4). In fact, gains of 24.14% in term of ultimate load deflection, and 40% in term of ultimate deflection, were obtained compared to river sand specimen.

The study shows that glass textile reinforced concrete based on dune sand is an essential lever for optimizing the mechanical TRCs properties. Even for thin-walled parts, the use of this sand leads to significant gains in terms of strength and deformability.

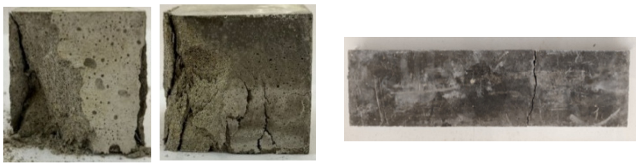

Fig 12. Rupture mechanism of designed and testes samples

IV. CONCLUSION

This work experimentally focused on the fine aggregate matrix design on the compressive and four-point flexural response of fine aggregate textile-reinforced concrete (TRC) samples. The matrix formulation was modified by replacing river sand with dune sand. Accordingly, the following main key results can be highlighted.

- The tests carried out highlighted the advantages of using dune sand, which resulted in a significant improvement in the behavior of the CRT under compressive and bending loads.
- The dune sand addition within the TRC matrix considerably enhances the bending behaviour, with an improvement of 4,32 % in terms of flexural strength.
- The use of dune sand (DSG) significantly enhanced the ductility of the TRC. An increase of 24.14% in ultimate load deflection and a 40% improvement in ultimate deflection were achieved compared to specimens made with river sand (RSG)
- Dune sand stand out for its ability to form, with the fiber glass textile, a high-performance combination in bending, thus significantly optimizing the flexural strength of the TRC. This performance highlights its potential as a viable alternative, making it possible to reduce dependence on river sand while maintaining satisfactory concrete strength.

V. REFERENCES

[1] *F. Bouzeboudja and A. Si Salem, "Experimental investigation on flexural behavior of textile-reinforced concrete: Effect of reinforcement type and dune sand addition," World Journal of Engineering, ahead-of-print, 2023. https://doi.org/10.1108/WJE-05-2023-0139.*

[2] *F. Bouzeboudja, et al., "Valorization of natural materials in the composition of textile-reinforced concrete: Mechanical characterization," Advances in Science and Technology & Innovation, IEREK Series for Interdisciplinary Studies, ahead-of-print, 2024.*

[3] *M. Kurban, O. Babaarslan, and İ. H. Çağatay, "Investigation of the flexural behavior of textile reinforced concrete with braiding yarn structure," Construction and Building Materials, vol. 334, p. 127434, 2022. https://doi.org/10.1016/j.conbuildmat.2022.127434.*

[4] *M. Alma'aitah and B. Ghiassi, "Development of cost-effective low carbon hybrid textile reinforced concrete for structural or repair applications," Construction and Building Materials, vol. 341, p. 127858, 2022. https://doi.org/10.1016/j.conbuildmat.2022.127858*

[5] *F. Bouzeboudja and C. A. Ahmed, "Modeling of the interface between the concrete and the fibers grid in concrete slab," Journal of Building Materials and Structures, vol. 5, no. 1, pp. 137-146, 2018. https://doi.org/10.34118/jbms.v5i1.52*

[6] *S. Djenad, A. Si Salem, and M. A. Bouzidi, "Performance and compressive axial behaviour of new design partially-confined concrete columns with encased-FRP/Grids strips," Asian Journal of Civil Engineering, vol. 23, pp. 801–815, 2022. https://link.springer.com/article/10.1007/s42107-022-00450-y*

[7] *M. Zhang and M. Deng, "Tensile behavior of textile-reinforced composites made of highly ductile fiber-reinforced concrete and carbon textiles," Journal of Building Engineering, vol. 57, p. 104824, 2022. https://doi.org/10.1016/j.jobe.2022.104824*

[8] *B. T. Truong, "Formulation, performances mécaniques, et applications, d'un matériau TRC pour le renforcement et la réparation de structures en béton/et béton armé : Approches expérimentale et numérique," Ph.D. dissertation, Génie civil, Univ. de Lyon, Lyon, France, 2016. [Online]. Available: https://tel.archives-ouvertes.fr/tel-01695501*

[9] *M. Butler, V Mechtcherine,and S., Hempel " Experimental investigations on the durability of fibre–matrix interfaces in textile-reinforced concrete" Cement & Concrete Composites , vol. 31, p. 221–231. http://dx.doi.org/10.1016/j.cemconcomp.2009.02.005*

[10] *F. Bouzeboudja, A. Si Salem, and C. A. Ahmed, "Effect of chopped fibres addition on the behaviour of a new textile reinforced concrete under flexural loading," International Journal of Scientific Research in Science and Technology, vol. 10, no. 14, 2023. https://doi.org/10.32628/IJSRST52310141.*

[11] *S. Ait Taleb, A. Si Salem, and K. Ait Tahar, "Behaviour of a new graded beam reinforced with externally bonded composite sheets: Theoretical and experimental studies," European Journal of Environmental and Civil Engineering, vol. 21, no. 9, pp. 1171-1185, 2017*

[12] *M. Abdeldjalil and S. Yousfi, "Identification of sands of dune and concretes using a granular model - Case of arid region," Case Studies in Construction Materials, vol. 13, 2020. https://doi.org/10.1016/j.cscm.2020.e00458.*

[13] *M. Zhang, H. Liu, S. Sun, et al., "Dynamic mechanical behaviors of desert sand concrete (DSC) after different temperatures," Applied Sciences, vol. 9, no. 19, pp. 4151, 2019..*

[14] *T.-P. Huynh, A. S. Si Ho, and Q. Van Ho, "Experimental investigation on the performance of concrete incorporating fine dune sand and ground granulated blast-furnace slag," Construction and Building Materials, vol. 347, p. 128512, 2022. https://doi.org/10.1016/j.conbuildmat.2022.128512.*

[15] *Q. Liu, "Compressive strength test and numerical simulation of desert sand concrete after high temperature," Ningxia University, 2020. (In Chinese).*

[16] *X. Luo, G. Xing, L. Qiao, P. Miao, X. Yu, and K. Ma, "Multi-objective optimization of the mix proportion for dune sand concrete based on response surface methodology," Construction and Building Materials, vol. 366, 2023.*

[17] *Y. Liu, et al., "Orthogonal experiment on performance of mortar made with dune sand," Construction and Building Materials, vol. 264, p. 120254, 2020.*

[18] ASTM International. (2012). *Standard test method for flexural performance of fiber-reinforced concrete*. ASTM C1609-12.

