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STRENGTHENING MASONRY WITH CARBON FIBER REINFORCED POLYMER

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ABSTRACT
This study examines the effectiveness of carbon fiber reinforced polymer (CFRP) in enhancing the strength properties of masonry structures. The study focuses on applying epoxy-coated carbon fiber textiles to masonry specimens and analyzing their effects on load-bearing capacity and deformation resistance. The experimental methodology involved testing masonry walls comprising three bricks stacked together. For comparative testing, part of the prepared specimens was reinforced with CFRP, while the other half was left unreinforced. The strengthening specimens' failure mode was the detachment at the junctions of the bricks, which showed joined mortar weakens. Compared, to that the strengthening specimens represent increased ductility, indicating improved structural stability. The study confirms that CFRP is an effective method for strengthening masonry structures. The results indicate that CFRP reinforcement can significantly enhance the durability and service life of masonry buildings. Future research should focus on the long-term performance of CFRP under various environmental conditions and its application in large-scale construction projects.

INTRODUCTION

Prolonging life cycle of unreinforced masonry (UM) structures is an active and innovative field of engineering research. The need for such strengthening is an indisputable fact that a significant part of the buildings currently in operation have long exceeded their originally calculated service life (Askouni & Papanicolaou, 2017). Moreover, the reinforcement of building structures is related to the fact that their technical condition does not meet the requirements of modern building regulations (Babatunde, 2017).

Stone structures are the earliest building systems in the world. Today, it is estimated that stone structures contain more than 70% of the world's housing stock. Moreover, a significant part of these structures includes historical buildings which need to be preserved for the next generation. It is often necessary to strengthen such expensive and historically significant structures since their dismantling and replacement can be more expensive or impossible to repair

(Erdogmus, 2015). Aging structures need to withstand increased loads due to increasing operational requirements, but also withstand the adverse effects of an ever-changing and dynamic environment, such as earthquakes, floods etc.

Reinforcement of masonry structures with composite materials is an effective method that significantly improves the operational characteristics and extends the service life of masonry structures (Can, 2018). Recently developed fibre-reinforced composite material (FRP), comprised of high strength, lightness, corrosion resistance, and flexibility, emergent a promising solution for strengthening existing UM buildings and structures (Tan & Patoary, 2004). The FRP comprise the textile fibre materials embedded in a polymer solution such as epoxy resin. The primary material used in composite structures is a textile which comprises a variety of solutions namely: glass, basalt, and carbon.

Despite numerous experimental and numerical studies conducted in this field, the use of FRP solutions remains largely unexplored in the Kazakhstan region. However, the extreme weather conditions highlight the need for modern composite materials to strengthen ageing buildings against natural hazards or manmade hazards. Enhancing material properties is a fundamental objective in modern engineering practice. Various techniques are employed to improve the key characteristics of materials, one of which involves the application of epoxy resin to textile materials. This coating process has the potential to enhance the mechanical performance of the base material by reinforcing and protecting textile fibers, thereby increasing durability and resistance to external factors. By ACI 549.4 R-13, fabric coating is defined as the application of a polymer intended either for coating or for glueing filaments without completely penetrating and impregnating the fibers, as is observed in fibre-reinforced polymer (FRP) materials. A number of previous studies have shown that impregnation of fabric with epoxy resin increases the mechanical strength of the joint, and the strength of adhesion under friction and stiffness. After impregnation with epoxy resin, textiles take on the appearance of a stiff, thin fabric, effectively reducing slippage between the threads. In cases where a coating is applied, the filaments experience a more uniform stress distribution, which leads to an increase in the participation of filaments in load-bearing functions (Vega & Torres, 2018). This observation provides valuable information about the structural improvements achieved through epoxy impregnation and coating of fabric mater

The basic concept of external reinforcement is following carbon fiber reinforced polymer with high tensile strength prevent transverse deformation of the masonry during axial compression. This makes it possible to restrain the formation of force cracks and limit their width, which in turn increases the load-bearing capacity of the masonry

MATERIALS AND METHODS OF RESEARCH

1 Sample preparation and deposition process

1.1 Tensile test

The reason for the tensile test is to compare the effect of epoxy resin application on the textile. In this project, commercially available textile-fibre materials, i.e., carbon, were used. The textile was strengthened with epoxy resin, and the material characteristics are shown in Table 1. The adhesive comprised of two components, was used as a binder for the production of samples: A – modified epoxy resin, B – plasticizer-hardener. The properties of the textile material, as provided in the manufacturer datasheets, are presented in Table 2. The epoxy-resin is prepared by thoroughly mixing 10 parts of the modified epoxy resin with 1 part of the hardener. The property of epoxy resin are given in Table 1.

Table 1. Property epoxy-resin according to manufacturer data shed

Appearance	Transparent viscous mass without mechanical impurities
Full cure time	24 hours at room temperature from +20 to +25 ° C
Operating temperatures	+10...+35°C
Ultimate strength	at least 8.0 MPa
Note – compiled by the authors	

Table 2. Properties of textile material (manufacturer's data)

Material	W [g/m²]	t [mm]	f [MPa]	E [GPa]	K[N/mm²]
Carbon fiber	220	0.035	4800	225	13.95
Note – compiled by the authors					

The coating process can be described as follows:

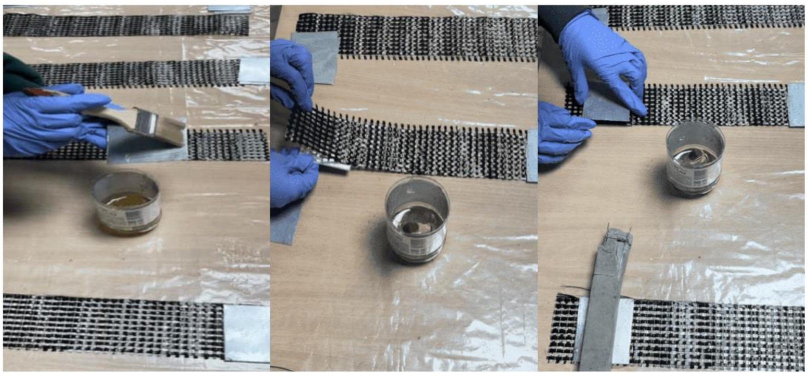
– textiles were cut into strips with nominal dimensions: width -80 mm and length – 350 mm;

– the textile material was placed on a flat surface and secured with tape to prevent movement Figure 1a;

– the epoxy resin was applied with a brush Figure 1a;

– an 80x60 mm aluminum plate was attached to both sides of the samples to improve grip in the testing machine Figure 1b;

– the samples were left for two days before the tests Figure 1, c.

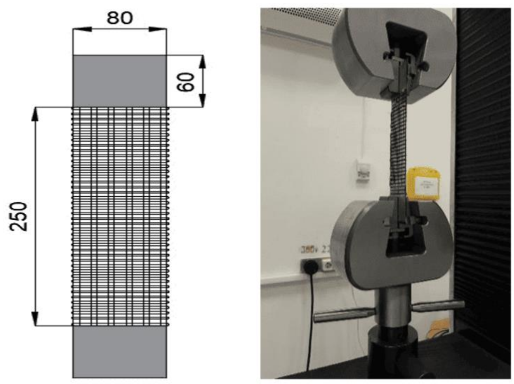


a b c

Figure 1. Sample preparation process: (a) – applying epoxy resin; (b, c) – attaching aluminum plates on both sides of the sample

Note – compiled by the authors

The tensile tests were carried out with motion control at a constant speed of 0.02 mm/sec on a universal testing machine WOW-200 equipped with a 200 kN load cell. It should be noted that the displacement was measured using measuring devices built into the testing machine, and no additional devices were used to measure elongation.



a) b)

Figure 2. STest scheme: (a) – geometry of the textile sample (all dimensions in mm); (b) – actual test scheme

Note – compiled by the authors

1.1 Tensile test

Compression testing of cement-sand mortar cubes is one of the main methods for determining the strength of a given building material.

In this study, a cement-sand mortar was used to connect the bricks to each other. The technical characteristics of the cement-sand mortar are presented in Table 2.

Table 2. Technical characteristics of cement-sand mortar

Brand of the solution	M150
Endurance	B12,5
Frost resistance	F50
Density	2000 kg/m³
The ratio of cement and sand	1:4
Brand of cement	M400
Full cure time	28 days
Note – compiled by the authors	

The sample manufacturing process can be described as follows:

– a special prefabricated metal mold was used to make the sample cubes from cement-sand mortar. The size of 1 cube is 100x100 mm:

– the sample forms were lubricated with machine oil;

– each cell was filled with cement-sand mortar;

– then compacted the mixture inside the mold by bayoneting it with a rod to remove air bubbles and fill all the voids;

– a day later, the finished cubes were removed from the mold and left for 28 days to completely harden.

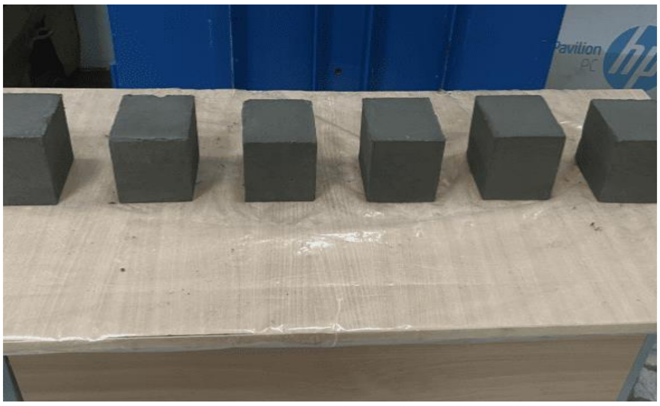
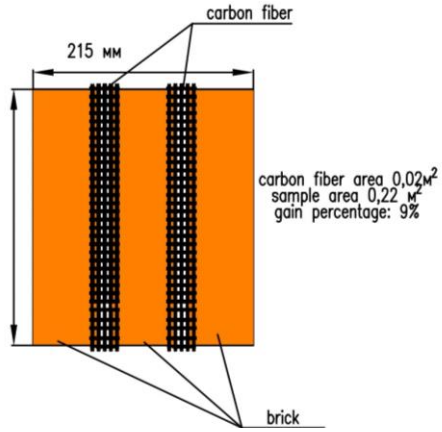


Figure 3. The process of making samples (cubes) from cement-sand mortar – finished samples every other day

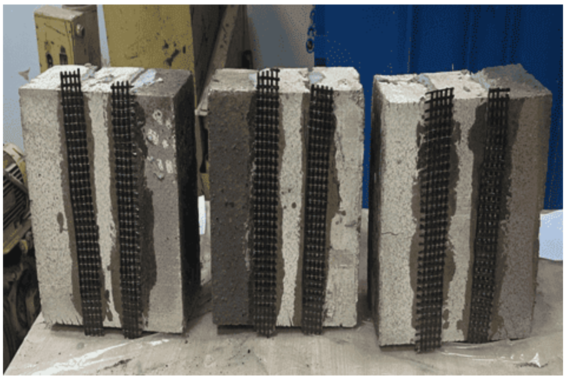
Note – compiled by the authors

1.3 Brick triple test

In present experimental campaign, the masonry walls were reinforced with carbon fiber polymer. The samples were tested according to the European standard BS EN 1739:2007. In this method, special reinforced carbon fiber nets are glued to the outer surface of the masonry, which are then coated with epoxy resin. This creates an additional reinforcing structure that increases the strength and stability of the brickwork. The specimen reinforcement scheme is shown in Figure 4.



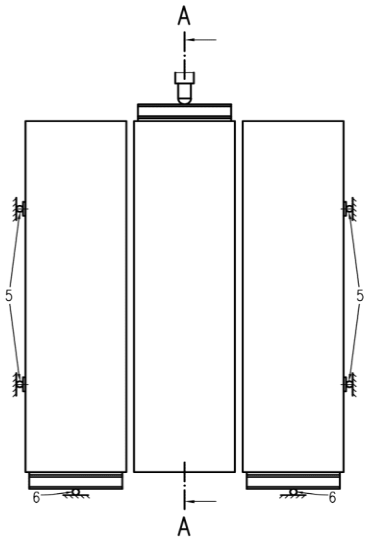
a)



b)

Figure 4. Sample strengthening scheme (a) - schematic representation; (b) – real specimens
Note – compiled by the authors

Spacement was placed into the load cell, load was applied vertically from the top of the sample in the middle brick to determine the adhesive property between bricks. The load was applied with a load block using a hydraulics actuator the displacement and the load was recorded in each step. The reinforced part with FRP potentially can postpone the failure and increase the strength of the masonry wall.



a)

b)

Figure 5. Diagram of an alternative test facility: 1 – hydraulic jack; 2 – soft fiberboard; 3 – clock type indicator or motion sensor; 4 – mechanical or continuous connection; 5 – side supports with force sensor; 6 – steel roller; 7 – steel rollers with a diameter of 40 mm [53]
Note – compiled by the authors

The sample preparation process can be described as follows:

- commercially available ceramic hollow bricks with dimension of 250x120x65 mm were selected for testing;
- each sample consisted of 3 bricks, which were connected with a cement-sand mortar 10 mm thick, then the samples were left for 28 days to completely harden.;

- after 28 days, half of the samples were reinforced with carbon fiber. First, the first layer of epoxy resin was applied to the seams of the brick on one side using a brush. Then carbon fiber (260 mm long, 40 mm wide) was applied to this layer, smoothing it to ensure a tight fit. After that, a second layer of epoxy resin was applied over the carbon fiber, completely impregnating the fabric. The finished samples were left for two more days.

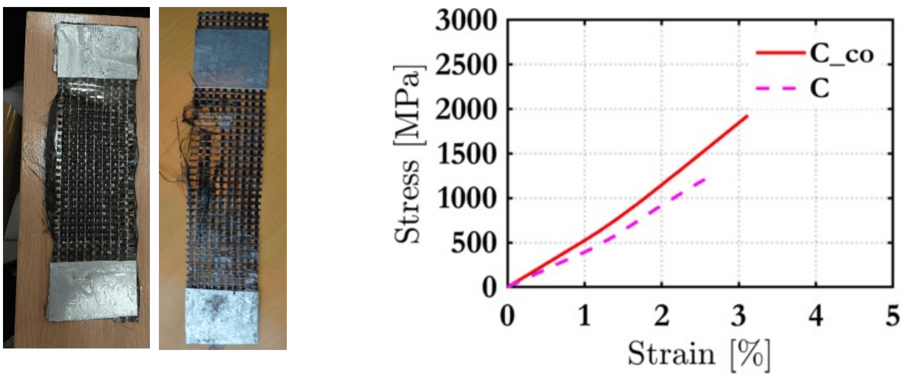
Compression tests were carried out at the hydraulic actuator with 200 kN load cell. The load cell is a consisting of racks, slats, upper and lower beams and a drive, the main working element of which is a bottle-type hydraulic jack. The movements were measured using a displacement sensor.

RESULTS AND DISCUSSION

Three trials were reviewed in this article.:

1) Carbon fiber tensile testing;
2) compression test of cement-sand mortar cubes;
3) compression testing of carbon fiber reinforced brick samples

The results of the tensile test shown in Figure 7a, b were textile rupture jccored in a centre part of the specimens. The graph of the stress-strain state is shown in Figure 7 c and Table 4 shows the maximum stress and modulus of elasticity. As expected, the trend was linear in all cases before the collapse.



a) b) c)

Figure 7. Failure modes during tensile testing of textiles:
(a) – uncoated; (b) – coated; (c) – Stress strain plot

Note: compiled by the authors

Figure 7c shows a direct comparison of stress-strain graphs of coated (C_co) and uncoated (C) textile samples. The results show the positive effects of epoxy coating.

Table 4. Tensile test results

Textile	Tension [MPa]	Modulus of elasticity [GPa]
C	1207 (159) *(13) **	134 (6) * (4.4) **
C_co	1939 (52) *(2.71) **	165(3) *(1.8) **
Note – compiled by the authors		

*Standard deviation, **Coefficient of variation

Hardening textiles with epoxy resin increases load resistance by 60%, and the modulus of elasticity increases by 23%, which indicates a significant strengthening of the textile material, making it more durable.

However, the application of epoxy resin has a drawbacks. One of them is the reduced flexibility of textiles. Increased strength is achieved through flexibility, which limits the use of textiles on flat surfaces. This limitation may affect the versatility of the material, making it less suitable for use on curved or uneven surfaces.

The test results confirm the postponement of failure risks due to reinforcement with epoxy resin. These results highlight the potential benefits of epoxy coated textiles and the importance of considering specific application requirements in practical use.

From a practical point of view, the choice in favor of using textiles coated with epoxy resin should be based on the specific requirements of the intended application, such as the shape of the applied surface.

Compression tests of cement-sand mortar cubes were carried out on a PGM-1500MG4 test hydraulic press for 1,500 kN. Structurally, the press is a machine consisting of a loading device and a force meter Figure 8.

Figure 8. Compression testing of samples (cubes)– samples after the test
Note – compiled by the authors

In general, the test showed that the cement-sand mortar in these samples has certain compressive strength limits, when exceeded, the material begins to break down. Cracks and splinters indicate points of maximum stress and structural failure. This behavior is typical for cement-based materials when they are subjected to high compressive loads.

Table 5 shows the test result of the samples.

Table 5. Compression test result (average value)

Sample	Load Pк [kN]	Load R [MPa]
Cube 100x100	23,75	2,256
Note – compiled by the authors		

Figure 9a shows the process of testing a sample on a hydraulic press. First, the samples were tested without reinforcement. They were tested without any additional enhancements, which allowed us to evaluate their natural properties and stability. Without reinforcement, the sample showed low strength, manifested in fracture and breaking apart. Based on this result, it can be concluded that without additional reinforcement, the material is not able to withstand high loads.

Figures 9b, show the process of testing a sample reinforced with FRP in a hydraulic press. It can be seen that the sample is under load, but the structure remains relatively intact, although there are noticeable cracks. Reinforcement with epoxy resin and carbon postponing failure, preventing its complete destruction and allowing it to withstand a higher load compared to a non-reinforced sample.

a) b)

Figure 9. The testing process:
(a) – a sample without reinforcement; (b) – a sample reinforced with FRP
Note – compiled by the authors

The graph of the load versus displacement (average value) for non-reinforced and reinforced samples is shown in Figure 10. For non-reinforced samples (W), the load increases rapidly, reaching a maximum load value of 21 kN with a displacement of 0.4 mm. After that, the load stabilizes and begins to decrease, which indicates the beginning of sample destruction. This shows that non-reinforced samples reach their ultimate strength with relatively little movement.

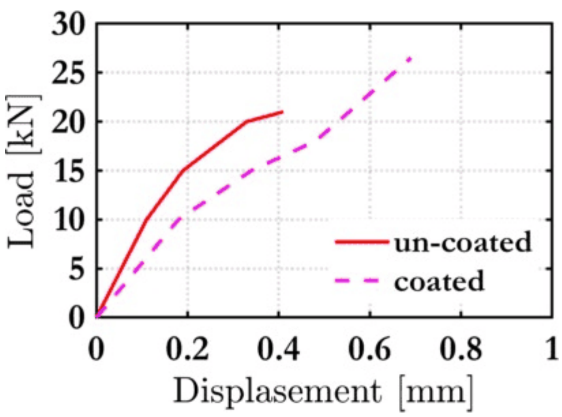


Figure 10. Comparison of reinforced and non-reinforced samples
Note – compiled by the authors

For reinforced samples (WC), the maximum applied load reached a maximum value of 27 kN with a displacement of 0.7 mm. Even though the reinforcement area was insignificant, carbon fiber-reinforced samples showed better load resistance compared to non-reinforced ones.

In general, the graph shows an improvement in the mechanical characteristics of reinforced samples compared to non-reinforced ones. Reinforced samples achieve higher strength, and withstand higher loads. The test results are shown in Table 6.

Table 6. Compression test results

Sample	Maximum load [kN]	Displacement [mm]
W	21	0,4
WC	27	0,7
Note – compiled by the authors		

CONCLUSION

According to the acquired results from the current experimental work, the following findings can be concluded:

– The reinforced samples showed a improvement in strength characteristics. The maximum load increased by 22 percent compared to unreinforced one.

– The reinforced samples showed more stable behavior under load: after reaching the peak, the load did not drop sharply, but showed a gradual decrease, which indicates better resistance to fracture.

– The increased strength and improved deformation characteristics can be explained by the use of carbon fiber and epoxy resin, which effectively distribute the load and prevent rapid destruction of the material.

– The results confirm the effectiveness of using carbon fiber and epoxy resin to improve the mechanical properties of materials. Future work should focus on the increasing percentage of the strengthening zone to develop an effective cover area.

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REFERENCES

Askouni, P. D., & Papanicolaou, C. G. (2017). Experimental investigation of bond between glass textile reinforced mortar overlays and masonry: The effect of bond length. Materials and Structures, 50(2), 164.

Babatunde, S. A. (2017). Review of strengthening techniques for masonry using fiber reinforced polymers. Composite Structures, 161, 246–255.

Белов, В. В., & Деркач, В. Н. (2010). Экспертиза и технология усиления каменных конструкций. Инженерно-строительный журнал, 17(7), 14–20. // Belov, V. V., & Derkach, V. N. (2010). Ekspertiza i tekhnologiya usileniya kamennykh konstruktsii [Expertise and technology of reinforcement of stone structures]. Inzhenerno-stroitel'nyi zhurnal – Magazine of Civil Engineering, 17(7), 14–20. (In Russ.)Can, Ö. (2018).

Investigation of seismic performance of in-plane aligned masonry panels strengthened with Carbon Fiber Reinforced Polymer. Construction and Building Materials, 186, 854–862.

de Andrade Silva, F., Butler, M., Hempel, S., Toledo Filho, R. D., & Mechtcherine, V. (2014). Effects of elevated temperatures on the interface properties of carbon textile-reinforced concrete. Cement and Concrete Composites, 48, 26–34.

Dushimimana, A., Ziada, M., & Tuhta, S. (2018). Effect of carbon fiber reinforced polymer (CFRP) composites applied to walls and slabs of masonry building. Development, 5(4), 2434–2442.

Erdogmus, E. (2015). Use of fiber-reinforced cements in masonry construction and structural rehabilitation. Fibers, 3(1), 41-63.

Hemeda, S. (2018, October). Carbon Fiber Reinforced Polymers (CFRP) for Strengthening and Seismic Retrofitting of Historic Circular Masonry Stone Columns. In International Congress and Exhibition "Sustainable Civil Infrastructures: Innovative Infrastructure Geotechnology" (pp. 114–137). Cham: Springer International Publishing.

Koeckritz, U., Cherif, C., Weiland, S., & Curbach, M. (2010). In-situ polymer coating of open grid warp knitted fabrics for textile reinforced concrete application. Journal of Industrial Textiles, 40(2), 157–169.

Makashev, K., Triantafyllou, S. P., Thermou, G. E., & Tizani, W. (2023). Bond behaviour of light and heavy carbon fibre TRM to masonry interfaces. Construction and Building Materials, 400, 132508.

Орлович, Р., Мантегатса, Д., Найчук, А., & Деркач, В. (2010). Современные способы ремонта и усиление каменных конструкций. Архитектура, дизайн и строительство, 1(44), 86–87. // Orlovich, R., Mantegatstsa, D., Naichuk, A., & Derkach, V. (2010). Sovremennye sposoby remonta i usilenie kamennykh konstruktsii [Modern methods of repair and reinforcement of stone structures]. Arkhitektura, dizain i stroitel'stvo – Architecture, Design and Construction, 1(44), 86–87. (In Russ.)

Tan, K. H., & Patoary, M. K. H. (2004). Strengthening of masonry walls against out-of-plane loads using fiber-reinforced polymer reinforcement. Journal of Composites for Construction, 8(1), 79–87.

Umair, S. M., Abbas, H., Ahmed, S., & Waheed, A. (2015). Fiber reinforced polymer and polypropylene composite retrofitting technique for masonry structures. Polymers, 7(5), 963–984.

Vega, C., & Torres, N. (2018). External strengthening of unreinforced masonry walls with polymers reinforced with carbon fiber. Ingeniería e Investigación, 38(3), 15–23.

Yin, S., Xu, S., & Li, H. (2013). Improved mechanical properties of textile reinforced concrete thin plate. Journal of Wuhan University of Technology – Mater. Sci. Ed., 28(1), 92-98.

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