University of Banja Luka I Faculty of Architecture, Civil Engineering and Geodesy
ISSN 2712-0570 I UDC 72

2025_13(1)

AGG+ Journal for Architecture, Civil Engineering, Geodesy and Related Scientific Fields
АГГ+ часопис за архитектуру, грађевинарство, геодезију и сродне научне области

087-097

Categorisation I Preliminary report
DOI I 10.61892/AGG202501002K
Paper received I 10/03/2025
Paper accepted I 20/06/2025

Tamaz Khmelidze
Georgian Technical University, Georgia, t.khmelidze@gtu.ge,
https://orcid.org/0000-0002-4430-8811

Gela Kipiani
Georgian Technical University, Georgia, gelakip@gmail.com,
https://orcid.org/0000-0001-6811-3595

Vladimer Kikadze *
Georgian Technical University, Georgia, kikadze.vladimer@gtu.ge,
https://orcid.org/0000-0003-4050-9103

A STUDY ON THE BOND BETWEEN BASALT COMPOSITE REINFORCEMENT AND CONCRETE

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Tamaz Khmelidze

Georgian Technical University, Georgia, t.khmelidze@gtu.ge, https://orcid.org/0000-0002-4430-8811

Gela Kipiani

Georgian Technical University, Georgia, gelakip@gmail.com, https://orcid.org/0000-0001-6811-3595

Vladimer Kikadze *

Georgian Technical University, Georgia, kikadze.vladimer@gtu.ge, https://orcid.org/0000-0003-4050-9103

A STUDY ON THE BOND BETWEEN BASALT COMPOSITE REINFORCEMENT AND CONCRETE

ABSTRACT

Based on experimental and theoretical research, the stress-deformation state of the bond between Georgian-origin basalt composite reinforcement and concrete was studied. The bonding mechanism between basalt composite reinforcement and different classes of concrete was revealed, along with the stress-deformation state of structures reinforced with basalt composite reinforcement. The bond strength (stress) between concrete and reinforcement was determined, which, at the moment of failure, exceeded the cohesive strength of concrete in the boundary zone. The effectiveness of concrete structures reinforced with Georgian basalt composite reinforcement was also recorded. The results of the experimental-theoretical research will be applied in the calculations of real concrete structures, taking into account the bond stresses between basalt reinforcement and concrete. An empirical formula was derived for calculating the anchorage length of basalt-plastic reinforcement in concrete.

Keywords: *basalt, reinforcement, concrete, experiment, bond*

* Corresponding author I

1. INTRODUCTION

In the construction industry, composite materials play a significant role, primarily due to their cost-effectiveness, durability, and high resistance to corrosion. The biggest challenge in reinforced concrete structures is selecting the type of reinforcement, as it must meet both reliability and strength requirements while extending the service life of these structures.

One of the major causes of steel reinforcement failure is corrosion, which results from the influence of aggressive environments and the penetration of moisture through microcracks in concrete elements during operation. Corrosion reduces the load-bearing capacity of the structure, eventually leading to its failure.

Currently, scientific and technical progress is evident across all areas of production, requiring a large number of new construction materials with specific properties. There is an increasing demand for materials with high strength, stability, fire resistance, and corrosion resistance. The discovery of new materials is rare, indicating that most "conventional" materials have already been created, and the expectation of new types is virtually minimal. Therefore, it is necessary to develop modern materials using existing ones.

In recent years, alongside traditional steel reinforcement, increasing attention has been given to polymer composites—specifically basalt composite reinforcement, which is made from basalt fibers and an epoxy (or sometimes vinyl-ether) resin (matrix). There are two main methods for producing it: pultrusion and needle-pultrusion. The pultrusion method involves drawing roving (blunt material) through a circular cross-section die, impregnating it with a liquid resin, and simultaneously winding it spirally onto the surface of the formed strand or applying quartz sand. Needle-pultrusion is a filler-free method, during which the round strand is formed from impregnated roving into a mold and simultaneously twisted with two threads in a spiral on the surface, under conditions of continuous pulling at a specified speed [1], [2], [3], [4], [5], [6], [7], [8], [9], [10].

Due to its high tensile strength (approximately 3 times that of steel) and chemical resistance, basalt composite reinforcement is being actively introduced into the construction sector. However, the lack of a normative base and the absence of practical experience with the real-world applications of reinforced concrete structures significantly hinder its implementation in our country. Among the available standards, two current Russian standards are noteworthy: GOST 31384-2017, "Protection of concrete and reinforced concrete structures against corrosion. General technical requirements" (sections 6.10 and 8.13) [12], and SP 63.13330.2018, "Concrete and reinforced concrete structures. General provisions " [13], which permit the use of composite reinforcement in reinforced concrete structures.

Additionally, it should be noted that there are currently no methods for the calculation and design of concrete structures reinforced with basalt composite reinforcement that would take into account the low modulus of elasticity, thermal properties, and long-term strength of the composite reinforcement, which are determined by the specific characteristics of the polymer binders. It is necessary to conduct both broad experimental studies of the composite reinforcement itself and of reinforced concrete structures in normal operating conditions, as well as under high and cyclic temperature influences. An experimental database for the calculation and design of structures should be established. Initially, the evaluation of the bond between composite reinforcement and concrete should be made as a prerequisite for their combined performance.

Research in various areas, such as the bonding mechanism of polymer reinforcement with concrete and the determination of stresses in the boundary zone, is undoubtedly very relevant.

The goal of the research was to determine the feasibility of using basalt composite reinforcement based on Georgian basalt in construction, the minimum anchorage lengths for various concrete classes, and the bond stresses with concrete, as well as to perform an analytical and graphical evaluation of the experimental research results. Finally, the obtained results were compared with theoretical calculations for specific structures.

The motivation for conducting the research was the close collaboration with the company "Basalt Fibers" in Rustavi, Georgia, where basalt fibers are produced, and various products, including basalt composite reinforcement, are successfully manufactured. These products are continuously supplied to European countries (Austria, the Netherlands, and Germany).

The introduction of composites into the construction sector took about three decades from the beginning of production, and another 40 years to pass the first stage of calculations. However, in the development of engineering mechanics for composites, clear progress is evident. In recent decades, for the first time in human history, it has become possible to obtain materials with predetermined properties and their industrial production.

Based on the analysis of the normative documents for the calculation of concrete structures with composite reinforcement [11], [12], [13], [14], [15], [16], [17], the following conclusions can be drawn:

- The main standards and recommendations have been developed in the USA, Canada, Japan, the UK, Italy, and Switzerland (based on Eurocodes) over the past 15 to 20 years.
- The draft of the normative documents has been prepared in Russia and Ukraine.
- The basic principles of calculation are the same as those for reinforced concrete structures, with the linear behavior of composite reinforcement taken into account.
- The specifications for the work of composite polymer-reinforced structures include normalized coefficients for working conditions and material properties.
- The formulas for calculating the parameters of composite structures, with minor modifications, are similar to those for traditional reinforced concrete structures. Structural requirements are typically taken with more caution than in reinforced concrete structures.
- Norms for composite structures with both unstressed and stressed reinforcement have been established.
- Normative requirements have mainly been developed for glass, carbon, and plastic reinforcement materials. As for aramid, boron, and basalt composites, the available standards and recommendations are minimal, and they are not standardized.
- In the Russian and Ukrainian normative projects (standards), general structural solutions and technological conditions for geotechnical constructions are mostly proposed. The methodology for calculating composite structures and the normalization of the calculation characteristics of composite reinforcement have not been addressed in the documents. However, a number of works can be found on the internet indicating the interest of scientific circles in Ukraine and Russia (builders, aerospace engineers and military engineers) in studying these issues thoroughly, and in preparing relevant standards, recommendations, and norms at the government level.

2. MAIN PART

As mentioned above, the main goal of the research was to experimentally study the stress-deformation state of the bond between Georgian-origin basalt composite reinforcement and concrete, specifically determining the stresses at the interface between the reinforcement and concrete, and through these stresses, determining the minimum anchorage lengths of the reinforcement in concrete for different concrete classes and reinforcement diameters.

In the Educational, Scientific, and Expert Testing Laboratory of the Faculty of Civil Engineering at the Georgian Technical University (GTU), 16 specimens were made (see Fig. 2) – concrete cubes with a side length of 100 mm, in which basalt composite reinforcement rods with a diameter of 8 mm were anchored. The concrete classes were B12.5, B22.5, B35, and B40. Two months after the samples were made, they were transferred to the laboratory of the company "Basalt Fibers" in Rustavi, where steel tubes with a length of 300 mm and an outer diameter of 35 mm (wall thickness of 3 mm) were prepared for testing (see Fig.3). Epoxy glue and a mixture of M400 grade cement in a 30/70% ratio were used for anchoring the reinforcement rods in the steel tubes. A total of 12 specimens were tested – three in each series (the fourth specimen was a backup).

To determine the nominal diameter of the basalt profiled reinforcement, the hydrostatic weighing method was used.

The preparation of the samples and the testing process fully complied with the American standard ISO 10406-1:2015 [15].

During the experiments, no sliding of the reinforcement rod or movement of the rod out of the concrete occurred at the early stages of loading.

The test was conducted using a Hydraulic Press CONTROLS Model 70-C0820/C (Fig.1)

Figure 1. Hydraulic Press CONTROLS Model 70-C0820/C (“photography by author“)

Figure 2. Concrete cubes anchored with basalt composite reinforcement.
("photography by author")

Figure 3. Test specimens.
("photography by author")

The bond stress τ_r with concrete, in MPa, during the cube axial pull-out test was determined using the formula:

$$\tau_r = \frac{P}{C \cdot L_{fb}} \tag{1}$$

Where P is the load applied to the rod, n;

C - is the nominal length of the rod's embedded section, c = πd, mm;

L_{fb} - is the anchorage length of the rod in the concrete, mm.

The elongation S of the rod, in mm, is determined by the formula:

$$S = \frac{P \cdot L}{E_f \cdot A}, \tag{2}$$

Where P is the load applied to the rod, n;

L - is the length, the distance from the upper surface of the test machine's stationary traverse to the placement point of the sliding measuring device on the free end of the rod, mm;

E_f - is the modulus of elasticity of the composite rod, MPa;

A - is the cross-sectional area of the rod, $A = \frac{\pi \cdot d^2}{4}$, mm².

The test results are presented in the form of a table (Table 1).

Table 1. *Bond Strengths of Basalt Composite Reinforcement Rods with Different Classes of Concrete (N/mm²)*

Concrete Class	Reinforcement Ø8	Actual Reinforcement Diameter, d (mm)		Nominal Length of Reinforcement,c= πd		Anchorage Length in Concrete, l (mm)	Failure Load, P (N)		Bond Stress ε_r , (N/mm²)	Note
		In one series	Average	In one series	Average		In one series	Average		
B12,5	1	7,23	7,48	2,27	2,34	100,0	15696	15300	6.54	
	2	7,14		2,24		100,0	14959			
	3	8,06		2,51		100,0	15248			
B22,5	1	7,44	7,19	2,34	2,26	100,0	19358	19758	8.75	
	2	6,88		2,16		100,0	19751			
	3	7,24		2,27		100,0	20275			
B35	1	7,11	7,33	2,23	2,30	100,0	25358	24784	10.78	
	2	7,27		2,28		100,0	24657			
	3	7,62		2,39		100,0	24413			
B40	1	7,80	7,48	2,45	2,35	100,0	27571	27474	11.67	
	2	7,61		2,39		100,0	28214			
	3	7,02		2,20		100,0	26487			

If we compare the obtained results with foreign data, we find that the basalt-plastic reinforcement made from Georgian basalt fibers is competitive in terms of its mechanical properties. For example, according to the data from the Architectural and Construction University of Kazan, Russian Federation, comparison with the results of similar experiments conducted at the company " Armplast " (Table 2; Figure 3) shows a slight advantage of the Georgian basalt composite reinforcement based on the experiments conducted at the Technical University of Georgia (GTU).

Table 2. *Comparative Data on the Bonding of Basalt Composite Reinforcement with Concrete*

Concrete Class	Basalt-Polymer Reinforcement	Bond Stress with Concrete, N/mm²		Note
		GTU	„Armplast“	
B12,5	Ø8	6.54	6.04	+8.29%
B22,5	Ø8	8.75	8.29	+5.54%
B35	Ø8	10.78	10.37	+3.95%
B40	Ø8	11.67	11.61	+0.52%
			Average	4,82%

For the tested samples, diagrams of **"Bond Stress – Concrete Strength"** were constructed.

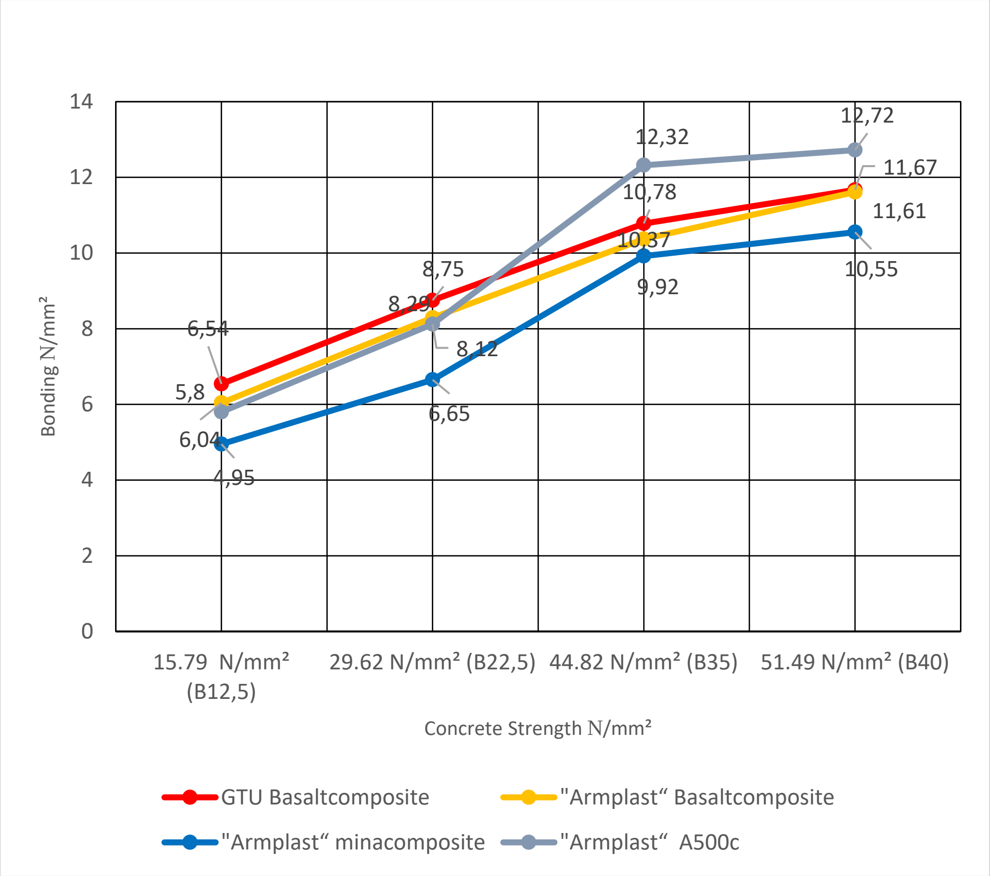

Chart 1. *Graph of Comparative Data on the Bonding of Basalt Composite Reinforcement with Concrete (“diagram by author“)*

The data presented in the graph enabled the determination of an additional coefficient for the bonding of composite reinforcement with concrete (coefficient k_4), which is equal to the ratio of the bond strength of the composite reinforcement to that of steel reinforcement with concrete. Such coefficient values are embedded in Canadian and Japanese standards for calculating the anchorage lengths of reinforcement in concrete.

The bond coefficients (k_4) for different concrete classes are calculated as follows:

B12,5 – $k_4 = \frac{6.54}{4.95} = 1.32;$

B22,5 – $k_4 = \frac{8.75}{6.65} = 1.32;$

B35 – $k_4 = \frac{10.78}{9.92} = 1.09;$

B40 – $k_4 = \frac{11.67}{10.55} = 1.11.$

The obtained values of the k_4 coefficient (greater than one) indicate that concrete has a stronger bond with basalt composite reinforcement than with steel reinforcement, which is due to the presence of an epoxy adhesive layer on the surface of the basalt reinforcement and the cohesive strength between concrete and basalt composite in the boundary zone.

Using bond stress, the minimum anchorage length of the stretched basalt rod in concrete can be calculated using an empirical formula.

$$\ell_a = k \cdot \sigma f \cdot d_a \qquad (3)$$

Where σf – bond stress, N/mm²; da – composite reinforcement diameter, mm; ℓ_a – anchorage length of reinforcement (in the experiments, we used 100 mm); k – empirical coefficient, whose value depends on the class of concrete used and the diameter of the reinforcement.

Concrete class B12.5: $k = \frac{\ell_a}{\sigma f \cdot d_a} = \frac{100}{6.53 \cdot 8} = 1.91;$

Concrete class B22.5: $k = \frac{\ell_a}{\sigma f \cdot d_a} = \frac{100}{8.75 \cdot 8} = 1.43;$

Concrete class B35: $k = \frac{\ell_a}{\sigma f \cdot d_a} = \frac{100}{10.78 \cdot 8} = 1.16;$

Concrete class B40: $k = \frac{\ell_a}{\sigma f \cdot d_a} = \frac{100}{11.67 \cdot 8} = 1.07.$

Based on the values of the k coefficient, the anchor lengths of basalt composite reinforcement in concrete can be easily calculated using formula (3) under the following structural considerations:

- The minimum anchor length is 200 mm;
- The use of smooth reinforcement anchors is not allowed;
- In the compressed zone, the minimum anchor length for profiled composite reinforcement is 21d;
- The anchor length of composite reinforcement in concrete should be increased by 30% if the reinforcement is placed in the upper part of the structure at a height of 30 cm or at a 450-degree angle, while the anchor length for reinforcement placed in the compressed zone can be reduced by 20%.

3. CONCLUSION

1. Failure Mechanism and Bond Interface Behavior.

The pull-out of basalt composite reinforcement from concrete of any strength class occurs within the interface zone between the reinforcement and the concrete, indicating a cohesive-type failure. This behavior suggests that failure is governed by the bond strength of the concrete, which increases proportionally with concrete class. No depth-related damage (e.g., visible cracks) was observed in the test specimens, implying that the bond strength at the failure point exceeds the cohesive strength of the surrounding concrete in the interface zone.

2. Performance in Low-Strength Concrete

In low-strength concrete (class B12.5), the reinforcement pullout occurs uniformly and without deformation of the ribbed or twisted surface of the rebar. This indicates a relatively weak bond, suggesting that the mechanical interlock between the composite bar and the matrix is insufficient for effective load transfer in low-strength matrices.

3. Recommended Use in High-Strength Concrete

To fully utilize the mechanical properties of basalt composite reinforcement, it is recommended for use primarily in high-strength concrete (class B40 and above). Under such conditions, the pull-out of the composite reinforcement results in a failure pattern similar to that of steel rebar with a periodic profile, thereby allowing the application of established steel anchorage methods in design practices.

4. Design Implications and Anchorage Recommendations

The findings reinforce the importance of anchorage length and proper embedment. The minimum anchorage length for basalt fiber rods in concrete can be calculated using empirical formulas that take into account the bond stress between the reinforcement and the concrete. This calculation is crucial for accurate structural design and reliable performance.

5. Directions for Further Research

Further studies are recommended to expand the understanding of bond behavior over time, particularly under environmental stressors (e.g., temperature cycles, moisture, chemical exposure). Future work should also focus on refining anchorage length models for basalt reinforcement, investigating its compatibility with various concrete mixes, and validating these findings through full-scale structural testing.

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AUTHORS’ BIOGRAPHIES

Tamaz Khmelidze

Tamaz Khamelidze graduated in 1970 from the Georgian Polytechnic Institute with a qualification in construction engineering. From 2009 to 2021, he served as a Professor in the Department of Civil and Industrial Construction at the Faculty of Engineering of the Georgian Technical University. Since 2021, he has been the Head of the Department of Construction Machinery. He is a member of the Editorial Board of the scientific-technical journal *Construction*, a recognized constructor of Georgia, and the author of more than 130 scientific works, including 28 textbooks, guides, and methodological references. He is the co-author and general editor of the multi-volume Encyclopedic Lexicon of Construction and a member of the Terminology Association of the Ivane Javakhishvili Tbilisi State University Institute of Linguistics, as well as the Vukol Beridze Linguistic Association.

Gela Kipiani

Gela Kipiani graduated from the Faculty of Mechanics and Mathematics at Tbilisi State University. In 1989, he completed his studies at the Leningrad Engineering and Construction Institute, specializing in construction mechanics. In 1997, he defended his doctoral thesis and was awarded the degree of Doctor of Technical Sciences. From 1997 to 2007, Professor Kipiani served as Head of the Scientific and Research Department at the Georgian Technical University. Between 2014 and 2018, he was Deputy Rector for Science and Research at the Aviation University of Georgia. He was the head of master’s and doctoral educational programs. Since 2020–2021, he has held the position of Professor in the Department of Construction Machinery at the Georgian Technical University (GTU), a laureate of the State Prize of Science and Technology of Georgia, an Honored Builder of Georgia, and the author of more than 300 scientific works, including nine patents, 18 monographs, and 26 manuals. He serves as Deputy Editor-in-Chief of the scientific-technical journal *Construction* and is President of the AIP Progress of Education and Science.

Vladimer Kikadze

Vladimir Kikadze graduated from the Faculty of Construction at the Georgian Technical University with a Bachelor’s degree in Construction Engineering, specializing as a Structural Engineer. In 2020, he obtained a Master’s degree in Engineering from the same faculty, specializing in civil and industrial construction. Since 2021, he has been pursuing doctoral studies at the Faculty of Construction of the Georgian Technical University. Vladimir Kikadze has been employed as a Structural Engineer at Georgian Technical Group LLC since 2018.

ИСТРАЖИВАЊЕ ВЕЗЕ ИЗМЕЂУ БАЗАЛТНЕ КОМПОЗИТНЕ АРМАТУРЕ И БЕТОНА

Сажетак: На основу експерименталних и теоријских истраживања, у овом раду је проучавано напонско-деформационо стање везе између базалтне композитне арматуре грузијског поријекла и бетона. Откривен је механизам пријањања између базалтне композитне арматуре и различитих класа бетона, као и напонско-деформационо стање конструкција армираних базалтном композитном арматуром. Одређена је чврстоћа (напон) везе између бетона и арматуре, која је у тренутку лома прелазила кохезиону чврстоћу бетона у граничној зони. Такође је забиљежена ефикасност бетонских конструкција армираних грузијском базалтном композитном арматуром. Резултати експериментално-теоријског истраживања биће примијењени у прорачунима стварних бетонских конструкција, узимајући у обзир напоне пријањања између базалтне арматуре и бетона. Изведена је емпиријска формула за прорачун дужине сидрења базалтно-пластичне арматуре у бетону.

Кључне ријечи: *базалт, арматура, бетон, експеримент, веза.*