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STRESS-STRAIN BEHAVIOR OF COMPOSITE REINFORCED BEAMS

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Abstract
The present article presents a comprehensive analysis of research findings on the performance of composite reinforced elements. These elements have gained widespread application in the rehabilitation of concrete structures, both in newly constructed buildings and existing facilities, within the Republic of Uzbekistan and internationally. The study elucidates the mechanical behavior, effectiveness, and practical implications of using composite reinforcement systems in structural restoration.

Keywords: composite, basalt, concrete, flexibility, strength, messura, polymer

Introduction

In recent years, the President of the Republic of Uzbekistan together with the Cabinet of Ministers has implemented significant policy measures aimed at enhancing the population's quality of life and improving living standards. These initiatives necessitate the development of **economically efficient and highly durable construction structures** that can be widely and effectively applied across industrial facilities, residential buildings, and essential engineering infrastructure. Within this strategic framework, the incorporation of **composite**

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materials into construction practice has emerged as a pertinent and timely area of research. Composite materials offer advantages that can **improve the overall reliability and techno-economic performance** of structures, particularly in their capacity to withstand **permanent, transient, and seismic loads** in industrial, residential, and public building applications. Such properties underscore the relevance of composite materials as innovative solutions in modern construction and structural reinforcement contexts.

The implementation of flexible structural elements reinforced with composite reinforcements in industrial, residential, and public buildings, as well as in various engineering structures, necessitates a **rigorous scientific foundation that integrates contemporary theoretical developments with empirical evidence.** In order to advance the reliable application of these composite systems, it is essential that the theoretical framework be supported by **results derived from controlled experimental research protocols.** Furthermore, scientifically grounded recommendations and **practical engineering guidelines** should be developed on the basis of these research outcomes to ensure effective and safe utilization in structural design and rehabilitation practices. Such an evidence-based approach will enhance **design validity, performance predictability, and practical applicability** of composite-reinforced flexible elements across a broad range of structural contexts [1-5].

With each passing year, the **scope of construction and renovation activities in the Republic of Uzbekistan continues to expand significantly,** reflecting rapid socioeconomic development and increased infrastructure investment. To successfully realize these ambitious and large-scale construction programs, it is imperative to adopt **innovative and advanced construction technologies** that enhance efficiency and durability. In this context, the **integration of polymer composite reinforcements into construction practice** within Uzbekistan warrants dedicated investigation under the specific climatic, economic, and technical conditions prevailing in the country. The localized study of polymer

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composite reinforcement systems is necessary not only for evaluating their performance and suitability but also for developing normative and practical guidelines tailored to domestic construction requirements. Consequently, conducting **systematic research on the reinforcement of concrete structures with polymer composite materials** represents a pressing problem of both social and economic importance, with potential implications for advancing national construction practices and improving structural resilience.

It is therefore pertinent to undertake comprehensive experimental and theoretical investigations to characterize the stress–strain behavior, crack initiation and propagation, uniformity of deformation, failure mechanisms, and strength characteristics of flexural concrete elements reinforced with basalt-plastic composite reinforcements. Such research should aim to elucidate the complex interactions between concrete matrices and basalt-plastic reinforcement under bending loads, providing a scientific basis for performance evaluation and design optimization. To achieve these objectives, experimental studies are required to assess the bending moment and transverse force resistance of flexible concrete elements reinforced with basalt plastic rods, produced from ordinary heavy concrete, under controlled loading conditions. These investigations will generate empirical data essential for validating theoretical models and developing reliable design recommendations for practical engineering applications.

Materials, constructions and test models: Test models-sample beams with a rectangular cross-section were prepared for conducting experimental studies. Ordinary heavy concrete was used for the beams. Portland cement of the Turon cement plant in Beshariq district of Fergana region with an activity of 42.5 MPa was used as a binder for concrete. As fillers, quartz river sand from Akbarabad quarry, Kuva district, Fergana region, with a fraction of 5-15 mm and a bulk modulus of M2.25 was used. The composition of the concrete was chosen so that its cubic strength would have a compressive strength corresponding to the class

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B20 and B35. Granite limestone was sieved, washed in a special device and then dried (Table 1)[6-9].

Granulation composition of ordinary heavy concrete aggregates

Table 1.

Filler type	Residue in % by weight on a sieve with a hole size of mm								
	20	15	10	5	1,25	0,63	0,315	0,14	0,07
Granite limestone	2-4	4-6	90-95	92-100	-	-	-	-	-
Quartz sand	-	-	-	-	1-2	4-5	12-15	45-50	90-100

The consumption of materials for 1 m3 concrete mixture of class B30 is given in table 2.

Concrete composition for sample beams

Table 2.

№	Naming	Amount	Unit of measure
1	Portland cement M400 of "Turon" cement factory, Beshariq district, Fergana region	380	kg
2	pebble	1170	kg
3	Quartz sand	670	kg
4	Water	165	litr
5	Density of concrete:	2385	kg/m^3
6	Concrete water/cement ratio (S/S)	0,43	

The consumption of materials for 1 m3 concrete mixture of class B20 is given in table 3.

Concrete composition for sample beams

Table 3.

№	Naming	Amount	Unit of measure
1	Portland cement M400 of "Turon" cement factory, Beshariq district, Fergana region	300	kg
2	pebble	1220	kg
3	Quartz sand	720	kg
4	Water	150	litr
5	Density of concrete:	2390	kg/m^3
6	Concrete water/cement ratio (S/S)	0,50	

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The materials were dosed with an accuracy of ±0.1 kg by weight. An electronic scale with high accuracy was used for this purpose. The results of the cube tests are presented in Table 4.

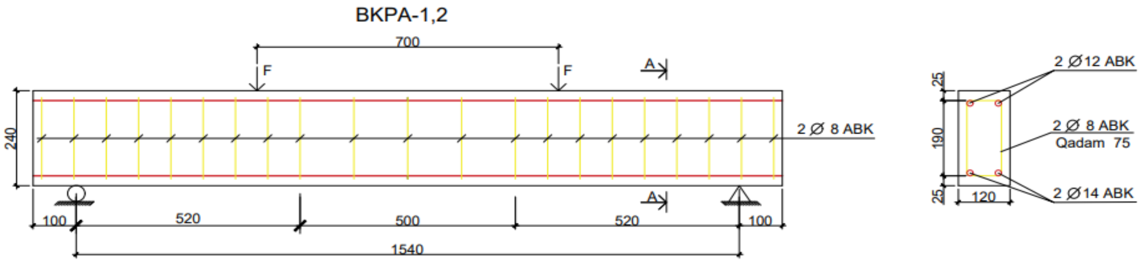
Test results of cubes made of sample beam concrete

Table 4.

№	Beam cipher	Age of concrete	Edge of sample cubes, cm	Compressive strength of concrete, MPa	Strength of concrete		
					R_b, MPa	R_{bt}, MPa	E_b*10-3 MPa
1	2	3	4	5	6	7	8
1	BKPA -1	30	10	26,35	14,3	1,33	30,1
2	BKPA -2	30	10	25,42	13,9	1,30	29,6
3	BKPA -3	30	10	25,63	14,0	1,30	29,7
4	BKPA -4	30	10	26,34	14,3	1,33	30,1
5	BKPA -5	30	10	35,84	19,3	1,63	34,2
6	BKPA -6	30	10	35,45	19,1	1,62	33,8

Together with the beam samples, cubes with dimensions of 10x10x10 cm were prepared from the same mixture. After 28 days of storage under conditions of normal temperature t=20±20C and relative humidity φ=60-65%, the sample cubes were tested in a hydraulic press until failure under compressive force.

After determining the cubic strength of concrete, the prismatic strength corresponding to it was calculated according to the expression Rb=0.75R, and its tensile strength was calculated according to the formula R_bt=0.5∛(R^2).



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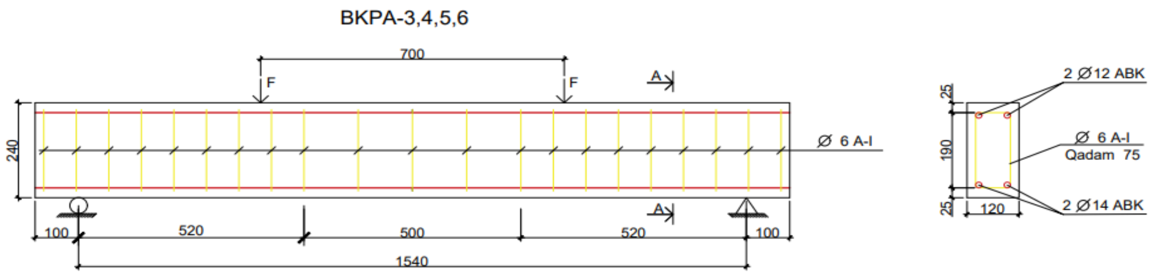

Figure 1. Schemes of reinforcement and loading of sample beams.

For experimental studies, 4 B20, 2 B30 beams with cross-sectional dimensions of 12x24 cm and length of 174 cm equipped with concrete and composite reinforcements were prepared. The beams were made in wooden molds. The inner surface of the molds was covered with metal sheets. In 2 test samples made of B20 class concrete, 2Ø14BKA reinforcements were placed in the tensile area, 2Ø12BKA in the compressive area, and Ø8BKA reinforcements were placed in 7.5 cm increments as working reinforcements (Fig. 2.2). In 2 test samples made of B20 class concrete, 2Ø14BKA was placed in the tensile area as working reinforcement, 2Ø12BKA in the compressive area, and Ø6A-I reinforcements were placed in steps of 7.5 cm as clamps (Fig. 2.3). In 2 test samples made of B30 class concrete, 2Ø14BKA was placed in the tensile area as working reinforcement, 2Ø12BKA in the compressive area, and Ø6A-I reinforcements were placed in steps of 7.5 cm as clamps (Fig. 2.3). The composite reinforcements for the tie rods were welded to the longitudinal reinforcements with mild steel wires. Reinforcement wedges were installed and fixed in the formwork at the project site. Beam samples were made from heavy concrete of B20 and B30 class. Together with the sample beams, cubes of 6 and 9 pieces with a size of 10x10x10 cm were made from the same concrete at the same time.[10-15].

The dimensions of the sample beams prepared for the experiment, the interval of application of the loads acting on the sample beams, the classes of concrete used and the number, diameter of longitudinal tensile and compressive reinforcements, transverse reinforcements (clamp) number and diameters are given in table 5.

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Main characteristics of sample beams.
Table 5.

Sample №	Sample password	Dimensions, sm			Reinforcement			Load range, sm	Design class of concrete
		b	*h*	h_0	Transverse reinforcement (clamps)	Longitudinal stretchy	Longitudinal compressible		
BKPA - 1		12	24	18,5	2Ø 8 BKA	2Ø 14 BKA	2Ø 12 BKA	70	B20
BKPA - 2		12	24	18,5	2Ø 8 BKA	2Ø 14 BKA	2Ø 12 BKA	70	B20
BKPA - 3		12	24	18,5	Ø 6 A-I	2Ø 14 BKA	2Ø 12 BKA	70	B20
BKPA - 4		12	24	18,5	Ø 6 A-I	2Ø 14 BKA	2Ø 12 BKA	70	B20
BKPA - 5		12	24	18,5	Ø 6 A-I	2Ø 14 BKA	2Ø 12 BKA	70	B30
BKPA - 6		12	24	18,5	Ø 6 A-I	2Ø 14 BKA	2Ø 12 BKA	70	B30

The sample beams were tested in bending on a force stand. The stand is specially designed to load the beams through two cumulative forces and test the midsection in pure bending.

The beams were mounted on 2 hinged supports of the stand for testing samples. One of the hinges is fixed and the other is movable. The distance between the forces was 700 mm, and the distance from the supports to the load was 420 mm. The distance from the base to the edge of the beams is 100 mm. The load was delivered using a 24-ton manually operated hydraulic jack. For this, dividing traverses were used.

After the tests, the location of the cracks was determined, the samples were photographed and the height of the cracks was measured, the distances between them were determined, the protective layers of the working fittings were determined and the working height was measured.

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During the test, the deformations of concrete and reinforcements, the time of formation of normal and oblique cracks and the amount of load, the stiffness of the beam were measured and recorded.

During the experiment, the failure of BKPA-1,2 samples occurred at values close to the calculated loads, the load of BKPA-3,4,5,6 samples was almost 2 times higher than the calculated loads. In sample beams 1, 2, it was noted that the experimental load differs from the calculated load by 10-20% on average. In sample beams 3, 4, 5, 6, it was noted that the experimental load differs from the calculated load by 85-95% on average.

In most of the damaged samples on the slope sections, the value of the given force (0.9-0.95) after reaching the Kult values, the nodes of the connecting rods with the longitudinal reinforcements were broken and the compression areas of the beam were sheared. observed. It was observed that the concrete lost its strength after the strength value reached (0.9-0.95) Kult values in most of the samples with failure in the compressive part.

It was observed that the amount of bending moments Mcrc during the formation of cracks in the sample beams depends on the value of the distance "a" (shear interval) between the load and the support.

Conclusions

Normal cracks in BKPA-1.2 sample beams a=42 cm (a/h=1.95) at bending moments equal to 6.8-7kN, normal cracks in BKPA-3.4 sample beams 7.6-7 At bending moments equal to .9 kN, normal cracks were formed in BKPA-5.6 sample beams at bending moments equal to 11-11.2 kN. In this case, the ratio of the crack forming moment to the breaking moment was (M_crc^t)/(M_ult^t)=0.220.

The ratio of the experimental value of the cracking moments to the calculated value of the BKPA-1,2,3,4 sample beams, the ratio of the experimental and

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calculated cracking moments is 1.445 and 1.458, the experimental and calculated cracking moments of the BKPA-5,6 sample beams the ratio was 2.022 and 2.004. The values of the experimental M_crc^t and calculated M_crc^h bending moments normal to the element's longitudinal axis in the sample beams are presented in Table 6.

Formation of normal cracks in sample beams

Table 6.

Sample beam cipher	The distance between the forces, sm	Bending moment in the formation of normal cracks, kNm		M_{ult}^t	$\frac{M_{crc}^t}{M_{ult}^t}$	$\frac{M_{crc}^t}{M_{crc}^x}$
		Experimental M_{crc}^t	Accounting M_{crc}^x			
BKPA-1	42	3,15	2,18	14,6	0,215	1,445
BKPA -2	42	3,15	2,17	13,7	0,21	1,451
BKPA -3	42	3,15	2,16	22,7	0,229	1,458
BKPA -4	42	3,15	2,18	23,8	0,132	1,445
BKPA -5	42	4,73	2,34	26	0,175	2,022
BKPA -6	42	4,73	2,36	26,9	0,176	2,004

The opening width of normal cracks was acrc=0.2-0.35mm at loads equal to half of the destructive load, the further increase of loads caused intensive development of normal cracks and a significant increase in opening width. When the ratio of step load to breaking load reached 0.6-0.85, the opening width of normal cracks was 0.4-0.7mm. The subsequent increase in loads resulted in violent opening of normal cracks.

It was found that the results of calculation of the opening width of cracks normal to the longitudinal axis of the element according to the method presented in ShNQ satisfactorily agree with the laws and quantities of changes obtained in the experiments.

Based on theoretical calculations, the values of M_crc^h are from 4.44 kN·m to 5.37 kN·m. The average value of M_crc^h was equal to 4.9 kN·m. The difference between the average value of M_crc^h and the smallest and largest values is 0.93

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kN·m (5.2%) and 0.38 kN·m (3%), respectively. In other words, almost stable values for M_crc^h were obtained in the calculations.
The ratio of the experimental M_crc^T to the calculated (theoretical) M_crc^h was greater than 1 and averaged 1.23 in BKPA-1,2 sample beams, in BKPA-3,4,5,6 sample beams and the average was 1.85. It was found that the average value of the experimental crack-forming moments in BKPA-1,2 samples is equal to 22% of the breaking moments. In BKPA-3,4,5,6 samples, the average value of the experimental crack-forming moments was found to be 9-11% of the breaking moments.
In the process of testing the sample beams under load, cracks directed obliquely to the longitudinal axis of the element were formed a little later than normal cracks. After the formation of normal cracks, the formation of oblique cracks was observed in the sample beams only after increasing the load in at least 1-2 stages.
In the experiments, it was found that the formation, development and opening width of oblique cracks depends on the amount of reinforcement of the sample beams with collars, the diameter and pitch of the collars, the shear interval a/h_0, the amount and diameter of the longitudinal working reinforcement, and the strength of the concrete.
In theoretical calculations, the transverse force forming oblique cracks was determined according to the following formula:

$$Q_{crc}^{h} = 0{,}6\, R_{bt,ser} b\, h_0 \qquad (1)$$

For cases with a shear interval a>1.5x_0, as a result of entering the ratio h_0/a instead of the coefficient 0.6 in the above formula, it was observed that the ratios of the experimental and theoretical oblique crack-forming forces are significantly improved. In this case, the formula for finding transverse forces in the formation of oblique cracks is expressed as follows:

$$Q_{crc}^{h} = \frac{R_{bt,ser} b h_0^2}{a} \qquad (2)$$

but, 0.6R_(bt,ser) should not exceed bh_0.

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In BKPA-1.2 sample beams (a=42cm), the initial oblique cracks were formed at loads Q_crc^h=14.2-14.8 kN, where the ratio (Q_crc^t)/(Q_ult^t) was 0, It was 8. In BKPA-3.4 sample beams (a=42cm), the initial oblique cracks were formed at loads Q_crc^h=14.5-14.9 kN, where the ratio (Q_crc^t)/(Q_ult^t) was 1, It was 25. In BKPA-5.6 sample beams (a=42cm), the initial oblique cracks were formed at loads Q_crc^h=18.2-18.9 kN, where the ratio (Q_crc^t)/(Q_ult^t) was 1, It was 37.

As the load increased, intensive opening of oblique cracks occurred. Especially at the load level of 0.8Qult and more, oblique cracks developed rapidly, their opening width was 1.0mm and more. In this way, the oblique cracks became critical cracks and the failure of the beams occurred.

At loads (0.5-0.7) Kult, the opening width of oblique cracks in the beams was in the range of 0.2-0.5 mm[16-18].

Formation of oblique cracks in sample beams

Table 7.

Sample beam cipher	Shear span (distance from support to force), sm	Transverse force in the formation of oblique cracks, kN		$\frac{Q_{crc}^t}{Q_{crc}^x}$	Q_{ult}^t, kN	$\frac{Q_{crc}^t}{Q_{ult}^t}$
		Experimental Q_{crc}^t	Accounting Q_{crc}^x			
BKPA -1	42	14,2	12,75	1,11	35	0,41
BKPA -2	42	14,8	12,35	1,19	34	0,44
BKPA -2	42	14,5	12,45	1,16	54	0,27
BKPA -2	42	14,9	12,65	1,18	57	0,26
BKPA -2	42	18,2	15,45	1,18	62	0,29
BKPA -2	42	18,9	15,35	1,23	64	0,30

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