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# EFFECT OF NUMBER OF LAYERS OF COMPOSITE MATERIAL IN THE REINFORCEMENT OF MASONRY SAMPLES

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## *Abstract*

Materials based on carbon fiber fabric are increasingly used in construction, including the strengthening of existing structures. Various reinforcement schemes using carbon fiber-based fabric are implemented in the reconstruction and repair of a large number of objects. As experience shows, materials based on carbon fiber canvases are well suited for strengthening both masonry and reinforced concrete structures.The article analyzes the results of experimental studies of stone samples reinforced with composite materials based on carbon fiber with a different number of layers of the material. The influence of several layers of reinforcement on the bearing capacity of masonry is determined. The analysis of different similar studies with the same material and different number of layers was performed. Analytical dependences are proposed to determine the increase of the shear force Q of the masonry with respect to the standard Q0. Based on the results of the comparison between the series and between the previously performed tests, for a more objective determination of the value of the physical characteristic k, the introduction of a correction factor for the second and third layers is proposed. The convergence of theoretical values with experimental data is from 10% to 40% in the direction of the load-bearing capacity, which, given the small number of samples, is justified.

*Keywords: samples of masonry, reinforcement, composites based on carbon fiber, layers of amplification, the relative load bearing capacity..*

## 1. Introduction

This article presents the results of experimental studies of stone samples reinforced with composite materials based on carbon fiber with different number of layers. The effect of several layers of reinforcement on the load-bearing capacity of masonry was also determined and correction coefficients were introduced for several layers of reinforcement material.

## 2. Experimental research

To consider the effect of the number of layers on the load-bearing capacity, samples were made [6], the design solution of which was the same as in the previously performed works [1]. The samples in [1] of the K-II - K-IV series were tested using the same method of experimental research. In order to be able to compare the test results, the load was recalculated and it was reduced to a single strength of the KU-1 series solution equal to 4.7 MPa. The results of previous tests are shown in table 1. A comparative table of the effect of the number of layers in the tests performed is presented in table 2.

Table 1 – The results of previously conducted tests

| Conditional serial number | Sample reference number | The tensile strength of the mortar in compression *R*, MPa | Resistance to main tensile stresses *Rtw = 0,8Rt* | Conversion factor *Kp = RtwI/Rtw* | PBreaking load *Pp*, kgf | Reduced breaking load | The average value of the breaking load, kgf | The increase in load capacity, % |
|---|---|---|---|---|---|---|---|---|
| K-II | U-1-230-1 | 9,98 | 3.7909 | 0.69 | 60.70 | 41.66 | 43.07 | 38.93 % |
| | U-1-230-2 | 10,62 | 3.9106 | 0.67 | 65.26 | 43.41 | | |
| | U-1-230-3 | 11,25 | 4.0249 | 0.65 | 68.30 | 44.15 | | |
| K-III | U-1-530-1 | 10,06 | 3.8061 | 0.68 | 66.78 | 45.65 | 43.07 | 49.81 % |
| | U-1-530-2 | 11,50 | 4.0694 | 0.64 | 74.38 | 47.55 | | |
| | U-1-530-3 | 8,55 | 3.5088 | 0.74 | 62.22 | 46.13 | | |
| K-IV | U-3-230-1 | 6,12 | 2.9686 | 0.88 | 43.98 | 38.54 | 39.44 | 27.21 % |
| | U-3-230-2 | 6,45 | 3.0476 | 0.85 | 47.02 | 40.14 | | |
| | U-3-230-3 | 7,05 | 3.1862 | 0.82 | 48.54 | 39.63 | | |

Table 2 – Effect of the number of layers on the excess load capacity

| Previously conducted tests | | | | Current tests | | | | |
|---|---|---|---|---|---|---|---|---|
| | Conditional series number | Excess % | The number of layers, n | Conditional series number | Excess % | The number of layers, n | The difference between the series, % | 1 layer difference, % |
| K- II | U-1-230 | 39,83 | 1 | KU-2 | 39,89 | 3 | 0,06 | 0,03 |



 

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| K-III | U-1-530 | 49,81 | 1 | KU-3 | 71,72 | 2 | 21,29 | 21,29 |
| K- IV | U-3-230 | 27,21 | 1 | KU-4 | 38.71 | 3 | 11,5 | 5,75 |

Attention should be paid to the increase in the load-bearing capacity of KU-3 series samples by 21.29% when using a double layer of FibArm Tape 530 material, and a slight increase (up to 5%) of the KU-2 series when using a triple layer of fibarm Tape 230 material. For the KU-4 series, the increase was 11.5%, that is, the second and third layer of FibArm Tape 230 showed an increase of 5.75%.

The relative increase is obtained by dividing the values for a double and triple layer and for a single layer. The effect of layers is shown in figure 1.

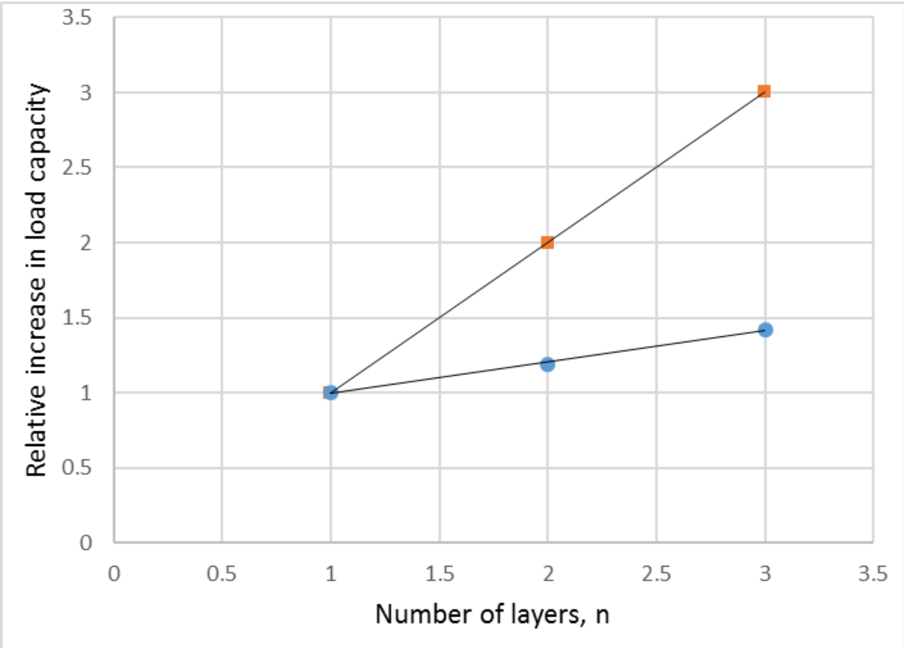


Fig. 1 - Dependence of the number of layers on the load-bearing capacity (theoretical (■) and actual data (●)) on the example of the KU-4 and U-3-230 series

In the reinforcement albums for stone buildings [2], it is recommended to use no more than 3 layers of composite material to strengthen the masonry walls of buildings and structures operated in earthquake-prone regions with a site seismicity of 7-9.

Thus, based on the results of comparison between the series and between previously performed tests, for a more objective determination of the value of the physical characteristic k, it is proposed to introduce a correction factor for the second and third layer. The correction factor for the second layer is suggested to be 0.2, and for the third layer 0.1.

So for the KU-2 and KU-4 series n = 1+0,2+0,1 = 1.3;

For the KU-3 series, n = 1+0.2 = 1.2.

Based on the results of the analysis, tests of masonry and the proposed coefficients, the value of the physical characteristics of the composite material will be as follows:

$$k=(A_{ai}/A_k)\cdot b_{fib}\cdot \delta_{fib}\cdot R_{fib}\cdot n,\ [m^2/m^2\ \cdot m\cdot m\cdot Pa=m^2\cdot N/m^2=N] \quad (1)$$

where:

$A_{ai}$ – the area of application of composite material, m2

For tests conducted in the area of strengthening is:



 

$A_{a2}$ = 0.4047 – for the KU-1 and KU-2 series;

$A_{a3}$ = 0.7041 – for the KU-3 series;

$A_{a4}$ = 1.1236 – for the KU4 and KU5 series;

$A_{a5}$ = 2.2472 - for the KU-6 and KU-7 series.

$A_k$ – the area of the surface of masonry m2:

$A_k$ = 1.06 · 1.06 = 1.1236;

$b_{fib}$ - width of carbon fiber, m:

$b_{fib}$ = 0.3 – for the KU-2 and KU-3 series;

$b_{fib}$ = 0.9 – for the KU-4 series;

$b_{fib}$ = 1.5-for ku – 6-KU-8 series;

$b_{fib}$ = 1.5 ·0.2 – for the KU-5 series, taking into account that the fiber width is 20% of the mesh width.

$\delta_{fib}$-tape thickness of one layer, m:

$\delta_{fib}$ = 0.128·10-3 – for the KU-2 and KU-4 series;

$\delta_{fib}$ = 0.445·10-3 – for the KU-6 and KU-8 series;

$\delta_{fib}$ = 0.294·10-3 – for the KU-3 series;

$\delta_{fib}$ = 0.334·10-3 – for the KU-5 series;

$\delta_{fib}$ = 0, 250·10-3-for the KU-7 series;

$R_{fib}$-average value of the carbon fiber tensile strength, PA:

$R_{fib}$ = 3.6·106;

n - the number of layers of carbon fiber:

for 3 layers, n = 1,3 for the KU-2 and KU-4 series;

for 2 layers, n = 1,2 for the KU-3 series;

for the 1st layer, n = 1 for the ku-5 – KU-8 series.

Thus the refined physical characteristic *k* is equal to:

For the KU-2 series k =(0.4047/1.1236) $0.3 \cdot 0.128 \cdot 10^{-3} \cdot 3.6 \cdot 10^{6} \cdot 1.3$=64,74;

For the KU-3 series k=(0.8094/1.1236) $0.3 \cdot 0.294 \cdot 10^{-3} \cdot 3.6 \cdot 10^{6} \cdot 1.2$=274,5;



 

For the KU-4 series $k=(0.7041/1.1236)\ 0.9 \cdot 0.128 \cdot 10^{-3} \cdot 3.6 \cdot 10^{6} \cdot 1.3=337{,}83$;

For the KU-5 series $k=(1.1236/1.1236)\ 1.5 \cdot 0.2 \cdot 0.334 \cdot 10^{-3} \cdot 3.6 \cdot 10^{6} \cdot 1=360{,}72$;

For the KU-6 series $k=(1.1236/1.1236)\ 1.5 \cdot 0.445 \cdot 10^{-3} \cdot 3.6 \cdot 10^{6} \cdot 1=2403{,}0$;

For the KU-7 series $k=(2.2472/1.1236)\ 1.5 \cdot 0.250 \cdot 10^{-3} \cdot 3.6 \cdot 10^{6} \cdot 1=2700{,}0$;

For the KU-8 series $k=(2.2472/1.1236)\ 1.5 \cdot 0.445 \cdot 10^{-3} \cdot 3.6 \cdot 10^{6} \cdot 1=4806{,}0$;

At the obtained values of k, the theoretical increase in the load-bearing capacity of stone samples reinforced with a composite material based on carbon fiber is from 14% to 73% (see figure 2 and 3).

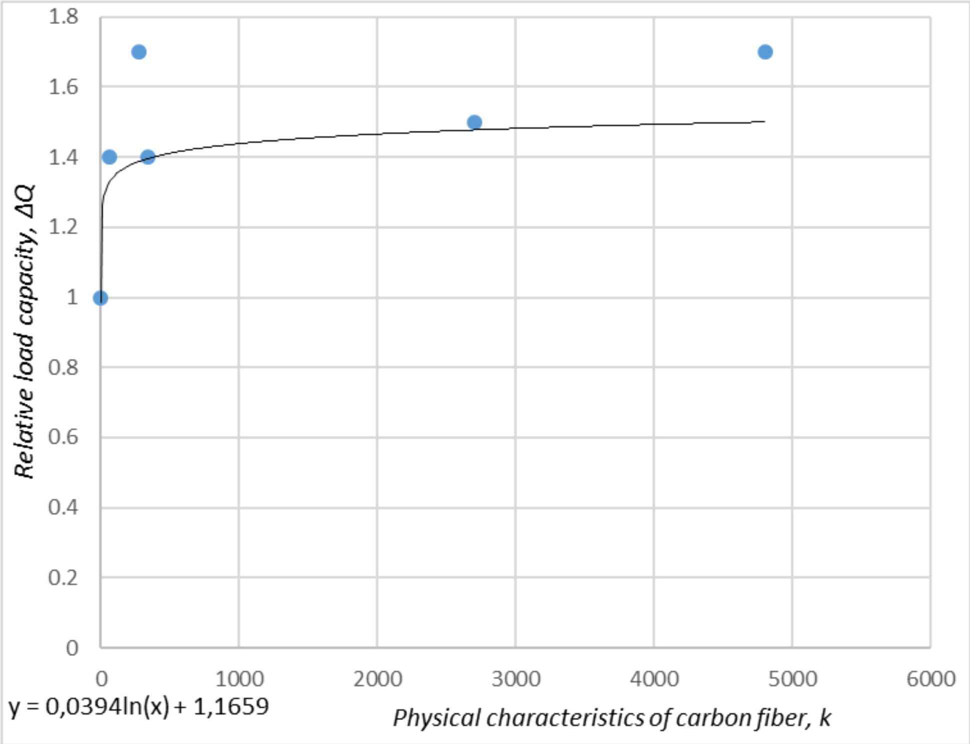


Fig. 2 - Dependence of the relative load capacity on the physical characteristic *k*



 

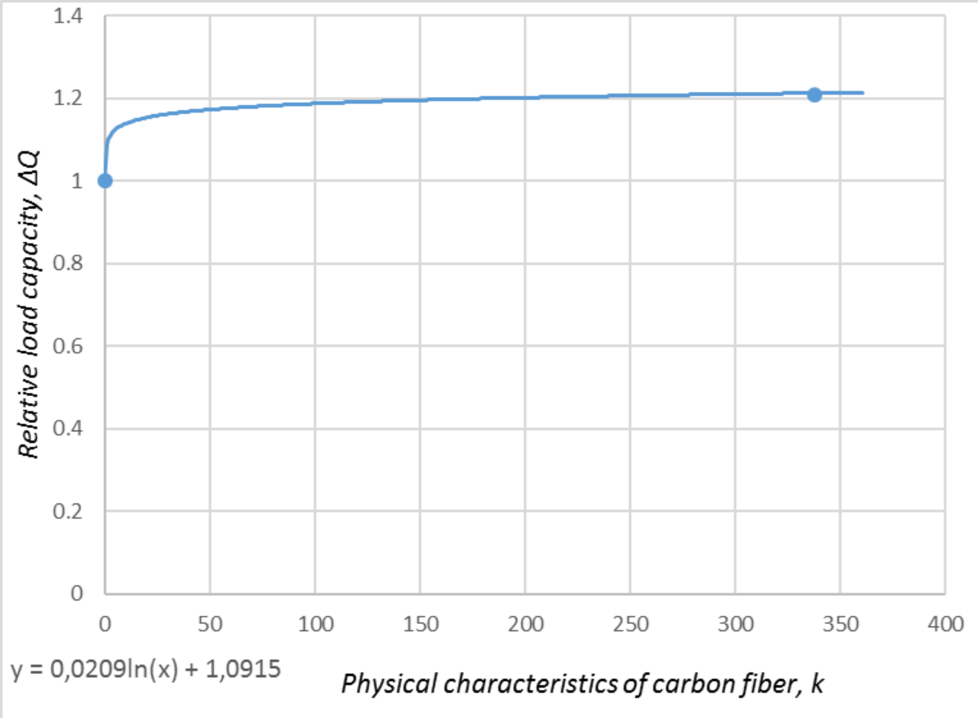


Fig. 3 - Dependence of the relative load capacity on the physical characteristics *k* for the KU-5 series

As a result of the analysis of the conducted tests, the following analytical dependencies are proposed to determine the increase in the shear force *Q* of the masonry in relation to the standard $Q_0$:

- for reinforced masonry using carbon ribbons and fabrics, the load-bearing capacity is proposed to be determined by dependence:

$$Q = (0.0394 \cdot \ln \cdot (k) + 1.1659) \cdot Q_0, \quad (2)$$

- for reinforced masonry using carbon mesh, the load-bearing capacity is proposed to be determined by dependence:

$$Q = (0.0209 \cdot \ln \cdot (k) + 1.0915) \cdot Q_0, \quad (3)$$

where $Q_0$ is the load-bearing capacity of masonry without reinforcement, it is assumed to be equal to the load-bearing capacity under the action of the main tensile stresses.

For the tested series, the theoretical carrying capacity of the reinforced samples will be:

for the KU-2 series, Q = (0.0394·ln·(64,74)+1,1659) ·21170=26192,8 kgf;

for the KU-3 series, Q = (0.0394·ln· (274,5)+1,1659) ·21170=26716,1 kgf;

for the KU-4 series, Q = (0.0394·ln· (337,83)+1,1659) ·21170=26791,3 kgf;

for the KU-6 series, Q = (0.0394·ln· (2403)+1,1659) ·21170=27502kgs;

for the KU-7 series, Q = (0.0394·ln· (2700)+1,1659) ·21170=27544,2 kgf;



 

for the KU-8 series, Q = (0.0394·ln· (4806)+1,1659)·21170=27753,1 kgs.

for the KU-5 series, Q = (0.0209·ln· (360,72)+1,0915)·21170=24238,5 kgs.

The convergence of theoretical values with experimental data is from 10% to 40% in the direction of the load-bearing capacity, which, given the small number of samples, is quite justified.

In previous studies [1], the increase in masonry strength due to composite fiber reinforcement was described as a dependency:

$$Q = (0.35 \cdot \ln \cdot (k + 80) - 0.53) \cdot Q_0, \quad (4)$$

## 3. Conclusion

At the same time, the increase in masonry strength reached 120%, which is primarily due to different technologies used for gluing composite fiber. In the current tests, an improved version of the epoxy-based adhesive was used [3-4]. In [1], in addition, the leveling layer between the masonry and the composite material was not used. The fibarm Repair FS repair compound was used as the leveling compound for these tests [5], that is, the contact of the composite material with the masonry surface was carried out through the leveling repair compound.

## 4. References

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