Effect of Non-Metallic Composite Reinforcement on Load-Bearing Capacity

Justyna Sobczak-Piastka 1, Sofiya Burchenya 2, Yuriy Famulyak 2

1 UTP University of Science and Technology, Faculty of Civil and Environmental Engineering and Architecture, Al. prof. S. Kaliski Str. 7, 85-796 Bydgoszcz, Poland
2 Lviv National Agrarian University, Faculty of Civil Engineering and Architecture, 80381, V. Velykoho Str., Dublyany, Zhovkva district, Lviv region, Ukraine

justynas@utp.edu.pl

Abstract. It is known that non-metallic composite reinforcement was invented in the 60's of the last century, and already then, a large number of scientists began to investigate its physical and mechanical characteristics. Despite its rather old age, this reinforcement has not been sufficiently studied for its work in building structures. Fiberglass composite reinforcement (Arvit) is a high-quality construction material with many advantages: 4-5 times less weight compared to metal of the same diameter; it does not rust or oxidize; tensile strength is 2 times higher than metal reinforcement; it does not conduct electricity; high resistance to temperature changes from -70 to +200 °C; easy to transport. The distinctive features of work of fiberglass composite reinforcement in bending spacer elements are still insufficiently studied, which in design and production practices leads to the non-use of such reinforcement in the construction of elements of buildings and structures. The experimental results of the test specimens are presented in the article. In first test specimen, longitudinal working reinforcement was made of two metal rods ø8 class A400S, in second - two fiberglass rods ø8 AKS 600.

1. Introduction

It is known that non-metallic composite reinforcement was invented in the 60's of the last century, and already then, a large number of scientists began to investigate its physical and mechanical characteristics [1]. Despite its rather old age, this reinforcement has not been sufficiently studied for its work in building structures. To date, non-metallic composite reinforcement is used to reinforce monolithic foundations where there are low loads (low-rise buildings) and industrial floors, brick and aerated concrete masonry, to strengthen the roadways, to reinforce structures that are used in corrosive environments and high vibration conditions, etc. [2-6].

Fiberglass composite reinforcement (Arvit) is a high-quality construction material with many advantages: 4-5 times less weight compared to metal of the same diameter; it does not rust or oxidize; tensile strength is 2 times higher than metal reinforcement; it does not conduct electricity; high resistance to temperature changes from -70 to +200 °C; easy to transport [2].

However, such reinforcement has several disadvantages: the modulus of elasticity is 4 times smaller than that of metal reinforcement; it practically does not bend; when trying to bend it will just break; it is not weldable, which slows down the production process; low heat resistance with high heat and fire.

The concrete structure reinforced with composite cores collapses with extreme heat and fire. Fiberglass
is not afraid of high temperature, but its binder plastic loses strength when heated above +200 °C; aging [7].

The distinctive features of work of fiberglass composite reinforcement in bending spacer elements are still insufficiently studied, which in design and production practices leads to the non-use of such reinforcement in the construction of elements of buildings and structures. The purpose of this study is to investigate the load-bearing capacity and deformability of a spacer element reinforced with non-metallic composite reinforcement. The obtained results are compared with the results of studies of a spacer element reinforced with metal rod reinforcement.

2. Presenting main material and results

To accomplish this task, two test specimens B-1 and B-2 were designed and manufactured with a cross section of 80x150 mm, a length of 1500 mm and a design span of 1300 mm. In the test specimen B-1, longitudinal working reinforcement was made of two metal rods Ø8 class A400S, in B-2 - two fiberglass rods Ø8 AKS 600. The longitudinal reinforcement of the compressed zone and the transverse reinforcement of both specimens was reinforcement Ø6.5mm class A-240S. The longitudinal reinforcement of the compressed zone and the elongated zone and transverse integration into the spatial frameworks by means of the knitting wire BP-1, which reinforced the bending elements (figure 1).

![Spatial frameworks](image)

**Figure 1.** Spatial frameworks: (a) spatial framework of test specimen B-1; (b) the spatial framework of test specimen B-2.

The production of test specimens was carried out under laboratory conditions. Three concrete cubes with a rib size of 100 mm were manufactured simultaneously with the production of the specimens. Concrete for the production of test specimens was planned in class C16/20, after testing the cubes, the average value of the cubic strength corresponded to the concrete class C8/10 and was $f_{c,\text{cube}} = 10$ MPa. The mechanical characteristics of the core reinforcement were determined by standard specimens made from the cut-off parts of the reinforcement of the test specimens, see in table 1. The mechanical characteristics of fiberglass reinforcement were adopted according to the certificate issued by the supplier company Imperial-Trade, LLC and DSTU NB B.2.6-185 [8].
The study of the bending specimens was carried out on a special metal stand, where the loading was performed by two symmetric concentrated forces applied to the upper face of the beam specimen (figure 2).

**Table 1. The results of determining the characteristics of steel**

| Type of reinforcement | Kind of reinforcement | Cross-section size, diameter, [mm] | Cross-sectional area, $A_r$, [cm$^2$] | Characteristic value of reinforcement resistance, $f_{yk}$, [MPa] | Modulus of elasticity of reinforcement, $E_s \times 10^5$, [MPa] | Boundary relative deformation of elongation, $\varepsilon_{ud}$ |
|----------------------|----------------------|-----------------------------------|----------------------------------------|-------------------------------------------------|-------------------------------------------------|-----------------------------------------------|
| **Fiberglass AKS 600** | longitudinal stretched | $\varnothing 8$ (7) | 0.385 | 600 | 0.55 | 0.270 |
| **Rod class A400C** | longitudinal stretched | $\varnothing 8$ | 0.503 | 463 | 1.96 | 0.020 |

**Figure 2. General view of the stand**

The specimens were based on two supports: movable and stationary. The load was created by a hydraulic jack with a power of 20 tons and applied in degrees $F = 0.05 \div 0.1 F_{max}$ with an interval of $25 \div 30$ minutes between them. The deflections of the specimens were measured using a clock-type indicator with a scale of 0.01 mm. The deflectometer was attached to the g-shaped frame which was installed in the middle of the test specimen. The growth and width of the crack opening were measured with a measuring microscope MPB-2M.

Before carrying out the experimental study, a theoretical calculation of the test specimens was carried out based on the deformation model. The theoretical value of the fracture moments of the specimen B-2, reinforced with fiberglass reinforcement, was found as for reinforced concrete. The criterion for the
formation of cracks was assumed as the value $\varepsilon_{ctu} = -\frac{2f_{ctm}}{E_{ck}}$ [9]. Comparison of experimental and theoretical values of fracture loads and fractures is summarized in table 2.

**Table 2.** Experimental and theoretical values of cracks formation and fracture in test specimens

| Specimen code | Experimental load at which the first cracks were formed $F_{crc}$ [kN] | Theoretical load at which the first cracks were formed $F_{crc}$ [kN] | Experimental load at which the specimens were destroyed $F_{des}$ [kN] | Theoretical load at which the specimens were destroyed $F_{des}$ [kN] |
|---------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| B-1           | 8.19                                           | 6.28                                           | 37.0                                            | 29.0                                            |
| B-2           | 5.46                                           | 5.33                                           | 27.3                                            | 31.0                                            |

The development of cracks and the general appearance of the test specimens at the time of fracture are shown in figure 3 and figure 4.

As the external concentrated load increased, new normal cracks emerged between the first cracks formed. The process of crack opening and growth took place gradually (see figure 3).

It should be noted that the number of cracks in the test specimens is almost the same at the time of their destruction. The maximum width of crack opening at a load of $0.72F_{des}$ for test specimen B-1 was $a_{crc} = 0.2$ mm, for B-2 – $a_{crc} = 0.65$ mm at $0.72_{des}$. At loads close to the operational in the test specimen B-2, the width of the opening crack is 3 times greater than that of the model B-1. The maximum crack opening width was for the test specimen, B-1 - $a_{crc} = 0.6$ mm at $0.95F_{des}$, and for the test specimen B-2 – $a_{crc} = 0.9$ mm at $0.80F_{des}$.

The destruction of the test specimen B-1 was due to the achievement of the flowability of the reinforcement, followed by the destruction of the compressed zone of concrete, and of the test specimen B-2 - due to the destruction of the compressed concrete when reaching extreme fiber deformation limit values.
After the experiment ended, concrete was broken around the fiberglass reinforcement to investigate how the composite reinforcement behaved during the destruction of the specimen. Reaching the rods, we saw that the rods did not break and were whole and undamaged figure 4.

Figure 4. View of fiberglass working reinforcement after the destruction of specimen B-2

Deflections were also recorded at each stage of loading the test specimens. The dependence of the deflections on the external load is shown in table 3 and figure 5.

Table 3. Experimental and theoretical deflections of test specimens

| Specimen code | Loads \( F_{\text{exp}} \), [kN] | Experimental deflections, \( f^{\text{exp}} \), [mm] |
|---------------|-------------------------------|----------------------------------|
| B-1           | 2.73                          | 0.20                             |
| B-2           | 0.22                          |                                  |
| B-1           | 4.09                          | 0.60                             |
| B-2           | 0.60                          |                                  |
| B-1           | 5.46                          | 0.85                             |
| B-2           | 1.12                          |                                  |
| B-1           | 6.83                          | 1.12                             |
| B-2           | 1.85                          |                                  |
| B-1           | 8.19                          | 1.40                             |
| B-2           | 3.50                          |                                  |
| B-1           | 10.9                          | 2.12                             |
| B-2           | 5.15                          |                                  |
| B-1           | 16.3                          | 3.25                             |
| B-2           | 7.05                          |                                  |
| B-1           | 21.8                          | 4.40                             |
3. Conclusions
The experimental study has shown the following:
1. The loads at which the first cracks in the test specimen B-1 were formed are 1.5 times higher than in the test specimen B-2.
2. The load at which the test specimens are destroyed is 1.35 times higher in the specimen B-1 compared to that of the specimen B-2.
3. The crack opening width of the specimen B-2 is almost 3 times greater than that of the specimen B-1.
4. The deformability of the test specimen B-2 is 2-2.5 times higher than that of the specimen B-1, depending on the loading level.

Acknowledgment(s)
“...This article/material has been supported by the Polish National Agency for Academic Exchange under Grant No. PPI/APM/2019/1/00003”.

References
[1] “Recommendations for the calculation of structures with fiberglass reinforcement,” Research Institute of Concrete and Reinforced Concrete Gosstroy of the USSR, p. 17, 1978.
[2] Arvit composite fittings. URL: https://arvit.com.ua/production/ (accessed 25.03.2019).
[3] S. P. Waxman, “Features of reinforcement of foundations by non-metallic composite fittings,” Collection of scientific works. Series: Industry Engineering, Construction. No. 1 (46), PoltNTU. pp. 174-180, 2016.
[4] Yu. A. Klimov, “The use of non-metallic composite reinforcement for reinforcing concrete structures”. Building materials, products and sanitary equipment: scientific and technical collection, 2011/ 42, pp. 13 -17, 2011.
[5] D. V. Popruga, O. I. Valova, “The use of fiberglass composite fittings in bending elements made of concrete on wastes of mining and processing enterprises,” Bulletin of the Krivoy Rog National University, No. 44, pp. 147-150, 2017.
[6] S. Burchenya, Y. Famulak, “Comparison of load-bearing capacity and deformability of complex...
lightweight concrete elements, reinforced and unreinforced with composite reinforcement,”
Resource-economic materials, structures, buildings and structures: Coll. of sciences. work. Rivne: NSULP, Issue 36. pp. 349-355, 2018.

[7] Composite fittings: construction application, characterization and comparison URL: https://isu.org.ua/kompozynna-armoratura-zastosuvannya-v-budivnyctvi-harakterystyky-i-porivnyannya (accessed 25.03.2019).

[8] DSTU N B 2.6-185. Guidelines for the design and manufacture of concrete structures with non-metallic composite reinforcement based on basalt and glassware. K.: Minregionstroy of Ukraine, p. 28, 2012.

[9] DBN B.2.6-98: 2009 Construction of buildings and structures. Concrete and reinforced concrete structures. Main provisions of K.: Minregionstroy of Ukraine, p. 71, 2011.