Stress-strained state of steel-adhesive bonding on the acrylic adhesives

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Abstract. Experimental results of determination of strength and deformation properties of acrylic glues of different compositions at short term, long term and cycle loading, as well as the character of their destruction are given in the article. Since acrylic adhesives are commonly used in construction activity, their physical-mechanical properties were determined, taking into account the type of action of the forces on them in the bonding of building constructions and elements. These forces include: compression, extension and shear. In the process of experiments in the composition of the acrylic adhesive the ratio of polymer, hardener and filler was taken into account.

1. Introduction
In the modernization, repair and reconstruction of existing buildings and facilities of various industries, for bonding of concrete elements, where an old concrete is bonded with an old and an old with a new concrete, the polymer adhesives are widely used. They are also used for fixing cracks in concrete and for bonding of building constructions as well, including reinforced-concrete constructions by means of building-in of protrusion bars and anchor bolts into concrete for various purposes. However, the applied polymer adhesives have a number of drawbacks, which the acrylic ones are deprived of [1]. The compositions of these adhesives were developed with the participation of the authors of the O.M. Beketov National University of Urban Economy in Kharkiv. These adhesives are cheaper, more technological, simple and reliable in the manufacturing [2-7].

2. Problem statement. Main material and results
The main purpose of the research is to investigate physical and mechanical properties of acrylic modified glues, according to their widespread use in the industrial and civil engineering taking into account the type of joint influence efforts, were defined.
Since acrylic adhesives are commonly used in construction activity, their physical-mechanical properties were determined, taking into account the type of action of the forces on them in the bonding of building constructions and elements. These forces include: compression, extension and shear. In the process of experiments in the composition of the acrylic adhesive the ratio of polymer, hardener and filler was taken into account. As a result of the experiments in the determination of the physical-mechanical properties of the appointed compositions of adhesives, it was identified that their strength
is as following: under compression \( f_c = 60 \) to \( 80 \) MPa, under extension \( f_{ex} = 13 \) to \( 15 \) MPa, under shear \( f_{sh} = 21 \) to \( 26 \) MPa. [8-11]

Such compositions of the acrylic adhesives provide a reliable bonding of concrete elements and also the building-in of anchor steel bars of different profiles (plain and periodic) into concrete.

At the same time, the increase of strength of the acrylic adhesives, shear, will allow reducing the depth of building-in of the reinforcing bars of the periodic profile into concrete, for example.

On the basis of the indicated, the author, by means of modifications by various additives, received the compositions of an acrylic adhesive of the improved strength. For example, finely dispersed zinc oxide (ZnO) and mica as well as methacrylic acid were used as modifying additives. They were the most effective in the increasing of the adhesive's strength, especially on the shift.

As the result of the conducted experiments, the strength of the modified acrylic adhesives was indicated. The analysis of these experiments shows that the strength of the modified acrylic adhesives is higher than the strength of the composition specified above. It was determined that the usage of the specified above additives increases the strength of the acrylic adhesive under compression from \( 23 \) to \( 34\% \) \( (f_c = 83.6 \) to \( 98.6 \) MPa), extension – from \( 38 \) to \( 72\% \) \( (f_{ex} = 18 \) to \( 28 \) MPa) and shear – from \( 32 \) to \( 42\% \) \( (f_{sh} = 32 \) to \( 41 \) MPa) [11].

The patterns of change of deformability of the acrylic adhesives were studied experimentally. It allowed to indicate the values of their elastic moments and other characteristics of deformability.

In turn, it allowed to conduct the studies of the stress-strained state and the calculation of bonding of the constructions made on the acrylic adhesives.

The experiments were conducted on the acrylic adhesive samples with the size under compression 40x40x160 mm, and at expansion on the samples – the briquettes with a cross-section 10x20 mm. The composition of the acrylic adhesive was accepted as follows: the acryl compound – 200 mass-parts; the filler is quartz sand with the grain size 0.63 mm – 600 mass-parts; the modifier is zinc oxide – 8 mass-parts. The tests were provided on the pressure machines where the range of weighing device was from 1 to 200 kN. The levels of forces and deformations were recorded automatically. During a short-term load, forces were applied at speeds, causing a voltage change in the samples with speed equal to 0.6; 0.3 and 0.1 MPa/s.

The compression and extension tests of the acrylic adhesive samples at various load rates (Figure 1) displayed that the deformations are of linear character to the tensioning equal to \( 80 \) – \( 86\% \) of the destructive ones. During the load of the samples of the acrylic adhesive to the volumes equal 0.8 from the tensile strength, their redeformation was taking place due to the indicated diagrams and regardless to the load speed. Obviously these deformations are elastic.

In addition to elastic deformations, at the loads higher than \( 80\% \) of the destructive ones, the plastic deformations which do not disappear at the infinitely long time after the full unload occurred. The amount and rate of development in time of such deformation depend on the value and time of action of the load. The destructions of the samples during compression, extension and shear were of unstable failure nature (Figure 2).

Since creation of the elastic limit and full deformations depend on the value of a current load and the time interval of its impact during the fracture, the limits of elasticity and strength depend also on the time of impact of the load. Thus, the limits of elasticity and strength of the material are changing in time from priority limit of strength (maximum value) to the limit of long term resistance (minimal value).

In connection with this, the experiments on determination of deformation development in the acrylic adhesive samples were provided when the permanent long-term load didn't change in time and became constant. The values of these loads were 0.2; 0.3; 0.42; 0.68 and 0.85 from the destructive ones. The diagrams of such deformations development of are presented in Figure 3.
Figure 1 The diagram of compression (a) and extension (b) of the acrylic adhesive samples at the load speeds: 1 – 0.6 MPa/s; 2 – 0.3 MPa/s; 3 – 0.1 MPa/s

Figure 2 The nature of acrylic adhesive samples destruction at: (a) compression; (b) extension; (c) shear
The analysis of the diagrams displayed that if the constant tensioning is below the limit of the sustained resistance, then the deformation curve is divided into two sections in time:
1. the section of formation of instantaneous deformations;
2. the section of formation of viscous deformations, developing in time.

If the constant tensioning is higher than the limit of the long-term resistance, then the deformations occur. They are developing during a limited period of time and at the end of this interval cause the destruction of the acrylic adhesive. The deformation curve in this case is divided into four sections in time (Figure 3).

In section I instantaneous deformation occurs, in section II plastic deformation occurs, the development of which begins with the speed that is equal to the speed of instantaneous deformation's growth at the first section, and continues with a gradually decreasing speed.

Then plastic deformation grows proportionally to time with the speed equal to the speed of development of elastic limit deformation (section III of deformation's development curve in time).

At the end of section III, resistance of the material depletes and at section IV the snowballing process of destruction of the material which ends with the destruction of the samples takes place.

Figure 3 The diagrams of creep of acrylic adhesive at (a) extension and (b) compression
Since in section IV a change in the limit length of samples mainly occurs, rather than the deformation of samples in general, this is not taken into account in the determination of resistance and deformability of adhesive anchors.

3. Conclusions
1. The analysis of the obtained results also shows that the limit of the long-term resistance is about 85% of short-term destructive forces.
2. As it can be seen from the diagrams (Figure 3), the creep deformation had a linear character regardless of the value of the long-acting loads. Moreover, the performed experiments have shown that acrylic adhesive regardless of the load type has a sufficiently high strength. It can be used for bonding of structural building constructions that accept static loads.
3. By means of the experiments the patterns of acrylic adhesives deformability's changing, which allowed to indicate the values of their elastic moments and other characteristics of deformability, were defined. In turn, it will allow to provide the studies of the stress-strained state and the calculation of constructions bonding of the made on the acrylic adhesives.

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