Application of energy efficient materials in reconstruction of buildings and structures of transport infrastructure

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Abstract. The article analyzes in detail the results of the performed reconstruction works with the application of thermosetting polymers. The method of adhesive anchoring of reinforcement rods with fixing them in the concrete body with acrylic glue was carried out on transport infrastructure facilities (railway steam shop and railway itinerary post). It has been determined that strengthening the foundation with application of the thermosetting polymers (adhesive anchor joints) gives a significant reduction in the consumption of concrete, metal and labor costs. The advantage of such acrylic adhesives is the possibility of varying the ratio of monomeric and polymeric part (powder) containing redox system, within acceptable concentrations, without significant changes in adhesion and cohesion parameters. The obtained results are very important in practice, because in the conditions of preparation of the adhesive (especially in construction conditions) it is difficult to determine the exact number of components. The experimental research data can be used for attachment joints projecting and industrial technological lines development, as well as for further polymeric adhesive materials, widely applied in industrial and civil engineering, improvement.

1. Introduction
The application of plastics based on acrylic polymers for the manufacture of load-bearing elements is quite limited. Above mentioned is due to the low values of plastics elasticity modulus and due to the high materials deformation. More widely polymers used as adhesives for fixing and connecting the joints of structural elements that have sufficient rigidity with the allowable distribution of the load [1].

Polymer adhesives are currently used in building industry mainly in three directions: during finishing works (flooring, wall decoration, etc.), during the manufacture of building structures (fencing structures, roofs, waterproofing), during the installation of sanitary equipment and pipelines [2].

The wide usage of gluing in technology is due to the fact that with the help of mineral, organic and combined adhesives strong and reliable connections of materials and structures can be obtained, and often better and more economical than with any other method. In some cases, gluing is the only possible method of bonding. Mineral and organic (natural) adhesives have long been used to join stones, bricks, wood, paper, cardboard, wall and floor tiles and other materials. To improve the adhesive properties of mortars (mineral adhesives), they have long been introduced organic impurities. With the advent of high-strength synthetic adhesives, it has become possible to combine load-bearing
building structures that are exposed to significant static, dynamic, vibratory and other loads. Such adhesives provide sufficient thermal, fire and frost resistance of adhesive connection, as well as resistance to moisture, solvents, acids, alkalis, fungi and more.

Epoxy and acrylic glues are widely used as material in structural joints, as their properties meet all necessary requirements for adhesives to create reliable high-strength joints [3, 4].

2. Problem statement
Durability requirements in construction are generally lower than in mechanical engineering and other industries. However, adhesive joints in construction are used for at least 50 years, must be non-toxic during operation, have a relatively low cost [5, 6].

Both abroad and in Ukraine, extensive experience has been gained in the application of adhesive anchoring of reinforcing rods for anchor installation works during the reconstruction, repair and reinforcement of concrete and reinforced concrete structures [7]. This anchoring has a number of advantages:

- reduced terms of repair and reconstruction of buildings and structures;
- lower energy and material consumption;
- reduced cost and complexity of work;
- installation of reinforcing rods in various weather conditions is possible;
- in some cases, this method is almost the only possible one (for example: changing the thickness of the foundation by a small value with significant increases in loads);
- simplicity, reliability and high manufacturability of works;
- the ability to apply design loads to the reconstructed and reinforced structures and areas in 6-24 hours, instead of 72 hours, as for structures reinforced in the usual way;
- fastening of reinforcing rods in existing concrete and reinforced concrete structures using acrylic glue is economically justified and the most progressive;
- acrylic glue is low-component, simple and reliable in preparation. The factory supplies glue components in a set that facilitates the organization of maintenance of anchor installation works;
- acrylic glue is an environmentally friendly substance and does not affect humans and the environment.

The method of fixing the reinforcing rods with a rigid cement-sand mixture (vibrating) allows you to load the anchor device in three days. The disadvantage of vibrating is the need to use a special mechanism for compaction of the mixture, the multicomponent nature and complexity of its preparation, high complexity. Therefore, the attachment of reinforcement rods on existing concrete or reinforced concrete structures using epoxy, siloxane and especially acrylic adhesives is the most progressive, economical and less time consuming [8, 9].

3. Basis of calculation
The calculation of anchor rods was performed in accordance with [8] and Building Norms of Ukraine “Steel structures. Design standards”. The magnitude, direction and character of the loads from the equipment on the rod must be specified in the design task.

According to [8], the cross-sectional area of the rod is determined from the condition of strength by the formula:

\[ A_s = k_0 P \cdot (R_s) ^{-1} \]  

(1)

where \( k_0 = 1.35 \) for dynamic loads; \( k_0 = 1.05 \) for static loads.

Under the action of dynamic loads, the cross-section of the rods determined by formula (1) must be verified for endurance by formula:

\[ A_e = 1.8 \mu P \cdot (\alpha R_s) ^{-1} \]  

(2)
where $\chi$ is load factor (taken according to Table 1 data); $\mu$ is the coefficient taken depending on the diameter of the rod [8]; $\alpha$ is the coefficient that takes into account the number of load cycles [8].

During the calculation of the building structures fastenings, the pre-tightening force and the cross-sectional area of the rods are determined as for static loads, unless there are special instructions in the project.

During the group installation of rods for equipment mounting, the value of the design load $P$ per rod should be determined for the most loaded rod by the formula:

$$P = N \cdot n^{-1} + M y_i (\sum y_i^2)^{-1}$$

(3)

where $N$ is the calculated longitudinal force; $M$ is the calculated bending moment; $n$ is the total number of rods; $y_i$ is the distance from the axis of rotation to the most removed rod in the stretched joint area; $y_i$ is the distance from the axis of rotation to the $i$-th rod, taking into account both stretched and compressed rods.

**Table 1. Values of load factors $\chi$ and tensile strength, depending on the design of the anchor rods.**

| Construction of the rod | With a limb | With anchor plate | Direct | Conical (spacer) |
|-------------------------|------------|------------------|--------|-----------------|
| Rod Diameter, $d$, mm   | 12-48      | 12-140          | 56-125 | 12-48           |
| The minimum laying depth, $l_{anch}$ | 25$d$ | 15$d$ | 30$d$ | 10$d$ (8$d$) | 10$d$ (8$d$) |
| The smallest distance between the rods | 6$d$ | 8$d$ | 10$d$ | 5$d$ | 8$d$ |
| Load factor, $\chi$ | 0.4 | 0.4 | 0.25 | 0.6 | 0.55 |
| Pull stability coefficient, $k$ | 1.9 | 1.9 | 1.5 | 2.5(2) | 2.3(1.8) |

During the installation of rods with bends, the depth of their laying in concrete is taken to be $15d_s$ for rods with anchor plates $10d_s$ and for rods installed in wells - $5d_s$.

During the installation of paired rods, a common anchor plate with a distance between the boreholes equal to the design distance between the axes of the rods should be provided, or single rods with a “run” in depth should be installed. The depth of laying of paired rods at a distance between their axes of $8d_s$ and more should be assigned $5d_s$, at a distance of less than $8d_s$ - equal to $20d_s$.

The distance from the edge of the plate to the axis of the rod should be chosen at least $2d_s$, and the area of the anchor plate should be at least $32d_s$.

4. **Main material and results**

To confirm the abovementioned advantages of the method of adhesive anchoring of reinforcement rods of $\text{Ø}20$ A500 and $\text{Ø}25$ A500 with fixing them in the body of concrete with acrylic glue, research and industrial implementations were carried out on transport infrastructure facilities (railway steam shop and railway itinerary post).

The main purpose of the steam shop reconstruction was to replace the obsolete overall boiler with a new gas boiler. Under the designed boiler it was necessary to reconstruct the existing foundation. To determine the physical condition of the foundation and the scope of the proposed work, a survey of this structural element was carried out.

The survey has found following data:

- the existing foundation has a complex configuration with the maximum geometric dimensions in plan $5.4 \times 3.6$ m. The depth of foundation laying is $3.6$ m;
- the concrete body of the foundation is in good condition but needs cosmetic repairs;
- the designed gas boiler has the following parameters: length of the boiler $6,820$ mm, width of the boiler $4,300$ mm, height of the boiler $5050$ mm, heat output - $2.9$ MW.
Thus, based on the overall dimensions of the gas boiler, it is necessary to change the configuration of the existing foundation with increasing its geometric dimensions and to provide the required bearing capacity of the zones, which need to be erected.

The geometric dimensions of the reconstructed foundation need to be 7300×4800 mm (Figure 1). The depth of the foundation remained initial. The purpose of experimental and industrial implementation was to change the configuration of the foundation and its dimensions by connecting the existing concrete body with freshly laid concrete by the application of adhesive anchoring of reinforcing rods. At the same time, the volume of the existing foundation $V = 83.1 \text{ m}^3$ is preserved.

Technological sequence of operations during the reconstruction of the foundation:
- digging a trench along the perimeter of the foundation to a depth of 3.6 m;
- cleaning of existing foundation surface from dust and dirt, concrete exfoliated areas reflection;
- marking of places under the holes, during which the distance of the reinforcement to the foundation boundary and between the rods must be at least $5d$, of the installed rods ($\varnothing 20$ and $\varnothing 25$ mm) and is equal to $25 \times 5 = 125$ mm.

It was accepted: boreholes are located with a step of 550 mm on height of the foundation (Figure 2), and along the perimeter set the bay of the rods 300 mm;

**Figure 1.** Reconstruction scheme of the foundation: 1 - new foundation zone, 2 - old foundation zone.

**Figure 2.** Cross-section of the reconstructed object: 1 - new foundation zone, 2 - old foundation zone.
drilling of holes in the body of existing concrete. Holes were drilled to a depth of 17.5d, of laying the reinforcing rod (Ø20 and Ø25), which is 450 mm. The direction of the drilled holes relative to ground level is horizontal. Holes were drilled with a diameter of 30 mm;

- preparation of anchors made of crescent-shaped reinforcing rods Ø20 and Ø25 A500;
- filling holes with high-viscosity modified acrylic glue, which included special impurities that increase its adhesive and cohesive strength;
- installation of formwork from metal boards. The inner surfaces of the boards, before filling with concrete, were coated with a special mixture to prevent adhesion of metal to concrete;
- installation of reinforcing rods. The reinforcement was installed by slow immersion in a hole filled with glue. Total amount of rods, which were installed: Ø20 A500 - 311 units and Ø25 A500 – 216 units;
- to ensure the design position of the reinforcing rods, annular retainers were installed. To ensure the stability of the spatial structure, the releases of the installed anchors were connected to the vertically and horizontally located rebars with a knitting wire. The created reinforcing design provided perception of design loadings;
- application of acrylic glue without modifying impurities on the already prepared surface of the existing foundation
- laying of concrete in the formwork. At the time of laying the mobility of concrete was 3-4 cm. Concrete was laid in layers, which thickness does not exceed 1.25 of the length of the working part of the vibrator. The minimum thickness of the concrete layer was 200 mm. The total volume of stacked concrete was 61.1 m³.

As a result of the implementation of the development and preservation of the existing foundation saved: 7.1 tons of metal, 83.1 m³ of concrete, 290 people labor per days. In addition, the application of reinforcement anchoring with acrylic adhesives can reduce the time of commissioning of the object by 7 times.

Second object of thermosetting polymers application was reconstruction of a foundation of the railway itinerary post.

On the basis of the survey it was established: the inspected condition of the foundation is unsatisfactory; the bearing capacity is minimal.

The main purpose of experimental and industrial implementation is to restore the bearing capacity of the strip rubble foundation by increasing its cross-sectional area. Connection of the old foundation with freshly laid concrete is made using adhesive anchoring of reinforcing rods (Figure 3).

![Figure 3](image)

**Figure 3.** Technological schemes of adhesive anchoring process: a – boreholes drilling in concrete body; b – filling of acrylic adhesive into the boreholes; c - installation of a reinforcement rod in a borehole; d - installation of a reinforcement rod in design position.

The technological process of strengthening the foundation took place in the following order:

- the concrete pad and the surface of the rubble foundation were cleaned of soil, rubbish and dust. Rubble completion of the zones formed as a result of falling of a stone is performed;
• performed marking of holes for installation of reinforcement rods. According to the given scheme, holes are located along all perimeter of the foundation in 1 row with a step of 300 mm;
• vertical holes were drilled in the concrete pad to depth ≈400 mm, which is not less than 17.5d, = 17.5×20 = 350 mm and a diameter of 30 mm;
• reinforcement rods were prepared in the amount of 1180 units;
• holes were filled with modified acrylic glue. This adhesive was prepared directly on the building site;
• reinforcement rods Ø20 A500 were installed vertically, by slow immersion in holes filled with acrylic adhesive;
• to ensure the design position of the reinforcement rods were installed annular retainers. After gaining the design strength of glue, the installed rods were connected to the horizontally located rods of the reinforcement with a knitting wire. The stability of the manufactured structure was ensured by anchors installed into the rubble masonry of the foundation with acrylic adhesives;
• formwork was installed from pre-made wooden boards in accordance with the requirements of technical conditions;
• the surface of the concrete pad of the foundation was covered with ordinary acrylic glue, which contains only acrylic polymer and filler in the form of quartz sand;
• laying of heavy concrete with a mobility of 3-4 cm was performed in layers, followed by compaction with a vibrator. The thickness of the compacted layer ranged from 200 to 600 mm. The total volume of concrete laid in the formwork was 47.2 m³;
• after 72 hours or 3 days produced removal of the formwork of the structure (Figure 4).

![Figure 4](image)

**Figure 4.** Formwork removal of the reconstructed foundation.

Observations, that continue for today, on the operation of reconstructed foundations and joints of reinforced concrete elements, operating under loads, indicate the full integrity of the anchor joints.

**5. Conclusions**

1. As a result of the reconstruction and strengthening of the foundation with the application of thermosetting polymer materials (acrylic adhesives), a significant reduction in the consumption of concrete, metal and labor costs was achieved.
2. A new field of application of adhesive joints of metals based on thermosetting polymers are building structures, in particular the transport infrastructure facilities. The following requirements are set for adhesives and adhesive joints abovementioned structures:

- strength under static and dynamic loads;
- ability to harden without heating and at minimum pressure;
- simplicity of preparation of a surface under gluing;
- resistance to the influence of variable temperatures;
- low sensitivity of the joint strength to fluctuations in the thickness of the adhesive seam.

Some types of developed acrylic adhesive compositions meet these requirements, because they harden without heating and in the case of the filler application provide stable adhesive compounds to temperatures from -30°C to +80°C [10].

3. The application of thermosetting polymers for bonding metal during the repair of steel pipelines for gas and water supply without their dismantling is effective. Acrylic adhesives can be used to glue metal capsules that support electrical cables directly to stone or concrete walls without the use of special stands. Also, it is proposed to glue metal shapes to wood in the manufacture of large wooden beams.

The advantage of such adhesives is the possibility of varying the ratio of monomeric and polymeric part (powder) containing redox system, within acceptable concentrations, without significant changes in adhesion and cohesion parameters [11]. This is very important in practice, because in the conditions of preparation of the adhesive (especially during the construction) the exact number of components is hard to determine.

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