Application of Polymer-cement Corrosion Protection for Different Strength Concrete of Reinforced Concrete Elements

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Abstract. This paper presents analysis of experimental data on increase of crack formation of reinforced concrete flexural members through deposition of protective polymer-cement coating improving the durability of civil structures in hostile environmental conditions. Polymer-cement coating is a composite based on low-molecular poly-butadiene as filling material with Portland cement. As a result of the research, we have obtained the data on load-carrying capacity of the members, relative level of crack formation and growth of deflection with load increment, depending on the thickness of covering layer, along with different strength of concrete in reinforced concrete flexural members. Research results will enable us to design civil structures withstanding various hostile environmental conditions owing to universal chemical stability of the coating, its high adhesion to different surfaces, including the concrete, thus ensuring preservation of performance characteristics of proposed structure, up to its destruction.

1. Introduction

One of the most effective methods of improving the durability and reliability of reinforced concrete structure operating in hostile environmental conditions is application of various protective coating and implementation of the so-called secondary protection of reinforced concrete structures. This kind of protection method imposes heightened requirements on mechanical strength and adhesion to reinforced concrete, since in the course of erection works and operation minor shocks may occur causing the damage of protective coating, which results in permeation of hostile medium in the source material of the structure, thus reducing the ultimate lifetime of the structure. One of such materials is rubber concrete [1] and rubber concrete-based mastics: their application technology was elaborated in details in investigation of sandwich beams at static and dynamic loads [2]. Rubber concrete is notable for high physical and mechanical characteristics, high adhesion to different surfaces and universal chemical durability. [3, 4]. Owing to the rubber concrete characteristics [5], and owing to the increased moment of flex cracking [6], it is used in manufacture of civil structures intended for operation in specific conditions. In our investigations we used special composition of rubber concrete that may be referred to the types of polymer-cement protection [7, 8 and 9].

Based on the types of the materials used, chemical-resistant coatings may refer to epoxy group coatings [10, 11], styrene-butadiene coatings [12], polyurethane-based coatings [13] and the coatings from polymeric materials of other types [14, 15]. In investigations under consideration the coating technology consists in layer-by-layer coating with subsequent solidification of layers, that does not ensure adequate reliability under long-term hostile environmental effects and in cases of minor
mechanical damages the coatings will no longer satisfy the requirements imposed on them. In our investigations the coating is considerably thick, thus ensuring substantial mechanical strength; apart from this, the coating thickness is often calculated depending on the extent of environmental hostility to which the structure will be exposed in operation, and the lifetime of the structure. Additional factor improving mechanical strength of the coating may be disperse reinforcement. The effectiveness of such reinforcement used in the rubber concrete has been thoroughly studied for different types of fibers and reinforcement percentage [16].

Considerable number of investigations in this field revealed positive effect of coating not only on the durability of the structure service, but also on mechanical properties of the protected elements. Generally, the coating increases the level of flex and tension cracking and promotes improvement of reinforced concrete compression strength [2, 14, and 15]. Such kind of phenomenon can be accounted for a number of factors: decrease of peak strains in vulnerable spots of reinforced concrete owing to polymer-cement layer; physical and chemical interaction under the contact of concrete with polymer-cement coating; flattening of concrete deformations and involvement of polymer-concrete layer in overloaded sections; improvement of concrete tensile strength and ultimate tensibility of concrete. Based on our earlier investigations, we are able to evaluate the coating effect at different percentage of reinforcement [17, 18], and different thickness of coating [19] on the relative moment of crack formation for flexural reinforced concrete members coated with polymer-cement layer against hostile environmental media. Apart from this, strength characteristics of the concrete and coating material affect performance characteristics of such kind of structures. Our further research is focused on evaluation of the effect of concrete strength on the relative level of crack formation in flexural members in combination with the change of the coating thickness.

2. Experimental investigation
To conduct our investigations, we prepared a series of specimens of twelve beams with dimensions 60×120×1400 mm and test specimens – cubes with dimensions 100×100×100 mm. The specimens were manufactured to technology similar to that applied in investigation of the effect of reinforcement percentage and coating thickness [17, 18, and 19]. The variable factors for our experiment were concrete strength coating thickness. The concrete strength was regulated by means of various compositions, and its actual value was determined at the time of the test conducted for the test specimens. The second factor was the coating thickness: as in the previous investigations, it was 3, 4 and 5 mm, which corresponds to 10 to 16 % of the member thickness, given that coating is deposited at three sides. Along with protective coating, we manufactured one more reference specimen without any coating to determine the basic level of crack formation. It should be noted that in the process of reinforced concrete specimen manufacture with deposition of coating their width was less than the reference member by the magnitude of deposited coating, so that the width of the coated component is the same as the width of the reference specimen. All the elements with polymer-cement coating, the reference element and test specimens were tested concurrently for the corresponding concrete strength.

To fix the moment of the crack formation, during the tests we stuck strain gages in pairs on each element in the tight and tension zones and on reinforcement. By the sensor mounted on the reinforcement we determined the destruction of the element at the moment when reinforcement reached the yield point determined by the test results of reinforcement test specimens. It should be noted that destruction of elements took place along the tension zone, while in all cases no delamination of polymer-cement protective coating was observed, up to its destruction. At the moment of the first crack formation the strain gages indicated abrupt change of deformation growth, which is deemed to be the reliable evidence of specific level of crack formation.

Comparison and analysis of the results of experimental investigations would be more convincing if we use the relative level of crack formation for each element, obtained by division of the load under which the first crack was formed by the load under which the element was destructed (M CRC/Mu). Fig.1 presents experimental dependencies of the relative level of crack formation on coating thickness at
different average cube strength of concrete. Positive effect of application of polymer-cement protection reveals itself in the rise of the level of crack formation, while relative level for the elements without coating was below 0.2; the values for the coated beams were close 0.4, which almost by two times enhances the performance efficiency of proposed structures exposed to hostile environmental conditions.

![Figure 1. Dependence of the relative level of crack formation on coating thickness and average concrete strength: 1 – 22.3 MPa; 2 – 29.7 MPa; 3 – 32.9 MPa; 4 – corresponding beams without coating.](image)

By methods of regression analysis for graphic presentation of obtained experimental data we have obtained the dependence of relative level of crack formation at combined change of concrete strength (R) of reinforced concrete elements and the thickness (δ) of polymer-cement protection against hostile media:

$$\frac{M_{cr}}{M_u} = 0.05 \times R + 0.329 \times \delta - 0.001 \times R^2 - 0.04 \times \delta^2 - 0.855$$  \hspace{1cm} (1)$$

The yield surface plotted by equation (1) is presented on Fig. 2. From consideration of the dependence (1) it is evident that with improvement of concrete strength, a certain decrease in the relative level of crack formation occurs. Decrease of the relative level of crack formation with improvement of concrete strength was investigated in research paper [20], with improvement of concrete strength the plastic properties positively affecting the crack resistance will degrade. A similar phenomenon occurs on increase of coating thickness, as compression strength of the coating (determined by test specimens – prisms 40×40×160 mm) is higher than the strength of concrete elements and amounts to 65 MPa, brittleness of specimens increases. Besides, as the thickness of the coating layer increases, the effect of modifying the concrete surface consisting in reduction of surface stresses in the concrete will degrade.

3. Conclusion
Analysis of experimental data reveals that in terms of maximum relative level of crack formation the coating thickness of 4 to five mm will be optimal, as at such thickness of coating the concrete strength has insignificant impact on resistance of investigated structures to crack formation under load, and the factor of concrete strength change may be excluded from consideration in calculation models.
Figure 2. Dependence of the relative level of crack formation on concrete strength and thickness of polymer-cement coating

4. References
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