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THE IMPACT OF A POLYUREA LAYER ON CRACKING AND PERFORMANCE OF REINFORCED CONCRETE BEAMS UNDER BREAKING LOAD

WPŁYW WARSTWY POLIMOCZNIKA NA ZARYSOWANIE I PRACĘ POD OBCIĄŻENIEM NISZCZĄCYM BELEK ŻELBETOWYCH

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Abstract

The paper discusses the results of laboratory experimental studies on reinforced concrete components (beams) with an outer polyurea layer. The important part of the study is the comparison of the results concerning the load-displacement relation for the reference beams (without the polyurea layer on their external surfaces) and those with the polyurea layer. The main conclusion from this part of the research is that the beam elements covered with a polyurea layer are protected against corrosion processes even in an emergency state. The occurrence of scratches, even of large size, is neutralized by the coating that effectively bridges them.

Keywords: polyurea, corrosion, reinforced concrete beams, breaking load, cracks, durability

Streszczenie

W artykule zaprezentowano wyniki laboratoryjnych badań eksperymentalnych dotyczących elementów żelbetowych (belek) wraz z zewnętrzną warstwą polimocznika. Istotną częścią pracy jest porównanie wyników zależności obciążenie – przemieszczenie dla belek referencyjnych (bez warstwy polimocznika na powierzchniach zewnętrznych) oraz tych taką warstwę posiadającą. Kluczowym wnioskiem płynącym z tej części badań jest ten mówiący o tym, że elementy belkowe pokryte warstwą polimocznika zabezpieczone są przed korozją nawet w stanie awaryjnym. Występowanie rys nawet znacznych rozmiarów jest zneutralizowane poprzez skuteczne ich mostkowanie powłoką.

Słowa kluczowe: polimocznik, korozja, belki żelbetowe, obciążenie niszczące, rysy, trwałość

1. INTRODUCTION

Reinforced concrete (RC) structures that were designed and produced correctly tend to be highly durable. It is commonly assumed that core structural elements, which are critical for the safety of a building facility, should serve their purposes throughout their whole service life. The durability of RC beams and pre-cast concrete products determines (according to a rough estimate) the service life of a whole building. As a result of increasing loads exerted on RC elements, crack formation and propagation, and adverse effects of aggressive media, the ultimate limit state (ULS) and the serviceability limit state (SLS) may eventually be exceeded. Such phenomena are

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indicated in RC structures by excess cracking and deflection of these elements. Cracking states of RC elements are particularly important as they are the main factor determining the durability and safety of structures. Crack formation is actually inherent to the performance of RC structures since this is how these materials naturally respond to the state of strain to which they are subjected. However, the development of wide cracks is very disadvantageous, as they enable penetration by fluids causing corrosion of rebars and affect the rate of concrete degradation, which makes RC elements less durable. As far as cracking is concerned, the safety of structures can be improved by introducing certain design measures (when new elements are designed) or by repairing existing RC elements in the process of filling and closing the cracks. The process of repairing RC structures is often labor- and cost-intensive as well as difficult to complete during the operation of a building facility [1]. There is a number of deeply studied and documented techniques for improving the performance of existing RC elements. Such modifications are introduced by using additional external reinforcing elements (such as steel sections and carbon fiber tapes) and fixing the cracks. A certain disadvantage of these solutions is that they are labor-intensive and an adequate space around an RC element is required to allow the assembly of reinforcements [2, 3].

This paper attempts at providing additional expertise on these topics by introducing polyurea, a material that has not yet been widely recognized. The study shows potential benefits from the application of polyurea on RC beams. The results of experimental research presented in the paper mainly serve to show how polyurea-coated RC beams behave before and after their final failure. Observations and results are also compared to those concerning reference elements (without the additional polyurea layer). Before the study, the authors of the paper defined the following questions:

– Can polyurea be the material that makes it possible to protect RC elements to such extent that their reinforcement is protected against corrosion even if cracks of significant width appear?
– Are there any technical capabilities to maintain the integrity of structural elements even after their final failure?
– Can polyurea be the material that will provide both protection of highly cracked elements against corrosion and their integrity following their failure?

This paper attempts to answer these questions. Note that the paper is not a comprehensive source of information on polyurea and its applications. In fact, it is a continuation of the authors' earlier studies [4].

2. EXPERIMENTAL RESEARCH

Six RC beams were subjected to laboratory bending tests. The elements were made of concrete characterized by an average compression strength of 72.30 MPa (tests of three cube specimens measuring 150x150x150 mm). The RC beams were reinforced with two #10 mm rebars in the compression area (the upper one) and two #14 mm rebars in the tension area (the lower one). The transverse reinforcement of the beams was made of #6 mm rebars in the form of clevises with the main spacing of 15 cm at the beam midspan and with smaller spacing of 10 cm in the support area. The dimensions and arrangement of the reinforcement used in the RC beams are shown in Figure 1.

All the RC beams were divided into two batches. The first batch (three specimens labeled as B.2.1, B.2.2, and B.2.3) were marked as control specimens and had no polyurea coating. The second batch (three specimens labeled as P.2.1, P.2.2, and P.2.3) were polyurea-coated on all their outer surfaces (Fig. 2).

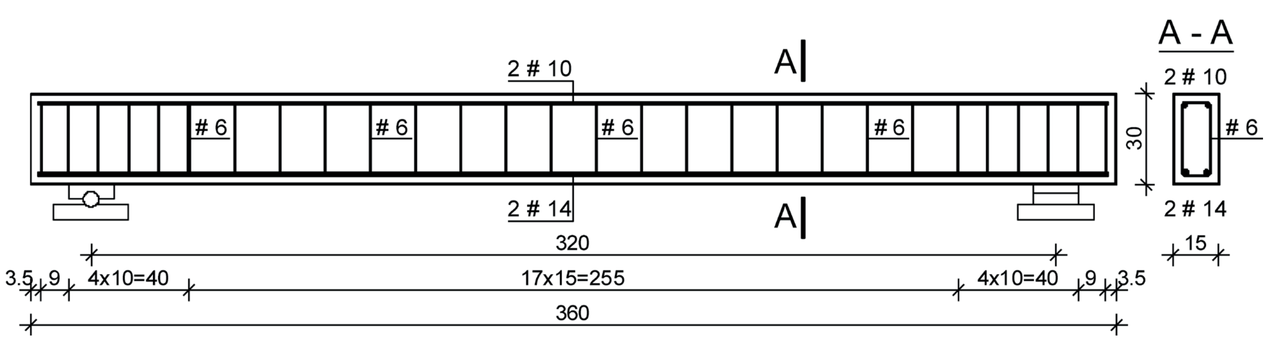

Fig. 1. The dimensions and arrangement of rebars in the RC beams (dimensions in cm)

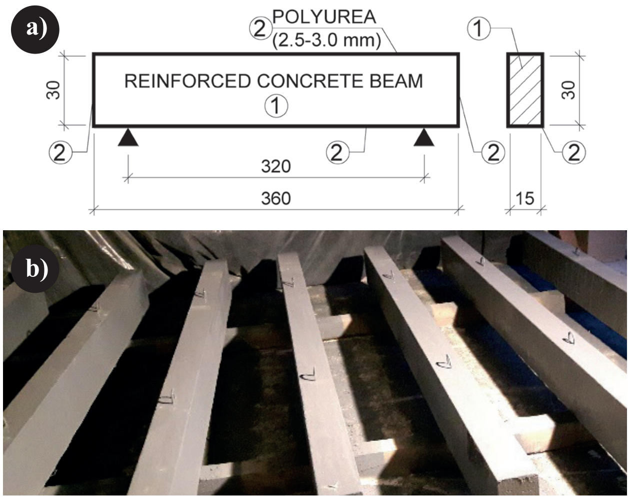

Fig. 2. Polyurea-coated elements: (a) application arrangement; (b) final polyurea-coated elements

The RC beams were coated with aromatic polyurea which is the most common type of coating used in the construction industry. The final product is obtained as a result of the reaction between an isocyanate component and a resin blend component at high temperature (between 65°C and 80°C) and at high pressure (between 120 bar and 200 bar). Aromatic polyurea is the reaction product of the methylenediphenyl diisocyanate (MDI) prepolymers as the isocyanate component and a multifunctional resin blend. The final product is characterized by a short bonding time and high levels of chemical and water resistance, and elasticity. The tensile strength of the coating was 24.08 MPa (at the test speed of 50 mm/min) and 23.03 MPa (at the test speed of 100 mm/min), and its engineering strain was 417% and 391%, respectively. The process of polyurea application involved three main phases: surface preparation of the RC beams (grinding to remove cement wash), prime coat application (two layers of prime coat and dry quartz sand), and polyurea coating application (two layers of the coating were applied with an average total thickness of 2.5 mm to 3.0 mm). Details on preparatory work before laboratory tests are given in the authors' earlier paper [4].

The RC beams of both batches were tested on one test stand whose general arrangement is shown in Figure 3.

The test stand was built using the following components: a steel main frame of the test stand, a steel

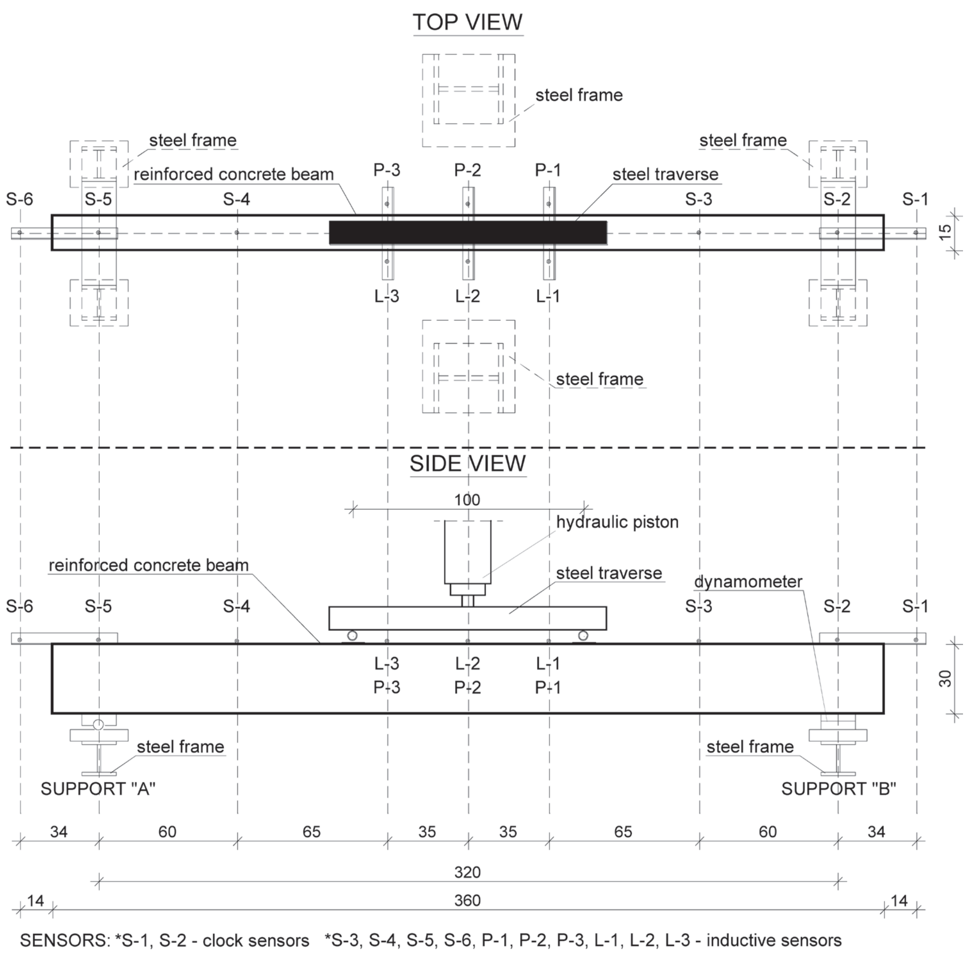

Fig. 3. The test stand

frame providing supports of the RC beams, a stand-alone steel frame supporting strain sensors, a hydraulic piston mounted to the upper part of the frame, a hydraulic pump driving the piston, and a computer workstation for data acquisition. The load was exerted on the RC beams by a steel traverse that was oriented symmetrically to the beam axis and produced load in the form of two concentrated forces 100 cm apart. Test specimens were positioned on the horizontal steel frame and supported pivotally at two points 320 cm apart along the axis. The test stand was also equipped with 12 sensors measuring the displacement of the RC beams while these were subjected to load. The set of 12 sensors included 10 inductive sensors and two dial gauges (marked as S-1 and S-2 in Fig. 3). A force gauge mounted under one of the pivot supports additionally recorded changes in response under each beam.

3. RESULTS

The main results collected during the tests, namely the relation between load and strain, the deflection of the beams, and the cracking state, are provided below.

The following quantities were measured during the tests: vertical displacements, the force exerted by the hydraulic piston, and the response at one of the supports. For the uncoated beams, forces exerted on the beams increased in steps up to a failure; in the case of the polyurea-coated beams, an unloading/loading cycle was applied. The value of the force was obtained from the indication of the device driving the hydraulic piston and also verified with a force gauge mounted between the piston and the traverse.

The relation between the force (exerted by the hydraulic piston) and the deflection of each beam at its midspan is shown in Figures 4 and 5.

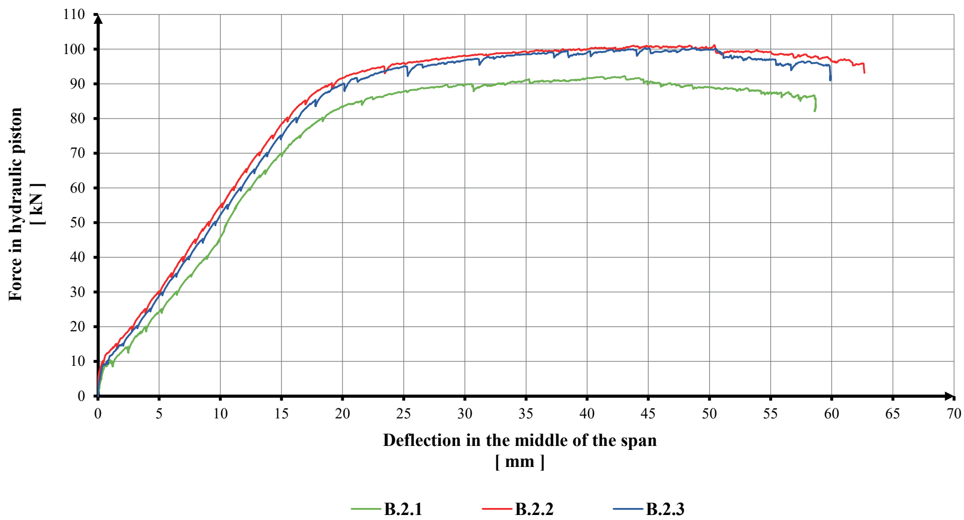

Fig. 4. The relation between the force exerted by the hydraulic piston and the deflection of the beams without any polyurea layer

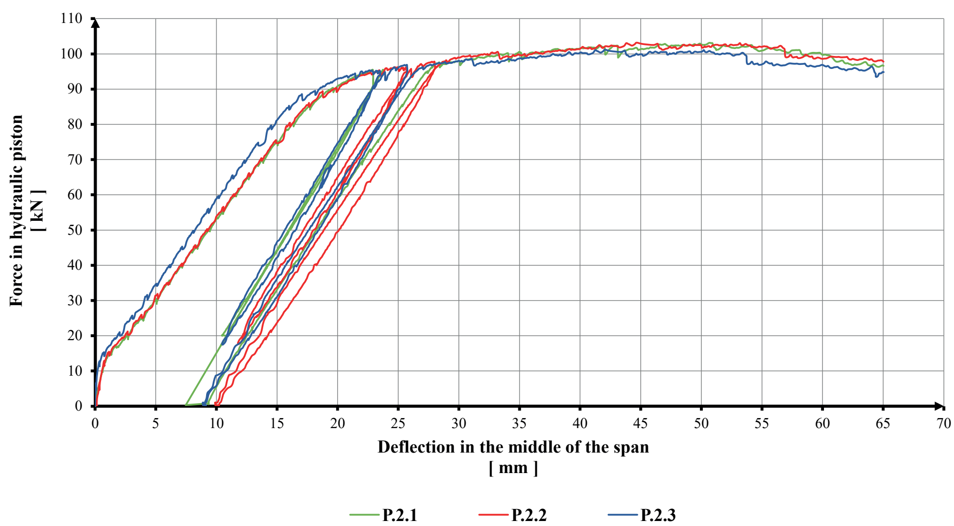

Fig. 5. The relation between the force exerted by the hydraulic piston and the deflection of the beams with a polyurea layer

The first and apparently the most important conclusion from the tests is that the application of the polyurea coating on the RC beams made it possible to additionally subject them to an unloading/loading cycle. The unloading point was set at 90% of the breaking force found for the uncoated reference beams. The load exerted on the specimens (P.2.1 to P.2.3) was removed as soon as it reached 90% of the breaking force obtained for the reference beams. Then, the specimens were again subjected to the load and exhibited their previous bending strength (the one they had before the unloading/loading cycle). The secondary strength (the one after the unloading/loading cycle) of the polyurea-coated RC beams was achieved without any excess increase in the deflection of these elements, i.e. with no loss in bending stiffness (Fig. 5). The following conclusion can be drawn on this basis: the main difference with respect to the behavior of the beams under load close to the breaking one is that polyurea-coated components can be subjected to the load for the second time with only small permanent deformations (very similar behavior was observed in the case of concrete rings [5]).

If we analyse the curves in Figure 6, we will notice that the values and curves of displacements of five out of six RC beams tested are comparable. We can see that in the initial phase of loading, when the beam stiffness mainly depends on properties of concrete, the displacements of the coated beams are smaller than those of the reference specimens. The differences between the curves of deformation of the specimens are smaller under a higher load, i.e. when the beam stiffness is related to characteristics of the reinforcing steel. The diagram (Fig. 6) shows that displacements of beam B.2.1 are the largest. The reason for this is that this beam was the first one that was loaded after the test stand was built, so the settlement of the test stand structure contributed to the deformations of this beam. It should be emphasized that the results for the other specimens are stable and coherent.

All the beams failed in a way that is characteristic of bent elements: the concrete was crushed (debonded) in the compression area of the beam cross-section, or the reinforcement yielded in the tension area of the beam cross-section. The failure of the reference beams occurred when concrete debonded in the upper (compression) area of the element cross-section. During initial phases of loading the reference beams, vertical cracks appeared in the middle part of these beams. As the load increased, the cracks elongated and widened. Finally, in accord with the characteristic failure mechanism of bent elements, the beams underwent a sudden failure as soon as the concrete strength in the upper part of the beam cross-section was exceeded. In contrast to the reference beams, the polyurea-coated ones failed when the reinforcement yielded in the lower (tension) area of these elements. In accord with the characteristic failure mechanism of bent elements, when the bending strength of the RC beams was exceeded, they indicated failure and failed as the reinforcement yielded in the lower part of the cross-section. At the same time vertical cracks widened rapidly near the area where the reinforcement yielded, and beam deflections increased.

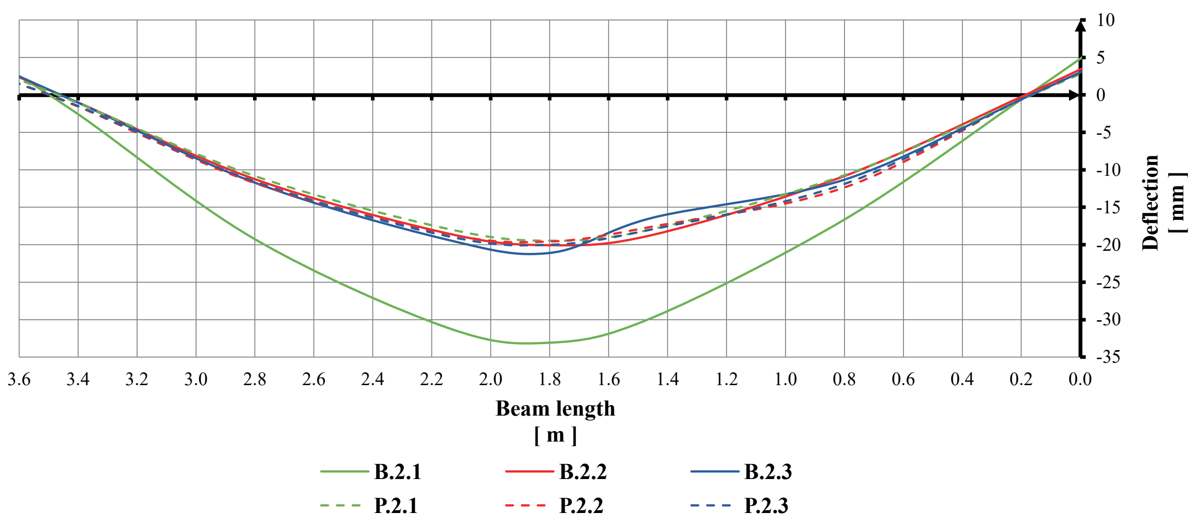

Fig. 6. Deflection of the beams under load equal to 90% of the breaking force

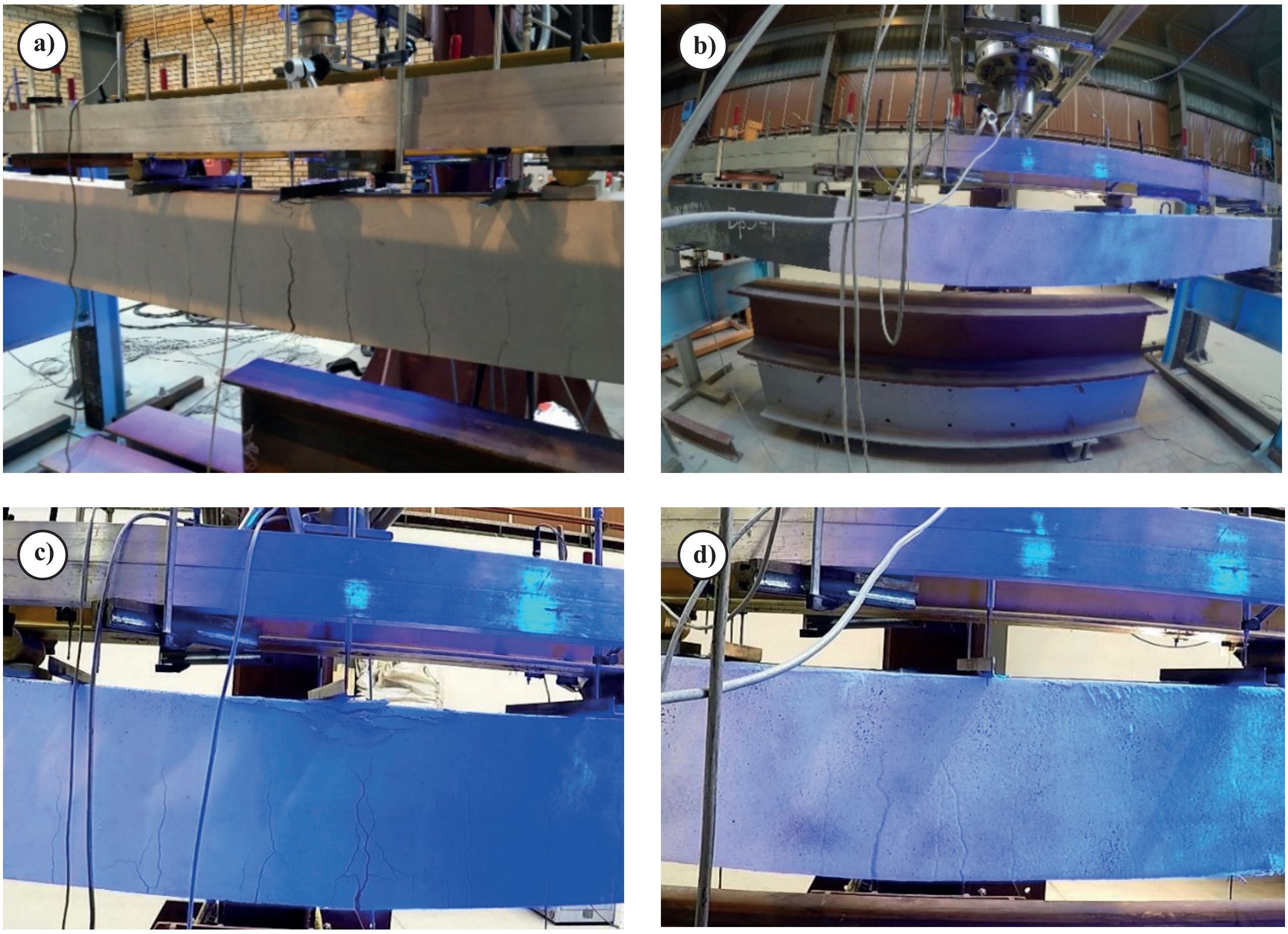

Fig. 7. Visible cracks: (a) (c) beams with no polyurea layer; (b) (d) a beam with a polyurea layer (wide cracks are fully covered)

The polyurea coating remained well bonded to concrete and covered all the cracks until the beams failed completely as a consequence of bending (the cracking states of both types of elements are compared in Fig. 7). Another crucial difference in the behavior of RC beams with and without the polyurea coating can be therefore underlined: in the case of the polyurea-coated elements, even very wide cracks remain impenetrable to factors that make the reinforcement corrode.

4. CONCLUSIONS

The tests described in the paper and the analysis of the results allow us to conclude that:

– The application of polyurea on RC elements makes it possible to subject them to load for the second time (after the load has been removed) even if 90% of the maximum breaking force was achieved.
– The polyurea coating is very efficient at bridging cracks of even significant wideness, limiting the exposure of the internal structure of reinforced concrete (an RC beam) to corrosive factors.
– Polyurea ensures integrity of RC elements even when too much load is exerted on them (no pieces of concrete fall off).

Considering these conclusions and the fact that the research work presented in the paper is only at its initial stage, it can be stated that further research in this area is likely to provide modern building engineering with valuable knowledge.

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