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**STRUCTURAL BEHAVIOUR AND COMPRESSIVE
STRENGTH OF CONCRETE RINGS STRENGTHENED WITH
A POLYUREA COATING SYSTEM**

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ABSTRACT: The study is the next part of the research project related to the possibilities of application polyurea coating in civil engineering. This project focus on the impact of polyurea coating applications mainly on steel, concrete and reinforced concrete components currently used in civil engineering. The main goal of the paper is a presentation of structural behaviour and compressive strength of concrete rings strengthened by spraying polyurea coating system. The work in initial parts focus on describe experimental test with used three different types of samples of concrete rings, supplemented with describe samples preparation and testing procedure. The emphasis was placed here on the description of polyurea coating system influence on mechanism of failure of the tested elements. The paper in the next parts focus on differences in structural aspects of concrete rings with dependency on how and which surface was covered by polyurea. The paper is supplemented with a presentation of results of experimental research, a formulation of conclusions, and an evaluation of the obtained findings.

Keywords: polyurea, coating system, concrete rings, energy absorbing materials, structural behaviour, compressive strength

1. INTRODUCTION

Concrete rings are relatively widespread type of structural elements in today's civil engineering. This type of components are used in sewage wells and systems, construction of culverts and in water. Nowadays, these prefabricated units are mainly designed for previously specified environmental conditions and loads. It causes that are not flexible in meaning of changing conditions. Every change of load state or/and service conditions may lead do unexpected single damage or even failure. It is especially important when we take into account that this kind of concrete structural members are used in very hard conditions.

Engineering practice shows that there are no solutions that could prolong the use of concrete rings by reinforcing them in a situation of environmental changes or modifications in the workload of the element. This research investigates a new external strengthening system and relates to polyurea coating system applications. The main advantage here is a quick preparation process that allow to secure the structural member by direct spraying the coating on its surface after appropriate preparation. This kind of technology can minimize the repair time and effort required to complete the external strengthening.

Polyurea coating system was invented in the 80's of the 20'th century in the United States, and very quickly appeared in Europe. The polyurea, also known as polyurea elastomer, is material which is created by reacting two components: isocyanate and resin blend. Mixing of the components takes place at high temperature (from 65^oC to 80^oC) and high pressure (from 120 bars to 200 bars) in specific proportions of the abovementioned mixture components. Some of the characteristics of the used spraying membrane are: very fast bonding time, very good chemical resistance and water resistance and high elasticity. Polyurea is characterised by low-out gassing, low shrinkage resistant to moisture

and well adhere with many materials (steel, plastic and concrete). It has also very good resistant to thermal shock and, above all, tightness, which makes this technology more and more widespread in the nowadays industry. Polyurea coating system is also used as waterproofing, or to protect concrete and steel structures against corrosion as well as in ballistic protection systems (Ref. 1-4).

In the recent years the researchers have been searching for application of this spraying coating as material that allows for strengthening structural members and the whole structures in typical construction site conditions. It is due to a fact that polyurea has very good adhesion to concrete, steel and more specific materials and can be easy applied in hard to reach places.

In elaboration of A. E. Marawan et al. (Ref. 5) there is a detailed discussion devoted to the issue of bending of reinforced concrete beams strengthened externally by spraying polyurea coating. A. E. Marawan et al. obtained surprising results concerning bearing capacity of the beams. It was noted and stated that utilized material can be used as material improving carrying capacity of reinforced concrete structures subjected to bending.

S. Parniani et al. (Ref. 6) focused on evaluation of fatigue and monotonic behaviour of concrete beams strengthened with polyurea coating. The Authors carried out an analysis of the results and stated, that an application of polyurea coating improves capacity against bending as well as ductility of reinforced concrete beams.

S. K. Ha et al. (Ref. 7) in their paper focused on structural behaviour and performance of fast-setting polyurea-urethane (PUU) lining as structural linear material for water pipes repair. The Authors found and

confirmed, on the basis of prior studies, that fast-setting PUU lining can be used as strengthening coating in order to repair water pipes.

In relation to the above, works (Ref. 5-7) present results which indicate that application of polyurea coating system can strengthen concrete (reinforced concrete) and steel structures. Analysis of this works and results was basic to propose polyurea coating system as strengthening solution for concrete rings (Ref. 2).

This paper is next part of the research project related to the possibilities of application polyurea coating in civil engineering and focuses on specific kind of concrete elements – concrete rings. Naturally, this work is complementary to studies related to the use this type of coating as a strengthening material for concrete (reinforced concrete) members. This article shows results of experimental tests concerning static compression of three types of concrete rings samples. Their most important experimental property: compressive strength has been analysed as far as the manner of application used material on specimens is concerned. The influence of the manner of application spraying coating on specimens on its failure mechanism has been also closely monitored.

2. EXPERIMENTAL INVESTIGATION

2.1. Description of used samples

The experimental tests were performed for nine concrete rings made with C25/30 W6 class of concrete strength of dimensions 0.80 m x 0.90 m (D x H) (Fig. 1).

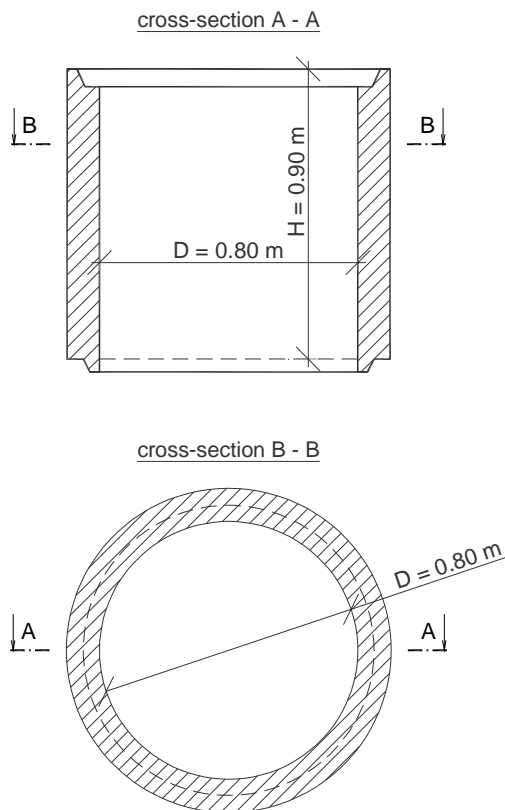


Fig. 1 Scheme of the concrete rings

In the test were used three types of specimens, namely:

- first type of samples are reference ones – three concrete rings without any additional coatings,
- second type – three concrete rings with polyurea coating system on external surface (Fig. 2),
- third type – concrete rings with spraying membrane on external and internal surface (Fig. 2).



Fig. 2 Tested concrete rings covered by polyurea coating system

2.2. Samples preparation

Concrete rings were purchased in a local prefab manufacturer. Before samples were strengthened with polyurea coating system, they were checked for possible damage and scratches. Next specimens were checked if their surface was clean, dry, free of oil and other substances which could have worsened the adhesion to the surface. Finally, concrete rings were painted by special primer suitable for concrete surface in combination with dried quartz sand (Fig. 3). The preparation of the surface is the most important stage in the process which mostly influence on quality of polyurea coating, so it was one of the most laborious stage of the experiment. After all, the specimens were ready for application used spraying membrane.



Fig. 3 Sample of concrete ring covered by special primer suitable for concrete surface in combination with dried quartz sand

The next step was to prepare the appropriate stand for spraying polyurea coating (spray chamber) to provide suitable application conditions – in accordance with the Product Data Sheet (PDS) given by the manufacturer. Before the concrete rings were spraying, humidity and temperature of the specimens and in the spray chamber were checked (Fig. 4).



Fig. 4 Measurement of temperature and humidity before application polyurea coating

Target polyurea spraying on concrete rings was made in the spray chamber after preheating the ingredients in two separate barrels to the right temperature ($25^{\circ}\text{C} \div 30^{\circ}\text{C}$). Bearing in mind that aggregate's settings play a prominent role in a quality of the used spraying system, the parameters of machine were checked before started application.



Fig. 5 Spraying polyurea coating system on concrete ring

The coating was applied in two layers, the first was sprayed directly on the isolated surface and the second directly on the first one in a perpendicular direction to first application. This allowed to be sure that coating would be completely rain-tight and without any welds (Fig. 5).

2.3. Materials

The concrete rings were made with C25/30 W6 class of concrete strength which is confirmed in Declaration of Conformity no. 4/02/2017 given by manufacturer.

Polyurea coating was made by material MasterSeal M 689 (BASF Polska). This product has 21.00 MPa tensile strength and 425% elongation, in accordance with the Technical Data Sheet (TDS).

2.4. Testing procedure

All specimens were tested in a laboratory where a suitable stand was constructed to perform static compression test (Fig. 6). Samples in the form of concrete rings were strained perpendicular to their longitudinal axis. The force was linear and uniform spread over their entire height. The load was applied through a hydraulic piston (Fig. 6). The force was linearly distributed on height of concrete rings through a very rigid billet of steel (Fig. 6). All samples were strained with a constant load increase corresponding to a piston stroke of 0.5 mm/s. Strain of elements was stopped when components were lost compressive of load capacity.



Fig. 6 Frame used in testing concrete rings

In the first phase of the tests, the compressive strength of the control specimens (without any coating) was checked to determine the reference level for further testing. In subsequent phases of the tests, static compression test of concrete rings with coating on one surface and on the end of tests, samples with coating on two surface were tested.

3. ANALYSIS OF EXPERIMENTAL RESULTS

3.1. Main results – ultimate load

The ultimate load – compressive strength of each concrete rings was determined by the peak load attained during test and listed in Table 1. The last column contains average compressive strength values for three samples of a given type, after rejecting extreme results significantly different from the other two.

Tab. 1 Experimental compressive strength of the examined elements

Type of samples	Sample no	Compressive strength [kN]	Average compressive strength [kN]
Reference samples (without any additional coatings)	1	58.84	57.60
	2	66.20	
	3	56.35	
Samples with polyurea on external surface	4	52.68	59.14
	5	58.87	
	6	59.40	
Samples with polyurea on external and internal surface	7	78.03	70.22
	8	70.59	
	9	69.85	

All specimens showed failure mechanism by scratch the concrete in extension zone of the elements. The average compressive strength for control samples was 57.60 kN, while the samples with polyurea coating on external surface were failed at average 59.14 kN that showed increasing in peak load about 2.7% (1.54 kN gained). The last type of samples with spraying membrane on both surface were failed at average 70.22 kN that showed increasing in peak load about 21.9% (12.62 kN gained).

In connection to the above, the main results indicated that used polyurea coating on both (internal and external) surface of concrete rings gave better results. In case of samples with spraying membrane on both surface increase in compressive strength was really noticeable and that increase was more than 20%.

3.2. Failure mechanism, deformation of elements

The research and measurement stand (Fig. 6) was equipped with a number of resistance strain gauges and sensors that measured the deformation of the cross section of concrete rings in two mutually perpendicular planes:

- vertical plane – parallel to the direction of applied load,
- horizontal plane – perpendicular to the direction of applied load.

The above mentioned sensors have allowed to control and record the deformation of the cross section of concrete rings depending on the applied load in real time. The data collected in this way was used to analyze the mechanisms of destruction of individual three types of tested samples.



Fig. 7 Concrete ring without any additional coatings after destruction

The first type of specimens (reference samples) – concrete rings without any additional coatings, were destroyed as previously predicted. This type of samples lost its bearing capacity by scratching the concrete in the extension zones situated on internal and external surface of the components. This scratching has already appeared with very small deformations of the cross section of the tested specimens. Failure mechanism of reference samples was always the same, it means concrete rings cracked up on four separately and smaller elements (Fig. 7).



Fig. 8 Concrete ring with polyurea coating on external surface after destruction and unloading

The second type of specimens – concrete rings with polyurea coating system on external surface, were destroyed in very similar way like first type. It should be note that after samples lost compressive capacity, they were still remained in one piece. This type of specimens lost its bearing capacity by scratching the concrete in the extension zones situated mainly on internal surface of the elements. The cross sectional deformation of the samples after their unloading decreased. Subsequently the shape of the cross section wanted to return practically to the initial state – shape of circle. After complete removal of the load, there were slight permanent deformations of the cross section (Fig. 8).



Fig. 9 Concrete ring with polyurea coating on external and internal surface after destruction and unloading

The third type of specimens – concrete rings with polyurea coating system on external and internal surface, also were destroyed by scratching concrete in the extension zones on perimeter of the element. Lost bearing capacity of this type of samples took place with significantly higher force in addition to first and second type of samples. Locally loosened concrete sites were not localized, as was the case with the second type of specimens. The cross sectional deformation of the samples after their unloading decreased. Subsequently the shape of the cross section wanted to return practically to the initial state – shape of circle. After complete removal of the load, there were very slight permanent deformations of the cross section (Fig. 9).

Examining the mechanisms of failure of the three types of concrete rings tested, it is clear that the polyurea coating system has measurable benefits. That was note in bearing capacity and has benefit influence for safety of using concrete rings. It should be emphasized that in the case of samples with used coatings, there was no complete destruction of the

elements – defragmentation into smaller pieces. From the point of view of their use in the construction industry is very good result, due to durability and safety of their use in the phase of breakdown.

Another important parameter was appeared during the testing of concrete rings. It was the reduction of the cross sectional deformation after completely unloading of the elements. The applied polyurea coating was flexible enough that after the unloading it wanted to return to the initial state. This phenomenon resulted in a significant reduction of the permanent deformation after unloading of the samples (Fig. 8, 9).

4. CONCLUSIONS

The main premise of this article was to presentation of possibility using polyurea coating system as strengthening of concrete rings together with description main results of tests and failure mechanism. Based on the experimental research and described results, a number of conclusions may be considered for polyurea coating system.

Key findings of this work are summarized below:

- the manner of application polyurea coating on concrete rings affects on their compressive strength. The highest bearing capacity is exhibited by samples with coatings on two surface, while the least by specimens without any coatings.
- the utilized system is very ease of application onto any surface (also onto curved surfaces).
- the used spraying membrane has ability of increasing stability of concrete rings under compressive load.
- the used material provides additional reinforcement for concrete rings and can increase compressive capacity by 21.9% for standard application in two layers on two surface of used samples.
- one of the most important aspect is that used coating on tested samples protected them from fragmentation and is retained its tightness in the phase of breakdown.
- moreover, further research is needed in order to explore the influence of polyurea coating system on structural members.

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