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# DETERMINING PROPERTIES OF POLYUREA COATINGS AS A MATERIAL POTENTIALLY STRENGTHENING STRUCTURAL ELEMENTS

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**ABSTRACT:** The paper discusses the results of experimental research on polyurea. In authors' opinion, this material could be used to improve load-carrying capacity and integrity of structural elements made of various materials. The paper presents the results of research on basic mechanical properties of polyurea, its impact on integrity of cellular concrete specimens and full-scale concrete rings. The additional polyurea layer on outer surfaces of test specimens improves mainly their integrity following their complete failure. It must be noted, however, that when the additional layer is present, it does not improve all strength properties of test specimens such as resistance to compression of cellular concrete specimens. It was revealed that this property may be negatively influenced by the level of constrainment.

**Keywords:** corrosion, durability of concrete elements, polyurea coatings system, concrete rings.

## 1. INTRODUCTION

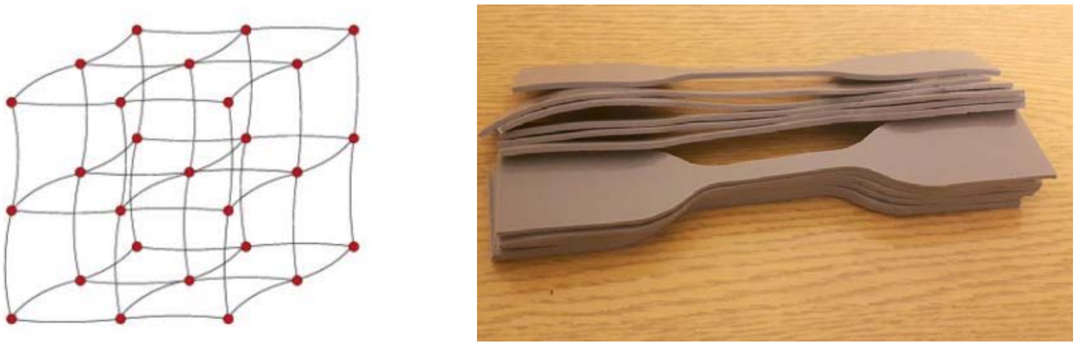
Industrialization and improper management of natural resources have led to changes in the environment exerting adverse impact on building structures. Such changes combined with often inadequate building operation practices result in deterioration of durability of structural elements, which in numerous cases makes a building less safe to use. Building operation, mechanical and corrosion-related damage, and material aging are aspects that are closely related with each other. Wrong practices of building operation or incorrect technical solutions are the reasons why repairs, refurbishments, renovations and reinforcements of structural elements often have to be made (Badowska et al. 1974, Baszkiewicz and Kamiński 2006, Bródka 1995).

Corrosion processes combined with improper operation and aging of structural elements lead to damage to building components, which necessitates additional spending during their lifetime. The severity of this global issue depends on the environment, climate zone, and quality of materials. Traditional building materials, such as concrete, steel, wood and isolating materials, are often characterized by inadequate durability and poor functional properties. This speeds up corrosion processes on the one hand and decreases strength of structural elements over time on the other so finally works are required to reinforce such elements. Thus, products that make it possible to improve a number of functional properties of a structure are gaining interest. The characteristics of building materials that are sought after include both protecting building elements against corrosion and aging and reinforcing them at the same time. Polyurea can be listed among products that have all the above characteristics (Banera et al. 2017, Gruener 1983).

This paper presents the application of polyurea coatings as a product used to reinforce structural elements and improve their functional properties such as protection against corrosion and aging. The focus is on demonstrating polyurea as a functional product suitable for reinforcing structures to ensure that their integrity is maintained after load-carrying capacities of structural elements have been exceeded.

## 2. POLYUREA COATINGS SYSTEM

Polyurea, a modern material unique in terms of its characteristics, was invented in 1980s in the United States. Polyurea coatings were used in Europe for the first time in 1990s, and the beginning of the 21st century saw a dynamic growth in the number of applications of this technology. In terms of materials science, polyurea is derived from the reaction of an isocyanate component and an amine blend and has a chain structure composed of ‘n’ molecules that are strongly cross-linked with each other (Fig. 1). Polyurea is an elastomer that is derived from the chemical reaction (polyaddition) of an aromatic or aliphatic isocyanate component and a multifunctional amine or an amine blend. Aromatic polyureas are derived from methylenediphenyl diisocyanate (MDI) while aliphatic polyureas from hexamethylene diisocyanate (HDI) or isophorone diisocyanate (IPDI), which form a stiff chain section (Banera et al. 2017, Szafran and Matusiak 2016, Szafran and Matusiak 2017).



a) b)

Fig. 1. Polyurea: a) chain structure, b) photo of samples.

## 3. POLYUREA – ADVANTAGES AND DISADVANTAGES

### 3.1. Advantages

In contrast to traditional isolating materials, polyurea membranes have excellent functional properties, chemical resistance, and mechanical strength. The material properties of polyurea that make it usable in a wide range of applications and are at the same time its advantages include (Banera et al. 2017, Szafran and Matusiak 2016, Szafran and Matusiak 2017):

- fast reactivity and bonding, which significantly reduces the time required to apply the product;
- adherence to most building materials after preparing the substrate for product application;
- resilience and elasticity in a wide range of temperatures below and above 0°C;
- high mechanical strength, with tensile strength of over 20 MPa and tear strength of over 50 MPa;
- high chemical resistance to most organic and inorganic acids, bases, salt solutions and amines;
- effective crack bridging; experimental studies have shown that a coating can bridge cracks up to 5 mm in width;
- UV resistance.

### 3.2. Disadvantages

In addition to unquestionable advantages, the polyurea coating technology has also its flaws which should be known to justify the use of the product. The main weakness of the technology is that certain technological rules have to be observed and special equipment is necessary to apply the system. Another requirement is preparation of the substrate before polyurea is applied with the preparation method depending on the type of the substrate. What also needs to be stressed is that you must not apply polyurea on surfaces that are dirty, oily and unprepared or in adverse ambient conditions, for instance when it is raining.

## 4. BASIC EXPERIMENTAL RESEARCH

Basic properties of polyurea coatings were determined for aromatic polyurea as the most common type of coating utilized in the construction industry. Basic tests were designed to determine mechanical properties of polyurea in terms of static tension according to EN ISO 527:2012. The tests were done to evaluate tensile strength of polyurea using dumbbell-shaped samples. The tensile strength of the material was determined for three test speeds of 50, 100, and 500 mm/min on a custom test bench (Fig. 2). All tensile tests were done on the INSTRON 5582 tensile tester. The results of polyurea tensile tests are shown in Figure 3 and Table 1.

Fig. 2. Tensile strength test of polyurea - test bench.

Tab. 1. Strength characteristics of a polyurea coating.

| Test speed [mm/min] | Number of tests [-] | Tensile strength [MPa] | Engineering strain [ % ] |
|---|---|---|---|
| 50 | 5 | 24.08 | 417 |
| 100 | 5 | 23.03 | 391 |
| 500 | 3 | 19.47 | 332 |

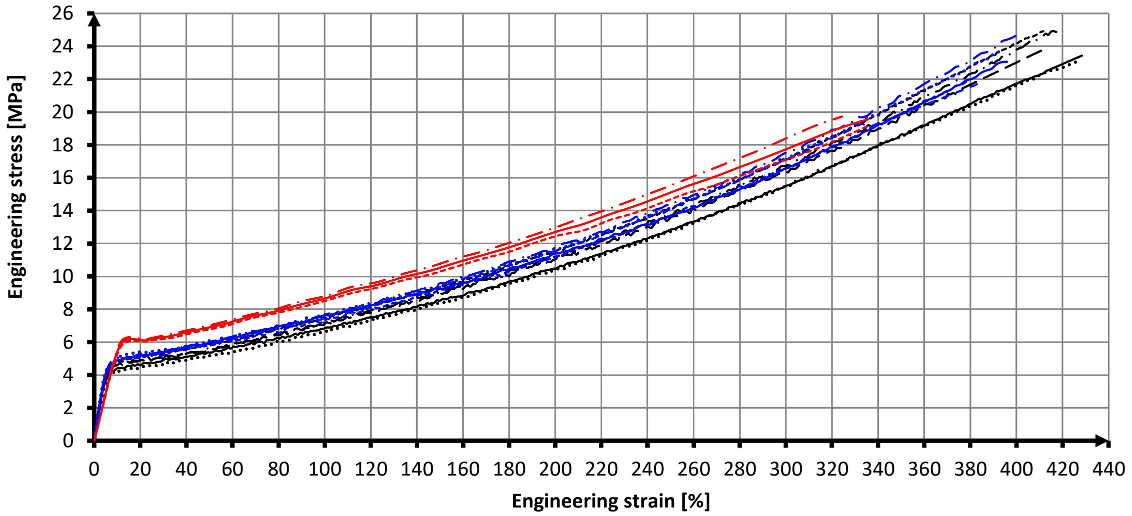


Fig. 3. Diagram – engineering stress vs. engineering strain.

The coating tensile strength was 24.08 MPa with engineering strain of 417% at the test speed of 50 mm/min, 23.03 MPa with engineering strain of 391% at the test speed of 100 mm/min, and 19.47 MPa with engineering strain of 332% at the test speed of 500 mm/min (Table 1). The analysis of the results confirmed that the tensile strength and the nominal engineering strain of the membrane depend on the test speed, and these properties are lower at higher specimen loading speeds.

The test stand was also equipped with an infrared camera which recorded changes in temperature of specimens while they were subjected to tension. Thermal imaging is currently used in a number of industries such as the construction industry, in laboratory tests and during inspections of building facilities. Thermal images can help localize defects (failures) in construction materials during their normal operation (Szczepanik et al. 2008). Thermal imaging was used during the tests of all batches of specimens to record their temperature distribution on an ongoing basis during the tensile test. All the specimens were positioned at the same distance from the infrared camera, and their surface temperatures were measured over time. The graph of specimen surface temperature vs. time is shown in Figure 4.

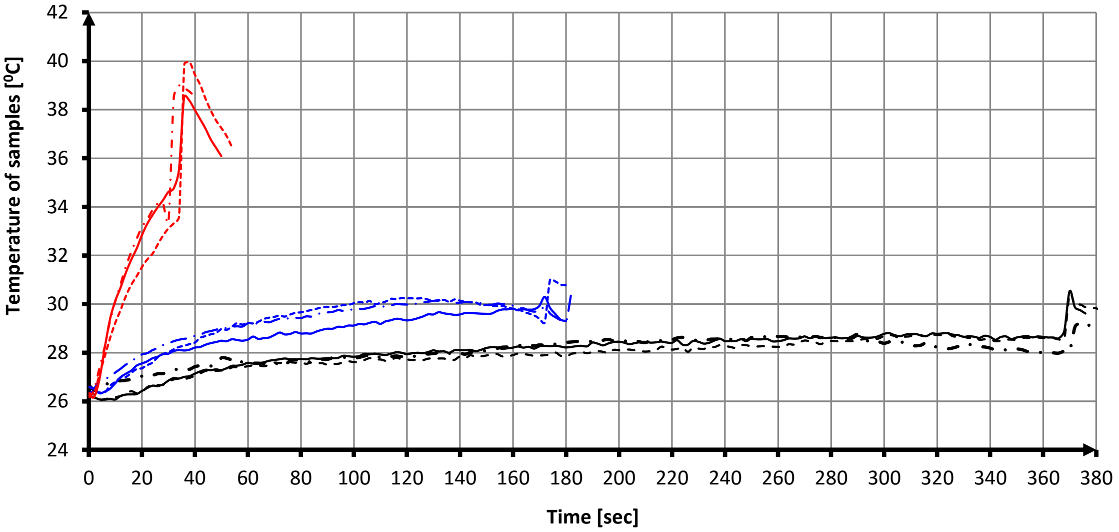


Fig. 4. Diagram – temperature of specimens vs. time.

The average maximum recorded temperature was 28.8°C at the test speed of 50 mm/min, 30.6°C at the test speed of 100 mm/min, and 39.2°C at the test speed of 500 mm/min (Fig. 4). The analysis of the results indicates that stretching polyurea specimens is an exothermic process during which the material warms up and transfers heat to the environment. Peaks of the maximum recorded temperatures depend on the coating test speed, and their values are higher at higher specimen loading speeds. It can be also concluded that the recorded temperature gradients will have no significant effect on the performance of polyurea-coated structural elements.

## 5. SIMPLE PHYSICAL TESTS

Examples of simple physical tests of polyurea coatings were tests designed to determine compressive strength of cellular concrete specimens covered with a polyurea coating. The tests were done according to EN 772-1:2015 on three types of cylindrical specimens 10 cm in diameter: type I – control samples without any coating, type II – samples with a polyurea coating on their circumference, and type III – cylindrical samples covered with polyurea on their whole surface (Fig. 5). The compression strength of cellular concrete specimens was determined using a specially designed test stand (Fig. 6) at a test speed of 3.0 mm/min. All compression tests were done on one INSTRON 3384 tensile tester. The results of the cellular concrete compression strength tests are listed in Table 2.


a) b) c)

Fig. 5. Cellular concrete samples: a) type I - control sample, b) type II - sample with a polyurea on its circumference, c) type III - sample with polyurea on its whole surface.

Tab. 2. Strength properties of cellular concrete specimens.

| Specimen batch designation [-] | Test speed [mm/min] | Number of tests [-] | Breaking force [kN] | Breaking stress [MPa] |
|---|---|---|---|---|
| Type I | 3.0 | 8 | 24.21 | 3.08 |
| Type II | 3.0 | 8 | 23.95 | 3.05 |
| Type III | 3.0 | 8 | 18.65 | 2.37 |

Compressive strength of cellular concrete specimens was 24.21 kN at the breaking stress of 3.08 MPa for the uncoated elements, 23.95 kN at the breaking stress of 3.05 MPa for the elements with the coating on their circumference, and 18.65 kN at the breaking stress of 2.37 MPa for specimens with the coating on their whole surface. For the cylindrical specimens, breaking forces and breaking stresses depend on how the polyurea coating was applied. The results indicate that both these properties are lower for the polyurea-coated specimens. The reason for this might be that constrained specimens have no capacity to deform, which is more evident at a higher level of constrainment.

Fig. 6. Compressive strength test of cellular concrete - the test bench.

The cracking pattern in the specimens was in line with deformation of cylindrical elements under compressive load. In the case of the uncoated specimens (type I), slightly oblique vertical cracks appeared already at small values of the compressive force, and when it increased, the cracks lengthened and their number grew at the circumference of the specimens. Finally, the specimens undergone a complete failure after cracks occurred in the whole volume of the specimens and the internal structure of the material delaminated (Fig. 7a). In the case of the polyurea-coated specimens (types II and III), cracks appeared according to the same mechanism as for the uncoated elements. The polyurea coating efficiently covered the surface cracking to the extent that the cracks were not visible even at high levels of deformation of the specimens (Fig. 7b).

a) b)

Fig. 7. Deformations and failures of specimens under load:
a) type I - control sample, b) type III - sample with polyurea on its whole surface.

All the specimens failed in a characteristic conical way similar to that of concrete specimens in compression strength tests (Fig. 8). In contrast to control samples (type I), the polyurea-coated specimens (types II and III) kept their integrity after the maximum load was exceeded.

Fig. 8. Cellular concrete samples after the failure.

## 6. FULL-SCALE TEST

Tests of full-scale structural components were done using concrete rings of 800 mm in inner diameter and 900 mm in height with a shell of 100 mm in thickness. The tests aimed at assessing the crushing strength of concrete rings reinforced with a polyurea coating. The crushing strength of concrete rings was determined according to EN 1917:2002. Nine C25/30 concrete rings were subjected to the crushing strength test. Three components comprising the first batch were marked as control samples and were not polyurea-coated (Fig. 9). Three components of the second batch were coated with polyurea on their outer surface (Fig. 10). Three components of the third batch were coated with a membrane on their inner and outer surface (Fig. 11).

Fig. 9. Concrete ring after failure: type I.

Fig. 10. Concrete ring after failure: type II.

Fig. 11. Concrete ring after failure: type III.

During the tests of the concrete rings, cracked cross-sections were observed. Cracks appeared on tension surfaces of the shell, i.e. according to the deformation of the cross-section under load (Fig. 12). For concrete rings without the polyurea coating (type I), for the maximum load exerted on the components, the largest cracks measured about 0.4 mm in width. When the maximum load was exceeded, the cracks virtually did not develop in the components up to the point of final failure of the components. Observing cracks in polyurea-coated concrete rings (type II and III) was practically impossible. Polyurea effectively bridged the cracks to the extent that only those about 2 to 5 mm in width were visible. Since the polyurea coating covered the cracks, their widths could not be reliably measured. The application of the polyurea coating on the concrete rings had no impact on the mechanism of crack occurrence and development in the cross-section of the test objects.

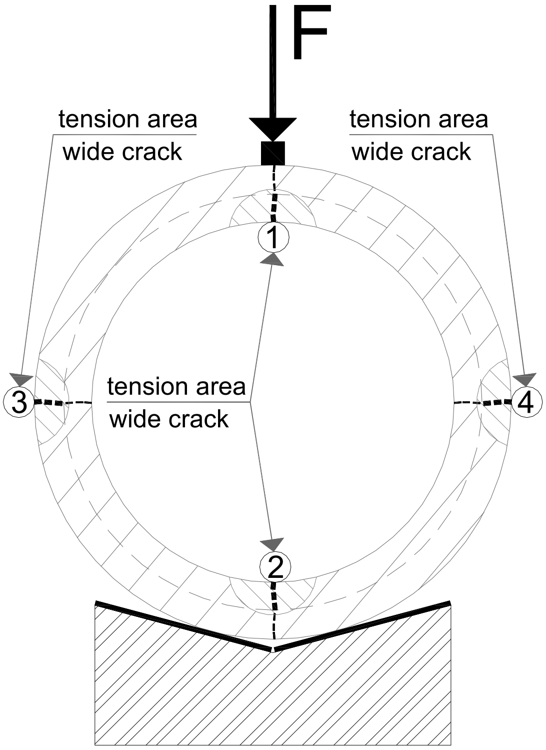


Fig. 12. Cracks occurring in concrete rings during the test.

The control samples (type I), i.e. the concrete rings without any coating, failed dynamically upon exceeding their crushing strength. In line with the classical theory of a failure mechanism, these components broke up into four smaller separate pieces (Fig. 9). The concrete rings with polyurea coatings on their surfaces (type II and III) failed when they were largely deformed and the concrete cracked in tension areas (Fig. 10, Fig. 11). The samples finally lost their load-carrying capacity with the largest deformations. Despite very large straining, the polyurea coating remained continuous on surfaces of the shell.

Tab. 3. Results of the crushing strength tests of concrete rings.

| Sample | Crushing strength [kN] | Average crushing strength [kN] | Load-carrying capacity gain over control samples |
|---|---|---|---|
| **C-1** | 58.8 | **60.5** | - / - |
| **C-2** | 66.2 | | |
| **C-3** | 56.4 | | |
| **E-1** | 52.7 | **57.0** | **- 3.5 kN**<br>**- 5.8 %**<br>(no effect) |
| **E-2** | 58.9 | | |
| **E-3** | 59.4 | | |
| **A-1** | 78.0 | **72.8** | **+ 12.3 kN**<br>**+ 20.3 %** |
| **A-2** | 70.6 | | |
| **A-3** | 69.8 | | |

Table 3 summarizes the relation between the crushing strength and the limit load of each type of concrete rings. Average values of the crushing strength out of three tests of each type of samples were also calculated and are given in Table 3.

The analysis of the results showed that the crushing strength of the components coated on both surfaces was higher by 20%, and polyurea helped the rings maintain their integrity after their crushing strength was exceeded (Szafran and Matusiak 2020).

## 7. CONCLUSIONS

The main goal of the considerations and tests described in the paper was to present polyurea coatings as a product that improves functional properties of structural components. Based on the results of the experimental research and their analysis, the following conclusions can be drawn:

- polyurea has unique functional properties and can be used in a number of modern industries,
- due to its extraordinary elasticity and adherence to the substrate, the product considered in the paper can efficiently bridge cracks in concrete elements and thus help protect them from corrosion and aging,
- the application of the coating on elements made of brittle materials, such as cellular concrete, has a positive impact on their ability to maintain integrity after their compressive strength was exceeded,
- the polyurea provides additional reinforcement improving the crushing strength of concrete rings,
- the application of the coating on concrete rings makes them maintain their integrity after their crushing strength was exceeded.

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