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ANALYSIS OF THE ASSESSMENT OF THE CONSUMPTION STATE OF CONCRETE ABRASIVE SURFACES USING SPATIAL SCANNING

ANALIZA OCENY STANU ZUŻYCIA ŚCIERANYCH POWIERZCHNI BETONOWYCH Z ZASTOSOWANIEM SKANOWANIA PRZESTRZENNEGO

Key words: abrasion resistance, spatial scanning, surface damage, underwater concrete.

Abstract The article presents the results of the analysis of surface damage of abraded underwater concretes with the use of spatial scanning. The concrete abrasion test was carried out using the ASTM C1138 underwater method. Spatial scanning was used to prepare a map of wearing of the abraded surfaces of the specimens. This map enabled a better prognosis of the abrasion wear of the concrete, particularly in the context of designing hydrotechnic reinforced concretes.

Słowa kluczowe: odporność na ścieranie, skanowanie przestrzenne, uszkodzenia powierzchni, betony podwodne.

Streszczenie W artykule przedstawiono wyniki analizy uszkodzeń powierzchni ścieranych betonów podwodnych z zastosowaniem skanowania przestrzennego. Badanie ścieralności betonów wykonano metodą podwodną wg ASTM C1138. Skanowanie przestrzenne umożliwiło wykonanie mapy zużycia powierzchni ścieranych próbek, która pozwoliła na lepsze prognozowanie zużycia ściernego betonu, szczególnie w aspekcie projektowania betonów hydrotechnicznych ze zbrojeniem.

INTRODUCTION

Taking into account environmental actions in designing objects and structures, together with static and dynamic loads, can be important for the durability and safe use of the designed objects. Hydrotechnic concrete structures are exposed, among others, to the erosive action of the environment caused by the solid particles transported by the water (water erosion) and the air (wind erosion). The concrete for making hydrotechnic structures, besides the specified compressive strength, should also have the highest possible wear resistance. The abrasion wearing caused by the river or sea debris, transported by the water, is different than the abrasion of the road pavements or airfield plates **[L. 1–3]**.

In the investigation of the abrasion wear of concrete or other materials, it is necessary to select a method that can best reflect the abrasion of the material in the natural environment. The most often used method of testing the abrasion of concrete in EU countries is Boehme's disk, according to PN-EN 14157. However, this method does not reflect the mechanism of the wear of the concrete observed in the hydrotechnic structures [**L. 4–5**]. The most often method used for testing the wear resistance of concrete for the hydrotechnic structures is an American method, which is called the "underwater method", according to ASTM C1138 [**L. 6–8**]. The underwater method is intended for testing the wear resistance of the concrete surfaces in hydrotechnic structures. It simulates the conditions of the wear of concrete under abrasion, which are present on the surfaces of the hydrotechnic structures as a result of the movement of debris transported by the water. The method consists in the wearing of the surface of the concrete specimen placed on the bottom of a steel cylinder. The abrasive materials are steel balls of various diameters placed in the water in which the specimen is immersed. The balls are moved by a special stirrer. The use of the underwater

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method makes it possible to determine the average abrasion wear of the concrete. However, it is impossible to determine the maximum depth of the losses. To determine the maximum losses of concrete, a 3D scanner was employed after wearing. The scanner was also used for preparing a map of the wear of the abraded surfaces of the specimens. This map enabled better prognosis of the abrasion wear of the concrete, particularly in the context of designing hydrotechnic reinforced concretes.

RESERCHER MATERIALS

One cubic meter of the concrete was prepared using Portland cement CEM I 42.5 R with the density 3.1 kg/m^3 (400 kg), river sand up to 2 mm (593 kg), natural gravel aggregate with the maximum grain diameter 16 mm and density 2.64 kg/m^3 (1110 kg), polycarboxylate superplasticizer (8 kg), and a viscosity modifying admixture (4 kg). The water to cement ratio of the concrete was 0.4. The compressive strength of concrete after 28 days of curing in water was 54.45 MPa.

RESEARCH METHOD

The abrasion tests were conducted using the underwater method according to ASTM C1138. The cylinder specimens with a height 100 ±13 mm and a diameter of about 6 mm are placed (with the tested surface upwards) and tightly fitted in the testing container, which is steel pipe with the internal diameter 305 ±6 mm and height 450 ±25 mm. The rotating machine is a drill or similar machine keeping the stirrer, which makes the abrasive moving in rotational-vertical way at the bottom, with the speed 1200 ±100 rotations per min. The scheme of the testing machine used in the underwater method is presented in the **Fig. 1**.

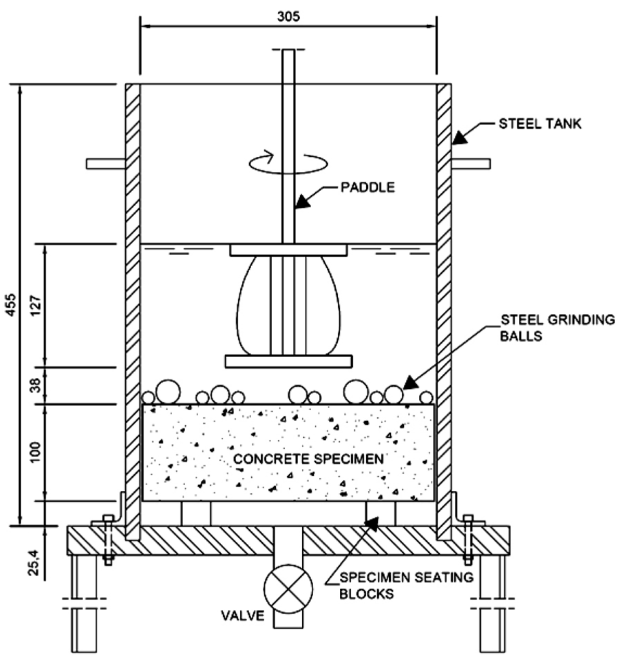

Fig. 1. Scheme of test apparatus according to ASTM C 1138
Rys. 1. Schemat urządzenia badawczego wg ASTM C 1138

Seventy balls made of the chrome steel with the nominal diameters from 0.5” to 1.0” are used as the abrasive. The balls (after weighing) are placed on the surface of the specimen and the system is immersed in water up to the level 165 ±5 mm. Then the stirrer with the specific shape is run with the given speed. According to the requirements of the ASTM C1138, the specimen should be worn within at least 3 cycles of 12 hours each. In the presented investigation, the specimens were worn for 72 hours (6 cycles of 12 hours each). The specimens were weighed after each cycle, following their rinsing and superficial drying. Determination of the wearing losses is performed by the determination of the average depth of wear at the end of each period ADA_t, m. This is the ratio of the volume of the material lost in the given period VL_t, m^3, to the surface area of the specimen A, m^2.

In the presented tests, the specimens were abraded after 28 and 56 days of curing, with 3 specimens for each time of curing.

An optical scanner, Atos Triple Scan produced by the GOM Company, was used for imaging the specimens’ surfaces after abrasion tests. The scanner was installed on the industrial robot with integrated rotating table. **Fig. 2** presents an industrial robot with the optical scanner. The measurement, after preparing the head movements, was conducted in the automatic cycle, enabling the best repeatability of the scanning conditions (positioning of the head and external lighting). The head is equipped with a structural light emitter and a two-camera optical system. This makes possible scanning the surface and photogrammetric measuring the reference points (markers), which enables joining the scans from different directions. A specimen with visible markers on the surface is presented in **Fig. 3**. The LED technology and use of the narrowband (blue) filters enable the significant reduction of the influence of infrared radiation. The average time of the measurement of one specimen in the automatic cycle was about 1 minute and covered the measurements done from four directions, selected by the operator. ATOS Professional V8.0 software was used for data processing.

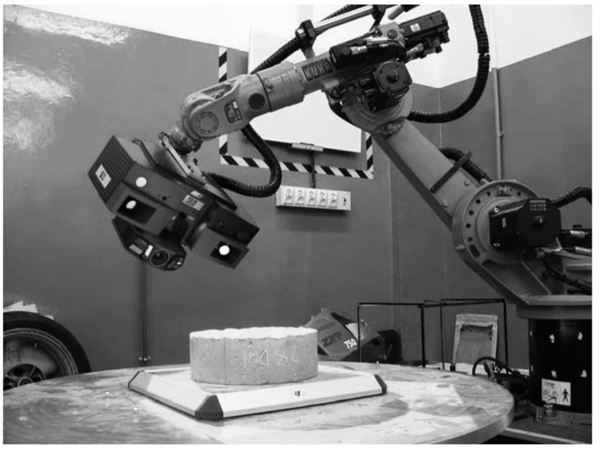

Fig. 2. Industrial robot with the optical scanner Atos Triple Scan
Rys. 2. Robot przemysłowy ze skanerem optycznym Atos Triple Scan

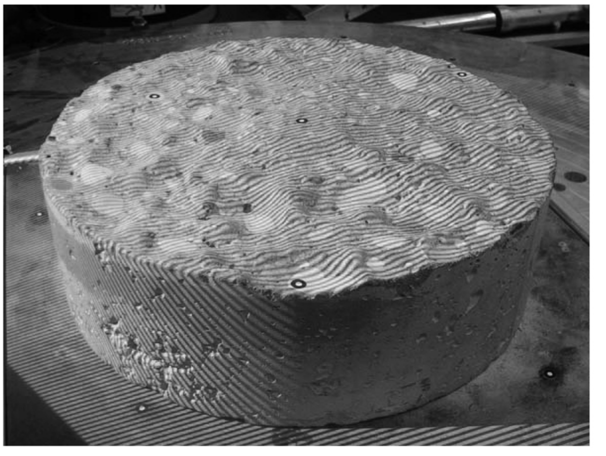

Fig. 3. Concrete specimen during scanning
Rys. 3. Próbka betonowa w trakcie skanowania

RESULTS

The average value of the depth of the abrasion loss (depth of wear – DOW) is a final result of the testing of abrasion using the underwater method. The use of the 3D scanner enables not only the determination of the average value of DOW, but also the maximum value of DOW, which is very important in the case of materials with various hardnesses of the components. This is particularly significant for the reinforced concretes, where information on DOW_{max} affects the estimation of the thickness of the concrete cover of the reinforcement. The results of measurements for the tested specimen are presented in **Tab. 1.** The used software also enabled the development of the spatial image of the surface of the worn concrete and a very accurate map of the losses and wear profiles at any place on the specimen surface (**Fig. 4**). Such information on the wear of the surface makes it possible to better design structural and repair concretes considering their required abrasion resistance. An additional advantage is the fact that the time of measurement after positioning the scanner is about one minute. In the case of the underwater method, the weighing of the specimens on the hydrostatic balance is very labour-consuming.

Table 1. Results of abrasion testing of the concrete
Tabela 1. Wyniki badań ścieralności betonu

Underwater method		3D Scan			
ADA_t [mm]	average volume [cm^3]	ADA_t [mm]	average volume [cm^3]	DOW_{min} [mm]	DOW_{max} [mm]
9.75	6760	9.80	6843	4.71	–11.14

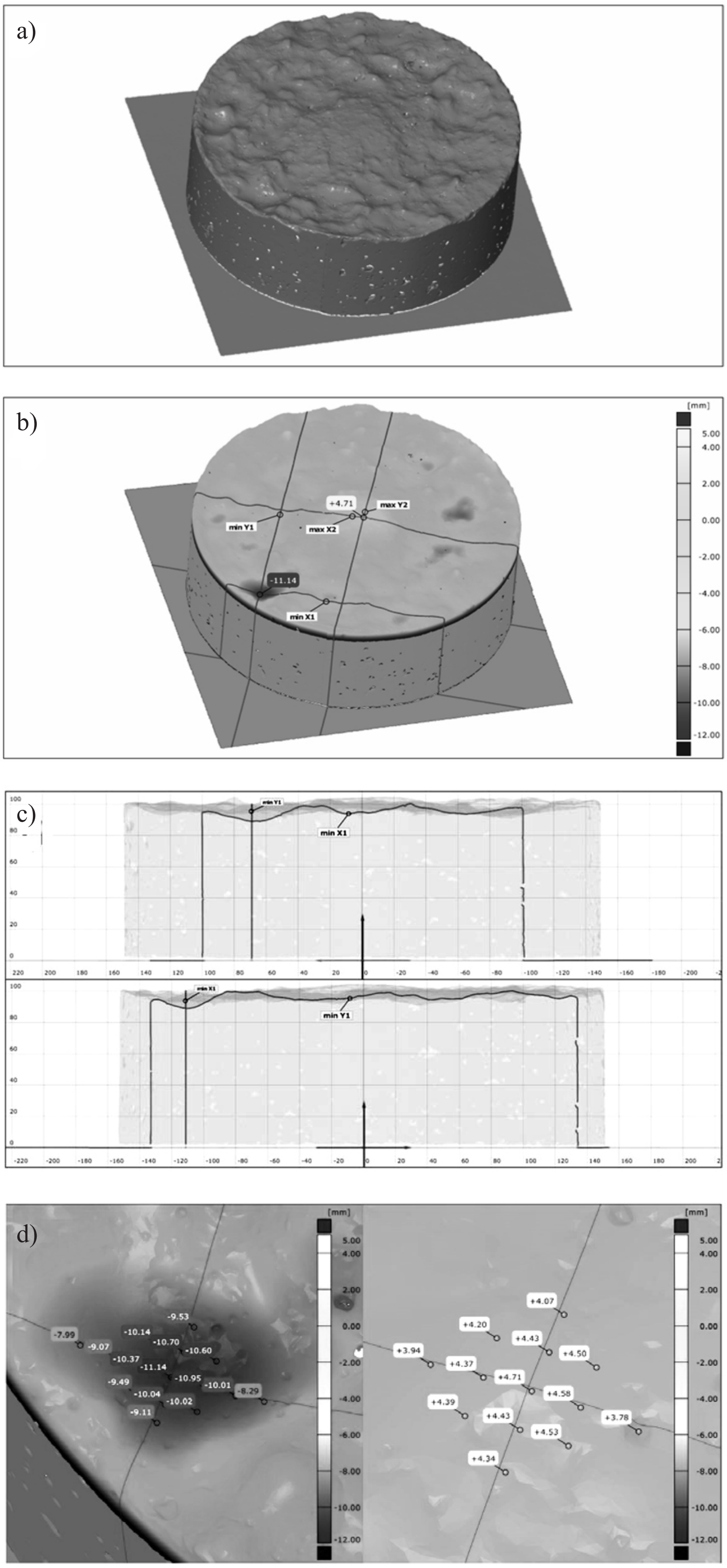

Fig. 4. Results of imaging of the surface of the specimen worn by the underwater method using spatial scanning: a) specimen image, b) spatial map of the worn surface, c) example of the sections done in the point of DOW_{max}, d) detailed image of 3D surface in points

Rys. 4. Wyniki obrazowania powierzchni próbki ścieranej metodą podwodną z zastosowaniem skanowania przestrzennego: a) obraz próbki, b) przestrzenna mapa powierzchni ścieranej, c) przykładowe przekroje wykonane w punkcie DOW_{max}, d) szczegółowy obraz powierzchni 3D w punktach: DOW_{max} i DOW_{min}

CONCLUSIONS

The imaging of the surfaces of the worn concrete specimens by the spatial scanning method enables one to obtain a very accurate description of the specimen's surface at any place. The use of professional software makes it possible to develop spatial surface maps of the concrete abrasion and profiles of the specimen geometry at any location. In this way, it is possible to more effectively design repair materials and structural concretes for hydraulic objects.

The 3D scanner also enables one to significantly shorten the time of measurements of the specimens' abrasion with a hydrostatic balance used in the underwater method according to ASTM C1138.

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