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Use of a 3D scanner for imaging concrete sample surfaces abraded with the ASTM C 1138 method

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Abstract

In the case of most concrete constructions, aggression caused by abrasion is not the basic type of destructive environmental impact. However, in the case of certain structures, such as hydraulic constructions, it is indeed a basic impact. In addition to corrosion, the largest proportion in the general destruction of concrete hydro structures is made up by erosion from debris, wind and ice. In tests of abrasive wear on concrete, the so-called underwater method, which is described in detail in the American Standard ASTM C 1138. The abrasive wear of a concrete sample is the result of the surface impact of test steel beads placed in water and set in motion by means of a stirrer. The result of the test is the average sample area consumption, calculated using the weight loss of the concrete sample during the test. However, this method does not allow for an accurate display of the sample surface. There is no possibility of determining the size of the maximum wear of depth.

In surface imaging tests of concrete samples subjected to abrasion, in the device using the ASTM C 1138 method, an Atom Triple Scan GOM optical scanner was installed on an industrial robot with an integrated rotary table. Thanks to the use of a 3D scanner, it was possible to compile a map of the concrete sample surfaces. The scanner software allowed cross profiles to be made at any place in the samples tested. Thanks to the exact depiction of the abraded concrete surfaces used, it is possible to properly assess the concrete used in hydraulic constructions and as a repair material.

Keywords: abrasion resistance; 3D scanner; surface damage; hydrotechnical construction; underwater method

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1. Introduction

Besides static and dynamic loads, engineering objects and structures are exposed to environmental actions, which can have significant effects on theirdurability and safety in use. The intensity of these direct actions is the basis for categorization of the environment, taking into consideration, among others: the results of cyclic freezing and thawing of the concrete, the influence of carbon dioxide, the action of the sodium chloride used for de-icing or contained in sea water, as well as the chemical corrosion of concrete, which leads to the destruction of the cover of the reinforcing steel; and abrasive wearing of the surfaces of concrete elements and structures. Hydrotechnical concrete structures are exposed to, among other things, the erosive action of the environment caused by solid particles transported by water (water erosion) and air (wind erosion). The concrete for making hydrotechnical structures, besides having the specified compressive strength, should also have the highest possible wear resistance. Abrasive wearing caused by river or sea debris, transported by water, is different from the abrasion of road pavements or airfield plates [1].

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In the investigation of the abrasive wear of concrete or other materials, it is necessary to select a method which can best reflect the abrasion of the material in the natural environment. The most often used method for testing the abrasion of concrete in EU countries, is Boehme's disk, described in EN 14157 [2]. However, this method does not reflect the mechanism of concrete wear, as observed in hydrotechnical structures [3-5]. The most often used method for testing the wear resistance of concrete in hydrotechnical structures is an American method: the so-called underwater method, described in ASTM C1138 [6]. The underwater method is intended for testing the wear resistance of concrete surfaces in hydrotechnical structures. It simulates the conditions of concrete wear under abrasion, which is present on the surfaces of hydrotechnical structures, as a result of the movement of debris transported by water. The method consists of the wearing of the surface of a concrete specimen, placed at the bottom of a steel cylinder. The abrasives are steel balls of various diameters, placed in the water in which the specimen is immersed. The balls are moved by the action of a special stirrer. The testing of concrete abrasion with the underwater method is described in detail in section 2.2, below.

The use of the underwater method makes it possible to determine the average abrasive wearing of concrete, though it is not possible to determine the maximum depth of the losses, in this manner. To determine maximum losses, a 3D scanner was employed after wearing. The scanner was also used for preparing a map of the wearing on the abraded surfaces of the specimens. This map enabled a better prognosis of abrasive wear, particularly in the context of designing hydrotechnical reinforced concretes.

2. Materials and methods

2.1. Materials

One cubic meter of concrete was prepared using Portland cement CEM I 42.5 R, with a density of 3.1 kg/m^3 (400 kg), river sand up to 2 mm (593 kg), natural gravel aggregate with a maximum grain diameter of 16 mm and a density of 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 the concrete, after 28 days of curing in water, was 54.45 MPa.

2.2. Abrasion testing

The abrasion tests were conducted using the underwater method, according to ASTM C1138 [6]. The scheme of the testing equipment used in the underwater method is presented in Fig. 1. Cylinder specimens with heights of 100 ± 13 mm and diameters of about 6 mm, were placed in the testing container (with the tested surface facing upwards), which was a steel pipe with an internal diameter of 305 ± 6 mm and a height of 450 ± 25 mm, with a tightly fitted base. A rotating machine, such as a drill or similar machine, was used as the stirrer, making abrasive movements in a rotational-vertical way at the bottom, with a speed of 1200 ± 100 rotations per min.

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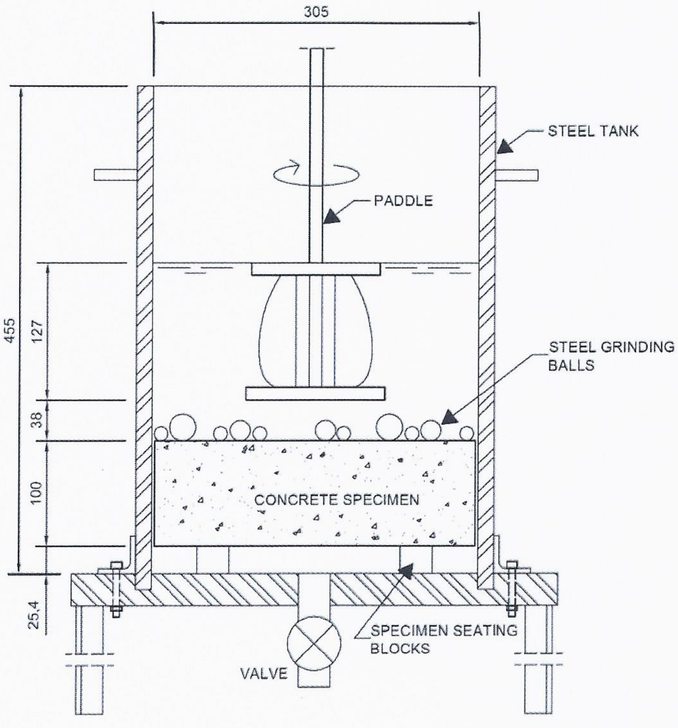

Fig. 1. The scheme of test apparatus according to ASTM C 1138 [6].

Seventy balls made of chrome steel, with nominal diameters between 0,5" and 1,0", were used as an abrasive. After weighing, the balls were placed on the surface of the specimen, with the system then being immersed in water up to a level of 165 ± 5 mm. A stirrer with a specific shape was then run with the given speed. According to the requirements of the standard [6], the specimen should be worn for at least 3 cycles of 12 hours each. In the investigation presented here, the specimens were worn for 72 hours (6 cycles of 12 hours each). The specimens were weighed after each cycle, after being rinsed and dried superficially .

The calculation of the wearing losses was performed by determination of the average depth of wearing, at the end of each period ADA_t [m]:

$$ADA_t = \frac{VL_t}{A} \tag{1}$$

This was the ratio of the volume of the material lost in a given period, VL_t [m^3], to the surface area of the specimen A [m^2].

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

2.3. Imaging of the surfaces of tested specimens

An Atos Triple Scan optical scanner, produced by the GOM Company, was used for imaging the specimen surfaces, after the abrasion tests. The scanner was installed on an industrial robot with an integrated rotating table (Fig. 2).

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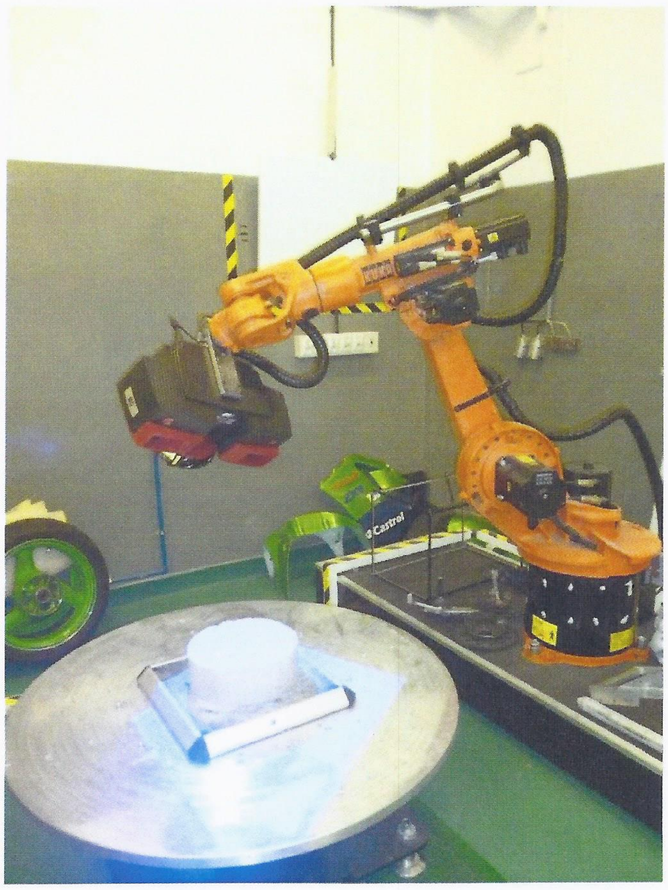

Fig. 2. Industrial robot with Atos Triple Scan optical scanner.

After preparing the head movements, measurement was conducted in the automatic cycle, thus enabling the best repeatability of the scanning conditions (positioning of the head and external lighting). The head was equipped with a structural light emitter and a two-camera optical system. This made it possible to scan the surface as well as to measure the reference points (markers) photogrammetrically, which enables joining of the scans from different directions. The specimen during scanning is presented in Fig. 3 (with visible markers on the specimen surface). LED technology and the use of narrowband (blue) filters enabled a significant reduction in the influence of infrared radiation.

The average time for measuring one specimen in the automatic cycle was about 1 minute and covered measurements taken from four directions, selected by the operator. ATOS Professional V8.0 software was used for the data processing.

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Fig. 3. Concrete specimen during scanning.

3. Results and discussion

The average value for the depth of abrasion loss (depth of wear – DOW) is the final result of the testing of abrasion using the underwater method. The use of a 3D scanner enables, not only the determination of the average value of the DOW, but also its maximum value, which is very important in the case of materials with components of varying hardness. This is particularly significant for reinforced concretes, where information on the DOW_{max} affects estimation of the thickness of the concrete cover of the reinforcement. The results of measurements for the specimens tested are presented in Table 1. The software used, also enabled development of a spatial image of the surface of the worn concrete, as well as a very accurate map of the losses and wearing profiles in all areas of the specimen surface (Fig. 4). Such information on surface wearing, makes it possible to design better structural and repair concretes, in consideration of their required abrasion resistance. An additional advantage is the fact that the time of measurement, after positioning the scanner, is only about one minute. In the case of the underwater method, the weighing of the specimens on a hydrostatic balance is very labour-consuming. As a comparison, in 2009 the authors reported on the results of imaging of concrete specimens worn using the underwater method, with the use of 2D scanning [7]. A coordinate testing machine, ECLIPSE CNC, enabling accurate imaging of the surfaces of the specimens tested, was used for description of the wear surface of the concretes tested. A model of the elements examined was created with I-DEAS 10.0 software, which allows writing of the data in VDA format.

Table 1. Results of abrasion testing of the concrete.

Underwater method		3D Scan			
ADA_t [mm]	average volume [cm^3]	ADA_t [mm]	average volume [cm^3]	DOW_{min} [mm]	DOW_{max} [mm]
97.5	6760	98.0	6843	4.71	11.14

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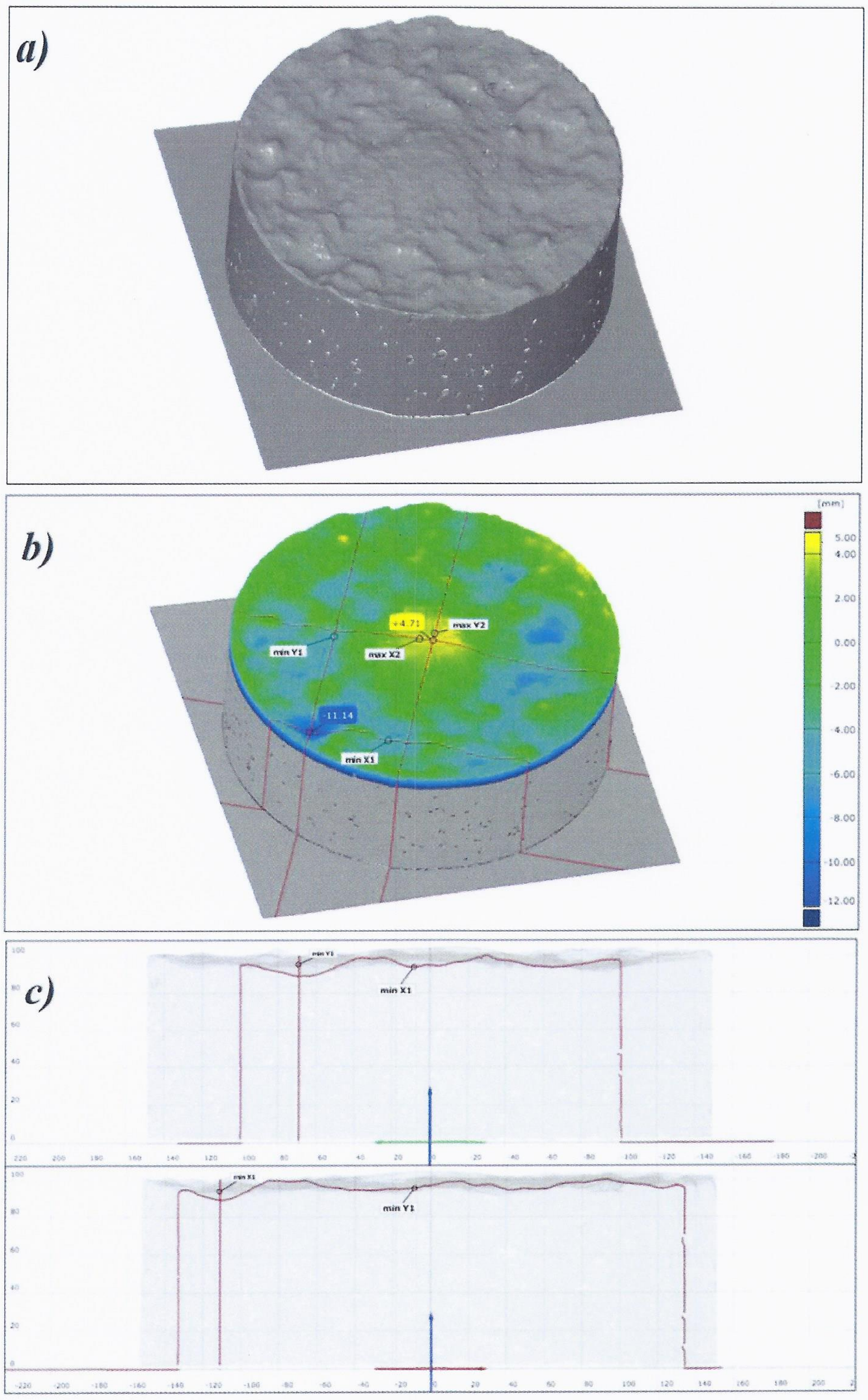

Fig. 4. Results of imaging of the surface of a specimen worn by the underwater method using a 3D scanner: a) specimen image; b) spatial map of the worn surface; c) example of the sections done at the point of DOW_{max}.

Gauging point calibration and the definition of the reference system and safety planes were conducted before measurement. HOLOS-NT measuring software, utilizing the previously created element model, was used to measure the surface of the specimens. With more than 6000 measurements conducted for each specimen, the resultant time taken for scanning of the surface of the specimens was several hours.

The 3D surface imaging made it possible to obtain very accurate projections of the surface; the accuracy was over a dozen micrometers. The use of ATOS Professional V8.0 software made it possible to conduct sections in any place of the specimen (Fig. 4c).

4. Summary

Imaging of the surfaces of worn concrete specimens with a 3D scanner, makes it possible to obtain very accurate descriptions of any part of specimen surfaces. The use of professional software makes it possible to develop spatial surface maps of concrete abrasions and profiles of specimen geometry, in any place. In this way, it is possible to more effectively design repair materials and structural concretes for hydraulic objects.

Using the underwater method with a hydrostatic balance, according to ASTM C1138, and 3D scanners, also significantly shortens the measurement time of the abrasions of specimens.,

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