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MECHANISMS OF HYDRO-ABRASIVE DAMAGE AND METHODS OF EXAMINATION OF HYDRO-ABRASIVE RESISTANCE OF CONCRETE IN HYDRAULIC STRUCTURES

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ABSTRACT

Durability of hydraulic engineering structures in most part depends on the resistance of the concrete surface to mechanical abrasion. Hydro-abrasion represents a concrete surface damage caused by the impact of waterborne solid particles and effects of hydraulic forces on the concrete. This form of progressive deterioration of concrete surface occurs, to a varying extent, in almost all hydraulic engineering structures. Therefore, hydro-abrasion wear of concrete in general causes reduction of the service life of a hydraulic engineering structure, as well as an increase in operating costs due to the necessary maintenance, and the downtime of the structure during the repair period. Because of the complexity of the problem, a large number of parameters must be taken into consideration when the abrasion resistance of concrete is researched. A very important factor is the choice of the kind of abrasion stress, which will be used in the research. In this paper, some of the mechanisms of hydro-abrasive damage and testing methods of hydro-abrasive resistance of concrete was presented, with the critical review of the advantages and disadvantages of the testing equipment, in terms of simulated approximation of abrasion in a natural environment.

Keywords: hydro-abrasion erosion, concrete, hydraulic structures, mechanism of hydro-abrasive damage, methods of examination of hydro-abrasive resistance.

SAŽETAK

Trajnost hidrotehničkih objekata u najvećoj meri zavisi od otpornosti površine betona prema mehaničkom habanju. Hidro-abrazija predstavlja oštećenje površine betona nastalo usled udara čvrstih čestica nošenih vodom i dejstva hidrotehničkih sila na beton. Ovaj vid progresivne deterioracije površine betona javlja se u različitoj meri kod gotovo svih hidrotehničkih objekata. Stoga, hidro-abrazivno habanje betona generalno uzrokuje smanjenje upotrebnog veka hidrotehničkog objekta, kao i povećanje troškova zbog neophodnih popravki i neaktivnosti objekta u periodu reparacije. Zbog složenosi problema, mora se u obzir uzeti veliki broj parametara prilikom istraživanja otpornosti betona prema habanju. Veoma je bitan odabir naprezanja habanjem koje će se koristiti pri ispitivanju. U ovom radu su prikazane neki mehanizmi nastanka hidro-abrazivnog oštećenja i metode ispitivanja hidro-abrazivne otpornosti betona, sa kritičkim osvrtom na prednosti i nedostatke uređaja za ispitivanje u pogledu približnosti simuliranja habanja u prirodnim uslovima.

Ključne riječi: hidro-abrazivna erozija, beton, hidrotehnički objekti, mehanizmi nastanka hidro-abrazije, metode ispitivanja hidro-abrazivne otpornosti.

INTRODUCTION

Durability of hydraulic engineering structures in most part depends on the resistance of concrete surface to mechanical abrasion. The abrasive wear of concrete in hydraulic structures is most often caused by the action of water-borne particles (silt, sand, gravel and other solid particles) rolling and eroding the concrete surface during hydraulic processes. Abrasive-erosive concrete damage represents a continuing issue in maintenance of hydraulic structures and necessitates taking this process into account when designing the structures and choosing the concrete mixtures [1].

The choice of testing methodology of concrete resistance to abrasive wear is very important. Erosion of concrete of hydraulic structures is a long-term process, and it usually develops over a period of several months or even years before the damage can be assessed. For this reason the accelerated concrete abrasion methods are necessary. Several studies, performed on the basis of the accelerated tests, have been published until now. Majority of equipment for testing of abrasive resistance of concrete described in professional literature was used for simulating mechanisms of sand blasting [2-4] and grooving with dry friction [5-7]. Many papers [8-10] and test methods according to ASTM standards [11] describe research performed in the conditions similar to natural environment impacts, using equipment allowing a concrete abrasion process based on aggregate and water mixture model. Momber and Kovačević [12] also applied the accelerated water jet test method for hydraulic concrete wear test. Momber [13] performed tests of accelerated cavitation on concrete by means of a cavitation chamber. For solving the problems in this study, the method of abrasive water jet could be applied for a very rapid wear of concrete by a mixture of water and solid particles moving at high velocity. The same researchers applied this method for parametric study of concrete abrasion [14] and for research of hydro-abrasion of mortar and concrete by means of acoustic emission [15]. A very complex test of behavior of concrete exposed to accelerated abrasive jet was presented in the paper [16]. In the general case, the construction of the equipment for testing of concrete abrasion by pressurized jets does not allow movement of a total of granular composition of water abrasive. Most often, acting as the abrasive, a mixture of fine fractions of sand and pressurized water is used to act upon the concrete surface at high velocity. It should be pointed out that it is difficult to formulate a universal and general criterion of acceptable damage level for hydraulic structures.

When analyzing the various tests results, only those results based on the same friction mechanisms during samples abrasion can be compared. These mechanisms are described with four basic external parameters related to the grain in the water jet: mineralogical composition (hardness), size, velocity and glancing angle at which the jet hits the sample. Change of one of these parameters causes change of abrasion mechanisms and renders the comparative analysis of test results impossible. Laboratory simulation of abrasion process in the conditions similar to the natural makes the correct assessment of concrete abrasive resistance possible.

THE MECHANISM OF HYDRO-ABRASIVE DAMAGE

Hydro-abrasive damage of concrete surfaces of hydraulic structures develops in several phases. Lui et al. In their research [17] state that in chronological term, abrasion advances in three phases, as displayed in Figure 1. The first to occur is erosive peeling of a thin layer of concrete surface, by action of the water molecules, which is closely correlated to the flow velocity and corresponding hydraulic pressure, figure, Figure 2 (a). Afterwards, solid particles act on the concrete aggregate grains, creating surface cracks, Figure 2 (b). Eventually, there occurs abrasive-erosive process related to the toughness of water-borne particles, flow velocity and bond strength of concrete component materials, Figure 2 (c). Therefore, hydro-abrasive erosion was not caused only by the action of waterborne particles, but there are other factors as well.

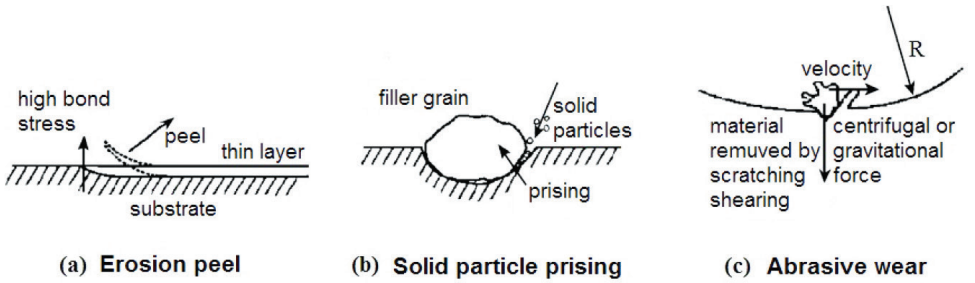

Figure 1. Applied stresses from water-borne sand on concrete surface

Volkart in his research [18] discusses the effect of hard water-borne particle impact on the concrete surface. He states that the momentum of a hard particle is mostly defined by its mass, velocity and attack angle, whereby velocity and attack angle depend on the characteristics of the water flow, Figure 2. Particle strength and surface toughness of concrete, as well as the particle shape affect the abrasion degree of the concrete surface caused by the impact. When analyzing hydro-abrasive wear, one should take into consideration the total number of dynamic contacts in a unit of time, particle concentration and distribution of particle size and shape.

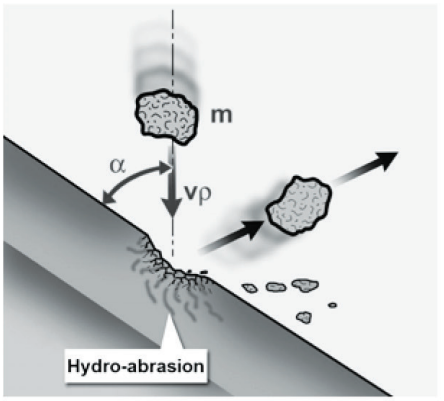

Figure 2. Effects of water-borne hard particle impact on the concrete surface

THE METHODS OF EXAMINATION OF HYDRO-ABRASIVE RESISTANCE OF CONCRETE

The procedure of concrete abrasive resistance test according to ASTM C1138 [11] the so called, underwater test was developed by Liu [19] for the needs of assessment of resistance of concrete surfaces subjected to the action of abrasive from water of hydraulic structures, such as dam lakes, overflows, etc. The test device consists of a cylindrical steel tank having diameter of 305 mm and height of around 457 mm, water agitation paddles and 70 steel grinding balls, Figure 3.

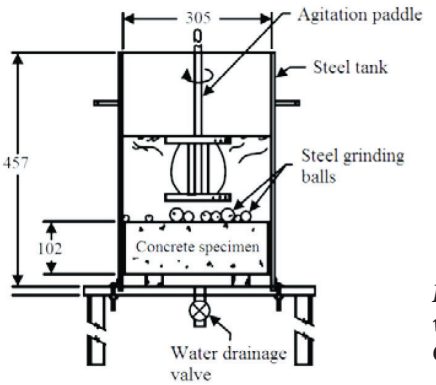

Figure 3. Diagram of the abrasive wear method according to ASTM C1138 and Liu

The concrete specimen having diameter of 305 mm and height of around 100 mm is placed on the bottom of the tank. The Steel tank is filled with water up to the designed height, and the steel balls are placed on the surface of the test sample. The agitation paddle immersed in water spins at 1200 revolutions per minute, stirs water and moves the steel balls which impact the concrete surface. The test lasts 6 times 12 hours, which is duration of one period of testing, the total being 72 hours. The assessment parameter of the concrete resistance to wear is the average depth of the damage.

Water and sand jet abrasive wear method was used by Liu et al. [17] on the occasion of testing of hydro-abrasive resistance of various kinds of concrete. The testing device consists of a sheet metal basin, having dimensions 2500×1800×1500 mm, Figure 4. The basin is one-third filled with water. Abrasive added to the water is quartz sand with the maximum grain size of 5 mm. Abrasive content in the mixture is 400 kg/m3. The relative homogeneity of the water and abrasive mixture is provided by the mixing blades which are located in the basin, and powered by the pump mixer. Also, there are four pumps inside the basin, which collect the water and abrasive mixture from several places. The mixture drawn by the pumps is collected into a pipe which ends in a rectangular nozzle having dimensions 200×10 mm through which a test concrete plate is sprayed – the plate is located below the nozzle, but above water. The velocity of water and abrasive at the nozzle is controlled and amounts to 10 m/s which corresponds to the pressure of 0,17 MPa. Water temperature is kept at 30 °C. The attack angle of the mixture jet and concrete plate can vary, but usually an angle of 45° is used. Concrete test plate has dimensions 200×200×50 mm and it is situated 200 mm below the nozzle. The time of exposure of the specimen to hydro-abrasive action is 180 minutes. Assessment of abrasive resistance of concrete is performed on the basis of the loss of mass of the specimen in a unit of time (g/min).

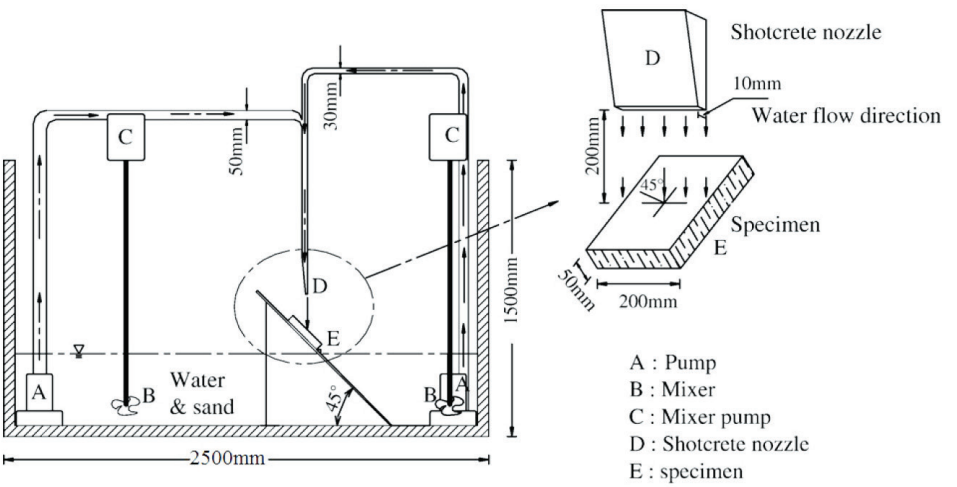

Figure 4. Diagram of the abrasive wear method using a jet of water and abrasive mixture

A similar device, partially modified and adapted to different test conditions was used in the research at the Faculty of Civil Engineering and Architecture of Niš [20-22].

CONCLUSION

In general, because of the complexity of the problem, a large number of parameters must be taken into consideration when abrasion resistance of concrete is researched. Very important factor is the choice of the kind of abrasion stress which will be used in the research. In addition, when choosing the research methodology, it is necessary to find a sensible balance between complexity of the model and practicability. In particular, the following conditions should be considered when choosing the abrasive test method which will simulate the actual conditions:

- abrasion wear conditions being simulated in the controlled laboratory conditions should, to a great extent, coincide with the conditions in practice
- mixture of water and abrasive used in the tests should correspond to the actual situations in practice
- the principal parameters affecting the abrasion wear process in practice should also be dominant during the laboratory testing, which must be facilitated by the construction of the testing device
- construction of the device should facilitate varying of the attack angle between the abrasive and surface of the tested specimen
- abrasion wear test should be short and simple to perform
- The measured abrasion wear damage results must be easy to reproduce.

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