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Abrasion resistance of concrete micro-reinforced with polypropylene fibers

Zoran J. Grdic [a,*], Gordana A. Toplicic Curcic [a], Nenad S. Ristic [a], Iva M. Despotovic [b]

[a] University of Nis, The Faculty of Civil Engineering and Architecture, Aleksandra Medvedeva 14 Street, 18000 Nis, Serbia
[b] Belgrade University College of Applied Studies in Civil Engineering and Geodesy, Hajduk Stankova 2 Street, 11000 Belgrade, Serbia

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ABSTRACT

This paper presents a research of abrasive resistance of classic concrete and micro-reinforced concrete with two types of polypropylene fibers. Water/cement factor was varied from 0.5 to 0.7, while the content (in%) of the remaining components remained constant. An accelerated test of abrasive erosion of concrete was performed on the equipment allowing the high-velocity jet of water/sand mixture to act on the surface of the test specimens. The research results demonstrate that the abrasive resistance of concrete is in an inverse function of the water/cement factor; the concretes with higher compressive strength and higher bending strength have also the higher abrasive resistance; the micro-reinforced concretes demonstrate higher abrasive resistance in comparison to the benchmark concrete.

1. Introduction

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. The order of magnitude of damage is several centimeters, but in some cases they can be significantly higher after only several years of abrasive action. Weak abrasive–erosive actions do not represent a big problem, but very pronounced actions may endanger the structural integrity of concrete, as well as the functionality of the structure [1]. Abrasive–erosive protection of the hydraulic structures made of concrete requires durable concrete mixtures resistant to abrasion–erosion.

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 Kovacevic [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: mineralogic 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

* Corresponding author. Tel.: +381 18 588 181, mobile: +381 63 8 216 244; fax: +381 18 588 208.

E-mail addresses: zoran.grdic@gaf.ni.ac.rs (Z.J. Grdic), gordana.toplicic.curcic@gaf.ni.ac.rs (G.A.T. Curcic), nenad.ristic@gaf.ni.ac.rs (N.S. Ristic), ivicka2006@yahoo.com (I.M. Despotovic).

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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.

Abrasive resistance of concrete depends of several parameters such as: aggregate properties, mixture material proportion, concrete strength, type and quantity of added cement materials, addition of fibers, hardening conditions, surface treatment. Many previous studies demonstrated that abrasive resistance of concrete mostly depends on its compressive strength. For this reason, the high strength concretes with high resistance to abrasive action are sometimes used as for coating of hydraulic structures [17]. High quantity of cement in the mixture of these concretes causes increase of hydration temperature and concrete shrinking, which generates a potential for the onset of cracks and reduction of service life of the structure. In order to increase the service life of a hydraulic structure, and to retain it for as long as possible in a safe and reliable condition, the hydraulic concrete must have a high resistance. Therefore, in the majority of concrete mixtures, cement is in part replaced by additional cement materials such as fly ash [12–16,18], silica powder [19], blast furnace slag, milled basalt [20] in order to reduce the hydration heat and increase durability/service life.

The polypropylene fibers are primarily used for reduction of cracks in fresh concrete, but also exhibit the secondary effects, improving a number of characteristics both of fresh and hardened concrete. The addition of fibers has a positive effect, because in the early phase, (2–6 h upon placing of concrete) contribute to reduction of both size and frequency of the cracks because they allow concrete to endure higher internal stresses. Also, addition of fibers to concrete improve the hydration of cement by reducing the separation of water from the fresh concrete. In a later period, in a somewhat more mature concrete, the fibers bind the potential cracks and reduce the risk of concrete destruction [21–23]. The polypropylene fibers in concrete significantly increase the abrasive resistance [24–27], cavitation resistance [28,29], impact and destruction. This property is ascribed to a high quantity of energy absorbed when the fibers are separated, broken or extracted from concrete after failure. The polypropylene fibers reduce the water permeability of concrete and absorption of fluids.

Resistance of concrete to abrasive action, apart from the composition of the concrete mixture, also depends on the external conditions to which concrete is exposed. The research by various authors demonstrated that the concretes produced with various mineral admixtures (silica powder, fly ash, blast furnace slag, milled basalt) [19,20,30,31], addition of still fibers [32–34], addition of polypropylene fibers [24–27,34] or with aluminate cements [35], high strength concretes [36–38] and rolled concretes [6] have to a lesser or larger extent a better abrasive resistance in comparison to the benchmark concrete produced without any admixtures, with the common Portland cement. This paper presented research of abrasive resistance of the concrete with the admixture of polypropylene fibers of FIBRILs F120 and FIBRILs S120 types.

2. Details of the experiment

2.1. Materials used in the experiment

The benchmark concrete was produced with the Portland cement CEM I 42.5 R, whose properties are presented in Table 1.

For preparation of concrete, the aggregate obtained by mixing three fractions 0/4, 4/8 and 8/16 mm from the river aggregate of the Southern Morava River was used. Granulometric composition of the aggregate is presented in Fig. 1.

Two types of polypropylene fibers were used for production of micro-reinforced concretes: the concretes marked "F120" used the FIBRILs F120 fibers, and the concretes marked "S120" used the FIBRILs S120 fibers, produced by "Motvoz" Grosuplje from Slovenia. The polypropylene fibers of FIBRILs F120 type belong to the group of fibrillated fibers composed of a great number of fibers of a very small diameter, Fig. 2, left hand side, while the FIBRILs S120 fibers belong to the group of monofilament fibers of circular cross sections and smooth surface, Fig. 2, right hand side. The fibers characteristics are given in Table 2.

Table 1
Physico-mechanical properties of cement.

Binding time (min)	Start 135 end 160
Mill fineness – sieve residue 0.09 mm (%)	3.2
Specific mass	3.0 g/cm^3
Loose material bulk density	925 kg/m^3
Compacted material bulk density	1521 kg/m^3
Bending strength after 2 days	5.99 N/mm^2
Bending strength after 28 days	7.21 N/mm^2
Compressive strength after 2 days	33.67 N/mm^2
Compressive strength after 28 days	54.21 N/mm^2

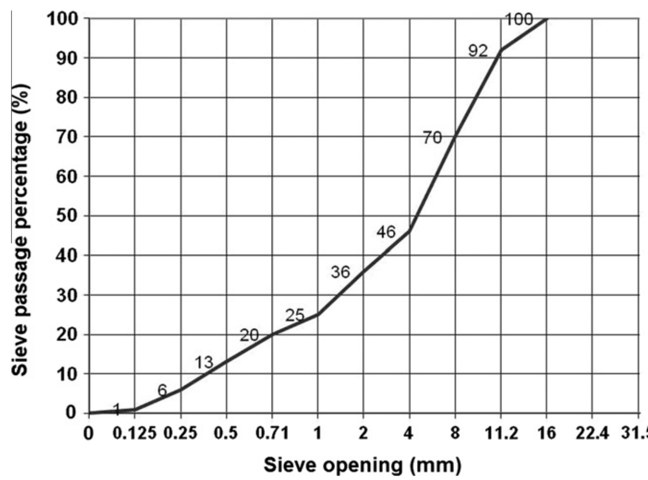

Fig. 1. Granulometric composition of the aggregate.

2.2. Concrete mixture composition

Regarding the fact that additives in our country have been used only since relatively recently, there are no additives in the composition of the structural concrete of existing hydraulic structures in Serbia. The goal of the research has been to determine the degree of abrasive resistance of classic concretes, and in this manner assess durability and potential for repairing the existing hydraulic structures in Serbia. By selecting various water/cement factors, three different consistencies of concrete have been covered (rigid, plastic and fluid), in order to provide thorough placing of fresh concrete in various structural elements of hydraulic structures.

Nine mixtures for testing fresh and hardened concrete properties were made. As benchmarks, three concrete mixes were used, each with different water/cement factor ω_c = 0.5, 0.6 and 0.7, which are designated as E_1, E_2 and E_3 respectively. Also, three mixtures of micro-reinforced concrete with polypropylene fibers FIBRILs F120 ($F_{1/120}$, $F_{2/120}$, $F_{3/120}$) were made, as well as three mixtures with polypropylene fibers FIBRILs S120 ($S_{1/120}$, $S_{2/120}$, $S_{3/120}$), with water/cement factors as in plain concrete. The compositions of the concrete mixtures are given in Table 3.

3. Experimental research

The scheme of the equipment for concrete abrasive resistance testing is displayed in Fig. 3. Similar equipment was used by the researchers in Taiwan for testing of abrasive resistance of concrete [19,39].

The equipment consists of a tin basin, with dimensions 2.0 × 2.0 m at the base and 1.5 m of height, whose front side is covered with a panel of transparent plexiglass for visual observation during the tests. For the test, the basin is filled up to one third of its height with the mixture of water and sand, with granulation from 0 mm to 4 mm, in the mass ratio of 10:1. The sand used as the abrasive for wearing concrete was also used for production of concrete mixtures. Two electrical motors turn the vanes making