Drop weight impact-water impact relationship of hybrid fiber reinforced concrete

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Abstract. The dams’ spillway and its stilling basin are the hydraulic structures that are subjected to very fast water flow, which exposes them to the impact of water and water-dragged materials. To produce an appropriate concrete mixture that is capable to resist such loads, three hybrid fiber-reinforced mixes were prepared using the same materials and a constant total fiber volume fraction of 2.5%, while the fiber hybridization scheme was the only variable. All mixtures had a quantity of 0.5% polypropylene fiber (PP) with length of 18 mm. The first mixture (M1) involved 2% steel fibers with length of 6 mm, while M2 contains 2% of 15 mm steel fibers. A quantity of 1% was added from the two steel fibers for M3. The water-jet impact and drop-weight impact tests were conducted to compare the impact response of the mixtures. The obtained results showed that the abrasion resistance of M2 was higher than that of M1 and M3 by 42 and 21%, respectively. Furthermore, its impact resistance was greater than the average value of that for the other mixes by 43.8%. Finally, the splitting tensile strength can be considered an acceptable scale to describe the abrasion resistance of concrete.

Keywords. Abrasion; hydraulic structures; water-jet test; drop-weight; hybrid fibers.

1. Introduction
Huge constructions are mainly designed to be fully functional for a long period of time. Thus, all the possible applied loads must be considered and well-studied. The abrasive load is one of the worthwhile loads. Abrasion damage can be defined as the gradual and continuous peeling of the upper concrete surface by the horizontal friction and/or by the direct impingement of the very high-velocity water flow that carries different quantities and sizes of sediments [1]. To check the abrasion resistance of concrete, several standard wearing test procedures were invented [2-5]. Among them, only the underwater method [2] simulates the abrasion resistance of concrete in hydraulic structures. It supplies a frictional abrasive load on the concrete surface. To simulate the impact abrasion load, the water-jet test method, which was suggested by Liu et al. [6] can be used. This test is not a standard one, yet it was adopted by many previous studies [7-15] to evaluate the impact abrasion of different types of concretes. On the other hand, several constructions may be susceptible to impact forces according to various causes of dynamic loads, such as wars and accidents [16, 17]. Several impact testing procedures were suggested depending on the source of the load, function of the structural element, and the used material compositions. For the fiber-reinforced concrete mixtures, the repeated drop-weight impact test, which complies with ACI 544-2R [18], was the highly recommended one [19-23]. This is due to its easiness, and its low-cost requirements, as it depends on simple mechanical device, and it can be performed in-situ or in laboratory [18].
Strategic structures like the dam’s stilling basin, which is used to dissipate safely the excess kinetic energy at the end of the spillway's chute [24, 25], is the one that may be subjected to both previously mentioned loads [26-29]. From the available literature knowledge, several factors govern the resistance of concrete against the dynamic impact and the impact abrasion loads, such as the concrete grade, water to cement ratio, the addition of the cementitious materials, tensile strength, surface curing, energy of the striking load, velocity of the water flow, and the angle of that flow [30-34]. However, the inclusion of fibers, whether synthetic or metallic fibers, highly enhances the mechanical properties of the resulted concrete [35-39].

After a detailed research about the previously carried out studies, one can notice that there are several researchers dealt with the abrasion and impact problems and examined the effect of the fiber inclusion. However, according to the best of the authors’ knowledge, there is no previous research that attempted to compare both types of impact loads for hybrid fibrous concrete. This work aims to investigate the impact abrasion and the dynamic impact resistance of three hybrid fibers reinforced concrete mixtures that contain different quantities and types of fibers with a summation of 2.5% by volume. Furthermore, the relationship between the two considered resistances is studied.

2. Experimental work

2.1 The abrasion test apparatus

In this study, the water impact testing device, which was firstly suggested by Liu et al. [6], was depended to evaluate the abrasion damage of the tested samples. It consists of a steel tank with a length of 2000 mm, a height of 1500 mm, and a width of 750 mm. It must be filled with water mixture with a quantity of 1000 liters. This mixture contains well-graded sand, as an abrasive material, with diameters ranging between 3.35 and 0.3 mm, which was added with a concentration of 0.03 kg/liter. Concrete plates with dimensions of 200×200×50 mm must be placed on the sample holder inside the tank. Water jet with a velocity of 20 m/s hits the upper face of the plates perpendicularly by an electrical motor through a rectangular nozzle of 200×10 mm. However, a circular nozzle with a diameter of 50 mm, which provides approximately the same section area, was used in the current experiments. Generally, the main purpose of this alteration is to distribute the abrasion damage over a larger area than that occupied by a straight line. The entire testing time is six hours. In this study, to provide a clear imagination about the abrasion damage, the time was expanded to be 12 hrs divided into six two-hour steps. The weights of the sample must be recorded before and after each time step, the abrasion loss is the difference between its weights. Figure 1 shows the used abrasion apparatus.

2.2 The impact test apparatus

In the present study, the testing device, which is known as the repeated drop-weight impact method, that is introduced by ACI 544-2R [18] was used. An apparatus was manufactured for this investigation with several modifications. The standard height of falling was 450 mm, while the studied was 700 mm to magnify the produced energy of impact and to reduce the required number of impacts for time and efforts saving. The dropping mass was increased from 4.5 to 10 kg for the same previous purpose. Furthermore, the diameter of the sample was reduced from 150 to 125 mm. Thus, the required blows to reach the failure are expected to be quite lower. Finally, for each mixture, the standard limitations mention that the average of six samples represents the number of cracking impacts (Ncr) for that mixture, while in this study, the average of 12 samples was relied to overcome the problem of result scattering. Figure 2 displays the manufactured impact test device.
2.3 The prepared mixtures and the tested samples
Three hybrid fiber-reinforced concrete blends were prepared. Ordinary Portland cement type 42.5R was added with the same quantities for the all mixes. Silica fume was added also in an equal quantity, its specific surface and gravity were 21000 m²/kg and 2.2, respectively. As a filler, silica sand was used, its particle size ranged between 200 to 80 micrometres. The fineness of the added fly ash was 28.99. A superplasticizer of Sika ViscoCrete 5930 was added with the same weights to obtain the appropriate properties. The depended blend proportions are showed in Table 1.

| Material          | Cement | Silica Fume | Fly Ash | Silica Sand | Water | Superplasticizer |
|-------------------|--------|-------------|---------|-------------|-------|-----------------|
| Quantity (kg/m³)  | 800    | 240         | 120     | 960         | 232   | 47              |
Three types of fibers were used to cast the required samples. Micro-steel fibers of 6 and 15 mm were used as well as polypropylene fibers (PP) of 18 mm. Three fibers sets were prepared. The properties of the used fibers and the fibers combinations are listed in Tables 2 and 3, respectively. The total fibers quantity for each mixture was 2.5% by volume.

Table 2. The main properties of the added fibers.

| Property          | PP   | Steel Fibers 6 | Steel Fibers 15 |
|-------------------|------|----------------|-----------------|
| Length (mm)       | 18   | 6              | 15              |
| Diameter (mm)     | 0.5  | 0.12           | 0.2             |
| Aspect Ratio      | 36   | 50             | 75              |
| Density (kg/m³)   | 910  | 7800           | 7800            |
| Tensile Strength (MPa) | 350 | 2850           | 2600            |

Table 3. The combinations of the added fibers for the prepared three mixes.

| Mixture Name | PP (%) | Steel Fibers 6 (%) | Steel Fibers 15 (%) |
|--------------|--------|-------------------|---------------------|
| M1           | 0.5    | 2                 | 0                   |
| M2           | 0.5    | 0                 | 2                   |
| M3           | 0.5    | 1                 | 1                   |

For the abrasion test, three plates with dimensions of 200×200×50 were cast, one for each mixture. Twelve disks with a diameter and thickness of 125 and 65 mm, respectively, were made from each blend to conduct the drop-weight impact test. Finally, concrete cylinders of 200 mm diameter and 100 mm length were prepared to carry out the splitting tensile strength test according to [40], while cubes of 100 mm were cast to perform the compressive strength test. All of the three experiments were directed at the age of 28 days. The resulted compressive strength of M1, M2 and M3 was 78, 76.5 and 80 MPa, respectively.

3. Results and discussion

The obtained results of the water jet abrasion test of the current investigation were presented in the term of abrasion weight loss (AWL), which measured by grams. Figures 3 and 4 show the abrasion damage throughout the testing time, and the average values of the impact tests for each of the three examined mixtures. For the first stage of testing (first six hours of the abrasion test), the abrasion loss of M2, which contains 2% of 15 mm steel fibers and 0.5% of PP fibers, was the lowest as compared with that of the remaining mixtures. After six hours of the abrasive action, the wearing loss was 13.7, 15 and 15.5 grams for mixtures of M2, M1 and M3, respectively. Figure 4 displays the abrasion results for the second stage (the last six hours). The same result can be observed, the lowest abrasion erosion loss was recorded for the sample contained 2% of 15 mm length micro-steel fibers (M2). Specimen of 6 mm steel fibers and PP fibers (M1) showed the lowest abrasion resistance. The final abrasion losses for the mixtures of M1, M2 and M3 were 34, 24 and 29 grams, respectively. Thus, the wearing damages of M2 was lower than that of M1 and M2 by approximately 42 and 21%, respectively. According to the two figures, the average blows number (Ncr) for M2 was the highest, while those of the other mixtures were quite convergent. The mean Ncr of M2 was higher than that of M1 and M3 by 40 and 47.5%, respectively.
The relationship between the impact energy and abrasion loss is illustrated in Figure 5. The impact energy can be determined by the multiplying of the falling height and weight by the gravity value by the Ncr. It is another description for the impact resistance of concrete. After two hours of abrasion test, samples of M3 exhibited the lower abrasion resistance, while sample of M2 showed the highest. A result shifting occurred at the end of the testing period, M2 remained the sample of the highest wearing resistance but M1 gave the lowest abrasion resistance.

The impact energy of M1, M2 and M3 were 3350, 5600 and 2900 Joules, respectively. This indicated that the sample of M2, which showed the highest abrasion resistance, can resist an impact energy higher than that of M1 and M3 by 40 and 48%, respectively.

Obviously, one can notice that the combination of the 15 mm steel fibers with the polypropylene fibers (M2) provided the maximum abrasion and impact resistance with values far from those of the remaining tested fiber combinations. This can be interpreted due to the relatively high length of the 15 mm fiber comparing to the 6 mm length, so it can connect and protect larger areas of concrete. Thus, this type of mixture is highly recommended to be used in hydraulic structures that subjected to severe intensities of such loads.
Figure 5. Relation between impact energy and abrasion weight loss.

Figure 6 shows the relationship between the abrasion damage of the tested mixtures and their splitting tensile strength value. After two hours of testing, the abrasion weight loss of mixtures of M1, M2 and M3 was 5.5, 4.2 and 7 grams, respectively, while at the end of the test, it became 34, 24.5 and 29 grams, for the same sequence. Thus, as aforementioned, the abrasion resistance of M2 was higher than that of M1 and M3 by 42 and 21%, respectively. According to the results of the splitting tensile strength test, it can be noticed that the variation of fibers combinations significantly affected the resulted tensile strength value. The combination of 18 mm PP fibers and 15 mm steel fibers (M2) gave the highest tensile strength of 14 MPa, while it was 10.3 and 11.45 MPa for M1 and M3, respectively. According to the previous results, the increment of the tensile strength from 10.3 to 14 MPa (36%) was accompanied with an increment in the abrasive resistance of 42%. Thus, it is clear that the splitting tensile strength of a concrete mixture plays a governor role to determine the durability of the hydraulic concrete against the abrasion damage.

Figure 6. Relation between splitting tensile strength and abrasion weight loss.

4. Conclusions
The abrasion damage, impact resistance, splitting and compressive strengths of three hybrid fiber reinforced samples were tested at the 28-day age. The total fibers quantity was 2.5%. All the prepared mixtures contain 0.5% polypropylene fibers, 2% steel fibers of 6 mm length was added to the first mixture, while 2% steel fibers with length of 15 mm was added to the second. The third mixture involved 1% form the two types of steel fibers. Based on the results of the current experimental tests and in the limits of the chosen parameters, the following points are the main conclusions.
The combination of the PP fibers with 2% steel fibers of 15 mm length (M2) gave the greatest abrasion and impact resistances among the other types of fiber combination. Its abrasion and impact resistances were higher by 31.5 and 43.8% than the average values of those for the remaining mixes, respectively.

The energy of impact for the M2 was about 5600 Joules, while it was 3350 and 2900 Joules for M1 and M3, respectively.

For the same fiber’s contents (2.5%), the combinations of the fibers highly affected the value of the splitting tensile strength. On the other hand, the tensile strength can be considered as an appropriate indicator for the abrasion resistance of concrete. The abrasion resistance increased by 42% due to the increment of the tensile strength by 36%.

The mixing of 2% steel fiber with length of 15 mm and 18 mm PP fibers exhibited the highest resistances; therefore, it is the best choice to be used in hydraulic structures that carry severe abrasion and impact loads.

To increase the visibility of this research, the investigation of the influence of longer and different configuration steel fibers is recommended as an expanded future study. The hybridization of the 6- and 15-mm straight micro-steel fibers with 30 mm hooked-end steel fibers is suggested.

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