Review of Abrasion Mechanisms and Influential Variables on The Disintegration Resistance of Concrete

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Abstract. In many hydraulic constructions such as dams, spillways and stilling basins, large of amounts concrete can be damaged depending upon the long-term activity of water-borne solids. To a great extent, for hydraulic structures, the durability relies upon the resistance that the concrete surface offers to mechanical wear. The surface damage caused by the uninterrupted material removal process, induced by the impact of the water borne solid particles, is termed hydro-abrasion. In nearly all hydraulic structures, this kind of progressive deterioration of the concrete surfaces is observed, to different intensities. Obviously, such hydro-abrasive concrete wearing normally results in a reduction in the service life of the hydro-technical facility, and consequently because of the repairs necessitated, the non-functioning of the facility during the repair period results in an expenditure spike. The objective of this article is to: understand the mechanisms of concrete abrasion-erosion followed by brief discussion about the factors remarkably impact the rate of abrasion erosion also through these studies, it was concluded the improvement of the abrasion resistance needstomodify the concrete characteristics also increase the compressive strength.

Key words : mechanisms of concret abrasion, hydraulic structures, concrete surface

1. Introduction.
Erosion is one of the main issues present in hydraulic systems which involves by transport of fluids and solid particles. To address erosion, three components need to be taken into consideration: the solid surface, that remove material from the surface and fluid that carries these solid particles[1,2]. According to the ACI Committee 201.2R-08[1] The durability” of Portland cement concrete was defined as its ability to withstand influences from the atmosphere, chemical aggression, abrasion or other degradation processes. In other words, durable concrete will retain its original shape, quality and usability when exposed to the design operating settings and environmental conditions, concrete utilized in hydraulic systems should have good abrasion resistance against higher water and sediment pressure due to the high velocity flow. To increment the benefit life of hydraulic structure and to assure secure and reliable continuous working for long time, the used concrete should have high durability and abrasion resistance properties[3]. Many strategies are applied to improve abrasion resistance of concrete. Among these are the increasing of compressive strength also the addition of reinforcing fibers, fly ash, silicafume to the concrete mix [3].
abrasion - disintegration resistance is noticeably impacted by a number of factors. Similarly as aggravator the size dosage of concrete strength, mixture rate, the utilization of extra cementitious materials, fiber supplement, curing states. Furthermore surface completing. [4,5]. Various hydraulic structures are vulnerable to extreme erosion disintegration harm, like as stilling basin, spillway also culverts [6], as shown in Figure 1. Decomposition takes place due to the loads caused by the water flow of the sediment being transported. This becomes a serious issue when high velocities of water flow are encountered [7].

Figure 1. (a) Spillway dam presented deterioration by abrasion. (b) Defects in the concrete structure caused by abrasive process, located in the south and southeastern of the Brazil.

2. Causes of Erosion
Abrasion disintegration triggers damage to the cement surfaces by water-powered structures because of the abrasive impacts of the water-borne materials. The abrasion movement of the water-borne particles is distinguished into three phases [8,9]. In the first stage, pre-abrasion peeling occurs, which may be heavily reliant on the stream speed and weight of the water on the focus surfaces. In the second stage, those waterborne particles cause impact forces on the focus surface. This force is a function of solid characteristics for water-borne particles, within the third and final stage, abrasion wear takes place and the surface rapidly deteriorates. For the greater part, the paramount elements that influence the abrasion-induced disintegration are the hardness and state of those water-borne particles, stream speed on the focus surface, and the properties of the materials of the cement.

3. Laboratory Tests of Concrete Abrasion Resistance
Many abrasion tests have been created universally to assess the scraped area of the concrete surfaces under specific circumstances. These tests can be classified as standard and nonstandard tests.

3.1 ASTM C1138 (under water method)
The ASTM C1138 [10] is a standard test that simulates the abrasive damage to concrete caused by the effect of the water-borne particles like sand, gravel, etc. The test involves a mechanical apparatus which has a drill press, an unsettling paddle, and a barrel shaped steel compartment. Furthermore, 70 steel grinding balls in different sizes are included. Figure 2 shows the test device. The water within the tank is circulated using the agitation paddle, which is fueled by the bore drill turning at 1200 rpm speed. The circulating water moves the grinding balls which will make frictional drives on the cement.
surface, handling the abrasion impacts. The test may span six periods of 12 hours per test, which may last for a total of 72 hours.

![Diagram of underwater abrasion test](image)

**Figure 2.** The underwater abrasion test ASTM C1138/970.

### 3.2 Other standard ASTM abrasion tests

The ASTM C418[11] is a standard method used to investigate the concrete abrasive resistance by sandblasting. This test system addresses the abrasive damage caused by the water-borne particles and the abrasive damage due to their movement across the cement surface. The test device provides cutting action with a different severity that abrades the weakest concrete component.

The ASTM C779 [12] is another standard method that includes three different procedures to evaluate the abrasive damage caused on the horizontal surfaces of the concrete. The three methods differ in the quantity and type of the abrasive load to which the cement is subjected. Procedures (A, B and C) can be applied to estimate the abrasive resistance of the concrete. All of them depend on portable equipment so they are adequate for field and laboratory experiments. Revolving discs, dressing wheel and the ball-bearing are the procedures A, B additionai to C.

Finally, the ASTM C944[13] is a test procedure that provides a method to evaluate the resistance for both concrete in additional to mortar for either cored or cast samples. This test is basically comparable to procedure B (dressing wheel) of ASTM C779 test method. The C944 test process has been effectively applied in the evaluation of the concrete of bridges and highways which are undergone to traffic loads.

### 3.3 Böhme disc method

This method is a standard method which is compatible with European standard EN 13892-3[14]. It is utilised to assess the mechanical wearing resistance of the concrete. The test sample is a cube
shape with a length of $71 \pm 1.5$ mm. The test is cramped and settled in the path of the Böhme circle processor, which provides a uniform wearing drive on its surface. It needs to be pivoted for 16 cycles and submit to a wearing stack of 294 N. Each cycle involves 22 revolutions. The weight of the test sample is measured immediately after the test, and after each four cycles[15,16].

3.4 Water-jet test method

This is a non-standard test method developed by researchers from Taiwan [8,17] to determine the wearing resistance of concrete due to water and sand impact. The test rig includes a tin basin measuring $2500 \times 1800 \times 1500$ mm, as shown in Figure 3. The basin is filled with water up to one-third of the height. 5 mm grain size is added to the water. The abrasive in the mix is 400 kg / m$^3$. A relatively homogeneous mixture of water and abrasive is ensured by the propellers fixed inside the tank and powered by a pump mixer. Four pumps placed inside the basin help to draw in a mixture of water and abrasives from different places. The mixture thus pumped is collected into a single tube which ends in a nozzle having a rectangular $200 \times 10$ mm opening, over which the concrete test plate, which is just below the nozzle but also above the water, is tested. The speed of the water mixture and the abrasive at the nozzle outlet is controlled to 10 m / s, which corresponds to a pressure of 0.17 MPa. The water temperature is maintained at $30^\circ$ C. The impact angle of the water-sand mixture jet relative to the concrete slab can be varied, and the $45^\circ$ angle is usually used. The concrete test plate with dimensions $200 \times 200 \times 50$ mm is located 200 mm below the nozzle. The exposure time of the sample to hydro-abrasive action is 180 minutes. Concrete resistance assessment based on wear is evaluated based on the loss of sample mass in unit time (g / min).

![Figure 3. Schematic drawing of the equipment used to test the abrasion of concrete.](image)

4. Influential Factors on the Abrasion Erosion Resistance of Concrete

Several variables would be present to provide the impact abrasion resistance of the concrete depending upon the elements identified, including the hydraulic properties, as well as the sediment characteristics as revealed in Table 1. For example, stream direction, effect angle, shape and hardness from the claiming water-borne particles, as well as components related to the properties of the concrete materials like compressive strength, water-cement ratio, blend proportions, use for supplementary materials, and fibre support.
4.1 Influence of Impact Angle

Liu et al. [18] investigated the influence exerted by the angle of impact on the concrete loss due to abrasion. The water jet method has been used in that analysis. The test reveals that abrasion damage happens at the 90° impact angle more than at the 60°, 30°, and 45° angles, a decreasing trend for lower angles, considering different water-cement ratios.

4.2 Influence of water-borne particles

One of the most important factors that controls the wear damage is the nature of the particles that roll and hit against the concrete surface during the operation of the hydraulic structures. Liu et al., [18] assessed the impact of the concentration of the sand and the size and content of the erodent in terms of the abrasion rate of the concrete. Tests were conducted using the water jet test to determine the abrasion damage of the concrete based on the effect of the water flow and the sand quantity. Four different mean diameters of the sand (0.6, 1.2, 2.5 and 5 mm) and four different sand contents (0, 110, 230 and 340 kg/m³) were used in the experiment. Slabs with dimensions of 200×200×50 mm were cast. It was found that the sand concentration resulted in an incredible impact upon the abrasion rate. The abrasion erosion damage to the concrete surfaces is an unimportant point when the concentration of the sand is zero. When the sand content increases in the water, the abrasion disintegration also rises. The test findings indicated that when the impact angle was 45° and the sand contents were 110, 230, and 340 kg/m³, the abrasion rates were respectively, 10, 17 and 23 times compared to when the water contained no sand. Similarly, when the impact angle was 90°, the abrasion rates were 23, 37, 57 times of the point when the water contained no sand as shown in Figure 4.

![Figure 4. Effect of sand concentration on concrete abrasion.](image)

4.3 Influence of compressive strength

One of the factors responsible for concrete abrasion is compressive strength, according to several researchers such as Yen et al., [19] based on the water jet test, revealing the effect of the compressive strength of the concrete on the abrasion resistance. In general, the results depict that the resistance of concrete to abrasion damage increased when the compressive strength was increased and the w/c ratio decreased, irrespective of the fly ash content. Omoding et al.,[6] found that abrasion-erosion loss in
conventional concrete mixtures follows a power function of its compressive strength. A generic abrasion resistance model for concrete has been proposed based on compressive strength. The use of compressive strength for prediction of abrasion resistance is limited by the fact that with compressive strengths of less than 60 MPa the influence of supplementary cementitious materials, coarse aggregate hardness, quantity and gradation becomes prominent. Ayoob et al. n.d. [20] examined the abrasion erosion of self-compacting concrete under the influence of the water impact. The water jet test method was employed to evaluate the abrasion. The plate specimens used were six mixtures having 30, 40 and 50 MPa design strengths, with 0, 0.5, 0.75 and 1.0 % steel fibre. The test results showed that by increasing the strength from 30 to 40 MPa the abrasion losses can be reduced by around 17 %, and when steel fibres were used, having volumetric values of 0.75 and 1.0 %, the abrasion resistance can be improved by above 23 %.

4.4 Influence of water to cement (w/c) ratio

Rahmanzadeh et al. [21] analyzed the abrasion quality test cube shape samples 150 × 150 × 150 mm during 28days about age, utilizing the Water sand blast test, of the ASTM-C778 standard. the results demonstrated that a increment in the water-cement proportion created an increment in the abrasion profundity. By expanding those water-cement proportion from 0.3 on 0.46, abrasion depth gradually expanded.

4.5 Effect of Fibers

Hlaváček et al., [22] Who examend the resistanse concrete of the erosive impact of water from water jet, Furthermore monitored it. The tests were performed on the concrete without fibres addations and on the concrete with polypropylene Also steel fibres. The water stream hit the concrete surface In angle 90°. The stream rate was 1.1 l/min same time the water weight was 80 MPa. Following impacting the concrete with water jet, no cracks in the concrete were watched. Those steel fiber stayed solidly anchored under the bond grid. Horszczaruk [23] who tested three different types of polypropylene fibres. The F1 is C3H6 polypropylene, 19 mm in length; the F2 is a virgin homopolymer, 12-19 mm in length and the F3 another virgin homopolymer 19 mm in length. The test was managed to assess the abrasion resistance of the concrete employing the Bӧhme disc and underwater methods. Four types of samples were examined, one sample without fibres and three samples with the different types of polypropylene fibres. The results showed that the addition of the polypropylene fibres increased the concrete resistance to abrasion. It also increased the splitting tensile strength and compressive strength of the concrete. Fibre inclusion enhanced the abrasion resistance by 29.43, 40.1 and 42.44% for F1, F2 and F3 when compared with the sample without fibres, respectively. The test results showed that the estimation of the abrasion damage in hydraulic structures is not possible by using the Bӧhme disc. Grdic et al.[24]evaluated the abrasion resistance of concrete reinforced with fixed content of two types of polypropylene fibers with variable water-tocement ratio. The fibers were 12 mm in length and were used with a by-weight content of 0.91 kg/m3. The researchers found that adding polypropylene fibers have a positive impact on the concrete by improving its abrasion resistance, while increasing the water-to-cement ratio reduces the abrasion resistance.

4.6 Effect of fly ash

For many decades in the past, fly ash was used in the concrete industry. First, it was used to minimise the hydration heat, as well as early age cracking. Lately, it has been considered an important material for high-strength concrete. Yen et al., [19]investigated the effect of fly ash class F on the abrasion damage caused to the high strength concrete. The investigation was performed by the underwater method that complies with the ASTM C1138 standard. Five sample types were prepared using different concentrations of fly ash. concrete was partly compensated by class F fly ash with five types
of compensations (0, 15, 20, 25 and 30%). Test outcomes revealed that resistance to the abrasion erosion for 28 and 91 days for the 0% and 15% compensations were almost the same. On the other hand, the abrasion resistance showed a decrease by 22, 32 and 55% for the 20, 25 and 30% compensations, respectively, at the same test ages.

Hasan [25] utilized a streamlined test setup that used by Liu et al. [8] to assess the abrasion resistance for concrete. In this test, 100mm diameter and 50 mm height cylindrical shaped concrete samples were subjected with a immediate and verhandi water jet, as well as incorporates sand particles. Author reasoned that over general, the utilization of fly ash brings about preferred abrasion resistance over typical concrete. However, other changed mixes utilizing fume seethe indicated substantially superior abrasion imperviousness that for fly ash.

4.7 Effect of silica fume

Based on the ASTM C1138 underwater method, Kang Jing et al., [26] tested the effect of the action of adding silica fume also the crumbled rubber tyre on the abrasion resistance of concrete. Eight samples were cast with the same cement, water, superplasticiser and aggregate proportions. The first sample was the control, while the second sample contained 7% of silica fume as a substitute for the cement content by weight. The remaining six samples were rubberised concrete which were composed of two kinds of recycled crumb rubber. Four samples were made including rubber in which the largest particle size was 2.36 mm and with 9, 12, 15 and 18% of cement weight, while the last two specimens were cast with rubber of 1.0 mm largest particle size and with two concentrations of (6% and 9%) cement weight. From the test results it was evident that the abrasion resistance, compressive strength of the silica fume samples compared with the control concrete were increased by 86% and 28.7%, respectively. While the impact of adding the rubber decreased the compressive strength, it significantly increased the resistance of concrete to abrasion. Rubberised concrete samples showed higher abrasion resistance than the silica fume samples but with lower compressive strength. For the same quantity, rubber with largest particle size of 2.36 mm offered less abrasion resistance and compressive strength when compared with the 1.0 mm rubber.

Eren et al.,[27] tested the influence of added silica fume on the concrete abrasive resistance. A special equipment was developed for this test. Three different dosages of silica fume of (0, 5, 10%) by concrete volume were added to the mixture. The results of the experiment indicated that the silica fume increases the surface wear resistance of the concrete. In fact, 15% and 17% increase in the wear resistance were achieved after the addition of 5% and 10% of silica fume, respectively.

| Reference | Number of samples | Materials | Test method | Main conclusions |
|-----------|-------------------|-----------|-------------|------------------|
| Liu et al.[18] | six square slabs, 200x200x50 | Portland cement | The water jet | Abrasion damage occurs at impact angle of 90, 60, 30 45° from maximum to minimum |
| Liu et al.[18] | six square slabs, 200x200x50 | Portland cement | The water jet | Abrasion rate increased when the mean particle size increased. |
| Yen et al.[19] | Twenty batches | Portland cement | ASTM C1138 (underwater) | Concrete resistance was increased when compressive strength increased. |
| Author(s) | Type | Composition | Test Method | Findings |
|-----------|------|-------------|-------------|---------|
| Omoding et al[6] | Ten samples | Portland cement | ASTM C1138 (underwater) | Abrasion-erosion loss in conventional concrete mixtures follows a power function of its compressive strength. |
| Ayoob et al. n.d[20] | Six SCC mixtures | SCC(Self-Compacting Concrete) | Water jet test | Increasing the strength from 30 to 40 MPa the abrasion losses can be reduced by around 17%. |
| Rahmanzadeh et al.[21] | Five mixtures | Portland cement and Super plasticizer | Water Sand Blast | Increment in (w/c) ratio can cause an obvious reduction in concrete abrasive resistance. |
| Horszczaruk[22] | Three different types of polypropylene fibers | Polypropylene fibers | Bohme disc method and underwater method | Polypropylene fibers addition increases the concrete resistance to abrasion. |
| Horszczaruk[23] | Four types of high performance concrete (HPC) | High performance concrete | Underwater method that conforms with ASTM C1138 | HPC without fibers have the minimum abrasive resistance |
| Grdic et al[24] | Nine mixtures | Two types of polypropylene fibers | The water jet method | Polypropylene fibers addition has a good impact to increase the concrete resistance. Abrasion resistance was reduced by 22, 32 and 55% for 20, 25 and 30% compensations, respectively. |
| Yen et al[19] | Five sample types | Different concentrations of fly ash | Underwater method ASTM C1138 | The abrasion resistance of the concrete samples increment when they have needed addition time to age to their maximum structural safety. |
| Hassan[25] | Eleven sample types | Portland cement, silica fume, Fly Ash | The water jet method | |
| Kang Jing et al[26] | Eight samples | Silica fume | Underwater method ASTM C1138 | Abrasion resistance and the compressive strength of the silica fume samples compared with the control concrete were increased by 86% and 28.7%, respectively. |
| Eren et al[27] | Three different dosages of silica fume | Silica fume | A special equipment | The silica fume increases the surface wear resistance of the concrete. |
5. Conclusions

The structure of the paper is such that mechanisms of concrete abrasion-erosion are first discussed together with conclusions drawn from other cementitious composites and brittle materials with factors influencing.

1. In common, the abrasion weigh lose declines when the age of the samples increment. This will be refer straightforwardly to the change in the surface hardness expected to, the quality improvement of samples.

2. Dependent upon the literature review of past investigations and standards, ASTM C1138 abrasion test for concrete be able to provided a perfect qualitative apparatus will examine the abrasion of surfaces that are presented on water-brone particles over water hydraulic structures. Nonetheless this test doesn't consider the impact of the falling of the falling water and water-brone particles starting with higher levels. otherwise, vast literature may be available on an non-standard test, method water jet test using to determine the wearing resistance of concrete because of water and sand impact.

3. In fact, the abrasion disintegration will be impacted by its compressive strength, tensile strength, aggregate quality utilization of specific cements elastic modulus for concrete water-cement proportion concrete surface treatment, concrete care Furthermore additives (mineral additives, polymers, fibers).

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