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Abrasive Effects Observed in Concrete Hydraulic Surfaces of Dams and Application of Repair Materials

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1. Introduction

This chapter presents the main abrasive effects observed in concrete hydraulic surfaces of dams of hydroelectric power plant (HPP). These types of hydraulic structures are subject to solicitations for dynamics order due to water flow at high speed usually causing to erosion, cavitation and abrasion. These effects are harmful and cause of defects on the surface hydraulic of dam. Thus, maintenance is needed on the surface of the structure, when is applied a repair material (RM). The RMs must have characteristics, especially mechanical and chemical properties, consistent with the base material or substrate.

We analyzed the defects from the abrasive processes caused by the flow of water from the reservoir that occurred in two concrete dams in Brazil. One is located in the state of São Paulo, southeastern Brazil. The other is located in the state of Paraná, southern of country. Have been proposed RM different for application at surfaces hydraulic of dams, which had their performance verified in laboratory and field.

The steel fiber concrete was developed based on the concrete mixture used in one slab of the spillway for the dam in the Southeast, case one. The average mixture used was 1: 1.61: 2.99: 0.376, with cement consumption of 425 kg/m^3. The mortar mixtures were made following the information given by the manufacturers. Tests of the RM were conducted in laboratory: abrasion resistance of concrete (underwater method), flexural tensile resistance, compressive strength tests, elasticity modulus, resistance to adherence, accelerated aging in UV ray chamber and humidity and permeability tests.

In case study 2 were analyzed in the laboratory and applied field, the dam of the South, were made from mixtures of concrete with addition polymeric and elastomer materials proceeding from the recycling industry, such as agglutinated low-density polyethylene (LDPE), crushed polyethylene terephthalate (PET) and rubber from useless tires. The contents of recycled material were 0.5%, 1.0%, 2.5%, 5.0% and 7.5%. Mixtures with added recycled material and RC were analyzed in the laboratory in the mechanical properties of compressive strength, splitting tensile strength and grip. Considering the results of the

laboratory were selected for field application the concretes with contents of 2.5 and 5.0%. Besides the concretes with addition of recycled materials were applied in field. The materials used in the field were examined in tests of abrasion resistance of concrete (underwater method) and accelerated aging tests performed in a moist chamber with SO_2 and baths by immersion in NaCl, Na_2SO_4 and distilled water, where the specimens were followed by the technique of the corrosion potential.

The tests were carried out in laboratory on concrete samples in order to simulate the environmental conditions, which are usually found, among others, for controlling the mechanical resistance and the aging imposed conditions, such as solar radiation, humidity and chemical attack.

2. Mechanisms of surface wear in hydraulic structures of concrete

The durability of a concrete structure is strongly influenced by the inappropriate use of materials and physical and chemical effects of the environment where it operates. The immediate consequence is the anticipated need of maintenance and execution of repairs (Galvão et al, 2011).

In the case of hydraulic structures of concrete, one of the main forms of degradation is related to abrasive processes. In general, the erosion caused by surface wear of the hydraulic structures of concrete, is defined as the disintegration of the material exposed to the phenomena of deterioration (Kormann, 2002).

Normally, concrete is measured and produced by following certain criteria for structural and operational conditions that can support the loads and overloads for several years without wear. However, for a variety of factors, including design parameters and construction, selection and quality of materials, operational changes, as well as interaction with the environment, the structures are damaged, and the degree of deterioration is directly related to these factors.

To recover the surfaces that have suffered such damage, various materials and application techniques have been developed. These repair materials should be appropriate to the characteristics of the phenomenon of wear as well as the operating conditions of the structures. Other considerations, such as access to sites of repair, time of execution of services, cost of operations, staff expertise on the handling of materials and equipment, should be estimated so taht whole recovery program is carried out with full success.

Maintenance of structures on surfaces of concrete dams should be done by combining the characteristics of cost, feasibility, performance, durability, usage, time of application of the materials and compatibility between them (Kormann et al, 2003).

2.1 Physical causes of concrete deterioration

Physical causes of concrete deterioration were grouped by Metha & Gerwick (1992) in two categories. The first category consists of the surface wear due to abrasion, erosion and cavitation. The second category is composed by cracking due to volume variation, structural loading and exposure to high temperatures.

According to Mehta & Monteiro (2006), the term abrasion refers to dry friction, as in the case of wear of industrial floors and pavements due to vehicle traffic. Erosion is usually used to

describe the wear by the abrasive action of fluids satisfaction suspended solids occurring as coatings on hydraulic structures of channels and spillways. The cavitation damage to hydraulic structures, and relates to the loss of mass by the formation of vapor bubbles caused sudden change of direction in rapidly flowing waters.

In the manual of the American Concrete Institute (1999) are considered like erosive processes in concrete structures: cavitation, abrasion and wear by chemical attack.

This differentiation of works cited is purely arbitrary, as emphasized by Mehta & Monteiro (2006). Generally, the physical and chemical damage, ultimately complement each other. When occur physical damage, such as abrasion, there is increased exposure of the concrete surface to agents such as acid rain, and therefore the attack by chemical compounds is favoured. When occur the chemical damage, such as leaching, the concrete is more porous, facilitating the process of abrasion, and so on. These facts make both processes of deterioration, physical or chemical, a cycle of difficult to dissociation or stabilization.

It is understood then, that the abrasion term refers to wear by dry friction and the erosion term is the wear by the impact of suspended solids carried by a fluid (Neville, 1996). In hydraulic structures for dams this fluid is water.

Although the terms abrasion and erosion differ by the type of environment in which the wear occurs, dry or suspended in water, wear that occurred on concrete surfaces hydraulic is called erosion by abrasion or simply abrasion.

2.2 Occurrence of abrasion in concrete hydraulic structures

Abrasion is caused by the impact of elements transported by water in hydraulic structures of concrete. How much more turbulent are the flows, along with the impact forces caused by debris, the greater the abrasion.

The debris transported by water flows ranging from their hardness until their types, and can be sand, stones, rubble, gravel, etc. The hydraulic structures most affected by abrasive processes are the surfaces of the spillways, stilling basin, walls of the upstream reservoir, drain pipes and hydraulic tunnels.

In hydraulic structures of concrete dams, turbulent flows of water with suspended debris, colliding into their concrete surfaces, can cause abrasions to various depths. Great damage by abrasion occurred at Dworshak Dam, whose abrasion consumed an approximate volume of concrete and foundation rock of 1,530 m^3, and approximate depths of 2 and 3 m (ACI, 1999)

2.3 The main factors affecting the resistance of concrete abrasion

The main factors affecting the abrasion resistance of concrete are the environmental conditions and dosing of aggregates, concrete strength, the mix ratio, the use of special cement, the use of supplementary materials, such as adding fiber and fly ash . Two other factors have an important effect on the abrasion resistance, surface finish and curing conditions (Horszczaruk, 2005).

The compressive strength proved to be one of the most important factors that correlate with the abrasion resistance of concrete. The compressive strength does not influence the abrasion resistance however is verified a correlation between them, if one is high; the other tends to be too.

Holland et al. (1987) established dependence between the concrete compressive strength and abrasion resistance underwater method in 72 hours. The tests showed that the abrasion resistance increases with the compressive strength. Holland studied the abrasion resistance of concrete with 11 to 15% silica fume and water/cement ratio (w/c) ranging between 0.24 and 0.34 to repair the Kinzua Dam in Pennsylvania. The concrete had, after 28 days, compressive strength of until 79MPa. The use of silica fume improved abrasion resistance compared to conventional concrete.

In the work of Horszczaruk (2005) presents the program takes nine high-strength concrete made of various types of cement and modified with steel fiber, PVC fiber and latex. The concrete was made with three types of cement: Portland CEM I 42.5R, CEM I 52.5R and CEM III 42.5. All mixtures contained fly ash (SiO_2, 93%) and silica fume (10% of cement mass). The mixtures contained the fraction of basalt aggregate with density of 3.03 kg/m3 and maximum size of 8 and 16 mm. The paper presents important findings: i) The ASTM C1138 method is suitable for determining the abrasion resistance of the high-strength concrete (HSC) to 28 days compressive strength of 80 to 120 MPa; ii) The period analysis method for underwater (HSC) should be at least 72 h; iii) The assumption of linear dependence of wear (HSC) is correct, omit the first stage of abrasion (12-24h). The rate of wear can be assumed constant (HSC over 80 MPa); and iv) The latex additive does not improve the abrasion resistance of concrete. The HSC with added PVC fiber showed improvement in this area.

2.4 Repair of concrete hydraulic structures

Repairs to damaged concrete structures are important not only to ensure the planned useful life, but also to provide good performance and security facing the most severe applications.

An adequate repair improves the function and performance of the structure, restores and increases its strength and stiffness, improves the appearance of the concrete surface, provides impermeability to water, prevents the penetration of aggressive species at the interface concrete/steel and improves its durability (Al-Zahrani et al, 2003).

The surfaces of hydraulic concrete dams are subject to wear by erosion (American Concrete Institute, 1999), fissures caused by the pressure of crystallization of salts in the pores (Tambelli et al, 2006) and by exposure to contaminants (Irassar et al, 2003), causing defects and constant maintenance and repair applications.

Various materials are marketed for repair of deteriorated concrete structures. The RM is the most commonly used is the mortars with silica fume, epoxy resin and polyester resin, the concrete with polymers and concrete reinforced with fibers.

To carry out repairs to a concrete structure should be considered the main causes of defects, the extent of deterioration, environmental conditions and external stresses imposed. Since then, it follows by the choice of RM itself, which meets the design specifications, as schematic design presented in Fig. 1.

The recovery services of hydraulic structures are extremely expensive. According to Smoak (1998), recovery operations and maintenance of infrastructure of water resources, located mainly in the most severe climatic zones of the United States accounted for spending more than U$ 17 billion.

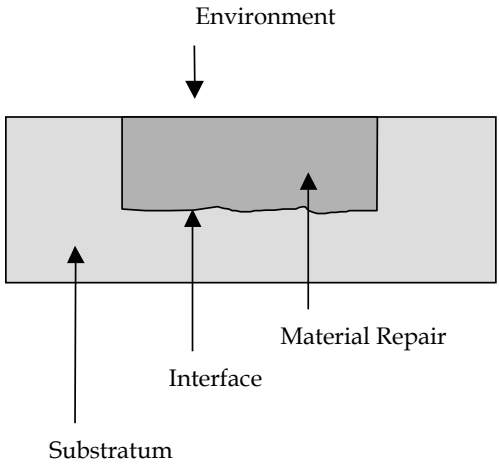


Fig. 1. Repair system: substrate/material repair

In Brazil, the concern about the safety of dams usually relates to the structural problems, mainly due to the catastrophic results of the loss of generation, supply capacity, indemnity expenses, cost of recovery and depreciation in the name and prestige of the Company (Cardia, 2008).

3. Case studies for the application of repair materials

We evaluated the state of degradation and the need to repair the spillway of two hydroelectric power plants, located in the south and southeastern of the Brazil. The hydraulic structures of these HPP have been degraded by the processes of abrasion, and thus, different materials were applied concrete repair these dams.

3.1 Case one

When performed visual inspection of the dam in southeastern Brazil were analyzed various structures such as the surface of the spillway surface of the slab, side walls, pillars of the gates and blocks of dissipation. These structures were found several points of deterioration and abrasive processes.

As noted in the inspections, the state of degradation of the dam due to abrasion processes requires additional repairs to the concrete hydraulic structure. To repair the dam shown in Fig, were proposed four types of RM: mortar with silica fume, epoxy mortar, mortar and polymer concrete with steel fibers. These repair materials were evaluated for mechanical properties of strength and durability. The highlight is the test of abrasion resistance according to ASTM C 1138. The samples subjected to abrasion tests were evaluated according to the wear surface.

Is shown in Fig. 2a, overview of the spillway. It is observed that the wall of the gate shows signs of erosion (highlighted). Is shown in Fig 2b, defect in a slab of the spillway caused by abrasion.

(a) (b)

Fig. 2. (a) Spillway dam presented deterioration by abrasion. (b) Defects in the concrete structure caused by abrasive process

3.1.1 Repair materials

a. Mortar with silica fume

According Ghafoor & Diawara (1999), the optimum silica fume content is around 10% mass of cement, replacing the fine aggregate. The proportion of the mixture used to construct the mortar with silica fume was 1: 3.66: 0.5: 0.1 (cement: sand: water: silica).

b. Epoxy mortar

The epoxy mortar was measured according to manufacturer's instructions. This type of material is composed of components A (resin) + B (hardener) and C (quartz sand).

c. Polymer mortar

For the production of polymer mortar was used an industrial product in which it was necessary to add only water. The water content indicated by the manufacturer was around 18%. However, the best workability was checked with a water content of 11%, which was then used in making the RM.

d. Concrete with steel fiber

The mixture used to prepare the RM of concrete with addition of steel fibers was 1: 1.985: 2.77: 0.45: 2.42 (cement: sand: gravel: water: steel fibers).

e. Concrete Reference

Although the mixture was made of the material considered as the reference concrete (RC) with characteristics similar to concrete used in dam construction. The content of the mixture of the RC was 1: 1.61: 2.99: 0.376 (cement: sand: gravel: water) with cement content of 426 kg/m^3.

3.1.2 Compressive strength

The compressive strength is considered one of the main evaluation parameters for resistance of cementitious materials on the request abrasion (Mehta & Monteiro, 2006; American

Concrete Institute, 1999; Neville, 1996). The values were analyzed for characteristic strength at 28 days of curing material. The average results were 48.3 MPa for the reference concrete, 45.4 MPa for the mortar with silica fume, 85.4 MPa for the epoxy mortar, 40.7 MPa for the polymer mortar and 39.7 MPa for concrete with steel fibers.

3.1.3 Preparation of specimen for testing abrasion underwater method

For the analysis of resistance to abrasion submerged by the method followed ASTM C 1138/97. Were fabricated specimens of concrete with diameters of 300 mm and height of 100 mm. On the test specimens was a void top center of approximate diameter of 200 mm and 50 mm height. The body of evidence resulting from this process was considered the substrate structure. After his cure at 28 days, resulting in gaps of various specimens were filled with the RM study. The preparation procedure of specimens is illustrated in Fig. 3. After 28 days of curing of the specimen substrate + RM, in a wet chamber with relative humidity greater than 95% and controlled temperature (23 ± 2) ° C, we evaluated the abrasion resistance of the repair systems studied.

(a) (b)

Fig. 3. Preparation of specimens for testing abrasion. (a) Release and compacting concrete reference. (b) System: substrate | repair material.

3.1.4 Abrasion resistance of concrete

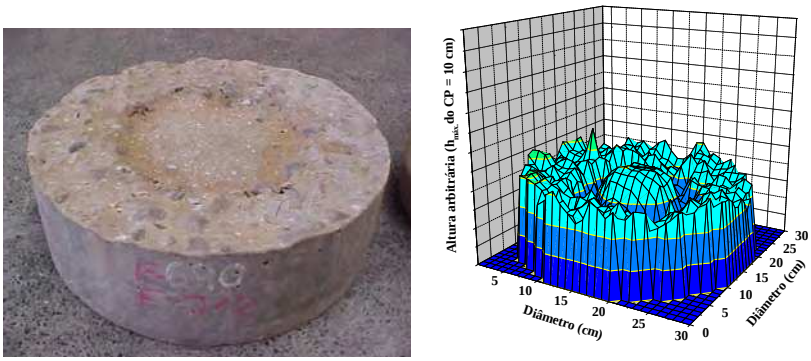
In Table 1, the values of mass loss, after 72h of abrasion (underwater method), of RC and system CR | RM, are presented.

Repair material	mass loss (%)		
	24 h	48 h	72 h
Mortar with silica fume	3.33	4.80	5.53
Epoxy mortar	1.31	1.66	2.03
Polymer mortar	4.72	5.97	6.40
Concrete with steel fiber	1.57	2.96	3.64

Table 1. Mass loss of concrete specimens under abrasion (underwater method).

The average mass loss for the substrate system|mortar with silica fume was 5.53% and was virtually in the region of the substrate and the interface between both materials.

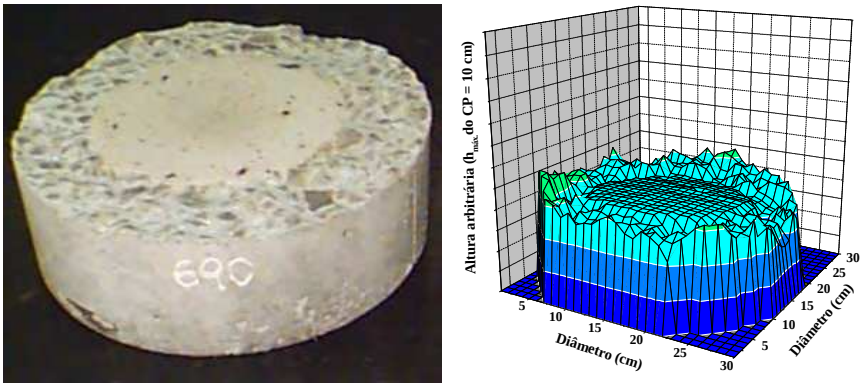
Fig. 4, shows the performance of the system substrate | mortar with silica fume, 72 hours after the test.



(a) (b)

Fig. 4. Results of testing of abrasion resistance of the RM with silica fume. (a) Specimen after test. (b) 3D schematic graph of wear occurred in the abrasion resistance test (underwater method).

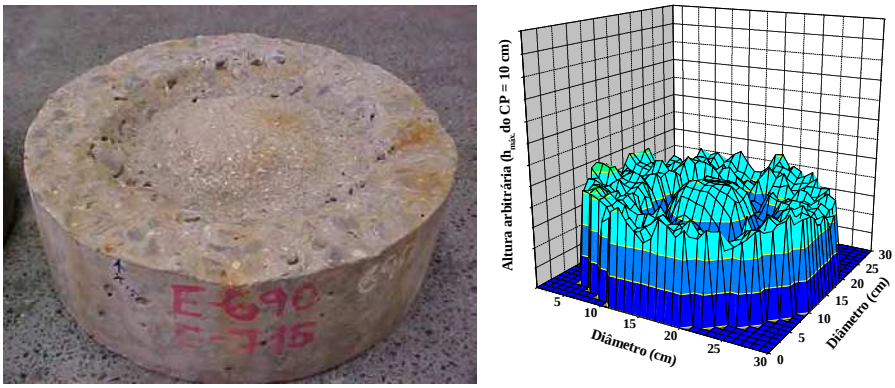
The mass loss for the substrate system | epoxy mortar was averaging 2%. It can be seen in Fig. 5 that much of the material was extracted from the substrate, with little influence in the region of interface. This effect can be attributed to high compressive strength of the material (over 90 MPa).



(a) (b)

Fig. 5. Results of testing of abrasion resistance of the RM with epoxy mortar .
(a) Specimen after test. (b) 3D schematic graph of wear occurred in the abrasion resistance test (underwater method).

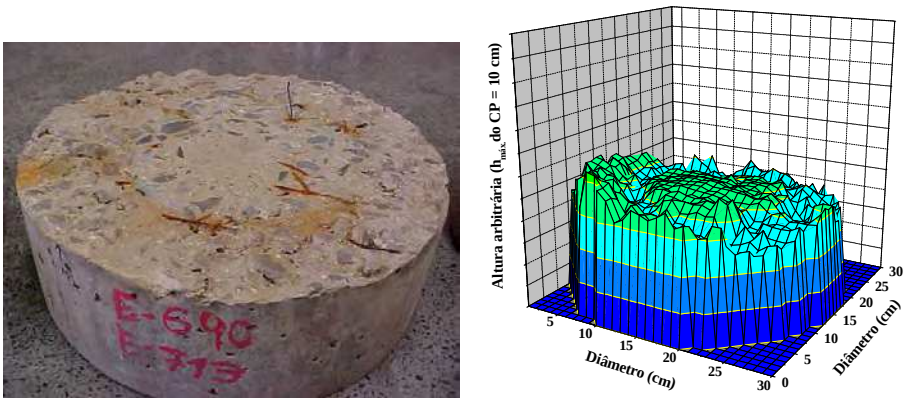
In Fig. 6, shows the performance of the system substrate | polymer mortar. The average weight loss was 6.4% and located in the substrate interface | polymer mortar.



(a) (b)

Fig. 6. Results of testing of abrasion resistance of the RM with polymer mortar . (a) Specimen after test. (b) 3D schematic graph of wear occurred in the abrasion resistance test (underwater method).

The effect of abrasion on the test substrate system | concrete with steel fibers was also not very pronounced. The mass loss was more intense in the region of RC, as shown in Fig. 7.



(a) (b)

Fig. 7. Results of testing of abrasion resistance of the RM with concrete with steel fibers. (a) Specimen after test. (b) 3D schematic graph of wear occurred in the abrasion resistance test (underwater method).

Horszczaruk (2009) conducted a study with high performance concrete (HPC) and high performance fiber-reinforced concrete (HPFCR) to analyze performance and hydraulic abrasion. The author found that the effect called the shadow zone. This effect was observed specifically in concrete reinforced with steel fibers than in the polymer concrete reinforced with polypropylene fibers. The effect of shadow zone caused a slight increase in abrasion resistance of HPC.

As shown in the graphs of Fig. 4 - 7, may be the poorest performance of the mortars with silica fume and polymer mortar, respectively, the second has more wear. The substrate system | concrete with steel fibers showed a good performance and wear observed was widespread. Already, for the substrate system|epoxy mortar, the wear was observed on the substrate with little or no loss of epoxy mortar.

The information obtained in the 3D schematic drawings of wear occurred in the abrasion resistance test underwater method corroborate the results in Table 1, where the materials of greater mass loss were made with RM mortar with silica fume and polymer mortar. Concrete reinforced with steel fibers had lower mass loss that these two mortars possibly due to the effect of shadow zone. The epoxy mortar, material with higher mechanical strength (85.4 MPa), showed little wear (Fig. 5) and therefore represented by the lower mass loss during the 72 hour test (Table 1).

3.2 Case two

As a case study 2 assessed the repair of the spillway chute Hydroelectric Plant located in southern Brazil, with the use of concrete repair materials with the addition of polymeric materials. Seeking a proposed sustainable polymeric materials were analyzed from the recycling industry. The materials agglutinated low-density polyethylene (LDPE), crushed polyethylene terephthalate (PET) and rubber from useless tires were added to the concrete for the construction of the repair material degrades the surface hydraulic and abrasive processes.

In Fig. 8a presents the overview of the spillway of the dam and in Fig. 8b, a detail of the displacement of the surface caused by hydraulic abrasive processes.

(a) (b)

Fig. 8. (a) Overview of the spillway of the dam. (b) Detail of the displacement of the surface caused by hydraulic abrasive processes.

3.2.1 Compressive strength

To determine the best mix for making RM were added to the concrete, recycled polymeric material in the contents of 0.5%, 1.0%, 2.5%, 5.0% and 7.5%

In Figure 9, shows the average results of compressive strength at 28 days to cure the concrete with the addition of recycled polymer materials (Galvão et al, 2011).

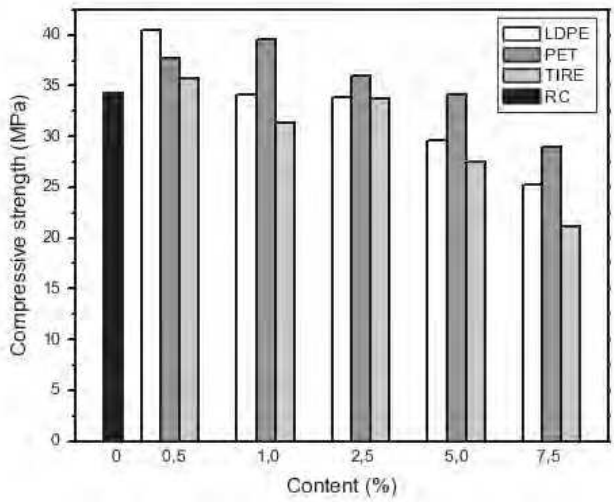


Fig. 9. Comparative graph of compressive strength, at 28 days, of concretes with additions of waste and its respective contents.

For the different materials studied and their respective contents verified that the results obtained from tests for compressive strength as a function of curing time were inversely proportional to the content of addition of recycled fibers. This trend was also observed by Choi et al (2005) when they studied the effects of adding waste PET bottles in the properties of concrete and by Al-Ismail & Hashmi (2008) in the bond strength between the surface of the waste polymer and cement paste.

The reduction in compressive strength of concrete mixtures with the addition of plastic aggregates may be due to a lower resistance of these particles, when compared to natural aggregate (Batayneh et al, 2007).

Al-Manas and Dalal (1997) and Soroushian et al (2003) also found that the compressive strength decreased with increasing aggregate content in plastics.

In the studies by Freitas et al (2009) was verified a reduction in compressive strength with increasing rubber content of added sugar. Li et al (2004) also observed reduction in axial compressive strength of concrete with fibers tire and is not related to any such loss characteristic of the material.

In the analysis of all the values of compressive strength (Fig. 9), were chosen levels of 2.5% and 5.0% addition of recycled material for the manufacture of polymeric materials to repair

the degraded surface at the dam. These were not necessarily the levels with greater resistance to axial compression. However, we considered the possibility of adding the larger volume waste polymer concrete giving them the appropriate final destination, the contents of 2.5% and 5.0% was therefore selected.

3.2.2 Abrasion resistance of concrete

The Table 2, shows the values of mass loss by abrasion of the RC and of the concretes with addition with recycled polymer materials.

Repair material	mass loss (%)		
	24 h	48 h	72 h
RC	2.50	4.24	6.57
Tire 2.5	3.26	5.22	8.41
Tire 5	3.19	5.03	7.39
PET 2.5	3.37	5.57	8.07
PET 5	2.86	4.55	5.04
LDPE 2.5	3.44	5.39	7.46
LDPE 5	1.95	3.32	3.94

Table 2. Mass loss of concrete specimens under abrasion (underwater method).

Analyzing the mass loss at 72 hours the test of resistance to abrasion (Table 2), it is observed that the CR had the best performance when compared to concrete with addition of residues in the polymer content of 2.5% . However the content of 5% waste polymer concretes with the addition of PET and LDPE showed better results than plain concrete. There is no linearity in the mass loss for 24, 48 and 72 hours of testing. Horszczaruk (2005) considers that the period of analysis method for abrasion resistance under water must be at least 72 hours for high strength concrete in hydraulic structures.

Soroushian et al (2003) observed that the addition of recycled plastic caused a reduction in abrasion resistance of concrete. The authors attributed this effect to the fact that the fibers were torn near the surface under the effect of change in the abrasion and wear characteristics of concrete with the presence of fibers from recycled plastic modified the surface characteristics of the material.

Analyzing the content of adding recycled polymeric material notes that for a greater amount of material added to the concrete there is a gain in resistance to abrasion. This increase occurs for all materials analyzed the levels of 2.5 and 5.0%. A similar effect was verified by Soroushian et al (2003) in abrasion resistance depending on the type of plastic fiber only to an increase in the content of virgin polypropylene fibers of 0.075% to 0.15% compared to the volume of cement.

Considering the type of recycled material used in addition, it appears that the concrete produced with waste LDPE have been the best performance for abrasion resistance. The material made from fibers tire had the highest values of mass loss, representing less resistance to abrasion. The concrete with the addition of PET showed intermediate values as between the other two types of waste studied.

3.2.3 Application in field

In order to check the performance of materials for the repair of hydraulic structures of concrete, there were applications of these materials studied in the spillways of HPP. RM were applied to concrete with the addition of recycled polymer materials (LDPE, PET and tire) in levels of 2.5% and 5.0%, in addition to mortar with silica fume, epoxy mortar, polymer mortar and concrete with steel fiber.

The application of RM consisted the steps of selecting points of application, cutting and scarification, dosage and application of the concrete itself. These steps are described in the work of Galvão et al (2011) and Kormann et al (2003).

The points of application of the repair materials were selected in the spillway after complete observation of the degradation state of the dam and location of defects exposed in concrete blocks.

The curved regions were avoided in the spillway for the implementation of repair material due to the existence of differential effects of cavitation, which could compromise comparative testing of field.

As a bridge bonding was applied on the dry surface substrate, a structural adhesive epoxy resin of high viscosity (Fig. 10a). This care has been taken to ensure good bond strength between the substrate and RM.

The concrete was cast into the point of application of the substrate with a trowel and pestle, removing air bubbles from the material (Fig. 10b).

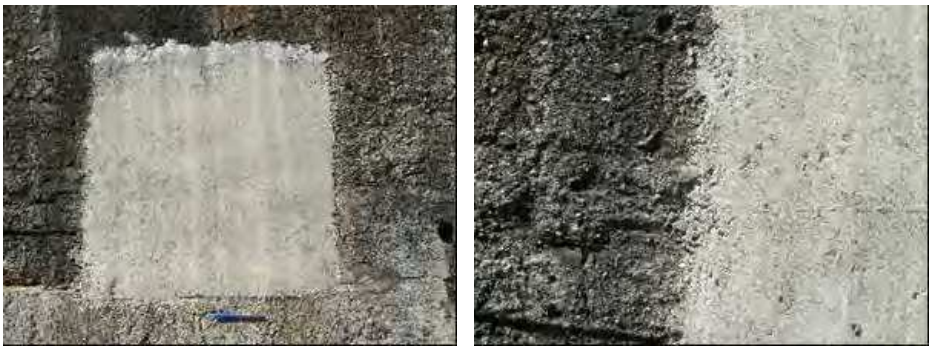
(a) (b)

Fig. 10. (a) Application of bridge bonding. (b) Launch of the repair material.

3.2.4 Performance of repair materials applied field

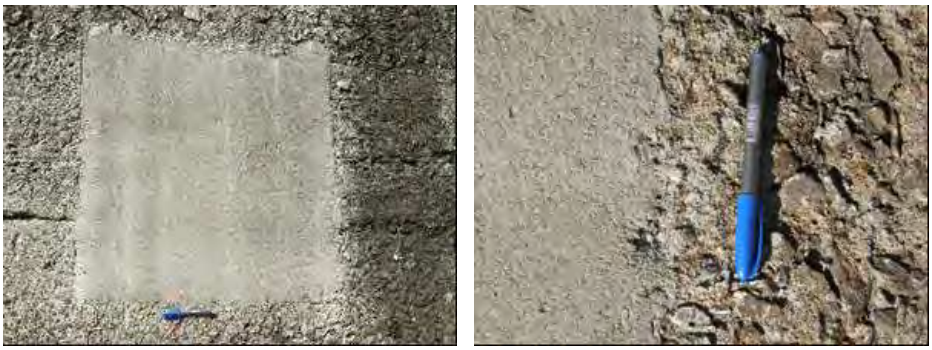
After two years of application, we observed the general state of conservation of repair materials, mainly related to the appearance of defects and interface between the RM and the substrate. In Fig. 11 and 12 are registered examples of points where they were applied in the field analyzed RM.

It can be seen in Fig. 11a the repair material applied to the surface of the hydraulic concrete structure is well adhered to the substrate. In the detail of Fig. 11b the interface between old concrete and the RM applied not showed flaws or defects, even after the period of water flow in the spillway of the dam and the middle attacks.



(a) (b)

Fig. 11. Application point of repair material. (a) Reference concrete without additions. (b) Detail of the border between the RM and the substrate.



(a) (b)

Fig. 12. Application point of repair material. (a) Concrete with addition of recycled LDPE in the content of 2.5%. (b) Detail of the border between the RM and the substrate.

It appears that the point of application above a superior performance compared with other repair materials. At this point the surface has good finish, smooth and free of imperfections, even after the occurrence of water flow in the spillway and aggression in the middle. At no point were visually observed cracks or fissures.

The defects in the substrate were completely contained at this point of application of RM made of concrete with added content in 2.5% recycled LDPE material.

4. Conclusion

For two case studies were analyzed in total 11 types of repair materials for hydraulic concrete surfaces.

In the case of mortars was proved the relationship between abrasion resistance and compressive strength of these materials. The repair material made of epoxy mortar performed better on the compressive strength presented as the material more resistant to abrasion underwater method. In turn, the polymer mortar material was lower mechanical strength and consequently the repair material with greater mass loss in abrasion tests.

The epoxy mortar has high mechanical strength. It was found that when the mechanical strength of the repair material was far superior to the concrete substrate, caused edge effect. Thus, the hydraulic structure, the water moving at high speed, may form a step that will facilitate the process of cavitation. The specimens with epoxy mortar in the abrasion test showed the edge effect mentioned. Was considered appropriate to seek similar mechanical strength between the substrate and repair material so that the structure suffers wear a uniform.

When we evaluated the addition of concrete with recycled polymer materials was observed that the inclusion of these materials reduced the compressive strength of concrete. The greater the content used was the lowest average compressive strength. This reduction was identified in the waste polymer when added to concrete in the contents of 0.5% to 7.5%. However, evaluating the abrasion resistance of the underwater method, considering the mass loss, it was found that the RC had the best performance when compared to concrete with addition of residues in the polymer content of 2.5%. However, the content of 5% waste polymer added to the concrete showed better results than plain concrete, indicating that, for polymer fibers, the increase in the level of addition may influence the increased resistance to abrasion

5. Acknowledgment

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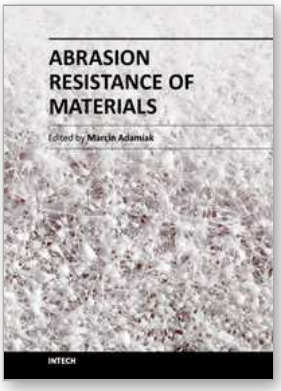

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