B-2-3 Performance of different coatings and repair mortars for abrasion resistance of concrete

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ABSTRACT: Abrasion of concrete is one of the major problems in hydraulic structures resulting from the abrasive effects of waterborne silt, sand, gravel, rocks, ice and other debris being circulated over a concrete surface. Abrasion results in deterioration of concrete and can eventually expose the reinforcement to corrosion. Thus, apart from section loss, the durability could be a major issue in hydraulic structures made of reinforced concrete. The protective coatings are used to avoid this distress and thereby to extend the service life of structures, while repair mortars are used to restore such abraded surfaces. This study focuses on investigating various types of concrete coatings and repair materials for their suitability as a protective and repairing layer on concrete surfaces. In this study, an experimental approach is adopted by applying various available concrete coatings and repair mortars on concrete specimens and exposing them to abrasive forces. The specimens treated with surface coating and repair mortars were subjected to under water abrasion according to ASTM C 1138 standard. Polyurethane and epoxy resin coatings were employed in the study and three types of repair mortars namely epoxy resin mortar, silica fume mortar and polymer modified mortar were used. For each type of surface coating and repair mortar, three cylindrical concrete specimens were cast along with their control specimens. Thus, a total of twenty-one cylindrical concrete samples were employed in this study. Abrasion volume loss was measured to quantify the influence of abrasion and thereby to gauge the performance of various coatings and repair materials. Important observations have been made in the paper about the resistance of each type of surface coatings and repair materials in resisting the underwater abrasion. The results show that epoxy resin coating and epoxy resin mortar gave the best resistance against under water abrasion.

KEY-WORDS: Hydraulic structures; abrasion; concrete coating; repair mortars; relative performance.

INTRODUCTION

Hydraulic structures, such as dams, bridge piers, spillway, drainage conduits, canals, drainage tunnels, etc. play an important role in the regulation and transport of water in reservoirs and open channels. These structures usually have concrete surfaces. Water flow containing suspended solid particles, such as sand and water-borne debris deteriorate the concrete severely, resulting in a shortened life of hydraulic concrete structures [1]. Although, it is not possible to prevent the abrasion phenomenon in hydraulic structures completely, but the life span of these structures can be increased to a great extent by adopting some appropriate control measures against abrasion. A majority of the hydraulic structures throughout the world are reaching to their expected design life. As a high cost and a huge amount of solid waste is involved with the replacement of such hydraulic structures, so demolishing of such structures will not be an economical choice. Thus, repair and maintenance of such structures becomes more important and seems to be a more sustainable approach. Based on the investigation carried out in the past and the study on the performance of various hydraulic structures shows that abrasion resistance coatings and repair mortars exhibit a major role in the enhancement of durability and the life-span of these structures and it results into a low life cycle cost the structures.

Concrete coating is a cover, typically liquid or semi-liquid, which is applied for hardening the concrete surface and which keeps the structure or surface longer and reduces the maintenance and repair costs. In the protection of concrete structures and concrete surface from direct wear, abrasion, reinforcing corrosion, and harsh environmental conditions, coatings play a vital role. Coating does not protect the concrete infinitely, but it delays its decomposition and prolongs its service life with the least possible maintenance and repair effort. The type, purpose, function and location of the concrete structure are the main factors for selecting the appropriate coatings and it application.

Liu [2] investigated the relative abrasion resistance of seven different types of concrete surface coatings. (i.e., two types of polyurethane coating, acrylic mortar, high modulus and low modulus epoxy resin mortar, furan resin and iron aggregate topping), other things being same the polyurethane coatings exhibited excellent abrasion resistance with essentially no loss in 72 hr. One of the main reasons for this excellent performance of polyurethane coatings may be that the resilience of the polyurethane coatings might have cushioned the impact of the abrasion charges. Korman et al. [3] investigated the performance of four repair materials as a function of reference conventional concrete (RefC). The materials are polymer-modified cement mortar (PMor), steel fibre concrete (SFco), epoxy mortar (EMor) and silica fume mortar (SFMo). The test method was slightly modified from ASTM C1138 where a 20 x 5 cm^2 void was left in the centre of the concrete sample in order to place the repairing material. SFco was found as the best material, followed by EMor. The greater advantage of EMor material is its high resistance at the initial stage, which is desirable for an emergency repair. The SFmo and PMor presented a visible border abrasion erosion effect; PMor presented the highest mass loss. Sebok et al. [4] conducted a detailed experimental investigation in order to predict the influence of adding epoxy resin solutions impregnation on the concrete surface against abrasion. The results of this study manifested that the abrasion resistance of untreated samples significantly influenced by compressive strength and aggregate size whereas for treated samples it's the compressive strength and absorption of applied resin, which affects the abrasion resistance more. Time of hardening also seems to affect the abrasion resistance value of concrete surfaces. Ramesh Kumar G.B. and Sharma, U.K. [5] studied the effect of using marginal aggregates in concrete abrasion. The test was done according to ASTM C 1138 and the result shows that the concrete containing weak aggregates having high L.A. value had more abrasion loss than the concrete containing sound aggregates having low L.A.

EXPERIMENTAL PROGRAM

In India, for tunnel lining works of the hydro power projects, a concrete having cube compressive strength of 25 MPa is commonly used [5]. The standards and codes do not specify any minimum acceptable value of abrasion resistance of concrete. In the absence of this, the abrasion resistance of concrete having cube compressive strength of 25MPa with sound aggregates (L.A. abrasion value less than 30%) is considered as benchmark value for acceptable abrasion resistance of concrete in this study. Type of repair mortars and protective coatings is the only variable for the present investigation.

Same strength grade of concrete M25 is employed for all the specimens. The proportioning of concrete mix is given in Table-1. Three types of ready-made pre-packaged repair mortars, i.e. silica fume mortar, epoxy resin mortar and polymer modified mortar were employed as repair materials while two types of coatings i.e., polyurethane and epoxy resin coating were used as a protective measure from abrasion. All repair mortars and protective coatings were obtained from Sika India. A total of 21 cylindrical specimens were cast for evaluating the abrasion resistance of concrete.

Table 1. Mix proportion of concrete

S.N.	Ingredients used	Content (kg/m^3)
1.	Cement (OPC 53 grade)	315 kg/m^3
2.	Coarse aggregate (crushed angular)	1360 kg/m^3
3.	Fine aggregate (river sand)	755 kg/m^3
4.	Water (tap water)	140 kg/m^3

Materials properties

All the test specimens were cast using Ordinary Portland Cement of 53 grade, fine aggregate, coarse aggregate and tap water. All the materials conformed to the specification of relevant Indian Standard Codes [6-10] were used in this investigation. Cursed angular aggregate of maximum nominal size of 20 mm were employed as coarse aggregate while the sand conforming to the zone II of IS 383:1970 [11] were used as fine aggregate throughout the present study. Some properties of repair mortars and concrete coatings as provided by the manufacturer is tabulated in Table 2.

Table 2. Properties of coatings and repair mortars

S.No.	Type of coating /repair mortar	Properties	Values	
1.	Silica fume mortar	Compressive strength (at 28 days)	85 MPa	
		Flexural strength (at 28 days)	11 MPa	
		Water penetration	5 mm	
		Hydraulic abrasion resistance index (at 28 days)	Abraroc	0.5 – 0.6
			Glass	1
			Granite	0.35-0.80
		Wear resistance Böhme	< 6 cm^3/ 50 cm^2	
2.	Epoxy resin mortar	Compressive strength (at 7 days, +30°C)	> 60 MPa	
		Bond strength (at 14 days, +30°C)	Dry substrate	> 4 MPa
			Moist substrate	> 4 MPa
3.	Polymer modified mortar	Compressive strength (at 28 days, +30°C)	55 MPa	
		Flexural strength (at 28 days, +30°C)	5 MPa	
4.	Polyurethane coating	Tensile strength (at 14 days, +27°C)	0.3 MPa	
		Elongation at break (at 14 days, +27°C)	> 900%	
		Water permeability	Negligible	
		Moisture permeability	25 g/m^2/day	
		Water absorption	Negligible	
5.	Epoxy resin coating	Compressive strength (at 7 days, +30°C)	40 MPa	
		Flexural strength (at 10 days, +30°C)	30-35 MPa	
		Tensile strength (at 14 days, +30°C)	18-20 MPa	
		Bond strength (at 14 days, +30°C, dry substrate)	2.5-3 MPa	

Mixing, casting and curing

A tilting type mixer was used in the laboratory to prepare the mix. Various ingredients used in the mix i.e. cement, sand, coarse aggregate and water were kept ready in the required proportions before the casting of each specimen. Uniformity of mixes was ensured by visual inspection of colour of the mix and concentration of each ingredient. On completion of mixing procedure, slump loss of fresh concrete was determined using slump cone test. In all the mixes, a slump value of 50-75 mm was maintained during the design of mixes. All the mixes were checked for bleeding and segregation visually. Bleeding and segregation were not observed in any of the mixes. For casting, cleaned and oiled moulds were placed on the vibratory table with a speed range of 12000 ±400 rpm and an amplitude range of 0.055 mm. Specimens were removed from the moulds after 24 hours and were kept in water for curing until the day of testing.

Preparation of specimens and testing

After a curing period of 28 days, all the specimens were removed from the curing tank and cube compressive strength tests were carried under laboratory ambient condition. Under water abrasion resistance method of ASTM C1138 [12] was adopted to investigate the performance of all repair mortars and protective coatings against abrasion throughout the study. To evaluate the performance of various repair mortars against abrasion, cement-sand mortar of strength grade M25 was considered as a benchmark repair mortar. Similarly, a cylindrical specimen made of M25 strength grade of concrete without any coating was taken as control specimen to measure the performance of various protective coatings. Before applying the repair mortar, surface preparation was done on the required number of specimens. Firstly, the cylindrical specimens were abraded in under water abrasion resistance testing machine (ASTM C 1138) for 24 hours with a speed of 1500 rpm and a uniform abraded surface of average depth of 7 mm was achieved for all the specimens (Fig.1a). To get a good bond between the abraded surface of the specimen and the repair mortar, specimens were further grinded with a grinding machine to an average depth of 5 mm (Fig.1b) and finally a rough surface was achieved with the help of a uniform hammering action on the surface of all specimens. (Fig.1c).

After that, the repair mortar was applied to prepared surface of specimens according to the instructions given by the manufacturer. For the application of the protective coatings on the specimens, the surface of the specimen was cleaned to remove the dust particles and smoothen to get an even surface in order to achieve a good bonding. All other general instructions as per the product manual given by the manufacture were followed during the application of all the coatings. After the required curing period, according to the respective type of coating and mortar, all the specimens were removed from the curing tank and under water abrasion resistance test as per ASTM C 1138 was carried out on all the specimens. Three specimens were tested for each result and the average values were found.

Under water abrasion resistance method of ASTM C 1138 [12] was originally developed in 1981 in order to evaluate the abrasion resistance of concrete surface subjected to abrasion action of water particle on hydraulic structures such as spillway aprons, stilling basin slabs, culverts and hydro power tunnels. A schematic view of the test apparatus as well as view of test setup fabricated in the laboratory is shown in Fig. 2. A cylindrical container made of steel, an agitating paddle, a drill press and steel grinding balls are the essential parts of the apparatus. To agitate the water in the cylindrical container, an agitating paddle is used which is powered by the drill press rotating at a speed of 1200 rpm. It results into the movement of the abrasive charge, i.e. steel balls on the concrete specimen and finally produces abrasion effects on the specimen surface. A total of 72 hours of exposure of abrasive action was given to each of the specimen as per standard procedure of ASTM C 1138. Abrasion loss was evaluated after every 12 hours of interval. Vernier caliper was employed to record the diameter and height of the specimen. Following expression was used to determine the abrasion loss of each concrete specimen:

$$V_t = \frac{(W_{air} - W_{water})}{G_w}$$

where,	V_t	=	Volume of the concrete specimen at desired time, m^3
	W_{Air}	=	Mass of the specimen in air at desired time, kg
	W_{Water}	=	Mass of the specimen in water at desired time, kg
	G_w	=	Unit weight of water, kg/m

$$VL_t = V_i - V_t$$

where,	VL_t	=	Volume of material lost at the end of time increment, m^3
	V_i	=	Volume of specimen before testing, m^3

The average depth of wear at the end of any time increment of testing based on volume of abraded material-

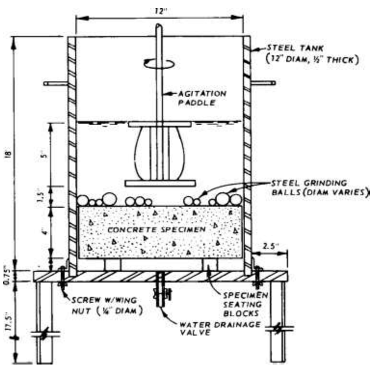
$$ADA_t = \frac{VL_t}{A}$$

where,	ADA_t	=	average depth of abrasion at the end of the test increment in question, m
	A	=	area of top of specimen, m^2

(a) (b)

(c)

Fig.1. A typical view of abraded surfaces (a) after an exposure time of 24 hours in under-water abrasion test apparatus (b) after grinding the surface with grinder (c) after the hammering action.



(a) (b)

Fig.2. (a) A schematic view of under-water abrasion test apparatus (b) A view of fabricated abasion test setup.

RESULTS AND DISCUSSION

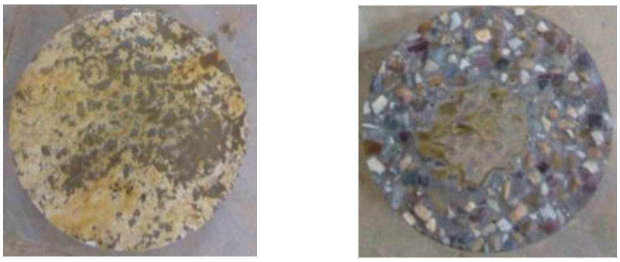
For each specimen, abrasion loss was measured in terms of volume of material lost and average depth of abrasion at each interval of 12 hours for a total duration of 72 hours. The underwater abrasion test results of all the coatings are shown in Table-3. It can be clearly noticed that in all the coatings, abrasion loss was increased as the duration of the test increased from 0 to 72 hours. Epoxy resin was observed to have better abrasion resistance as compare to polyurethane as well as control specimen, i.e. specimen without any concrete coating. Performance of polyurethane against abrasion was better than the control specimen to some extent but was too less as compare to that of epoxy resin. With respect to the control specimen, abrasion loss in case of epoxy resin was reduced by 65% while, in case of polyurethane, a reduction of only 7% was observed. Fig. 3 shows a typical appearance of the specimens coated with different types of concrete coatings before (at 0 hour) and after (at 72 hours) the underwater abrasion test. A comparison in the rate of abrasion loss among the different types of coatings used in the present study was made in Fig. 4. For polyurethane and control specimen, initial rate of abrasion loss was more or less same, but it reduced significantly in case of epoxy resin.

Table 3. Results of underwater abrasion test on coatings as per ASTM C 1138

	Time (hours)	0 h	12 h	24 h	36 h	48 h	60 h	72 h
Volume of material lost (m^3)	Control specimen	0.00000	0.00009	0.00015	0.00026	0.00030	0.00038	0.00043
	Polyurethane	0.00000	0.00008	0.00016	0.00022	0.00031	0.00037	0.00040
	Epoxy resin	0.00000	0.00002	0.00004	0.00007	0.00010	0.00012	0.00015
Average depth of abrasion (mm)	Control specimen	0.00	1.20	2.08	3.66	4.20	5.43	6.02
	Polyurethane	0.00	1.09	2.31	3.14	4.44	5.19	5.66
	Epoxy resin	0.00	0.31	0.59	0.97	1.42	1.70	2.17

At 0 hour At 72 hours At 0 hour

(a) Control specimen (without any coating) (b) Polyurethane coating



At 0 hour At 72 hours

(c) Epoxy resin coating

Fig.3. A typical appearance of specimens with different type of coatings before (at 0 hour) and after (at 72 hours) the underwater abrasion test

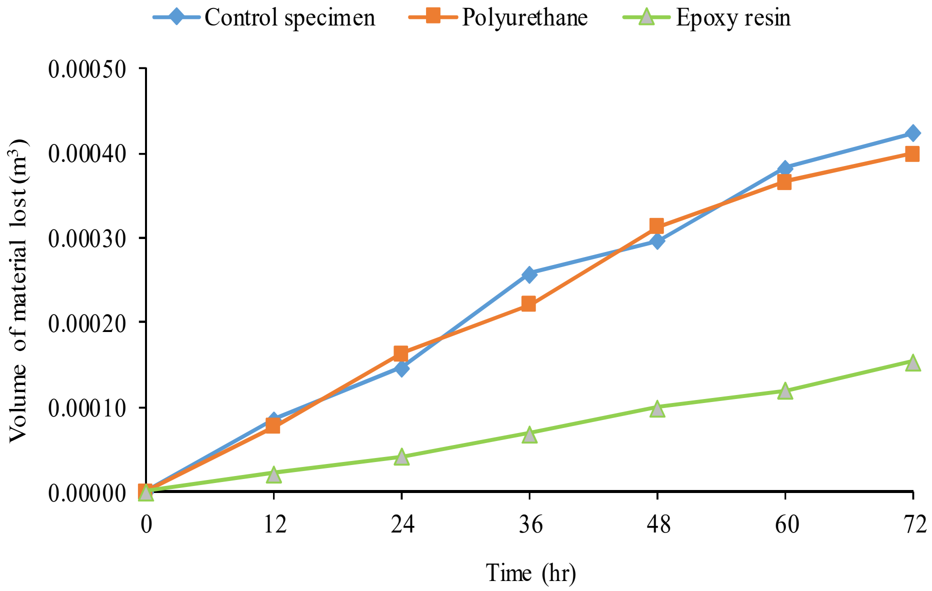


Fig.4. Variation in measured abrasion loss of different concrete coatings

Similarly, performance of all the repair mortars against abrasion was measured in terms of volume of material lost and average depth of abrasion by conducting the underwater abrasion resistance test as per ASTM C 1138. Test results at various time of exposure from 0 to 72 hours are shown in Table-4. As per the results obtained from laboratory test, epoxy resin mortar was considered to have highest abrasion resistance as compare to others. With respect to the performance of M25 repair mortar against abrasion, a huge reduction of 95% in the abrasion loss was seen in case of epoxy resin mortar. With a total reduction of 64% in the abrasion loss, polymer modified mortar was proved to be the second-best abrasion resistance mortar among all the repair mortars considered in the present investigation.

By reducing the abrasion loss of 16 %, silica fume mortar also exhibited better resistance against abrasion, but it was less as compare to epoxy resin mortar and polymer modified mortar. A better comparison among the various repair mortars in terms of rate of abrasion loss with respect to time is represented in Fig. 5. In the initial stage of first 12 hours of testing, M25 repair mortar and silica fume mortar showed more or less same rate of abrasion loss but, later on, it started deviating when an upper thin layer of silica fume mortar had been abraded. Least initial rate of abrasion loss was shown by epoxy resin and later on, it showed hardly any abrasion loss for the total duration of 72 hours of testing. Rate of abrasion loss for polymer modified mortar was in between that of silica fume mortar and epoxy resin mortar. Fig. 6 shows a typical appearance of the specimens with different types of repair mortars before (at 0 hour) and after (at 72 hours) the underwater abrasion test.

Table 4. Results of underwater abrasion test on repair mortars as per ASTM C 1138

	Time (hours)	0 h	12 h	24 h	36 h	48 h	60 h	72 h
Volume of material lost (m^3)	M25 repair mortar	0.00000	0.00006	0.00016	0.00023	0.00032	0.00040	0.00044
	Silica fume mortar	0.00000	0.00006	0.00013	0.00019	0.00026	0.00031	0.00037
	Epoxy resin mortar	0.00000	0.00001	0.00001	0.00002	0.00002	0.00002	0.00002
	Polymer modified mortar	0.00000	0.00002	0.00005	0.00008	0.00010	0.00013	0.00016
Average depth of abrasion (mm)	M25 repair mortar	0.00	1.53	2.87	4.00	5.20	6.33	7.07
	Silica fume mortar	0.00	0.21	0.71	1.07	1.88	2.48	3.48
	Epoxy resin mortar	0.00	0.14	0.18	0.25	0.28	0.32	0.32
	Polymer modified mortar	0.00	0.23	0.67	1.33	1.80	2.47	2.80

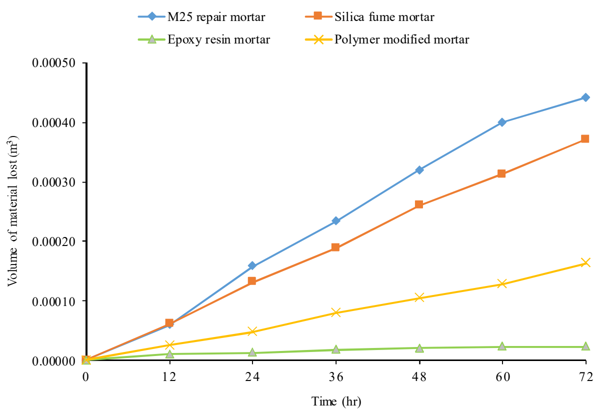
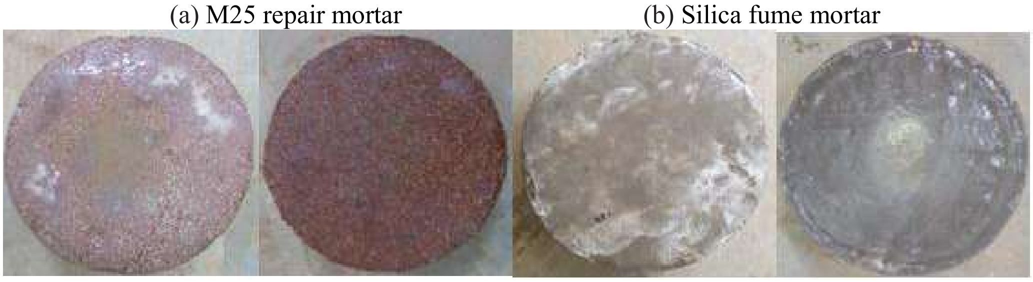


Fig.5. Variation in measured abrasion loss of different repair mortars

Before (at 0 hour After (at 72 hours) Before (at 0 hour) After (at 72 hours)

(a) M25 repair mortar (b) Silica fume mortar



Before (at 0 hour) After (at 72 hours) Before (at 0 hour) After (at 72 hours)

(c) Epoxy resin mortar (d) Polymer modified mortar

Fig. 6. A typical appearance of specimens with different types of repair mortars before (at 0 hour) and after (at 72 hours) the underwater abrasion test

CONCLUSIONS

To evaluate the abrasion resistance of two types of concrete coatings (polyurethane and epoxy resin coating) and three types of repair mortars (silica fume mortar, epoxy resin mortar and polymer modified mortar), a total of 21 cylindrical specimens were tested as per ASTM C 1138. Within the scope of the present study, following conclusions may be drawn:

1. With respect to control specimen i.e. specimen without coating, both polyurethane and epoxy resin coatings performed better against abrasion. Although, polyurethane coating did not provide too much abrasion resistance to the concrete surface but still it was a quite reasonable as far as the performance of uncoated concrete surface is concerned.

2. Epoxy resin coating increased the abrasion resistance of concrete surface to a great extent but, its higher cost as compared to polyurethane may limit its application as a surface coating on abrasion prone hydraulic structures.

3. In case of repair mortars, all the repair mortars (i.e. silica fume mortar, epoxy resin mortar and polymer modified mortar) were observed to have better abrasion resistance than that of M25 cement-sand mortar.

4. Epoxy resin mortar possesses highest abrasion resistance among all the mortars with almost negligible increment in the abrasion loss with time. Use of polymer modified mortar in the hydraulic structures is seemed to be more economical as it possesses high abrasion resistance and is cheaper as compared to other types of repair mortars.

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