GR-84-1

PRELIMINARY EVALUATION OF A TEST METHOD FOR DETERMINING THE UNDERWATER ABRASION-EROSION RESISTANCE OF CONCRETE

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16. ABSTRACT

A preliminary evaluation test program was conducted using abrasion-erosion test equipment developed by the Corps of Engineers' Waterways Experiment Station. The abrasion-erosion equipment simulates the abrasive action of waterborne particles flowing through or over concrete structures. The program also evaluated the relative abrasion-erosion resistance of various materials considered for use in the repair of abrasion-erosion damaged concrete. The tests showed that the equipment should be valuable in giving relative abrasion-erosion resistance for repair materials for concrete structures showing this type of damage. Of the materials tested, epoxy concretes showed the best abrasion-erosion resistance, followed by vinyl ester polymer concretes.

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Division of Research and Laboratory Services
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Denver, Colorado

SI METRIC

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

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INTRODUCTION

The Bureau of Reclamation has many concrete structures that show abrasion-erosion damage. Rocks, sand, silt, and other solids flow through or over Bureau canals, tunnels, drop structures, spillways, stilling basins, chute blocks, flip buckets, and other water-carrying structures, abrading and eroding them. Since shutting down an irrigation system or a powerplant to make repairs to damaged concrete is expensive, it is desirable to construct or repair damaged concrete structures with a material that resists abrasion-erosion wear.

How does one evaluate a material's resistance to this type of wear? Previously the Bureau has used two methods to evaluate abrasion resistance of materials: (1) Abrasion Resistance of Concrete by Sandblasting (ASTM: C 418-81), and (2) Abrasion Resistance of Horizontal Concrete Surfaces (ASTM: C 779-82, procedure A). However, both of these methods measure the dry abrasion resistance of materials, while most of the wear and tear on Bureau structures is from wet abrasion-erosion. With this in mind, a search for equipment to simulate underwater abrasion-erosion wear was made. The Corps of Engineers' WES (Waterways Experiment Station) abrasion-erosion test apparatus appears to have the capabilities for determining the relative resistance of materials to abrasion-erosion underwater. This apparatus simulates the abrasive action of waterborne particles; however, it is not intended to provide a quantitative measurement of the service life that may be expected from a specific material.*

SUMMARY AND CONCLUSIONS

The WES abrasion-erosion test equipment provides a suitable test method for evaluating the relative resistance of materials subjected to abrasive action of waterborne particles. The abrasion-erosion resistance of epoxy concretes was superior to all other concretes tested. Among the polymer concretes tested, the vinyl ester concretes were slightly better than the commercial methyl methacrylate concretes. One modified methyl methacrylate was tested which approached the resistance of epoxy concretes. An epoxy-modified portland cement concrete showed improved abrasion-erosion over conventional portland cement concrete.

DISCUSSION OF TEST METHOD AND EQUIPMENT

The WES abrasion-erosion test method simulates the behavior of swirling water containing suspended and transported solid objects which can cause abrasion of the surface and produce

* Test Method for Abrasion-Erosion Resistance of Concrete (Underwater Method), CRD-C 63-80, Corps of Engineers, U.S. Army, Waterways Experiment Station, *Handbook for Concrete and Cement*, December 1980.

potholes and related effects. The objective of this method is to provide an evaluation of the relative resistance of material surfaces to such action. The results of this test program are expected to be useful in the selection of material, mixtures, and construction practices where such action is occurring or is expected.

The test apparatus consists of a rotating device such as a drill press or similar tool having a chuck capable of holding and rotating the agitation paddle at a speed of 1200±100 r/min. The apparatus used in these tests is shown on figure 1. A steel pipe container (nominal 310-mm inside diameter by 450 mm high) fitted with a watertight steel base is used to hold the test specimen (fig. 2). An agitation paddle similar to that shown on figure 3 was used. The abrasive charge consisted of 70 steel grinding balls as specified in table 1. These specifications were used for purchasing the balls. Specifications regarding the wearing of balls during the tests and criteria for replacement of the balls have not yet been developed. A platform scale having a capacity of 50 kg and accuracy to 0.01 kg was utilized.

The test specimen was cylindrical in shape, with a diameter slightly less than the inside diameter of the container and a height of 100±13 mm. Specimens were either molded or cored and were soaked in water for a minimum of 48 hours prior to testing.

The test procedure was as follows:

1. The specimen was surface dried and mass was recorded to the nearest 0.01 kg.

2. The specimen was placed in the steel container with the surface to be tested facing up.

3. The specimen was positioned so that its surface was perpendicular to the rotation device shaft and the center of the specimen coincided with that of the shaft.

4. The agitation paddle was attached to the rotating device shaft with the bottom of the paddle approximately 40 mm above the surface of the specimen.

5. The abrasive charges (grinding balls) were placed on the surface of the specimen and the container was filled with water to approximately 165 mm above the surface of the specimen.

6. The rotating device was checked so that it was turning at 1200±100 r/min when the paddle was immersed. A test period of 24 hours generally produced abrasion in most surfaces, but

if simulation of more severe abrasion was desired, time was extended to 72 hours. Additional testing time may be required for special materials that are highly resistant to abrasion.

7. The specimen was removed from the container every 12 hours. It was flushed of abraded material and surface dried, then the mass was determined and recorded to the nearest 0.01 kg.

The abrasion-erosion loss was calculated by the following equation:

$$L = \frac{M_i - M_f}{M_i} \times 100$$

where:

L = abrasion-erosion loss, percent by mass

M_i = mass of the surface-dry specimen before tests in kg

M_f = mass of the surface-dry specimen at end of specific test period in kg

DISCUSSION OF RESULTS

Concrete Mixes

The materials used in this study were divided into four groups: (1) conventional portland cement concrete, (2) epoxy concrete, (3) epoxy-modified portland cement concrete, and (4) polymer concrete, including both vinyl ester polymer concrete and methyl methacrylate polymer concrete. The mixes for the specimens tested are given in table 2. Unless otherwise noted, all mixes used Clear Creek aggregate, a locally available, natural siliceous aggregate of marginally good quality.

The conventional portland cement concretes (mixes 1 and 11, table 2) may be used as a reference point to compare the abrasion-erosion resistance of the other concrete materials. Mix 1 is a 24-hour, steam-cured, 19.1 mm MSA (maximum size aggregate) concrete, and mix 11 is a 28-day, fog-cured, 9.5 mm MSA concrete. The 24-hour steam cure procedure is as follows:

1. Place the freshly cast concrete in an enclosed environment and keep the surface of the concrete continuously moist for 3 hours.

2. Slowly apply steam to increase temperature by not more than 17 °C per hour.

3. Leave at a temperature of 54 °C until a period of 24 hours has elapsed.

4. Remove concrete and allow to return to room temperature.

Test Results

Results from the abrasion-erosion test are given in table 3.

The fog-cured concrete (mix 11) showed a little more mass loss than the steam-cured concrete (mix 1) after 24 hours of testing (5.6 percent versus 3.8 percent, table 3), but the rate of mass loss remained nearly constant for both materials in testing from 24 to 48 hours (9 percent versus 7 percent mass loss at 48 hours for the fog-cured and steam-cured concretes, respectively). Figure 4 shows the surface condition of the steam-cured conventional concrete specimen after 48 hours of testing.

An epoxy-modified portland cement concrete (mix 5 – Nicklepoxy system) showed an improvement in abrasion-erosion resistance as compared to the conventional portland cement concrete specimens. The epoxy-modified concrete showed a mass loss of 3 percent after 48 hours.

Two epoxy concrete systems (mix 8 – polysulfide epoxy, and mix 9 – flexible amino epoxy) showed very high abrasion-erosion resistance. Both mixes showed no mass loss after 72 hours of testing.

The polymer concretes tested included vinyl ester polymer concretes (mixes 6 and 7, made with two resins from different sources and two different aggregates), three commercial MMA (methyl methacrylate) based polymer concretes (mixes 2, 3, and 4), and a laboratory formulated MMA system (mix 10).

The vinyl ester polymer concretes (mix 6 – vinyl ester with Clear Creek aggregate, and mix 7 – vinyl ester with limestone aggregate) showed very good abrasion-erosion resistance, with mass losses after 72 hours of 0.5 and 0.4 percent, respectively. Figure 5 shows the surface condition of a vinyl ester concrete specimen after 72 hours of testing.

The commercial MMA polymer concretes (mixes 2, 3, and 4), also showed good abrasion-erosion resistance, where mass loss ranged from 0.8 to 1.3 percent at 72 hours. The laboratory formulated MMA system had a very good abrasion-erosion resistance of 0.2 percent mass loss at 72 hours.

Compressive strength of the materials tested (with the exception of the portland cement concretes) are given in table 4, along with a summary of abrasion-erosion test results at 72 hours. The abrasion test results at this point show no relationship to compressive strength.

Two vinyl ester polymer concrete and one commercial MMA polymer concrete specimens were prepared and shipped to the Corps of Engineers' Waterways Experiment Station for testing using the Corps' equipment. Results of these tests are summarized in table 5. Specimens A and B are duplicates and showed a mass loss of 1.0 and 1.1 percent after 72 hours of testing. Specimen C, a commercial MMA polymer concrete, had a mass loss of 1.2 percent after 72 hours. These specimens were not directly comparable to the specimens used in the Bureau tests, but indicate the results are at least approximately comparable.

Table 1. – Abrasive charge.

No. of steel grinding balls	Diameter, mm
10	25.4 $\pm$ 0.1
35	19.1 $\pm$ 0.1
25	12.7 $\pm$ 0.1

Table 2. – Concrete mixes.

Mix 1 – Portland cement concrete, 24-hour steam cure

Aggregate gradation

Sieve size (mm)	Mass (%)
9.5 - 19.1	34.6
4.75 - 9.5	23.0
2.36 - 4.75	6.3
1.18 - 2.36	6.4
0.60 - 1.18	10.6
0.30 - 0.60	10.2
0.15 - 0.30	7.0
Minus 0.15	1.9
	100.0

Table 2. – Concrete mixes. – Continued

Material	Mass (%)
Aggregate (Clear Creek)	74.6
Cement	17.6
Water	7.7
Air-entraining agent	0.1
	100.0

W/C = 0.44

Mix 2 – Commercial MMA System No. 1, Crylcon Polymer Concrete)

Material	Mass (%)
Aggregate (Clear Creek)	
4.75 - 9.5 mm	28.3
2.36 - 4.75 mm	9.4
Polymer powder	56.7
Polymer liquid	5.6
	100.0

Mix 3 – Commercial MMA System No. 2, Concresive Polymer Concrete

Material	Mass (%)
Aggregate (Clear Creek)	
4.75 - 9.5 mm	28.5
2.36 - 4.75 mm	9.5
Polymer powder	56.0
Polymer liquid	6.0
	100.0

Mix 4 – Commercial MMA System No. 3, Silikal Polymer Concrete

Material	Mass (%)
Aggregate (Clear Creek)	
4.75 - 9.5 mm	28.3
2.36 - 4.75 mm	9.4
Polymer powder	56.7
Polymer liquid	5.6
	100.0

Mix 5 – Epoxy - Modified Concrete

Aggregate gradation

Sieve size (mm)	Mass (%)
4.75 - 9.5	23.8
2.36 - 4.75	10.7
1.18 - 2.36	7.9
0.60 - 1.18	17.2
0.30 - 0.60	14.4
0.15 - 0.30	14.4
Minus 0.15	11.6
	100.0

Material	Mass (%)
Aggregate (Clear Creek)	71.7
Portland cement, type I	19.4
Water	5.1
Epoxy (Nicklepoxy)	
Part A	3.3
Part B	0.5
	100.0

W/C = 0.26

Mix 6 – Vinyl Ester Polymer, Concrete System No. 1, Reichhold Vinyl Ester Resin and Clear Creek Aggregate

Aggregate gradation

Sieve size (mm)	Mass (%)
4.75 - 9.5	33.3
2.36 - 4.75	16.7
0.30 - 0.60	44.4
0.15 - 0.30	5.6
	100.0

Material	Mass (%)
Aggregate (Clear Creek)	82.5
Fly Ash (Comanche)	9.2
Vinyl ester resin (Reichhold STF905)	8.3
	100.0

Table 2. – Concrete mixes. – Continued

Material	Mass (%) of total mix
Methyl ethyl ketone peroxide	0.12
Cobalt Naphthenate (6% solution)	0.04

Mix 7 – Vinyl Ester Polymer Concrete System No. 2, Shell Vinyl Ester Resin and Limestone Aggregate

Aggregate gradation

Sieve size (mm)	Mass (%)
4.75 - 9.5	40.0
2.36 - 4.75	10.0
0.15 - 0.30	40.0
Minus 0.15	10.0
	100.0

Material	Mass (%)
Aggregate (limestone)	91.2
Vinyl ester resin (Shell DPV 706)	8.8
	100.0

Material	Mass (%) of total mix
Cumene hydroperoxide	0.35
Cobalt Naphthenate (6% solution)	0.07

Mix 8 – Epoxy Concrete System No. 1, Polysulfide Epoxy Resin

Aggregate gradation

Sieve size (mm)	Mass (%)
9.5 - 19.1	27.8
4.75 - 9.5	20.7
2.36 - 4.75	15.1
1.18 - 2.36	11.5
0.60 - 1.18	7.2
0.30 - 0.60	5.0
0.15 - 0.30	3.4
Minus 0.15	9.3
	100.0

Table 2. – Concrete mixes. – Continued

Material	Mass (%)
Aggregate (Clear Creek)	83.5
Epoxy (Probond ET 150G)	
Part A	10.9
Part B	5.6
	100.0

Mix 9 – Epoxy Concrete System No. 2, Flexible Epoxy Resin

Aggregate gradation

Sieve size (mm)	Mass (%)
4.75 - 9.5	29.1
2.36 - 4.75	21.0
1.18 - 2.36	16.0
0.60 - 1.18	10.0
0.30 - 0.60	7.0
0.15 - 0.30	3.9
Minus 0.15	13.0
	100.0

Material	Mass (%)
Aggregate (Clear Creek)	85.7
Epoxy (Flexocrete III)	
Part A	9.9
Part B	4.4
	100.0

Mix 10 – Laboratory Formulated MMA Polymer Concrete

Aggregate gradation

Sieve size (mm)	Mass (%)
4.75 - 9.5	35.0
2.36 - 4.75	16.0
1.18 - 2.36	12.2
0.60 - 1.18	9.0
0.30 - 0.60	7.0
0.15 - 0.30 (Ottawa Sand F-95)	9.0
Minus 0.15 (Pulverized silica flour 295)	11.8
	100.0

Table 2. – Concrete mixes. – Continued

Material	Mass (%)
Aggregate (Clear Creek except as noted)	88.4
Methyl methacrylate system (Degadur 330)	11.6
Benzoyl peroxide	0.2
	100.0

Mix 11 – Portland Cement Concrete, 28-day Fog Cure

Aggregate gradation

Sieve size (mm)	Mass (%)
4.75 - 9.5	39.7
2.36 - 4.75	9.2
1.18 - 2.36	9.1
0.60 - 1.18	15.0
0.30 - 0.60	15.0
0.15 - 0.30	9.1
Minus 0.15	2.9
	100.0

Material	Mass (%)
Aggregate (Clear Creek)	75.1
Portland cement	16.6
Water	8.3
Air-entraining agent	0.06
	100.0

W/C = 0.50

Table 3. – Abrasion-erosion results – percent mass loss.

Mix No.	Material	Time (hours)					
		12	24	36	48	60	72
1	Steam cured concrete	2.13	3.81	5.43	7.00	[1]	–
2	MMA, PC system No. 1[2]	0.05	0.16	[3]	0.59	–	1.34
3	MMA, PC system No. 2	[4]	0.11	–	0.42	–	0.84
4	MMA, PC system No. 3	[4]	[5]	–	0.63	–	1.26
5	Epoxy-modified concrete	[4]	1.91	–	3.19	–	5.05
6	Vinyl ester PC system No. 1	[4]	0.17	–	0.35	–	0.53
7	Vinyl ester PC system No. 2	0.22	0.33	0.39	0.42	[3]	0.44
8	Polysulfide epoxy concrete	[4]	0	–	0	–	0
9	Flexible epoxy concrete	[4]	0	–	0	–	0
10	Laboratory MMA PC	[4]	0.05	–	0.10	–	0.16
11	Fog cured concrete	[4]	5.58	[4]	9.07	[1]	–

[1] Test stopped after 48 hours.
[2] MMA is methyl methacrylate, PC is polymer concrete.
[3] Loss was so low after 24 hours the specimen was tested for 12-hour cycles, but mass measured and recorded at 24-hour intervals.
[4] Loss was low, the specimen was tested for 12-hour cycles, but mass was recorded only at 24-hour intervals.
[5] Scale problems prevented accurate measurement.

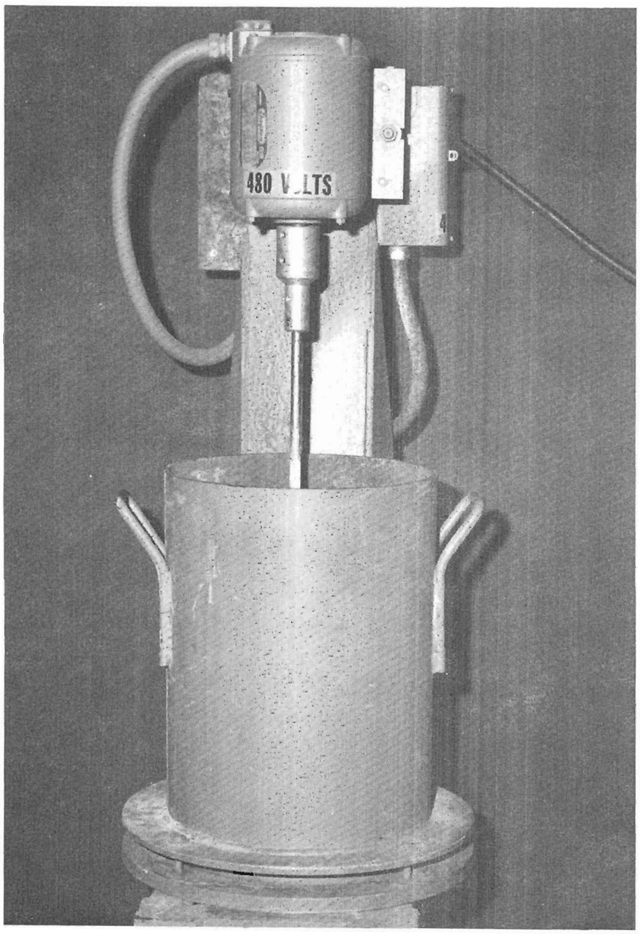
Table 4. – Compressive strength.

Mix No.	Material[1]	Compressive strength, MPa	Abrasion-Erosion % mass loss at 72 hours
2	MMA PC system No. 1	58.8	1.34
3	MMA PC system No. 2	44.9	0.84
4	MMA PC system No. 3	54.2	1.26
5	Epoxy modified concrete	57.3	5.05
6	Vinyl ester PC system No. 1	83.4	0.53
7	Vinyl ester PC system No. 2	88.3	0.44
8	Polysulfide epoxy concrete	59.4	0.0
9	Flexible epoxy concrete	73.9	0.0
10	Laboratory MMA PC	18.8	0.16

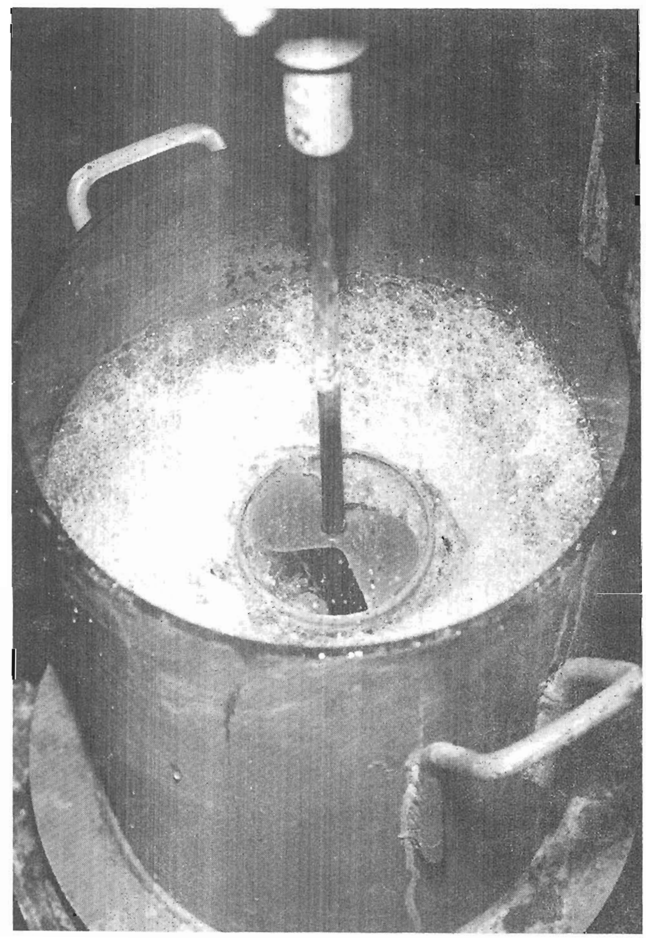
[1]MMA–Methyl Methacrylate, PC–Polymer concrete

Table 5. – Abrasion-erosion tests performed at Corps of Engineers' Waterways Experiment Station.

Time, hours	Specimen A Vinyl ester polymer concrete	Specimen B Vinyl ester polymer concrete	Specimen C MMA polymer concrete
	Percent mass loss		
0	0.0	0.0	0.0
12	0.3	0.3	0.2
24	0.5	0.4	0.3
36	0.7	0.7	0.7
48	0.7	0.8	0.8
60	0.9	1.0	1.0
72	1.0	1.1	1.2



a. Photo P801-D-80920



b. Photo P801-D-80921

Figure 1. – WES abrasion-erosion apparatus.

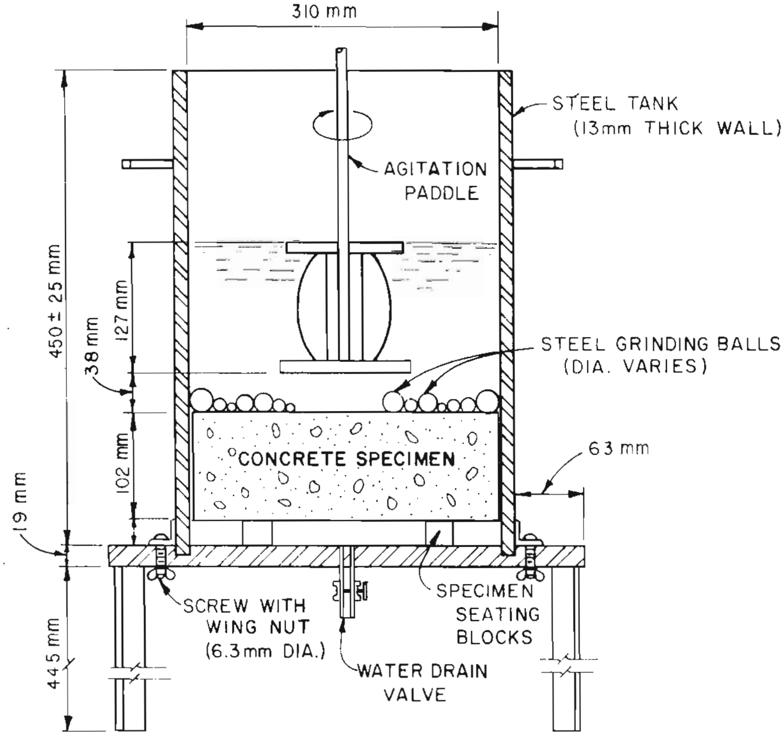


Figure 2. – Test setup details.

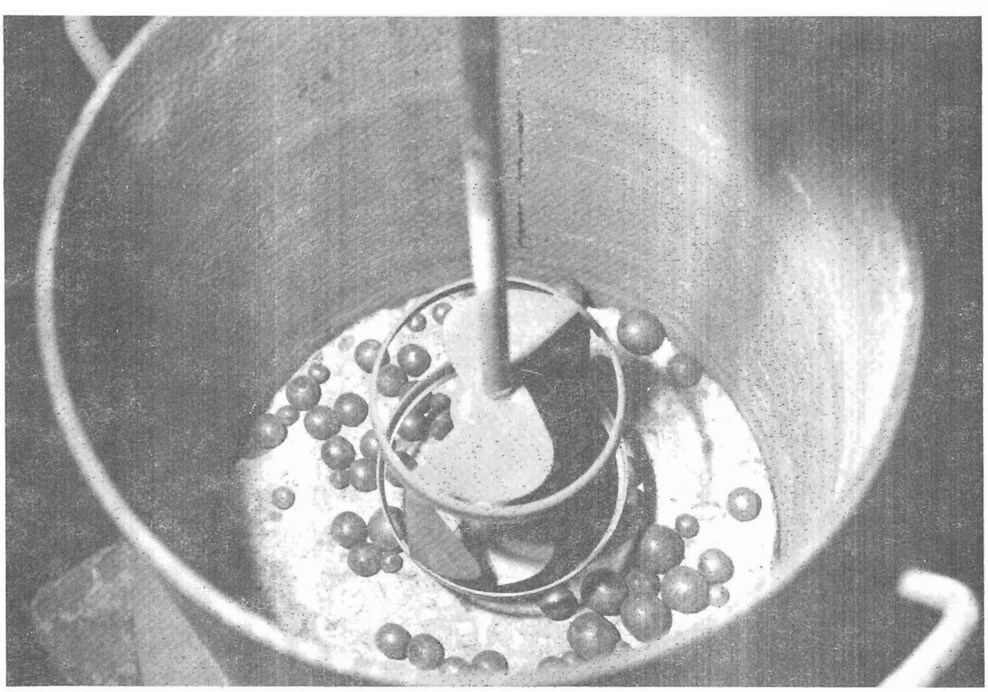


Figure 3. – Agitation paddle. Photo P801-D-80922

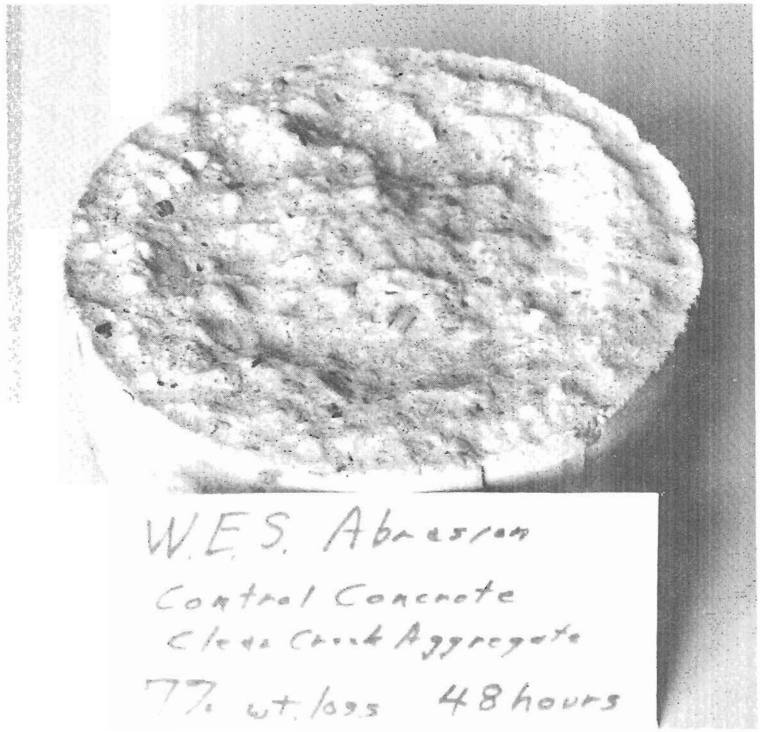


Figure 4. – Typical surface condition of a tested specimen – conventional concrete after 48 hours of testing. Photo P801-D-80923

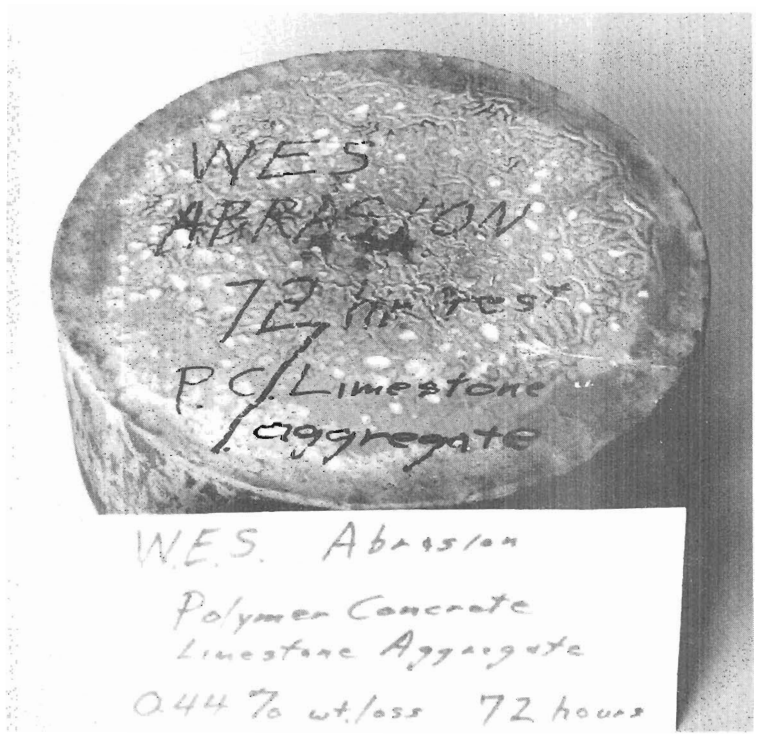


Figure 5. – Typical surface condition of a tested specimen – vinyl ester concrete after 72 hours of testing. Photo P801-D-80924

GPO 848-507

Mission of the Bureau of Reclamation

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