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Portland Cement, Concrete, and Heat of Hydration

When portland cement is mixed with water, heat is liberated. This heat is called the heat of hydration, the result of the exothermic chemical reaction between cement and water. The heat generated by the cement's hydration raises the temperature of concrete.

During normal concrete construction, the heat is dissipated into the soil or the air and resulting temperature changes within the structure are not significant. However, in some situations, particularly in massive structures, such as dams, mat foundations, or any element more than about a meter or yard thick, the heat can not be readily released. The mass concrete may then attain high internal temperatures, especially during hot weather construction, or if high cement contents are used.

Fig.1 demonstrates the effect of element size on concrete temperature with time due to the heat of hydration.

Temperature rises of 55°C (100°F) have been observed with high cement content mixes.⁽²⁾ These temperature rises cause expansion while the concrete is hardening. If the temperature rise is significantly high and the concrete undergoes nonuniform or rapid cooling, stresses due to thermal contraction in conjunction with structural restraint can result in cracking before or after the concrete eventually cools to the surrounding temperature. Contractors often insulate massive elements to control temperature changes. As a rule of thumb, the maximum temperature differential between the interior and exterior concrete should not exceed

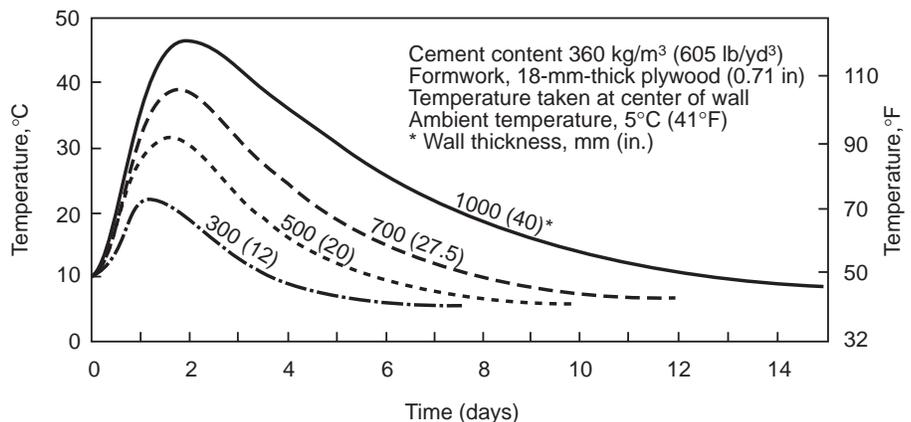


Fig. 1. Effect of member thickness on temperature of concrete. Reference 1.

20°C (36°F) to avoid crack development.⁽³⁾ The potential for thermal cracking is dependent on the concrete's tensile strength, coefficient of thermal expansion, temperature difference within the concrete, and restraint on the member.

Concrete placed in cold conditions benefits from the heat generated by cement hydration, helping protect it from freezing and providing a more favorable curing temperature. Adding insulation to the formwork helps trap the heat in the concrete, allowing it to achieve the required strength.

Heat of Hydration of Portland Cements

The heat of hydration of cement is usually determined in accordance with ASTM C 186, *Standard Test Method for Heat of Hydration of Hydraulic Cement* (see box). Table 1 has heat of hydration values for a variety of portland cements from 1992 to 1996. Although this data is very limited, it confirms the general trends expected: Type III cement has higher heat of hydration than other cement

types (average = 88.5 cal/g at 7 days) and Type IV has the lowest (average = 55.7 cal/g at 7 days).

Portland cement evolves heat for a long time.⁽⁴⁾ Reference 4 and Fig. 2 present heat of hydration data out to 13 years. Fig. 2 shows that the rate of heat generation is greatest at early ages. Usually, the greatest rate of heat liberation occurs within the first 24 hours and a large amount of heat evolves within the first 3 days. For most concrete elements, such as pavements, long-term heat generation is not a concern as this heat is dissipated into the environment.

Factors Affecting Heat of Hydration

Materials can be selected to minimize or maximize the heat of hydration, depending on the need. Cements with higher contents of tricalcium silicate and tricalcium aluminate, as well as a higher fineness, such as Type III cements, have higher rates of heat generation than other cements.

Tricalcium silicate and tricalcium aluminate chemically generate more

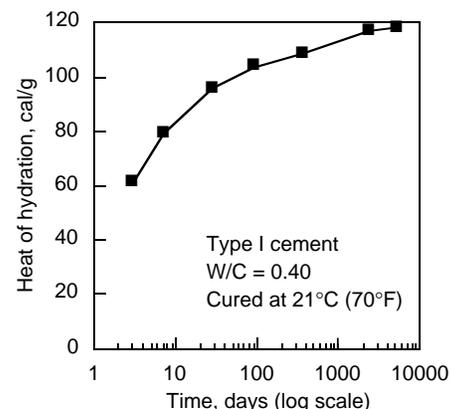


Fig. 2. Average heat of hydration of a Type I cement at various ages to 13 years. Reference 4.

heat, and at a faster rate, than dicalcium silicate or other cement compounds. Sulfate content, in its relation to controlling the hydration of calcium aluminate, participates in the rate of heat liberation.

Higher fineness provides a greater surface area to be wetted, resulting in an acceleration of the reaction between cement and water. This causes an increase in the

Table 1. ASTM C 186 Heat of hydration for selected portland cements, calories per gram*

Type I cement			Type II cement			Type II (moderate heat) cement		Type III cement			Type IV cement			Type V cement	
No.	7 day	28 day	No.	7 day	28 day	No.	7 day	No.	7 day	28 day	No.	7 day	28 day	No.	7 day
1	82.0	—**	16	77.7	101.4	32	67.6	36	88.0	99.0	38	60.0	—	41	81.5
2	85.6	—	17	82.6	88.8	33	65.0	37	89.0	95.0	39	57.3	—	42	66.5
3	81.6	—	18	88.7	89.4	34	54.3				40	49.7	65.5	43	79.3
4	80.2	—	19	88.0	—	35	64.7							44	80.4
5	78.4	—	20	73.6	—									45	76.1
6	88.3	90.2	21	88.5	—									46	61.4
7	88.2	106.1	22	77.1	89.7										
8	87.7	93.5	23	87.3	—										
9	88.9	97.7	24	81.9	100.3										
10	76.4	91.7	25	88.3	99.4										
11	84.4	91.7	26	86.5	96.8										
12	84.4	98.5	27	79.5	—										
13	83.5	—	28	79.4	—										
14	79.5	—	29	80.0	—										
15	83.0	—	30	80.0	—										
			31	77.6	—										
Avg.	83.5	95.6	Avg.	82.3	95.1	Avg.	62.9	Avg.	88.5	97.0	Avg.	55.7	NM	Avg.	74.2
Max.	88.9	106.1	Max.	88.7	101.4	Max.	54.3	Max.	NM	NM	Max.	49.7	NM	Max.	81.5
Min.	76.4	90.2	Min.	73.6	88.8	Min.	67.6	Min.	NM	NM	Min.	60.0	NM	Min.	61.4

* This table is based on limited data provided by various testing laboratories and cement companies. The cements were tested between 1992 and 1996.

** No data available.

NM: not meaningful.

1 cal/g = 4.184 kJ/kg

Tests for Heat of Hydration

Two methods of determining the heat of hydration are commonly used. ASTM C 186, *Standard Test Method for Heat of Hydration of Hydraulic Cement*, uses a heat of solution procedure. In this test, a sample is dissolved in an acid solution inside a well-insulated container and the temperature rise is recorded. After correction for the

dry cement heat of solution and the heat capacity of the container, the heat of hydration for the desired hydrating period can be calculated. Samples can be hydrated any length of time with this technique.

The other common method is conduction calorimetry. In this non-standard procedure, a sample of cement is placed in a conductive container and kept at a specific tempera-

ture (for example, by a thermoelectric device). Water is added and the energy required to maintain the sample temperature is continuously recorded. By integration, the heat of hydration at any time can be obtained; however, the length of the test is usually limited to 3 days as the rate of heat evolution becomes too low to measure beyond that time period.

rate of heat liberation at early ages, but may not influence the total amount of heat developed over several weeks.

Other factors influencing heat development in concrete include the cement content, water-cement ratio, placing and curing temperature, the presence of mineral and chemical admixtures, and the dimensions of the structural element.

In general, higher cement contents result in more heat development. ACI 211.1, *Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete*, states that as a rough guide, hydration of cement will generate a concrete temperature rise of about 4.7°C to 7.0°C per 50 kg of cement per m³ of concrete (10°F to 15°F per 100 lb of cement per yd³ of concrete) in 18 to 72 hours.

When comparing concretes of equal cement content but different water-cement ratios, mixes with higher water-cement ratios have more water and microstructural space available for hydration of the cement (more of the cement hydrates and it hydrates at a faster rate), resulting in an increased rate of heat development. The increase in heat of hydration at 7 days resulting from an increase in water-cement ratio from 0.4 to 0.6 is about 11% for Type I cement. The effect is minimal for moderate- and low-heat cements.⁽⁴⁾ The water-cement ratio effect is minor compared to the effect of cement content. However, a lower water-cement ratio in concrete achieved by increasing the cement content results in greater heat generation.

Higher temperatures greatly accelerate the rate of hydration and the rate of heat liberation at early ages (less than 7 days). Chemical admixtures that accelerate hydration also accelerate heat liberation and admix-

tures that retard hydration delay heat development. Mineral admixtures, such as fly ash, can significantly reduce the rate and amount of heat development.

Specifications for Reduced Heat Cements

When heat generation must be minimized in concrete, one way to achieve this is to choose a lower heat cement, such as a Type II cement with the optional moderate heat of hydration requirements. Not all Type II cements are made for a moderate level of heat development, however, so the moderate heat option must be specifically required (see Table 1). Type IV, low heat of hydration cement, can also be used to control temperature rise, but it is rarely available.

ASTM C 150, *Standard Specification for Portland Cement*, allows two independent approaches to control heat of hydration in cement. The first method is to specify chemical requirements. For Type II cement, an optional limit on the sum of the tricalcium silicate (C₃S) and tricalcium aluminate (C₃A) contents is set at 58%. For Type IV cement, limits are placed on the C₃S and C₃A contents at a maximum of 35% and 7%, respectively, while maintaining a minimum dicalcium silicate (C₂S) content of 40%. The second method uses physical requirements. For Type II cement, the optional maximum heat of hydration is 70 calories per gram (290 kJ/kg) at 7 days. For Type IV cement, the maximum heat of hydration is limited to 60 calories per gram (250 kJ/kg) at 7 days and 70 calories per gram (290 kJ/kg) at 28 days. Either the chemical approach or the physical approach

should be specified, but not both.

ASTM C 595, *Standard Specification for Blended Hydraulic Cements*, and ASTM C 1157, *Standard Performance Specification for Blended Hydraulic Cement*, both provide the option of specifying moderate- and low-heat of hydration cements using physical limits. For moderate heat of hydration, C 595 adds the suffix MH to the cement type, calling out limits of 70 calories per gram (290 kJ/kg) at 7 days and 80 calories per gram (330 kJ/kg) at 28 days, while C 1157 (cement Type MH) has limits of 70 calories per gram (290 kJ/kg) at 7 days as the only requirement. For low heat of hydration, both C 595 (LH suffix) and C 1157 (Type LH) have limits of 60 calories per gram (250 kJ/kg) at 7 days and 70 calories per gram (290 kJ/kg) at 28 days.

Controlling Concrete Temperature Rise

The temperature rise of concrete can be controlled by selecting appropriate materials and construction practices. For cold weather, ACI 306R, *Cold Weather Concreting*, recommends minimum mixing and placing temperatures based on the size of the concrete member and the ambient air temperature. (As temperatures and member thickness decrease, conditions become more critical.) ACI 306R offers guidance on increasing the temperature of fresh concrete, including heating aggregates and mixing water. Other options include reducing the length of the required protection period by using Type III cement, by using an accelerating admixture, or by using an extra 60 kg/m³ (100 lb/yd³) of cement. Also, insulation could be used to trap the heat in the fresh concrete,

thereby protecting it.

For massive structures, or to control temperature rise in hot weather, ACI 305R, *Hot Weather Concreting*, recommends controlling mixing and placing procedures to minimize delays and to use the cooler parts of the day for placing operations. There are numerous methods to minimize the concrete temperature rise. These include cooling the mixing water, using ice as part of the mixing water, using a moderate-heat Type II (ASTM C 150) portland cement or moderate- or low-heat blended cement (ASTM C 595 or C 1157), and keeping cement contents to a minimum level. A fly ash or other pozzolan or slag can be used, chemical admixtures (retarder, water-reducer/retarder) can be used, or the aggregate can be cooled. Also, water curing controls temperature increases better than other curing methods. Reference 1 discusses the effect of formwork material on temperature rise. Steel formwork retains the least heat.

A proposed concrete mixture can be tested for temperature rise in a mock-up sample in a laboratory or the field. Fig. 3 presents results from such a mock-up, showing how the temperature rise differs between the interior and exterior of a massive member for a high-cement-content mixture. The Army Corps of Engineers' *Test Method for Temperature*

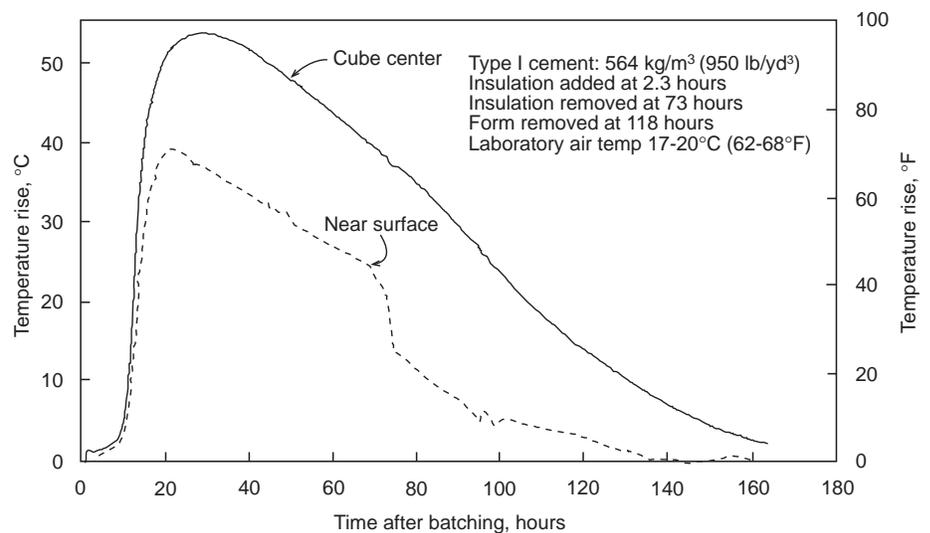


Fig. 3. Temperature rise of a high-cement-content 1.2-meter (4-ft) test cube. Reference 2.

Rise in Concrete, CRD C 38, is a procedure to evaluate preconstruction mixes for heat development.

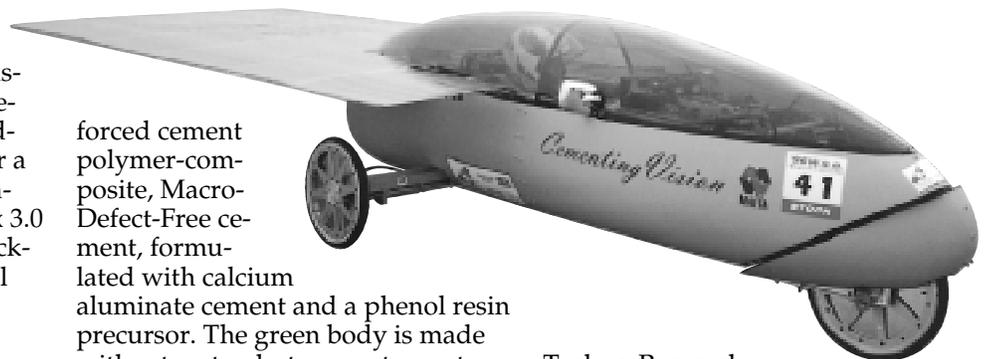
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Cement on the Go

Researchers of MAETA Techno-Research, Inc., a subsidiary of MAETA Concrete Industry Ltd., Yamagata, Japan have developed a car body made of an advanced cement-based material for a solar-powered car. The body measures 3.6 x 0.7 x 0.9 m (11.8 x 2.3 x 3.0 ft). The molded panels have a thickness of 2.5 mm (0.1 in.) and a total weight of 33 kg (73 lb). The solar-powered car ran in the 500 km World Solar Car Rally in Akita, averaging 45 km/h (27 mph). The trial run was made to study the feasibility of utilizing cements in the transportation industry. The car received the "Hans Tholstrup" award for its outstanding achievement as an earth-friendly, low-energy material body. The material is a fiber rein-

forced cement polymer-composite, Macro-Defect-Free cement, formulated with calcium aluminate cement and a phenol resin precursor. The green body is made without water, but generates water during the heating process that initiates cross-linking of the phenol resin precursor. The material was invented by a research group of MAETA Concrete Industry Ltd. in 1992, and patent applications have been granted in the United States and Europe. Researchers of MAETA



Techno-Research, Inc. are now working on further developments of applications in the transportation industry.

The car was exhibited at the MAETA Workshop on High Flexural Polymer-Cement Composite, held October 3-4, 1996 in Sakata, Japan.

CONTINUING STUDIES OF CONCRETE IN SULFATE SOILS

by David Stark, Construction Technology Laboratories, Inc.

As the design and fabrication of concrete evolve, new methods develop to protect concrete exposed to sulfates. In order to evaluate new materials, new concrete mixtures were added to the PCA/CALTRANS sulfate soils test facility in California (see box) in 1989. Results of these tests, applied properly, can make concrete more durable in sulfate exposures. Test variables and 7-year results are described in this report.

Test Variables

Ten concrete mixtures were added to the test facility and are listed in Table 1. Variables include coarse aggregate (three sources), silica fume, high range water reducer (HRWR), curing, and surface treatment. Several minor mix adjustments also were made to permit workability and form placement.

Aggregates. Three sources of coarse aggregate were included in the program because visual inspections of specimens in earlier studies indicated that wetting and drying of the Na_2SO_4 solutions appeared to have resulted in numerous coarse aggregate popouts. For this purpose, the usual standard coarse aggregate from Elgin, Illinois, with a maximum particle size of 25 mm (1 in.) was used for eight of the ten mixtures (Nos. 51 and 54 to 60). The second coarse aggregate (Mix 52), from Eau

Claire, Wisconsin, was selected to avoid possible surface popouts of the type previously observed with the Elgin coarse aggregate. The third source of coarse aggregate (Mix 53) was a crushed dolomite rock from Thornton, Illinois, and also has an excellent service record. This rock has no history of popouts.

Cement. A single ASTM Type II portland cement (alkali content of 0.52% Na_2O equivalent) was used for all mixtures. Various cement factors were used in the mixtures. Calculated compound composition was as follows:

C_3S - 53%	C_3A - 7%
C_2S - 22%	C_4AF - 9%

Silica Fume. Silica fume was used at a dosage of 8% by mass of cementitious material in two of the test mixtures (Nos. 54 and 55) to reduce concrete permeability, thus minimizing possible deterioration due to sulfate attack.

High-Range Water Reducer. A high-range water reducer was used in Mix 54 (with 8% silica fume) and Mix 57 (without silica fume).

Surface Treatment. Two mixtures were used for sealer applications after 28 days of moist curing followed by 7 days of air drying at 50% relative humidity and 23°C (73°F).

Sacramento Sulfate-Soils Test Facility

For 57 years, the Portland Cement Association and Caltrans have maintained a test facility in Sacramento, California, continually evaluating means to improve the performance of portland cement concrete embedded in sulfate-bearing soils. Periodically, deteriorated concrete specimens were replaced with those made from other mixtures to evaluate newer mixtures and materials. (References 1 through 4). Variables from the studies included cement content, air content, cement fineness, cement type, cement tricalcium aluminate (C_3A) content, effects of slag, fly ash and calcined shale, steam curing, and coatings of epoxy and linseed oil. Certain general findings have been developed in this program:

- Reduction in the ratio of water to cementitious materials appears to be the most effective means of improving the performance of concrete in a sulfate exposure condition, regardless of cement type or composition.
- Wetting and drying of concrete in sulfate-bearing solution, compared to continuous immersion in the solution, provides the most severe exposure condition for sulfate attack.
- ASTM type of portland cement has been of less significance for sulfate resistance when low or high water-cementitious materials (w/cm) ratios are used. Cement composition, particularly C_3A content, is of greater importance for sulfate performance when intermediate (0.45 to 0.55) w/cm are used, with lower C_3A content as found in Type II and V cements resulting in improved sulfate resistance.



Fig. 1. Concrete beams after 7 years in sulfate-rich soil in Sacramento test facility. (# S66900)

Fabrication of Concrete

All but two concretes were mixed with sufficient water to provide a 0.52 w/cm. All concretes were non-air-entrained (air contents ranged from 1.0 to 2.1 percent).

After mixing, the concrete was placed into forms and vibrated, spaded, fin-

Table 1. Concrete Variables for Test Mixtures

Mix no.	Cement content, kg/m ³ (lb/yd ³)	w/cm	Coarse aggregate	Silica fume, kg/m ³ (lb/yd ³)	Chemical admixture	Slump, mm (in.)	Moist cure, days	Sealer
51	307 (517)	0.52	Dolomitic-siliceous gravel (Elgin)	None	None	85 (3.4)	28	None
52	307 (517)	0.52	Siliceous gravel (Eau Claire)	None	None	95 (3.7)	28	None
53	307 (517)	0.52	Crushed dolomite (Thornton)	None	None	25 (1.0)	28	None
54	282 (476)	0.52	Dolomitic-siliceous gravel (Elgin)	24 (41)	HRWR	115 (4.6)	28	None
55	205 (345)	0.56	Dolomitic-siliceous gravel (Elgin)	18 (31)	None	175 (6.9)	28	None
56	307 (517)	0.52	Dolomitic-siliceous gravel (Elgin)	None	None	90 (3.5)	7	None
57	307 (517)	0.48	Dolomitic-siliceous gravel (Elgin)	None	HRWR	90 (3.6)	28	None
58	307 (517)	0.52	Dolomitic-siliceous gravel (Elgin)	None	None	90 (3.6)	28	Silane
59	307 (517)	0.52	Dolomitic-siliceous gravel (Elgin)	None	None	150 (6.0)	28	None
60	307 (517)	0.52	Dolomitic-siliceous gravel (Elgin)	None	None	95 (3.7)	28	Siloxane

ished with a wood float, and covered with damp burlap and polyethylene sheeting. After removal from the forms the day after casting, all mixes but one were transferred to moist curing at 23°C (73°F) until 28 days of age. Concrete specimens for Mix 56 were moist-cured only for 7 days. After moist curing, all specimens were transferred to air drying at 50% RH for a minimum of 28 days.

Concrete beams for two of the mixtures, Nos. 58 and 60, were treated with sealers. After the 28-day moist curing period, these concretes were air-dried for 7 days at 50% RH and 23°C (73°F). For Mix 58, one application of a water-based alkylalkoxysilane was brush-applied at the recommended rate of 3.7 sq m per liter (150 sq ft per gal), and for Mix 60, a proprietary blend of silane, siloxanes, stearates, and aluminum compounds in a blended solvent also was brush-applied in one application, but at a recommended rate of 3.1 sq m per liter (125 sq ft per gal). All test beams were then shipped to Sacramento for placement in the storage facility.

Exposure Conditions at the Test Facility

In 1989, all prisms were installed in

the sulfate soils test facility; Fig. 1 shows them as they appeared 7 years later. For the test exposure, each beam was embedded horizontally half-depth 75 mm (3 in.) in prepared soil containing sodium sulfate (Na₂SO₄) at a dosage of 65,000 ppm SO₄, leaving the top finished surfaces of the concrete beams slightly above the soil. The bottom of the basin facility was lined to minimize leakage and loss of solution during storage. After totally flooding the basin, atmospheric drying allowed the solution level to drop to soil level, thus permitting precipitation from the saturated sulfate solution, at which point, the basin was again flooded as before. Thus, the beams are air-dried to the top surface of the soil, then reimmersed in the desired sulfate concentration. Roughly 10 to 15 such cycles per year were anticipated, depending on atmospheric drying and periodic precipitation. In the upper portion, sulfate salts precipitated out on the beams during drying while the bottom portion remained continuously in the highly concentrated solution (in the soil).

Performance Evaluation

All concrete beams in the sulfate soils facility are visually inspected once each year for durability perfor-

mance. As in all previous studies,⁽¹⁾ numerical ratings from 1.0 to 5.0 are tabulated. For example, a rating of 1.0 indicates the sharp fresh appearance of the top finished surface, corner and edges, with solid definition of original formed surfaces. A rating of 5.0 would represent severe loss of cement paste and mortar on finished and formed surfaces, edges and corners, and loss of coarse aggregate particles. Intermediate ratings represent performance between these extremes (see Fig. 2).

Program Results

Seven-year results for these test beams are shown in Table 2. At each evaluation, the ponding sulfate solution was drained to better expose each beam. After seven years, all of these beams displayed some deterioration. However, degrees of distress varied, as follows.

- All beams ranged from generally minor to severe deterioration, depending on mixture variables. In all cases, each of three companion beams for a given mixture show similar performance.
- The least deterioration was observed for mixtures treated with sealers (Nos. 58 and 60). Ratings

Table 2. Visual Ratings of Concrete Beams in Sulfate Soils

Mix no.	Cement content kg/m ³ (lb/yd ³)	w/cm	Coarse aggregate	Moist curing, days	Admixture or sealer	Strength, 28 days MPa (psi)	Visual rating at 1,3,5,7 years*			
							1	3	5	7
51	307 (517)	0.52	Siliceous dolomitic gravel	28	None	43.1 (6250)	1.0	1.5	2.4	4.2
52	307 (517)	0.52	Siliceous gravel	28	None	42.8 (6210)	1.0	1.2	3.7	3.7
53	307 (517)	0.52	Crushed dolomite	28	None	40.0 (5795)	1.0	1.4	2.5	3.5
54	282 (476)	0.52	Siliceous dolomitic gravel	28	Silica fume + HRWR	46.9 (6795)	1.0	1.4	3.7	4.0
55	205 (334.5)	0.56	Siliceous dolomitic gravel	28	Silica fume	37.8 (5485)	1.3	2.4	4.2	4.3
56	307 (517)	0.52	Siliceous dolomitic gravel	7	None	28.0 (4064)	1.0	1.4	2.6	3.2
57	307 (517)	0.48	Siliceous dolomitic gravel	28	HRWR	48.2 (6990)	1.0	1.3	2.4	2.9
58	307 (517)	0.52	Siliceous dolomitic gravel	28	Silane	37.5 (5440)	1.1	1.0	1.3	1.3
59	307 (517)	0.52	Siliceous dolomitic gravel	28	None	37.1 (5380)	1.0	1.7	2.3	3.0
60	307 (517)	0.52	Siliceous dolomitic gravel	28	Siloxane	34.5 (5010)	1.1	1.1	1.3	1.7

*A rating of 1 is no deterioration and a rating of 5 is severe deterioration. Each rating is the average of three companion beams, each of which are rated by two or three observers.



Fig. 2. Illustration of durability range corresponding (l. to r.) to numerical rating of 1.1, 2.5, and 5.0, respectively. (#A2885)

were 1.3 and 1.7, respectively, for the silane- and siloxane-based coatings.

- Three mixtures, Nos. 51, 54, and 55, revealed the greatest deterioration. These reached ratings of 4.2, 4.0, and 4.3, and were, respectively, the control mixture and the two mixtures with silica fume. These results may differ from those of other researchers due to the difference in exposure conditions: alternate wetting and drying in outdoor soils exposure as op-

posed to continuous immersion in the laboratory. This needs further study.

- Type of coarse aggregate had only a minor but variable effect on sulfate resistance. Beams with the crushed dolomite aggregate and the mixture with plain siliceous gravel, Mixes 53 and 52, resulted in less deterioration than mixtures with the standard siliceous dolomitic gravel.
- A minor reduction in w/cm, using HRWR to maintain workability, appears to have a small beneficial effect on performance in these tests (Mix 51 versus Mix 57).

To date, the current rates of deterioration of test beams due to sulfate attack range from minor to severe.

Acknowledgments

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sponsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the views of the Portland Cement Association.

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Reinforcement News
Soft-Metricated Rebar

During 1995 and 1996, the Concrete Reinforcing Steel Institute (CRSI) worked with ASTM, the American Association of State Highway and Transportation Officials, (AASHTO), and numerous U.S. state departments of transportation to achieve the adoption of soft-metricated reinforcing steel as the metric standard for rebar usage in the United States.

As a result, specifications for soft-metric rebar are now available from ASTM (A615/A615M and A706/A706M) and AASHTO (M31). CRSI is developing soft-metric design and construction aids for contractors, engineers, architects, and others.

CRSI rebar producers are now offering the new soft metric bars. These bars are the same size as existing inch-pound bars (see table for designations). The number designation indicates the nominal diameter in mm for the metric bars, and in eighths of an inch for inch-pound

bars. Contact CRSI for further information on the new soft-metric products: tel. 847-517-1200; fax 847-517-1206; e-mail info@crsi.org.

Metric bar designation	Inch-pound bar designation
#10	#3
#13	#4
#16	#5
#19	#6
#22	#7
#25	#8
#29	#9
#32	#10
#36	#11
#43	#14
#57	#18

New Literature

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Our purpose is to show various ways of using concrete technology to your advantage and avoiding problems. If there are problems or ideas readers would like discussed in future issues, please let us know. Items from this newsletter may be reprinted in other publications subject to prior permission from the Association.

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