NATIONAL BUREAU OF STANDARDS REPORT

10 984

Interim Report No. 3

EVALUATION TESTING OF COATING MATERIALS FOR CONCRETE REINFORCING BARS

Title of Project

Nonmetallic Coatings for
Concrete Reinforcing Bars

Sponsored by

Federal Highway Administration
U. S. Department of Transportation
Washington, D. C. 20590

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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ABSTRACT

This project was undertaken to determine the feasibility of using organic coatings to protect steel reinforcing bars embedded in concrete from corrosion.

Studies carried out during the period of this report were as follows: continuation of screening tests to select the most promising coating materials; abrasion and impact testing of coated steel plates; and evaluations of the physical durability of coated steel reinforcing bars. The evaluations of coated rebars took into consideration: the integrity of the coating films; bend and impact resistances of the coatings; and hardness of the coatings.

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Interim Report No. 3
Selection of Coating Materials

1. Study Identification: Order No. 2-1-0614.

   Title: Nonmetallic Coatings for Concrete Reinforcing Bars.

2. Project Initiated: 9-17-71.

3. Research Agency: National Bureau of Standards.

4. Objectives

To investigate the feasibility of using epoxy coatings and other organic coatings to protect from corrosion steel reinforcing bars embedded in portland cement concrete bridge deck. This corrosion is accelerated by chloride ions used as de-icing agents. The selection of appropriate protective coatings will be based on physiochemical testing with consideration being given to economics involved in coating and fabrication of reinforcement steel.

5. Background

A discussion of the historic aspects of the problem of accelerated corrosion of steel reinforcing bars by chloride ions was given in the first interim report, NBS Report No. 10690. This report also covered the initial selection of potential materials to protect the steel bars.

The second interim report, NBS Report No. 10857 covered the procurement of samples of organic coatings, methods used to cure coating materials, and screening tests performed on cured specimens.

6. Discussion of Activities

The work covered by this interim report includes the continuation of screening tests on cured specimens as well as the physical durability tests on coated panels and coated reinforcing bars. The corrosion characteristics of coated reinforcing bars also were investigated.

6.1 Coating Materials Received

Twelve more coating materials were received which made a total of 39 materials (the original 27 materials were listed in Table 1 of NBS Report No. 10 857). The 12 new materials are described briefly in Table 1.

Three additional epoxy powders should be received within the near future from CIBA-GEIGY Corporation, H. C. Price Company, and Hysol Corporation. It is felt that a good representation of epoxy and other appropriate organic coatings has been incorporated into the project and no further soliciting of materials will be made.

6.2 Immersion Testing

As described in NBS Report No. 10 857, cured epoxy specimens have been immersed in water and aqueous solutions of 3M $CaCl_2$, 3M NaOH, and a solution containing saturated $Ca(OH)_2$, saturated $CaSO_4 \cdot 2H_2O$ and 0.5M $CaCl_2$. The weights of the specimens are measured periodically. The current data are given in Table 2. Except for the specimens cast from Val-Chem 84-W-7, the agreement between weight changes of different specimens of the same material is good, if allowances are made for the two to threefold differences in immersion times.

It has been concluded that any materials for which weight changes of more than ±3 percent occur would react with constituents of concrete and protective coatings for steel reinforcing bars embedded in concrete.

Epoxy powders will be included in the immersion testing and the results described in a subsequent report.

6.3 Chloride Permeability

Investigation of the permeation of thin epoxy films by chloride ions has been continued (Section 6.5 NBS Report No. 10 857); the current data are presented in Table 3. The concentrations of chloride ions in the compartments originally containing only distilled water have been included because these data probably are more useful in judging the effectiveness of an epoxy than are the permeability values. The threshold of chloride ions reported [1] to induce the corrosion of steel rebars is .02M. Therefore, films no. 11 and one of no. 16 possibly would not be effective barriers to the migration of chloride ions. At a later data, in a subsequent report, the results of the permeability studies will be compated with those from corrosion testing of coated rebars.

6.4 Abrasion and Impact Resistances of Epoxy Coatings

The abrasion and impact resistances of epoxy coatings have been studied by applying the coatings to 4 x 4 x .050 in. cold-rolled steel plates and using the appropriate test methods. The steel plates were degreased using mineral spirits. Epoxies were cured according to the manufacturers instructions.

The abrasion resistances were determined in accordance with ASTM Designation D 1044-56, using a Taber Abraser and Taber CS-10 wheels with 1000g load per wheel. After each 200 cycles the wheels and specimens were gently cleaned with a soft bristle brush. The abrasion data are given in Table 4 in units of weight loss in mg per 1000 cycles. The abrasion resistance of two solvent containing systems, code numbers 3 and 16, was poor compared to that of solventless liquid epoxies and powder epoxies.

Both direct and reverse impact resistances were determined in accordance with ASTM Designation G14-69T. A Gardner Laboratory impact tester was used along with a four pound hammer. The impact data are presented in Table 4. The reverse impact is not only more severe than the direct impact, but it is also a better indication of the flexibility of a coating, i.e., a low reverse impact value is indicative of a brittle material.

6.5 Accelerated Corrosion Tests

The cathodic disbondment test, ASTM Designation G8-69T, provides a significant single laboratory test method for assessing the effect of electrical and electrochemical stress on the bond of barrier coatings on steel. By the procedure for this test a coated specimen into which a single intentional holiday has been introduced is immersed in an electrolyte (salt solution) at a potential of 1.5 volts and the potential is removed and the area around the holiday examined to determine the area of the coating that has been disbonded.

The disbondment test was modified and used to compare the different coatings applied to reinforcing bars at NBS or by commercial suppliers of the coating materials.

An electrolyte of sodium chloride (approximately 7% NaCl by weight) was used with 6 in. lengths of coated bars as the electrodes. A potential of 2 volts was applied and the electrodes observed periodically for evolution of hydrogen gas at the cathode and for liberation of iron ions at the anode. Before immersion, bare ends or obvious mechanical damage to the coating were covered with films of silicone rubber.

Pinhole or surface defects not sealed with the rubber become locations at which hydrogen gas is evolved from the cathode and from which iron ions go into solution at the anode. Insulating coatings free from defects will not permit flow of current or evolution of hydrogen. For such coatings the potential stresses were increased until failure, as evidenced by hydrogen evolution or occurence of solution of iron ions (rust color). Table 5 lists coatings tested in this way. It should be noted that some coatings may have a pigment or inhibitor incorporated in them which contribute to early evolution of hydrogen. Coatings held at a potential of 2 volts or more in a strong electrolyte continuously for 30 days or more without evolution of hydrogen or introduction of ferric iron color to the electrolyte probably can be expected to provide good protection to the bar in a chloride environment. Those which permit immediate evolution of hydrogen at a potential of 2 volts are of doubtful value. Bars removed from the test were inspected and the bars which had been the anodes (connected to the + terminal), were placed in the electrolyte (or in fresh electrolyte if the solutions were badly colored with iron) and allowed to stand in the open beaker for observation of rust formation or other evidence of failure.

These initial screening evaluations will be followed by long-term corrosion tests of the coated bars cast in 2 3/4 x 4 3/4 x 15 in. rectangular blocks of concrete to form "lolli-pop" specimens. Also the coatings which screening tests showed to be the most promising, will be subject to the disbonding test closely following the procedure specified in ASTM Designation G8-69T for epoxy coatings.

6.6 Coated Reinforcing Bars

Firms handling materials which are felt to have the most promise as protective coatings for rebars, have applied these coatings to no. 6 rebars (3/4 inch diameter) supplied by the National Bureau of Standards. Some of the physical properties of the coating films as well as the physical durabilities of the coated no. 6 reinforcing bars have been determined and will be discussed within this section.

6.6.1 Inspection of Coated Reinforcing Bars

The film thicknesses, the number of holidays per unit bar length, and the visual evaluations of the coated rebars are given in Table 6. The film thicknesses were measured with a Mikrotest Model 790 000 Magnetic Gage. The numbers of holidays were estimated using a Tinker and Rasor Model M-1 Detector.

The following tentative conclusions concerning the integrity of the coating films are supported by an analysis of the information contained with Table 6:

1. The application methods effectiveness in producing thin holiday free films decrease in the sequence: Electrostatic spray gun $>$ fluidized bed $>$ dipping $\geq$ brush.

2. Powder coatings cover the deformation pattern better than do liquid coatings, because most liquids have a tendency to run before curing leaving high points on the deformation only partly coated.
3. The thicker the film thickness for a given coating, the fewer the number of holidays.
4. Good application practices are imperative if a coating material is to realize its fullest potential.

6.6.2 Bend Test on Coated Reinforcing Bars

The no. 6 bars were bent at a 120° angle with a radius of curvature of ca. 3 in. using a Greenlee Tool Company Model 770 bar bender. Portions of the bars in contact with the bending machine were protected with rubber tubing having an o.d. of 1 1/2 in. and i. d. of 3/4 in.

The results of the bend tests are given in Table 7. Cracking and disbonding took place on areas of some bars that were under tension during the bending. The four different polyvinyl chloride coated rebars gave excellent performances even though their film thicknesses ranged from 2 to 35 mils. A greater variation was observed in the case of the epoxy coated rebars as some performed well while a few were classified as failing. The epoxy coatings which did not perform well were either brittle or were applied heavily which produced a thick film. The effect of the film thickness is illustrated by comparing the coated rebars, 22 and 31, which were both coated with the same material but applied by different methods. However, coated rebar no. 22 had a film thickness of ca. 25 miles while the film thickness of coating no. 31 was ca. 8-9 mils. When bent, substantial cracking was observed in the coating of no. 22, while no. 31 was completely free from cracking. In two series of rebars no. 28B and no. 32, epoxy coatings were applied to an unprepared surface (the mill scale was not removed). Almost total disbondment was observed when both series of bars were bent; while the epoxy adhered well to the mill scale, the mill scale "popped-off" from the steel substrate.

6.6.3 Impact Resistance and Hardness of Coatings on Reinforcing Bars

The impact resistance of coated rebars determined by the dropping test, supplements the evaluations made in accordance with the method of ASTM Designation G14-69T which are reported in Table 4.

The dropping test is intended to give an indication of the relative ability of the coatings to resist physical damage on impact and handling such as bars may receive during delivery and installation in a bridge deck.

The impact resistance was determined by dropping an 18 in. length of coated no. 6 bar on concrete so that impact occurred along the 18 in. length of bar as follows:

1. A single bar was dropped 1 meter from a horizontal position to concrete pavement.
2. The bar was dropped in the same manner from a height of 2 meters.
3. A single bar was taped loosely between two no. 7 bars of the same length and the assembly dropped from a height of 2 meters to concrete.

The bars were inspected after each drop for such indications of damage as:

1. Shattering of the coating to expose bare metal.
2. Cutting of the coating to expose bare metal.
3. Cracking of the coating.
4. Disbonding of the coating.

The coating on each bar is rated in Table 8 relative to the other bars tested. These ratings, together with results of bend tests (Table 7) and drop impact rests made in accordance with ASTM Designation G14-69T (Table 4) are indicative of the ability of the coatings to resist physical damage.

Included in Table 8 are pencil hardness values for each of the coatings. Pencils with lead hardness from H to 8H were used to mark the coating. The hardness is designated as the softest pencil that leaves a mark in the coating.

7. Future Work

The long term type of testing such as immersion, chloride ion permeability, and corrosion studies will be continued. Evaluation of the physical durabilities of coated reinforcing bars should be completed in the next three months.

7.1 Pullout and Creep Testing

Apparatus for conducting the creep test on coated reinforcing bars embedded in concrete was designed and a prototype unit fabricated. A No. 6 (3/4 in. diameter) uncoated bar was cast into a 10 x 10 x 12 in. concrete block. It will be used with the prototype test rig to put the creep apparatus in operation at full load.

If the system functions properly, additional test rigs identical to the prototype will be constructed.

The necessary modifications and grips to accommodate the pullout tests in the tensile machine were made.

Coated reinforcing bars will be cast into concrete blocks 10 x 10 x 12 in. and cured as a preliminary to conducting pullout and creep tests. At the same time bars will be embedded in concrete blocks 2 3/4 x 4 3/4 x 15 in. to form "lolli-pop" specimens for long term corrosion tests.

During the next three months, the pullout tests will be started. These will require approximately one month to complete.

The creep tests will be started at about the same time but will require one year or more to complete.

The long-term "lolli-pop" corrosion tests will be started late in 1972 and will continue for one year or more.

8. References

1. D. A. Hausmann, Steel Corrosion in Concrete, Materials Protection and Performance 6, 19 (1967) November.

TABLE 1 COATING MATERIALS RECEIVED BETWEEN APRIL 1 TO JUNE 30, 1972

Material and Source	Chemical Type	Comments
1. ROSKOTE 201 (Royston Laboratories, Inc.)	Coal tar epoxy	Black, two component liquid system.
2. Formula 72-65 (Celanese Coating Company)	Epoxy	Two component, black powder which cures at 175° - 180°C.
3. Corvel 1555 (Polymer Corporation)	Epoxy	Two component, black powder which cures at 190°C.
4. Formula 902-1 (CIBA-GEIGY Corporation)	Epoxy	One part liquid system, (contains both epoxy resin and curing component) 45.7% solids Iron oxide colored with three pigments. Similar to powder as this epoxy is cured by heating to 205°C.
5. Farboil White [a/] (Nordson Corporation)	Epoxy	White powder.
6. Resiweld 7259 (H. B. Fuller Company) [b/]	Epoxy	Two component solventless liquid system, with ketamine curing agent. Orange colored.
7. IFDP-43 (Fuller)	Epoxy	Two component black powder which cures at 180°C.
8. P-15 (Fuller)	Epoxy	Two component orange powder which cures at 180°C.
9. Hercotuf 100A (Hercules, Inc.)	Polypropylene	White powder that melts above 200°C to yield a clear coating when cooled to 25°C. Thermo-plastic, one component system.
10. Flintflex 531-6000 (DuPont)	Epoxy	Gray, sandable primer powder which cures at 180°C.

TABLE 1 COATING MATERIALS RECEIVED BETWEEN APRIL 1 TO JUNE 30, 1972 (cont)

Material and Source	Chemical Type	Comments
11. Flintflex 531-6015 (DuPont)	Epoxy	Earth red powder which cures between 166°-200°C
12. Flintflex 531-6020 (DuPont)	Epoxy	SCR brown powder coating which cures at 180°C.

a/ Laboratory designation.

b/ Second submitted sample. First sample described in NBS Report 10 857.

TABLE 2 WEIGHT CHANGES OF EPOXY DISCS IMMERSED IN AQUEOUS SOLUTIONS

Code Number	Material	Immersion Time (weeks)	PERCENT WEIGHT CHANGES			
			Water	3M $CaCl_2$	3M NaOH	Saturated $Ca(OH)_2$, Saturated $CaSO_4 \cdot 2H_2O$ and 0.5M $CaCl_2$
1	EPI-TOP 100 (Celanese)	20	1.8	1.0	1.5	1.9
		6	1.1	0.7	1.3	1.8
2	Versamid-GenEpoxy (General Mills)	20	2.5	1.6	1.7	2.8
		6	1.9	0.8	1.0	1.7
3	Green Primer (General Mills)	20	-1.7	-2.0	-1.5	-1.9
		6	-0.6	-1.1	0.5	-0.9
4	Colma-Kote M undercoat (SIKA)	20	1.8	1.2	1.3	1.6
		6	1.0	0.4	0.8	1.0
5	Colma Fix (SIKA)	20	1.0	1.1	1.2	1.5
		6	0.6	0.4	0.7	1.0
6	Colma-Kote M topcoat (SIKA)	20	2.2	1.4	1.7	2.2
		6	1.2	0.5	0.9	1.2
7	Epoloid 7-WE-20 (ROWE)	20	17	19	16	18
8	Epoloid 2027 (ROWE)	20	-4.4	-5.3	-3.7	-4.1
9	Chemfast E. P. (Celanese)	20	-6.8	-10	5.7	1.5
12	EHS-58 (GACO)	18	1.2	0.0	1.0	1.5
13	EHS-55 (GACO)	18	3.9	1.3	2.5	2.8
16	Val-Chem 84-W-7 (Mobil)	11	0	-1.0	-0.3	-0.7
		6	-2.0	-1.9	-0.5	-2.3
17	Concresive 1170 (Adhesive)	13	1.5	0.7	1.9	1.9
		6	1.0	0.4	1.6	1.1
18	Concresive 1026 (Adhesive)	13	0.4	0.0	0.5	0.6
		6	0.5	0.0	0.5	0.6

TABLE 3 PERMEABILITY OF CHLORIDE IONS

Code Number	Material	Film Thickness (mils)	Exposure Time (weeks)	Concentration a/ (moles per liter)	Permeability b/
1	EPI-TOP 100 (Celanese)	3	5	$<1\times10^{-5}$ c/	$<5\times10^{-6}$
2	Versamid-GenEpoxy (General Mills)	3	15	1×10^{-4}	2.0×10^{-5}
3	Green Primer (General Mills)	3	5	$<1\times10^{-5}$ c/	$<5\times10^{-6}$
4	Colma-Kote M undercoat (SIKA)	3	15	1×10^{-4}	2.0×10^{-5}
6	Colma-Kote M topcoat (SIKA)	3	15	1×10^{-4}	2.0×10^{-5}
11	Resiweld 7259 (Fuller)	3	5	9×10^{-4}	4.5×10^{-4}
13	GACO EHS-55 (GATES)	3	15	1×10^{-2}	2.0×10^{-3}
16	Val Chem 84-W-7 (Mobil)	7 3	15 5	2×10^{-3} 2×10^{-1}	6.9×10^{-4} 2.9×10^{-1}
17	Concresive 1170 (Adhesive)	3	5	$<1\times10^{-5}$ c/	$<5\times10^{-6}$

a/ Concentration of chloride ions in the chamber originally containing only distilled water.

b/ Permeability units are: (grams per day)/exposed area (in^2)/film thickness (mils); i.e. theoretically, the number of grams of chloride ion passing per day through a film having an exposure area of one square inch and a thickness of one mil.

c/ Millivolt readings were in the region of distilled water and upper limit of the chloride ion concentration was estimated.

TABLE 4 ABRASION AND IMPACT RESISTANCE OF CURED EPOXY COATINGS ON STEEL PANELS

Code Number	Material	IMPACT RESISTANCE[b/] Film Thickness (mils)	Reverse Impact (in lb.)	Direct Impact (in lb.)	ABRASION RES Weight loss per 1
1	EPI-TOP 100 (Celanese)	7	20	90	71
2	Versamid-GenEpoxy (General Mills)	7	4	120[d/]	56
3	Green Primer (General Mills)	8	40	160	107
4	Colma-Kote M undercoat (SIKA)	5	4	40	70
5	Colma Fix (SIKA)	7	8	20	58
6	Colma-Kote M topcoat (SIKA)	6	4	20	71
11	Resiweld 7259 (Fuller)				89
16	Val-Chem 89-W-9 (Mobil)	5	8	50	148
17	Concresive 1170 (Adhesive)	6	7	50	58
18	Concresive 1026 (Adhesive)	7	12	110	52
19	Formula 902-1 (CIBA-GEIGY)	1	>160	>160	51
	Formula 902-1 (CIBA-GEIGY)	4	160	>160	--
28	Formula 72-65 (Celanese)	8	40	60	88
29	Corvel 1555 (Polymer)	8	50	60	57

a/ Epoxy coatings applied to 4x4x.050 inch steel plates (cold rolled).

b/ Four pound hammer used.

c/ Tabor CS-10 wheels, with 1000g load per wheel.

d/ Bond at the steel-epoxy interface severed at 10 in lb.

TABLE 5 ACCELERATED CORROSION TESTS

Code Numbers	Material	Source	Coating: Thickness (mils)	Coating: Applied By[a/]	Time (hrs) to Produce H_2 Evolution at Voltage Shown — Volts Applied: 2	5	8	10	15
34		NARMCO	2 - 3	NBS, brush	<1/4	-	-	-	-
14+16	Vinyl Primer 80-R-8 (liquid) + 89-W-9 (epoxy, liquid)	Mobil	10 - 12	NBS, brush	>15	>24	>264	-	<16
16	Val-Chem 89-W-9 No primer (epoxy, liquid)	Mobil	8	NBS, brush	-	>1	-	<1/4	-
14+16	Vinyl Primer 80-R-8 + Val Chem 89-W-9. Two coats	Mobil	15 - 20	NBS, brush	>1/4	>1/4	-	>1/4	<1/4
25	Epoxy Blue (powder)	Republic Steel	6 - 11	Republic, E.S. Spray	>6	-	>1	-	-
26	Vinyl Primer (powder) - Transparent	Republic Steel	2 - 3	Republic	<1/4	-	-	-	-
35	Witmer T 830 (urethane, liquid)	WITCO	25 - 30	NBS, brush	>140	-	<8	-	-
36	Witmer 530 (urethane, liquid)	WITCO	8 - 12	NBS, brush	<1/4	-	-	-	-
2+3	Green Primer + GenEpoxy (epoxies, liquids)	General Mills	10 - 15	NBS, brush	<1/2	-	-	-	-
6	Colma-Kote M, topcoat (epoxy, liquid)	SIKA	5 - 8	NBS, brush	<1/2	-	-	-	-
4	Colma-Kote M, undercoat (epoxy, liquid)	SIKA	20 - 30	NBS, brush	<1/2	-	-	-	-

TABLE 5 ACCELERATED CORROSION TESTS (cont.)

Code Numbers	Material	Source	Coating Thickness (mils)	Coating Applied By[a]	Time (hrs) to Produce H_2 Evolution at Voltage Shown — Volts Applied: 2	5	8	10	15
5	Colma-Fix, Straw (epoxy, liquid)	SIKA	8 - 10	NBS, brush	<1/4	-	-	-	-
5	Colma-Fix (epoxy, liquid)	SIKA	40 - 50	SIKA, brush	>288	>24	-	>24	>24
4	Colma-Kote M undercoat (epoxy, liquid)	SIKA	20 - 30	SIKA, brush	<48	-	-	-	-
37	Epoxy, Black liquid	US STEEL	15 - 35	NBS, brush	<1/4	-	-	-	-
13	Concresive 1026, Black (epoxy - coal tar, liquid)	Adhesive Eng. Co.	3 - 4	NBS, brush	<1/4	-	-	-	-
19	Formula 902-1 (epoxy, liquid)	CIBA-GEIGY	4	CIBA, dip	>24	-	-	-	-
19	Formula 902-1 (epoxy, liquid)	CIBA-GEIGY	1 - 2	CIBA, dip	<1/4	-	-	-	-
25	Formula 72-65, black (epoxy, powder)	Celanese	1 - 2	Celanese, E.S. spray	<1/4	-	-	-	-
1	EPI-TOP 100, red (epoxy, liquid)	Celanese	8 - 10	NBS, brush	<1/4	-	-	-	-
1	EPI-TOP 100	Celanese	4 - 5	Celanese, brush	<1/4	-	-	-	-
20	Inhibitor #PA5615 + Epoxy 320-122 (powders)	Shell	8 - 12	Shell, E.S. spray	<1/4	-	-	-	-
11	Resiweld 7259, two orange coats (epoxy, liquid)	H. B. Fuller	8 - 10	NBS, brush	<1/4	-	-	-	-

TABLE 5 ACCELERATED CORROSION TESTS (cont.)

Code Numbers	Material	Source	Coating Thickness (mils)	Coating Applied by[a]	Time (hrs) to Produce H_2 Evolution at Voltage Shown, Volts Applied: 2	5	8	10	15
27	ID DP-43, black (epoxy, powder)	H. B. Fuller	8	Fuller, E.S. spray	<1/4	-	-	-	-
29	CORVEL 1555, Yellow (epoxy, powder)	Polymer Corp.	3 - 4	Polymer, E.S. spray	<1/4	-	-	-	-
30	PVC - VCA 1403, Light Green (powder)	Polymer Corp.	15 - 18	Polymer, E.S. spray	>168	(silicone disbonded)			
31	ScotchKote 202, Green (epoxy, powder)	H. C. Price	8 - 9	Price, E.S. spray	> 96	-	-	-	>96
22	ScotchKote 202, Green (epoxy, powder)	Robroy	25	Robroy, Fl.Bed	>648	-	-	-	72
23	PVC, Dark Olive Green (powder)	Robroy	25	Robroy, Fl.Bed	>120	(still running)			
24	PVC-Plastisol Purplish black (powder)	Robroy	35	Robroy, Fl.Bed	>480	-	-	-	72 Still running

a/ E.S. spray denotes electrostatic spray gun and Fl. Bed denotes fluidized bed.

b/ Rating: Poor - immediate (1 to 15 minutes) hydrogen evolution from - electrode at 2 volt potential and appearance of ferric iron color.

Fair - hydrogen evolution began with 1/2 hr. at 2 volts or quicker at higher voltage.

Good - withstood stress of 5 or more volts for 1 hr. or more

Excellent - no hydrogen evolved in 1 hr. or more at 15 volts

c/ Coating contains iron oxide as pigment. Iron oxide from coating goes in solution.

d/ Test will be repeated. Mechanical damage to coating noted.

e/ Hydrogen evolution was very slow and uniformly from many very small sites.

TABLE 6 INSPECTION OF COATED STEEL REINFORCING BARS [a/]

Code Number	Material	Chemical Type	Color	Application Method	Film Thickness (mils)	No. of Holidays per 4 foot bar	Visual Inspection and Comments
1	EPI-TOP 100 (Celanese)	Epoxy, liquid	Reddish brown [b/]	Brush	4 - 5	40	Deformation not well coated and slightly exposed. Accumulation of epoxy in low lying regions.
2	Versamid-GenEpoxy (General Mills)	Epoxy, liquid	Clear	Brush	5 - 15	ca. 10	Deformations not well covered, long uncovered regions. Material is brittle.
3	Green Primer (General Mills)	Epoxy, liquid with solvent	Dull Green	Brush	2 - 5	ca. 30 - 40	Deformations appear to be well covered,
4	Colma-Kote M undercoat (SIKA).	Epoxy, liquid	Orange	Brush	20 - 30	none	Deformation not well defined as the epoxy is concentration in the low lying regions between the deformations.
5	Colma Fix (SIKA)	Epoxy, liquid	Dark Tan	Brush	40 - 50	none	Longitudinal deformations are not well covered. Excess epoxy in regions between the deformations.
10	Resiweld 7251 (Fuller)	Epoxy, liquid	White	Brush	10	ca. 10	Susceptible to abrasion; coating comes easily off of rebars. Rough texture. Epoxy accumulates between deformations.
11	Resiweld 7259 (Fuller)	Epoxy, liquid	Orange	Brush	10 - 12	none	Coating easily chips off of rebar. Regions where deformations are not well covered. Evidence of epoxy dripping from bar.
16	Val-Chem 89-W-9 (Mobil)	Epoxy, liquid with solvent	White	Electrostatic spray gun	2 - 4	40	Deformation not well covered, accumulation of epoxy in low lying areas.

TABLE 6 INSPECTION OF COATED STEEL REINFORCING BARS [a] (cont.)

Code Number	Material	Chemical Type	Color	Application Method	Film Thickness (mils)	No. of Holidays per 4 foot bar	Visual Inspection and Comments
19	Formula 902-1 (CIBA-GEIGY)	Epoxy, liquid with solvent	Reddish brown	Single dipping	1	40	Good coverage, well defined deformation pattern. No bad dipping regions observed.
				Triple dipping	4	ca. 4	
22	ScotchKote 202 (Robroy)	Epoxy, powder	Light Green	Fluidized bed	25	none except at ends	Good even build-up film. Large thickness characteristics of fluidized bed application.
23	PVC (Robroy)	Polyvinyl-chloride powder	Dark Olive Green	Fluidized bed	25	none except at ends	Good even build-up film. Thermoplastic coating.
24	Plastisol PVC (Robroy)	Plastisol polyvinylchloride, powder	Purplish Black	Fluidized bed	35	none	Deformation pattern not well defined. Thermoplastic.
25	Blue Epoxy (Republic Steel)	Epoxy, powder	Blue	Electrostatic spray gun	6 - 11	none	Good coating material. Some bad spraying techniques evident, bars sprayed from one direction giving the underside of deformations a thin coating.
26	PVC (Republic Steel)	Polyvinyl-chloride, powder	Clear	Electrostatic spray gun	2 - 3	Too many to estimate	Top of deformations not covered. When received, coated rebars were sticky. Thermoplastic
27	ID DP-43 (Fuller)	Epoxy, powder	Black	Electrostatic spray gun	8	ca. 1	High gloss coating. Even build-up. Very tough coating that does not chip off.

TABLE 6 INSPECTION OF COATED STEEL REINFORCING BARS [a] (cont.)

Code Number	Material	Chemical Type	Color	Application Method	Film Thickness (mils)	No. of Holidays per 4 foot bar	Visual Inspection and Comments
28	Formula 72-65 (Celanese)	Epoxy, powder	Black	Electrostatic spray gun	1 - 2	Cannot estimate	Either very high number of holidays or electrical conducting pigments. Rough texture.
29	Corvel 1555 (Polymer)	Epoxy, powder	Yellow	Electrostatic spray gun	3 - 4	Cannot estimate	Either very high number of holidays or electrical conducting pigment. Deformations do not appear to be well coated. Tough coating that is not susceptible to chipping.
30	VCA 1403 (Polymer)	PVC, powder	Dull Green	Fluidized bed	15 - 18	none	Thermoplastic coating. Deformation pattern not well defined, possibly due to tendency of material to flow when cured at elevated temperatures.
31	ScotchKote 202 (Price)	Epoxy, powder	Green	Electrostatic spray gun	8 - 9	none	Good even build-up film. Deformations well covered. Tough coating that is not susceptible to chipping.
32	Farboil White (Nordson)	Epoxy, powder	White	Electrostatic spray gun	4 - 6	40	Mill scale was not removed and coating chips off easily due to disbonding between the scale and the steel rebar.

a/ Number 6 steel reinforcement bars coated by applicators or coatings producers. Unless otherwise state, the mill scale was removed by sand blasting.

b/ A few orange and clear colored coated rebars were also submitted, with EPI-TOP 100 being the vehicle.

TABLE 7 BENDING TEST ON COATED STEEL REINFORCEMENT BARS a/

Code Number	Material	Chemical Type	Film Thickness (mils)	Results of 120° bend b/
1	EPI-TOP 100 (Celanese)	Epoxy, liquid	4 - 5	Slight cracking near edge of deformation, length of cracks were ca. 1/8 inch.
2	Versamid-GenEpoxy (General Mills)	Epoxy, liquid	5 - 15	Complete failure in bend area. Almost complete disbonding
3	Green Primer (General Mills)	Epoxy, liquid with solvent	2 - 5	Few small crack ca. 1/8 in. long. Good performance.
4	Colma-Kote M undercoat (SIKA)	Epoxy, liquid	20 - 30	Severe cracking at almost every transverse deformation in bend area. Lengths of cracks were 1/2 to 3/4 in.
5	Colma Fix (SIKA)	Epoxy, liquid	40 - 50	Severe cracking at deformations. Cracks were ca. 1/8 in. wide and undercutting disbondment between the film and steel took place.
10	Resiweld 7251 (Fuller)	Epoxy, liquid	10	Severe cracking which extended from longitudinal to longitudinal deformation. Dis-bonding between the coating and steel was observed.
11	Resiweld 7259 (Fuller)	Epoxy, liquid	10 - 12	Same as Resiweld 7251.
16	Val-Chem 89-W-9 (Mobil)	Epoxy, liquid with solvent	2 - 4	Miniature cracks, good performance

TABLE 7 BENDING TEST ON COATED STEEL REINFORCEMENT BARS [a/] (cont.)

Code Number	Material	Chemical Type	Film Thickness (mils)	Results of 120° bend [b/]
19	Formula 902-1 (CIBA-GEIGY)	Epoxy, liquid with solvent	4	No cracks, excellent performance.
22	ScotchKote 202 (Robroy)	Epoxy, powder	25	Substantial cracking extending from longitudal to longitudinal deformation, some disbonding between the coating and steel was observed.
23	PVC (Robroy)	Polyvinylchloride, powder	25	No cracks, excellent performance.
24	Plastisol PVC (Robroy)	Plastisol polyvinylchloride, powder	35	No cracks, excellent performance.
25	Blue Epoxy (Republic Steel)	Epoxy, powder	6 - 11	Many small (ca. 1/8 inch long) thin cracks, considered as moderate cracking.
26	PVC (Republic Steel)	Polyvinylchloride, powder	2 - 3	No cracks, excellent performance.
27	ID DP-43 (Fuller)	Epoxy, powder	8	Substantial cracking extending from longitudal to longitudinal deformation. Some disbonding was observed.

TABLE 7 BENDING TEST ON COATED STEEL REINFORCEMENT BARS a/ (cont.)

Code Number	Material	Chemical Type	Film Thickness (mils)	Results of 120° bend b/
28	Formula 72-65 (Celanese) A. Rebars sandblasted B. Mill scale left on bars	Epoxy, powder	1 - 2	A. Slight cracking, good performance. B. Substantial cracking and disbonding observed.
29	Corvel 1555 (Polymer)	Epoxy, powder	3 - 4	No cracks, excellent performance.
30	VCA 1403 (Polymer)	Polyvinylchloride, powder	15 - 18	No cracks, excellent performance.
31	ScotchKote 202 (Price)	Epoxy, powder	8 - 9	No cracks, excellent performance.
32	Farboil White (Nordson) c/	Epoxy, powder	4 - 6	Complete failure as total disbonding in bend area; probably attributable to disbonding between mill scale and steel.

a/ Number 6 steel reinforcement bars coated by applicators or coating producers. Unless otherwise stated the mill scale was removed by sand blasting.

b/ Crack rating in order of decreasing performance: Excellent > Good > Moderate > Substantial > Severe > Complete failure

c/ Mill scale was not removed.

Table 8 Impact Resistance and Hardness of Coatings

Code	Supplier	Material	Impact Rating	Pencil Hardness Rating
1	Celanese	EPI-TOP 100	Good	>8H
2	General Mills	Versamid-GenEpoxy	Poor	>8H
3	General Mills	Green Primer	Good	>8H
4	SIKA	Colma-Kote M (undercoat)	Poor	>8H
5	SIKA	Colma-Fix	Poor	>8H
10	Fuller	Resiweld 7251	Poor	>8H
11	Fuller	Resiweld 7259	Poor	>8H
16	Mobil	Val Chem 89-W-9	Fair	>8H
19	CIBA	Formula 902-1	Excellent	> 8H
21	Shell	Corlar	Poor	>8H
22	Robroy	ScotchKote 202	Excellent	> 8H
23	Robroy	PVC	Excellent	8H
24	Robroy	PVC Plastisol	Excellent	H
25	Republic Steel		Good	> 8H
27	Fuller	ID DP-43	Good	>8H
28	Celanese	Formula 72-65	Fair	>8H
29	Polymer Corp.	Corvel 1555	Good	>8H
30	Polymer Corp.	Corbond PVC VCA-1403	Poor	H
31	H. C. Price	ScotchKote 202	Excellent	> 8H
32	Nordson Corp.	Farboil	Fair	> 8H

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