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CEMENTITIOUS MATERIALS FOR THIN PATCHES

Final Report

SPR 304-041

Oregon Department of Transportation

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by

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for

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16. Abstract

Ten cementitious patching materials, which were suitable for thin, vertical repairs according to the manufacturers, were evaluated. Compatibility with cathodic protection systems was a particular concern. The materials were tested for propensity to crack and delaminate, compressive strength, bond strength, length change, and resistivity. Three materials, ThoRoc SP20 Spray Mortar, Re-Crete 20, and Polyfast LPL had the best results; consequently, they are recommended for field trials.

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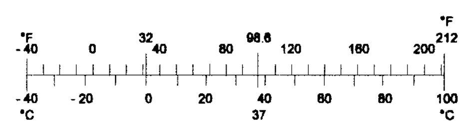
SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	Millimeters	mm
ft	feet	0.305	Meters	m
yd	yards	0.914	Meters	m
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	Hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	Milliliters	mL
gal	gallons	3.785	Liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	Grams	g
lb	pounds	0.454	Kilograms	kg
T	short tons (2000 lb)	0.907	Megagrams	Mg
		TEMPERATURE (exact)		
□F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	□C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
ºC	Celsius temperature	1.8 + 32	Fahrenheit	ºF



* SI is the symbol for the International System of Measurement

(4-7-94 jbp)

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CEMENTITIOUS MATERIALS FOR THIN PATCHES

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1.0 INTRODUCTION

1.1 BACKGROUND

The Oregon Department of Transportation (ODOT) maintains over 120 coastal bridges longer than 15 m (50 ft). Most of these bridges are reinforced concrete structures. Approximately 33% of the bridges are over 60 years old. Twelve are historic structures.

Normally, the steel embedded in concrete is passive due to the high pH pore solution of the concrete. However, chloride ions degrade the passive layer and may initiate corrosion at approximately 0.74 kg Cl/m^3 (1.25 lb Cl/yd^3) (*McDonald 1998*). Because the corrosion products are more voluminous than the steel consumed, tensile stresses develop in the cover concrete and cause the concrete to crack and spall. With the loss of the cover concrete, the steel is exposed directly to the marine environment, which leads to rapid corrosion.

Many of Oregon's reinforced concrete coastal bridges are experiencing corrosion of the internal steel reinforcement due to the marine salt. Consequently, ODOT has installed over 40,000 m^2 of thermal sprayed zinc anodes on five bridges for cathodic protection, and the agency plans to have three more bridges under cathodic protection by the end of 2002. The steps include the following:

- Remove all damaged concrete and previous patches,
- Excavate into the sound concrete to provide adequate patch retention,
- Clean all exposed steel and concrete that will be covered by patching material,
- Connect all steel for electrical continuity,
- Install anchors for patches thicker than 38 mm (0.5 in),
- Rebuild the profile of the beam,
- Apply the anode and electrical terminal plates, and
- Connect the anodes to the electrical system.

Sodium chloride may be added to patching materials to reduce the difference in chloride levels between the base concrete and the patch. Currently, ODOT allows additions up to 1.2 kg Cl/m^3 (2.0 lb Cl/yd^3). The logic behind these additions is that sections of reinforcing steel in concrete with different chloride levels (original and patch concrete) may develop a corrosion cell. Decreasing the chloride difference reduces the electrochemical potential of the corrosion cell and, therefore, reduces the possible corrosion effects from the cell. Additions of sodium chloride also lower the resistivity of the patches, which is beneficial for achieving adequate current density in cathodic protection. The effect of sodium chloride additions on durability of patches has not been investigated.

The patching material may be applied as shotcrete, form and pour, or a hand application depending on the agreement between the engineer and contractor. Beginning with the rehabilitation of Cape Creek Bridge in 1990, ODOT has used extensive surface preparation, forming, and wetting to reduce the extent of shrinkage cracking and delamination. Any cracks and delamination in a patch must be repaired prior to applying the anode. Even with careful attention to application, every bridge rehabilitation project that included cathodic protection has experienced problems with shrinkage cracking and adhesion of thin patches. Only one material has performed to acceptable levels, and it is limited to patches thicker than 19 mm (0.75 in).

1.2 SHRINKAGE

Shrinkage involving water is classified as autogenous shrinkage, plastic shrinkage, or drying shrinkage. Autogenous shrinkage is a volume decrease with no mass change that occurs during cement hydration. Except for concretes with very low water-to-cementitious materials ratios (*w/cm*) and for large concrete volumes such as dams, autogenous shrinkage is relatively insignificant (*Aitchin 1999*, *Mehta 1994*). During plastic and drying shrinkage, water is lost to the surrounding environment. When the water loss occurs while the concrete is fresh, the resulting volume change is plastic shrinkage. For hardened concrete, the volume change is drying shrinkage. If the concrete is restrained from shrinking freely, tensile stresses develop. The high tensile stresses and the low fracture resistance of concrete often result in shrinkage cracking.

The factors and interactions that control shrinkage are complex and not fully understood. For durable repairs with good resistance to cracking, a patching material would ideally have low shrinkage, low elastic modulus, low coefficient of thermal expansion, high strength, and high creep. However, mineral and chemical admixtures used to increase strength and decrease permeability can increase the susceptibility to cracking (*Bloom 1995*). For example, a low *w/cm* reduces the amount of water that can escape to the environment and the degree of drying shrinkage. However, lowering *w/cm* and adding silica fume to obtain higher strength has been shown to increase shrinkage (*Wiegrink 1996*).

Wet curing and curing membranes postpone the start of drying, but eventually the moisture level of the concrete is dictated by its surroundings. Consequently, drying shrinkage is often evident within thirty days but may take over a year to complete. (*ICRI 1996*)

Maximizing the amount of coarse aggregate also reduces the extent of shrinkage. The aggregate provides restraint against shrinkage if the particles form a contiguous network. In addition, the aggregate reduces the volume of water and cement paste that undergoes shrinkage. Varying the amount of water and aggregate to minimize cracking, however, can produce trade-offs in performance such as workability, thin layer capability, and resistivity. Generally, the amount of coarse aggregate is limited or eliminated in order to patch thin sections. To compound the problem, thin patches are especially prone to shrinkage because the high surface-to-volume ratio promotes relatively easy water loss.

1.3 ADHESION

Surface preparation is a critical step in repairing concrete (*ACI 1997*). Deteriorated concrete must be removed, and the sound concrete must have an adequate profile to achieve a good bond with the patch. Many of the manufacturers have minimum profile requirements ranging from 2 mm (0.06 in) to 6 mm (0.25 in). Further requirements may include fractured aggregate. However, impact and milling methods used to remove concrete can cause microcracking in the sound concrete, which can degrade the performance of the repair. Further surface preparation include cleaning and saturating the surface with water immediately prior to patching to avoid losing water from the patch into the concrete. Some manufacturers recommend brushing on a thin layer of their patching material to infiltrate the surface followed immediately with the bulk application of the patch.

1.4 OBJECTIVE

This study was conducted to produce a list of appropriate products for thin-layer repairs of concrete structures that undergo cathodic protection. The emphasis was on evaluating materials for shrinkage cracking, adhesion, and resistivity.

2.0 EXPERIMENTAL METHOD

Discussions were conducted with manufacturers to develop a list of potentially suitable patching materials. The following criteria were considered in selecting the materials:

- Must be cementitious,
- Can be applied to vertical surfaces,
- Can be applied in thin layers down to 6 mm (0.25 in),
- Has a resistivity compatible with cathodic protection,
- Can be applied by hand.

Six manufacturers provided ten different patching materials for evaluation. Table 2.1 describes the materials based on information provided by the manufacturers. Resistivity data were only available for Eucopatch, Recrete 20, and Polyfast LPL; consequently, the compatibility with cathodic protection was unknown for most of the materials. Oregon DOT requires the resistivity of patches used in conjunction with cathodic protection to be between 2,000 and 20,000 ohm-cm without the addition of sodium chloride. No sodium chloride was added to the patching materials in this project because it was expected that the additions would not affect the performance measures.

Table 2.1: Patching materials included in the evaluation

Material Name	Manufacturer	Description	Working Time at 21 – 23°C
Emaco S88 CI	ChemRex	One-component Fiber-reinforced Sprayable Contains silica fume	45 minutes
ThoRoc SP20 Spray Mortar	ChemRex	One-component Fiber-reinforced Sprayable Contains silica fume	45 minutes
Sonocrete Sonopatch 100 without polymer	ChemRex	Two-component but used only with water in this experiment per Chemrex	15 minutes
ThoRoc All-Crete 20	ChemRex	One-component	10 minutes
Tectonite	Tectonics International	One-component Magnesium oxyphosphate cement	10 minutes
Rapid Set Non-Shrink Grout	CTS Cement Manufacturing	One-component	20 minutes
Re-Crete 20	Dayton Superior	One-component	10 minutes
Polyfast LPL	Dayton Superior	One-component Polymer-modified	20 minutes
SikaTop 123 Plus	Sika	Two-component Polymer-modified	15 minutes
Eucopatch	Euclid Chemical	One-component	<10 minutes

Six 457 x 229 x 3658 mm (18 x 9 x 144 in) rectangular prisms previously used for a chemical deicing evaluation were used for the test specimens. Each prism had one large, recessed face (457 x 3658 mm) and one large, flat face of sound concrete. The prisms were positioned so that the two large faces were vertical. Twenty-seven areas approximately 460 x 610 mm (18 x 24 in) on the flat faces of the five prisms were abraded with a SASE SPT-2000, hand-held scarifier.

A 6 mm (0.25 in) profile was desired after abrading to meet the recommendations of some of the manufacturers, but only a 2 – 3 mm (0.08 – 0.1 in) profile was achieved. A higher energy impact method would have been necessary to obtain a 6 mm (0.25 in) profile; however, such a procedure would have had a high likelihood of producing microcracks in the concrete. It is anticipated that removing deteriorated concrete down to sound concrete would result in a deeper profile.

Three separate patches with nominal thickness levels of 6, 13, and 19 mm (0.25, 0.50, and 0.75 in) of each material were applied to the prisms. Plywood forms with the three thickness levels were attached to the abraded sections with epoxy to provide a recessed area in which the patching materials were applied. Each material and thickness combination was placed on a randomly selected abraded section.

Prior to patching, the concrete surface and forms were soaked with a sprinkler for at least 30 minutes and covered with plastic sheeting. Water was occasionally sprayed onto the concrete under the sheeting to maintain a wet surface. Immediately before applying a patch, the sheeting covering that area was removed.

Batches were mixed at the prisms using a mixer connected to a drill. The amount of mortar powder ranged from 3.6 kg to 12.3 kg (8 to 27 lb). Generally, the minimum amount of water was used based on manufacturers' recommendations with more water added as necessary to make a workable mix. In some cases, less than minimum water was used in subsequent patches in order to achieve an adequate consistency. Mixing time ranged from 2 to 4 minutes. The patching material was rubbed onto the concrete to provide a bond coat, and then the form was filled with the material. Most forms were filled within approximately 10 minutes after mixing. The patches were finished by screeding, and Burke Wax Emulsion (Fast Dry) curing compound was immediately applied. A second coat of curing compound was applied within 1 hour. Tectonite was allowed to air cure without the curing compound, as indicated in the manufacturer's instructions. The curing compound was removed by sandblasting 19 – 22 days after placement.

The manufacturers recommend either using a curing compound or moist curing. Oregon DOT allows both methods. Curing compound was used in this project because it simplified the patch application process. The effect of curing method on patch integrity was not investigated.

Three 76 mm diameter x 152 mm long (3 x 6 in) compressive strength cylinders, one 102 mm diameter x 204 mm long (4 x 8 in) resistivity cylinder, and three 25 x 25 x 285 mm (1 x 1 x 11.25 in) length-change prisms were cast for eight of the ten materials. Tectonite and Rapid Set Non-Shrink Grout were not subjected to the full regimen of testing as explained in the Results section. The strength cylinders were cured for 28 days in a curing room at 95% relative humidity

(RH) and 23°C (73°F). The 28-day compressive strength was measured according to ASTM C 39 (*ASTM C 39 2001*).

The resistivity cylinders were cured for 14 days in the curing room, cut to 76mm (3 in) lengths, thermal sprayed with zinc, conditioned and measured for resistivity according to the ODOT Concrete Resistivity Procedure described in Appendix A. Conditioning involved 4 days at 100°C (212°F). After the initial set of resistivity measurements within the first 24 hours following conditioning, resistivity measurements were made every week for 9 weeks. The cylinders remained in the curing room during this time.

Using a modified ASTM C 157 procedure, the length-change prisms were cured for 24 hours at 23°C and 95% RH, removed from their molds, cured another 6 days in lime-saturated water, and dried under ambient laboratory conditions (24°C and 30% RH) (*ASTM C 157 2001*). Length measurements were made after the initial 24-hour cure, after the 6-day water cure, and at specific time intervals during drying.

Total crack length and bond strength were measured for the patches. Crack lengths were measured 0, 14, and 28 days after the curing compound was removed (19-22, 33-36, and 47-50 days after placement). Bond strength was measured 36 days after the curing compound was removed (55-58 days after placement). A 76 mm (3 in) diameter circular saw cut was made through each patch and into the base concrete. A 76 mm (3 in) diameter steel disk was attached to the sectioned patch with epoxy. A Dillon Portable Pull Tester with an 11,100 N (2500 lb) dynamometer was connected to a threaded hole on the exposed face of the disk. Tension was applied until failure, and the maximum applied stress and the location of the failure were recorded.

3.0 RESULTS

3.1 APPLICATION

The patching materials were applied to the prisms over 4 consecutive, sunny days with daytime temperatures ranging from 18°C to 28°C. Experiences with each patch are summarized in Table 3.1. The Comments section gives the amount of liquid used relative to the ranges provided in the manufacturers' instructions. Mixes that changed viscosity from relatively stiff to thin with only a small addition of water are listed as sensitive to water additions. The Comments section also includes notes on how well the materials could be placed and finished.

Only one patch of Tectonite and two patches of Rapid Set Non-Shrink Grout were applied. These materials set up too fast to place and finish a patch; consequently, further trials were discontinued. The Tectonite patch was not consolidated enough to conduct subsequent tests; crack measurements and bond tests were conducted on the Rapid Set Non-Shrink Grout patches.

Table 3.1: Materials application

Material	Nominal Patch Thickness (mm)	Estimated Air Temperature (°C)	Comments
Emaco S88 CI	6	24 - 28	Minimum water. Thin mix. Sensitive to water additions.
	13	24 - 28	Minimum water. Thin mix. Sensitive to water additions. Did not fill 50% of the form.
	19	18 - 21	Minimum water. Thin mix. Sensitive to water additions.
ThoRoc SP20 Spray Mortar	6	21 - 24	12 % less than minimum water. Thin mix. Sensitive to water additions. Applied with trowel. Screeded OK.
	13	18 - 21	Minimum water. Thin mix. Sagged. Tore when screeded.
	19	24 - 28	20% less than minimum water. Stiff mix. Screeded OK.
Sonocrete Sonopatch 100 without polymer	6	18 - 21	Maximum water. Good workability. Actual patch thickness was 3 – 4 mm because more material was needed than specified by manufacturer's literature.
	13	24 - 28	2% more water than maximum. Good workability.
	19	18 - 21	Maximum water. Thin mix. Applied with trowel. Screeded OK.
ThoRoc All-Crete 20	6	18 - 21	Minimum water. Good workability.
	13	18 – 21	More than minimum but less than maximum water. Too stiff. Patch had voids and tears. Immediately filled in voids and tears with a second batch mixed to a putty-like consistency.
	19	18 - 21	Minimum water. Workability OK.
Tectonite	13	18 – 21	Recommended water and full-strength set retarder. Too thin for vertical patch. Mix remained thin for approximately 10 minutes, then went from thin mix to initial set in approximately 2 minutes. Form was not filled or consolidated.
Rapid Set Non-Shrink Grout	6	24 - 28	20% less than maximum water. Good workability for about 1 minute, then it became too stiff to finish the patch. 20% of the form was not filled.
	19	21 - 24	Minimum water. Set up too fast to screed the entire patch. 30% of the form was not filled.
Re-Crete 20	6	18 - 21	17% less than minimum water used by mistake. Stiff mix. Screeded OK.
	13	18 - 21	Minimum water. Good workability.
	19	21 - 24	15% less than maximum water. Workability OK.
Polyfast LPL	6	21 - 24	Maximum water. Workability OK.
	13	18 - 21	7% more than maximum water. Good workability. A little sticky.
	19	24 - 28	10% more than maximum water. Fairly stiff. Tore when screeded. Sagged after placement.
SikaTop 123 Plus	6	24 – 28	Minimum Component A. Good workability, but started to get too stiff within about 7 minutes.
	13	24 – 28	15% less than maximum Component A. Good workability. Sagged after placement.
	19	21 - 24	17% less than maximum Component A. Workability OK. Sagged after placement.
Eucopatch	6	24 - 28	Minimum water. Workability OK.
	13	18 – 21	14% less than minimum water. Workability OK. Sagged after placement.
	19	24 - 28	15% less than minimum water. Workability OK. Some tearing when screeded.

3.2 CRACKING AND DELAMINATION

Table 3.2 shows the cracking and delamination that were observed for the patches. Only four patches had cracks or delamination. The 6 mm thick, Re-Crete 20 patch had extensive cracking, but it was prepared with the incorrect amount of water. This patch was not considered in further evaluations.

Table 3.2: Delamination survey and total length of cracks for each patch at various ages (Lengths are in mm)

Material	Nominal Patch Thickness (mm)	Time Coated with Curing Compound (Days)	Estimated Delaminated Area (%)	Total Crack Length at Three Times after Curing Compound Removal (mm)			Comments
				0 Days	14 Days	35 Days	
Emaco S88 CI	6	20					
	13	22					
	19	19					
ThoRoc SP20 Spray Mortar	6	20					
	13	21					
	19	21					
Sonocrete Sonopatch 100 without polymer	6	20					
	13	20					
	19	19	25		150	170	1 delamination. Only 1 crack, which was located in the delamination.
ThoRoc All-Crete 20	6	19					
	13	21					
	19	21					
Tectonite	13	20					
Rapid Set Non-Shrink Grout	6	21					
	19	22					
Re-Crete 20	6	19		950	950	950	Patch had incorrect amount of water.
	13	19					
	19	20					
Polyfast LPL	6	22					
	13	20					
	19	20					
SikaTop 123 Plus	6	21					
	13	20					
	19	21					
Eucopatch	6	22					
	13	21	15	330	330	440	1 delamination at bottom of patch. All cracks are in the delamination.
	19	21	50				1 delamination. Patch has 3 – 5 mm diameter, surface connected voids.

3.3 COMPRESSIVE STRENGTH

Table 3.3 shows the measured compressive strengths of the patching materials. All patches surpassed the minimum ODOT specification of 20.7 MPa (3000 psi).

Table 3.3: Twenty-eight day compressive strength measurements (Values are in MPa (psi))

Material	Test 1	Test 2	Test 3	Average
Emaco S88 CI	70.9 (10,300)	77.9 (11,300)		74.4 (10,800)
ThoRoc SP20 Spray Mortar	53.4 (7740)	48.1 (6970)	55.2 (8000)	52.2 (7570)
Sonocrete Sonopatch 100 without polymer	29.6 (4290)	28.1 (4070)	35.0 (5080)	30.9 (4480)
ThoRoc All-Crete 20	32.7 (4750)	37.3 (5420)	37.1 (5370)	35.7 (5180)
Re-Crete 20	41.1 (5960)	44.3 (6430)	46.0 (6670)	43.8 (6350)
Polyfast LPL	34.7 (5030)	48.6 (7050)	57.3 (8310)	46.9 (6800)
SikaTop 123 Plus	40.3 (5840)	48.1 (6980)	41.3 (5990)	43.2 (6270)
Eucopatch	29.5 (4280)	31.1 (4510)	31.3 (4530)	30.6 (4440)

3.4 BOND STRENGTH

Table 3.4 shows the measured bond strengths of the patching materials. Most failures occurred at the interface between the patch and base concrete. However, several tests failed in the base concrete, partially in the base concrete, or in the epoxy. Any test that failed fully or partially in the concrete or in the epoxy and was less than the ODOT specification of 0.689 MPa (100 psi) was not considered a valid bond test. Invalid tests were not used to calculate the average or evaluate the patching material.

Table 3.4: Bond strengths for each material/thickness combination (Values are in MPa (psi))

Material	Nominal Patch Thickness (mm)			Average
	6	13	19	
Emaco S88 CI	0.924 (134)[5]	1.81 (262)[3]	1.32 (191)[1]	1.36 (198)
ThoRoc SP20 Spray Mortar	1.46 (212)	1.17 (170)	1.22 (177)	1.28 (186)
Sonocrete Sonopatch 100 without polymer	1.32 (191)	0.49 (71)[2]	0.54 (78)	0.780 (113)
ThoRoc All-Crete 20	0.44 (64)[1]	0.731 (106)	0.924 (134)	0.827 (120)
Rapid Set Non-Shrink Grout	0.924 (134)		0.54 (78)	0.732 (106)
Re-Crete 20		1.32 (191)[2]	1.12 (163)	1.22 (177)
Polyfast LPL	2.29 (332)[1]	1.46 (212)[2]	1.12 (163)[2]	1.30 (188)
SikaTop 123 Plus	1.63 (237)	0.923 (134)[4]	1.22 (177)[3]	1.26 (183)
Eucopatch	1.46 (212)	0.61 (88)	---[6]	1.03 (150)

[1]Failed in epoxy.
[2]Approximately 25% of the fracture surface was in the base concrete.
[3]Approximately 50% of the fracture surface was in the base concrete.
[4]Approximately 75% of the fracture surface was in the base concrete.
[5]100% of the fracture surface was in the base concrete.
[6]Test sample broke at interface while sawing two out of two attempts.

3.5 LENGTH CHANGE

The change in length over time for the patching materials is reported in Appendix B and plotted in Figure 3.1. After an initial expansion, all materials except Polyfast LPL exhibited net shrinkage.

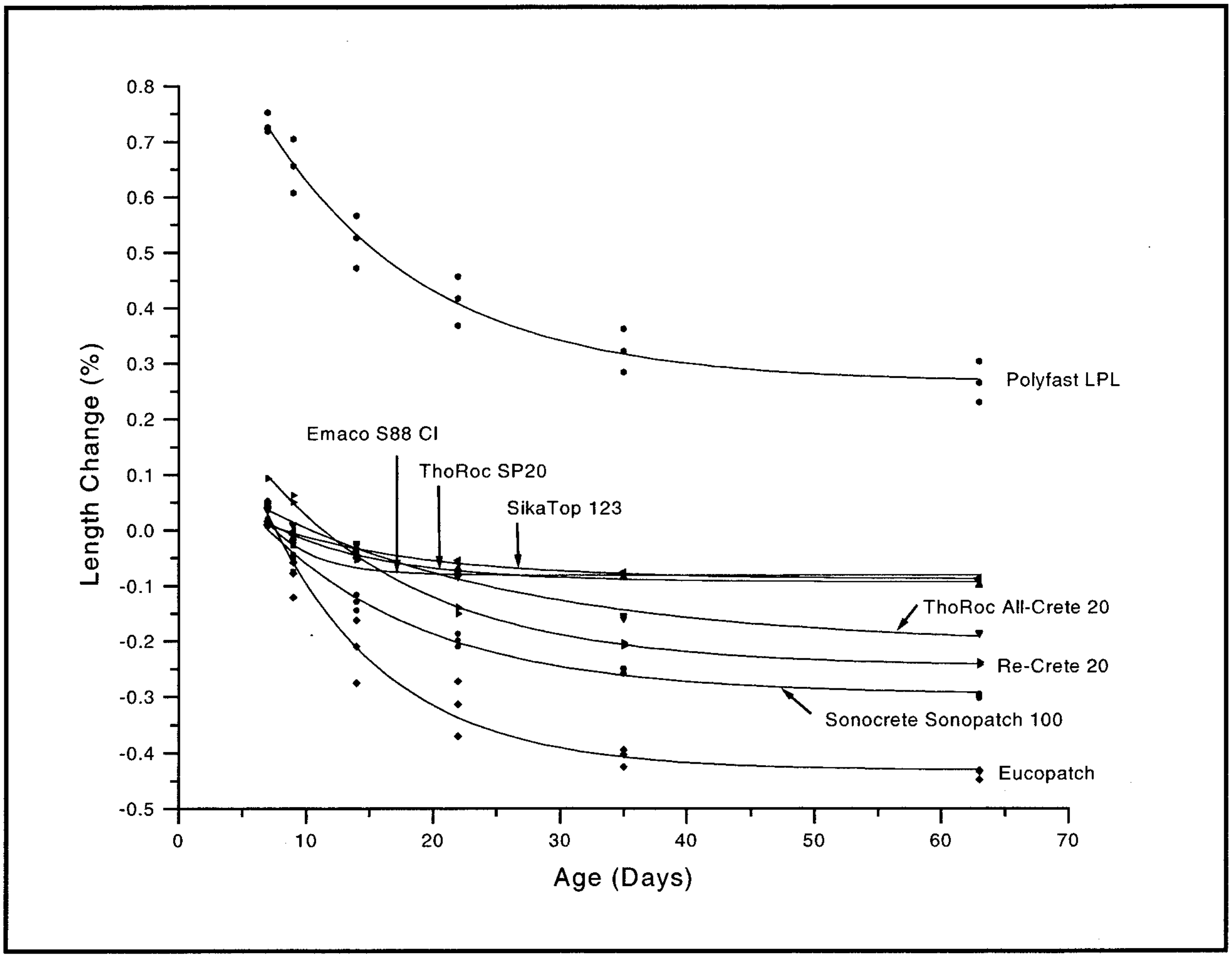

Figure 3.1: Change in length over time

3.6 RESISTIVITY

Resistivity measurements as a function of age are reported in Appendix C and plotted in Figure 3.2. The first set of measurements was made after 24 hours of conditioning at 95% RH according to the procedure given in Appendix A. The resistivity cylinders remained in the humidity chamber for subsequent measurements. All of the materials had resistivity greater than 20,000 ohm-cm after 24 hours, which would disqualify all of the materials according to the ODOT test procedure in Appendix A. By extending the time to 9 weeks to allow the resistivity to stabilize, 4 of 8 materials exhibited resistivity within the ODOT specification of 2,000 to 20,000 ohm-cm. The resistivity of Sonocrete Sonopatch 100 was still decreasing after 9 weeks. For this report, resistivity at 9 weeks was used to evaluate the materials.

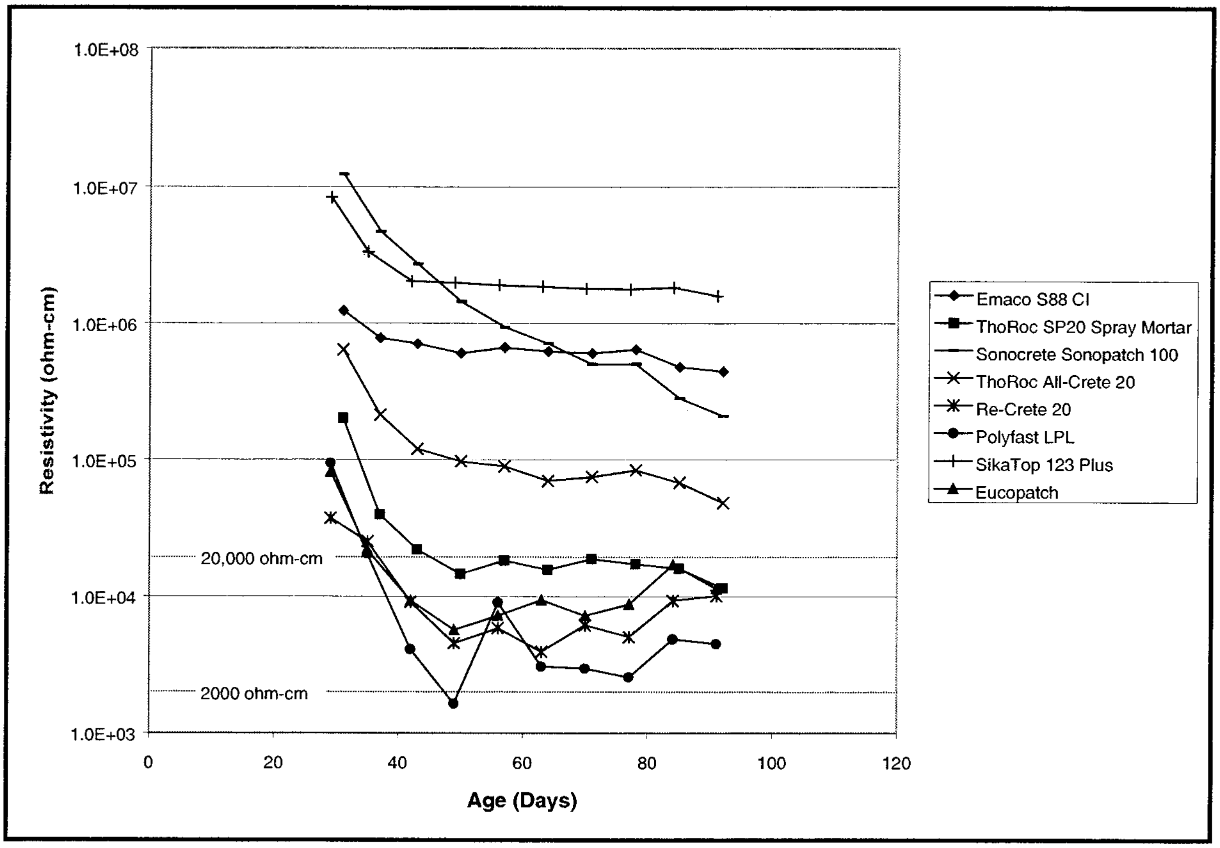

Figure 3.2: Change in resistivity over time

Table 3.5 compares resistivity data generated by J.E. Bennett Consultants, Inc. (JEB) with measurements from this report for three of the patching materials (*Bennett 2000*). The test specimens from the JEB work were cast into resistivity cells and placed in 80% RH for 1 week. After 1 week, the specimens labeled as "Outside" were placed outdoors in northeast Ohio. The specimens labeled as "80% RH" remained in the humidity chamber. There was no conditioning. Considering the variability inherent in resistivity measurements, the values in Table 3.5 show good agreement. In addition, there was agreement whether the values were within the 2,000 to 20,000 ohm-cm range or not.

Table 3.5: Comparison of resistivity data generated by J.E. Bennett Consultants, Inc. and ODOT (Values are in ohm-cm)

Material	27 – 30 Days			62– 63 Days		
	JEB[1]		ODOT[2]	JEB[1]		ODOT[2]
	Outside	80%RH	95%RH	Outside	80% RH	95% RH
Re-Crete 20	9,000	8,500	5,900	14,000	12,000	10,000
Polyfast LPL	13,000	11,000	9,000	20,000	15,000	4,500
Eucopatch	3,300	3,100	7,200	4,000	4,600	11,000

[1]The time in days for the JEB data is age after casting
[2]The time for ODOT is days after conditioning

The Polyfast LPL resistivity cylinder showed severe cracking while in the humidity chamber as shown in Figure 3.3. No cracking was observed in Polyfast LPL specimens for the other tests conducted in this study, and the resistivity cylinders for the other patching materials did not crack. The cause of the cracking was not investigated, and the manufacturer had no conclusive explanation.

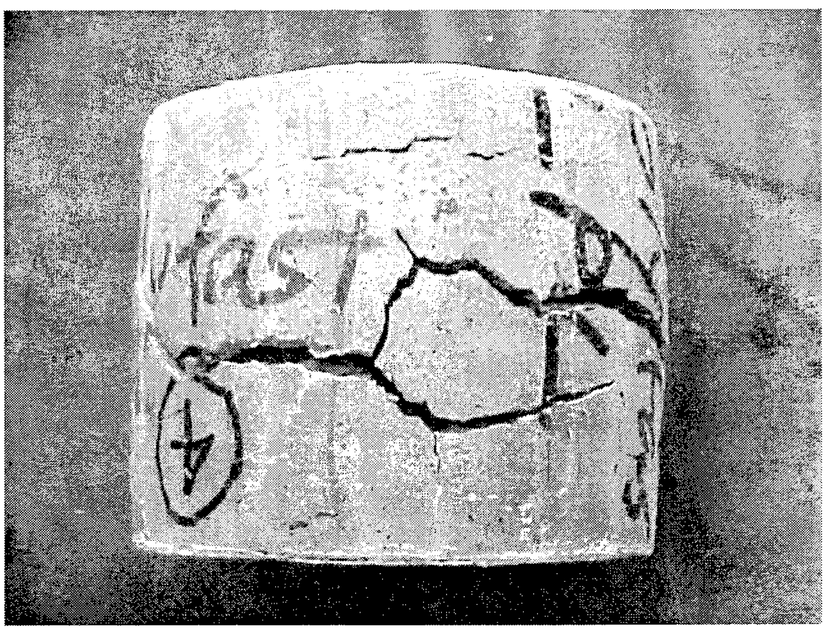

Figure 3.3: The Polyfast LPL resistivity cylinder after 9 weeks in the humidity chamber

4.0 DISCUSSION

Table 4.1 summarizes the sufficiency of each material for the evaluations conducted in this study. For each material and sufficiency category, an X is placed in the cell if the material was sufficient for that particular evaluation. An X for the delamination and shrinkage cracking categories means no delamination and shrinkage cracking respectively were detected in any of the patches for that particular material. For compressive strength and bond strength, all valid test results had to be greater than the minimum ODOT specifications for a material to receive an X. Resistivity at the end of 9 weeks in the humidity chamber had to be between 2,000 and 20,000 ohm-cm per, the resistivity range specified by ODOT.

Table 4.1: Sufficiency matrix

Material	No Delamination	No Shrinkage Cracking	Adequate Compressive Strength	Adequate Bond Strength	Adequate Resistivity
Emaco S88 CI	X	X	X	X	
ThoRoc SP20 Spray Mortar	X	X	X	X	X
Sonocrete Sonopatch 100 without polymer			X		
ThoRoc All-Crete 20	X	X	X	X	
Re-Crete 20	X	X	X	X	X
Polyfast LPL	X	X	X	X	X
SikaTop 123 Plus	X	X	X	X	
Eucopatch			X		X

Two materials, Sonocrete Sonopatch 100 and Eucopatch, exhibited delamination, shrinkage cracking, and inadequate bond strength. Further experience in mixing and applying these materials may have improved their performance. Also, one would expect to have higher and more consistent bond strengths with these materials and others if the base concrete were prepared with a profile deeper than 3 mm (0.1 in). The Sonocrete Sonopatch 100 may have better performance if it were made with the liquid latex instead of water. The manufacturer thought water would provide a patch with lower resistivity, but even with the water, the resistivity of the material was greater than 20,000 ohm-cm.

Sonocrete Sonopatch 100 and Eucopatch exhibited more shrinkage in the length change tests than the other materials. This result corresponds to the shrinkage cracking observed in these two materials. However, free shrinkage tests are not necessarily a good measure of a repair material's susceptibility to shrinkage cracking. An actual repair is constrained, while the prisms in a free shrinkage test are not. Other properties such as the tensile strength, creep properties, and elastic modulus are also important in the extent of shrinkage cracking that may occur.

Various restrained shrinkage tests may provide more insight into shrinkage cracking behavior (*Emmons 2000*).

No attempt was made to evaluate the resistance of the patching materials to weathering, chemical attack, abrasion, or freeze-thaw. Also, the evaluation was conducted under static conditions. Patches placed on the superstructure of a bridge would likely be exposed to cyclic stresses during setting and curing due to traffic on the bridge. The cyclic loading could affect the performance of the patches.

5.0 CONCLUSIONS AND RECOMMENDATIONS

ThoRoc SP20 Spray Mortar, Re-Crete 20, and Polyfast LPL met the requirements for no delamination, no shrinkage cracking, adequate compressive strength, adequate bond strength, and adequate resistivity. These three materials should be used for patches up to 19 mm (0.75 in) thick on actual structures. Surface preparation, mixing, application, and curing procedures should be documented for each patch, and the patches should be evaluated according to field procedures. In light of the unexplained cracking observed in the Polyfast LPL resistivity cylinder, this material should be thoroughly monitored if used for actual patches. The materials that exhibit acceptable field performance should be placed on the Qualified Products List for patches up to 19 mm (0.75 in) thick.

The test patches made in this project will be monitored for further cracking through August 2001. An addendum will be made to this report if any patches show signs of cracking that previously had not cracked.

6.0 REFERENCES

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APPENDIX A

CONCRETE RESISTIVITY TEST PROCEDURE

Test Specimens

Samples may be cores from test slabs or cast cylinders. Care should be taken to ensure the cylinders receive the same treatment as the structure. Any deviations from this treatment must be noted and submitted with the test cylinder. Transport the samples to the laboratory in sealed plastic bags. The specimens shall be 50 to 150 millimeters thick and 100 to 105 mm in diameter.

Place a conductive layer of thermal sprayed metal or HYDROGEL covering each end of the cylinders. These terminal plates will remain in place during the entire procedure.

Apparatus

Drying oven capable of 100°C

Ohmmeter with a range of 100 to 100,000 ohms.

Two test leads to connect the ohmmeter to two terminal plates.

Scale capable of measuring increments of 0.1% of the cylinder weight. One gram increments are acceptable for a 1000 gram specimen. A 1500 mm by 1500 mm (6 inch) cylinder of cement will weigh around 6000 grams.

Humidity chamber capable of 95% humidity at room temperature (25°C).

Conditioning

Dry the cylinders following ASTM C642-90-5.1 Heat to 100 °C (212 °F) for a minimum of 24 hours weighing periodically to determine when the cylinders are dry.

Procedure

1. Remove the cylinders from the oven.
2. Immediately measure and record the dry resistance, weight, date and time.
3. Place the cylinder in a humidity chamber at room temperature, 20 to 25 C°, and a minimum of 95% relative humidity.
4. After three hours, remove the specimen from the humidity chamber, blot excess water from the cylinder, and measure the weight, resistance, date and time.
5. After six hours, repeat step 4.
6. At 24 hours from the initial placement in the humidity chamber, remove the specimen and record the final measurements of weight, resistance, date and time.

Interpretation Of The Data

Resistivity of concrete can be calculated from the resistance values measured and the dimensions of the sample.

$$P=R*A/D$$

P= resistivity of the sample material
A= area of one end of the cylinder
D= depth of cover or thickness of the cylinder
R= measured resistance

The area and thickness should be in the same units, cm if the answer is desired in ohm-cm. A near saturation resistivity of 2,000 to 20,000 ohm-cm is desired for cathodic protection patch material. The characteristic curve of resistivity vs. time should be smooth (no abrupt changes)

ASTM C1202, Rapid Chloride Permeability, steps 1 through 10.5 may be used for preliminary evaluation if the initial voltage (V) and initial current (I) from the test are available. Resistivity may be calculated by using Ohms law (V=R*I) to find the initial resistance and then calculating the resistivity as above. This resistivity will correspond to the saturated resistance.

If there is no humidity chamber available substitute a soak in distilled water where the procedure requires a chamber with 95% humidity. Place the cylinder in the water soak for the required time interval.

APPENDIX B

LENGTH CHANGE MEASUREMENTS

Percent change in length compared to length after 24 hours of curing. Positive values represent expansion; negative values represent contraction.

Material	Age (Days)					
	7	9	14	22	35	63
Emaco S88 CI	0.02	-0.02	-0.05	-0.07	-0.08	-0.09
	0.02	-0.03	-0.05	-0.08	-0.08	-0.09
	0.02	-0.07	-0.05	-0.08	-0.08	-0.09
ThoRoc SP20 Spray Mortar	0.02	-0.01	-0.05	-0.07	-0.08	-0.10
	0.01	-0.02	-0.05	-0.07	-0.09	-0.10
	0.02	-0.01	-0.05	-0.07	-0.08	-0.10
Sonocrete Sonopatch 100 without polymer	0.01	-0.05	-0.14	-0.21	-0.26	-0.30
	0.01	-0.05	-0.13	-0.20	-0.25	-0.30
	0.01	-0.04	-0.12	-0.19	-0.25	-0.30
ThoRoc All-Crete 20	0.04	0.01	-0.03	-0.09	-0.16	-0.19
	0.04	0.01	-0.02	-0.08	-0.16	-0.19
	0.04	0.01	-0.03	-0.08	-0.15	-0.19
Re-Crete 20	0.09	0.06	-0.03	-0.14	-0.20	-0.24
	0.09	0.05	-0.05	-0.15	-0.21	-0.24
	0.09	0.05	-0.04	-0.14	-0.20	-0.24
Polyfast LPL	0.75	0.70	0.57	0.46	0.36	0.30
	0.73	0.66	0.53	0.42	0.32	0.26
	0.72	0.61	0.47	0.37	0.28	0.23
SikaTop 123 Plus	0.01	-0.01	-0.04	-0.06	-0.08	-0.09
	0.01	-0.01	-0.04	-0.06	-0.08	-0.09
	0.01	0.00	-0.03	-0.05	-0.08	-0.09
Eucopatch	0.05	-0.06	-0.16	-0.27	-0.40	-0.43
	0.05	-0.08	-0.21	-0.31	-0.40	-0.43
	0.04	-0.12	-0.28	-0.37	-0.43	-0.45

APPENDIX C

RESISTIVITY MEASUREMENTS

Resistivity measurements after curing. Cylinder dimensions are given for each material.

	Emaco S88 CI		ThoRoc SP20 Spray Mortar		Sonocrete Sonopatch 100		ThoRoc All-Crete 20	
	78.7 x 102.0 mm		78.1 x 102.0 mm		77.8 x 101.6 mm		80 x 101.6 mm	
Age (Days)	Resistance (ohms)	Resistivity (ohm-cm)	Resistance (ohms)	Resistivity (ohm-cm)	Resistance (ohms)	Resistivity (ohm-cm)	Resistance (ohms)	Resistivity (ohm-cm)
31	1.2E+05	1.2E+06	1.9E+04	2.0E+05	1.2E+06	1.2E+07	6.3E+04	6.4E+05
37	7.5E+04	7.8E+05	3.8E+03	4.0E+04	4.5E+05	4.7E+06	2.1E+04	2.1E+05
43	6.8E+04	7.1E+05	2.1E+03	2.2E+04	2.6E+05	2.7E+06	1.2E+04	1.2E+05
50	5.8E+04	6.0E+05	1.4E+03	1.5E+04	1.4E+05	1.4E+06	9.6E+03	9.7E+04
57	6.4E+04	6.6E+05	1.8E+03	1.8E+04	9.0E+04	9.4E+05	8.8E+03	8.9E+04
64	6.0E+04	6.2E+05	1.5E+03	1.6E+04	6.8E+04	7.1E+05	6.9E+03	7.0E+04
71	5.8E+04	6.0E+05	1.8E+03	1.9E+04	4.8E+04	5.0E+05	7.4E+03	7.5E+04
78	6.2E+04	6.4E+05	1.7E+03	1.7E+04	4.8E+04	5.0E+05	8.3E+03	8.4E+04
85	4.6E+04	4.8E+05	1.5E+03	1.6E+04	2.7E+04	2.8E+05	6.7E+03	6.8E+04
92	4.3E+04	4.4E+05	1.1E+03	1.2E+04	2.0E+04	2.1E+05	4.8E+03	4.9E+04

	Re-Crete 20		Polyfast LPL		SikaTop 123 Plus		Eucopatch	
	79.7 x 101.3 mm		78.5 x 101.2 mm		78.0 x 101.7 mm		77.7 x 101.2 mm	
Age (Days)	Resistance (ohms)	Resistivity (ohm-cm)	Resistance (ohms)	Resistivity (ohm-cm)	Resistance (ohms)	Resistivity (ohm-cm)	Resistance (ohms)	Resistivity (ohm-cm)
29	3.7E+03	3.7E+04	9.2E+03	9.4E+04	8.0E+05	8.3E+06	7.9E+03	8.2E+04
35	2.5E+03	2.5E+04	2.0E+03	2.0E+04	3.2E+05	3.3E+06	2.1E+03	2.2E+04
42	9.0E+02	9.1E+03	4.0E+02	4.1E+03	2.0E+05	2.0E+06	9.0E+02	9.3E+03
49	4.5E+02	4.6E+03	1.6E+02	1.6E+03	1.9E+05	2.0E+06	5.5E+02	5.7E+03
56	5.8E+02	5.9E+03	8.8E+02	9.0E+03	1.8E+05	1.9E+06	7.0E+02	7.2E+03
63	3.9E+02	3.9E+03	3.0E+02	3.1E+03	1.8E+05	1.9E+06	9.1E+02	9.4E+03
70	6.1E+02	6.2E+03	2.9E+02	3.0E+03	1.7E+05	1.8E+06	7.0E+02	7.2E+03
77	5.0E+02	5.1E+03	2.5E+02	2.6E+03	1.7E+05	1.8E+06	8.5E+02	8.8E+03
84	9.2E+02	9.3E+03	4.8E+02	4.9E+03	1.8E+05	1.8E+06	1.7E+03	1.7E+04
91	1.0E+03	1.0E+04	4.4E+02	4.5E+03	1.5E+05	1.6E+06	1.1E+03	1.1E+04