ROADWARE 10 MINUTE CONCRETE MENDER™

ASTM Testing and Evaluation

2001-2012

Since the 1990's, Roadware 10 Minute Concrete Mender™ has been tested in both laboratory and real world applications. **We believe that as good as lab based ASTM testing can be, the results are not conclusive to predict success in real world concrete repair applications. When repairing broken, distressed, and compromised concrete, the application in the field, over thousands of different concrete repair situations, is a more significant gauge of success.**

The ASTM testing data contained in this document should for comparison purposes and a base for specifying Roadware 10 Minute Concrete Mender™ in concrete repair applications.

ASTM and Product Testing Summery

Product: Roadware 10 Minute Concrete Mender™

Manufacturer: Roadware Incorporated, MN USA

Typical Properties	Value	ASTM Test
Hardness @ 72° F. (22° C)	72D	na
Compressive Strength	31 Mpa	C 881
Tensile Strength	30.8 Mpa	D 412
Elongation	6%	D 412
Bond Strength	13.6 Mpa	C882-99
Viscosity	<8 cps	na
VOC	5.5 g/l	na
Surface Tension	0.026 N/m	D 971
Gel time @ 72° F (22° C)	6-7 min	na
Cure time @ 72° F (22° C)	10 min	na
Ambient temperature range for application	-30C to 43C°F	na
Solids	98%	na

Yield

Part A	Part B	With 40-30 grit manufactured sand	Total Yield
1 liter	1 liter	4 liter	4.4 liters
1 liter	1 liter	0	2 liters

ROADWARE 10 MINUTE CONCRETE MENDER™

STANDARD PRODUCT DATA SHEET

1. Product Name

ROADWARE 10 Minute Concrete Mender™

2. Manufacturer

Roadware Incorporated

381 Bridgepoint Way

South Saint Paul, MN 55075

800-522-7623

651-457-6122

Fax 651-457-1420

e-mail sales@concretemender.com

www.concretemender.com

3. Product Description

Roadware 10 Minute Concrete Mender is a high-penetration two-part hybrid urethane that combines with sand to form a tough instant polymer concrete. This nearly water thin formula is designed to Microdowel™ deep into the host concrete creating extremely high bond strengths, reinforcement of the repair area as well as permanent repairs.

Roadware 10 Minute Concrete Mender produces polymer concrete repairs that absorb the shock and transfers the load of heavy traffic without cracking or dis-bonding. It is highly chemically resistant and can be applied in a wide range of temperatures. It is excellent for industrial floor repairs subject to forklift traffic and harsh conditions.

GENERAL USE

- Repairing hairline cracks or larger, where future movement is not anticipated.
- Repairing spalled control joints.
- Restoring integrity to distressed concrete.
- Connecting broken slabs.
- Repairing moving slabs.
- Repairing spalls and pop-outs in concrete.
- Securing bolts, equipment, or railings into concrete.
- Vertical repairs when combined with specified sand.
- Re-bonding delaminated floors
- Ramping elevated slabs
- Repairing concrete surface imperfections prior to coating.

SIZES

50 ml cartridge with mixer (80105)
300ml cartridge with mixer (80300)
2 gallon kits (7.57 liters) in two parts (80040)
10 gallon units (37.8 liters) in two parts (80050)

COLOR

10 Minute Concrete Mender is composed of an amber colored liquid and a violet colored liquid. The material is black when dispensed and cures to a gray finish. Alternate colors can be achieved by selecting different colors of manufactured sand. 10 Minute Concrete Mender will lighten in color when exposed to ultraviolet rays. This natural occurrence within urethanes will NOT affect the physical properties of the material or the repair. For colorfast repairs that are exposed to sunlight, we recommend coating the repair with paint or a standard concrete topping material.

Alternate cured colors available:

Natural or off-white

Red

Blue

Black

Brown

Custom colors available

YIELD

Roadware 10 Minute Concrete Mender™ is combined with manufactured silica sand or equivalent at the point of application. The gradation of the sand and the amount of sand used will determine yield. Listed below is the approximate yield of 1 part mixed polymer to 2 parts 30-40 grit silica sand.

Part A	Part B	With 40-30 grit manufactured sand	Total Yield
1 liter	1 liter	4 liter	4.4 liters
1 liter	1 liter	0	2 liters

LIMITATIONS

10 Minute Concrete Mender is a rigid material designed for use on interior or exterior concrete surfaces. It is not intended for repairing areas of movement such as exterior cracks and joints subject structural or ground movement. It must be applied to concrete free of surface moisture.

4. Technical Data

PHYSICAL/CHEMICAL PROPERTIES

Typical test results when tested in accordance with applicable ASTM standards and Roadware developed testing.

Typical Properties	Value	ASTM Test
Hardness @ 72° F. (22° C)	72D	na
Compressive Strength	31 Mpa	C 881
Tensile Strength	30.8 Mpa	D 412
Elongation	6%	D 412
Bond Strength	13.6 Mpa	C882-99
Viscosity	<8 cps	na
VOC	5.5 g/l	na
Surface Tension	0.026 N/m	D 971
Gel time @ 72° F (22° C)	6-7 min	na
Cure time @ 72° F (22° C)	10 min	na
Ambient temperature range for application (maximum)	-30C to 43C°F	na
Solids	98%	na

5. Installation

SURFACE PREPERATION

Preparation:

Surface Cracks (all depths and widths): Cracks should be free of dirt, oils, dust, latents and old crack repair materials. ALL SURFACES MUST BE CLEAN AND DRY. New concrete must be fully cured. A dry diamond blade attached to an electric hand grinder is recommended for preparing cracks and creating a clean surface for bonding. A wire brush or twisted wire wheel on a grinder may be used in some cases.

Surface Spalls and Deflections: Remove all loose materials back to sound concrete with a chisel or light chipper. DO NOT SQUARE CUT THE REPAIR AREA. If a square appearance is necessary, lightly score surface and remove material. Use a wire brush or twisted wire wheel to clean the repair area. All surfaces must be free of dirt, oils, dust, latents and old repair materials. For feather edge repairs in high traffic areas, score the repair edge with a dry diamond blade 10mm deep around the perimeter of the repair. New concrete must be fully cured.

Application Temperature:

Recommended application temperature is between 0° F and 100° F (-18° to 38°C). It is best to keep material at room temperature (60° to 80° F) prior to application. If manufactured sand is to be used with product, it also should be kept at room temperature. Avoid frost laden surfaces as this may adversely affect bonding and curing. 10 Minute Concrete Mender will fully cure in 10 minutes at 72° F (22° C). The temperature of the material and the temperature of the concrete surfaces will affect cure time. Warmer temperatures will decrease cure time and colder temperatures will increase cure time. In extremely cold environments, heat the concrete to remove frost before application. Successful repairs have been installed at temperatures -20°F (-29°C) and below.

MIXING

Cartridges: 10 Minute Concrete Mender is a two component material and must be thoroughly mixed at a ratio of 1 part "A" to 1 part "B" by volume. Mixing and metering of 10 Minute Concrete Mender is achieved with self-mixing cartridges provided by Roadware, Inc. Material is ejected from prepackaged cartridges through a supplied static mixing nozzle with a dual component caulking gun such as the Roadware 5300 Application Tool, Mixed material is applied directly into the repair area immediately after mixing.

Bulk: Due to the rapid setting nature of the product, pot-mixing of the components is not recommended for crack and joint repairs less than 7cm in width. 10 Minute Concrete Mender supplied in 7.5l and 34l kits may be bucket mixed in liter batches and applied immediately to the repair area. Combined 500ml of Part A with 500ml of Part B. Mix with a drill mixer or hand mixing stick for 30 seconds or until well blended. Add 2 liters of manufactured sand and mix for an additional 10 seconds. Pour the entire batch into the repair area immediately. SEE BULK MIXING INSTRUCTIONS INCLUDED WITH MATERIAL. 10 Minute Concrete Mender may be dispensed through a one-to-one ratio pump specifically designed to handle extremely low viscosity materials while maintaining exact ratios. The system must not allow the two components to combine until they reach the point of delivery. Contact Roadware for information on acceptable pumping equipment. All pumping equipment must be approved by Roadware, Inc. prior to application

APPLICATION

Surface Cracks (all depths and widths): Assemble cartridge according to directions. Remember to use the flow restrictor included with each cartridge set. Holding the application gun upward, place cartridge set into gun. Gently squeeze trigger to bleed-off air and start material flowing into mixers. Point mixer into waste container and squeeze trigger to start mixing process. DO NOT POINT MIXER UPWARD AFTER MATERIAL IS FLOWING. This may cause material to flow back into the tubes and cause clogging.

Pre-wet repair area with mixed Concrete Mender without sand. Fill with 30-40 grit manufactured sand and additional material to grade. Be sure to saturate all of the sand completely. Additional sand may be added to the repair as necessary. Saturated sand may be moved into place with a margin trowel or scraper. Work with one small section at a time. Do not stop flowing material for a period of more than 2 minutes. If material sets inside mixer, remove cartridge from gun and replace mixer. Fill all repair areas to grade. When material cures (turns gray) in about 10 minutes, remove excess material with a sharp scraper for a smooth and flat finish. Finished repairs may be "cleaned up" by sanding or buffing within a few hours of application.

Spalls: Pre-wet repair area with mixed Concrete Mender without sand. Fill with no more that one-inch of 30-40 grit manufactured silica sand and additional material. Add additional layers to grade if needed. Be sure to saturate all of the sand completely. Additional sand may be added to the repair as necessary. Saturated sand may be moved into place with a small squeegee or scraper. Work with one small section at a time. Do not stop flowing material for a period of more than 2 minutes. If material sets inside mixer, remove cartridge from gun and replace mixer. A trowel or scraper may be used to move saturated sand into place and to create a level surface. If required, surface friction may be maintained by adding additional manufactured to the surface as the material cures. Allow to cure (approximately 10 minutes). Finished repairs may be "cleaned up" by sanding or buffing within a few hours of application.

6. Availability

Roadware 10 Minute Concrete Mender is available from authorized Roadware distributors and dealers throughout the United States. Contact Roadware Incorporated for the nearest distributor or dealer.

7. Warranty

Roadware Inc. will warrant each Roadware Concrete Repair or Protective Coating Product against defects in material and workmanship for a period not to exceed one year from the shelf-life of each unopened drum or case of product. Roadware's sole warranty is that Roadware Products will meet current sales specifications. Every reasonable precaution is taken in the manufacture of all Roadware products and compilation of data that they shall comply with the manufacturer's exacting standards. As however, the effectiveness of each product depends on the applicators judgment of a proper condition, and since conditions and methods of use are beyond the manufacturer's control, no application warranty of any type is made, expressed or implied whether used in accordance with directions or not. Roadware shall not be held liable for repairs or portions thereof that are necessitated by damage which has resulted from structural failures, settling, shifting, distortions, splitting or cracking of the substrate. The forgoing warranties are in lieu of all other warranties expressed or implied including the implied warranty of merchantability and fitness or application for a particular use. Roadware Inc., shall in no event be liable for incidental, consequential of other, direct or indirect damages.

8. Maintenance

None Required

9. Technical Services

Roadware maintains trained distributors and factory representatives on a national level. Contact a local distributor for technical assistance or call Roadware Incorporated for direct factory technical assistance. 800-522-7623

10. Filing Systems

Additional product information is available from Roadware Incorporated and from Roadware's web site at www.concretemender.com.

Roadware 10-Minute *Concrete Mender*:

Evaluation of Bond Strength

Prof. David A. Lange, Ph.D., P.E., FACI

Department of Civil Engineering

University of Illinois at Urbana-Champaign

December 20, 2001

Introduction:

The bond strength of *Concrete Mender* was evaluated using procedures of ASTM C882 -99 "Standard Test Method for Bond Strength of Epoxy-Resin Systems Used With Concrete by Slant Shear." This report describes the procedures and results of the test.

Test Procedures and Results:

ASTM C882-99 provides procedures by which the bond strength of epoxy-resin systems are measured. The bond strength is determined by using the epoxy-resin system--or in this case, Concrete Mender--to bond together two equal sections of a 3 by 6-in. portland cement mortar cylinder, each section of which has a diagonally cast bonding area at a 30° angle from vertical. After suitable curing of the bonding system, the test is performed by determining the compressive load required to fail the composite cylinder.

Plain 3 by 6 in. mortar cylinders were cast for use as substrates. The mortar mix design (SSD) was 10 lb Type I portland cement, 30 lb river sand, and 4.8 lb water. After two days of curing, the cylinders to be used as substrates were sawn at a 30° angle from vertical into two equal sections. At 14 days, the surfaces of the sawn sections were sandblasted to achieve greater surface texture. Four extra cylinders were cast to be tested in compression to determine the strength of the mortar. All of the cylinders and sections were cured at 100% RH for 14 days and allowed to air dry for 14 additional days. The 28-day strength of the mortar determined as an average strength of the four whole cylinders was 6400 psi, well in excess of the 4500 psi required by ASTM C882-99 for the substrate material.

The composite cylinders were fabricated by bonding two matched cylinder sections together. The procedure for Cylinders #1 and #4 was generally in accordance with ASTM C882-99 Section 10.3.2 which is intended to be used for low viscosity bonding systems. In brief, the two cylinder halves were primed with neat *Concrete Mender*, positioned with a gap of approximately 0.02 in., wrapped with a self-adhesive aluminum foil except for a single opening, and then Concrete Mender was poured into the exposed joint opening until completely filled. The procedure for Cylinder #6 was generally in accordance with ASTM C882-99 Section 10.3.3 which is intended to be used for mortar bonding systems. In brief, the two cylinder halves were primed with neat *Concrete Mender*, a mortar of Concrete Mender and quartz sand was troweled onto one surface, the second cylinder half was then placed onto the mortar bed, and the cylinder was squeezed together by hand to form a bonded composite cylinder. All of the composite cylinders were cured for four days before testing.

Cylinders #1, 4, and 6 had very high bond quality with little or no trapped air. Typical photos are shown in Figures 1 and 2.The compressive loads required to fail the composite cylinders #1, 4, and 6 were 28516 lb, 29445 lb, and 26125 lb, respectively. ASTM C882-99 instructs the bond strength of the composite cylinders to be calculated by dividing the load carried by the specimen at failure by the area of the bonded surface (14.13 in.^{2}). The average bond strength of the three composite cylinders was 1984 psi.

Conclusions:

Concrete Mender has a bond strength of 1984 psi as measured in accordance with ASTM C882-99.

Fabrication of test specimens must be done with particular care to avoid entrapment of air. One method of reducing the risk of entrapped air is to use a *Concrete Mender* mortar for bonding the composite cylinders.

Figure 1. Specimen 4 with good interfacial contact.

[Split cylinder strength = 2084 psi]

Figure 2. Specimen 6 with good interfacial contact and greater mortar thickness.

September 16, 2002

Richard King

Roadware, Inc.

2100 Wentworth Ave.

South St. Paul, MN 55075

Dear Richard,

I am pleased to submit results of our measurement of surface tension of Concrete Mender conducted in accordance with our Wilhelmy Plate Method standard practice. Websites describing the Wilhelmy Plate Method for measuring surface tension include http://www.kibron.com/Science/ and http://www.tensiometry.com/ASTMethods.htm.

In our implementation of the test, we monitor the weight of a petri dish on an electronic scale as a glass slide is drawn up from a fluid in the petri dish. The weight of the petri dish is reduced by the pulling force of the glass slide on the liquid surface. The weight change is converted to surface tension by a simple equation.

The results of the tests are shown on the attached page. The surface tension of plain water, Concrete Mender Part A (lighter in color) and Part B (darker in color) are reported. Surface tension is reported in units of force/length (e.g. N/m). A summary of the surface tension of Concrete Mender and other reference fluids is shown below:

Fluid	Surface Tension (N/m)
water at 20°C	0.0729
ethanol	0.0223
benzene	0.0289
glycerin	0.0634
CONCRETE MENDER PART A	0.026
CONCRETE MENDER PART B	0.025
CONCRETE MENDER 30-40 s after mixing	0.026

Concrete Mender Parts A and B separately and Parts A/B together soon after mixing exhibit surface tension similar to ethanol or benzene. The results also confirm that the Concrete Mender readily wets the concrete surfaces (i.e. the contact angle is 0°). These findings, along with the previously measured viscosity measurements of about 10 cPs, describe a fluid that has favorable wetting, sufficiently low viscosity, and sufficiently high surface tension to be readily drawn into the cracks and pore structure of concrete by capillary action in the first minute after contact. These physical properties of Concrete Mender are consistent with the observed penetration of Concrete Mender into concrete substrates, and are an important element of the ability of Concrete Mender to achieve superior bond with concrete repair surfaces.

Sincerely,

Prof. David A. Lange

Attachment: a) Lab data

b) Invoice

ROADWARE 10 MINUTE CONCRETE MENDER
SURFACE TENSION TEST RESULTS

plate no		**wide (mm)**	**thickness (mm)**	**perimeter P (mm)**
1	*dark*	25.21	0.99	52.40
2	*light*	25.24	1.02	52.52
3	*mixed*	25.25	1.01	52.52

$\sigma = (F*g*\cos\theta)/P$
g =9.807 m/s^2
temperature of water = 20^0C
surface tension of water is 0.072-0.073 N/m

	Force 1 (kg)	**Force 2 (kg)**	**Force 3 (kg)**	**Ave. Force (kg)**	**P (mm)**	**σ (N/m)**
water	0.3901			0.3901	52.40	0.073
dark	0.1311	0.1318	0.1320	0.1316	52.40	0.025
water	0.3857	0.3872	0.3852	0.3860	52.52	0.072
light	0.1367	0.1368	0.1364	0.1366	52.52	0.026
water	0.3871			0.3871	52.52	0.072
mixed	0.1390			0.1390	52.52	0.026

Roadware 10-Minute *Concrete Mender*:

Microstructure and Properties

Prof. David A. Lange

Department of Civil Engineering

University of Illinois at Urbana-Champaign

June 19, 2000

Introduction:

Concrete Mender is a 2-part polymeric repair material used for repair of spalled or cracked concrete pavements and structures. The microstructure of bond, the rheology of the fluid material, the shrinkage of the material during the first week, and the elastic modulus of the cured material are key aspects of *Concrete Mender*'s successful field performance. The purpose of this study is to provide insight into the fundamental material-level behavior of *Concrete Mender*.

This study addresses several aspects of the material behavior of *Concrete Mender* that are essential elements of its superior field performance. Bond of repair materials is one of the most important issues in achieving long term performance in repair of concrete. It is well known that repair materials achieve their primary bond through mechanical interlock with the microstructure of the substrate. It is important that a repair material can penetrate and mechanically engage with the pore structure of the concrete. This study used scanning electron microscopy to investigate the interface between *Concrete Mender* and the concrete substrate.

A second issue is ease of application. A repair material must have attractive workability and flow in order to successfully consolidate against the concrete substrate. The ease of application in the case of *Concrete Mender* is largely a function of its viscosity. Rapid set is another aspect of application, and this is observed through a rapid increase in viscosity. This study measured the viscosity of *Concrete Mender* as a function of time to provide an understanding of how the fluid *Concrete Mender* interacts with the substrate within the first few minutes of contact.

Shrinkage of repair materials should be minimized so that high stresses do not form to debond the interface with the concrete substrate. The potential for shrinkage stresses are commonly evaluated by free shrinkage tests, although in practice it is important to realize that creep relaxation is an important mechanism for reducing the level of stress in the repair. The free shrinkage of *Concrete Mender* during the first week was measured.

Last, it is important to understand the stiffness of the repair material. Polymeric repair materials usually have a Modulus of Elasticity that is lower than that of the concrete substrate. This generally has a positive influence on durability because it means that the repair is relatively flexible and resistant to brittle fracture and debonding. A low Modulus of Elasticity also implies that the repair will not highly restrain the substrate and thus create local regions of high stress.

Experiments and Results:

Four experiments were conducted in this study. These experiments and results are discussed in the following sections.

A. **Microscopy**

Scanning electron microscopy was used to investigate the interface between *Concrete Mender* and a concrete substrate. The original concrete beam specimen was a normal portland cement concrete with a water:cement ratio of 0.44. The 28-day compressive strength was estimated to be 5500 psi. The mix design of the concrete was:

Constituent	Weight (lb)
Cement	643
Water	282
Coarse aggregate	1836
Fine aggregate	1080
Superplasticizer	702 ml
w/c ratio	0.44

The concrete beam was fractured and the two fracture surfaces were aligned with a 1/8" gap between. *Concrete Mender* was used to fill the 1/8" gap between the two faces of the fracture, using the manufacturer's instructions. Sand provided by Roadware was used to fill the repair.

After the *Concrete Mender* was fully cured, the specimen was sawed to isolate small samples of interface between the *Concrete Mender* and concrete. The small samples (approximately 10 x 10 x 10 mm) were potted, ground, and polished for investigation by electron microscopy. The samples were positioned so that all observations were nominally perpendicular to the original fracture surface. About 30 micrographs were acquired from four different samples and saved in high-resolution digital TIFF files.

The micrographs revealed a well-bonded interface and significant penetration of the *Concrete Mender* into the fine pore structure of the cement paste. Figure 1 shows the interface between the *Concrete Mender* (with sand aggregate) on the top half of the image and the concrete substrate on the lower half of the image from Sample 4. The interface between *Concrete Mender* and concrete is an intimate bond, and it is clear that the *Concrete Mender* has penetrated into the cement paste. Annotations on Figure 1 indicate the depth of penetration to be about 1 mm. The region of penetration is identifiable by observation of the texture of the surface. The impregnated region has a smoother, filled-in appearance, and the urethane provides integrity to the microstructure during polishing. Regions without urethane impregnation have a more abraded, rougher texture with more plucked-out grains due to the grinding/polishing process.

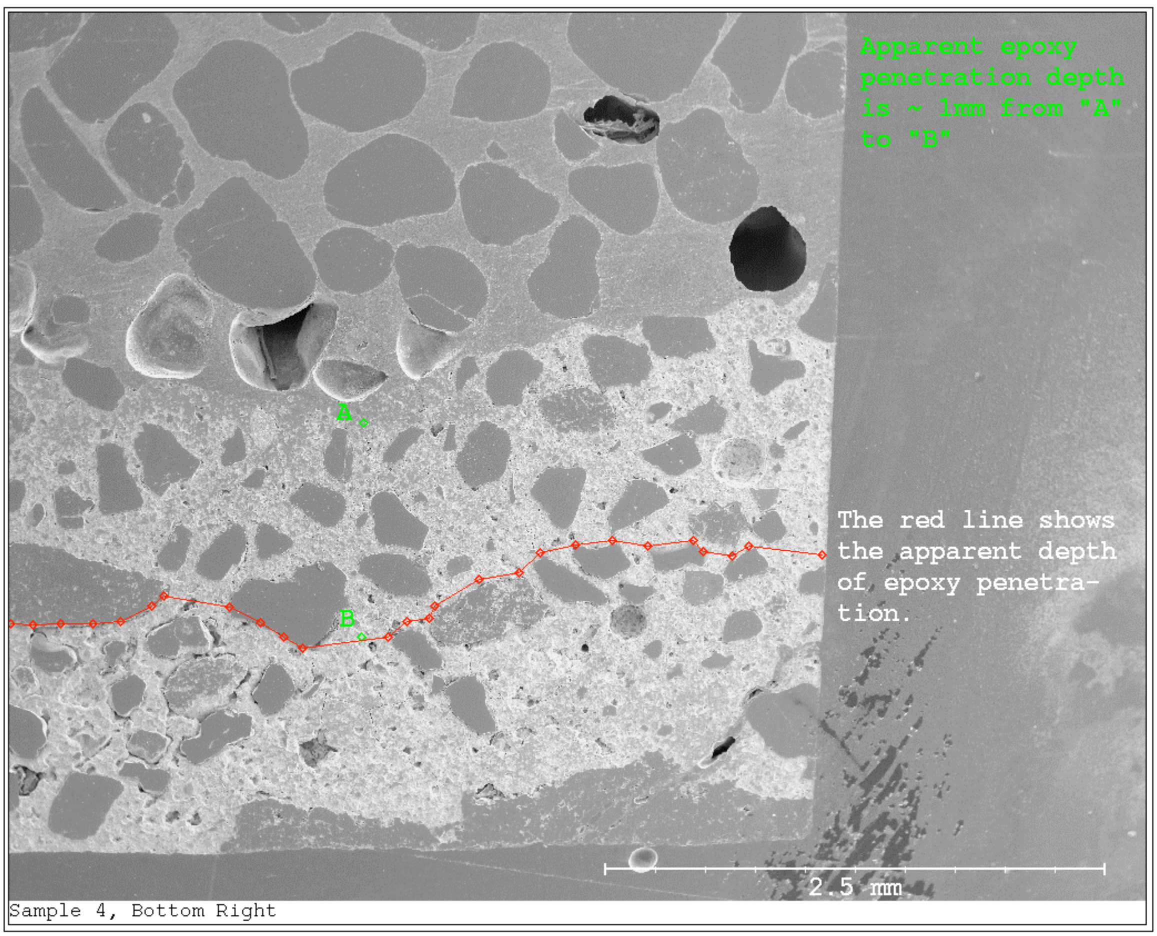


Figure 1

Figure 2 is an image of the interface of Sample 1 indicating that *Concrete Mender* fully penetrated small fissures near the interface. Figure 3 is another image from Sample 4, also annotated to indicate penetration of the *Concrete Mender*.

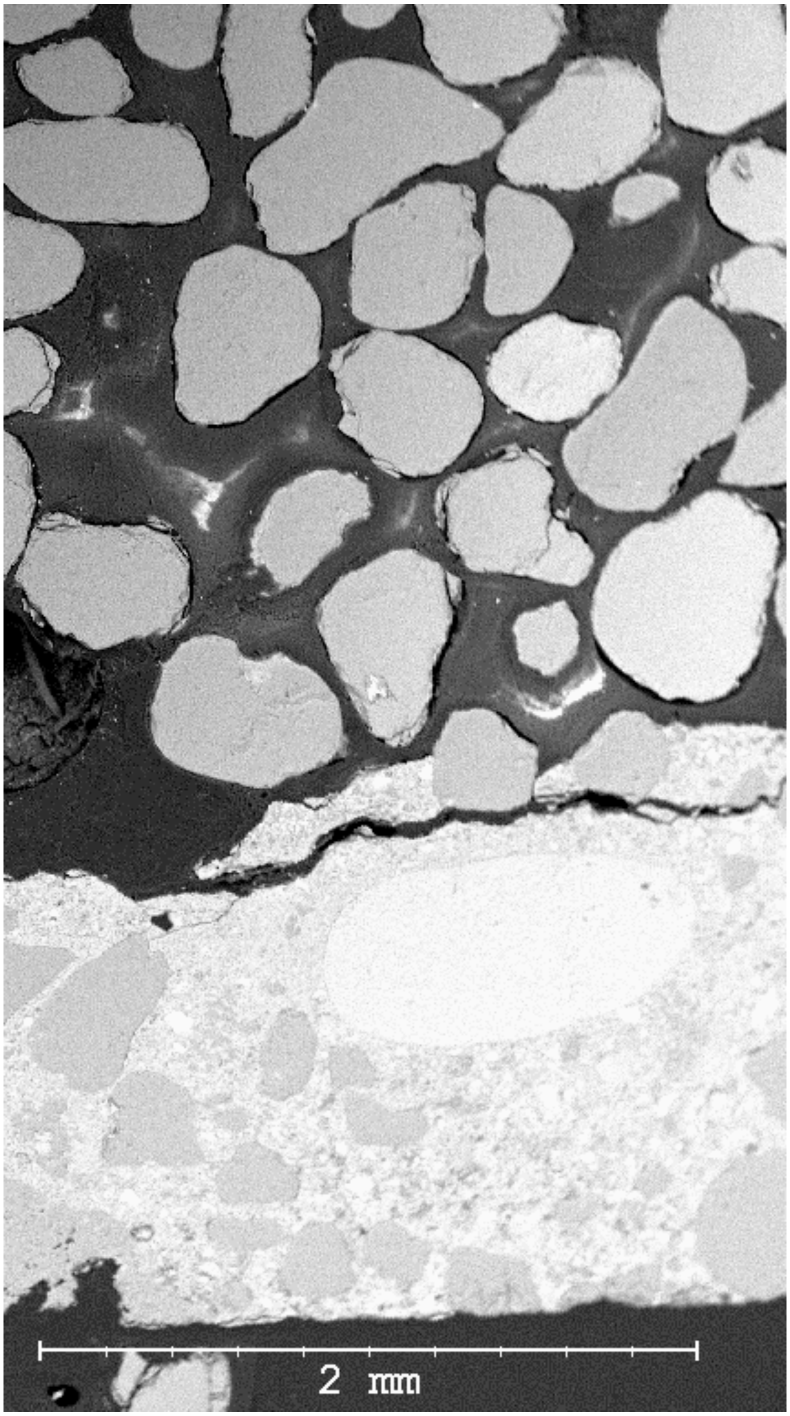


Figure 2

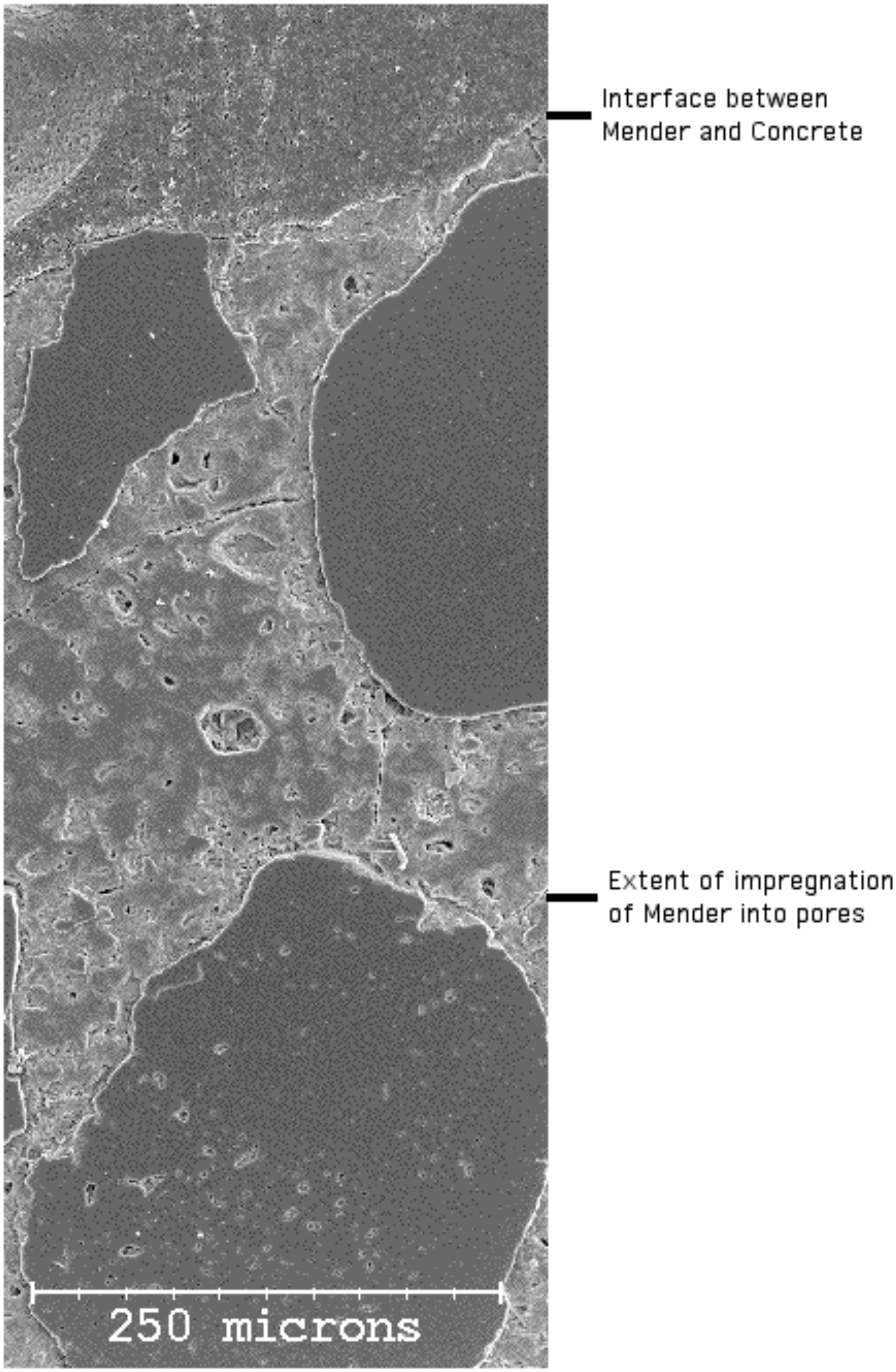
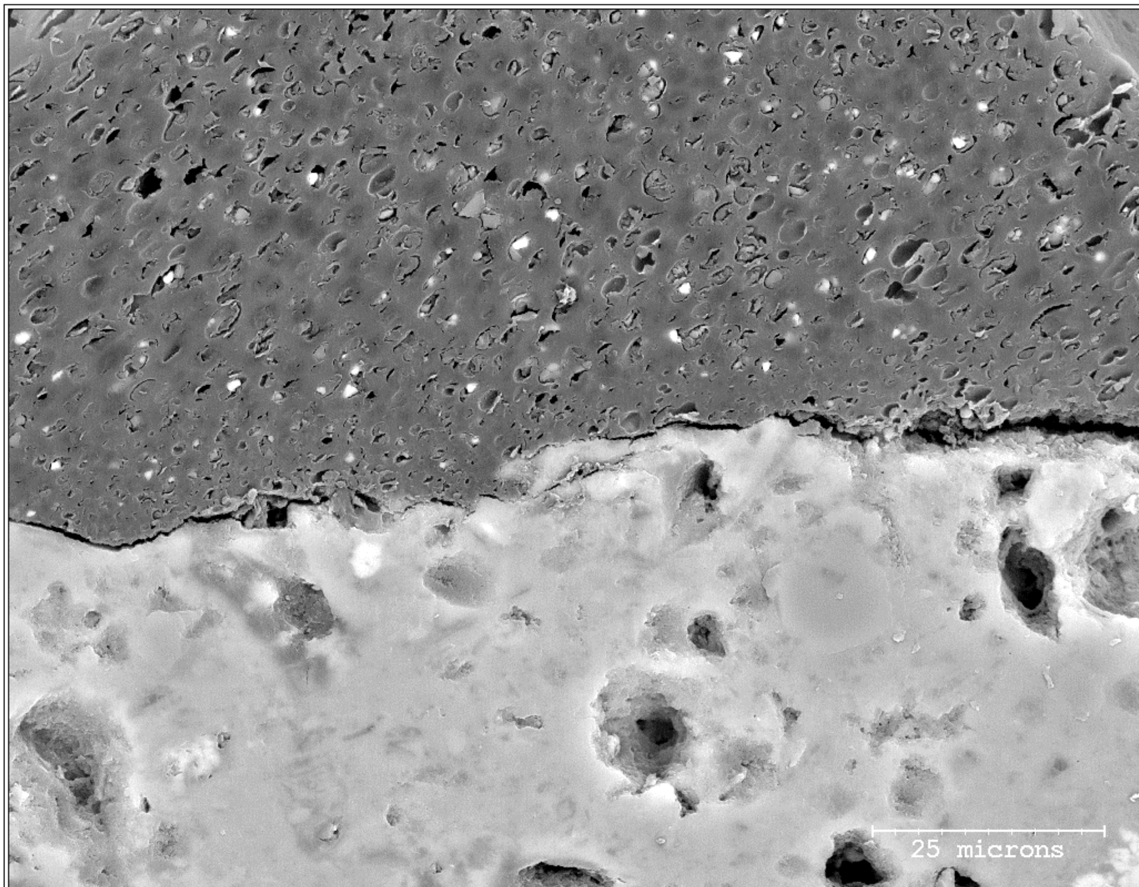

Interface between
Mender and Concrete
Extent of impregnation
of Mender into pores
250 microns

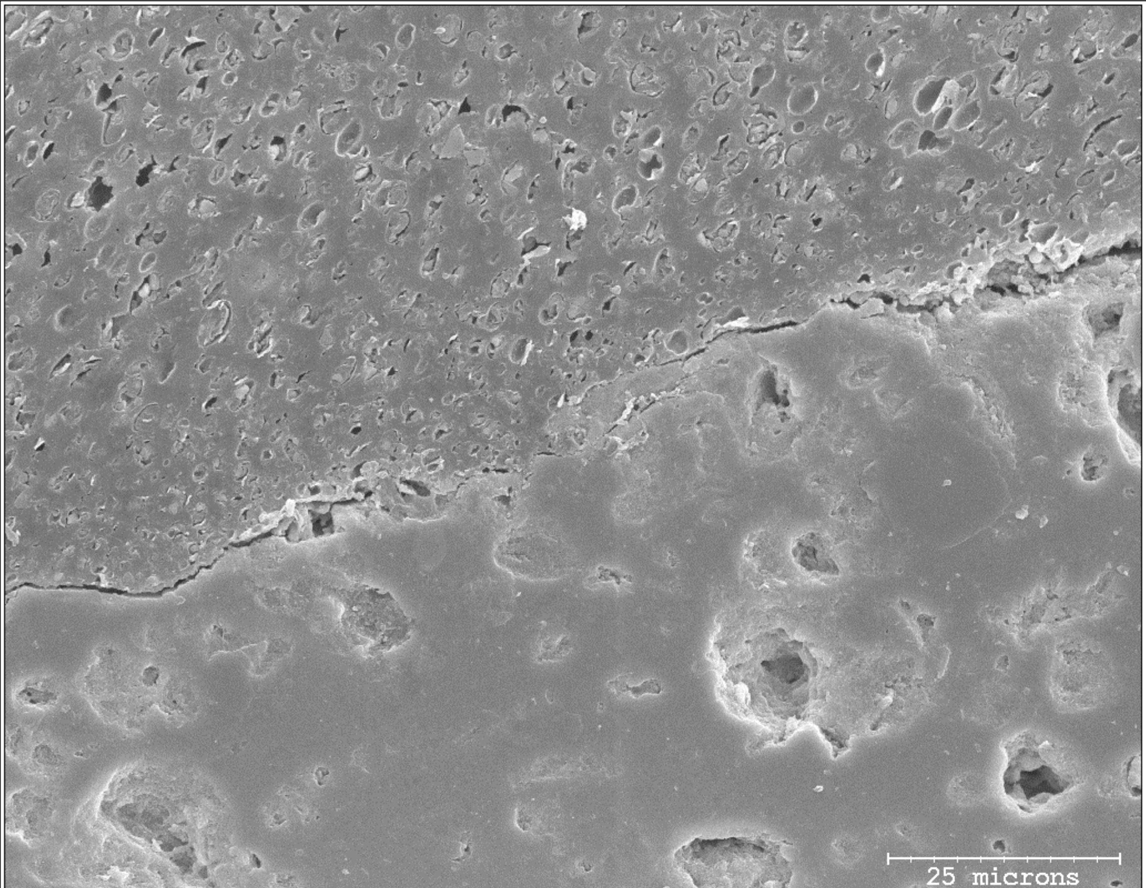
Figure 3

Figures 4 and 5 are high magnification images (1000X) taken from Sample 4. Both figures show the same region of the sample, but Figure 4 is a back-scattered electron (BSE) image and Figure 5 is a secondary electron (SE) image. In the BSE image, the grey tones reflect the relative atomic weight of the materials. The urethane, principally a hydrocarbon, is relatively dark material compared to the concrete material, which is dominated by compounds with calcium and silica. The light-toned specks in the *Concrete Mender* are likely to be super-fine aggregates introduced during the fabrication of the specimen. A network of fine, non-connected porosity characterizes the Concrete Mender. These small pores—less than 5 micron in diameter—may be small bubbles that persist from the mixing process or are created during curing of the urethane. The dense, smooth texture of the concrete substrate again indicates the presence of urethane in the cement paste pore structure. Some larger voids seen in the concrete substrate may from plucked-out grains or voids that were not filled with the urethane. It is reasonable that some larger voids are not filled when the urethane is drawn into the pore structure by capillary forces. Principles of physics tell us that smaller capillary pores exert greater capillary force and larger voids exert less capillary force. Thus, it is not unusual to observe large open voids within regions that exhibit general penetration of the finer pore structure. In other words, the urethane feels a greater pull from the fine pores of the cement paste (1 μm or smaller) than from larger (25 μm or bigger) air voids in the cement paste.



Sample 4, Interface, 1000x, bse

Figure 4



Sample 4, Interface, 1000x

Figure 5

B. **Rheology**

A Brookfield Viscometer was used to measure the viscosity of *Concrete Mender* as a function of time. The rotary viscometer was used with two cylindrical spindles with differing diameter. The larger LV-1 spindle at 60 RPM was used to measure the viscosity range of 0-50 cP, and the smaller LV-4 spindle at 60 RPM was used to measure the viscosity range of 50-5000 cP. Data from two test runs—one with the small spindle and one with the large spindle— were merged to give the results presented here.

The *Concrete Mender* was mixed using the standard applicator and placed into a glass beaker. The first reading of the viscosity of the mixed *Concrete Mender* was at 30 seconds after ejection from the applicator.

Figure 6 illustrates the viscosity vs. time relationship. In the first two minutes, the *Concrete Mender* has a low viscosity of about 10 cP. The lowest viscosity measured was 8.6 cP. After about three minutes, the polymerization process begins to accelerate, and the viscosity of the urethane mixture rises sharply.

Viscosity is related to the ease with which individual molecules of the liquid can move with respect to each other. It depends on the attractive forces between molecules, and on whether there are structural features that cause the molecules to become entangled. As the urethane mixture polymerizes, the chain molecules become longer, and have greater entanglement. Ultimately, the urethane properties evolve to that of a solid material that exhibits structural integrity and elastic solid behavior. *Concrete Mender* achieves solid-like behavior in about 10 minutes. The relationship of viscosity with time is one way of understanding the evolution of *Concrete Mender* from a liquid to a solid. As a liquid with a viscosity of only 10 cP, it can wet the concrete surface and be drawn into the concrete pore structure by capillary forces. The penetration of *Concrete Mender* into the pore structure would cease after perhaps three minutes when the viscosity of the urethane mixture rises to 1000 cP. For this reason, the best results with *Concrete Mender* are achieved when applied using the manufacturer's recommended procedure which uses a "static mixing nozzle" that allows the urethane to be applied to the concrete immediately after mixing. Other procedures that allow time to elapse between mixing and application will compromise the short time window of low viscosity.

Concrete Mender easily wetted the surface of the concrete substrate. Qualitatively, this observation indicates that *Concrete Mender* has a relatively low surface tension with respect to the solid surfaces in concrete. Surface tension is the force at the surface of a liquid due to adhesive forces of the liquid molecules for the solid walls of a container and the attractive forces of the molecules of liquid for each other. When the adhesive forces of the molecules for the solid walls of the container are greater than the attractive forces between the liquid molecules, then the liquid will wet the solid surface. In the case of porous solid such as cement paste, the liquid will wet the exposed surfaces and will be drawn into the pore structure under forces known as capillary tension. The extent of penetration of a liquid into pore structure is governed by the strength of capillary tension forces and the liquid viscosity. In the case of *Concrete Mender*, this balance is favorable, and significant penetration of the urethane mixture occurs within minutes of contact.

For comparison, the viscosities of several common liquids are shown below:

Liquid	Viscosity at 25°C (centipoise, cP)
Methanol	0.55
Benzene	0.65
Water	1.0
Ethanol	1.2
Ethylene glycol	16
Glycerin	1490

C. Shrinkage

A free shrinkage test was conducted on a sample of *Concrete Mender* from about 15 minutes after mixing until 7 days of age. The sample was neat *Concrete Mender* with no added sand. The sample was a 1" x 1" x 11" prism with two metal contact points embedded at the ends. Figure 7 illustrates the length change with time.

Assuming that the coefficient of thermal expansion, C_t = 1.0 X10-4in/in/°F (a textbook value for similar urethane material), the initial hour of measurement is dominated by thermal contraction when the temperature dropped from an estimated 110°F to 75°F. Subsequent shrinkage from 1 hour to 7 days represents inherent shrinkage that characterizes these kinds of polymers during their extended curing process. *Concrete Mender* has shrinkage of only 0.1% between 1 hour and 7 days, and a low shrinkage of only 0.05% between 2 hours and 7 days. An ICRI Guideline [1] suggests that a shrinkage of 0.05% is "low" , indicating that *Concrete Mender* will tend not to generate shear stresses that cause debonding of a repair material.

Note that this test of *Concrete Mender* was performed on a neat sample with no sand added. When sand is added, the overall shrinkage of the sand-Mender mixture will be proportionately reduced. For example, a sample of *Concrete Mender* with 50 vol% sand would have about 50% of the shrinkage of the neat urethane.

D. Elastic properties

Mechanical properties of two fully cured samples of *Concrete Mender* were measured. The first sample made of neat *Concrete Mender* and the second sample was a Mender:sand blend where the sand volume fraction was 54 vol%. The sand had a specific gravity of 2.65 and Modulus of Elasticity of 94 GPa. The samples were 1.0” x 1.0” x 11.2” prisms.

The 3-point beam deflection tests were performed using an Instron test machine. Using common beam formula, the load-deflection relationship was recorded, and the initial tangent used to calculate Modulus of Elasticity. The beams were tested to fracture, and the Modulus of Rupture (i.e. flexural strength) was calculated. Both samples exhibited nearly linear load-deflection until fracture. Both samples fractured in a brittle manner. The results were:

Sample	Modulus of Elasticity, psi (MPa)	Modulus of Rupture, psi (MPa)
Neat *Concrete Mender*	137,000 (944)	3450 (23.8)
Concrete Mender with sand (54 vol% sand)	739,000 (5100)	3990 (27.5)

The Modulus of Elasticity of a two-phase composite can be estimated by a “series model” as follows:

$$\frac{1}{E_C} = \frac{V_1}{E_1} + \frac{V_2}{E_2}$$

where EC is the Modulus of Elasticity of the composite, V_1 and V_2 are the volume fractions of the two phases, and E_1 and E_2 are the moduli of the two phases. With *Concrete Mender* being one phase (V_1 = 0.46; E_1 = 0.944 GPa) and silica sand being the second phase (V_2 = 0.54; E_2 = 94 GPa), the series model predicts a composite modulus of 2.0 GPa, somewhat lower than the 5.1 GPa as measured from the test results. Since the series model is an idealized condition that assumes no bond between the phases, the observed difference between the prediction and actual modulus is related to the presence of bond between *Concrete Mender* and the silica sand grains. The main point of this analysis is simply to understand the origin of the mechanical properties, and understand how *Concrete Mender* with sand can be considerably stiffer than the neat *Concrete Mender*.

Normal strength concrete has a Modulus of Elasticity of 25-35 GPa. *Concrete Mender* with or without sand will always be much less stiff than the concrete. Therefore, when under load, the *Concrete Mender* will deform more than the adjacent concrete. One concern about the combined behavior of two materials with vastly different moduli is that shear stresses can develop and debonding can occur. However, in practice, *Concrete Mender* is used for very thin repair and crack filling. These scenarios are often accompanied by multiple load paths that would mitigate potential for general debonding of the repaired section. Since *Concrete Mender* has strength on the order of the underlying concrete, and the interaction of the fresh urethane mixture with concrete microstructure facilitates high quality bond, thin repairs with

Concrete Mender will usually exhibit high strength and stiffness. Therefore, it is generally possible to achieve a “structural” repair of cracks to restore the mechanical performance of the original concrete.

Summary

The microstructure of the interface between *Concrete Mender* and concrete substrate indicates that high quality bond is achieved. The success of *Concrete Mender* is due to the compatibility of *Concrete Mender* with concrete materials. The fresh liquid has a low viscosity and a low surface tension that allows capillary forces to draw *Concrete Mender* well into the pore structure of the concrete. In the experiments using a 5500 psi concrete, penetration of 1 mm was measured, indicating that repairs using *Concrete Mender* fully engage the underlying substrate. The shrinkage of *Concrete Mender* is low and should not pose concern for debonding or delamination due to volume changes. The Modulus of Elasticity of *Concrete Mender*, as with almost all polymeric materials, is lower than that of concrete. The strength of *Concrete Mender* is on the order of normal concretes used in construction. When used for thin repairs and filling of cracks, it is reasonable to expect that repairs with *Concrete Mender* largely restore the structural performance of the original concrete.

Reference

1. International Concrete Repair Institute (ICRI), *Guide for Selecting and Specifying Materials for Repair of Concrete Surfaces*, ICRI Technical Guideline No. 03733, January 1996.

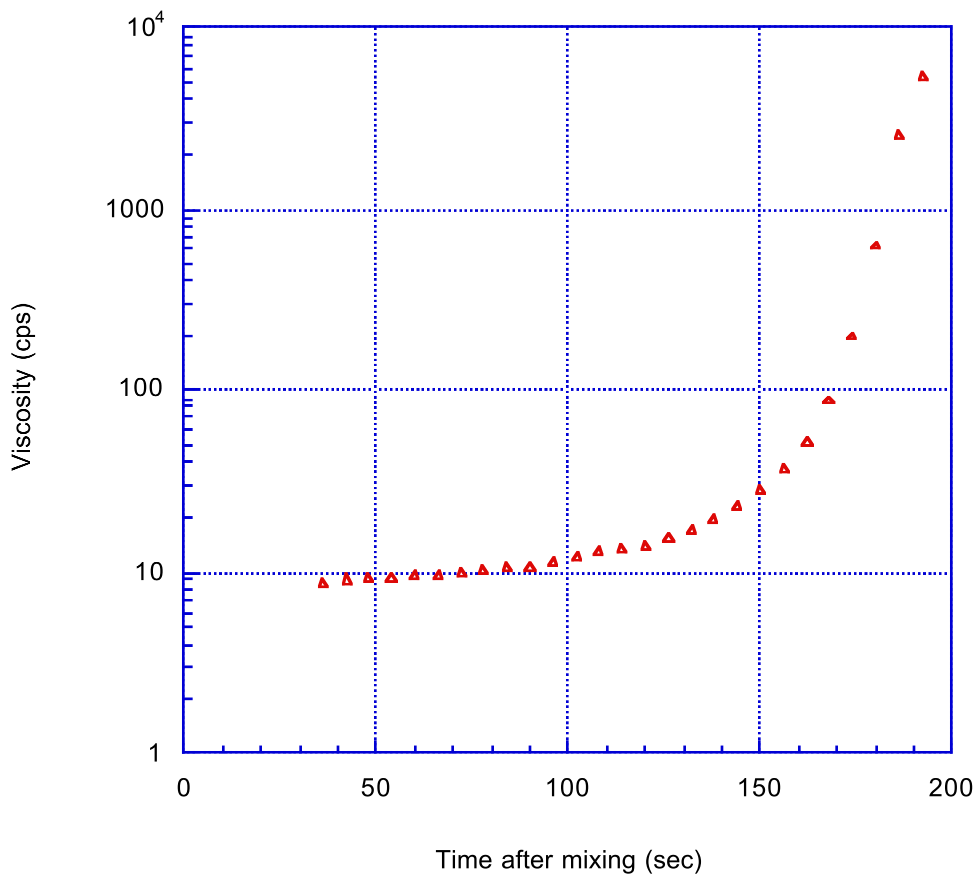


Figure 6. Viscosity of *Concrete Mender* (Time zero = time of ejection from nozzle)

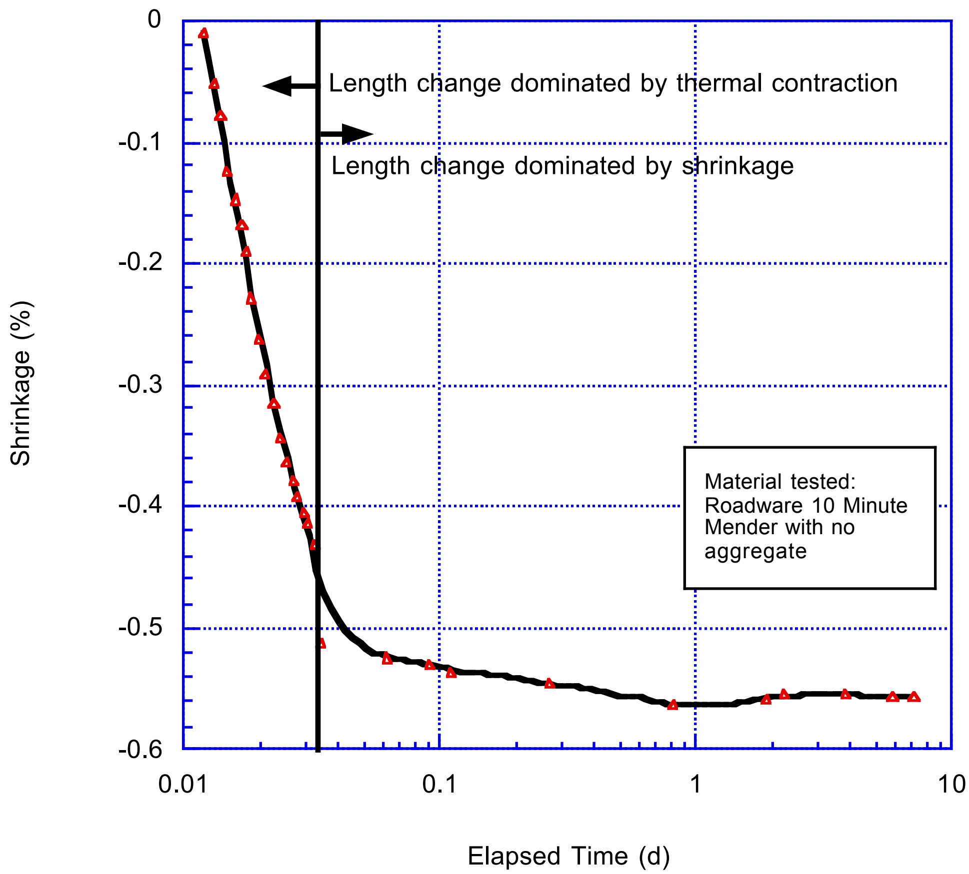


Figure 7. Length change with time