Performance of Utilibond and other bonding compounds during the first two hours

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Introduction:

This study measured the evolution of strength and evaluated the performance of three bonding compound materials. The parameters of interest included compressive strength, slant shear bond strength, and core punch out load. The measurements were taken within the two hour period after casting to characterize early performance. Bond strength was evaluated using procedures adapted from ASTM C882 -99 "Standard Test Method for Bond Strength of Epoxy-Resin Systems Used With Concrete by Slant Shear," compressive strength was determined using ASTM C109 “Standard Test Method for Compressive Strength of Hydraulic Cement Mortar, " and a nonstandard test referred to as the “Core Punch Out Test" was used to simulate field performance of the bonding materials. This report describes the procedures and results of each test.

Materials:

Each mortar repair material was mixed with an electric paddle mixer for 3 minutes in a lab environment at 23±1°C in the following manufacturers recommendations provided by the client.

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Utilibond	Water was added at a ratio of 1 part water to 10 parts bond compound [0.1:1 water: solid]
Product "A"	Water was added at a ratio of 1.6 parts water to 10 parts bond compound [0.16:1 water: solid]
Product "B"	Water was added at a ratio of 3.2 parts water to 10 parts bond compound [0.32:1 water: solid]

Test Procedures:

Slant Shear Bond Test:

ASTM C882-99 provides procedures by which bond strength is measured. The bond strength is determined by using the repair material to bond together two equal sections of a 3 by 6-in. portland cement mortar cylinder, each section of which has a diagonal bonding area at a 30° angle from vertical. The test is performed by determining the compressive load required to fail the composite cylinder. The bond strength is calculated as [Max Load]/[Area of Slant Surface]. 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 four 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. All of the cylinders and sections were cured at 100% RH for at least 14 days and then removed from the curing room allowed to air dry in the laboratory for at least two days. The 21-day strength of the mortar was previously determined to be in excess of the 4500 psi required by ASTM C882-99 for the substrate material. The composite cylinders were fabricated by bonding two matched sections together. The procedure for assembling test specimens 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 mated with the repair mortar, and each cylinder was squeezed together by hand to form a bonded composite cylinder. These cylinders are placed in a standard compression machine for testing at time intervals of 0.5 hr, 1 hr, and 2 hr after fabrication. The work was conducted in a lab environment held at 23±1°C. The age of each test specimen is the elapsed time after the test specimen was assembled.

Cube Compression Test:

ASTM C109 provides procedures to measure mortar compressive strength. The strength is determined by using the repair material to fill standard 2 inch cube molds. These samples are de-molded, and placed in a standard compression machine at the prescribed time intervals, and tested to failure. The final compressive strength is calculated as [Max Load]/[Area of Surface]. The work was conducted in a lab environment held at 23±1°C. The age of each test specimen is the elapsed time after the test specimen was assembled.

Core Punch Out Test:

The bonding materials were used to reinstate a drilled out core in a portland cement concrete slab. The slab dimensions were approximately 9"x 9"x 4". The concrete mix design (SSD) was 809 lb Type I portland cement, 1560 lb coarse aggregate, 1250 lb river sand, and 325 lb water per cubic yard. After two days of curing, the slabs were center-cored with a 4" diameter coring bit in a drill mounted to a heavy forklift. The 21-day strength of the substrate material was determined to be in excess of 7500 psi. The composite slabs were fabricated by bonding the removed core back into place with the repair material. In brief, the vacant cylinder in the slab was partially filled with repair material, and the previously removed core was reinserted until repair material was forced up to the surface on all sides to form a bonded composite slab. These slabs were placed in a standard compression machine using a special rig that allowed the actuator to force the unsupported composite core through the otherwise well-supported slab. Testing of the composite slabs was performed at time intervals of 0.5 hr, 1 hr, and 2 hr after fabrication. The work was conducted in a lab environment held at 23±1°C. The age of each test specimen is the elapsed time after the test specimen was assembled.

Results:

The experimental data from this study is summarized in Table 1. Figures 1-4 present the slant shear bond, compressive strength, core punch out load, and core punch out safety factor results, respectively. A section of photos is provided at the end of this report to help illustrate techniques and results. Photos 1-7 show the equipment and techniques used in the core punch out test. Photo 8 is a general view of slant and cube specimens.

Slant Shear Bond Test:

The slant shear test results, shown in Figure 1, revealed that the Utilibond material set significantly faster than the other two bonding materials, and gained 179 psi bond strength at 0.5 hour and 994 psi bond strength by 2 hours. These results are consistent with our previous tests of Utilibond materials, and demonstrate the trade-off between very early set and long-term strength. The Utilibond material in this study was designed for earlier set than a previously tested Utilibond material (Reference: our report dated March 25, 2003).

Product "B" material was an unstable slurry that tended to segregate. It seemed like the recommended water content of the Product "B" was considerably higher than should have been used for acceptable workability and flow. It was difficult to assemble slant shear specimens with the Product "B", and the test specimens were bonded by relatively thin layers of grout. The thinness of the grout layer is a likely explanation for low bond strengths because the dry substrate surfaces tend to absorb water from the bond material. Thus, the thin layer was particularly susceptible to de-watering by the absorption action of the substrate surfaces.

Product “A” bonding compound was slower than Utilibond to develop strength, but showed significant increase in strength between one and two hours. Product “A” material bond strength was low at under 100 psi at 0.5 and 1 hr, but jumped to 722 psi after 2 hr.

Cube Compression Test:

The cube compression test results, shown in Figure 2, indicated that Utilibond material set faster than the other two materials, reaching 440 psi by the 30-minute test. Product "B" material was the second fastest and reached 210 psi by the 30 minute test. Product "A" material remained low strength under 50 psi even at the 1 hour test. At 2 hours, Product "A" material reached 2050 psi, the Utilibond reached 1200 psi, and the Product "B" reached 750 psi. Again, segregation of the Product "B" material was noted during fabrication, and the cube strength values may have been negatively affected.

Core Punch Out Test:

The core punch out test was designed to simulate the performance of reinstated cores in the field. The results, shown in Figure 3, demonstrated that the Utilibond material gained strength the fastest and was strongest at all three test times.

The objective of Utilicoring technology is to restore a pavement to accept traffic loads as soon as possible. The AASHTO Guide for Design of Pavement Structures is used for concrete pavement design in the United States and other countries. The AASHTO Guide converts a mixed traffic stream of different axle loads and axel configurations into equivalent number of 18-kip single axle loads. An appropriate load condition to consider is the AASHTO H-25 loading with a maximum axle load of 40,000 lb supported by four tires. A worst case loading occurs when a 10,000 lb single tire load is positioned on the center of the reinstated core. The core bond area is calculated by multiplying the circumference of the core by the pavement depth. In the field, an 18-inch diameter core in an 8" pavement would have a bond area of 454 in^2. The average bond shear stress under the tire load would be 10,000/425 = 22 psi. Thus, the bond strength required to resist punch out of a core is relatively modest when compared to the capacity of the bonding materials after curing.

Figure 4 is an interpretation of the core punch out data in terms of the requirement to resist the AASHTO H-25 tire loading. The smaller 4-inch diameter cores used in the laboratory test and 4-inch slab thickness has a bond area of 50 in^2. Therefore, the 22 psi bond strength requirement corresponds to an applied load of 22 x 50 = 1,100 lb. A load capacity of 1,100 lb represents a safety factor of 1.0 against failure by punch out. Figure 4 indicates that all three bond materials ultimately reach bond strengths well in excess of that required to resist punch out.

The Utilibond material achieved a punch out safety factor of 4 at the 30-minute test. Product "B" surpassed a safety factor of 1.0 at the 1 hour test. Product “A” material surpassed a safety factor of 1.0 at the 2 hour test. All three materials easily achieved high safety factors at long curing times, but the Utilibond material excelled in terms of rapid set. Product "B" performed significantly better in the core punch out test than the slant shear or compression tests would have predicted. The reason for this is that the high water content of the grout was substantially reduced by the absorption by the cylindrical walls of the test specimen. In the slant shear test, the watery grout was hard to work with and the bond layer was very thin. In the core specimen, the bond thickness was defined by the configuration of the core, and so removal of water served to densify, not merely dewater, the grout.

On the whole, the core punch out test offers some advantages over the slant shear or compression tests. It is easy, it replicates the field condition, it "communicates" performance to the field engineers, and it incorporates the actual flow and workability of the bonding material into the test specimen fabrication.

Summary:

The Utilibond material excelled consistently as a rapid set material, and achieved the highest punch out loads at all test times. All three bonding materials proved capable of achieving high safety factors in the core punch out test, but the Utilibond material was the only bonding material that demonstrated satisfactory performance in the 30 minute tests. Since all three materials ultimately achieve high safety factors against core punch out, it is reasonable to emphasize attributes of performance such as rapid set time and workability. Rapid set time and workability are meaningful attributes in the field application, and effectively differentiate the performance of bonding materials for reinstatement of cores.

All three strength tests were effective for describing the set time of the bonding materials, but the relative magnitude of the three strength parameters were not always consistent with each other. For example, Product "B" material achieved high core punch out load values but had very low slant shear bond strength values. These differences occurred because the configuration of the specimens influenced the interaction of the dry substrate with the fresh mortars, and affected the material properties of the hardened mortar. The compression tests have the advantage of being easiest to execute, but may not reflect in-place performance. The slant shear test is attractive because it tests bond strength—not merely compressive strength—in a standard way. But it is possible, as shown in this study, that the compressive strength and bond strength of a given mortar may not correlate well (i.e. Product "B" performance). The core punch out test is an attractive laboratory test because it closely simulates the field condition and loading scenario of the pavement core reinstatement technique.

Table 1. Experimental data

Raw Data

	Compressive Cube Tests (load in lbs)			
	time (hrs)	0.5	1	2
Product “B”		652	2195	3104
		870	2412	3084
		1028	2333	2788
Product “A”		0	237	9017
		0	177	8404
		0	177	7198
Utilibond		1700	3342	5497
		1621	3506	4943
		1957	4449	4370
	Average compressive strength (psi)			
	time (hrs)	0.5	1	2
	Product “B”	213	578	748
	Product “A”	0	49	2052
	Utilibond	440	941	1234
	Slant Shear Tests (load in lbs)			
	time (hrs)	0.5	1	2
Product “B”		177	751	1008
		178	1166	778
		197	695	420
Product “A”		257	1028	10757
		237	751	8523
		276	520	11331
Utilibond		1463	4983	11726
		2669	7850	15978
		3480	8187	14455
	Average shear strength (psi)			
	time (hrs)	0.5	1	2
	Product “B”	13	62	52
	Product “A”	18	54	722
	Utilibond	179	496	994
	Punch Out Tests (load in lbs)			
	time (hrs)	0.5	1	2
Product “B”		0	10112	12360
		0	7865	12584
Product “A”		135	674	11924
		0	899	15899
Utilibond		3995	9591	16690
		5260	11034	16275
	Average punch out load (lb)			
	time (hrs)	0.5	1	2
	Product “B”	0	8989	12472
	Product “A”	67	787	13912
	Utilibond	4628	10313	16308
	Average safety factor against punch out			
	time (hrs)	0.5	1	2
	Product “B”	0.0	8.2	11.3
	Product “A”	0.1	0.7	12.6
	Utilibond	4.2	9.4	14.8

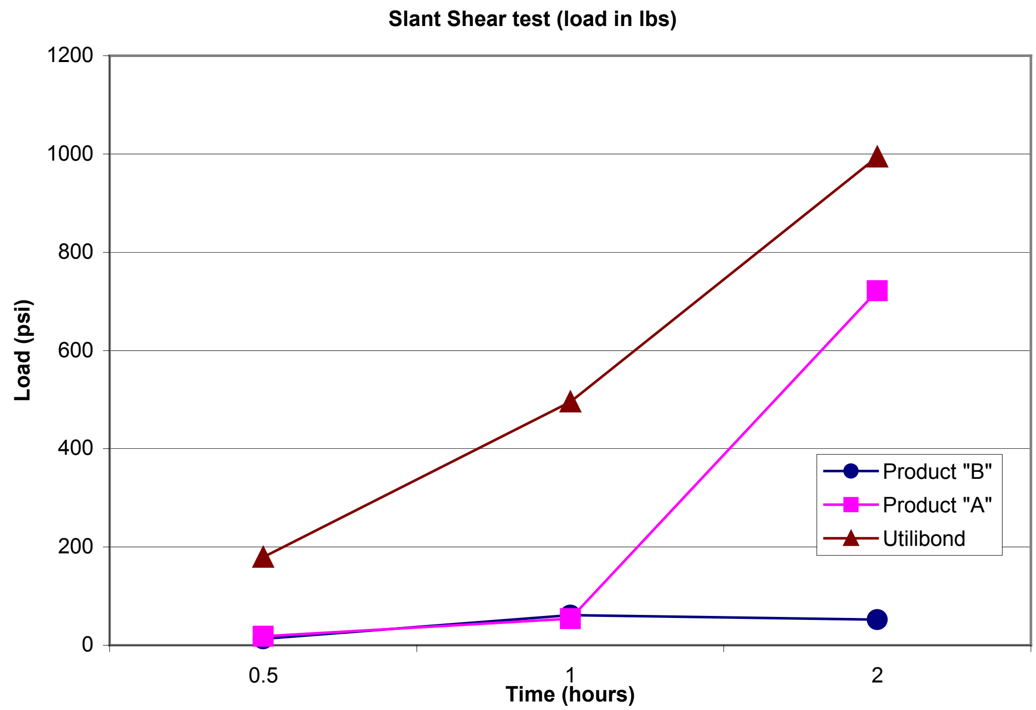

Figure 1. Slant shear strength development of three bonding materials

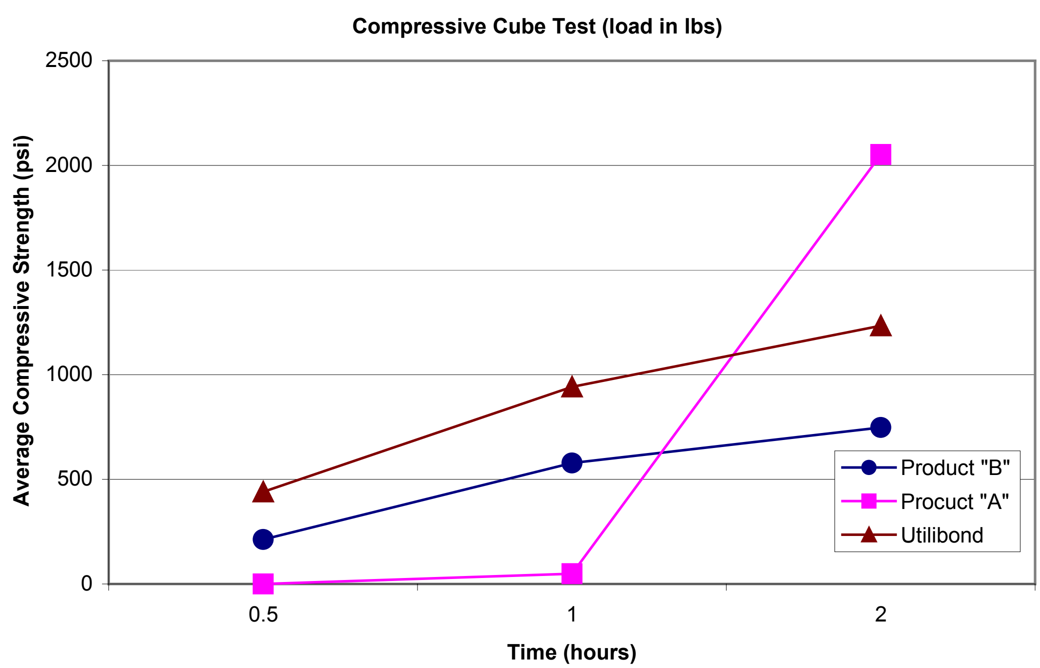

Figure 2. Compressive strength development of three bonding materials

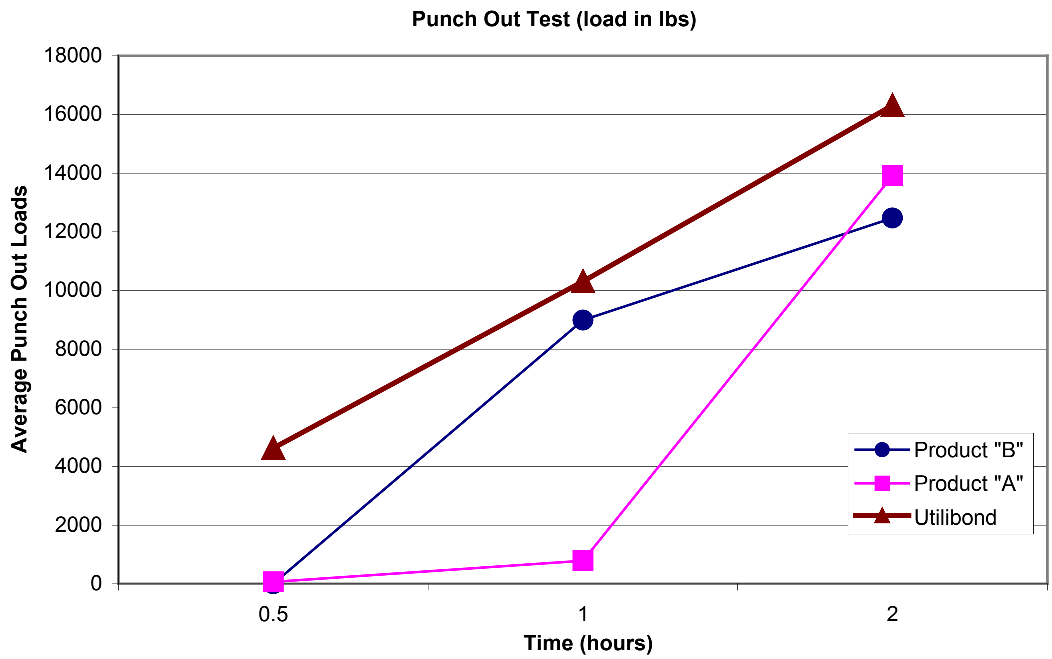

Figure 3. Development of bond strength of reinstated cores

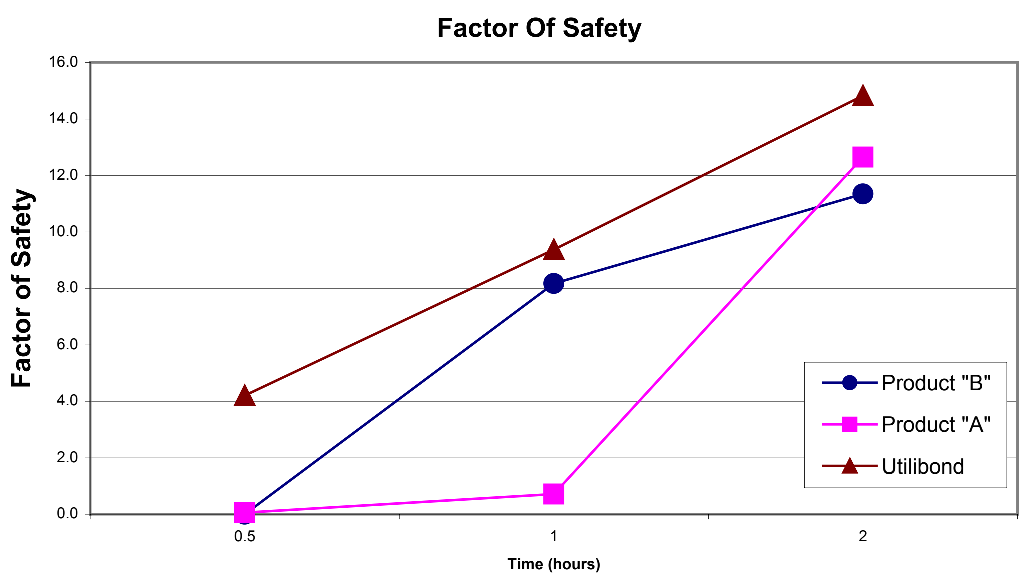

Figure 4. Development of bond strength safety factor of reinstated core.

Photo 1. Mixing equipment

Photo 2. Cast and cored test specimens

Photo 3. Close-up of cored specimen

Photo 4. Reinstatement of core

Photo 5. Support plate for punch out test shown on top of specimen

Photo 6. Top platen (left) and bottom support plate (right)

Photo 7. Compression test machine

Photo 8. Slant shear bond specimens and cube specimens after testing