CRACK SEALER FILL CHARACTERISTICS

Final Report

SR 500-230

CRACK SEALER FILL CHARACTERISTICS

State Research

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by

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16. Abstract

Laboratory testing was conducted to determine the extent of crack fill for crack sealers composed of methyl methacrylate, epoxy, urethane, and high molecular weight methacrylate. The test specimens consisted of eight-inch long concrete cylinders with a nominal 0.010 in. crack running the length of the cylinders and unsealed at the bottom. The following observations were made: all the sealers leaked to some degree from the bottom of the crack; thinner crack widths were more likely to be filled than wider crack widths; the fraction of the crack length filled in a cross-section through a cylinder was independent of the distance below the resin reservoir situated at the top of the crack; and a minimum of 70% crack fill was needed to prevent water leakage.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS					APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	millimeters squared	mm^2	mm^2	millimeters squared	0.0016	square inches	in^2
ft^2	square feet	0.093	meters squared	m^2	m^2	meters squared	10.764	square feet	ft^2
yd^2	square yards	0.836	meters squared	m^2	m^2	meters squared	1.196	square yards	yd^2
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	kilometers squared	km^2	km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	ml	ml	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	meters cubed	m^3	m^3	meters cubed	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	meters cubed	m^3	m^3	meters cubed	1.308	cubic yards	yd^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.									
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C	°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

Cracking in bridge decks is a widespread concern throughout the United States. For various reasons, cracks can occur throughout the life of a bridge deck. Cracks allow the ingress of water and chlorides that can lead to degradation of the reinforcing steel and the concrete. Consequently, the Oregon Department of Transportation (ODOT) deploys resin-based concrete crack sealers on bridge decks when personnel decide that crack sealing will significantly extend the life of the bridge deck. These sealers may be applied to cracks as narrow as 0.010 inch with the intent of preventing water and contaminants from penetrating the near surface of the deck. Sealer performance is expected to be controlled by the sealer's ability to penetrate into the crack, fill along the length of the crack, bond to the sides of the crack, form an impermeable mass, be flexible enough to avoid a parallel crack from forming, and maintain these attributes for years of service. ODOT has had mixed results with crack sealers; therefore, the agency has conducted limited laboratory investigations to compare products and to investigate potential laboratory tests that could be used to predict field performance.

Based on previous work by the Minnesota Department of Transportation (*Johnson et al. 2009*), ODOT conducted crack penetration tests in 2008 as described in Appendix A. The test method used pre-cracked concrete specimens with nominal crack widths 0.02 in. and 0.04 in., and the specimens were sealed at the bottom. It was decided that specimens with a nominal crack width of 0.01 in and unsealed at the bottom would provide a test more representative of field needs. This report describes the follow-up tests and results.

2.0 METHOD

Eleven crack sealing products covering a range of material types and viscosities were selected for evaluation. The products are listed in Table 2.1.

Table 2.1: Products used in evaluation.

Product Name	Material Type	Viscosity (cps)*
BASF Degadeck Crack Sealer Plus	Methyl Methacrylate	5-15
Dural 50 LM	Epoxy	80-120
ChemMasters Duraguard 401	Methyl Methacrylate	5-20
PolyCarb Mark 135	Epoxy	200-230
Urefast R60	Urethane	12-16
Kwikbond KBF 204	High Molecular Weight Methacrylate	18
Transpo T-70	High Molecular Weight Methacrylate	14-15
Transpo T-70 MX30	High Molecular Weight Methacrylate	<25
Kwikbond Flex 30	High Molecular Weight Methacrylate	<35
Unitex Bridge Seal (70% solids)	Epoxy	40
Sika Pronto 19TF	High Molecular Weight Methacrylate	25

*Reported by manufacturers

The investigation used 4 in x 8 in concrete cylinders for the test specimens. The cylinders were split lengthwise using the setup shown in Figure 2.1. The crack faces were cleaned of debris and loose concrete, and the two halves were fitted together. Steel hose clamps were placed around the cylinders, and the clamp tension was adjusted to achieve a nominal 0.01 in crack width measured on the two ends of the cylinders. Silicone caulk was used to seal the crack along the sides of the cylinders but not the ends. The cylinders were then placed in a moist room until needed to allow moisture to fully penetrate the cracks. One week before applying the crack sealer, the cylinders were removed from the moist room and allowed to dry at ambient laboratory conditions. The exposure to water followed by one week of drying was done to simulate expected Oregon field conditions in which sealers are likely to be applied a week after full saturation from rain. During the week of drying, a ring of tape and silicone caulk was placed around the circumference of one end of the cylinders to contain the sealers during application. Two cylinders for each crack sealer were prepared in this manner. Figure 2.2 shows cylinders ready for sealer application.

Small quantities of the crack sealer resins were mixed according to the manufacturers' instructions and poured into the prepared reservoirs. If possible, a surplus of resin was maintained in the reservoir before the resin set. However, some resins leaked through the length of the cylinder so quickly, that trying to maintain a pool of resin in the reservoir was futile. Figure 2.3 show cylinders with cured resin in the reservoir and resin on the ground cover from leakage.

After the resin cured, each cylinder was sectioned transversely at 0.5, 1, 2, 4, and 6 in from the top of the cylinder. The opposing faces of the cuts were examined so that each nominal cut location provided two sets of data. A low-power microscope and calipers were used to record the minimum and maximum crack width filled with sealer; the minimum and maximum crack width unfilled; a subjective estimate of the fraction of the crack length filled; and a subjective estimate of the representative crack width. The data from these measurements are tabulated in Appendix B.

Leak testing on select slices covering a range of filled crack lengths was conducted. The test was performed by creating a reservoir on one side of the slice with caulk, filling the reservoir with water, and waiting up to two hours to see if water leaked through to the opposite side. A test in progress is shown in Figure 2.4.

Figure 2.1: Set up to crack cylinders.

Figure 2.2: Cylinders ready for crack sealer to be poured into the reservoirs at the tops of the cylinders.

Figure 2.3: Cylinders with cured resin in the reservoirs and evidence of leakage on the ground cover.

Figure 2.4: Leak test.

3.0 RESULTS AND DISCUSSION

All of the crack sealers leaked to some extent from the bottom of the cylinders. The low viscosity resins tended to leak much sooner and more rapidly than the higher viscosity sealers. No attempt was made to quantify the leak rate.

Initially, the intent of slicing the cylinders was to determine the depth of penetration. However, it was observed after the first few slices that a simple measure of penetration was not possible or even applicable. The crack width varies across a cut surface. Generally for specimens in this investigation, smaller crack widths were more likely to be filled than larger crack widths. The effect is illustrated in the graphs for the various sealer resins shown in Appendix C using the measurements tabulated in Appendix B. In these graphs, the saw-cut location is given along the x-axis relative to the top of the cylinder. If the cylinder is thought of as a core through a bridge deck, the cut locations would be the depth below the riding surface. At each location, closed symbols are plotted for the minimum and maximum crack widths that were filled (4 points: 1 minimum and 1 maximum read for each of the two cut surfaces at that location); open symbols are used for the minimum and maximum crack widths that were not filled. The closed and open symbols in essence define a range of filled and unfilled crack widths. Figure 3.1 illustrates the effect by showing the results for all the cylinders combined. The graphs show that the effect was independent of the depth below the surface.

The depth below the surface also had little influence on the fraction of the crack that was filled as shown in Figure 3.2 for the combined results from all cylinders. Except for the Dural LM 50, all the products showed low levels of crack filling as shown in Table 3.1. Material type had no discernible effect on the extent of crack fill. The epoxies, with their relatively high viscosities, filled cracks as well as (or as poorly as) the lower viscosity materials.

The extent of crack fill is important to prevent water infiltration. The results of the leak testing, shown in Table 3.2, revealed that a minimum crack fill of 70% was required to prevent water from leaking through a slice. However, this threshold would be for situations in which the unfilled portions of the crack were dispersed along the crack length so that no one void provided a path for appreciable water infiltration. Only the Dural LM 50 met the 70% threshold for all its slices analyzed for this report.

Analysis was conducted on two cores removed from bridge decks that had undergone crack sealing. One deck was sealed with SikaPronto 19, a HMWM, and the other was sealed with Dural 335, an epoxy. The crack sealed with Dural 335 was caulked on the bottom of the bridge deck before the sealer was applied. Figure 3.3 shows the SikaPronto 19 was present to a depth of 2 in. with at least 80% crack fill for the first 1.5 in. Based on the laboratory results, this level of penetration and fill should be sufficient to seal the crack from water intrusion. The trend found in the laboratory tests of narrower crack sections more likely to fill than wider sections was also observed in the SikaPronto core. It is unknown whether the SikaPronto resin beyond 2 in. had leaked out of the bottom of the deck or had not penetrated deeper than 2 in. The Dural core had 90% and greater crack fill for the entire depth of the core where a crack was visible as shown in Figure 3.4. Also, the trend of larger crack widths having a lower probability of fill was not observed in this core. The extensive crack fill may have been due to the fact that the sealer could not leak out the bottom of the crack during application because of the caulk.

The laboratory study showed that higher viscosity materials may provide the advantage of less resin leakage through the bottom of the bridge deck during application. However, in preparing the laboratory specimens, the mating crack surfaces were cleaned in order to achieve a nominal crack width of 0.010 in. In actual bridge deck cracks, one would expect to have debris in the cracks, which may impact the extent of crack sealer penetration and fill characteristics. Bridge decks would also have some cracks that are much wider than 0.010 in. Consequently, the performance advantage of lower viscosity resins versus higher viscosity resins under actual field conditions is unclear. A field evaluation is recommended to determine the effect of resin viscosity and crack width on the likelihood of resin leakage and extent of crack filling.

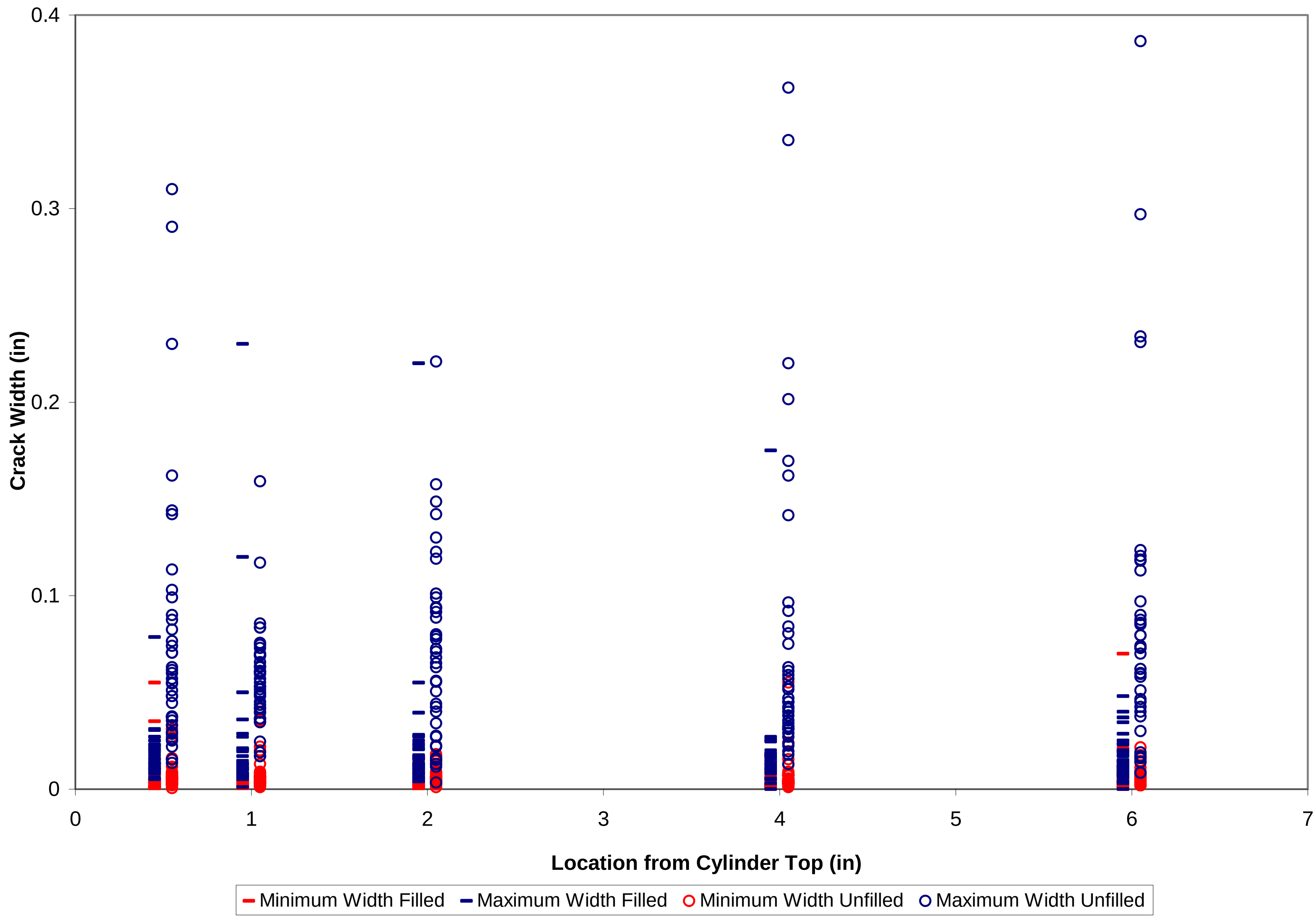


Figure 3.1: Compiled crack width filled results.

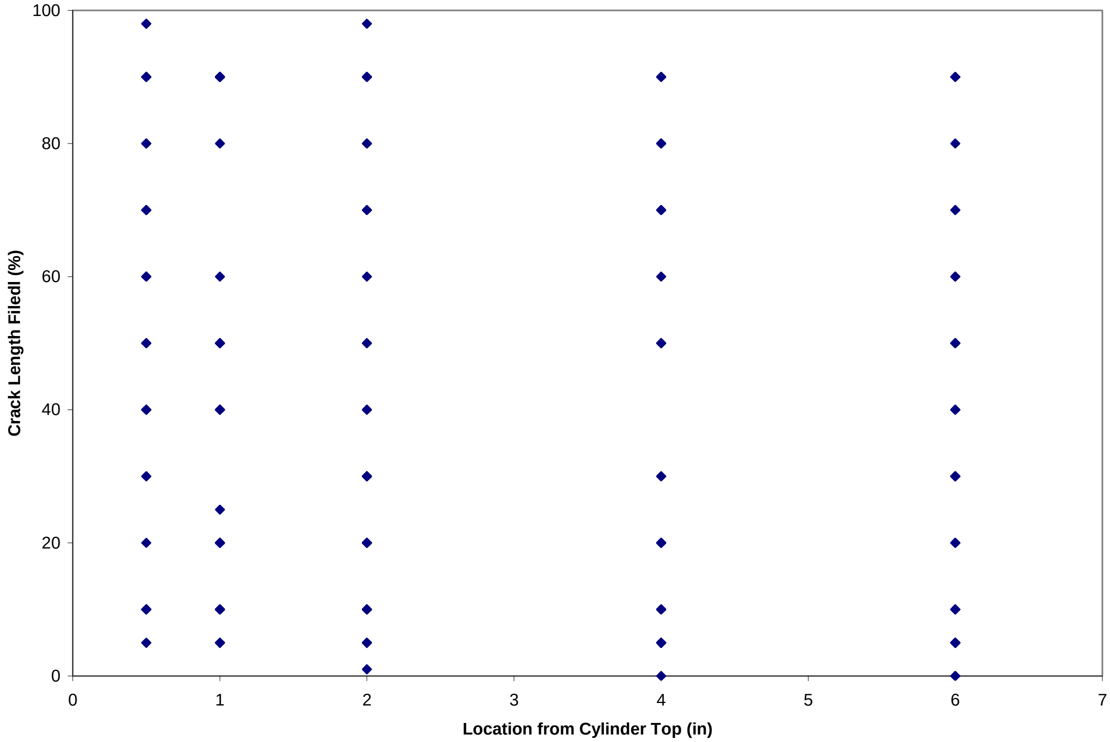


Figure 3.2: Crack length filled vs. location compiled for all resins.

Table 3.1: Range of crack length filled for each product compiled from all cut surfaces.

Product Name	Material Type	Range of Crack Length Filled (%)
BASF Degadeck Crack Sealer Plus	Methyl Methacrylate	20-90
ChemMasters Duraguard 401	Methyl Methacrylate	1-25
Urefast R60	Urethane	20-90
Dural 50 LM	Epoxy	70-98
PolyCarb Mark 135	Epoxy	30-90
Unitex Bridge Seal (70% solids)	Epoxy	5-80
Kwikbond KBF 204	High Molecular Weight Methacrylate	5-40
Transpo T-70	High Molecular Weight Methacrylate	5-50
Transpo T-70 MX30	High Molecular Weight Methacrylate	5-30
Kwikbond Flex 30	High Molecular Weight Methacrylate	5-70
Sika Pronto 19TF	High Molecular Weight Methacrylate	0-80

Table 3.2: Leak test of select slices.

Crack Length Filled (%)	Slice Thickness (in)	Result
20-50	2	Leaked
50	1	Leaked
60	0.5	Leaked
60-70	2	Leaked
70-80	1	No Leak
90	1	No Leak

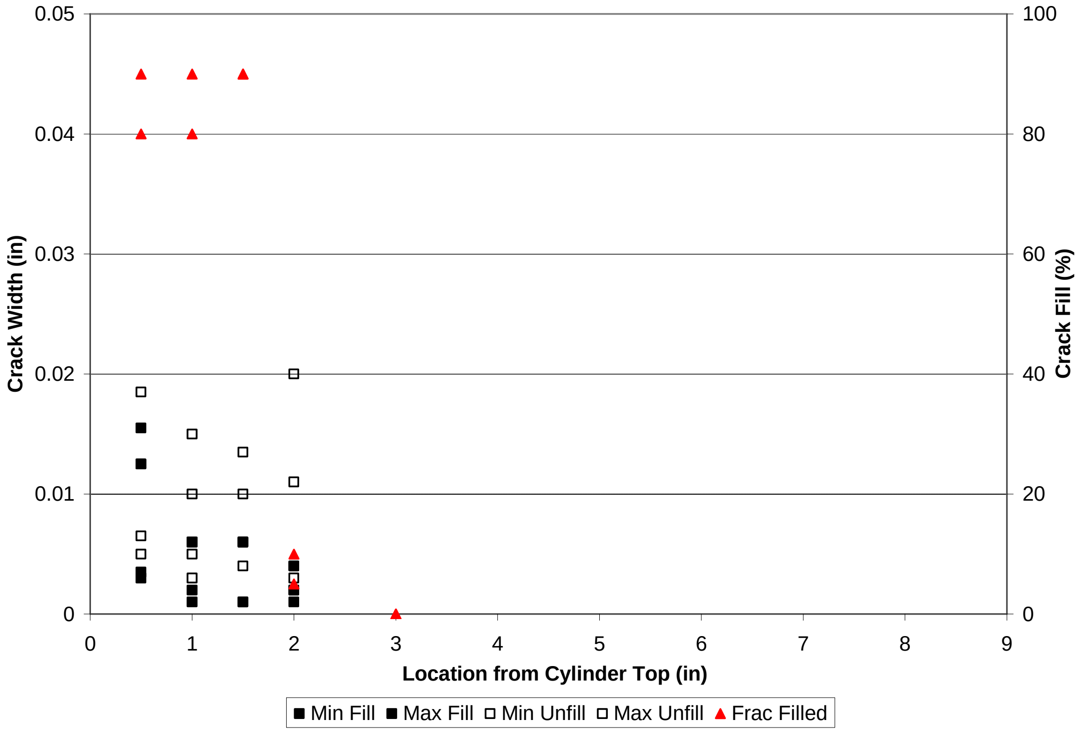


Figure 3.3: Crack fill data for SikaPronto 19 from a bridge core.

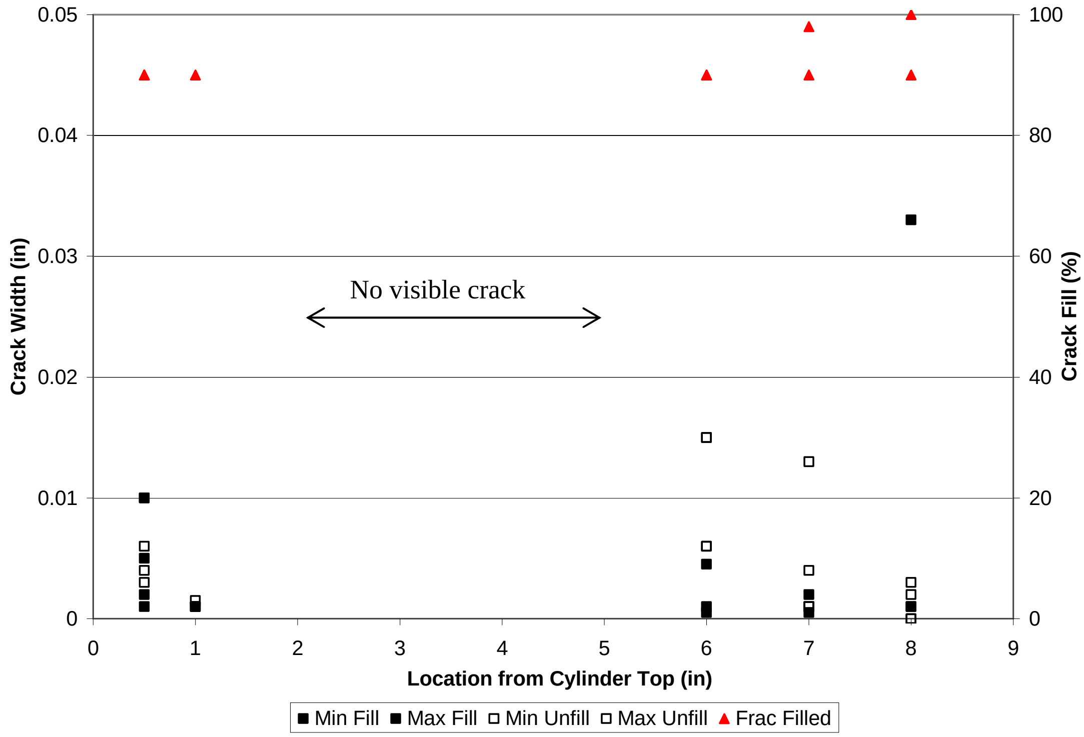


Figure 3.4: Crack fill data for Dural 335 from a bridge deck core.

For Figure 3.4, four data points for Max Fill were greater than 0.05 in. and are not shown on graph. Crack was caulked at the bottom of the deck prior to crack sealing.

4.0 CONCLUSIONS

This laboratory investigation provided the following conclusions:

- Regardless of viscosity, crack sealing resins leaked through a nominal 0.010 in. wide crack when the resins were applied to the top of an 8 in. long concrete cylinder. Though higher viscosity resins showed less resin leakage than lower viscosity resins, resin leakage could be a concern in field applications.

- Thinner crack widths were more likely to be filled than wider crack widths.

- The extent of crack fill was independent of the distance below the resin reservoir at the top of the cylinder.

- A minimum of 70% crack fill was needed to prevent water leakage.

- Only one of the eleven crack sealers tested consistently met the 70% threshold.

5.0 REFERENCES

Johnson, K., E. Schultz, A.E, French, C., and Reneson, J. *Crack and Concrete Deck Sealant Performance*. MN/RC 2009-13, Minnesota Department of Transportation, March, 2009.

APPENDIX A:
INITIAL CRACK SEALER INVESTIGATION

INTRODUCTION

Cracks that allow water to penetrate a bridge deck can reduce the life of the deck. Cracks are common in older decks and even in decks less than a year old. The Oregon Department of Transportation (ODOT) will seal cracks as small as 0.01” wide in an effort to extend bridge deck life. However, ODOT has experienced crack sealing applications that have not sealed all the cracks or began to leak within a year after applying the sealer. Consequently, ODOT would like a set of tests that can be used to predict which crack seal products will perform well under conditions in Oregon. The objective of the effort described in this report was to investigate tests that could be effective for evaluating products.

APPROACH

Discussions were held at the beginning of the effort on what characteristics are important for successful crack sealing. The outcome of those discussions identified the following items:

- Deep penetration into cracks.
- Tolerance to moisture that may be present in cracks.
- Tolerance to debris that may be present in cracks.
- Ability to maintain a bond to the crack surface when exposed to crack motion due to traffic.

The approach of the experimental effort was to investigate procedures that might produce useful comparative tests for the items listed above. The consensus of the initial discussions was that tests should be done on concrete specimens with actual cracks instead of specimen configurations with idealized cracks.

A concrete block design that allowed for controlled cracking was developed based on experiments conducted by WISDOT (REF). A schematic of the block is shown in Figure A-1. All blocks were made from Sakrete 5000 Plus Concrete mixed according to the manufacturer’s instructions and cured in a moist room for at least 28 days. The blocks were cut in half to create 6”x6”x8” specimens. Each specimen was cracked by applying compressive force through round bars positioned in the grooves.

Cracks were formed by placing small aluminum foil spacers along the edge of one half and clamping the two halves together. Crack width was determined by averaging the measured crack width at 1” intervals on both ends of the specimens and averaging the values. The width was then adjusted by tightening or loosening the clamping pressure. The ends and bottom were sealed with silicone caulk.

Initially, target crack sizes were 0.01” and 0.02”. However, even without foil spacers, the average minimum crack width ranged from 0.015” to 0.02”. Therefore, the nominal crack sizes were increased to 0.02” and 0.04”, which could be consistently achieved.

Specimens designated as wet had their crack surfaces wetted before clamping, and then the specimens were returned to the moist room. These wet specimens were removed from the moist room one week prior to crack sealing and allowed to dry under ambient laboratory conditions. This procedure was a reasonable attempt to mimic field conditions in which a bridge deck could be allowed one week to dry before sealing. The dry specimens were set aside in ambient laboratory air without wetting. These specimens were not clamped together until two days before applying the crack sealers.

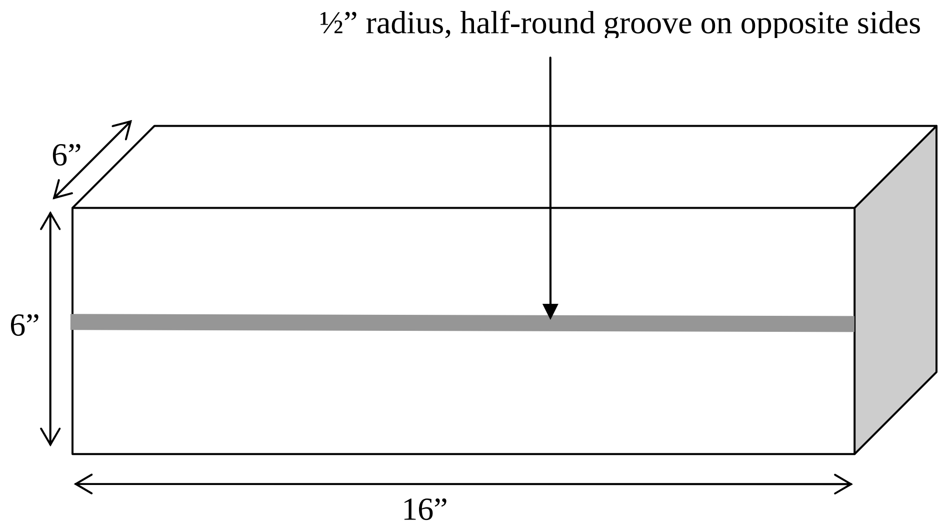


Figure A-1: Concrete block schematic.

Two crack sealer products were used in these experiments: Degadeck Crack Sealer Plus and Dural 50 LM. Relative to each other, the Degadeck product is a low viscosity high modulus sealer, and the Dural material is a high viscosity low modulus sealer. The crack sealers were mixed according to the manufacturers' instructions and used to fill the eleven specimens in one batch. The sealer was slowly poured into one end of unsealed groove on each specimen to minimize air entrapment. Excess was removed from the groove to avoid forming a resin plug that would affect the water leak tests. After curing, the clamps were removed, and one inch was cut from each end in order to measure the depth of crack penetration. The caulk was removed from the bottom groove, and the ends of the top groove were sealed with duct tape to form a reservoir. The top groove was flooded with water and covered with plastic sheeting to prevent evaporation. After two days, the blocks were checked to see if the water level in the groove had changed, which would indicate water leakage. After leak testing, most specimens were recracked to check how well the resin had bonded to the concrete and penetrated the cracks.

One specimen was used to measure the rate at which cracks dry. The specimen configuration is shown in Figure A-2. The intent of the arrangement was to allow moisture to escape through the crack only along the long dimension of the specimen, which would mimic crack drying in a through-crack in an 8"-thick bridge deck. The specimen was kept in the moist room since casting and after each preparatory step. The crack surfaces were wet just prior to installing the plastic tube and sealing the crack with caulk. The hole for the tube was dried with compressed air and heat and a bead of caulk applied to the edge of the tube embedded in the hole. The two halves were placed together, clamped to an average crack width of 0.019”, and the crack caulked along the 8”-dimension of the specimen. After the caulk seal had cured, the plastic tube was capped, and the specimen was placed in the moist room for five days. The specimen was moved from the moist room to the ambient laboratory environment. An Ingius moisture sensor connected to an IntelliRock datalogger was used to measure the moisture level by removing the cap from the tube, inserting the probe, and allowing the readout to stabilize. The sensor was left in place for six weeks.

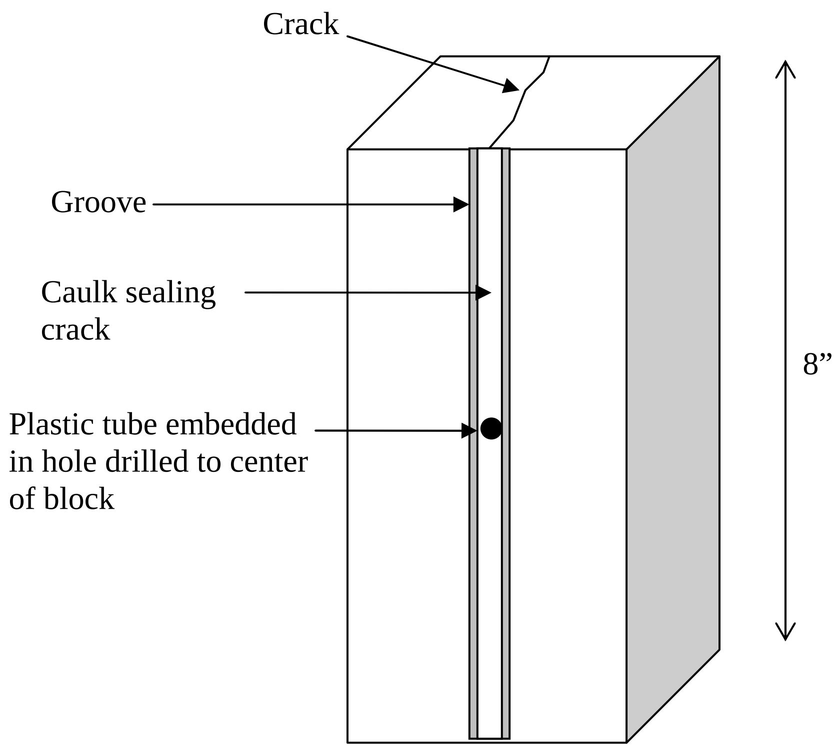


Figure A-2: Crack drying specimen.

Tensile tests based on ASTM D 638 were conducted on the resins. All tests were conducted at ambient laboratory temperature, but one set of samples was exposed to 14 days of water soaking and another set of samples was exposed to 50^{o}C for 24 hours followed by cooling and storage in a desiccator jar. The intent was to determine any effect on tensile properties due to moisture saturation or drying.

RESULTS AND DISCUSSION

Most of the specimens used for the low viscosity Degadeck sealer leaked during filling. Prior to using the Dural sealer, a second coat of caulk was applied to the specimens. Only one of the Dural specimens leaked, but it is unknown whether this was due to the higher viscosity of the material or the additional layer of caulk. For the specimens that did not leak, however, both products were able to penetrate to the bottom of the cracks as shown in Table A-1. In field applications of sealing through thickness cracks, containing the sealer within the cracks, especially low-viscosity sealers, will need to be considered.

Specimens that did not leak during sealing were subsequently tested for water leakage. None of these specimens showed any water penetration.

Table A-1: Results from the crack specimens.

Material	Condition	Average Crack Size (in)	Minimum Sealer Penetration Depth (in)	Post-Sealing Fracture Description
Dural 50 LM	Wet	0.025	5	Completely filled. All concrete fracture.
Dural 50 LM	Wet	0.020	5	Completely filled. Combination of bond failure and concrete fracture.
Dural 50 LM	Wet	0.022	5	Completely filled. Mostly bond failure.
Dural 50 LM	Wet	0.039	5	Completely filled. Combination of bond failure and concrete fracture.
Dural 50 LM	Wet	0.038	5	Completely filled. Mostly bond failure.
Dural 50 LM	Wet	0.037	5	Completely filled. All bond failure.
Dural 50 LM	Dry	0.040	5	Completely filled. All concrete fracture.
Dural 50 LM	Dry	0.038	5	Completely filled. All concrete fracture.
Dural 50 LM	Dry	0.039	5	Completely filled. All concrete fracture.
Dural 50 LM	Wet	0.039	Specimen leaked	Bottom 2/3 of crack filled. Combination of bond failure and concrete fracture.
Dural 50 LM	Wet	0.037	5	
MBT Degadeck Crack Sealer Plus	Wet	0.024	Specimen leaked	Some resin 1/2" from bottom of crack.
MBT Degadeck Crack Sealer Plus	Wet	0.021	Specimen leaked	Resin 1" from bottom of crack. Bond failure.
MBT Degadeck Crack Sealer Plus	Wet	0.020	Specimen leaked	No resin in crack.
MBT Degadeck Crack Sealer Plus	Wet	0.041	Specimen leaked	Some resin 1/2" from bottom of crack.

Material	Conditio n	Average Crack Size (in)	Minimum Sealer Penetration Depth (in)	Post-Sealing Fracture Description
MBT Degadeck Crack Sealer Plus	Wet	0.035	Specimen leaked	Some resin 1" from bottom of crack.
MBT Degadeck Crack Sealer Plus	Wet	0.039	Specimen leaked	Filled up to 1" from top of crack. Bond failure.
MBT Degadeck Crack Sealer Plus	Dry	0.039	5	Completely filled. Combination of bond failure and concrete fracture.
MBT Degadeck Crack Sealer Plus	Dry	0.040	4.8	Completely filled. Combination of bond failure and concrete fracture.
MBT Degadeck Crack Sealer Plus	Wet	0.038	Specimen leaked	Some resin 3/4" from bottom of crack.
MBT Degadeck Crack Sealer Plus	Wet	0.038	Specimen leaked	Some resin 1/2" from bottom of crack.
MBT Degadeck Crack Sealer Plus	Dry	0.041	5	

The results of recracking the specimens after crack sealing are shown in Table A-4. The fracture surfaces verified that all the cracks that had shown complete fill at the ends of the specimens were in fact filled. The fracture surfaces exhibited various combinations of debonding and fractured concrete as shown in Figure A-3. Fractured concrete indicates that the resin and resin-to-concrete bond were stronger than the concrete. A comparison of the wet and dry crack conditions shows that moisture may reduce bond strength. Unfortunately, all the MBT Degadeck wet crack conditions leaked sealer, so a thorough comparison for this sealer is not possible.

Figure A-3: Fracture surface showing a combination of debonding and concrete fracture.

Degraded bond in the wet specimens is not surprising after seeing the results of the crack drying test in Table A-2. After one week, moisture readings were still at 100%. Once the moisture level of the crack began to decrease from 100%, the rate of decline was approximately 1.5 percentage points per week. The data show that cracks retain high levels of moisture for weeks. Consequently, cracks in Oregon bridge decks west of the Cascades would be expected to be damp well into the summer months. This could be problematic for resins that are sensitive to moisture.

Table A-2: Crack drying results.

Elapsed Time	Moisture Level (%)
0	100
1	100
2	98
3	97
4	95
5	94
6	92

Average crack width was 0.019”.

Four more specimens were cracked as described above in an effort to create the narrowest cracks. Iterations of brushing the crack faces with a steel brush, knocking out loose pieces, blowing with compressed air, and putting the two halves together produced crack widths 0.010” and smaller as shown in Table A-3. These specimens were tightly clamped, crack widths measured, and sealed with duct tape. Only the dry crack condition was tested. Unfortunately, leaking during crack sealing was a problem again. However, the more viscous sealer, Dural 50 LM, was able to penetrate to the bottom of the cracks even in one specimen that leaked. It is expected that the less viscous MBT Degadeck sealer would also have filled the cracks if the specimens had not leaked.

It is unlikely that crack sealing on bridges will include a surface treatment on the bottom of the deck to keep the sealer from leaking through the deck. Consequently, the problem of the crack sealers leaking in these tests highlights the importance of including an evaluation of how well the sealers will be naturally contained in the range of cracks expected in the field. This evaluation could be done using specimens with nominal 0.010" and 0.040" wide cracks to bracket the typical range of crack sizes. In practice, larger cracks would be filled with sand prior to filling.

Table A-3: Results of specimens with fine cracks.

Material	Crack Size	Sealer Penetration	Post-Sealing Fracture Description
MBT Degadeck Crack Sealer Plus	0.005	Leaked	Resin penetrated 3/4" into crack.
Dural 50 LM	0.010	Leaked but still had full penetration	Completely filled. Mostly concrete fracture.
MBT Degadeck Crack Sealer Plus	0.008	Leaked	Did not fill completely. Areas of concrete fracture.
Dural 50 LM	0.008	Full penetration	Completely filled. All concrete fracture.

The tensile strength and elongation results are shown in Table A-4 and Table A-5, respectively. The strength of MBT Degadeck Crack Sealer Plus was greater than that of Dural 50 LM as expected. The ductility of the Degadeck product was much larger than the 5.5% reported in the manufacturer's literature. After testing, some of the Degadeck bars were snapped by hand to verify the brittle nature of the material. The unusually high ductility values obtained in the tests could not be explained. There was no degradation of tensile properties of either product due to water saturation or drying.

Table A-4: Tensile strength results.

Material	Condition	Test 1 (psi)	Test 2 (psi)	Test 3 (psi)	Test 4 (psi)	Average (psi)
Dural 50 LM	Ambient	2046	2045	1909	2164	2041
	14-day water saturation	2268	2270	2146	2167	2213
	24 hours at 50^{o}C drying	3240	2932	2843	2580	2899
MBT Degadeck Crack Sealer Plus	Ambient	5905	4343	2663	5791	4676
	14-day water saturation	6622	8760	8925	5238	7386
	24 hours at 50^{o}C drying	5677	3249	8078	3637	5160

Table A-5: Tensile elongation results.

Material	Condition	Test 1 (%)	Test 2 (%)	Test 3 (%)	Test 4 (%)	Average (%)
Dural 50 LM	Ambient	47	53	53	50	51
	14-day water saturation	59	66	59	72	64
	24 hours at 50^{o}C drying	38	47	47	41	43
MBT Degadeck Crack Sealer Plus	Ambient	66	59	28	28	45
	14-day water saturation	82	59	28	28	49
	24 hours at 50^{o}C drying	3	22	28	25	20

CONCLUSIONS

- Crack sealers may leak through cracks that penetrate the full thickness of bridge decks. Ideally, a crack sealer needs to be viscous enough not to leak out of the cracks, but low enough viscosity to penetrate a range of crack sizes.

- The moisture level within bridge deck cracks is expected to be high for weeks after the last rain.

- Moisture in cracks may reduce the bond strength of the crack sealer resin to the surface of the crack.

- Water absorption and drying of in-place crack sealers are unlikely to affect the performance of the sealers.

REFERENCES

Pincheira, J.A. and M.A. Dorshorst. 2005. *Evaluation of Concrete Deck and Crack Sealers*. Report No. WHRP 06-09. Madison, WI: Wisconsin Department of Transportation.

APPENDIX B:
CRACK FILL DATA

Product	Cylinder ID	Slice Location from Top of Cylinder (in)	Estimated Representative Crack Size (in)	Minimum Crack Width Filled (in)	Maximum Crack Width Filled (in)	Minimum Crack Width Unfilled (in)	Maximum Crack Width Unfilled (in)	Estimated Crack Length Filled (%)	Comments
BASF Degadeck Crack Sealer Plus	1	0.5	0.007	0.004	0.01	0.031	0.063	90	
	1	0.5	0.008	0.005	0.031	0.015	0.048	90	
	1	1	0.005	0.001	0.013	0.022	0.042	90	
	1	1	0.0045	0.0005	0.013	0.017	0.0365	90	
	1	2	0.004	0.001	0.004	0.017	0.034	90	
	1	2	0.005	0.0005	0.055	0.0145	0.065	80	
	1	4	0.004	0.001	0.003	0.005	0.031	90	
	1	4	0.003	0.0005	0.0055	0.003	0.0225	90	
	1	6	0.0025	0.001	0.003	0.006	0.04	90	
	1	6	0.004	0.0005	0.015	0.002	0.073	90	
	8	0.5	0.004	0.001	0.015	0.027	0.033	98	
	8	0.5	0.0025	0.0005	0.01	0.006	0.0135	98	
	8	1	0.003	0.004	0.007	0.035	0.048	90	Slice between 1" and 2" leak tested. No leak after 1.5 hrs.
	8	1	0.003	0.0005	0.0055	0.04	0.0395	90	
	8	2	0.004	0.003	0.006	0.007	0.056	90	Crack throughout width of cylinder was branched in many numerous smaller cracks
	8	2							
	8	4	0.008	0.002	0.005	0.004	0.057	20	
	8	4	0.011	0.0015	0.005	0.0035	0.0235	20	
	8	6	0.008	0.004	0.006	0.009	0.017	50	Slice between 4" and 6" leak

									tested. Leaked
	8	6	0.014	0.0005	0.0035	0.0085	0.074	50	
Dural 50 LM	6	0.5	0.011	0.007	0.013	0.016	0.31	70	
	6	0.5	0.0095	0.001	0.066	0.0165	0.043	90	
	6	1	0.009	0.004	0.011	0.036	0.117	90	
	6	1	0.0085	0.0005	0.017	0.0155	0.0171	90	
	6	2	0.01	0.006	0.013	0.018	0.044	90	
	6	2	0.011	0.001	0.0235	0.002	0.029	90	
	6	4	0.011	0.002	0.013	0.007	0.029	70	
	6	4	0.0075	0.001	0.032	0.009	0.017	80	
	6	6	0.012	0.009	0.017	0.011	0.016	70	Slice between 4" and 6" leak tested. No leak after 1.5 hrs.
	6	6	0.0115	0.0035	0.0325	0.003	0.1755	70	
	9	0.5	0.01	0.003	0.023	0.008	0.23	90	
	9	0.5	0.01	0.004	0.0425	0.021	0.023	90	
	9	1	0.007	0.007	0.027	0.02	0.017	90	
	9	1	0.012	0.003	0.041	0.0195	0.1545	80	
	9	2	0.009	0.005	0.012	0.013	0.013	98	
	9	2	0.01	0.003	0.027	0.0165	0.1455	90	
	9	4	0.005	0.002	0.009	0.024	0.084	90	
	9	4	0.006	0.002	0.0085	0.013	0.03	90	
	9	6	0.008	0.008	0.008	0.014	0.019	90	
	9	6	0.005	0.001	0.0445	0.002	0.1545	70	
ChemMasters Duraguard 401	11	0.5	0.013	0.002	0.008	0.004	0.162	10	
	11	0.5	0.013	0.0015	0.0135	0.005	0.055	10	
	11	1	0.001	0.001	0.001	0.006	0.049	5	
	11	1	0.017	0.002	0.0105	0.003	0.0605	5	
	11	2	0.016	0.0015	0.008	0.006	0.08	5	
	11	2	0.019	0.01	0.025	0.0065	0.071	1	
	11	4	0.015	0.006	0.0185	0.0055	0.22	5	
	11	4	0.017	0.0035	0.017	0.007	0.1695	5	

	11	6	0.019			0.006	0.0085	0	
	11	6	0.018	0.003	0.0075	0.003	0.00845	10	
	13	0.5	0.0135	0.0035	0.0115	0.005	0.0615	10	
	13	0.5							Split during slicing
	13	1							
	13	1	0.018	0.002	0.007	0.001	0.0415	25	
	13	2							
	13	2							
	13	4							
	13	4							
	13	6							
	13	6							
PolyCarb Mark 135	18	0.5	0.01	0.0045	0.023	0.0115	0.0355	90	
	18	0.5	0.009	0.001	0.0225	0.0065	0.0295	90	
	18	1	0.008	0.002	0.0205	0.013	0.0595	90	
	18	1	0.01	0.002	0.23	0.004	0.0655	80	
	18	2	0.008	0.0025	0.22	0.0035	0.0425	60	
	18	2	0.008	0.0015	0.016	0.0145	0.04	90	
	18	4	0.0075	0.001	0.0175	0.0045	0.0195	80	
	18	4	0.009	0.0015	0.0175	0.0035	0.0425	80	
	18	6	0.0115	0.003	0.0345	0.006	0.1235	70	
	18	6	0.01	0.002	0.014	0.004	0.0425	60	
	19	0.5	0.01	0.0035	0.0135	0.004	0.026	50	
	19	0.5	0.01	0.005	0.025	0.005	0.057	50	
	19	1	0.01	0.001	0.0085	0.0035	0.05	40	
	19	1	0.014	0.002	0.0145	0.0035	0.0345	40	
	19	2	0.011	0.001	0.0205	0.0065	0.0225	70	
	19	2	0.095	0.0035	0.0165	0.0035	0.063	50	
	19	4	0.011	0.005	0.027	0.003	0.3354	50	
	19	4	0.0105	0.004	0.016	0.0035	0.0325	70	
	19	6	0.016	0.0065	0.0145	0.002	0.045	30	
	19	6	0.0145	0.0035	0.0195	0.0045	0.0465	30	
Urefast R60	21	0.5	0.01	0.002	0.02	0.006	0.0155	80	
	21	0.5	0.0105	0.001	0.027	0.0025	0.2905	90	
	21	1	0.011	0.001	0.0285	0.0015	0.019	50	

	21	1	0.0115	0.0045	0.021	0.003	0.0855	50	
	21	2	0.008	0.0035	0.0175	0.0035	0.02715	30	
	21	2	0.0085	0.0045	0.021	0.004	0.221	40	
	21	4	0.0135	0.0015	0.025	0.003	0.034	30	
	21	4	0.0135	0.002	0.0265	0.004	0.0515	60	
	21	6	0.14	0.004	0.019	0.0045	0.0795	20	
	21	6	0.0165	0.005	0.025	0.002	0.09	80	
	22	0.5	0.0105	0.001	0.021	0.0035	0.0375	50	For most of the cylinder the sealant in the cracks was interrupted by many pockets and breaks in the material.
	22	0.5	0.0095	0.001	0.025	0.003	0.048	40	
	22	1	0.0105	0.0015	0.011	0.002	0.061	40	
	22	1	0.01	0.002	0.02	0.003	0.0245	20	
	22	2	0.0105	0.002	0.0155	0.003	0.079	20	
	22	2	0.01	0.001	0.027	0.001	0.0725	30	
	22	4	0.01	0.0005	0.015	0.001	0.031	30	
	22	4	0.011	0.001	0.0185	0.0015	0.013	50	
	22	6	0.014	0.0015	0.0235	0.002	0.3865	40	Large gap across 1/3 of crack length in this cut. Gap not included in crack width estimates.
	22	6	0.0105	0.0045	0.04	0.004	0.706	30	
Kwikbond KBF 204	26	0.5	0.008	0.003	0.0125	0.0025	0.0285	40	
	26	0.5	0.011	0.0015	0.012	0.0055	0.0875	40	
	26	1	0.012	0.0025	0.0115	0.004	0.073	20	
	26	1	0.0155	0.0035	0.0085	0.008	0.159	10	
	26	2	0.008	0.0035	0.012	0.0065	0.0034	30	
	26	2	0.0145	0.002	0.011	0.006	0.022	40	
	26	4	0.016	0.002	0.012	0.004	0.2015	20	
	26	4	0.0135	0.0015	0.0165	0.007	0.045	20	
	26	6	0.02	0.004	0.02	0.003	0.0139	10	
	26	6	0.016	0.07	0.023	0.007	0.085	10	
	27	0.5	0.01	0.001	0.019	0.005	0.051	40	
	27	0.5	0.015	0.0005	0.0305	0.007	0.025	30	

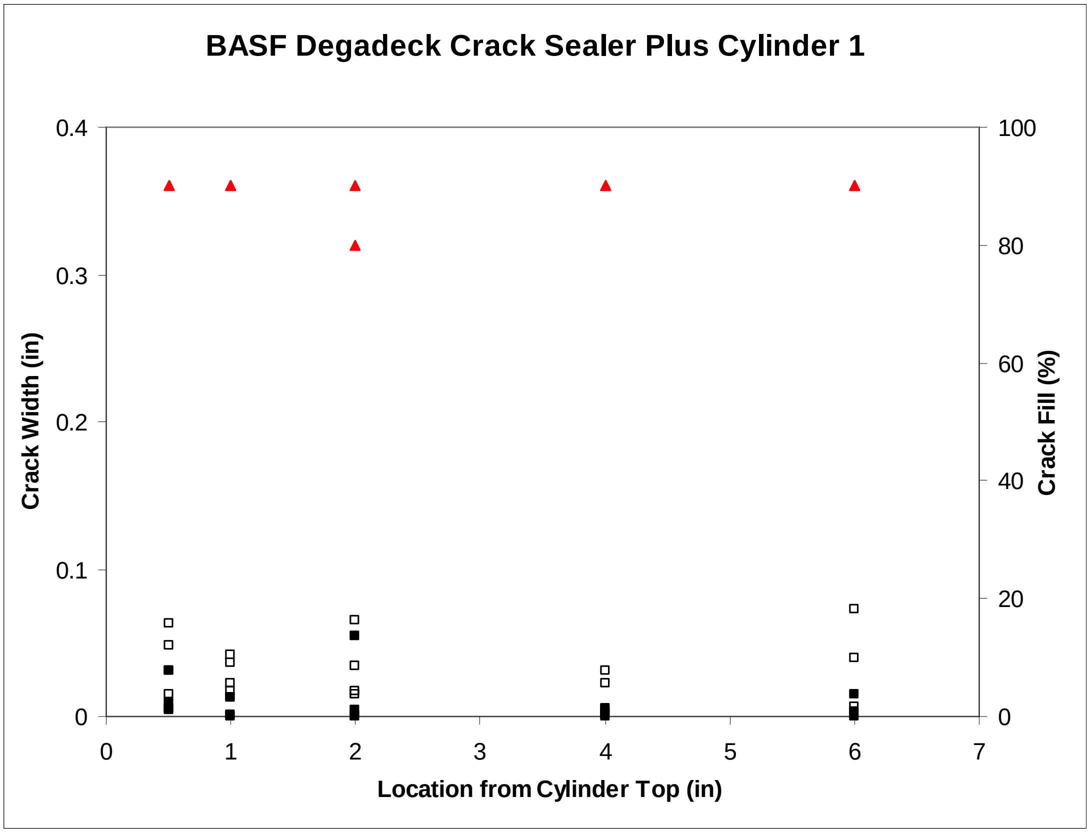
	27	1	0.0205	0.001	0.01	0.0065	0.0605	10	
	27	1	0.02	0.003	0.012	0.009	0.07	10	
	27	2	0.016	0.0075	0.0235	0.008	0.0885	10	
	27	2	0.017	0.0005	0.028	0.0065	0.0555	10	
	27	4	0.026	0.0065	0.017	0.0125	0.01785	5	
	27	4	0.0275	0.0105	0.025	0.0155	0.4085	5	
	27	6	0.0285	0.021	0.048	0.0175	0.062	20	
	27	6	0.022	0.0005	0.037	0.0085	0.073	5	
Transpo T-70	31	0.5	0.01	0.0035	0.0055	0.0045	0.0765	10	
	31	0.5	0.008	0.005	0.006	0.0035	0.09	30	
	31	1	0.008	0.005	0.0065	0.003	0.0755	40	
	31	1	0.014	0.001	0.005	0.003	0.045	10	
	31	2	0.014	0.0025	0.007	0.003	0.0505	10	
	31	2	0.0145	0.002	0.01	0.0045	0.101	30	
	31	4	0.0075	0.002	0.01	0.003	0.04	20	
	31	4	0.005	0.001	0.0105	0.0025	0.027	50	
	31	6	0.0135	0.001	0.011	0.005	0.231	40	
	31	6	0.01	0.001	0.007	0.002	0.297	40	
	32	0.5	0.022	0.005	0.016	0.003	0.074	10	
	32	0.5	0.018	0.005	0.0785	0.006	0.103	10	
	32	1	0.0185	0.002	0.017	0.005	0.069	20	
	32	1	0.015	0.003	0.008	0.002	0.057	20	
	32	2	0.011	0.0015	0.016	0.004	0.119	20	
	32	2	0.0215	0.0015	0.0275	0.004	0.094	20	
	32	4	0.012	0.0005	0.0175	0.003	0.038	10	
	32	4	0.0205	0.0025	0.0185	0.003	0.3625	5	
	32	6	0.0105	0.0005	0.0105	0.007	0.0595	10	
	32	6	0.0145	0.0005	0.012	0.0075	0.097	20	
Transpo T-70 MX30	36	0.5	0.0015	0.003	0.0135	0.008	0.1135	20	
	36	0.5	0.012	0.007	0.0175	0.009	0.0545	5	
	36	1	0.016	0.005	0.01	0.0065	0.053	5	
	36	1	0.012	0.006	0.0135	0.006	0.0365	5	
	36	2	0.011	0.0035	0.0135	0.0055	0.0775	5	
	36	2	0.015	0.006	0.016	0.005	0.1225	5	
	36	4	0.015	0.005	0.175	0.055	0.032	10	

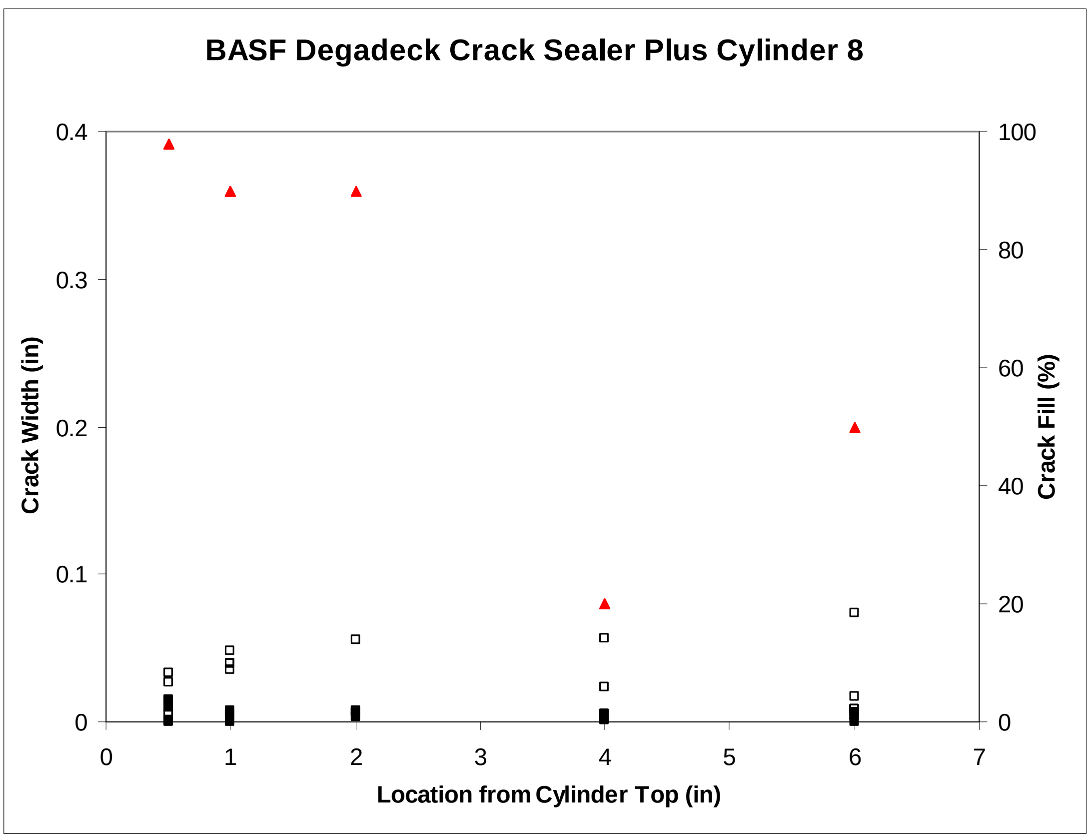
	36	4	0.015	0.003	0.011	0.008	0.047	5	
	36	6	0.011	0.001	0.013	0.0035	0.03	5	
	36	6	0.009	0.001	0.007	0.0055	0.086	5	
	39	0.5	0.016	0.004	0.005	0.0065	0.06	10	
	39	0.5	0.011	0.055	0.009	0.005	0.099	5	
	39	1	0.014	0.0035	0.013	0.006	0.0835	20	
	39	1	0.0135	0.002	0.01	0.006	0.069	20	
	39	2	0.012	0.001	0.013	0.005	0.068	20	
	39	2	0.015	0.001	0.017	0.0055	0.0115	20	
	39	4	0.015	0.008	0.009	0.004	0.092	5	
	39	4	0.019	0.002	0.013	0.007	0.1415	5	
	39	6	0.013	0.003	0.014	0.0065	0.0375	10	
	39	6	0.001	0.001	0.012	0.0045	0.0735	30	
Kwikbond Flex 30	41	0.5	0.009	0.001	0.022	0.0055	0.142	70	
	41	0.5	0.0085	0.0025	0.0155	0.0065	0.144	60	Slice between 0.5 and 1" leak tested. Leaked within 1 minute.
	41	1	0.0085	0.0075	0.021	0.006	0.055	60	
	41	1	0.0155	0.007	0.05	0.008	0.0635	50	Slice between 1 and 2" leak tested. Leaked within 1 minute.
	41	2	0.013	0.005	0.0395	0.0065	0.142	50	
	41	2	0.02	0.015	0.0225	0.0055	0.1575	20	
	41	4	0.025	0.004	0.0255	0.009	0.063	10	
	41	4	0.022	0.0145	0.0245	0.008	0.061	5	
	41	6	0.03	0.0005	0.0175	0.0215	0.118	5	
	41	6	0.0335	0.0105	0.0285	0.0145	0.234	5	
	43	0.5	0.0105	0.001	0.011	0.0075	0.037	60	
	43	0.5	0.0105	0.001	0.027	0.0055	0.0375	60	

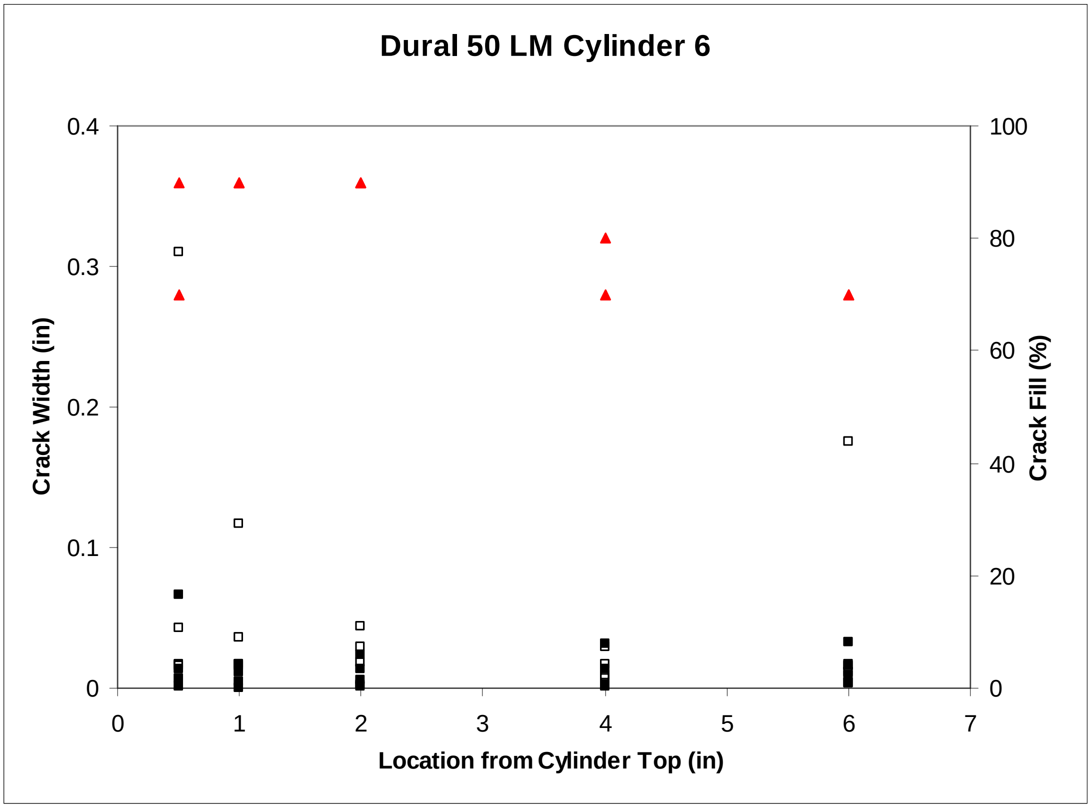
	43	1	0.011	0.0005	0.036	0.004	0.053	50	
	43	1	0.009	0.001	0.12	0.0065	0.0695	40	
	43	2	0.013	0.001	0.009	0.006	0.099	30	
	43	2	0.009	0.0015	0.0115	0.005	0.016	30	
	43	4	0.009	0.0015	0.02	0.004	0.053	50	
	43	4	0.0095	0.002	0.014	0.003	0.059	20	
	43	6	0.009	0.0015	0.012	0.005	0.06	50	
	43	6	0.011	0.0005	0.012	0.003	0.051	50	
Unitex Bridge Seal (70%)	46	0.5	0.013	0.002	0.0105	0.0085	0.0705	10	
	46	0.5							Split during slicing
	46	1							
	46	1	0.012	0.0045	0.0195	0.007	0.0835	10	
	46	2	0.017	0.0005	0.005	0.009	0.0915	5	
	46	2	0.012	0.0005	0.004	0.0025	0.1485	10	
	46	4	0.0155	0.006	0.01	0.003	0.075	5	
	46	4	0.0145	0.006	0.013	0.007	0.162	10	
	46	6	0.012	0.007	0.007	0.002	0.0875	5	
	46	6	0.0145	0.004	0.004	0.006	0.07	5	
	48	0.5	0.011	0.035	0.008	0.0005	0.0445	80	
	48	0.5	0.009	0.0015	0.0205	0.003	0.0825	70	
	48	1	0.011	0.0205	0.0075	0.0035	0.0745	50	
	48	1	0.01	0.0075	0.006	0.005	0.0435	40	
	48	2	0.011	0.012	0.012	0.0025	0.0275	70	
	48	2	0.009	0.0005	0.0105	0.0045	0.015	80	
	48	4	0.0095	0.0025	0.0085	0.004	0.045	80	
	48	4	0.0085	0.001	0.0175	0.0055	0.0355	70	Slice between 4 and 6" leak tested. No leak after 1.5 hours.
	48	6	0.0115	0.0045	0.0095	0.0065	0.058	60	
	48	6	0.0145	0.002	0.0095	0.0025	0.1185	30	
Sika Pronto 19TF	51	0.5	0.006	0.003	0.009	0.0025	0.0705	80	
	51	0.5	0.007	0.0005	0.0105	0.002	0.022	70	
	51	1	0.0135	0.001	0.0065	0.0035	0.063	10	

	51	1	0.0125	0.0025	0.008	0.0045	0.0515	10	
	51	2	0.0155	0.001	0.0085	0.003	0.13	10	
	51	2	0.017	0.0035	0.0085	0.008	0.0935	10	
	51	4	0.021	0.0065	0.0115	0.0045	0.0965		
	51	4							Split during slicing
	51	6							
	51	6	0.02	0.0075	0.0115	0.0085	0.0795	5	
	52	0.5	0.06	0.0005	0.0215	0.0035	0.018	60	
	52	0.5	0.0035	0.0005	0.003	0.0025	0.09	60	
	52	1	0.003	0.0005	0.004	0.002	0.1175	60	
	52	1	0.003	0.0025	0.007	0.0005	0.118	30	
	52	2	0.006	0.0005	0.004	0.0005	0.056	20	
	52	2	0.01	0.0005	0.006	0.0025	0.027	30	
	52	4	0.013	0	0	0.0025	0.0805	0	
	52	4	0.01	0.0025	0.008	0.004	0.0415	5	
	52	6	0.045	0	0	0.0165	0.1205	0	
	52	6	0.015	0.0075	0.0085	0.006	0.113	5	

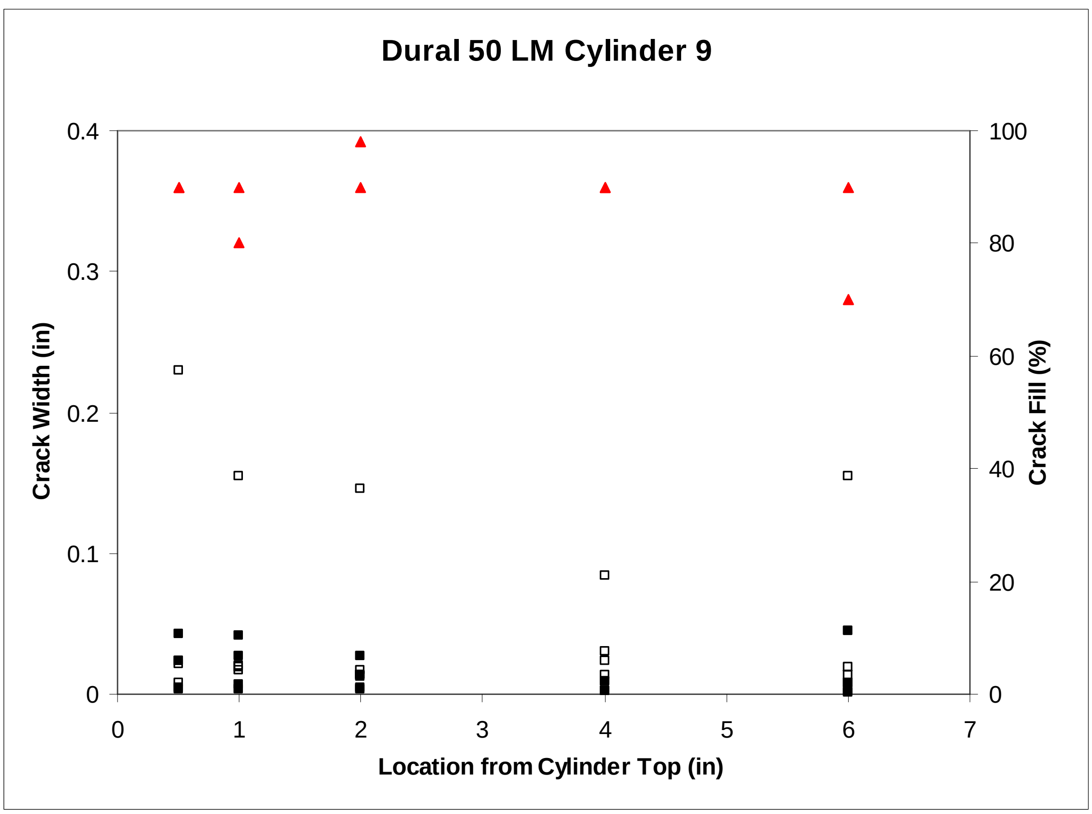
APPENDIX C:
GRAPHS OF CRACK SEALER DATA


BASF Degadeck Crack Sealer Plus Cylinder 1
Crack Width (in)
Crack Fill (%)
Location from Cylinder Top (in)

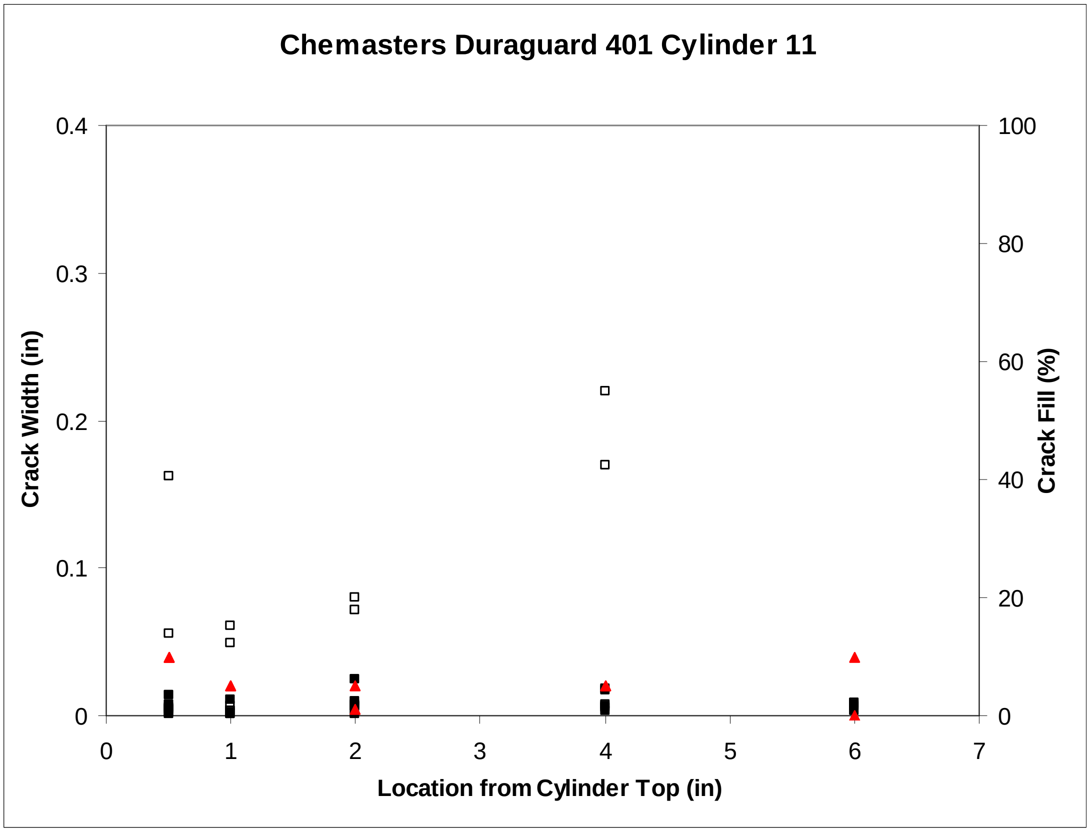

BASF Degadeck Crack Sealer Plus Cylinder 8
Crack Width (in)
Crack Fill (%)
Location from Cylinder Top (in)

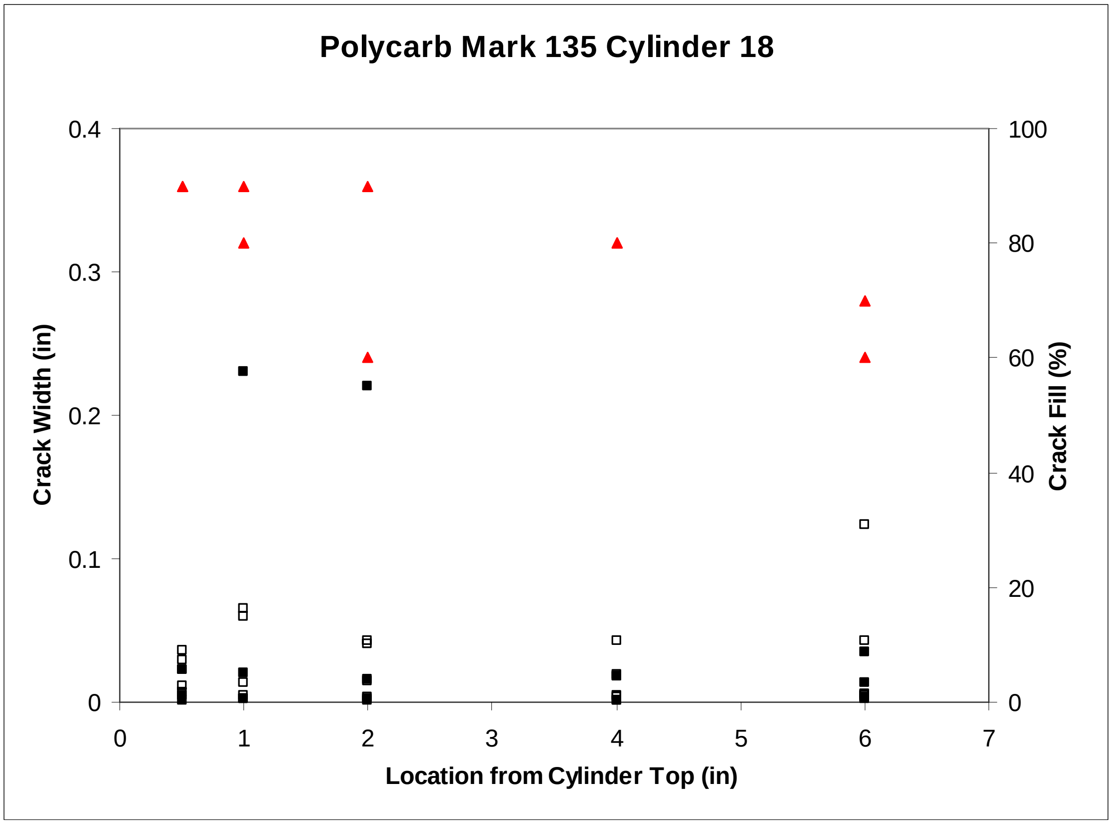


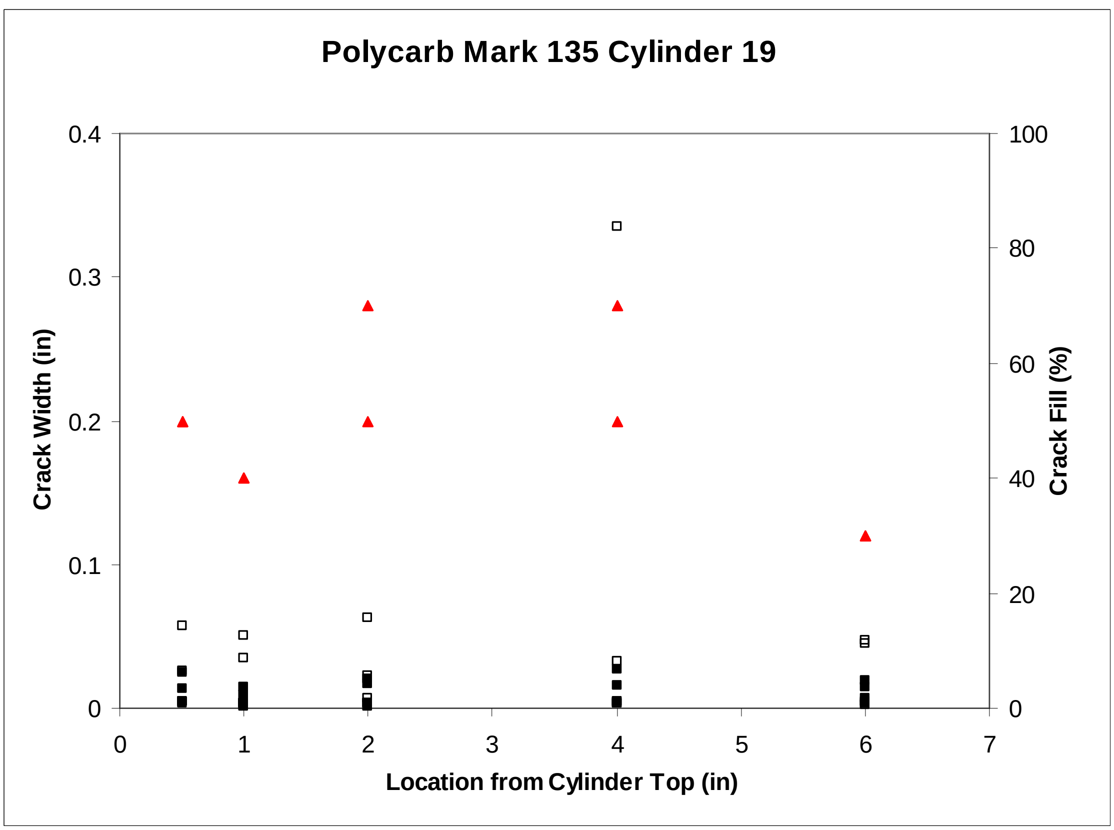
Dural 50 LM Cylinder 6
Crack Width (in)
Crack Fill (%)
Location from Cylinder Top (in)
0.4
0.3
0.2
0.1
0
100
80
60
40
20
0
0
1
2
3
4
5
6
7

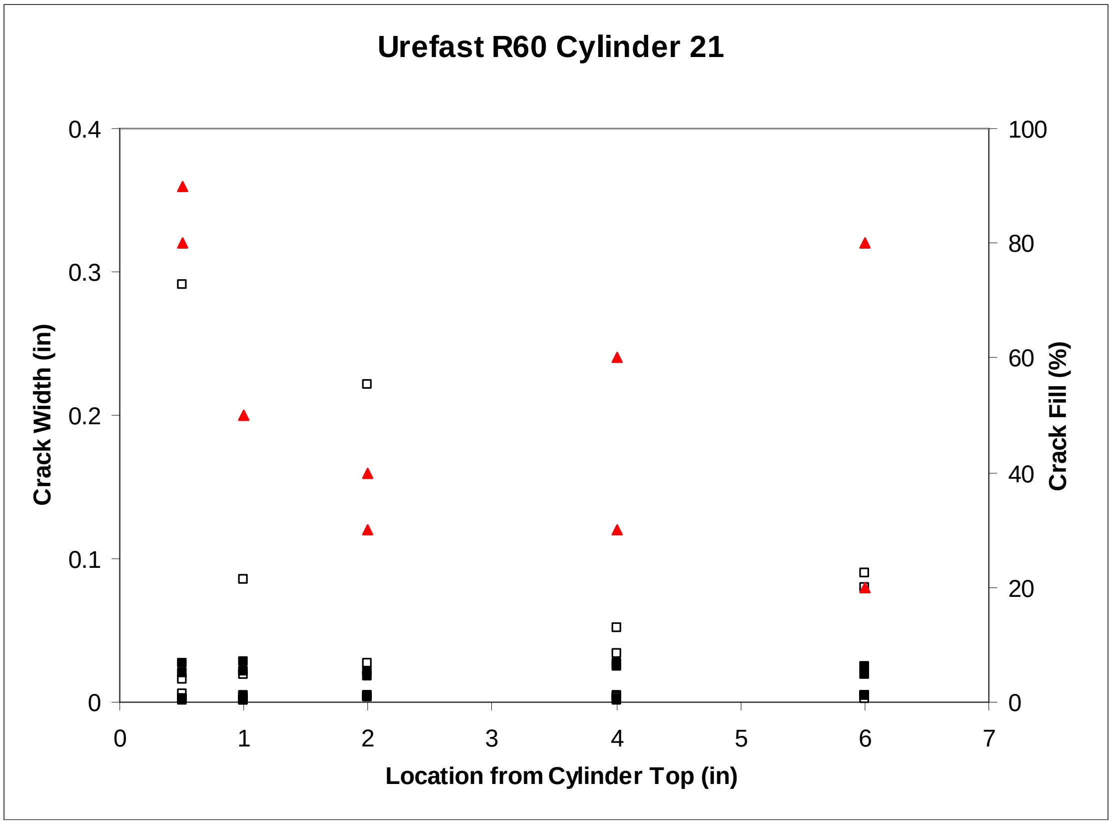


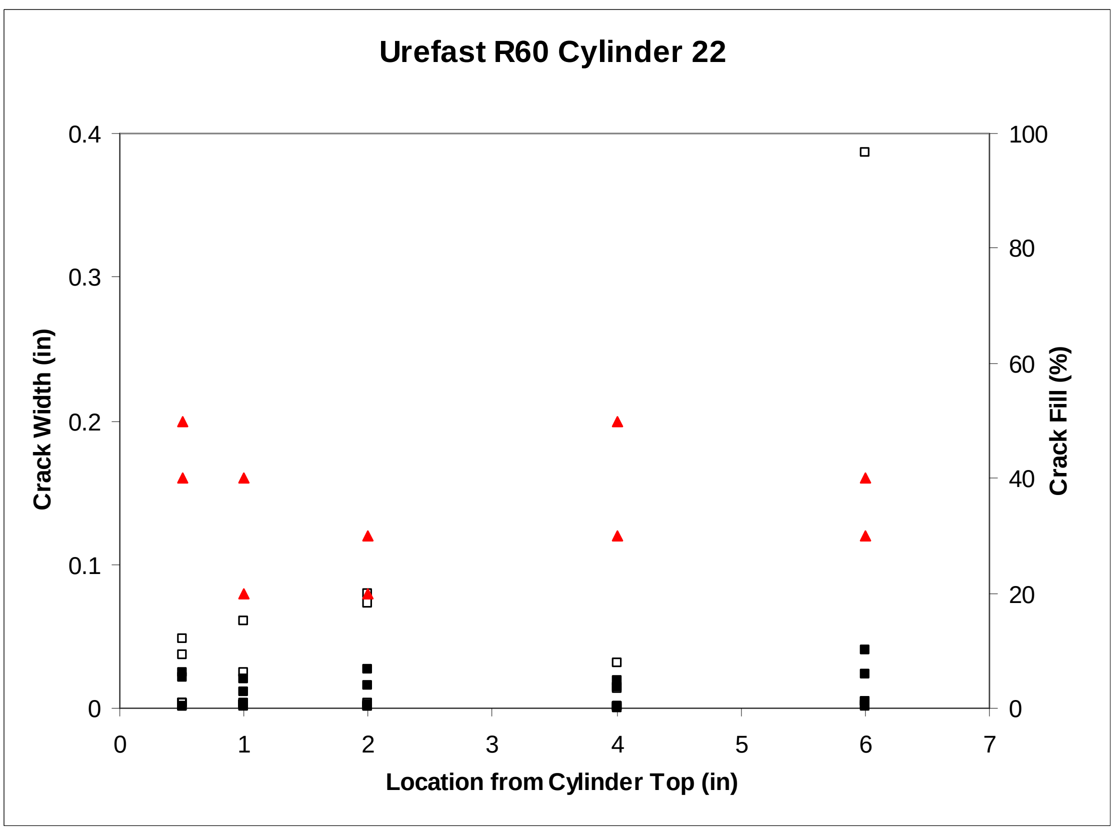
Dural 50 LM Cylinder 9
Crack Width (in)
Crack Fill (%)
Location from Cylinder Top (in)
0.4
0.3
0.2
0.1
0
100
80
60
40
20
0
0
1
2
3
4
5
6
7

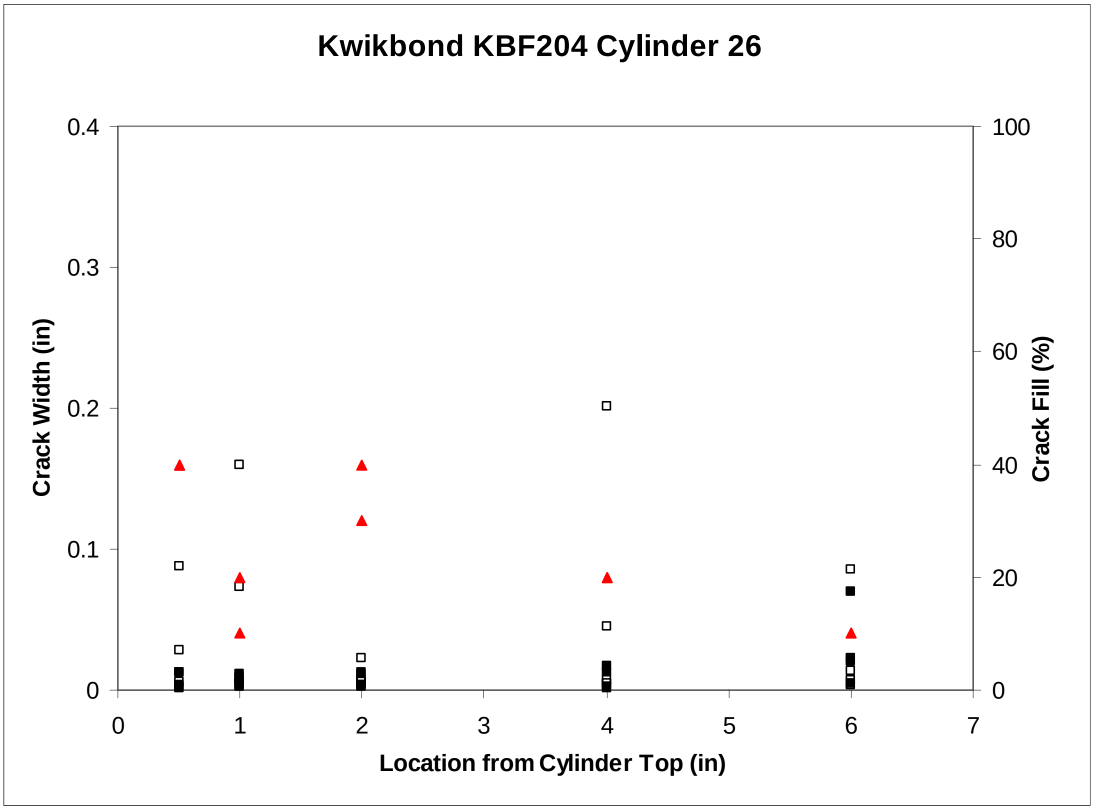

Chemasters Duraguard 401 Cylinder 11
0.4
0.3
0.2
0.1
0
Crack Width (in)
100
80
60
40
20
0
Crack Fill (%)
0
1
2
3
4
5
6
7
Location from Cylinder Top (in)

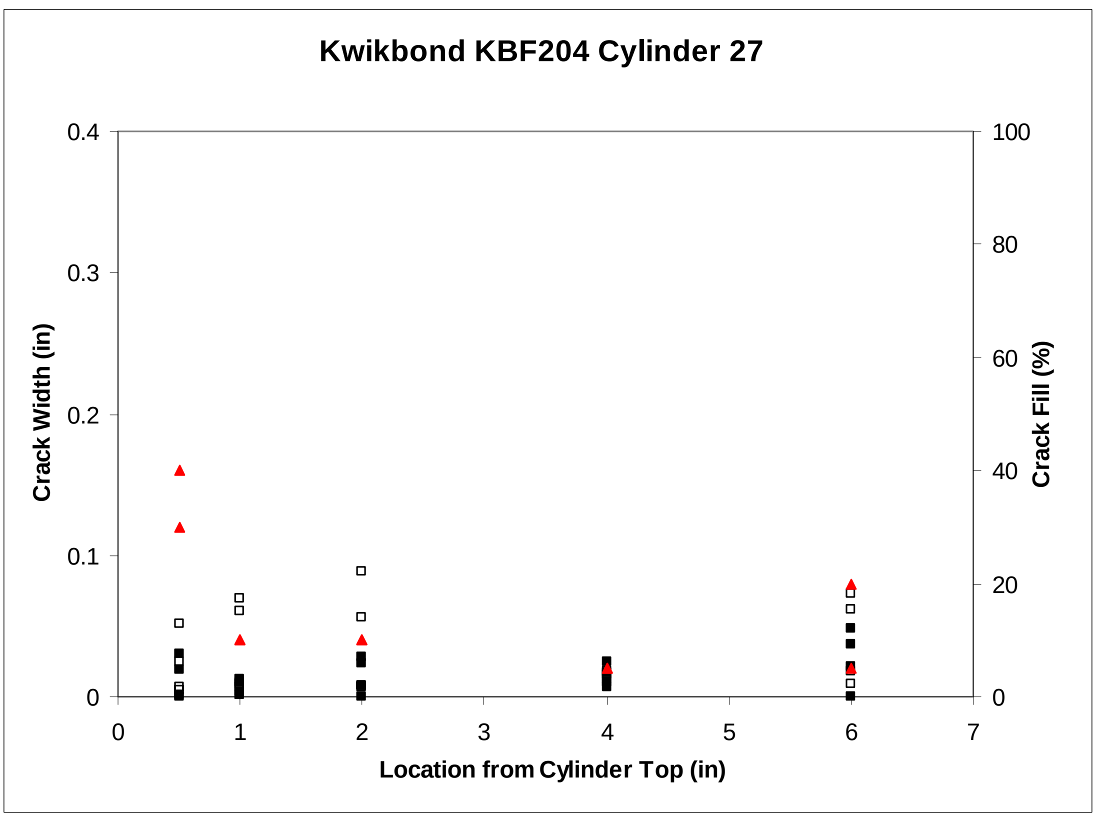

Polycarb Mark 135 Cylinder 18
Crack Width (in)
Crack Fill (%)
Location from Cylinder Top (in)
0.4
0.3
0.2
0.1
0
100
80
60
40
20
0
0 1 2 3 4 5 6 7

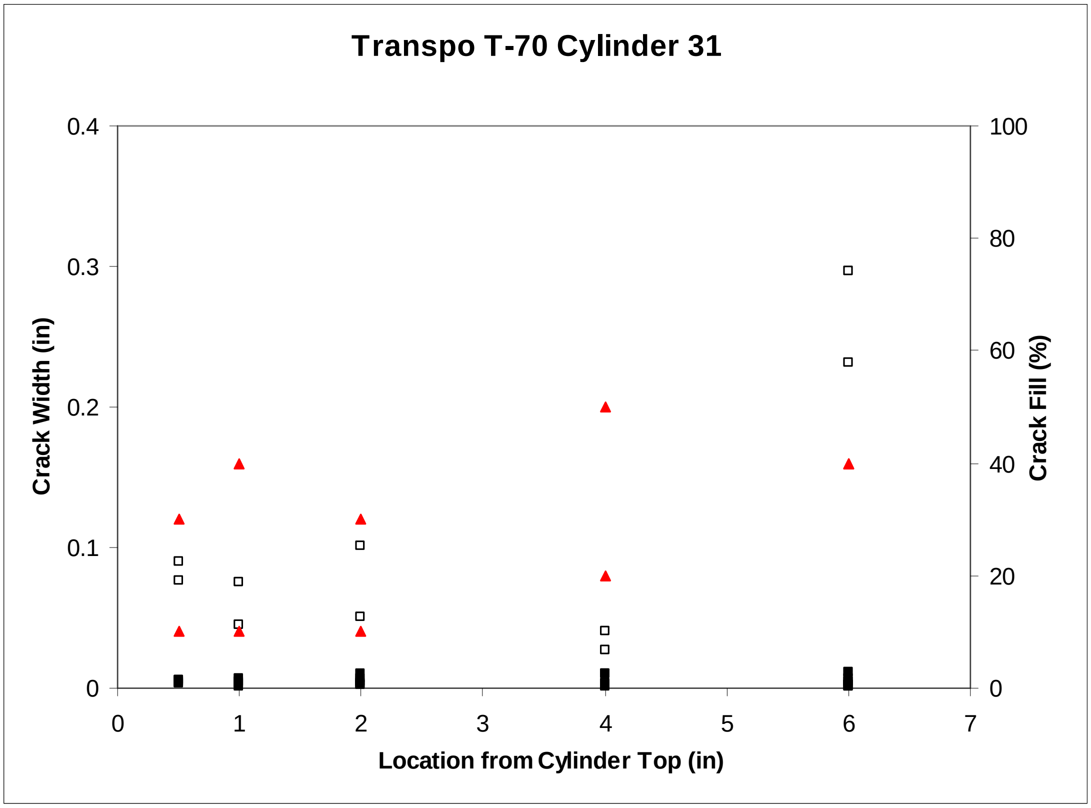

Polycarb Mark 135 Cylinder 19
Crack Width (in)
Crack Fill (%)
Location from Cylinder Top (in)
0.4
0.3
0.2
0.1
0
100
80
60
40
20
0
0 1 2 3 4 5 6 7

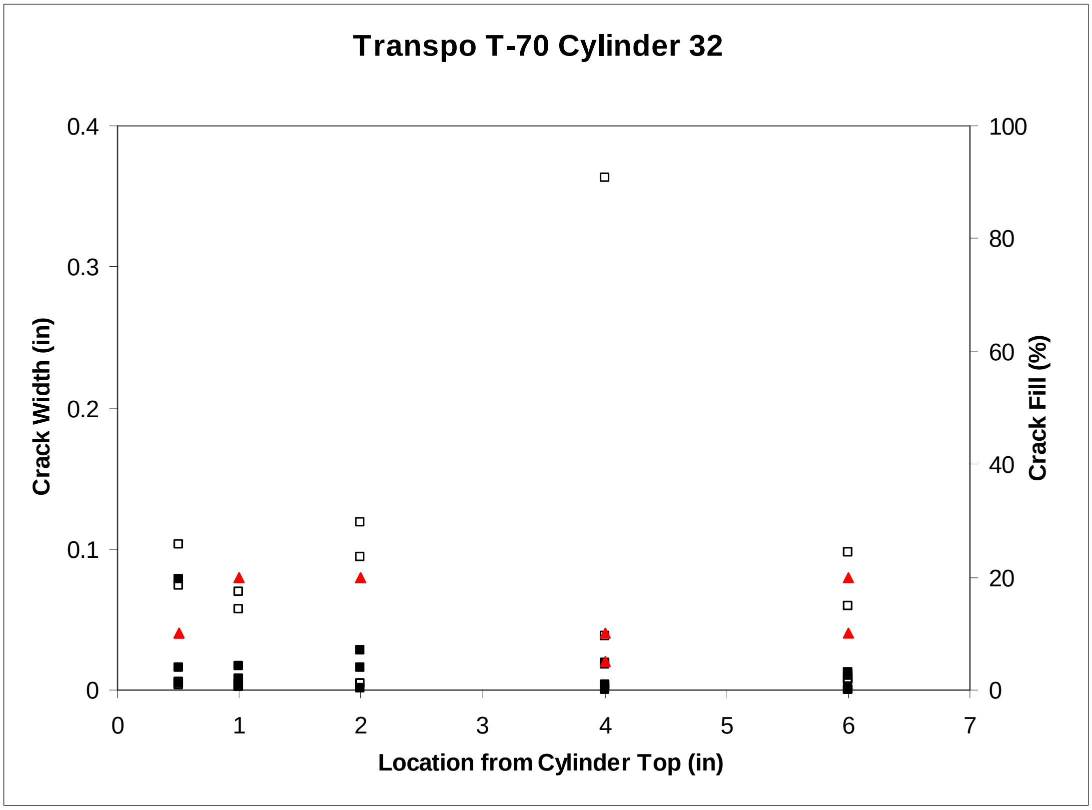

Urefast R60 Cylinder 21
Crack Width (in)
0.4
0.3
0.2
0.1
0
Crack Fill (%)
100
80
60
40
20
0
0 1 2 3 4 5 6 7
Location from Cylinder Top (in)

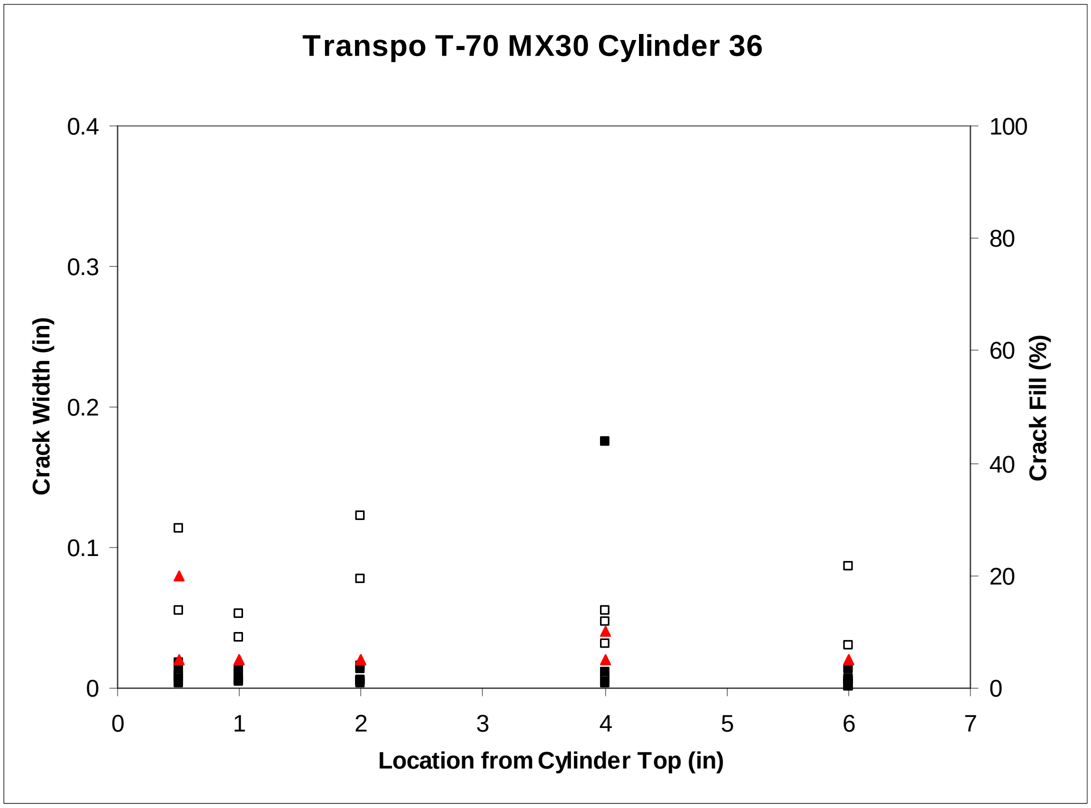

Urefast R60 Cylinder 22
Crack Width (in)
0.4
0.3
0.2
0.1
0
Crack Fill (%)
100
80
60
40
20
0
0 1 2 3 4 5 6 7
Location from Cylinder Top (in)


Kwikbond KBF204 Cylinder 26
0.4
0.3
0.2
0.1
0
Crack Width (in)
100
80
60
40
20
0
Crack Fill (%)
0
1
2
3
4
5
6
7
Location from Cylinder Top (in)

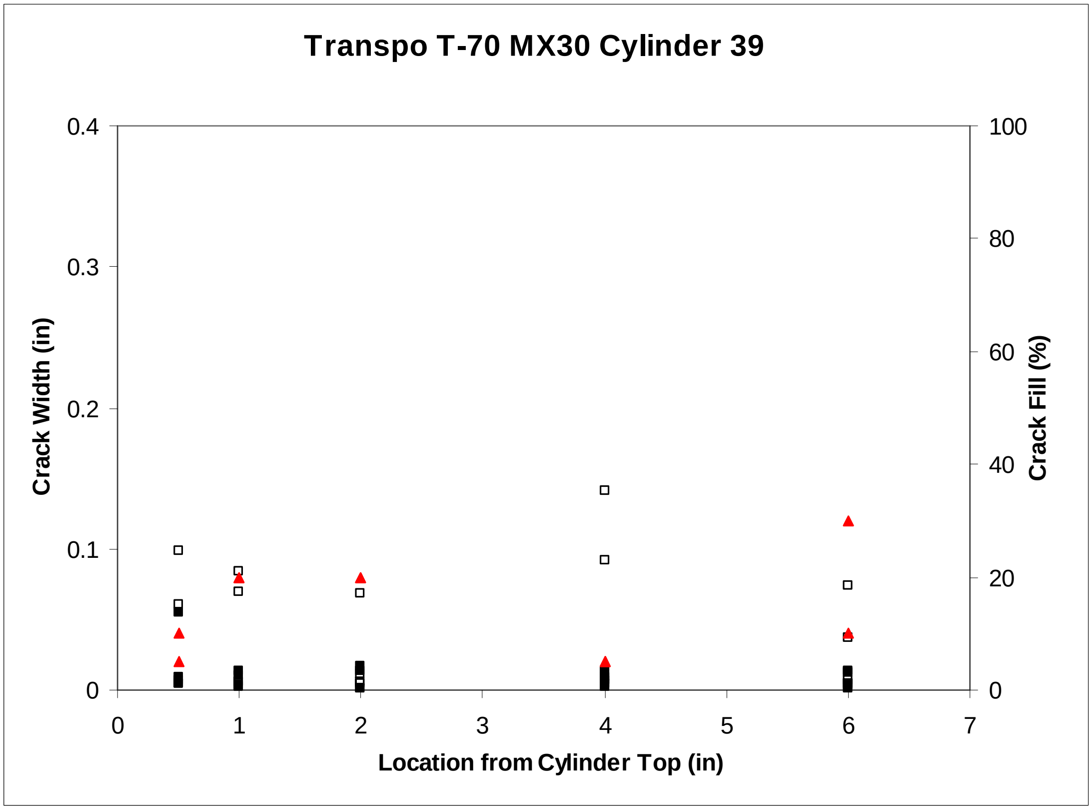

Kwikbond KBF204 Cylinder 27
0.4
0.3
0.2
0.1
0
Crack Width (in)
100
80
60
40
20
0
Crack Fill (%)
0
1
2
3
4
5
6
7
Location from Cylinder Top (in)


Transpo T-70 Cylinder 31
Crack Width (in)
Crack Fill (%)
Location from Cylinder Top (in)
0.4
0.3
0.2
0.1
0
100
80
60
40
20
0
0 1 2 3 4 5 6 7

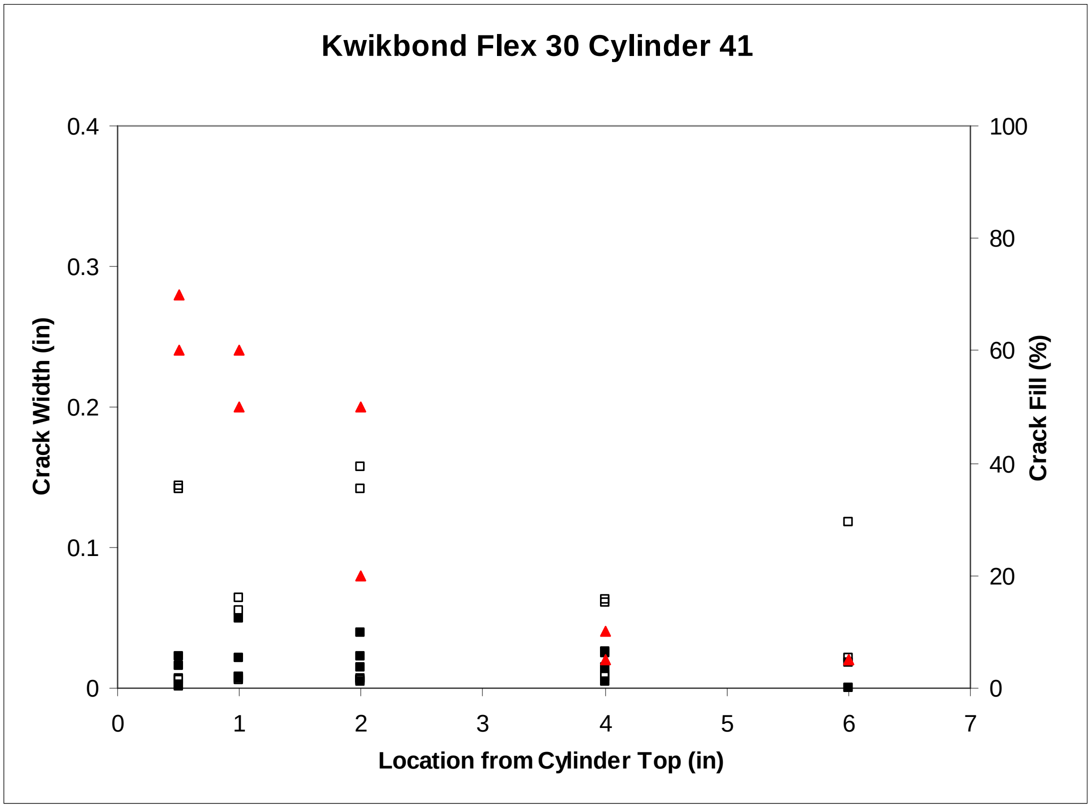

Transpo T-70 Cylinder 32
Crack Width (in)
Crack Fill (%)
Location from Cylinder Top (in)
0.4
0.3
0.2
0.1
0
100
80
60
40
20
0
0 1 2 3 4 5 6 7



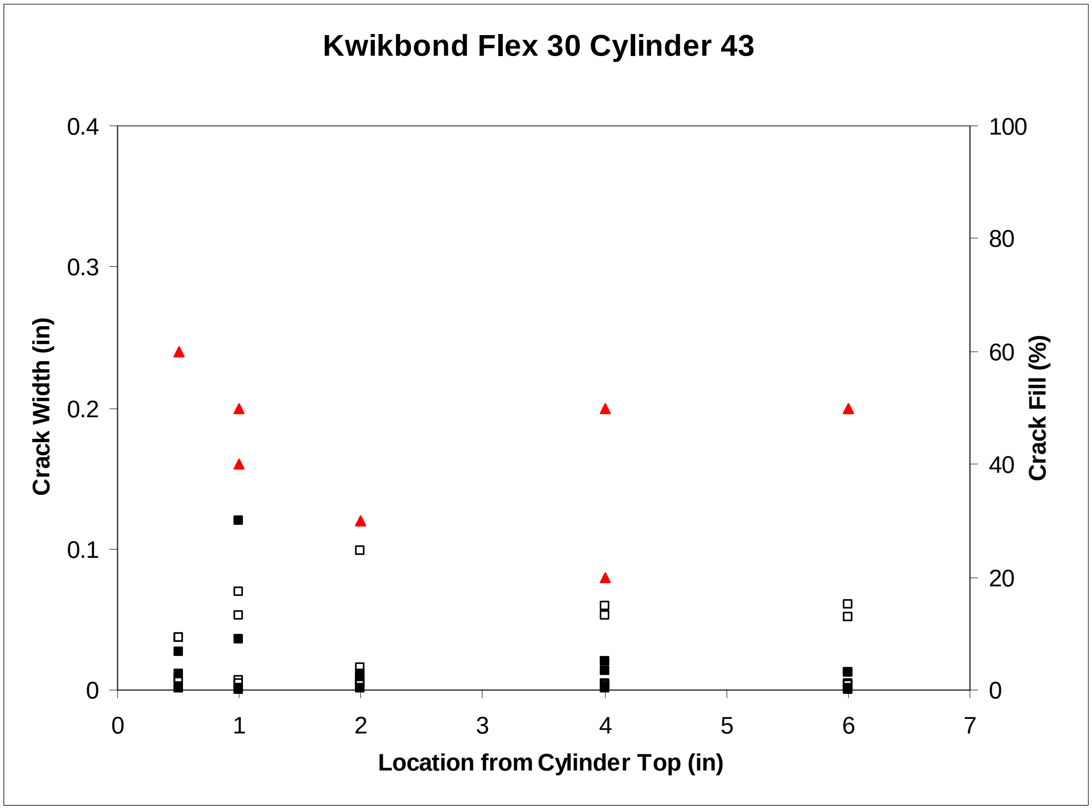
Transpo T-70 MX30 Cylinder 36
Crack Width (in)
Crack Fill (%)
Location from Cylinder Top (in)
0.4
0.3
0.2
0.1
0
100
80
60
40
20
0
0
1
2
3
4
5
6
7



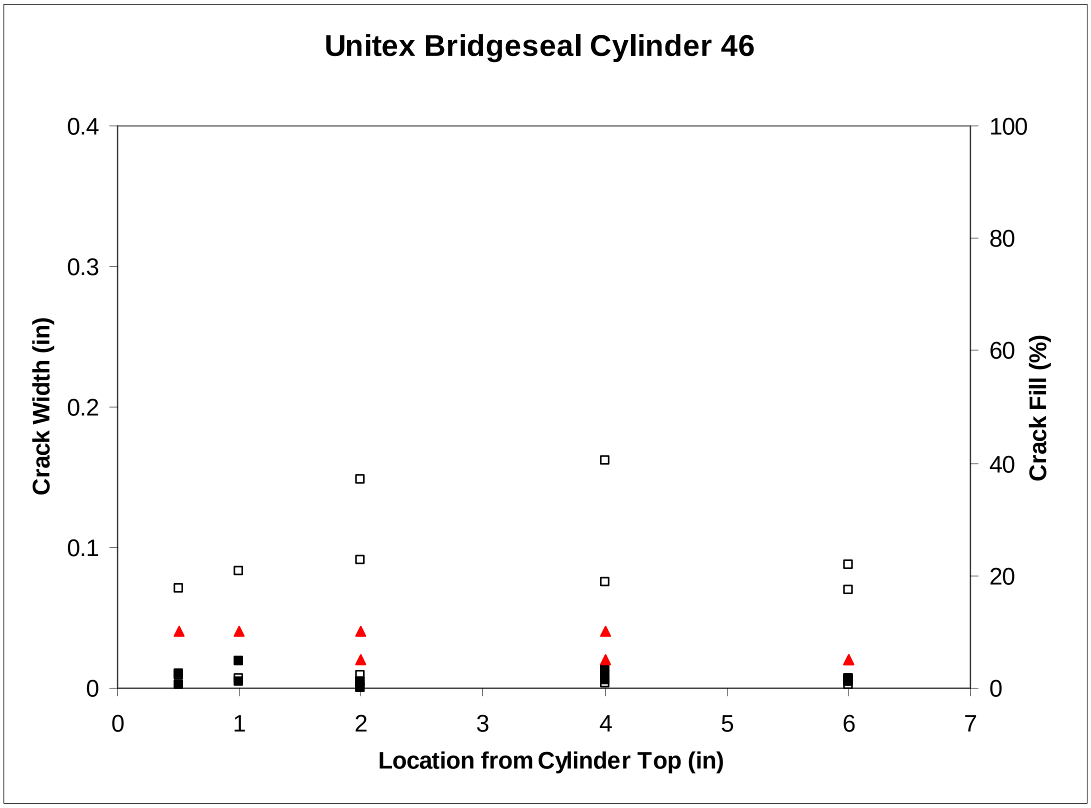
Transpo T-70 MX30 Cylinder 39
Crack Width (in)
Crack Fill (%)
Location from Cylinder Top (in)
0.4
0.3
0.2
0.1
0
100
80
60
40
20
0
0
1
2
3
4
5
6
7

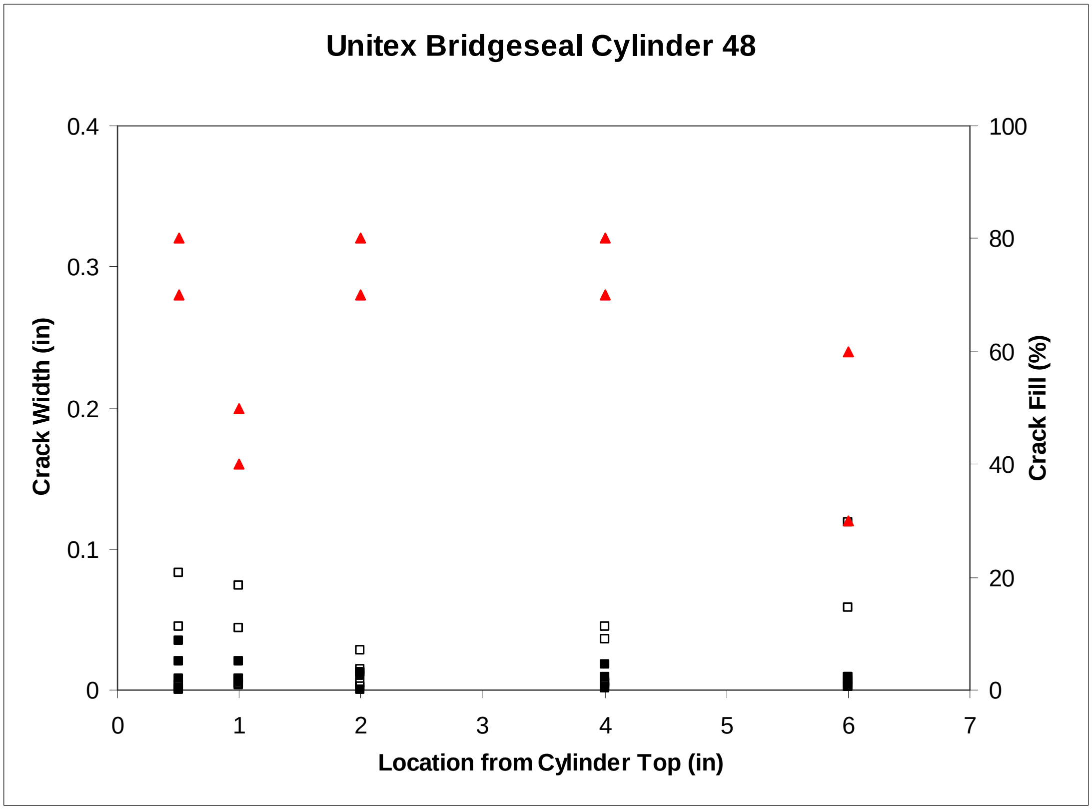


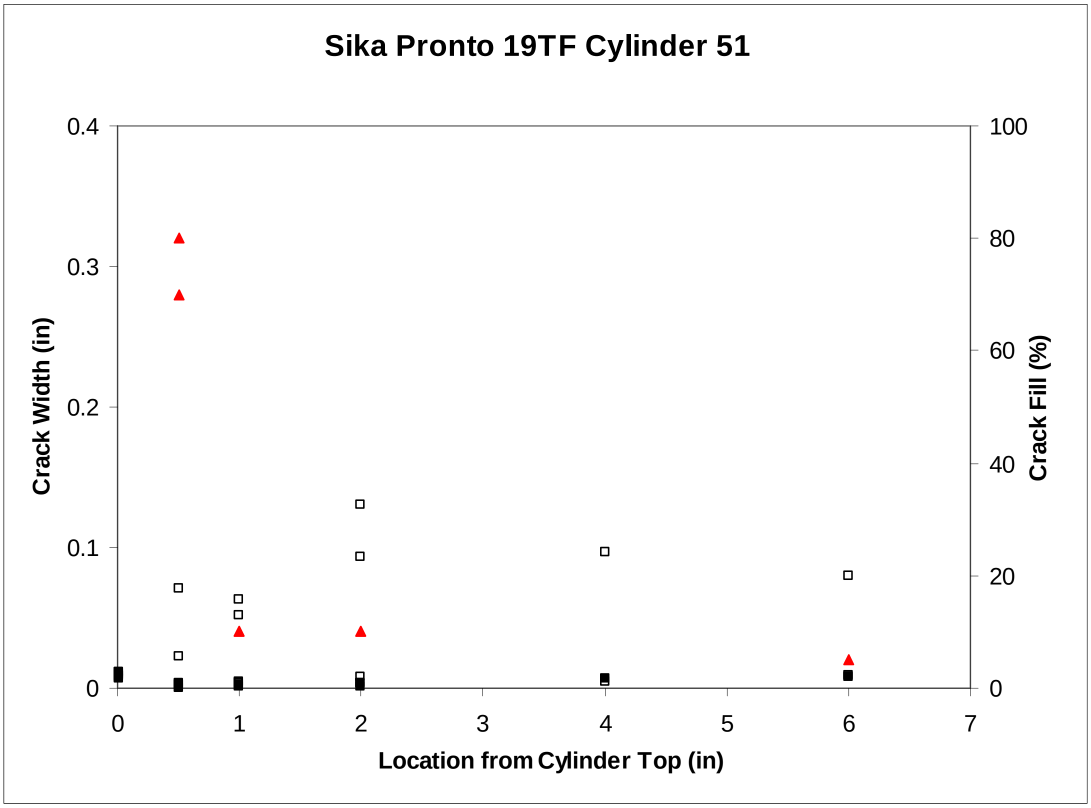
Kwikbond Flex 30 Cylinder 41
Crack Width (in)
Crack Fill (%)
Location from Cylinder Top (in)
0.4
0.3
0.2
0.1
0
100
80
60
40
20
0
1
2
3
4
5
6
7

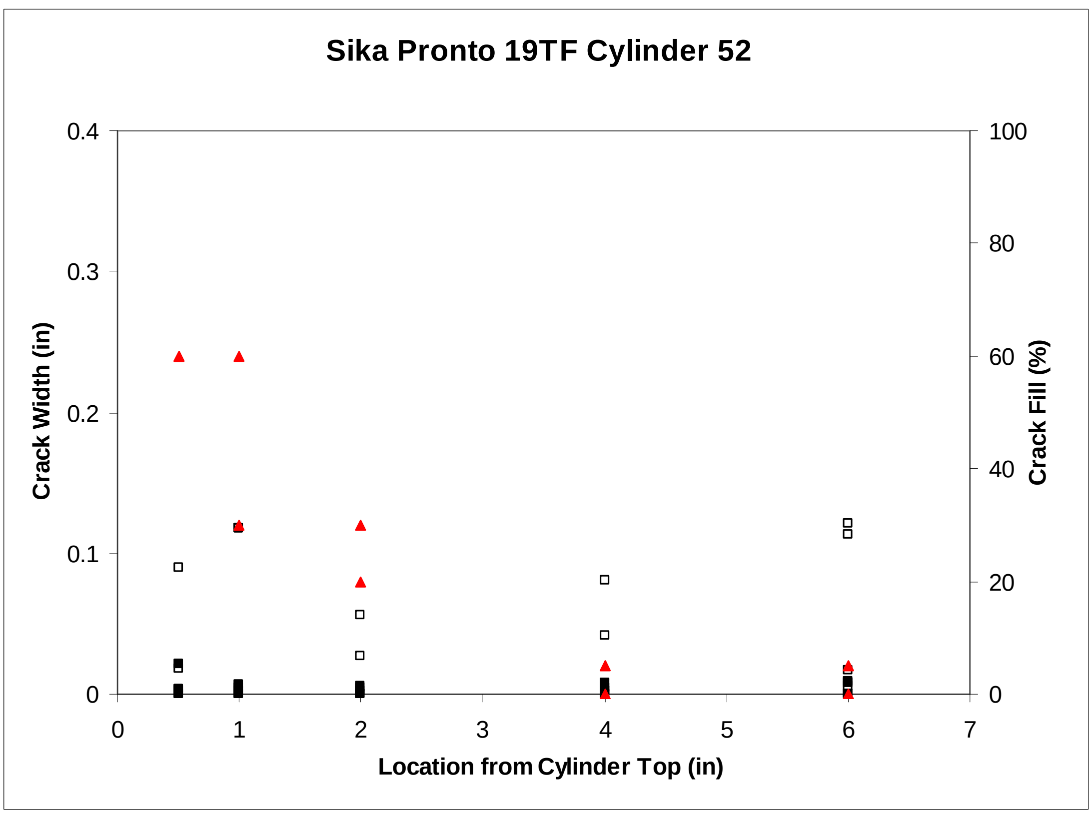


Kwikbond Flex 30 Cylinder 43
Crack Width (in)
Crack Fill (%)
Location from Cylinder Top (in)
0.4
0.3
0.2
0.1
0
100
80
60
40
20
0
1
2
3
4
5
6
7


Unitex Bridgeseal Cylinder 46
Crack Width (in)
Crack Fill (%)
Location from Cylinder Top (in)
0.4
0.3
0.2
0.1
0
100
80
60
40
20
0
0 1 2 3 4 5 6 7


Unitex Bridgeseal Cylinder 48
Crack Width (in)
Crack Fill (%)
Location from Cylinder Top (in)
0.4
0.3
0.2
0.1
0
100
80
60
40
20
0
0 1 2 3 4 5 6 7


Sika Pronto 19TF Cylinder 51
Crack Width (in)
Crack Fill (%)
Location from Cylinder Top (in)
0.4
0.3
0.2
0.1
0
100
80
60
40
20
0
0
1
2
3
4
5
6
7


Sika Pronto 19TF Cylinder 52
Crack Width (in)
Crack Fill (%)
Location from Cylinder Top (in)
0.4
0.3
0.2
0.1
0
100
80
60
40
20
0
0
1
2
3
4
5
6
7