Technical Research

A Comparison of Cured-In-Place Pipe (CIPP) Mechanical Properties: Laboratory vs. Field-Manufactured

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ABSTRACT

In the Cured-in-Place Pipe (CIPP) market, the mechanical properties of the rehabilitated line are important critera for resin selection and the determination of a project's success. Municipalities often have minimum requirements the CIPP must meet (Table 1). Resin suppliers normally report mechanical properties from laboratory-generated samples while the contractor measures results from field-generated samples. Typically, laboratory samples give higher physical properties than field-generated samples. This research examined the differences in properties between these samples.

INTRODUCTION

Cured-In-Place Pipe technology has been employed worldwide for more than 30 years. It is one of several options available for rehabilitating and upgrading underground municipal and industrial pipe infrastructure. Rehabilitating pipes by using thermoset polyester resins and polyester felt (CIPP) usually requires satisfying predetermined specifications for materials and installation. In the United States, these specifications customarily follow the standards published by the American Society for Testing and Materials International (ASTM International). The customer (i.e. municipality engineer, industrial business engineer, etc.) may also invoke specific material and/or process requirements such as special chemical resistance, strength requirements, and/or installation equipment contingencies.

Several issues have arisen over the years in the correlation of the properties of laboratory-produced coupons to those of field samples. The focus was to determine the major factors influencing the ultimate physical properties, compare those factors relating to the laboratory and field samples, and then explain why the field samples have lower strengths. The ultimate goal was to determine the parameter(s) that must be controlled for laboratory-manufactured samples to duplicate field sample results. This will allow the creation of more realistic, achievable standards and give raw material manufacturers a more realistic composite to test for retention of properties.

EXPERIMENTAL

The resin/felt composites were constructed by impregnating 0.24 in. (6 mm), needle-punched, polyester fabric felt with an applicable resin/initiator system. The composites were cured in a clamped mold, incorporating precision spacers, in a time/temperature programmable hot air oven. The composites were subjected to 110°F (43°C) for four hours, followed by 180°F (82°C) for 16 hours, and then cooled to 77°F (25°C) before demolding.

Static flexural physical properties of the panels were tested according to ASTM D790 and ASTM D638 on an Instron Model 4505 Universal Tester. The coupon thicknesses were measured with a Starrett micrometer. The coupon weights for the specific gravity measurements were measured with a Mettler AE160 scale with an accuracy of 0.0002 grams.

The degree of cure was measured with a TA DSC 1000. A sample size of 5 to 15 milligrams was weighed and sealed in the DSC aluminum sample pan. The samples were scanned from 32°F (0°C) to 399°F (200°C) at 18°F (10°C) per minute. The samples were rescanned to ensure all the energy was released on the first scan.

The resin-to-felt ratios were calculated using the felt manufacturer's theoretical air content per designed felt thickness. The average thickness of the specimens was used for the flexural and tensile static physical properties. The theoretical air content is 86.2% for the felt/resin system. Using the actual thickness of the felt and the final composite thickness determined the percent compression of the felt. The reduction in theoretical air content and ultimate air void space was determined and used to calculate the resin-to-felt ratio. We assumed that there is no entrained air in the composite.

The resin system used in this work is a typical filled isophthalic resin designed especially for CIPP applications. The isophthalic polymer is a two-stage, 1:1 isophthalic acid:maleic anhydride, all-propylene glycol that has been commonly used in corrosion applications.

The panels constructed in the laboratory were made between two, 1/8-inch (3.2 mm)-thick steel plates. The felt was saturated with the resin system then placed between two pieces of Mylar® film. All the bubbles were removed from the surface and then the panel was placed in a plastic bag. The bag was sealed and placed between the steel plates. One-quarter inch-thick (6 mm) spacers were placed between the steel plates, and several clamps were positioned around the edges to maintain the thickness during curing.

The thinner laboratory-constructed panels were made in the same manner, except the spacers were not used and varying amounts of clamping pressure was used.

RESULTS AND DISCUSSION

The testing and measurement data collected are compiled in Tables 2 and 3. The field-generated samples are labeled F-1 to F-10. The properties of the 10 samples in this study appear tightly grouped together. This infers that the processes used in the field create similar finished composites and are fairly consistent job-to-job. The remainder of the analysis is focused on the flexural and tensile properties and the factors that influence them.

The laboratory-manufactured samples are labeled L-1 to L-3. These three samples all have significantly higher flexural strengths than the field-generated samples. The flexural moduli are on the high end of the range of the field-manufactured samples, but the tensile strengths and tensile moduli fall within the range of the 10 field samples.

One theory tested was that a lower degree of cure in the field generated samples would cause the lower physical properties compared to the laboratory samples. An X-Y plot of the degree of cure verses flexural strength is shown in Figure 1. All of the samples, field and laboratory, were grouped between 95 and 100, which is satisfactory and a high level of cure. The points do not show any signs of having a relationship to each other.

Similar X-Y plots showing no relationship between the degree of cure and the flexural modulus, tensile strength, and tensile modulus data were also found. These results correlate with previous work relating the degree of cure to ultimate static physical properties. Results showed that specimens having a degree of cure over 85% had achieved their maximum flexural and tensile properties.

The next theory tested was whether differences in the percentage of resin in the felt caused the lower field values. This was done by analyzing the physical property data and the resin content. The resin content had to be calculated because standard tests used on composites, such as burnout, would not work. The resin and felt are hydrocarbon-based and have similar flammability.

Under ideal controlled conditions, the resin-to-felt ratio is 86.2:13.8. When no pressure was put on the molds in the laboratory samples, the felt achieved full saturation. The laboratory samples that were compressed and the field samples yielded lower resin-to-felt ratios. Cross sections of the laboratory and field samples were inspected for voids/entrained air and none was visible. Based on that, the assumption that there was minimal to no entrained air in the composite was validated

The X-Y plots of the resin ratio compared to physical properties (flexural strength, flexural modulus, tensile strength, and tensile modulus) are shown in Figures 2, 3, 4, and 5 respectively. These plots illustrate that there is no apparent relationship between the percent resin in the composite and its physical properties.

A general observation was made after viewing the test samples, that the surfaces of the field panels were rough and/or irregular, as well as resin-starved in some cases. Four representative field samples can be seen in Figure 6. Sample A is a flat panel; and samples B, C, and D are curved sections of pipe. The laboratory-manufactured samples have a smooth, uniform, and resin-rich surface. Panel A in Figure 7 is a representative picture.

A new theory was postulated that the poor surfaces of the field-generated panels were contributing to the lower values. This theory was based on the knowledge that test panels with flaws on their edges can decrease physical properties. When these flaws cover the whole panel, the decrease in properties may be even more pronounced. Compared to the smooth lab samples, the rough and irregular surface of the field samples creates points where cracks can easily propagate, causing premature failure.Two other differences were observed after inspecting several broken laboratory and field specimens - the ultimate bend in the specimen and the number of visible cracks.

The surface quality theory was tested by roughing the surface of a laboratory-made panel with a coarse sand paper to create surface flaws. Panel B in Figure 7 is one such panel. The scratches made by the sandpaper are more visible in the close-up photograph on the right.

Views of failed smooth and roughened specimens are shown in Figures 8 and 9. Several thin cracks are seen in the smooth panel and only three thick cracks are seen in the roughened panel. Arrows have been inserted to point out the cracks that formed during testing. The lower photograph in Figure 9 shows that six, narrow, visible cracks occurred during the test in the smooth laboratory specimen. The upper photograph in Figure 9 shows the roughened laboratory specimen with three, broader, cracks. Typically the smooth samples had six or more cracks, while the roughened ones had three or four.

Figure 10 contains two side views each of the smooth and roughened laboratory flexural specimens. The smooth laboratory specimen bent more than 50% further than the roughened specimen before failure in the three point flexural bend. All of the smooth laboratory samples had a similar large bend. Every one of the roughened samples had a similar small bend. This difference may be attributed to the resin-rich surface that may be adding some toughness to the surface. The difference could also be related to the numerous surface flaws and their contribution to the failure of the specimens.

The test results on a smooth and a roughened panel are compiled in Table 4 and the analysis of the data shows a 20% and 5% drop in the flexural strength and modulus respectively. This decrease was created with only a minor disruption of the surface. Incorporating a large number and variety of surface deformations, as seen in the field samples, could cause even lower values. The flexural strength and modulus test results on the roughened sample are in the top side of the range seen in the field samples presented in Table 2.

CONCLUSIONS

1. The processes used in the field to create the samples are fairly consistent from job-to-job.

2. The field application of the CIPP process generates a high degree of cure in the composite.

3. The variation found in the degree of cure seen in the samples does not cause any of the differences seen in the physical properties of the composite.

4. The tensile properties are not influenced by the percent of resin in the composite.

5. The tensile properties are not influenced by differences in the surface quality.

6. The flexural properties are not influenced by the percent of resin system in the composite.

7. Surface quality only has a minor effect on the flexural modulus.

8. Surface quality has a major effect on the flexural strength.

FUTURE RESEARCH

This work shows that changes in the surface to replicate the field samples allows us to more closely duplicate in the laboratory the field samples' properties.

1. Evaluate a variety of processes to simulate in the laboratory the methods that can cause the surface irregularities in the field.

2. Determine if surface irregularities effect the corrosion resistance and 10,000 hour creep testing.

REFERENCE

The original paper, of the same title, was first published in 2007, by David Herzog, Anthony J. Bennett, Kaleel Rahaim, and Jason D. Schiro, on behalf of Interplastic Corporation. It is available from the American Composites Manufacturing Association (ACMA).

Table 1: Minimum Physical Property Requirements of Cured Resin/Felt Composites

	FLEXURAL STRENGTH psi (MPa)	FLEXURAL MODULUS psi (MPa)	TENSILE STRENGTH psi (MPa)	TENSILE MODULUS psi (MPa)	COMMENTS
ASTM D5813	4,500 (31)	250,000 (1,720)	2,500 (17)	NA	If a value is specified, whichever value is greater is the minimum.
ASTM F1216 and ASTM F1743	4,500 (31)	250,000 (1,720)	3,000 (21)	NA	Tensile strength requirement is only for pressure pipes.
Green Book Table 500-1.4.2 (A)	5,000 (34)	300,000 (2,070)	4,000 (28)	250,000 (1,720)	Typically, but unofficially required, is that the static physical properties be 80% of the coupons' standard for field-generated samples.

Table 2: Flexural Properties and Other Sample Data

SAMPLE ID	SAMPLE ACQUISITION SOURCE	RESIN CONTENT %	FLEXURAL STRENGTH psi (MPa)	FLEXURAL MODULUS psi (MPa)	DEGREE OF CURE %
F-1	Field	78.90	6,320 (43.6)	563,000 (3,880)	99+
F-2	Field	79.94	7,300 (50.4)	580,000 (4,000)	95.5
F-3	Field	79.70	7,200 (49.7)	532,000 (3,670)	97.6
F-4	Field	79.54	6,140 (42.4)	544,000 (3,750)	99+
F-5	Field	77.81	6,270 (43.3)	571,000 (3,940)	98.2
F-6	Field	77.94	7,170 (49.3)	568,000 (3,920)	99+
F-7	Field	80.47	5,450 (37.6)	517,000 (3,570)	97.2
F-8	Field	79.82	6,910 (47.3)	536,000 (3,700)	99+
F-9	Field	78.72	6,560 (45.3)	555,000 (3,830)	99+
F-10	Field	78.98	6,800 (46.9)	537,000 (3,700)	97.8
L-1	Laboratory	85.66	9,450 (65.2)	703,000 (4,850)	99+
L-2	Laboratory	70.31	7,610 (52.5)	621,000 (3,590)	99+
L-3	Laboratory	66.09	10,290 (70.9)	687,000 (4,280)	99+

Table 3: Tensile Properties and Other Sample Data

SAMPLE ID	SAMPLE ACQUISITION SOURCE	RESIN CONTENT %	FLEXURAL STRENGTH psi (MPa)	FLEXURAL MODULUS psi (MPa)	DEGREE OF CURE %
F-1	Field	78.90	3,070 (21.2)	693,000 (4,780)	99+
F-2	Field	78.90	3,180 (21.9)	587,000 (4,050)	95.5
F-3	Field	79.70	3,430 (23.6)	680,000 (4,690)	97.6
F-4	Field	79.54	3,320 (22.9)	662,000 (4,570)	99+
F-5	Field	77.81	3,050 (21.0)	658,000 (4,540)	98.2
F-6	Field	77.94	3,180 (21.9)	640,000 (4,410)	99+
F-7	Field	80.47	3,010 (20.8)	623,000 (4,300)	97.2
F-8	Field	79.82	3,010 (20.8)	616,000 (4,250)	99+
F-9	Field	78.72	3,370 (23.2)	670,000 (4,620)	99+
F-10	Field	78.98	3,190 (22.0)	668,000 (4,610)	97.8
L-1	Laboratory	85.66	3,500 (24.1)	664,000 (4,580)	99+
L-2	Laboratory	70.31	4,220 (29.0)	646,000 (4,450)	99+
L-3	Laboratory	66.09	4,000 (27.6)	670,000 (4,620)	99+

Table 4: Tensile Properties and Other Sample Data

TEST	ASTM	UNITS	SMOOTH SURFACE	ROUGHENED SURFACE
Flexural Strength	D790	psi (MPa)	10,340 (71.3)	8,300 (57.2)
Flexural Modulus	D790	psi (MPa)	701,000 (4,840)	662,000 (4,560)

DATA

Figure 1: X-Y Plot of Degree of Cure vs. Flexural Strength

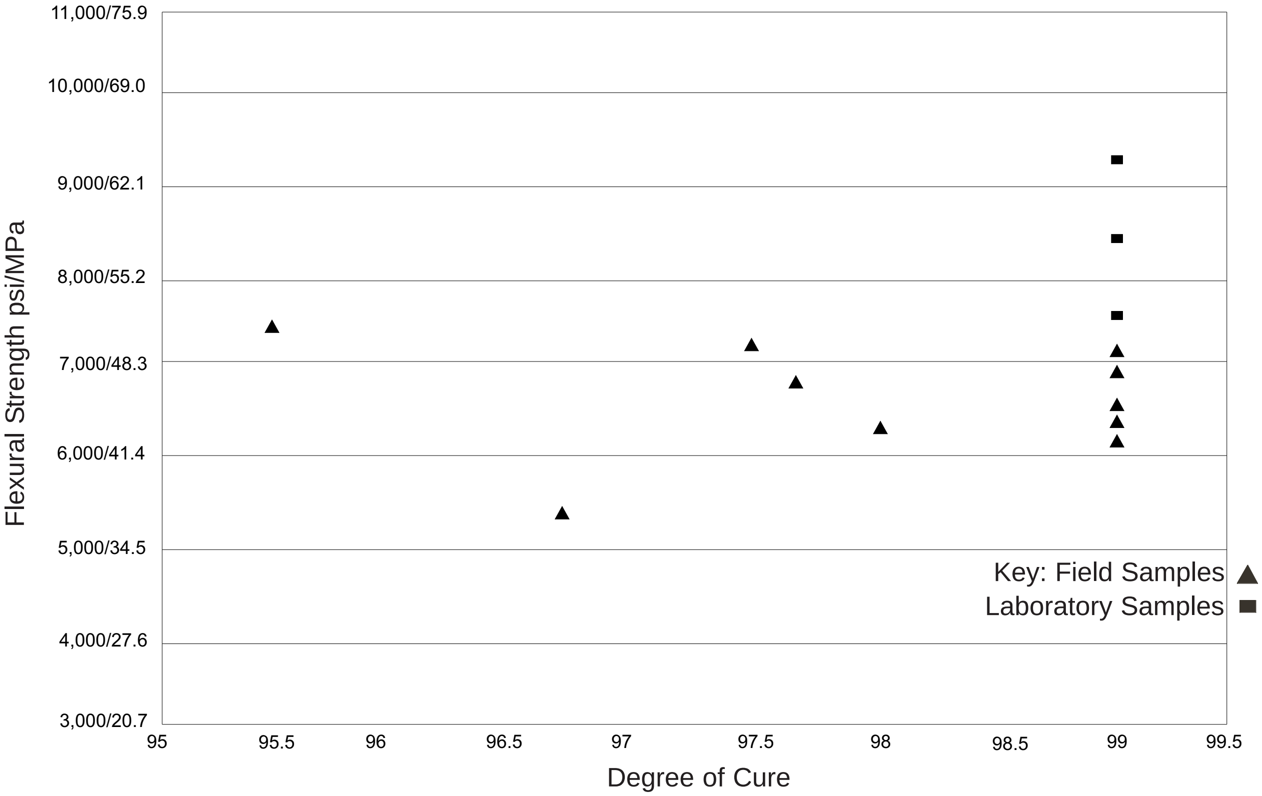


Figure 2: X-Y Plot of Resin System Content vs. Flexural Strength

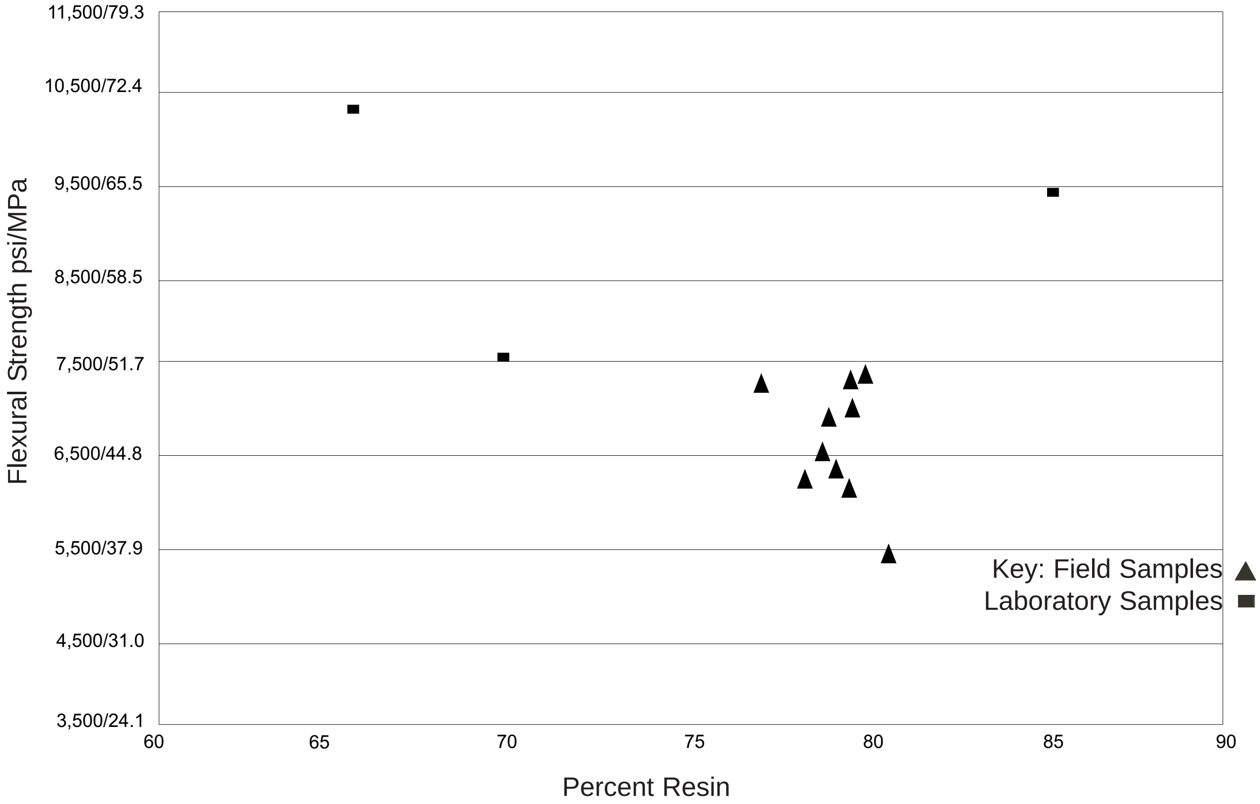


Figure 3: X-Y Plot of Resin System Content vs. Flexural Modulus

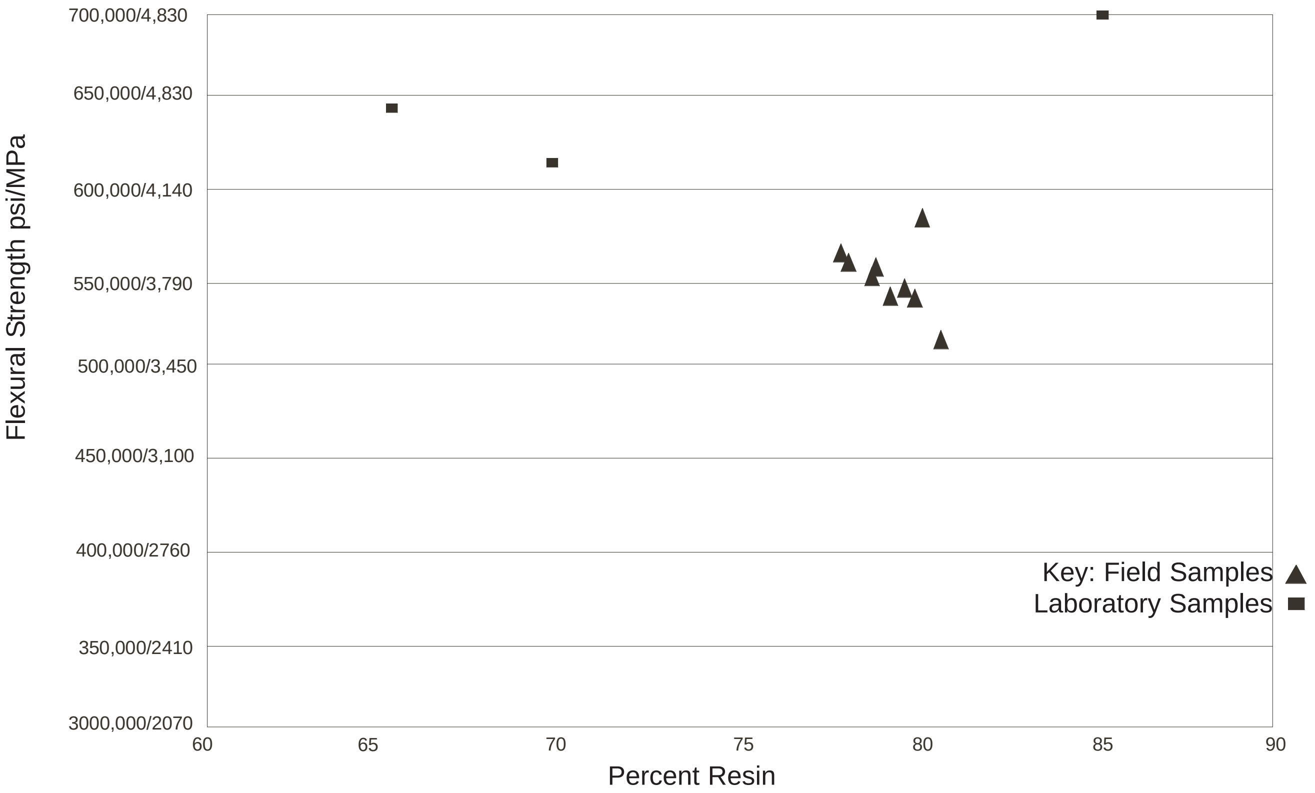


Figure 4: X-Y Plot of Resin System Content vs. Tensile Strength

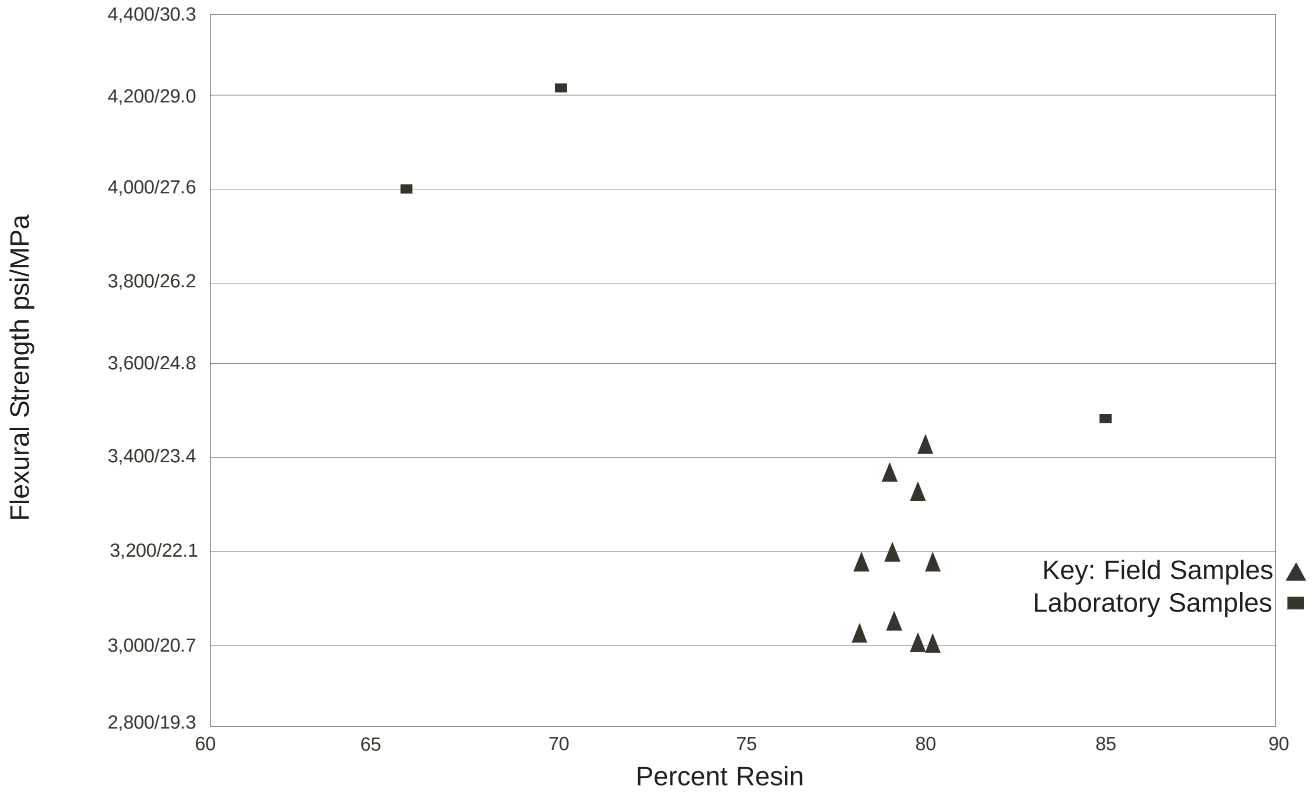


Figure 5: X-Y Plot of Resin System Content vs. Tensile Modulus

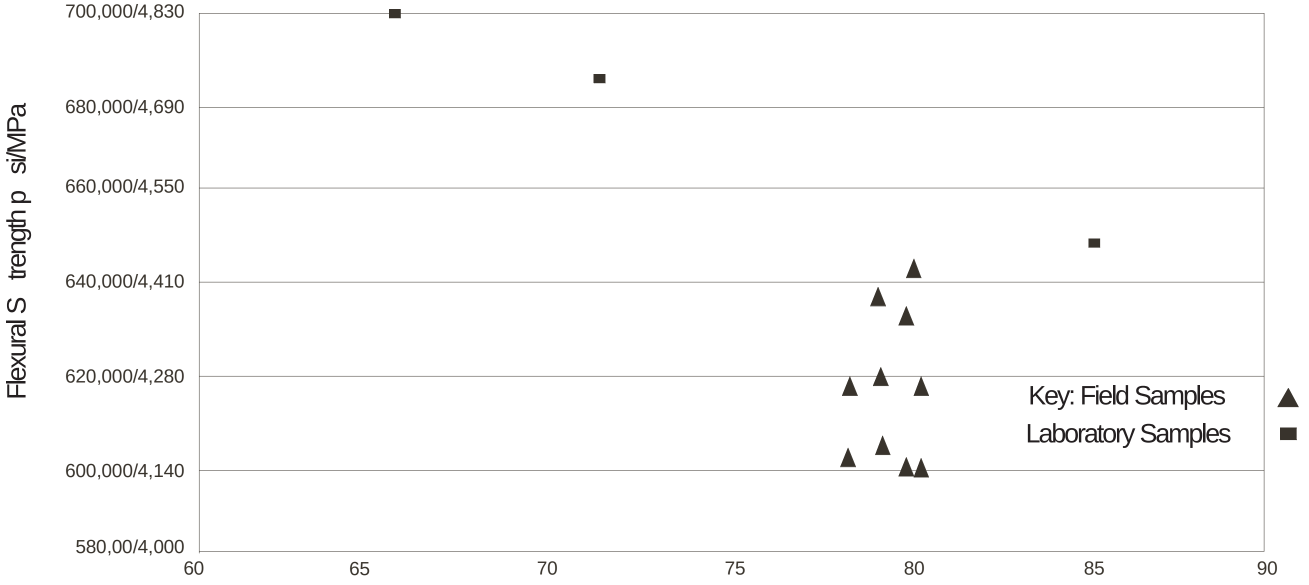


Figure 6: Field-Manufactured Panels

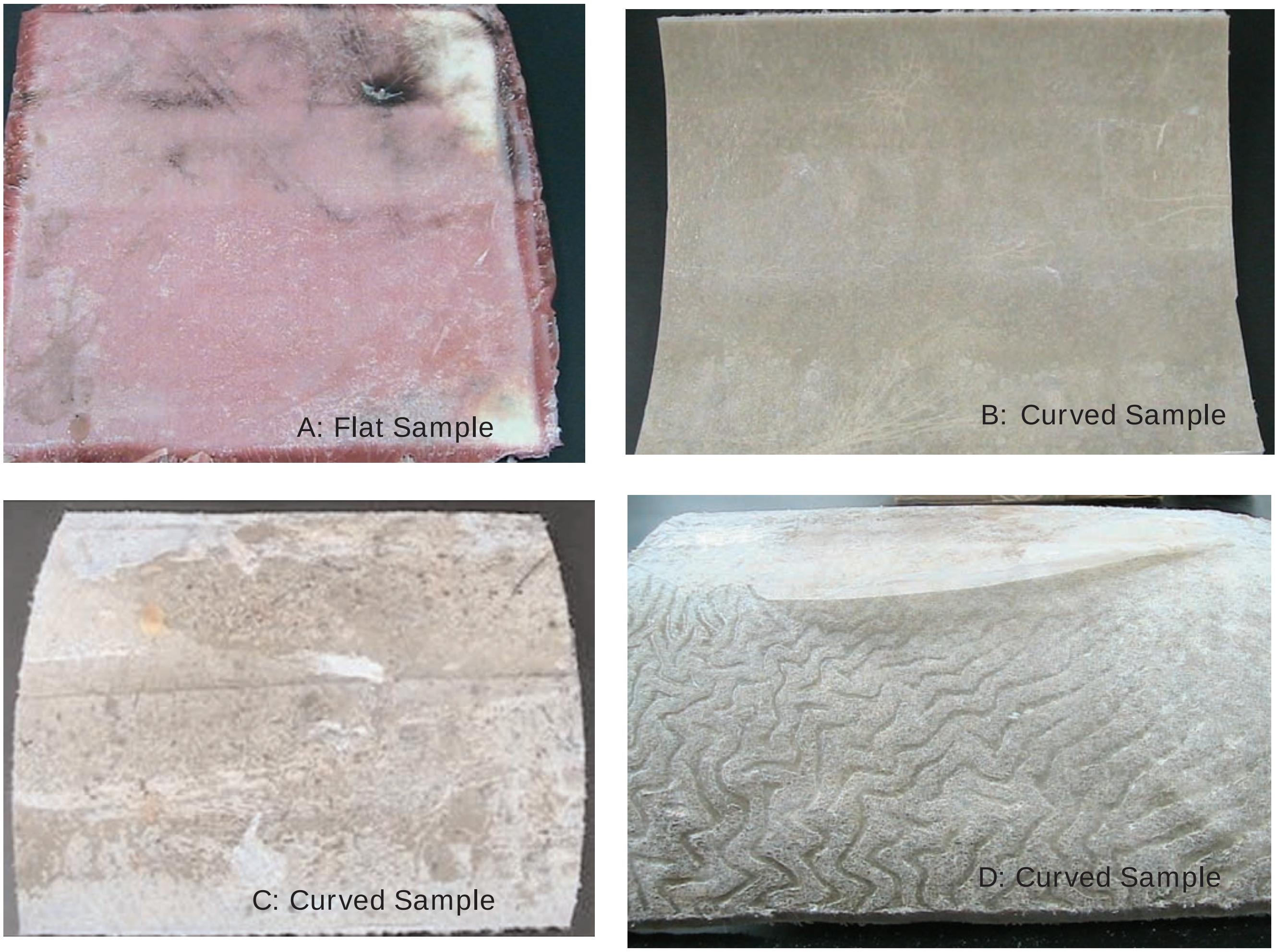
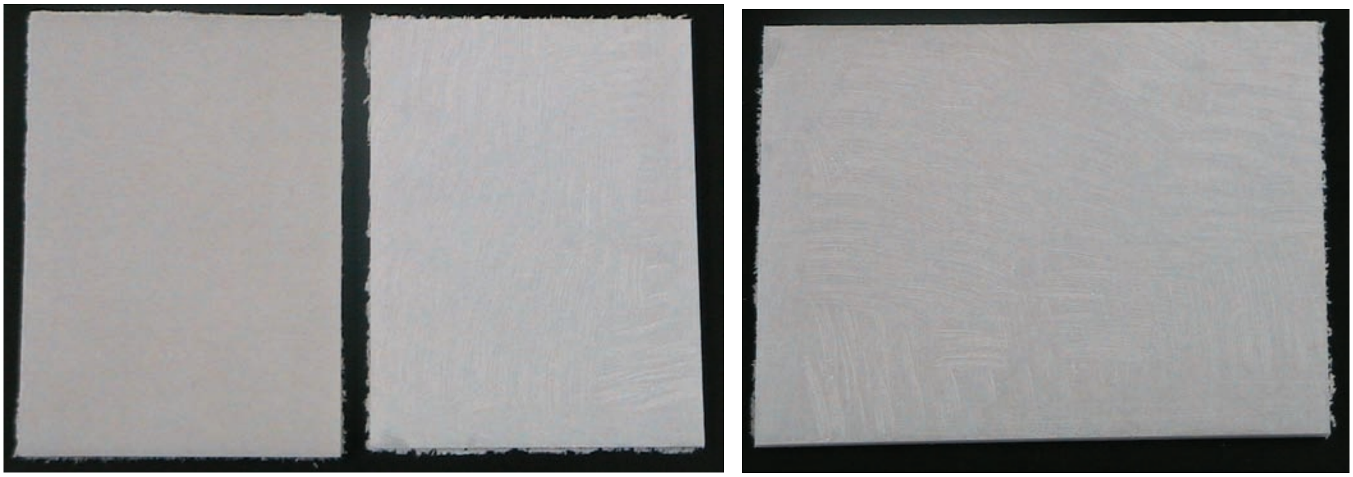


Figure 7: Laboratory-Manufactured Panels

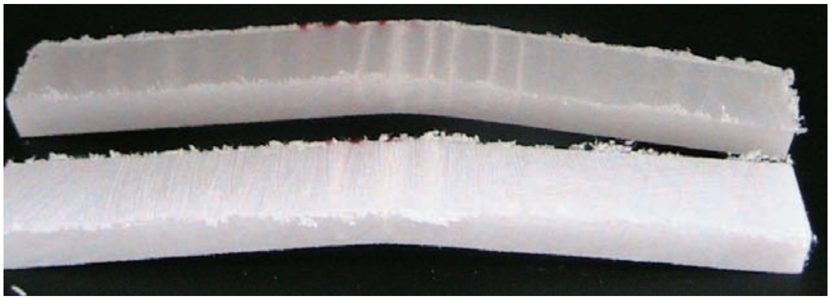


Smooth Surface

Rough Surface

Rough Surface Close-Up

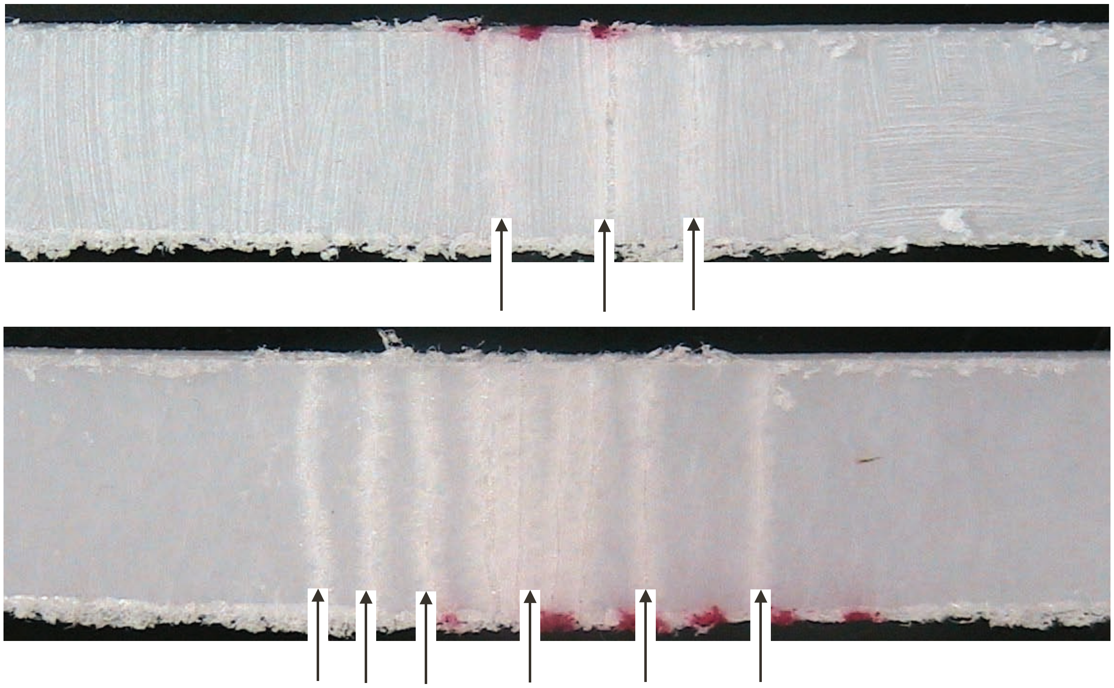
Figure 8: Smooth and Roughened Flexural-Tested Laboratory Specimens



Failed Roughened Specimen

Failed Smooth Specimen

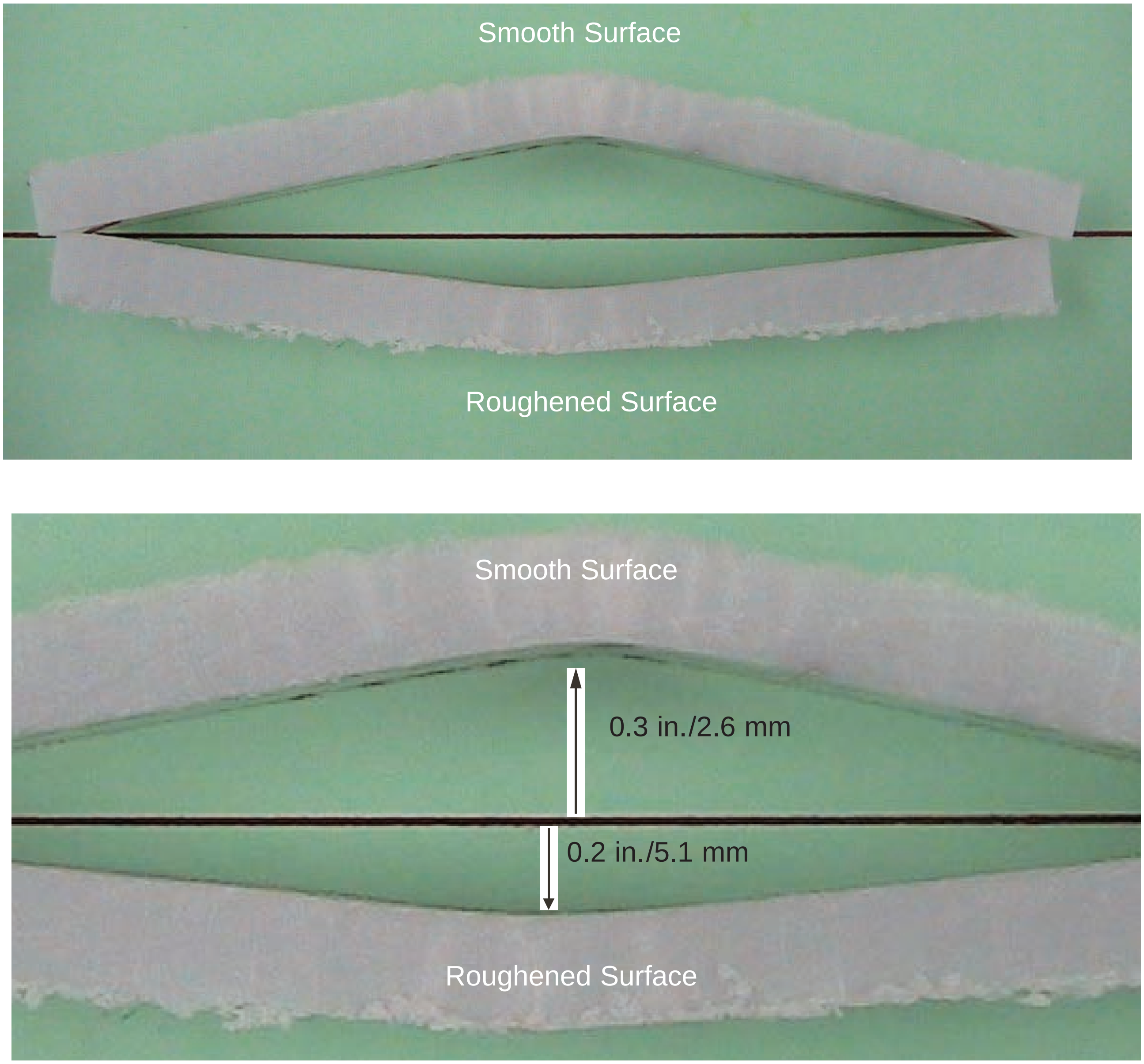
Figure 9: Top View of Smooth and Roughened Flexural-Tested Laboratory Specimens



Failed Roughened Specimen

Failed Smooth Specimen

Figure 10: Side View of the Smooth and Roughened Laboratory Flexural-Tested Specimens



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