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## BIBLIOGRAPHIES

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# Low Surface Characteristic Polyester Achieved in Ambient Cure Conditions

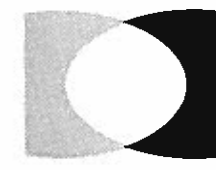
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## ABSTRACT

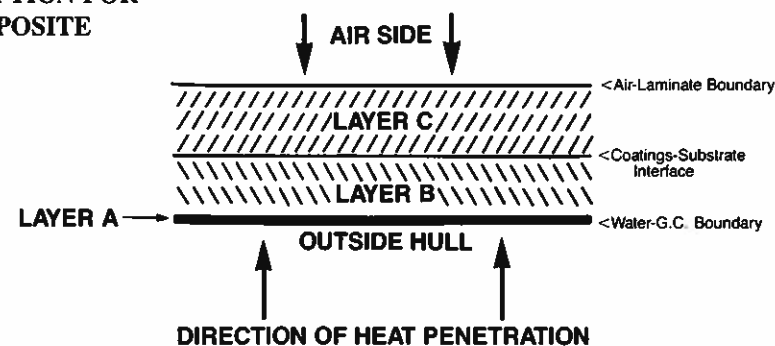
The superiority of highly corrosion resistant epoxy based vinyl ester resins in preventing marine laminate blister behind gel coats was discussed in our 1987 SPI paper, "A Study of Permeation Barriers to Prevent Blisters in Marine Composites and a Novel Technique for Evaluating Blister Formation" and the idea of this "cladding" laminate behind the gel coat is continued here to show superior results in accomplishing a low profile surface on a room temperature cured laminate. The "cladding" or interlamine technique in our previous paper will be further explored as a means of improving the surface profile or cosmetic appearance of gel coated laminates.

The importance of achieving a high degree of cure is examined by comparing ambient versus elevated temperature cured panels. Low surface characteristic composites also depend to a great extent on the capability of the unreinforced coating or gel coat; and the results of improving this potential will be described. The barrier laminate or "cladding technique" evaluation discussion is not limited to the unsaturated resin but also includes results observed when construction techniques are altered with various reinforcements. The results will also be shown to be consistent with the continuing requirements of reduced hydrolysis and blistering utilized in constructing composites in the marine craft and swimming pool industries.

## INTRODUCTION

The production of a cosmetically smooth gel coat surface is desired for aesthetic reasons for boat and swimming pool laminates. The phenomenon of "print through" and "pattern transfer" has created a demand for "low surface characteristic" resin systems. Print through is caused by the pattern of reinforcements, like woven roving, core materials, as well as other reinforcements, laminated directly behind the gel coat being transferred through to the gel coat. The causes of the print through cannot be simply described since

**FIGURE 1: STRUCTURE DESCRIPTION FOR A SKIN COATED COMPOSITE**



- Layer A:** A 25 mils wet drawdown of neopentyl glycol isophthalic gel coat as the standard protective polyester coating on the outside.
- Layer B:** A 60 mils interlamine made from a vinyl ester resin.
- Layer C:** A woven roving glass laminate substrate made from two-parts of unsaturated polyester laminating resin and one-part glass to a 1/4-1/2 inch thickness.

several factors influence its formation. Woven roving pattern transfer to the gel coat surface ultimately shows as a waffle-type pattern approximately 0.00003 to 0.0003 inches in depth. The rippling of the surface can be seen in reflected light where the light striking the surface will reflect differently on the peaks and valleys that correspond to the weave in the roving.

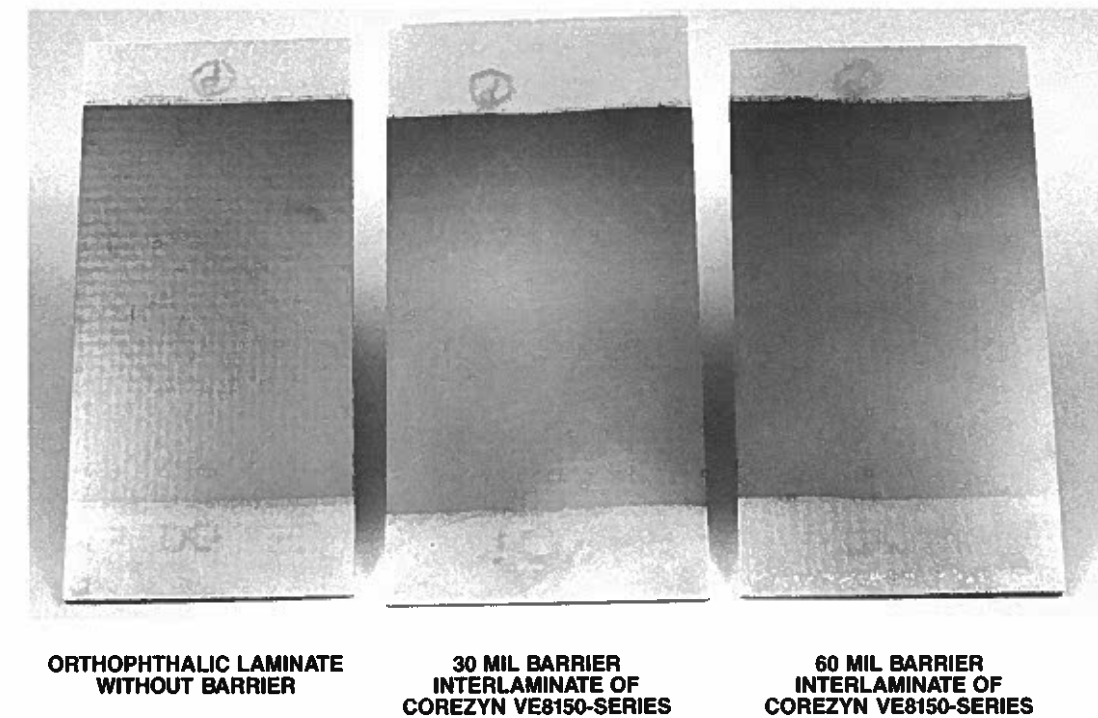
Low fiberglass print through resin systems have been developed for the purpose of minimizing the waffle pattern in marine laminates. The pattern from woven roving glass can be reduced through the use of all chopped glass reinforcement, glass mat, or the incorporation of new types of reinforcements. Recent attempts to alleviate the print through problem have focused on the formulation of polyester resins that are designated as "low profile" laminating resins (Ref. 1 and 2). One popular approach is to utilize a highly reactive dicyclopentadiene polyester like CoRezyn 123-458. Another approach is to blend a premium resin, such as a vinyl ester resin, to compound a modified polyester resin such as CoRezyn MVR 8021.

Figure 1 illustrates our proposed structure for a vinyl ester interlayer skin coat (Ref. 3), that was investigated as a profile barrier between a gel coat and woven roving back-up laminate. Localized internal composite stresses build and produce a deformation that exceeds the resin elastic limit or yield strength, which results in a permanent indentation. The introduction of a CoRezyn VE8150-Series vinyl ester cladding laminate behind the gel coat as both thermal and structural protection was investigated and compared with conventional laminating resin systems.

## THEORETICAL

Internal matrix stresses develop between the resin matrix and the glass fibers of a woven roving composite. These stresses depend on the following three variables: selection of reinforcement and resin used, back-up laminate design, and thermal history during and after fabrication of the part (Ref. 4).

**FIGURE 6: SURFACE PROFILE VS INTERLAMINATE SKIN COAT THICKNESS ON EXPOSURE TO 100 HOURS PROFILE TEST**

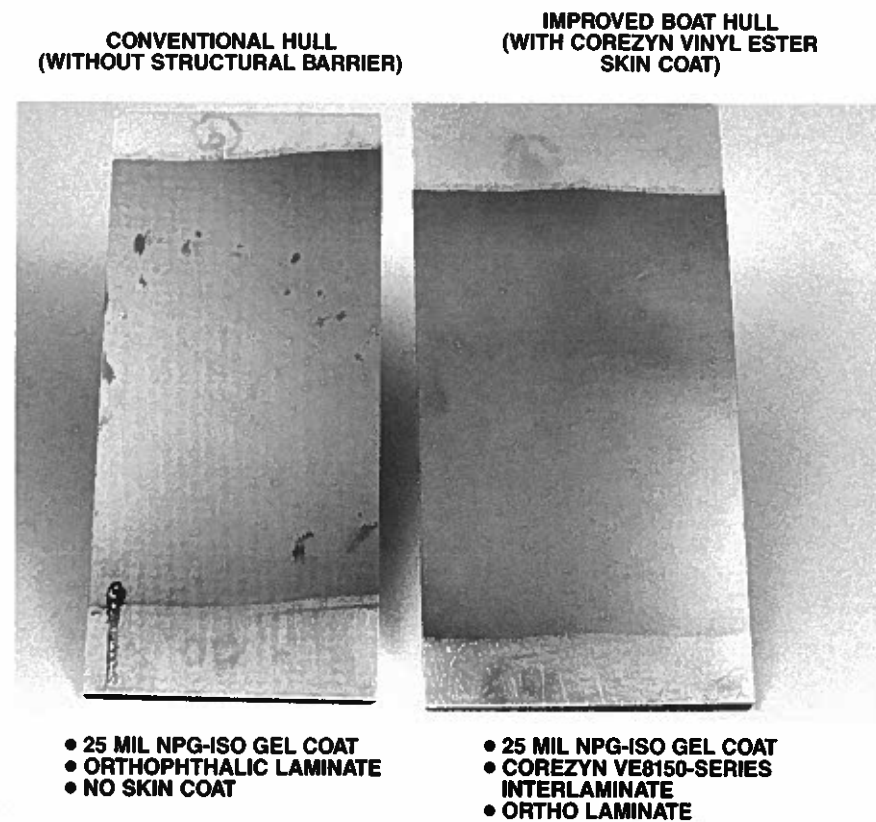


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Figure 5 is a photo showing the “print through” effects due to simulated residual postcure. The right panel with the 60 mil skin coat barrier of VE8151 has significantly less waffle pattern than the non-skin coat laminate. The relative surface profile effects of vinyl ester resins as a thin thermal barrier is shown in Table 6. A 60 mil skin coat is constructed next to the gel coat and allowed to cure sufficiently. It is then laminated over with a combination of woven roving and mat. Pictured in Figure 6 is an illustration of the effects that several thicknesses of the skin coat have on the degree of print through; i.e. the thicker the skin coat the less print through. This is evident by the visual and surface measurement readings compiled in Table 6. The 60 mil VE8151 (high heat distortion vinyl ester resin) barrier coating is not affected by the cycling or back up resin when compared to VE8117 (standard vinyl ester) and Corl063-40 (orthophthalic) skin coats with similar construction. In other words, when you improve the thermal stability of the skin coat, which is in turn dependent on the resin selection, you then yield improved low surface characteristics due to less “print through”.

**FIGURE 5: PRINT THROUGH EFFECT OF POSTCURE**  
CURE DWELL = 24 HOURS AT 150°F



**CONCLUSIONS**

The introduction of a high heat distortion vinyl ester cladding barrier is an effective means of improving ambient temperature profile characteristics in the manufacture of reinforced fiberglass parts. The vinyl ester offers fabricators a dual purpose raw material that acts both as a barrier against hydrolytic attack and also as a thermal barrier that inhibits the expansion and contraction of the conventional orthophthalic backup resin. A 60 mil interlaminar skin coat of CoRezyn VE8151 vinyl ester resin provides a special structural barrier that resists forces of both water and heat applied stresses which respectively blocks blister formation and print-through.

**ACKNOWLEDGEMENTS**

To Roy Netka, Marlene Resman, and Lee Baldwin who helped on the panel construction and testing.

The resin portion expands or contracts in response to curing and heat induced stresses. Differences in the physical properties between glass and cured orthophthalic resin are very significant. Woven roving reinforced composites, as pictured in Figure 2A, are heterogeneous with small zones of resin rich material surrounded by areas of fiberglass bundles. A comparison of the physical properties of fiberglass bundles, which are similar to those for 96% Silica Glass, and a general purpose laminating resin, CoRezyn 1063-40, are contained in Table 1. The resin rich pocket in a woven roving border will give well over 100 times the linear contraction of the surrounding glass. The glass acts as a miniature mold as diagrammed in Figure 2B.

The resin pocket, as pictured in Figure 2B, will shrink and pull away from the glass rich boundary, along the weaves, to form a dimpled pocket. The concave indentations, which form in the laminate, readily transfer from the back-up laminate interface to the gel coat and appear as the checker board pattern shown in Figure 2C. The internal laminate stresses originate from three sources: normal polyester resin cure, residual postcure, and thermal expansion-contraction forces.

During the curing process of a large laminate, a tremendous amount of heat and stress is generated due to polymerization. The first source of “print through” can be attributed to differential internal resin-glass expansion from gelation followed by the inherent volumetric contraction of the resin during curing. Print through is initiated shortly after reaching the maximum temperature. As the laminate begins to cool, the resin pocket contracts at a dissimilar rate and amount relative to the glass. The shrinkage during cure is a result of two predominate resin factors: the change in specific volume caused by the liquid to solid chemical crosslinking reaction, and the volume change due to thermal contraction as the material cools from peak exotherm down to ambient temperature. The shrinkage, “S”, of a polyester resin due to cure is defined to be:

$$S = [(1/SG_s) - (1/SG_l)] / (1/SG_l); \text{ or the reciprocal change in specific gravity}$$

The second cause of “print through” can occur on some parts after the finished part is pulled from the mold and begins to age. A hardness reading such as with a Barber Coleman Barcol GYZJ 934-1 Impressor, does not necessarily always assure complete resin cure. Fully cured resin is important in maintaining low surface profile since further cure during aging can cause the resin rich areas to “postcure” and further shrink from the glass rich areas. The use of multiple catalysts and proper catalyst level at temperature have been proven as methods to assure complete cure under ambient conditions. Low profile testing seems to relate to the degree of cure and type of resin used in the fiberglass part.

**FIGURE 2: TYPICAL WOVEN ROVING FIBERGLASS LAMINATE**

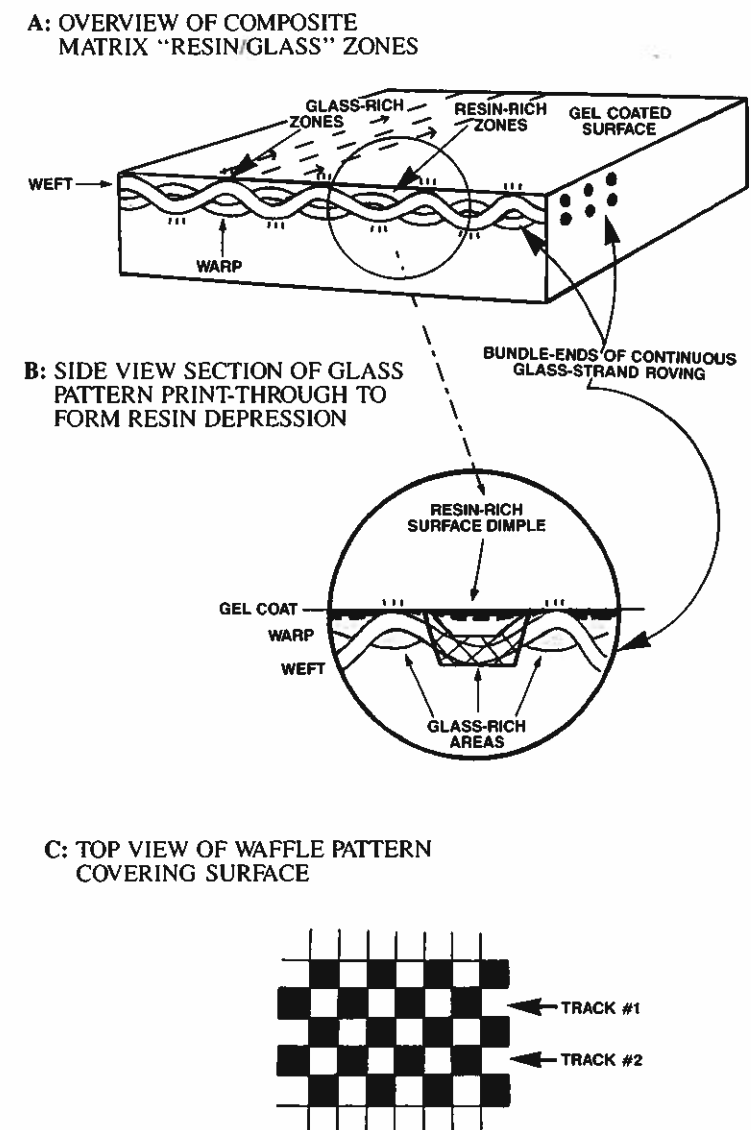


TABLE 1: PHYSICAL PROPERTIES OF GLASS AND RESIN

	96% Silica Glass*	Ortho-Resin 1/8" Casting
Specific Gravity, 77°F	2.18	1.19
Softening Temperature	2,732°F	NA
Heat Distortion Temperature	NA	163°F
Specific Heat	.185 BTU/#°F	.43 BTU/#°F
Linear Thermal Expansion	$4.4 \times 10^{-7}/^{\circ}\text{F}$	$8.5 \times 10^{-5}/^{\circ}\text{F}$
Modulus of Elasticity	$9.6 \times 10^6$ psi	$6.3 \times 10^5$ psi
Volumetric Shrink	~0	9.5%

\*From Perry's Chemical Engineers' Handbook, Sixth Edition, Table 23-20.

The third "print through" mechanism occurs when the finished part is placed in a warm environment such as the Florida sun. As it is alternately heated or cooled over time, cyclic differential expansion and contraction induce localized stresses since the composite structure is made from two distinct materials: glass and resin. The thermal contraction coefficient, "K", of a material is defined to be:

$$(1/^{\circ}\text{F})K = \frac{\Delta L/L_0}{\Delta T}$$

or the fractional dimension change per degree of temperature change.

All three causes of surface profile, volumetric shrink from normal resin cure, postcure after part manufacture, and cyclic thermal expansion and contraction, are all directly related to the thermodynamic properties of the polyester resin component. The liquid resin reactivity and cured laminate heat transfer capabilities are two factors that influence the shrinkage. Both can be significantly reduced in reinforced plastic parts. The composite design, utilizing a properly applied skin coat barrier, provides both a low amount of thermal expansion-contraction and a thermal barrier that will give a lower surface characteristic than what is general in the industry.

## EXPERIMENTAL

The purpose of the test was to obtain and analyze ambient temperature cure surface profile using several back-up resin systems. Special laboratory test panels were constructed with a black surface for accelerated profile test exposure. Numerical profile results were recorded on a Hommel Model P5-Z portable surface roughness tester using ten 15mm (~.6 inch) strokes in the weft direction and statistically analyzed. The tester instrument measures the arithmetic mean roughness "Ra", and the mean peak to valley height, "Rz". Data was taken for ambient cured, 150°F postcured, and profile cycled laminates.

The laminate structures used and pictured in Figure 1 were as follows:

Layer A –	G.C.	25 mil Black Gel Coat
Layer B –	Barrier	60 mil Interlaminar Skin Coat
Layer C –	33.3%	2 layers of 1½ oz. glass mat 1 layer of 18 oz. woven roving 2 layers of 1½ oz. glass mat 1 layer of 18 oz. woven roving 1 layer of 1½ oz. glass mat
	66.7%	Resin (~720gm) @ 77°F & MEKP
	100.0%	Resin/Glass Laminate Back-up Composite

The black gel coat CoRezyn B-815-NCN was catalyzed with 2.0% of Lucidol Lupersol DDM-9 methyl ethyl ketone peroxide (MEKP) and drawn down at 25 mils wet using a wet film applicator on a clean waxed glass plate. Layer A, NPG-Iso gel coat, was allowed to cure at ambient temperature for 1½ hours. When a Layer B interlaminar skin coat was used, the resin/glass barrier was constructed using a ¾ ratio of resin to glass mat consisting of four layers of ¾ ounce Owens Corning M722. The prepromoted thixotropic CoRezyn vinyl ester resin was catalyzed with 1.5% Witco HiPoint 90 MEKP and allowed to reach a 5-10 Barcol 934-1 reading. The final back-up laminate Layer C was applied and left undisturbed to cure at least five hours, until it cooled to ambient temperature.

Two panels for each composite construction were laminated simultaneously and cured for four days at ambient temperatures. One half of the first laminate was postcured at 150°F for 24 hours. This half of the laminate was utilized to determine relative profile change due to resin postcure characteristics. One half of the second laminate was tested in simulated day/night cycles. The other two halves of the laminates were left in a room temperature cured state to determine initial profile characteristics from the volumetric changes of polymerization.

Our low profile cycle tester consists of a bank of four 150-watt flood lights that were on a timer for 12 hours on and then 12 hours off. Five laminates six inches in width were arranged in a row that was approximately one foot below the bulbs with surface temperature reaching approximately 160°F. We ran the test for a total of 100 hours of heat exposure while rotating the laminate positions every twelve hours.

TABLE 5: BACK-UP RESIN BLENDED VERSUS PROFILE EFFECT

Formula Type Resin Blend*	Panel Cure Status	Visual Ranking, Cycled-Best to Worst Profile	Ra Value, 10 <sup>-6</sup> in., Arithmetic Mean Average Roughness	Rz Value, 10 <sup>-6</sup> in., Mean Groove Amplitude
Std. Vinyl Ester (VE 8117)	RT#1 Post RT#2 Cycled	1	6.9 1.9 7.5 3.0 6.0 0.9 7.7 3.1 6.7 0.8	28.3 13.2
DCPD/VE (1/2 Ratio)	RT#1 Post RT#2 Cycled	2	6.4 0.7 7.5 3.6 6.1 0.7 9.3 5.6	53.4 22.9
DCPD/Ortho	RT#1 Post RT#2 Cycled	3	8.4 2.6 7.7 4.1 7.4 3.4 8.2 5.4	37.4 18.7
DCPD/VE (2/1 Ratio)	RT#1 Post RT#2 Cycled	4	6.2 1.5 7.3 1.7 7.2 2.3 9.2 5.4	42.3 21.5
Iso/VE (MVR 8021)	RT#1 Post RT#2 Cycled	5	6.3 1.5 8.3 3.3 7.3 1.6 11.0 8.8	43.3 23.8

\*Mixtures of Table 4 generic resin types.

TABLE 6: SKIN COAT CONSTRUCTION VERSUS PROFILE EFFECT

Skin Coat Construction*	Panel Cure Status	Visual Ranking, Cycled-Best to Worst Profile	Ra Value, 10 <sup>-6</sup> in., Arithmetic Mean Average Roughness	Rz Value, 10 <sup>-6</sup> in., Mean Groove Amplitude
60 Mils VE 8151 (High HDT VE)	RT#1 Post RT#2 Cycled	1	8.2 1.2 8.9 1.3 9.0 1.7 8.3 1.6	43.2 8.0
60 Mils VE 8117 (Std. VE)	RT#1 Post RT#2 Cycled	2	7.3 4.3 9.1 3.0 7.2 1.5 8.1 7.2	49.8 11.0
30 Mils VE 8151 (High HDT VE)	RT#1 Post RT#2 Cycled	3	8.5 1.5 8.2 1.0 9.6 2.7 8.6 1.1	58.9 19.1
60 Mils Cor 1063-40 (Ortho)	RT#1 Post RT#2 Cycled	4	7.7 1.4 8.3 1.3 7.0 1.0 10.2 1.4	57.3 16.1
Without Barrier	RT#1 Post RT#2 Cycled	5	19.0 2.6 17.6 2.5 18.7 2.7 16.7 6.5	74.8 20.6

\*Figure 1 laminate construction using orthophthalic resin Cor 1063-40.

distortion CoRezyn VE8151 vinyl ester resin.

Vinyl ester resins are also well known for their cyclic fatigue resistance superiority (Ref. 8) over isophthalic and orthophthalic polyester resins. Any differences noted in the profile of a standard constructed panel should then be partially due to the relative thermal coefficients of expansion and cyclic constraction of the resin utilized in the laminate substrate underlying the gel coat barrier.

Tables 4, 5, and 6 each contain both a visual surface profile ranking in addition to two numerical surface roughness parameters. There are five glass bundles per inch in the weft direction and four in the warp direction in 18 ounce woven roving. The values compiled are the mean and standard deviation of ten linear test strokes of 0.6 inches in the weft direction. A high reading is obtained on a glass rich track in Figure 2C as opposed to a resin rich track. Fairly large standard deviations were observed since the profile measurement is taken along a line rather than over an area.

Table 4 contains the profile data obtained for the standard back-up laminate with various generic types of resin. The panels in Figure 3 illustrate the effect of the woven roving on the surface. The reference panel or "Standard" constructed without woven roving, has a

very good surface appearance after 100 hours of heat cycling with an Ra mean roughness of  $8.2 \times 10^{-6}$  inch and Rz mean groove depth of  $49.4 \times 10^{-6}$  inch respectively. Both room temperature and the 150°F postcured "Standard" panels were about the same demonstrating that even the orthophthalic resin CoRezyn 1063-40 does not exhibit the waffle pattern when the laminate is constructed with fiberglass mat. The panel with CoRezyn 1063-40 and woven roving has the worst visual appearance with a mean roughness of  $16.7 \times 10^{-6}$  and a mean depth amplitude of  $74.8 \times 10^{-6}$ . The visual ranking of the panels in Table 4 is dicyclopentadiene resin, standard thixotropic vinyl ester resin, high heat distortion vinyl ester, and isophthalic resin. The surface roughness ranking was slightly different with the dicyclopentadiene and VE8117 panel inverted due to increased roughness readings after 100 hours profile testing.

Table 5 evaluates the effect of several resin blends in the backup laminate. The blend approach appears to offer somewhat improved surface profile in the room temperature and 150°F postcured categories of cure. After cycle testing, no significant advantage in surface profile is indicated. The best panel is the one constructed of all vinyl ester.

TABLE 4: BACK-UP RESIN GENERIC TYPE VERSUS PROFILE EFFECT

Back-up Resin Type in Substrate*	Panel Cure Status	Visual Ranking, Cycled-Best to Worst Profile	Ra Value, 10 <sup>-6</sup> in., Arithmetic Mean Average Roughness	Rz Value, 10 <sup>-6</sup> in., Mean Groove Amplitude
Basis-No Roving (All Mat/Ortho)	RT#1	Standard	7.8 1.6	49.4 10.2
	Post		8.1 1.3	
	RT#2		8.6 1.2	
	Cycled		8.2 0.9	
Dicyclopentadiene (Cor 123-458)	RT#1	1	8.2 1.6	41.9 4.0
	Post		8.3 1.3	
	RT#2		6.4 0.8	
	Cycled		10.1 1.6	
Vinyl Ester (VE 8117)	RT#1	2	6.9 1.9	28.3 13.2
	Post		7.5 3.0	
	RT#2		6.0 0.9	
	Cycled		7.7 3.1	
High HDT Vinyl Ester (VE 8151)	RT#1	3	9.9 0.9	32.3 3.2
	Post		11.1 3.1	
	RT#2		11.0 2.8	
	Cycled		10.5 0.9	
Isophthalic (Cor 9595)	RT#1	4	12.6 6.4	50.6 24.0
	Post		14.2 5.0	
	RT#2		9.3 3.9	
	Cycled		11.7 5.9	
Orthophthalic (Cor 1063-40)	RT#1	5	19.0 2.6	74.8 20.6
	Post		17.6 2.5	
	RT#2		18.7 2.7	
	Cycled		16.7 6.5	

\*Except Standard, all are constructed with Figure 1 woven roving laminate and no skin coat.

TABLE 2: LAMINATING RESIN MECHANICAL/LIQUID CHARACTERISTICS

CoRezyn Product	Cor 1063-40	Cor 123-458	Cor 9595	MVR 8021	VE 8117	VE 8151
Generic Formula Type	All-PG/Ortho	All-MA/DCPD	All-PG/Iso	Iso/VE Blend	Bis A-Epoxy	High-HDT
Typical Application	General Purpose	Low Profile	Polyester Laminating	Modified VE Resin	Thixo-VE Resin	Thixo-VE Resin
<b>LIQUID PROPERTIES</b>						
Viscosity, cps	1400/436	1100/500	950/400	2100/750	1200/450	1250/460
Percent Non-Volatile	52	58	56	53	52	57
Weight per gallon, pounds	8.99	9.02	9.00	8.94	8.60	8.95
Specific Gravity <sup>2</sup>	1.082	1.086	1.083	1.076	1.035	1.077
<b>CURED 1/8 INCH CASTING PROPERTIES<sup>1</sup></b>						
Flexural Strength, psi	16,300	8,400	18,500	18,000	19,000	16,600
ASTM D790						
Flexural Modulus, psi × 10 <sup>5</sup>	5.45	4.37	5.18	4.6	4.7	4.67
Tensile Strength, psi	8,600	4,300	10,300	9,400	11,800	12,600
ASTM D638						
Tensile Modulus, psi × 10 <sup>5</sup>	6.32	5.63	5.65	5.0	5.0	4.29
Percent Elongation	1.5	0.8	2.0	4.5	4.5	4.2
Heat Distortion, °F	163	221	189	210	210	284
ASTM D648						
Barcol Hardness, 934-1	39	47	46	35	35	43
ASTM D2583						
Apparent Density, (lb/ft <sup>3</sup> ) <sup>3</sup>	74.4	72.2	74.0	72.2	69.7	73.9
Specific Gravity	1.195	1.160	1.189	1.160	1.120	1.188
ASTM D792						
Percent Volumetric Shrink <sup>4</sup>	9.5	6.4	8.9	7.2	7.6	9.4

1. All were catalyzed with 1% MEKP.  
 2. As compared to H<sub>2</sub>O @ 77°F, 8.31212 lb/gal.  
 3. As compared to H<sub>2</sub>O @ 77°F, 62.24 lb/ft<sup>3</sup>.  
 4. Percent Shrink = [(1/SG<sub>2</sub>) - (1/SG<sub>1</sub>)] / (1/SG<sub>1</sub>)

OBSERVATIONS/RESULTS

A compilation of standard mechanical and liquid characteristics of the resins evaluated in the study as back-up resins is contained in Table 2. The ambient temperature physical properties of 1/8" thick resin clear castings reveal a wide range of flexural and tensile characteristics. The capabilities of a cured resin rich pocket under localized compressive or tensile stresses will depend largely on back-up resin selection. Laminate design can dramatically decrease the influence of the back-up resin. Corrosion grade vinyl ester resins are noted for their high strength and high heat distortion relative to other polyesters (Ref. 5 and 6), and especially their low thermal coefficient of contraction (Ref. 7). These attributes make them an excellent barrier candidate against thermally applied stresses. The physical properties of a fiberglass laminate manufactured from any Table 2 resin will have similar overall composite strengths but a different capability for retaining that strength at elevated temperatures.

The laboratory profile test alternates between 160°F and ambient surface temperatures of approximately 75°F. A cyclic temperature change of 85°F induces expansion and contraction that is equivalent to the temperature change times the coefficient of thermal

expansion and contraction tabulated in Table 3. Differential stresses between the resin-rich pocket and the glass-rich zones of the roving are affected as diagramed in Figure 3 where the cycled uniform glass mat laminate shows no print through.

The data collected in the initial scan of the resins for this study is shown in Figure 4. This stress-strain diagram of several different polymers is a modified ASTM D648 "Deflection Temperature of Plastics Under Load" test. The experiment plots temperature on the Y-axis, as a measurement of applied stress, as each plastic bar expands proportional to the coefficient of expansion. The observed deflection, which is a measurement of resulting strain at the ordinate temperature under 264 psi load, is plotted on the X-axis. The heat distortion point is defined to be the temperature at which a resin test specimen has deflected on the abscissa 0.010 inches.

Note on Figure 4 that the slope of the CoRezyn 1063-40 orthophthalic resin curve becomes nearly horizontal as it distorts significantly at a low temperature. The slope on the temperature deflection graph is a ratio of "stress/strain" reaction to heat or essentially a thermal modulus. When subjected to the standard 2°C per minute temperature ramp, the stress-strain data obtained demonstrates that far less deformation occurs at all temperatures for the high heat

TABLE 3: COEFFICIENT OF THERMAL CONTRACTION OF COMPOSITES		
Composite Material	Contraction Coefficient K (%/°F × 10 <sup>-5</sup> )	Temperature T (range in °F)
96% Silica Glass <sup>1</sup>	.044	77-572
Rigid Styrene Polyester <sup>1</sup>	3.9-5.6	—
Glass Fiber Polyester Laminate <sup>1</sup>	1.2-4.0	—
Low Reactivity Orthophthalic Resin Casting <sup>2</sup>	8.5	70-300
Medium Reactivity Orthophthalic Resin Casting <sup>2</sup>	8.5	70-300
Vinyl Ester Resin Casting <sup>2</sup>	5.6	70-300
High Reactivity DCPD Resin Casting <sup>2</sup>	6.3	70-300
Isophthalic 35% Glass Laminate <sup>3</sup>	1.3	—
Orthophthalic 35% Glass Laminate <sup>3</sup>	1.3	—

1. Chemical Engineer's Handbook.  
 2. 12/79 Unpublished Data.  
 3. Phillips Data.

FIGURE 3: PRINT THROUGH DUE TO GLASS TYPE ON EXPOSURE TO 100 HOURS PROFILE TEST

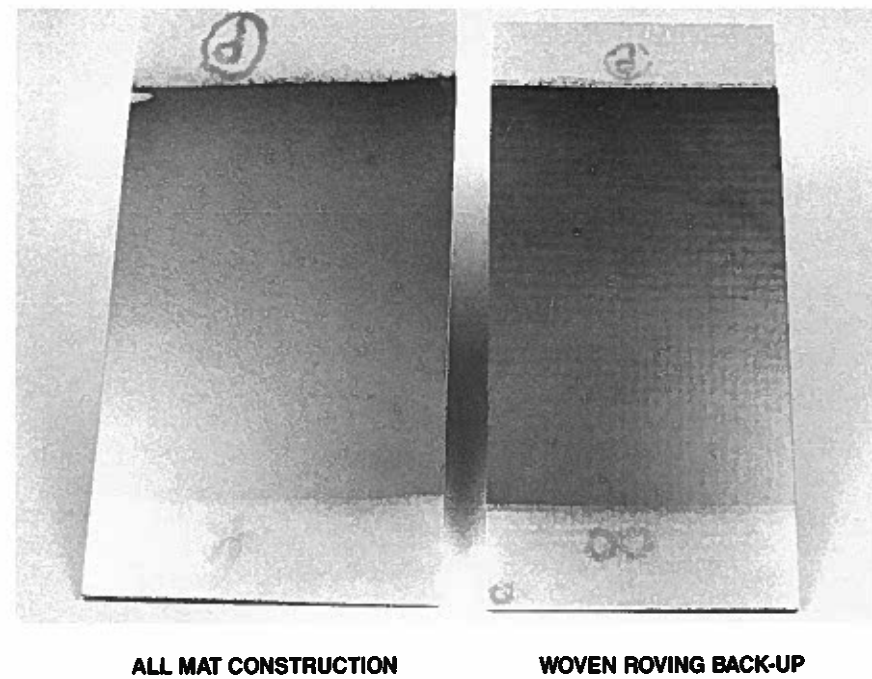


FIGURE 4: STRESS-STRAIN PLOT FROM ASTM D648 HEAT DISTORTION POINT DETERMINATION

