Technical Research

Techniques to Achieve
a Low HAP Isophthalic Resin
for Corrosion Resistant Composites

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Abstract

The EPA regulations relating to Hazardous Air Pollutants (HAP) accelerated the shift to lower HAP levels in polymers intended for unsaturated polyester resins. Styrene and methylmethacrylate are the two chemicals identified as HAPs used in unsaturated polyester resin solutions.

The regulations affect a majority of the manufacturing methods used by fiberglass fabricators. Those affected by the basic EPA categories of manufacturing are spray-up, hand lay-up, and filament winding. The levels of allowable HAPs for each process, based on the EPA regulations, are 46.2%, 40%, and 42% respectively. This is a dramatic change from the corrosion resistant isophthalic resins used for the past 30 years that contained 46% to 50% HAP, typically styrene monomer.

This paper presents a comparison of polymers that contain less than 38% HAP to the industry standard of a 1:1 isophthalic-maleic all propylene glycol polymer. The comparison references corrosion testing accomplished according to ASTM C581, water absorption at various temperatures, as well as the liquid and physical properties of these polymers.

Introduction

The composites industry has over 40 years of historical data on the performance of unsaturated thermoset isophthalic polyester resins in corrosion applications. Amoco Chemicals (now BP Chemicals), a major supplier of isophthalic acid and terephthalic acid to the unsaturated polyester resin market, has done extensive corrosion studies on isophthalic polymers to show their capabilities. Over the past 30 years, every unsaturated polyester resin manufacturer has collected case histories on the performance of their polymers. Manufacturers of corrosion resistant composites also have performance data and case histories on the corrosion resistant products they have made.

The federal government has developed regulations to address the emissions of HAPs based on the 1997 changes to the EPA's 1990 Clean Air Act. Styrene and methyl methacrylate were identified as HAPs in the 1997 revisions to the Clean Air Act and these are the two HAPs used in the unsaturated polyester resins. The simplest view of the regulations is to address the allowable levels of HAPs based on the method of use, which include: atomized spray-up, non-atomized spray-up, hand lay-up, filament winding and centrifugal casting. The regulation breaks the processes down further, into corrosion or noncorrosion applications. A 75% reduction in emissions, based on a resin containing 45% HAP, is required to meet the EPA point value of 190 as determined by the EPA model for emissions on a corrosion resin that is mechanically applied with an atomized or non-atomized method. The reduction in emissions used in this calculation was determined by the Composite Fabricators Association (CFA) *Vapor Suppressant Effectiveness Test Protocol.* We determined that the most stringent requirements in the proposed regulation is a maximum of 40% HAP for corrosion resins and then designed our products to meet them.

There are three methods of achieving a maximum content of 38% HAP. One of the methods is to keep the amount of unsaturated polymer the same and replace a portion of the HAP with a non-HAP compound. These compounds should also reduce the viscosity of the resin solution like styrene does. There are many diluents that can be used, ranging from ones that crosslink with the styrene and unsaturated polyester backbone, to non-reactive diluents that act as a plasticizer. Many chemicals can be used and we examined three: a reactive diluent that has aromatic and non-polar qualities like styrene; an acrylated reactive diluent with aliphatic and polar characteristics; and a non-reactive diluent with aromatic and non-polar qualities like styrene.

The second method to reduce the total VOC and HAP content is to increase the polymer/solids portion of the resin solution. This was achieved by manufacturing a lower molecular weight, unsaturated isophthalic polyester polymer. Lower molecular weight polymers have been created for industries, such as the marine, that use unsaturated polyester resins. It was found, however, that lower molecular weight polymers decreased the performance of the finished composites.

The third method to reduce HAP content is to suppress the emissions of HAPs by adding a compound, such as a wax, that forms a film on the surface of the part exposed to air during cure. This prevents HAPs from escaping into the atmosphere.

These three methods allow composite manufacturers to comply with the proposed regulations; however they do not address the impact on the field performance. This work explores the affect on the corrosion resistance and addresses some of the other issues created by this method.

Experimental

The six resins tested were:

Resin A: A typical isophthalic corrosion resin, made from a 1:1 maleic anhydride/isophthalic acid and all-propylene glycol. It is a standard, polyester, corrosion resin commonly used by the composites industry. This polymer was prepared in two stages and the final stage was processed to an acid number of less than 15 and an average molecular weight of greater than 1900. The final version of the resin used in this study was a mixture of 45% styrene monomer and 55% polymer solids.

Resin B: This polymer is the same as Resin A. However, it contains approximately 55% of the isophthalic polymer, approximately 37.5% styrene and 7.5% of a reactive non-HAP diluent. This non-HAP diluent is a nonpolar organic compound with an aromatic ring structure and ethylenic sites for crosslinking.

Resin C: This polymer is the same as Resin A. However, it contains approximately 55% of the isophthalic polymer, approximately 37.5% styrene and 7.5% of a reactive non-HAP diluent. This non-HAP diluent is a polar organic compound with an aliphatic structure and acrylic crosslinking sites.

Resin D: This polymer is the same as Resin A. However, it contains approximately 53.5% of the isophthalic polymer, approximately 37.5% styrene and 9.0% of a nonreactive non-HAP diluent. This non-HAP diluent is a nonpolar organic compound with an aromatic ring structure.

Resin E: This low molecular weight, isophthalic polymer is specially designed to give better corrosion resistance compared to a lower molecular weight version of the polymer in Resin A. It had a Mn molecular weight of less than 1600. When diluted to 62% solids with 38% styrene, it had a slightly higher viscosity compared to Resin A at 45% solids. Thirty eight percent styrene content was chosen based on the EPA regulations.

Resin F: This resin is an isophthalic unsaturated polyester resin sold in Europe. It consists of an unsaturated isophthalic polyester resin with a Mn molecular weight of less than 1750, 44.7% styrene, and a high level of a wax additive to suppress styrene emissions.

The static flexural and tensile physical properties of clear castings of the resins were tested according to ASTM D790 and ASTM D638 on an Instron Model 4505 Universal Tester. Hardness was measured with a Barber Coleman GYZJ 934-1 Barcol impresser gauge according to ASTM D2583.

The coupons were constructed according to ASTM C581 using a synthetic veil and 1.5 ounce chopped strand fiberglass mat. The coupons were immersed in 25% sulfuric acid, 15% hydrochloric acid, 5% nitric acid, 25% acetic acid, 5% sodium hydroxide solutions, and demineralized water at 160°F (71.1°C). The coupons were removed from the various corrosive media at one, three, six and 12 months. The flexural strength, flexural modulus, thickness, and weight were recorded for the coupons at each time interval.

Static flexural physical properties of the ASTM C581 coupons were tested according to ASTM D790 on an Instron Model 4505 Universal Tester. The thickness of the coupons was measured on three corners, at an equal distance from the two edges, with a Starrett micrometer No. 216. The coupons' weights were measured with a Mettler PE1600 scale with an accuracy of 0.02 grams.

Results & Discussion

Table 1 shows the physical properties of the castings made from the six resins.

Resins A and B had similar physical properties. They were made with nonpolar reactive diluents that are aromatic in structure.

Resin C shows a loss in heat distortion and moduli. It contains a polar reactive diluent. It is evident by the lower heat distortion, that a polar reactive diluent does not yield as high of a crosslink density as the aromatic reactive diluents.

Resin D had a higher elongation, lower heat distortion and lower moduli values than Resin A. This aromatic, nonreactive diluent appears to act like a plasticizer, making the casting more flexible like a thermoplastic system.

Resin E was specially designed to have good strengths and moduli with an acceptable elongation, while having a lower heat distortion temperature than Resin A.

Finally, Resin F had much poorer clear casting properties than the other resins in this study. Even though the casting properties are dramatically lower then the other resins, the physical properties in the ASTM C581 coupons were comparable. The data is shown in shown in Table 2. The low casting physical properties are not typical for this polymer; they are more typically seen in low molecular weight polymers. The high level of vapor suppressant may be causing the decrease in properties in the casting and it shows little to no affect in the reinforced coupons.

The liquid and HAP contents of the resins are listed in Table 3. Resins B, C, and D had significantly lower thixotropic indices than Resin A. However, with a higher level of the non-HAP diluent, these resins could be adjusted to comparable viscosities and thixotropic indices. The HAP content in Resins B, C, D, and E are all less than 35%.

Resin F has a vapor suppression factor of 77%, which lowers the HAP emissions so the resin meets the federal requirements.

The corrosion data is compiled in Tables 4 through 9 and graphs of the data are presented in Figures 1 through 6.

Following is the analysis of the compiled data.

25% Sulfuric Acid: Resin A performed the best of the six resins tested. It had little change in the flexural strength and modulus as well as the thickness and weight. There was a big drop in the weight at month one, but the remaining three periods showed little change. The other five resins all performed acceptably with 70% to 90% retention of strength, 85% to 100% retention of moduli, and less than 1% change in thickness and weight.

Hydrochloric Acid: Resin E had the best retention of strength and modulus properties with greater than 65% retention after 12 months. Resins A, D and F were comparable to each other and not quite as good as Resin E. Resins A, D and F had 50% to 60% retention of flexural strength at the end of 12 months. Resins B and C had unacceptable retention after 12 months.

Nitric Acid: Resin C had the best retention of strength and modulus properties with greater than 65% after 12 months. Resins A, B, D and F were comparable to each other and not as good as Resin C. Resins A, B, D and F had a low retention and are questionable for long term service in this corrosive environment. Resin E failed between six and 12 months.

Acetic Acid: Resin A performed the best of the six resins tested. It retained over 75% of its flexural strength and modulus and had less than 3% change in thickness and weight. Resins B, C and D had much lower retention and are questionable for long term service in this corrosive environment. Resins E and F failed with less than 60% retention of flexural strength and 40% flexural modulus after 12 months.

Sodium Hydroxide: Resins A B, C, D and F performed similarly, but none were good enough to recommend for long term use. They maintained 52% to 62% of their original flexural strength, 62% to 80% of their flexural modulus and less than 2% change in thickness and weight. Resin E completely failed in less than three months.

Demineralized Water: Resin F performed the best with 60% to 70% retention of flexural strength and modulus and less than 1% change in weight and thickness. This effect was probably due to the wax used to suppress the styrene's evaporation, which also would help repel water and further minimize the composite's ability to absorb water. Resins C and D had the next best performances with good retention of flexural properties and less than 2% change in thickness and weight. The results for Resins A, B and E are questionable for long term service due to their low retention of properties or the amount the drop in strength and modulus between three and 12 months.

The acids were separated into two groups: mineral (sulfuric, hydrochloric and nitric) and organic (acetic). Resin A had the best overall performance in the mineral acids. It performed the best in the sulfuric acid and ranked second in the hydrochloric and nitric acid environments. Resin A performed the best in the organic acid (25% acetic acid).

Resin E failed in the 5% nitric acid.

Resins D and F failed in the organic acid.

The rankings listed in Table 10 show Resin A was the best performer. Versions of this resin with various reactive and nonreactive non-HAP diluents show a slight degradation in their performances.

The lowest molecular weight polymer, Resin E, was definitely the worst performer in the test group. It completely failed in four of the six corrosive media tested.

Resin F did well in five of the six environments, which could be related to the high level of wax and its ability to minimize the amount of aqueous media that reached the cured resin. It was postulated that the wax additive was probably more easily attacked and dissolved by the organic acid than the mineral acids. Losing the wax on the surface, combined with the lower molecular weight of the resin, are the reasons it failed in the 25% acetic acid.

Changing the diluent can have a significant effect on the pricing of the resins too. Vinyl toluene and divinyl benzene are two non-HAP, aromatic, nonpolar, reactive diluents that can be substituted for all or part of the styrene. Using vinyl toluene and divinyl benzene as non-HAP reactive diluents to partially replace the styrene will cause the resin price to increase. The actual amount of the increase is directly related to the percent of the alternate reactive diluents used.

Wax is not typically used in the corrosion resins chosen to make tanks, pipe, ducting, or other composites that require secondary bonding. Tanks are an example of composites that can have many pieces bonded to them. These pieces might include manways, valves, covers, and internal flanges to improve agitation. All of these are integral parts that can cause catastrophic failure if the bond fails. Another example is ducting, which is usually assembled in the field. Joint failures could cause structural problems that could result in catastrophic failure. Poor bonding at joints could also allow corrosive fumes to leak out of the ducting. These fumes can be poisonous to nearby personnel, and corrosive to nearby equipment and structural components of the building such as beams and rafters.

Conclusions

Changing to an isophthalic resin with a lower HAP content requires establishing new lower levels of corrosion performance of the composites. Substituting reactive and nonreactive non-HAP diluents in the standard resin to partially replace styrene appears to cause a decrease in the overall corrosion resistance of those resin candidates. The level of decrease needs to be addressed for each specific environment since some of the non-HAPs performed better or worse than the standard resins under various conditions.

The change in the casting physical properties of the resin with the non-reactive diluent would lower the maximum service temperature for this resin due to the reduction in heat distortion.

The lower molecular weight resin performed worse than the high molecular weight standard, which was expected. The higher molecular weight versions of the isophthalic polymer have better overall corrosion resistance compared to the lower molecular weight, corrosion resistant isophthalics developed for this study.

The suppressed polymer had problems with organic acids, which may be attributed to the wax additive. Its ability to perform in corrosive environments needs further study.

The concerns about the secondary bonding also need further study.

References

This work is based on the original technical paper: *Evaluation of Various Techniques to Achieve a Low HAP Unsaturated Isophthalic Polymer for Use in Manufacturing Corrosion Resistant Composites.* It was published in 2001, by David J. Herzog, Anthony Bennett, and Matthew Kastl on behalf of Interplastic Corporation. It is available from the American Composites Manufacturing Association (ACMA).

Table 1: Casting Physical Properties of 1/8 inch (3.2mm) Thick Clear Casting

	ASTM	Units	Resin A	Resin B	Resin C	Resin D	Resin E	Resin F
Flexural Strength	D790	psi	18,500	16,400	14,600	15,300	19,000	11,900
		MPa	127.6	113.1	100.7	105.5	131.0	82.07
Flexural Modulus	D790	psi	5.4×10^5	5.0×10^5	4.1×10^5	4.5×10^5	5.2×10^5	5.2×10^5
		MPa	3,720	3,450	2,830	3,100	3,590	3,590
Tensile Strength	D638	psi	9,500	9,100	8,300	9,000	10,800	7,200
		MPa	65.5	62.8	57.2	62.1	74.5	49.7
Tensile Modulus	D638	psi	5.5×10^5	5.2×10^5	4.9×10^5	4.4×10^5	5.1×10^5	5.0×10^5
		MPa	3,790	3,590	3,380	3,030	3,520	3,450
Tensile Elongation	D638	%	2.1	2.2	2.1	3.4	3.0	1.6
Hardness, 934-1 Gauge	D2583		43	43	43	43	43	42
Heat Distortion	D648	°F	209	203	183	183	179	179
		°C	98	95	84	84	82	82

Table 2: ASTM C581 Coupon Physical Properties

	Flexural Strength psi/MPa	Flexural Modulus psi/MPa
Resin A	15,500/106.9	819,000/5,650
Resin B	15,850/109.3	775,000/5,350
Resin C	16,750/115.5	841,000/5,800
Resin D	15,850/109.3	775,000/5,350
Resin E	18,200/125.5	762,000/5,260
Resin F	15,250/105.2	781,000/5,390

Table 3: Liquid Resin Properties

	Test	Unit	Resin A	Resin B	Resin C	Resin D	Resin E	Resin F
Viscosity	CRSTP* 10#	cps	575	450	530	500	700	610
Thixotropic Index	CRSTP* 10#		3.0	2.3	2.2	2..1	2.1	2.6
HAP Content	EPA 311	%	47.5	34.1	35.0	34.2	34.9	44.2
VOC Content	CRSTP* 14	%	47.5	40.8	36.9	40.9	34.9	44.2
Solids Content	CRSTP* 14	%	52.5	59.2	63.1	59.1	65.1	55.8

* CRSTP is an internal test at Interplastic Corporation.
# The viscosity samples were adjusted to 77°F (25°C) run on a Brookfield LVT viscometer at 60 rpm and 6 rpm.

Table 4: Resin A Corrosion Properties

Environment	Month	Flexural Strength % Retention	Flexural Modulus % Retention	Weight % Change	Thickness % Change
25% Sulfuric Acid	1	83.9	91.1	-4.49	0.00
25% Sulfuric Acid	3	92.3	100	-0.08	-0.17
25% Sulfuric Acid	6	96.8	99.5	0.23	0.00
25% Sulfuric Acid	12	94.9	100	0.72	0.30
15% Hydrochloric Acid	1	75.5	57.3	0.37	0.53
15% Hydrochloric Acid	3	89.9	65.9	0.02	-0.27
15% Hydrochloric Acid	6	59.4	61.5	0.67	1.80
15% Hydrochloric Acid	12	53.0	68.7	0.14	2.07
15% Nitric Acid	1	77.4	88.8	-2.19	-3.15
15% Nitric Acid	3	79.4	100	-0.35	-1.44
15% Nitric Acid	6	79.4	93.4	-0.17	0.60
15% Nitric Acid	12	55.6	84.3	0.89	2.56
25% Acetic Acid	1	66.5	63.9	0.34	2.82
25% Acetic Acid	3	100	94.1	0.62	0.29
25% Acetic Acid	6	89.0	83.6	1.55	1.29
25% Acetic Acid	12	83.5	77.2	1.29	2.41
5% Sodium Hydroxide	1	91.0	95.6	-0.09	-0.56
5% Sodium Hydroxide	3	60.7	89.9	0.49	0.49
5% Sodium Hydroxide	6	55.0	88.5	0.22	-0.24
5% Sodium Hydroxide	12	52.3	79.4	-1.07	-0.28
Demineralized Water	1	72.9	88.3	1.09	12.33
Demineralized Water	3	79.4	100	-0.17	-0.94
Demineralized Water	6	66.5	78.8	2.32	3.30
Demineralized Water	12	44.5	76.3	4.14	6.15

Table 5: Resin B Corrosion Properties

ENVIRONMENT	MONTH	FLEXURAL STRENGTH % RETENTION	FLEXURAL MODULUS % RETENTION	WEIGHT % CHANGE	THICKNESS % CHANGE
25% Sulfuric Acid	1	100	88.0	-0.10	-0.31
25% Sulfuric Acid	3	95.3	84.8	-0.33	-1.62
25% Sulfuric Acid	6	99.0	90.5	0.09	1.21
25% Sulfuric Acid	12	95.7	87.8	0.29	1.02
15% Hydrochloric Acid	1	83.3	72.5	-0.19	-0.28
15% Hydrochloric Acid	3	92.8	79.9	-0.18	-0.29
15% Hydrochloric Acid	6	61.8	69.4	0.68	2.09
15% Hydrochloric Acid	12	60.2	79.5	-0.09	0.30
15% Nitric Acid	1	66.3	75.0	-1.50	-2.30
15% Nitric Acid	3	94.6	100	-0.56	-1.77
15% Nitric Acid	6	52.4	68.9	1.15	-4.65
15% Nitric Acid	12	56.7	65	0.54	-0.29
25% Acetic Acid	1	61.2	53	-1.39	-0.58
25% Acetic Acid	3	100	62.6	1.28	0.90
25% Acetic Acid	6	62.5	50.8	1.77	1.10
25% Acetic Acid	12	34.0	48.5	1.55	-1.38
5% Sodium Hydroxide	1	62.5	78.6	-0.43	0.02
5% Sodium Hydroxide	3	54.3	69.2	1.14	0.58
5% Sodium Hydroxide	6	59.7	79.7	-2.05	-0.60
5% Sodium Hydroxide	12	58.7	74.1	-1.41	-0.88
Demineralized Water	1	65.0	69.8	1.84	0.88
Demineralized Water	3	61.2	83.1	-0.44	0.60
Demineralized Water	6	50.5	72.9	0.11	-1.08
Demineralized Water	12	47.2	56.9	0.66	-1.52

Table 6: Resin C Corrosion Properties

Environment	Month	Flexural Strength % Retention	Flexural Modulus % Retention	Weight % Change	Thickness % Change
25% Sulfuric Acid	1	66.9	68.0	0.05	0.00
25% Sulfuric Acid	3	100	100	-0.34	-0.61
25% Sulfuric Acid	6	100	86.1	0.12	0.00
25% Sulfuric Acid	12	92.6	82.2	0.43	-0.31
15% Hydrochloric Acid	1	65.7	50.8	-0.64	0.00
15% Hydrochloric Acid	3	89.0	53.0	-0.39	-1.42
15% Hydrochloric Acid	6	50.2	58.7	1.00	1.10
15% Hydrochloric Acid	12	43.2	58.5	0.56	0.00
15% Nitric Acid	1	53.7	61.5	-4.41	-4.14
15% Nitric Acid	3	59.1	87.8	-0.98	-0.84
15% Nitric Acid	6	40.0	57.9	1.86	2.07
15% Nitric Acid	12	41.7	58.0	1.40	-0.26
25% Acetic Acid	1	47.2	37.5	0.89	1.91
25% Acetic Acid	3	90.8	64.8	2.09	2.03
25% Acetic Acid	6	51.9	39.6	3.93	3.31
25% Acetic Acid	12	51.0	55.4	0.63	-0.28
5% Sodium Hydroxide	1	46.0	76.9	-0.07	-5.02
5% Sodium Hydroxide	3	60.3	80.5	1.83	1.83
5% Sodium Hydroxide	6	56.8	67.9	-0.49	-0.49
5% Sodium Hydroxide	12	58.5	74.6	-1.39	-1.39
Demineralized Water	1	46.6	67.5	1.76	3.71
Demineralized Water	3	53.1	84.5	-0.20	0.29
Demineralized Water	6	53.7	70.0	4.92	1.68
Demineralized Water	12	86.2	86.2	-0.99	0.00

Table 7: Resin D Corrosion Properties

Environment	Month	Flexural Strength % Retention	Flexural Modulus % Retention	Weight % Change	Thickness % Change
25% Sulfuric Acid	1	100	88.0	-0.10	-0.31
25% Sulfuric Acid	3	95.3	84.8	-0.33	-1.62
25% Sulfuric Acid	6	99.0	90.5	0.09	1.21
25% Sulfuric Acid	12	95.7	87.8	0.29	1.02
15% Hydrochloric Acid	1	83.3	72.5	-0.19	-0.28
15% Hydrochloric Acid	3	92.7	79.9	-0.18	-0.29
15% Hydrochloric Acid	6	61.8	69.4	0.68	2.09
15% Hydrochloric Acid	12	60.2	79.5	-0.09	0.30
15% Nitric Acid	1	66.3	75.0	-1.50	-2.03
15% Nitric Acid	3	94.6	100	-0.56	-1.77
15% Nitric Acid	6	52.4	68.9	1.15	-4.65
15% Nitric Acid	12	56.7	65.0	0.54	-0.29
25% Acetic Acid	1	61.2	53.0	-1.39	-0.58
25% Acetic Acid	3	100	62.6	1.28	0.90
25% Acetic Acid	6	62.5	50.8	1.77	1.10
25% Acetic Acid	12	34.0	48.5	1.55	-1.38
5% Sodium Hydroxide	1	62.5	78.6	-0.43	0.02
5% Sodium Hydroxide	3	54.3	69.2	1.14	0.58
5% Sodium Hydroxide	6	59.7	79.7	-2.05	-0.60
5% Sodium Hydroxide	12	58.7	74.1	-1.41	-0.88
Demineralized Water	1	65.0	69.8	1.84	0.88
Demineralized Water	3	61.2	83.1	-0.44	0.60
Demineralized Water	6	50.5	72.9	0.11	-1.08
Demineralized Water	12	47.2	56.9	0.66	-1.52

Table 8: Resin E Corrosion Properties

Environment	Month	Flexural Strength % Retention	Flexural Modulus % Retention	Weight % Change	Thickness % Change
25% Sulfuric Acid	1	80.8	83.1	0.29	-0.28
25% Sulfuric Acid	3	68.1	74.9	0.1	-0.58
25% Sulfuric Acid	6	75.3	85.8	0.12	-1.55
25% Sulfuric Acid	12	87.9	100	-0.07	-0.93
15% Hydrochloric Acid	1	87.4	74.7	1.16	0.00
15% Hydrochloric Acid	3	93.4	87.1	-1.93	0.57
15% Hydrochloric Acid	6	66.5	82.7	1.93	0.30
15% Hydrochloric Acid	12	69.2	75.3	2.23	-2.15
15% Nitric Acid	1	63.2	100	0.36	-1.25
15% Nitric Acid	3	58.2	47.1	1.09	0.24
15% Nitric Acid	6	56.0	74.0	-0.72	-2.29
15% Nitric Acid	12	0.00	0.00	-6.00	-6.00
25% Acetic Acid	1	73.1	66.3	2.84	2.81
25% Acetic Acid	3	71.9	61.2	4.36	4.10
25% Acetic Acid	6	56.6	46.9	6.31	6.45
25% Acetic Acid	12	0.00	0.00	10.7	3.62
5% Sodium Hydroxide	1	60.4	79.5	-0.36	-2.09
5% Sodium Hydroxide	3	40.1	57.9	-0.91	-1.26
5% Sodium Hydroxide	6	0.00	0.00	-6.00	-6.00
5% Sodium Hydroxide	12	0.00	0.00	-6.00	-6.00
Demineralized Water	1	53.3	96.9	1.41	0.83
Demineralized Water	3	40.7	78.6	1.47	0.30
Demineralized Water	6	30.22	56.6	1.40	-0.05
Demineralized Water	12	61.5	73.8	2.08	1.81

Table 9: Resin F Corrosion Properties

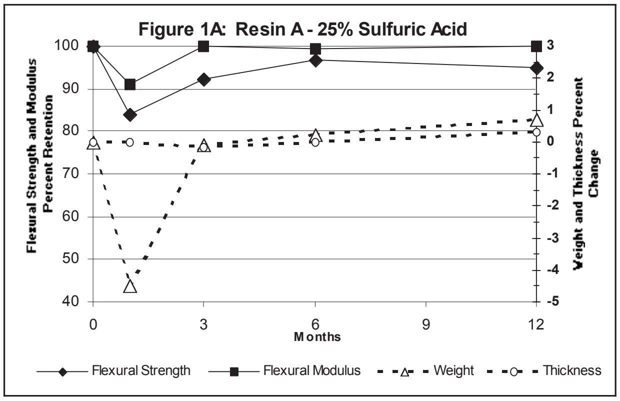
Environment	Month	Flexural Strength % Retention	Flexural Modulus % Retention	Weight % Change	Thickness % Change
25% Sulfuric Acid	1	63.6	58.0	-2.68	0.28
25% Sulfuric Acid	3	92.5	70.3	-0.56	0.29
25% Sulfuric Acid	6	60.3	59.0	-0.22	0.55
25% Sulfuric Acid	12	50.7	65.8	-0.47	1.42
15% Hydrochloric Acid	1	63.6	58.0	-2.68	0.28
15% Hydrochloric Acid	3	92.5	70.3	-0.56	0.29
15% Hydrochloric Acid	6	60.3	59.0	-0.22	0.55
15% Hydrochloric Acid	12	50.7	65.8	-0.47	1.42
15% Nitric Acid	1	83.3	55.3	-2.68	-2.86
15% Nitric Acid	3	100	73.9	-0.92	-0.30
15% Nitric Acid	6	80.0	64.5	-0.65	0.00
15% Nitric Acid	12	74.5	72.6	-1.36	-0.61
25% Acetic Acid	1	51.8	40.3	-1.87	0.00
25% Acetic Acid	3	69.5	48.5	2.22	-1.42
25% Acetic Acid	6	83.9	59.9	1.41	3.37
25% Acetic Acid	12	55.1	36.2	-0.73	1.97
5% Sodium Hydroxide	1	74.1	77.1	-0.37	1.30
5% Sodium Hydroxide	3	57.7	61.8	0.72	3.33
5% Sodium Hydroxide	6	57.6	63.4	-1.94	-2.09
5% Sodium Hydroxide	12	63.6	62.4	-1.64	-0.85
Demineralized Water	1	74.1	71.5	1.05	2.51
Demineralized Water	3	85.9	70.7	-0.37	0.02
Demineralized Water	6	55.1	60.4	1.62	2.30
Demineralized Water	12	70.7	59.8	1.39	-0.33

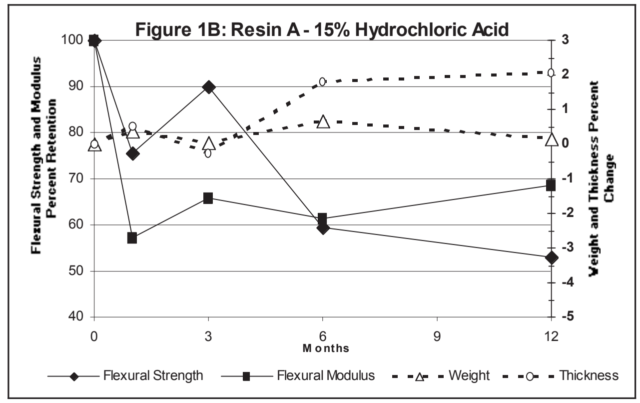
Table 10: Ranking of the coupons in the various corrosive media

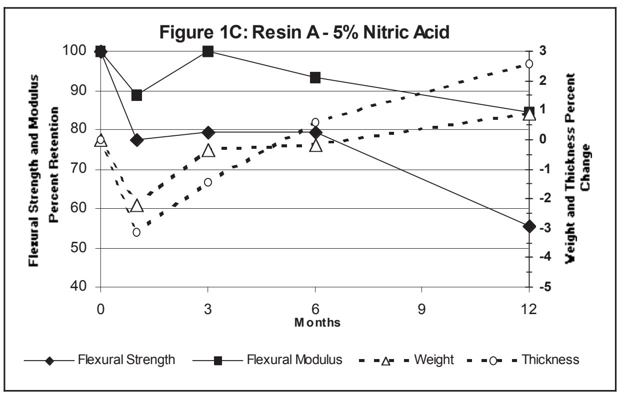
	Resin A	Resin B	Resin C	Resin D	Resin E	Resin F
25% Sulfuric Acid	1	2	2	2	2	2
15% Hydrochloric Acid	2	3	3	2	1	2
5% Nitric Acid	2	2	1	2	4	3
25% Acetic Acid	1	2	2	2	4	4
5% Sodium Hydroxide	1	1	1	1	4	1
Demineralized Water	3	3	2	2	3	1
Overall Total	**10**	**13**	**11**	**11**	**18**	**13**

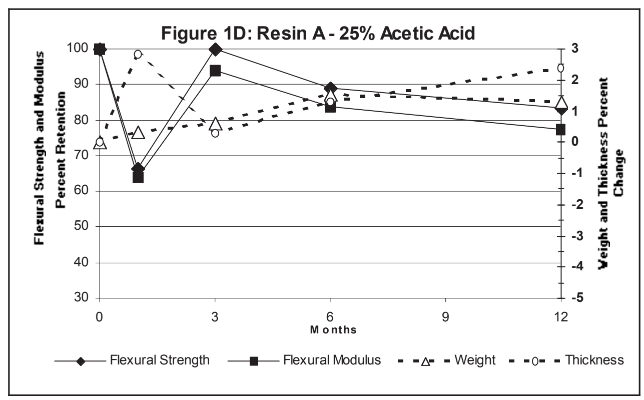
Performance ranked 1 to 5. A ranking of 1 indicates the best performance. Overall lowest total is the best performer.

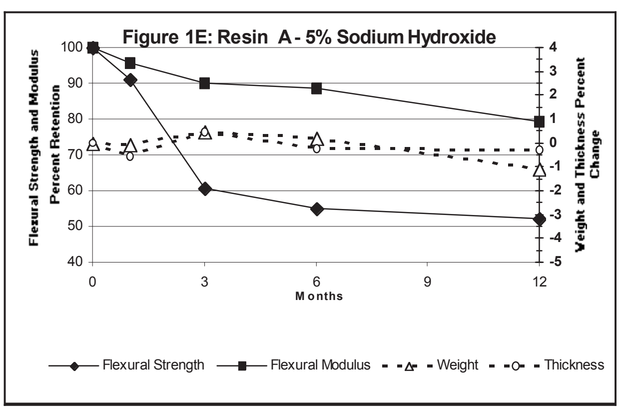
Resin A Performance

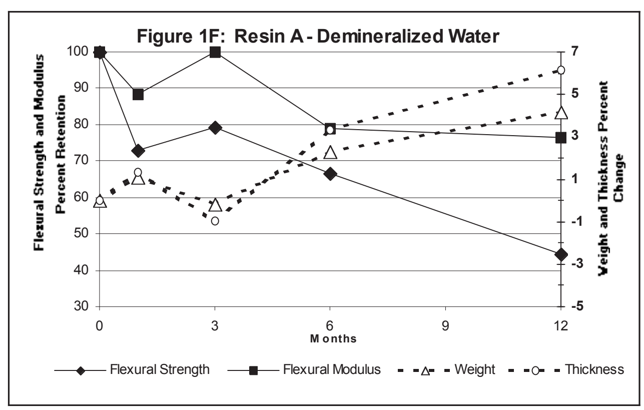




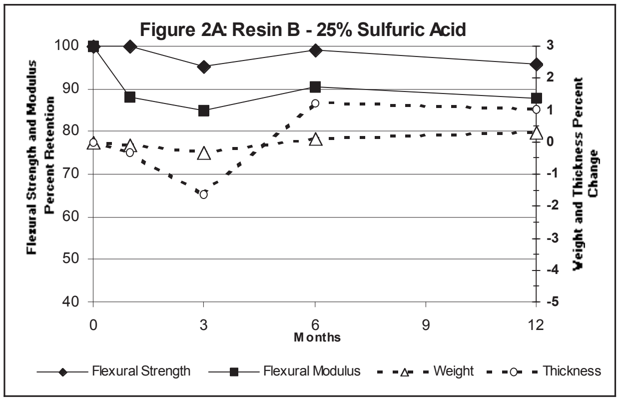


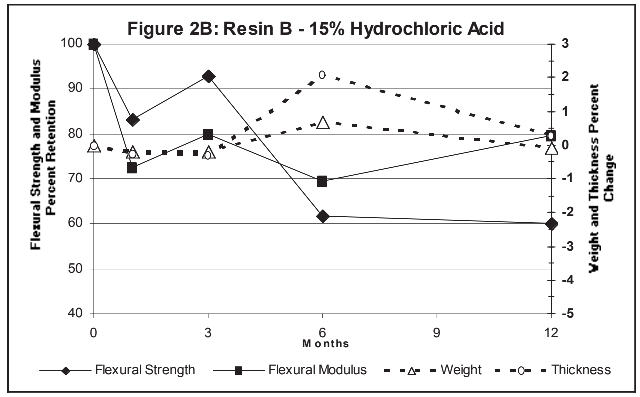


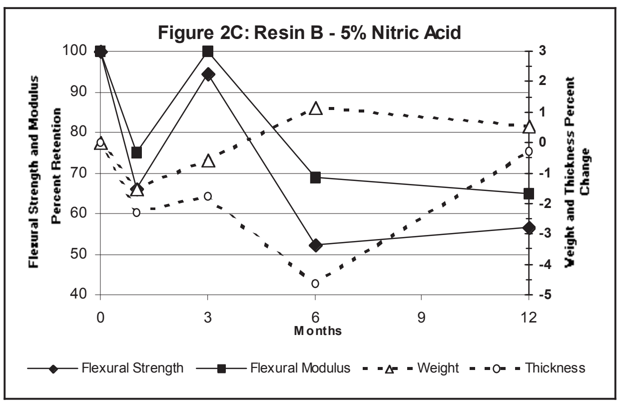


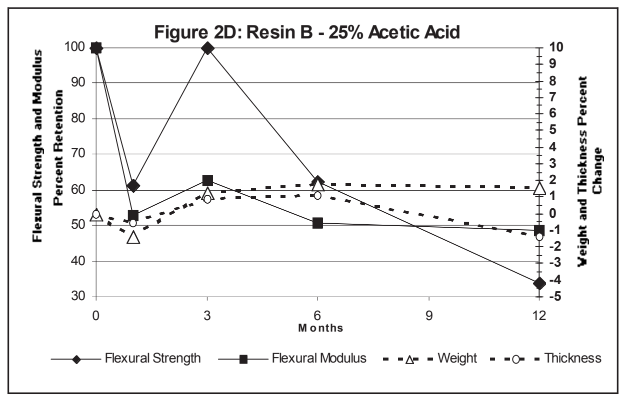


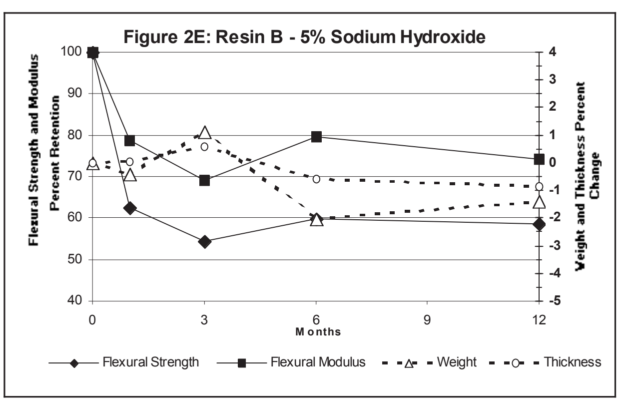
Resin B Performance

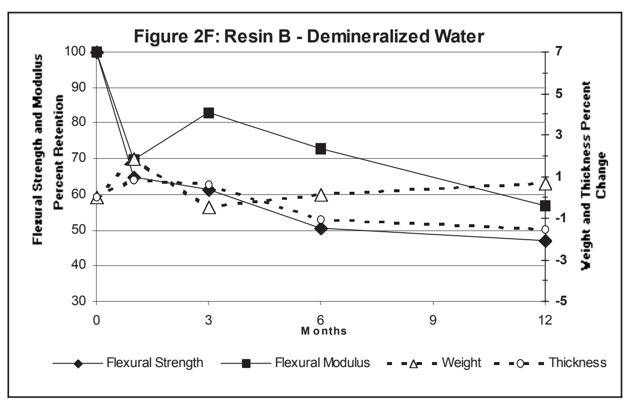












Resin C Performance

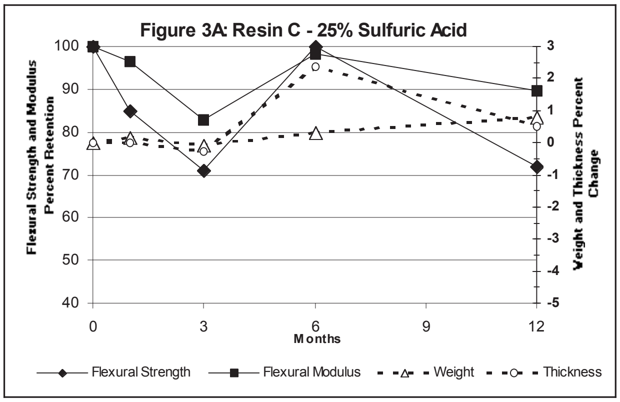


Figure 3A: Resin C - 25% Sulfuric Acid

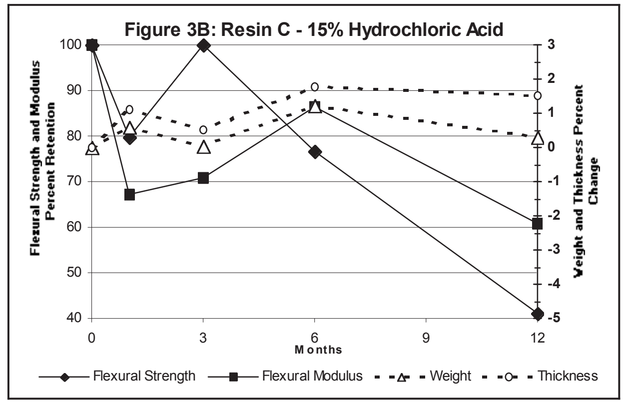


Figure 3B: Resin C - 15% Hydrochloric Acid

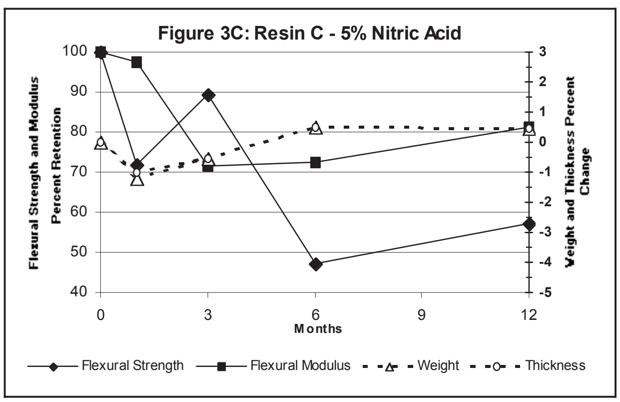


Figure 3C: Resin C - 5% Nitric Acid

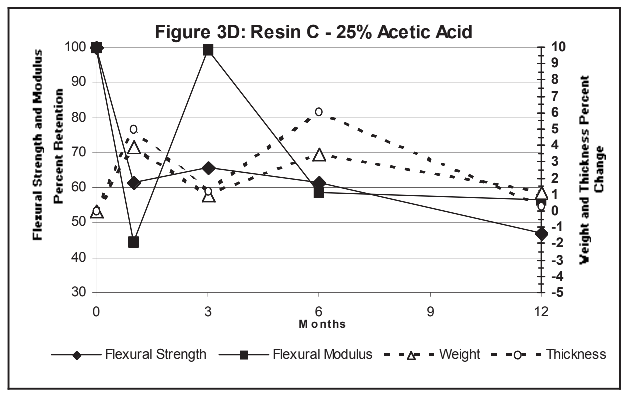


Figure 3D: Resin C - 25% Acetic Acid

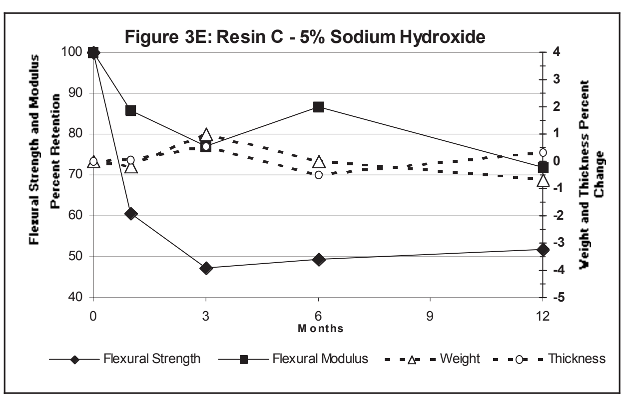


Figure 3E: Resin C - 5% Sodium Hydroxide

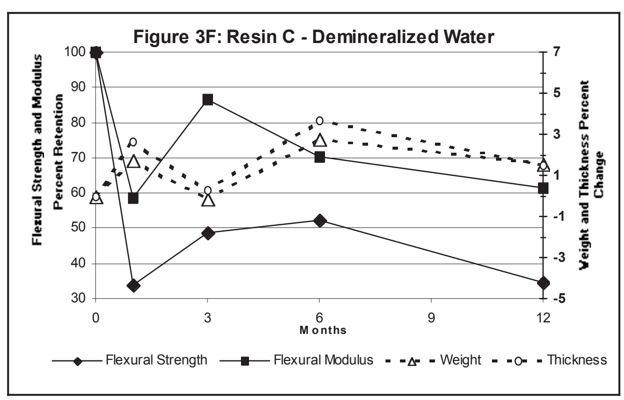
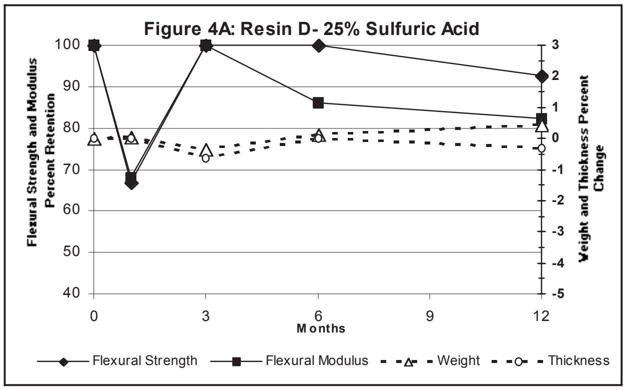
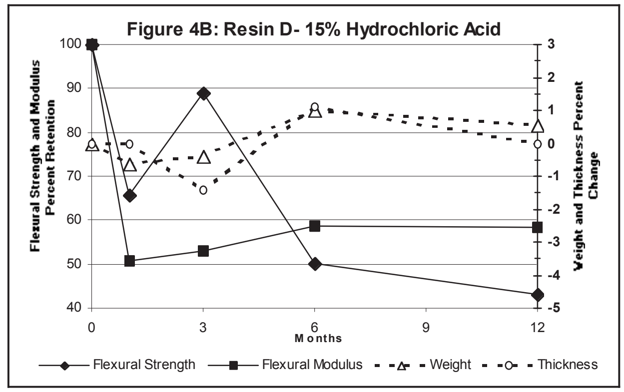
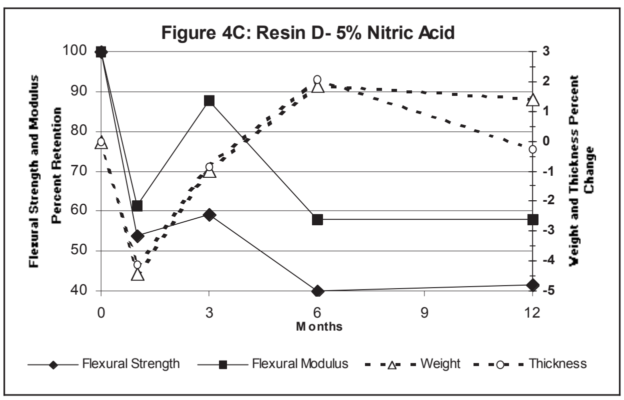


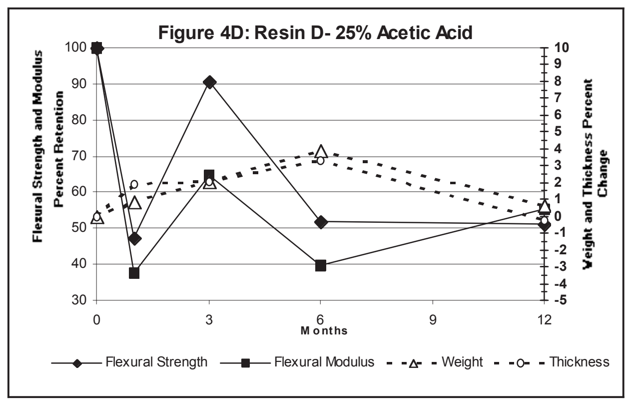
Figure 3F: Resin C - Demineralized Water

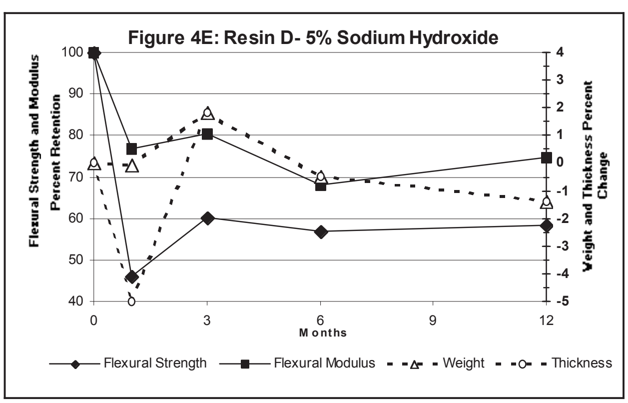
Resin D Performance

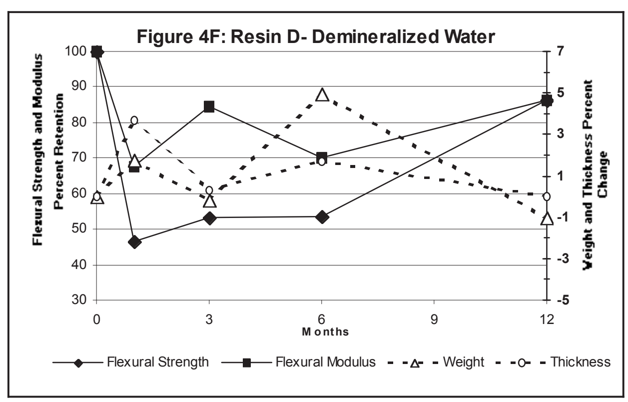




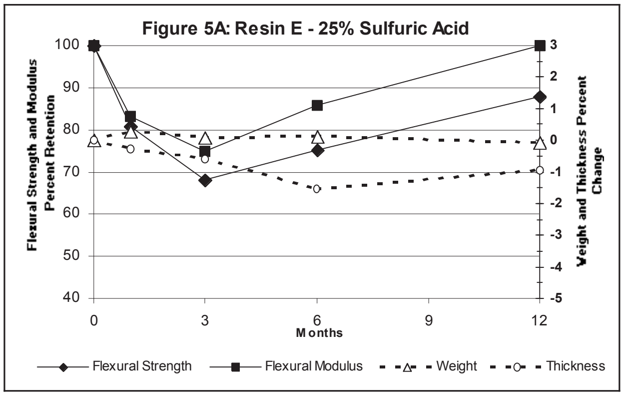


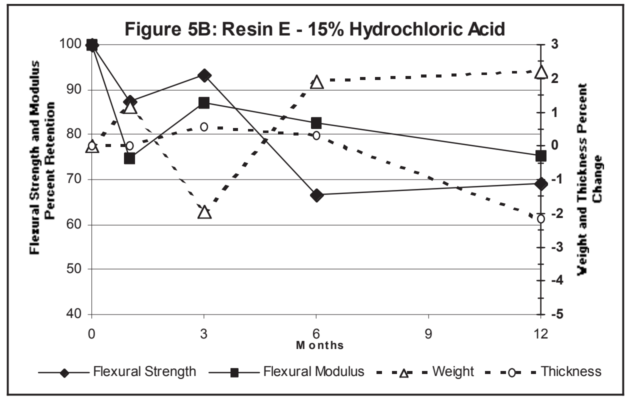


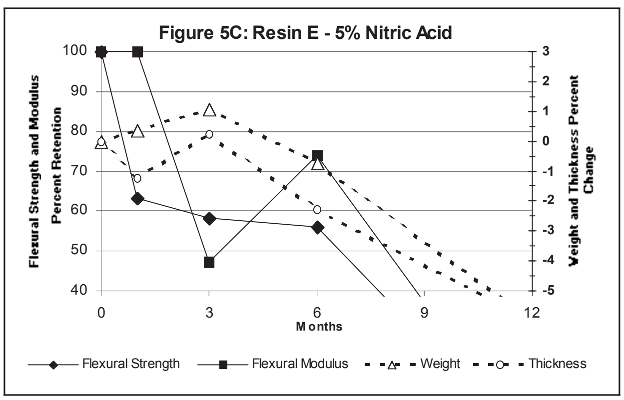


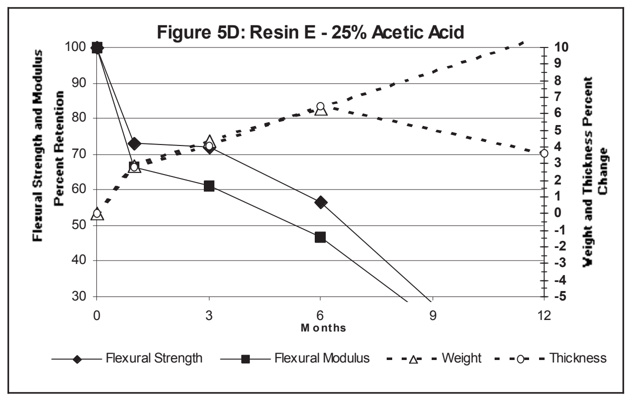


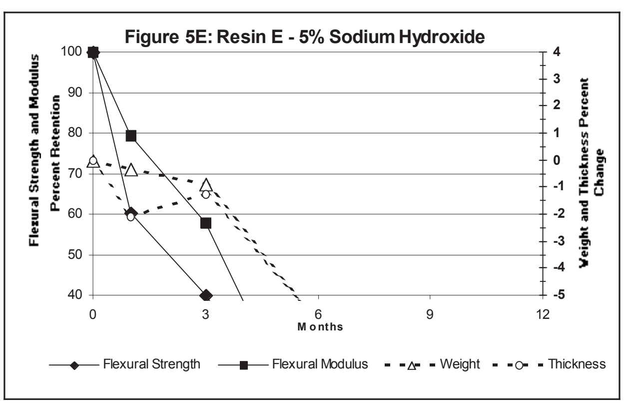
Resin E Performance

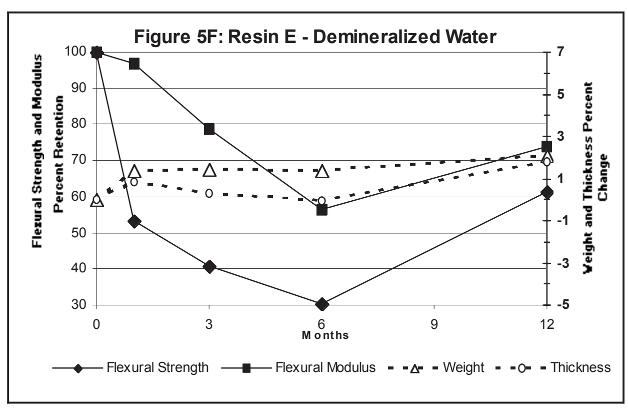




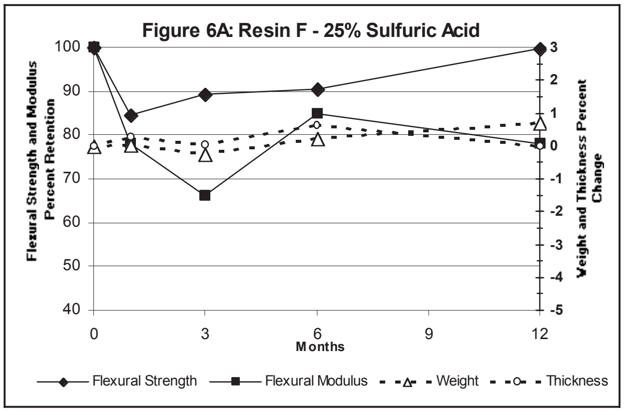


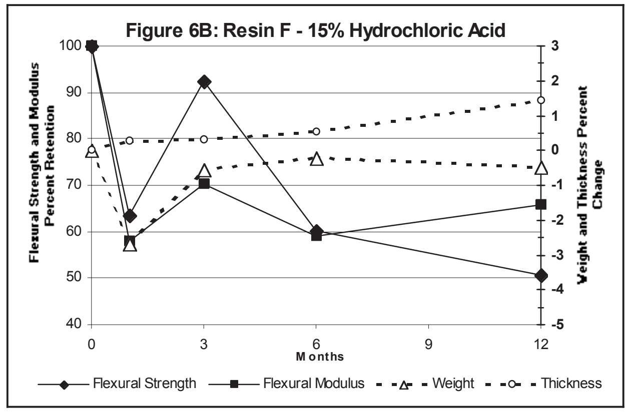


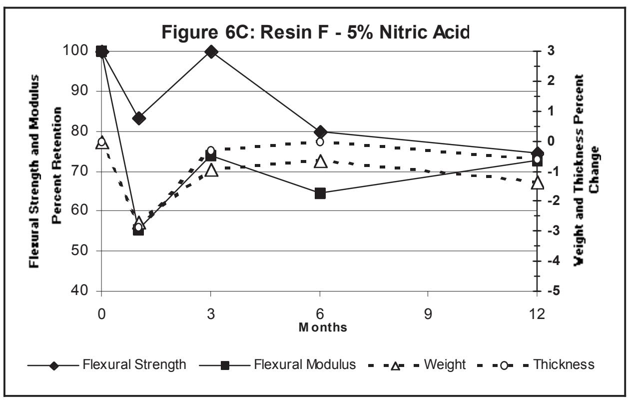


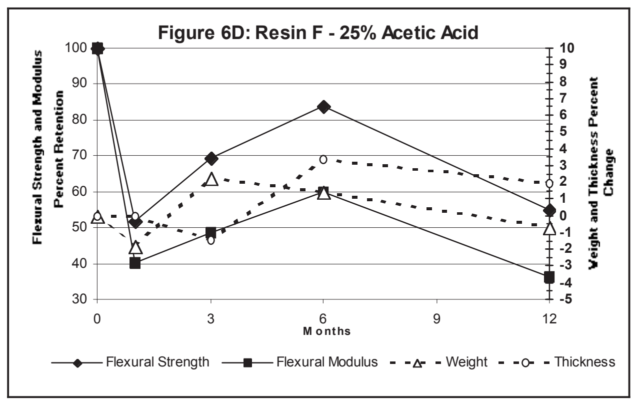


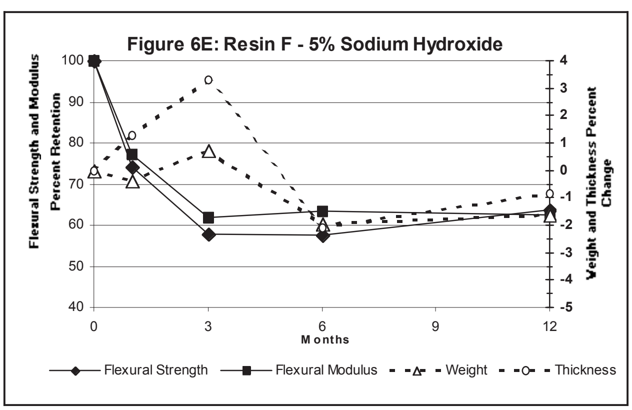
Resin F Performance

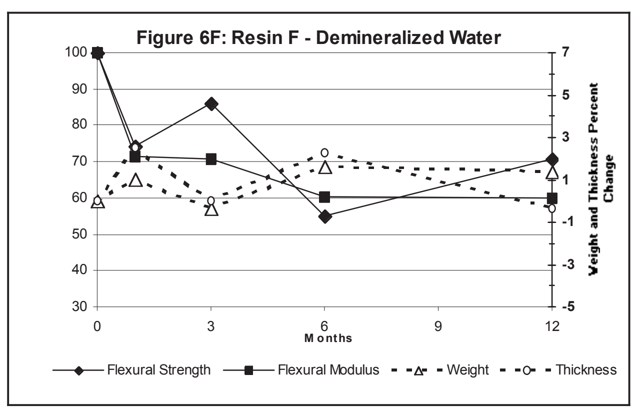












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