



# Technical Research

## The Effects of Surface Modified Alumina Trihydrate on a Vinyl Ester Resin

INTERPLASTIC CORPORATION  
Thermoset Resins Division

## ABSTRACT

Vinyl ester resins have typically been used in applications requiring highly corrosion resistant, high-strength composites. Sometimes fire resistant capabilities are also required. Typical applications include ducting, grating, pipe, tanks and flooring. Our test objective was to determine whether surface modified alumina trihydrate could enhance the physical performance of fiberglass reinforced plastics (FRP) composites.

This study was done in two parts. The first part is a comparison of a non-filled composite to a composite with 33% alumina trihydrate added. The second part is a comparison of two surface modified alumina trihydrate products to a product made with untreated alumina trihydrate. The testing was done on panels constructed according to ASTM C-581.

The effects on the liquid properties, smoke density, cone calorimetry, and corrosion resistance were investigated. The coupons were immersed in several corrosive media to evaluate the effects of the alumina trihydrates. Smoke density and cone calorimeter testing were done according to ASTM E-662 and ASTM E-1354, respectively.

## INTRODUCTION

Using fillers to help decrease the cost of the composite is a common practice in the FRP industry. A portion of the resin is replaced with a less expensive filler, such as alumina trihydrate, clay, talc, calcium carbonate or calcium sulfate.

When exposed to corrosive media, some of these fillers are more inert than others. This is important to remember if the composite will be used in corrosive environments. Calcium sulfate and calcium carbonate are not used in composites that will be exposed to acidic environments because acids can dissolve these fillers and form voids. A high concentration of voids or a blister shows up as a localized decrease in the composite's stiffness. Loss of stiffness could cause premature composite failure when stress is applied.

Alumina trihydrate (ATH) and calcium sulfate are commonly used fillers when the composite requires fire resistant properties. ATH and calcium sulfate do not require any other compounds to work as a fire resistant additive, whereas compounds such as antimony trioxide and antimony pentoxide work in a synergistic way with a halogen.

Evaluations have been completed on the fire and corrosion resistant properties of composites with alumina trihydrate or calcium sulfate added to

them. Calcium sulfate is limited to use in composites with fire resistant requirements, and to non-corrosive environments. When an application calls for both fire and corrosion resistant properties, ATH is generally the only cost-effective filler that meets those requirements.

ATH has been used for many years as a flame retardant and smoke suppressant in thermoset FRP composites. It lowers the smoke density and decreases the flame spread when it endothermically dehydrates. Three molecules of water are contained in ATH and are liberated when the composite's temperature reaches approximately 392°F/200°C. The released water cools the flaming area and dilutes the combustion gases with water vapor, which results in lower smoke density and decreased flame spread for the composite.

When ATH is added to a vinyl ester or polyester resin, the resin's viscosity increases. Surface modification of the ATH will decrease the resin's viscosity, improve the filler wet-out and improve its dispersion into the resin, and the composite's physical properties.

## EXPERIMENTAL

Our objective was to study the effects of surface-modified ATH on the performance properties of a vinyl ester resin commonly used in applications such as gratings, ducting, tanks, pipes and flooring. We examined the viscosity changes in the vinyl ester resin when either a treated or a non-treated ATH product was mixed into it. In addition, ASTM C-581 composite panels were prepared and test specimens were cut from them to measure their physical, flame and smoke, and corrosion resistant properties.

One lot of CoREZYN® CORVE8431 vinyl ester resin was used to make four sets of coupons for testing. This resin is designed to be filled with ATH and have low smoke density and slow flame spread properties. The four sets of coupons manufactured consisted of one without filler and three with filler.

Commercially available ATH products were evaluated in this study. SB432 and Micral SB932 from the Solem Division of J.M. Huber Corporation were the untreated ATH products. SB432SH, SB432SP, Micral 932SH and Micral 932SP were the surface-modified ATH products. The SB432 is a nine-micron, average particle size ATH (referred to as coarse ATH), while the Micral 932 is a two-micron product (referred to as fine ATH).

For the vinyl ester composites, the coarse and fine ATH products were blended in a 2:1 ratio of coarse to fine. The 432SH/932SH blend will be referred to as SH and the 432SP/932SP blend will be referred to as SP throughout this work. The total ATH loading in the composites was 33%.

A Brookfield Viscometer, model LVT, with spindle #2 at 6 and 60 RPM was used to check the viscosities of the resins at 77°F/25°C. The thixotropic index is the 6 RPM viscosity divided by the 60 RPM viscosity.

The coupons for the corrosion testing were made according to ASTM C-581 with 20% reinforcement and 80% resin or resin/filler mixture. A synthetic veil of Nexus, made by Burlington Industries, was used in place of the C-Glass. This is especially critical for the sodium hydroxide environments because fiberglass is attacked quite rapidly by this environment. The coupons were cut to size and engraved in the upper right corner.

The coupon edges were coated and the engraving sealed with the same resin to prevent wicking of the solutions via any fiberglass ends exposed when the panels were cut, and avoid any effect on the corrosion resistant testing. The coupons were then post-cured. The post cure cycle consisted of a four hour ramp from room temperature to 250°F/121°C, followed by two hours at 250°F/121°C and then cooled to room temperature in two hours.

The weights of the coupons were taken on a Sartorius Model 1204MP and recorded. Thicknesses were measured with a Starrett micrometer on the three non-engraved corners and the average of the three measurements was recorded. Initial flexural strengths, for calculating retention over the test period, were established by testing thick, medium, and thin coupons. Fifteen specimens were tested for the neat resin and the two resin/filler combinations.

The following test solutions made up the corrosive environments used in this study: 15% hydrochloric acid, 25% acetic acid, 5% nitric acid, 5% sodium hydroxide, 100% deionized water, and 90% fuel C/10% methanol. The 90% fuel C/10% methanol and 5% nitric acid were evaluated only at 77°F/25°C and the 15% hydrochloric acid was only tested at 160°F/71°C. All of the other media were run at 77°F/25°C and 160°F/71°C. Representative samples were pulled out of the solutions and tested at one, three and six months.

When the samples were pulled from the solutions, they were rinsed with fresh water and wiped dry. The coupons were weighed and their thicknesses measured. They were then stored in a sealed container for conditioning at room temperature for 24 hours before testing for flexural strength. Specimens were tested within 72 hours after the conditioning period.

Static physical properties of the ASTM C-581 coupons were tested according to ASTM D-790 (flexural) and ASTM D-638 (tensile) on an Instron

Model 4505 Universal Tester. The hardnesses were tested with a Barber Coleman Barcol Impressor 934-1 gauge.

Cone calorimetry data was generated with a model CS-237 cone calorimeter from Atlas Electric Devices.

Composite specimens were burned in a Newport Scientific ASTM E-662 smoke chamber to measure the smoke density they generated. The specimens were tested in the flaming and non-flaming modes.

## RESULTS & DISCUSSION

The viscosity study results are listed in Table 1. From the data, one observes that the addition of ATH to the resin increases the mix viscosity, and by blending coarse and fine particle-sized ATH, the viscosity can be reduced. Blending smaller-sized particle fillers with larger particles, while maintaining the same percent loading, in other systems can yield a higher viscosity, but with this combination of fillers, the viscosity was lower. This is likely due to the particle packing of the various sizes of ATH used in this combination. The viscosity was 20% to 30% lower for the blend of two particle-sized ATH fillers than the viscosity of a mixture made with only the coarse-sized ATH. Viscosities of the filled systems were comparable at 6 and 60 RPMs. The data also shows that with the proper surface treatment, one can reduce the viscosity of the mix more with surfaced-treated ATH than with untreated ATH.

Gel and cure times for both SH and SP were similar. The gel and cure times for the untreated ATH blend were 30% longer than the surface-treated blends. The increases in both gel and cure times are attributed to the untreated fine-particle-sized ATH. The mix with only the coarse-particle-sized ATH had a gel and cure time similar to the two surface-treated ATH blends.

All of the composites were post-cured to ensure the resin portion was thoroughly cured before testing. Flexural strengths of the filled mixes varied from 79 MPa to 135 MPa (11,450 psi to 19,580 psi) as shown in Tables 2, 2A, 2B, 2C and 2D. The composites with SH and SP surface treated ATH blends had significantly lower strengths than the untreated filler blend. However, the composite with SP filler blend increased an average of 50% and 35% in flexural strength in the first month of exposure to the various chemical environments at 77°F/25°C and 161°F/71°C, respectively. The composites constructed with the SH filler blend had a maximum increase of 14% and a decrease of 6% in the same testing.

The static physical properties showed an increase of 30 - 40% of the flexural moduli for the filled systems compared to the unfilled system. Composites made from filled systems normally have higher moduli than their

unfilled counterparts. The Barcol hardness was higher for the filled systems: 37 for the untreated, 37 for the SH and 46 for the SP ATH blends. The SP filler yielded the highest initial Barcol hardness, but the other filled system increased to the same point after one month of exposure to the various media.

Data on flexural strength, flexural modulus, and Barcol hardness for the initial samples are listed in Table 2. The data on the aged specimens are listed in Tables 2A, 2B, 2C and 2D. The data on weight and thickness changes are listed in Tables 3A, 3B, 3C and 3D.

## CORROSION TESTING RESULTS

**15% Hydrochloric Acid at 160°F/71°C:** The unfilled resin system, the SH system, and the SP system increased in flexural strength in the first month then decreased in flexural strength over the next five months. After six months, the SP ATH system retained 104%, while the SH system retained 87%, and the untreated ATH system retained 46%. The unfilled system had dropped to 91% of its original flexural strength after six months. Flexural modulus for the unfilled system dropped steadily to 72% of its original modulus during the six months test period, while the flexural modulus of the filled systems dropped and leveled off after three months. SH, SP and untreated ATH leveled off at 54%, 48%, and 34% retention, respectively.

The change in weight and thickness showed the same general trends. The unfilled system had the least change followed by SH, SP and the untreated ATH.

Hardness of the unfilled system did not change during immersion. The three filled systems showed a significant drop-off in the first three months and the composite with untreated ATH had softened to the point where it had no Barcol reading with the 934-1 Barber Coleman Impressor gauge. Both of the treated fillers maintained a hardness of approximately 5 after three months.

**5% Nitric Acid at 77°F/25°C:** The SH system and untreated ATH system maintained their flexural strengths at 95% and 85% over the six month period. The unfilled system initially increased and maintained its strength at 120% of its original. The SP system increased to 155% of its original flexural strength and then gradually declined to 120% retention after six months. Flexural modulus for each of the composites leveled off in three months and the best retention was the unfilled followed by SH, untreated, and finally the SP.

All four composites had < 1% weight change over

the six-month period. The thickness of all four composites changed < 1% in the first three months and < 2% after six months. The unfilled composite thickness decreased 1.1% and the untreated ATH increased by 1.8%.

Hardness of the unfilled composite did not change over the test period. The composite with non-surface treated ATH leveled off after three months and the two composites with surface treated ATH continued to drop over the six month period.

**25% Acetic Acid at 77°F/25°C:** SH, unfilled, and untreated ATH maintained their flexural strength over the six month period at 105%, 100%, and 95% retention, respectively. The SP system increased 50% in one month and then dropped 30% between three and six months. The SH system and the untreated ATH system maintained their moduli over the six month period at 100% and 90% retention, respectively. The SP and the unfilled systems dropped to 75% and 70%, respectively, in the six month timeframe.

The unfilled system had a 4% increase in thickness and a 2.5% increase in weight. There was < 1% weight change and < 2% thickness change for all three filled systems.

The hardness for the filled systems was similar with a three point drop in the six months. The unfilled system dropped 10 points in the same timeframe.

**25% Acetic Acid at 160°F/71°C:** The unfilled composite maintained approximately 100% of its flexural strength over six months. SP increased by 40% in one month then dropped to 97% retention in the next five months. SH decreased linearly over the six month period to 70%. The flexural strength of the untreated ATH was fairly level at 70% retention. Flexural modulus retention for the unfilled system was level at 100% for three months then dropped to 71% retention. The three filled systems had a similar profile with all decreasing in modulus over the six month period. SH, SP, and untreated ATH were "best-to-worst" in retaining flexural modulus.

The unfilled system had the least weight and thickness gain. All three of the filled systems gained weight and thickness over the six months. The SP, untreated, and SH were rated "best-to-worst," respectively. The Barcol hardness decreased from one month to the six month point for all four composites. The unfilled composite increased to a hardness of 40 after one month and then dropped down to less than 10 after six months. All of the filled systems had similar performance going from 35-40 to 25-30 after six months.

**5% Sodium Hydroxide at 77°F/25°C:** Both of the treated filler systems performed better in retention of flexural strength than the untreated and unfilled systems. SH

appeared the best, maintaining between 95% and 115% retention over the entire six months. SP increased over the testing period from 112% to 140% of original strength after six months. SH maintained 100% of its strength over the test period. The untreated and unfilled systems moduli appeared to level off after three months at 80% retention. The unfilled system did not lose any of its flexural modulus after six months while the three filled systems all declined. SP performed the best, followed by the SH, and then the untreated ATH blend at 88%, 83%, and 80%, respectively.

All four systems had a 0.3% increase in weight after one month and maintained it over the remaining time. The trend in thickness change was a slight loss in the six month period except for SH which showed a 3% increase in the final three months of testing. Hardnesses of the filled systems were 42 to 48 after one month and then declined 2 to 6 points over the test period. The unfilled system increased to 37 and then decreased by 6 points as did the filled systems.

**5% Sodium Hydroxide at 160°F/71°C:** SP surface treated ATH increased to 132% in one month, then declined to 80% after six months. SH and the unfilled system dropped but appeared to level off after three months at 80% to 85%. Untreated ATH performed the worst, dropping to 58% after being immersed for six months. The unfilled composite maintained 99% of its initial flexural modulus after six months. The three filled systems showed a decline in the six month period. SH performed the best with 78% retention, followed by untreated ATH at 72% and SP at 67%.

The unfilled system showed a 0.3% weight gain and the three filled systems performed similarly with a weight loss of 0.1% to 0.2%. Unfilled and untreated had a slight loss in their thicknesses, SP had a 1% increase, and SH decreased 1%. The Barcol hardness of the three filled composites ranged from 42 to 46 after one month of immersion. After six months of immersion, the untreated system had the highest hardness at 35, and the SH and SP systems Barcol dropped to 28 and 30, respectively. The unfilled system Barcol increased to 36 after one month and then declined to 24 after six months.

**De-mineralized water at 77°F/25°C:** The flexural strength for SP increased to 164% after one month and remained steady for the remaining period. All the filled systems retained a majority of their flexural strength. The two treated fillers had 90% or higher retention after six months and the untreated ATH was slightly lower at 75% after six months. Flexural moduli for the composites with SH and SP had 93% retention after six months and appeared stable.

Untreated was stable for one to six months at 85% retention. The unfilled composite dropped to less than 80% after six months.

The weight gain and increase in thickness was greatest for the unfilled composite, but still less than 1% in weight and 5% in thickness. Filled composites were very similar in weight and thickness changes with less than 1% increase.

**De-mineralized water at 160°F/71°C:** The flexural strength of the two surface treated ATH blends had a normal scatter at 110% to 120% retention. The unfilled composite increased to 130% retention in one month, then dropped to 88% after six months. The untreated ATH blend dropped to 78% retention after one month then slowly dropped to 60% after six months. Flexural modulus of SH and the untreated ATH were stable in the six months of exposure at about 95% and 75% retention, respectively. SP and the unfilled composite showed a continual decline in modulus over the six months to approximately 75%.

All four composites had less than 1% weight gain and all of them are within a span of 0.25%. Thickness change is scattered between +2% of 0 over the testing period with no trends. After increasing during the first month, the hardnesses of the coupons dropped 6 to 9 points for all of the composites over the remaining six month testing period. All of the filled systems started 8 to 10 points higher than the unfilled system.

**90% Fuel C and 10% Methanol at 77°F/25°C:** SH maintained 100% to 114% of its flexural strength in the six months of immersion. SP increased to 180% of its original strength and dropped off to 105% after six months. The untreated and the unfilled systems dropped 86% and 77%, respectively after one month, then a large drop to 39% and 23%, respectively after six months. The flexural modulus had a similar ranking as the flexural strength with SH retaining 46% after six months, followed by SP at 34%, untreated ATH at 20% and unfilled at 16%.

SH had the lowest increase in weight at 5.4% after six months, followed by SP at 6.2%, untreated ATH at 7.4%, and finally the unfilled at 13.4%. SP had a lowest increase in thickness at 6.2% with SH at 8.8%, followed next by the untreated ATH at 9.2%, and finally, the unfilled at 16%. SH was the only system to have a Barcol hardness measurable on the 934-1 gauge at 7.5 after six months. The other two filled systems decreased over the first three months to 22 to 25, but after six months were not hard enough to register on the 934-1 gauge. The unfilled system did not have a measurable hardness after one month of immersion.

Cone calorimetry data illustrated in Table 4 shows that the ATH filled composites have a lower peak heat release rate than the unfilled vinyl ester resin. In this study, the

SP ATH blend gave the lowest peak heat release rate. Peak heat release rate is a measure of the amount of heat generated when the composite burns, the higher the peak heat release rate the hotter the fire. Furthermore, the time to reach the peak heat release was longer for the filled vinyl ester resin than for the unfilled resin. Also, the time needed to reach the peak heat release rate was longer for the surface treated ATH blends than for the untreated ATH blend.

The average heat release rate was lower for the filled vinyl ester resin composites. Moreover, the average heat release rate for the surface treated ATH blend SP was lower than SH and significantly lower than the unfilled vinyl ester resin.

Specific extinction area data show the filled vinyl ester composites to have a lower specific extinction area than the unfilled resin. Both vinyl ester composites containing surface modified ATH blends generated less smoke than either the composite with the untreated ATH blend or the unfilled vinyl ester resin.

The time to ignition for the vinyl ester composites was 50% to 100% longer when surfaced treated ATH blends replaced the untreated ATH blend in the composite.

Smoke density data is listed in Table 5. As expected, the unfilled vinyl ester resin generated the highest level of smoke density in both the flaming and non-flaming modes. The ATH filled vinyl ester composites generated approximately 50% less smoke density than the unfilled vinyl ester resin. This is a significant reduction in smoke density. Based on the results of the ASTM E-662 test there was no significant difference in the smoke density for the vinyl ester composites containing either treated or untreated ATH, indicating that the surface treatments did not adversely affect the smoke suppression capabilities of the ATH.

## CONCLUSIONS

Surface modifying the ATH with the proper surface treatment lowers the vinyl ester resin/ATH blend viscosity. This in turn improves the wet-out of the glass fiber and the dispersion of the ATH within the composite. Improved dispersion thus improves the overall fire retardant properties of the composite. This is evidenced by such things as lower peak heat release rate, longer time to ignition, and lower specific extinction area. The ATH filled vinyl ester composites in this study have significantly lower smoke density than the unfilled vinyl ester resin.

From the corrosion study, this data shows, that for the filled systems the SH ATH blend performed best of the two surface treated ATH blends and better than the untreated ATH blend. The properties of the coupons manufactured with SH ATH were more consistent than the other filled systems and these properties did level off in several of the media over the time frame tested.

The unfilled system did better in the nitric acid and hydrochloric acid, as well as the sodium hydroxide. However, the unfilled system was comparable in acetic acid, and poorer in the solvents, de-mineralized water, and fuel C/methanol blend. This shows that the ATH can enhance the performance of the resin in these solvents and organic acid environments.

More monitoring work is being done on these sets of coupons, in these media, to complete a twelve-month immersion study so additional conclusions can be drawn. Additional work is also needed to evaluate the properties of the filled coupons in other environments.

Table 1: Viscosity Data on Resin and ATH Mixes

ATH System	Neat Resin	SB432	SB432/932	ST1	ST2
LVT #2 @ 6 RPM @ 77°F/25°C (cps)	360	650	475	425	425
LVT #2 @ 60 RPM @ 77°F/25°C (cps)	145	290	240	230	225
Thixotropic Index	2.48	2.24	1.98	1.84	1.89
Gel Time (min:sec)	16:00	27:15	38:00	28:00	29:30
Cure Time (min:sec)	28:00	44:00	59:30	45:30	48:45
Peak Exotherm (°F/°C)	380/193	284/140	276/136	280/138	280/138

Table 2: Initial Physical Property Data for the Composites

	With Unfilled Resin	With Untreated ATH	With ST2 ATH	With ST2 ATH
Flexural Strength MPa (psi)	104 (15,000)	135 (19,500)	86.2 (12,500)	79.3 (11,500)
Flexural Modulus MPa (psi)	5320(771,000)	8090 (1,170,000)	7048 (1,020,000)	7300 (1,059,000)
Barcol Hardness	28 - 32	35 - 40	35 - 40	44 - 48

Table 2A: Physical Property Data on Unfilled Resin in Various Corrosion Media

MEDIUM: 15% HYDROCHLORIC ACID @ 160°F/71°C	Month 1	Month 3	Month 6
Flexural Strength MPa (psi)	122 (17,690)	121 (17,545)	94 (13,630)
Flexural Modulus MPa (psi)	5324 (771,980)	4966 (720,070)	3841 (556,945)
% Flexural Strength Retention	118	117	91
% Flexural Modulus Retention	100	93	72
Barcol Hardness	30 - 35	32 - 36	30 - 34
MEDIUM: 5% NITRIC ACID @ 77°F/ 25°C			
Flexural Strength MPa (psi)	124 (17,980)	114 (16,530)	124 (17,980)
Flexural Modulus MPa (psi)	5352 (776,040)	5138 (745,010)	4131 (598,995)
% Flexural Strength Retention	119	110	119
% Flexural Modulus Retention	101	97	78
Barcol Hardness	30 - 35	26 - 30	25 - 30
MEDIUM: 25% ACETIC ACID @ 77°F/ 25°C			
Flexural Strength MPa (psi)	132 (19,140)	140 (20,300)	144 (20,880)
Flexural Modulus MPa (psi)	5386 (780,970)	1869 (271,005)	4931 (714,995)
% Flexural Strength Retention	127	135	139
% Flexural Modulus Retention	101	92	93
Barcol Hardness	30 - 35	32 - 36	20 - 25
MEDIUM: 25% ACETIC ACID @ 160°F/71°C			
Flexural Strength MPa (psi)	115 (16,675)	120 (17,400)	93 (13,485)
Flexural Modulus MPa (psi)	5228 (758,060)	5304 (769,080)	3759 (545,055)
% Flexural Strength Retention	111	116	90
% Flexural Modulus Retention	98	100	71
Barcol Hardness	30 - 40	26 - 32	5 - 10
MEDIUM: 5% SODIUM HYDROXIDE @ 77°F/ 25°C			
Flexural Strength MPa (psi)	112 (16,240)	110 (15,950)	117 (16,965)
Flexural Modulus MPa (psi)	5248 (760,960)	5062 (733,990)	4593 (665,985)
% Flexural Strength Retention	108	107	113
% Flexural Modulus Retention	99	95	86
Barcol Hardness	35 - 38	26 - 30	28 - 32
MEDIUM: 5% SODIUM HYDROXIDE @ 160°F/71°C			
Flexural Strength MPa (psi)	112 (16,240)	88 (12,760)	82 (11,890)
Flexural Modulus MPa (psi)	5131 (743,995)	5270 (764,150)	5262 (762,990)
% Flexural Strength Retention	108	85	79
% Flexural Modulus Retention	97	99	99
Barcol Hardness	34 - 38	32 - 36	20 - 28
MEDIUM: DEMINERALIZED WATER @ 77°F/ 25°C			
Flexural Strength MPa (psi)	117 (16,965)	96 (13,920)	98 (14,210)
Flexural Modulus MPa (psi)	5648 (818,960)	2566 (372,070)	5283 (766,035)
% Flexural Strength Retention	114	93	95
% Flexural Modulus Retention	106	49	99
Barcol Hardness	34 - 38	34 - 38	30 - 35
MEDIUM: DEMINERALIZED WATER @ 160°F/71°C			
Flexural Strength MPa (psi)	134 (19,430)	112 (16,240)	91 (13,195)
Flexural Modulus MPa (psi)	5724 (829,980)	5566 (807,070)	4062 (588,990)
% Flexural Strength Retention	129	109	88
% Flexural Modulus Retention	108	105	76
Barcol Hardness	34 - 38	32 - 36	25 - 30
MEDIUM: 90% FUEL C/10% METHANOL @ 77°F/ 25°C			
Flexural Strength MPa (psi)	80 (11,600)	76 (11,020)	24 (3,480)
Flexural Modulus MPa (psi)	2421 (351,045)	1655 (239,975)	835 (121,075)
% Flexural Strength Retention	77	73	23
% Flexural Modulus Retention	46	31	16
Barcol Hardness	0	0	0



Table 2B: Physical Property Data on Untreated ATH in Various Corrosion Media

MEDIUM: 15% HYDROCHLORIC ACID @ 160°F/71°C	Month 1	Month 3	Month 6
Flexural Strength MPa (psi)	106 (15,370)	84 (12,180)	61 (8,845)
Flexural Modulus MPa (psi)	4407 (639,015)	2917 (422,965)	2717 (393,965)
% Flexural Strength Retention	79	62	46
% Flexural Modulus Retention	55	36	34
Barcol Hardness	10 - 20	0	0
MEDIUM: 5% NITRIC ACID @ 77°F/25°C			
Flexural Strength MPa (psi)	118 (17,110)	115 (16,675)	114 (16,530)
Flexural Modulus MPa (psi)	7421 (1,076,045)	6517 (944,965)	6235 (904,075)
% Flexural Strength Retention	88	85	85
% Flexural Modulus Retention	92	81	77
Barcol Hardness	45 - 50	32 - 38	30 - 35
MEDIUM: 25% ACETIC ACID @ 77°F/ 25°C			
Flexural Strength MPa (psi)	112 (16,240)	123 (17,835)	120 (17,400)
Flexural Modulus MPa (psi)	7621 (1,105,045)	7104 (1,030,080)	6890 (999,050)
% Flexural Strength Retention	84	91	89
% Flexural Modulus Retention	94	88	85
Barcol Hardness	44 - 48	45 - 50	38 - 42
MEDIUM: 25% ACETIC ACID @ 160°F/71°C			
Flexural Strength MPa (psi)	102 (14,790)	102 (14,790)	80 (11,600)
Flexural Modulus MPa (psi)	5938 (861,010)	4221 (612,045)	4966 (720,070)
% Flexural Strength Retention	76	76	60
% Flexural Modulus Retention	74	52	62
Barcol Hardness	38 - 43	26 - 32	23 - 28
MEDIUM: 5% SODIUM HYDROXIDE @ 77°F/25°C			
Flexural Strength MPa (psi)	95 (13,775)	106 (15,370)	104 (15,080)
Flexural Modulus MPa (psi)	7704 (1,117,080)	6779 (982,955)	6441 (933,945)
% Flexural Strength Retention	71	78	77
% Flexural Modulus Retention	95	84	80
Barcol Hardness	45 - 50	44 - 48	38 - 42
MEDIUM: 5% SODIUM HYDROXIDE @ 160°F/71°C			
Flexural Strength MPa (psi)	116 (16,820)	92 (13,340)	79 (11,455)
Flexural Modulus MPa (psi)	7352 (1,066,040)	6759 (980,055)	5793 (839,985)
% Flexural Strength Retention	86	69	58
% Flexural Modulus Retention	91	84	72
Barcol Hardness	44 - 48	40 - 45	30 - 34
MEDIUM: DEMINERALIZED WATER @ 77°F/25°C			
Flexural Strength MPa (psi)	119 (17,255)	113 (16,385)	100 (14,500)
Flexural Modulus MPa (psi)	6883 (998,035)	7090 (1,028,050)	6366 (923,070)
% Flexural Strength Retention	89	84	74
% Flexural Modulus Retention	85	88	79
Barcol Hardness	34 - 38	44 - 48	38 - 42
MEDIUM: DEMINERALIZED WATER @ 160°F/71°C			
Flexural Strength MPa (psi)	106 (15,370)	96 (13,920)	81 (11,745)
Flexural Modulus MPa (psi)	6386 (925,970)	6690 (970,050)	5917 (857,965)
% Flexural Strength Retention	79	71	61
% Flexural Modulus Retention	79	83	73
Barcol Hardness	44 - 48	44 - 46	35 - 38
MEDIUM: 90% FUEL C/10% METHANOL @ 77°F/25°C			
Flexural Strength MPa (psi)	116 (16,820)	12 (1,740)	52 (7,540)
Flexural Modulus MPa (psi)	4572 (662,940)	3200 (464,000)	1628 (236,060)
% Flexural Strength Retention	86	83	39
% Flexural Modulus Retention	56	40	20
Barcol Hardness	30 - 35	24 - 26	0

Table 2C: Physical Property Data on ST1 ATH in Various Corrosion Media

MEDIUM: 15% HYDROCHLORIC ACID @ 160°F/71°C	Month 1	Month 3	Month 6
Flexural Strength MPa (psi)	96 (13,920)	86 (12,470)	75 (10,875)
Flexural Modulus MPa (psi)	5366 (778,070)	3738 (542,010)	3786 (548,970)
% Flexural Strength Retention	111	99	87
% Flexural Modulus Retention	76	53	54
Barcol Hardness	20 - 25	0 - 5	5 - 10
MEDIUM: 5% NITRIC ACID @ 77°F/ 25°C			
Flexural Strength MPa (psi)	82 (11,890)	77 (11,165)	81 (11,745)
Flexural Modulus MPa (psi)	6848 (992,960)	6428 (939,980)	6552 (950,040)
% Flexural Strength Retention	95	90	94
% Flexural Modulus Retention	97	92	93
Barcol Hardness	40 - 44	42 - 44	18 - 23
MEDIUM: 25% ACETIC ACID @ 77°F/ 25°C			
Flexural Strength MPa (psi)	99 (14,355)	100 (14,500)	89 (12,905)
Flexural Modulus MPa (psi)	7076 (1,026,020)	7379 (1,069,955)	6876 (997,020)
% Flexural Strength Retention	114	116	103
% Flexural Modulus Retention	100	105	95
Barcol Hardness	44 - 48	44 - 46	38 - 42
MEDIUM: 25% ACETIC ACID @ 160°F/71°C			
Flexural Strength MPa (psi)	98 (14,210)	81 (11,745)	60 (8,700)
Flexural Modulus MPa (psi)	6200 (899,000)	4441 (643,945)	5441 (788,945)
% Flexural Strength Retention	114	94	70
% Flexural Modulus Retention	88	63	77
Barcol Hardness	38 - 42	28 - 32	25 - 30
MEDIUM: 5% SODIUM HYDROXIDE @ 77°F/ 25°C			
Flexural Strength MPa (psi)	98 (14,210)	90 (13,050)	81 (11,745)
Flexural Modulus MPa (psi)	7131 (1,033,995)	6628 (961,060)	6083 (882,035)
% Flexural Strength Retention	114	105	94
% Flexural Modulus Retention	101	94	86
Barcol Hardness	44 - 48	45 - 50	40 - 44
MEDIUM: 5% SODIUM HYDROXIDE @ 160°F/71°C			
Flexural Strength MPa (psi)	88 (12,760)	70 (10,150)	64 (9,280)
Flexural Modulus MPa (psi)	6635 (962,075)	6510 (943,950)	5542 (803,590)
% Flexural Strength Retention	102	81	74
% Flexural Modulus Retention	94	92	78
Barcol Hardness	42 - 46	38 - 42	25 - 28
MEDIUM: DEMINERALIZED WATER @ 77°F/ 25°C			
Flexural Strength MPa (psi)	81 (11,745)	92 (13,340)	77 (11,165)
Flexural Modulus MPa (psi)	7338 (1,064,010)	7159 (1,038,055)	6531 (946,995)
% Flexural Strength Retention	94	106	89
% Flexural Modulus Retention	104	102	93
Barcol Hardness	44 - 48	45 - 50	38 - 42
MEDIUM: DEMINERALIZED WATER @ 160°F/71°C			
Flexural Strength MPa (psi)	88 (12,760)	100 (14,500)	84 (12,180)
Flexural Modulus MPa (psi)	6635 (962,075)	7104 (1,030,080)	6241 (904,945)
% Flexural Strength Retention	102	116	97
% Flexural Modulus Retention	94	101	89
Barcol Hardness	44 - 48	44 - 48	35 - 40
MEDIUM: 90% FUEL C/10% METHANOL @ 77°F/ 25°C			
Flexural Strength MPa (psi)	98 (14,210)	90 (13,050)	97 (14,065)
Flexural Modulus MPa (psi)	4297 (623,065)	4269 (619,005)	3262 (472,990)
% Flexural Strength Retention	114	104	113
% Flexural Modulus Retention	61	61	46
Barcol Hardness	25 - 28	24 - 28	5 - 10

Table 2D: Physical Property Data on ST2 ATH in Various Corrosion Media

MEDIUM: 15% HYDROCHLORIC ACID @ 160°F/71°C	Month 1	Month 3	Month 6
Flexural Strength MPa (psi)	111 (16,095)	90 (13,050)	83 (12,035)
Flexural Modulus MPa (psi)	5704 (827,080)	3400 (493,000)	3504 (508,080)
% Flexural Strength Retention	140	114	104
% Flexural Modulus Retention	78	47	48
Barcol Hardness	25 - 30	0 - 5	0 - 7
MEDIUM: 5% NITRIC ACID @ 77°F/25°C			
Flexural Strength MPa (psi)	123 (17,835)	119 (17,255)	97 (14,065)
Flexural Modulus MPa (psi)	6235 (904,075)	6090 (883,050)	5407 (784,015)
% Flexural Strength Retention	155	150	122
% Flexural Modulus Retention	85	83	74
Barcol Hardness	44 - 48	38 - 42	28 - 33
MEDIUM: 25% ACETIC ACID @ 77°F/25°C			
Flexural Strength MPa (psi)	119 (17,255)	121 (17,545)	89 (12,905)
Flexural Modulus MPa (psi)	7586 (1,099,970)	7517 (1,089,965)	5648 (818,960)
% Flexural Strength Retention	150	153	112
% Flexural Modulus Retention	104	95	77
Barcol Hardness	45 - 48	44 - 46	40 - 45
MEDIUM: 25% ACETIC ACID @ 160°F/71°C			
Flexural Strength MPa (psi)	110 (15,950)	87 (12,615)	77 (11,165)
Flexural Modulus MPa (psi)	6048 (876,960)	4483 (650,035)	5021 (728,045)
% Flexural Strength Retention	138	110	97
% Flexural Modulus Retention	83	62	69
Barcol Hardness	35 - 40	25 - 30	20 - 25
MEDIUM: 5% SODIUM HYDROXIDE @ 77°F/25°C			
Flexural Strength MPa (psi)	106 (15,370)	108 (15,660)	113 (16,385)
Flexural Modulus MPa (psi)	7379 (1,069,955)	7166 (1,039,070)	6028 (874,060)
% Flexural Strength Retention	134	136	143
% Flexural Modulus Retention	101	98	83
Barcol Hardness	40 - 45	40 - 45	38 - 40
MEDIUM: 5% SODIUM HYDROXIDE @ 160°F/71°C			
Flexural Strength MPa (psi)	105 (15,225)	84 (12,180)	64 (9,280)
Flexural Modulus MPa (psi)	7035 (1,020,075)	6593 (955,985)	4910 (711,950)
% Flexural Strength Retention	132	106	80
% Flexural Modulus Retention	96	90	67
Barcol Hardness	40 - 45	44 - 46	25 - 30
MEDIUM: DEMINERALIZED WATER @ 77°F/25°C			
Flexural Strength MPa (psi)	130 (18,850)	110 (15,950)	117 (16,965)
Flexural Modulus MPa (psi)	8966 (1,300,070)	7083 (1,027,035)	6759 (980,055)
% Flexural Strength Retention	164	139	147
% Flexural Modulus Retention	123	97	93
Barcol Hardness	40 - 44	45 - 50	40 - 45
MEDIUM: DEMINERALIZED WATER @ 160°F/71°C			
Flexural Strength MPa (psi)	106 (15,370)	85 (12,325)	93 (13,485)
Flexural Modulus MPa (psi)	7449 (1,080,105)	6752 (979,040)	5428 (787,060)
% Flexural Strength Retention	133	107	117
% Flexural Modulus Retention	102	92	74
Barcol Hardness	40 - 45	44 - 46	35 - 40
MEDIUM: 90% FUEL C/10% METHANOL @ 77°F/25°C			
Flexural Strength MPa (psi)	138 (20,010)	110 (15,950)	84 (12,180)
Flexural Modulus MPa (psi)	6704 (972,080)	4352 (631,040)	2462 (356,990)
% Flexural Strength Retention	182	140	105
% Flexural Modulus Retention	92	60	34
Barcol Hardness	25 - 30	20 - 25	0

Table 3A: Weight and Thickness Data for Unfilled Resin System

MEDIUM: 15% HYDROCHLORIC ACID @ 160°F/71°C	MONTH 1	MONTH 3	MONTH 6
% Weight Change	0.41	0.51	0.68
% Thickness Change	-0.59	0.60	-1.18
MEDIUM: 5% NITRIC ACID @ 77°F/ 25°C			
% Weight Change	0.38	0.51	0.55
% Thickness Change	0.28	0.54	-1.12
MEDIUM: 25% ACETIC ACID @ 77°F/ 25°C			
% Weight Change	0.42	0.59	0.55
% Thickness Change	-1.00	0.61	-1.01
MEDIUM: 25% ACETIC ACID @ 160°F/71°C			
% Weight Change	1.33	2.54	2.74
% Thickness Change	6.55	1.73	3.96
MEDIUM: 5% SODIUM HYDROXIDE @ 77°F/ 25°C			
% Weight Change	0.41	0.42	0.49
% Thickness Change	0.36	-0.62	-0.51
MEDIUM: 5% SODIUM HYDROXIDE @ 160°F/71°C			
% Weight Change	0.37	-0.37	0.25
% Thickness Change	-2.05	1.61	-0.67
MEDIUM: DEMINEALIZED WATER @ 77°F/ 25°C			
% Weight Change	0.38	0.55	0.47
% Thickness Change	0.60	-0.57	-0.21
MEDIUM: DEMINEALIZED WATER @ 160°F/71°C			
% Weight Change	0.65	0.69	0.72
% Thickness Change	0.60	-0.63	-0.28
MEDIUM: 90% FUEL C & 10% METHANOL @ 77°F/ 25°C			
% Weight Change	5.16	8.50	13.37
% Thickness Change	9.03	10.71	16.01

DATA

Table 3B: Weight and Thickness Data for Untreated ATH System

MEDIUM: 15% HYDROCHLORIC ACID @ 160°F/71°C	MONTH 1	MONTH 3	MONTH 6
% Weight Change	1.77	5.03	7.89
% Thickness Change	6.03	15.01	21.52
MEDIUM: 5% NITRIC ACID @ 77°F/ 25°C			
% Weight Change	0.19	-0.11	0.12
% Thickness Change	-0.88	0.39	1.83
MEDIUM: 25% ACETIC ACID @ 77°F/ 25°C			
% Weight Change	0.31	0.41	0.47
% Thickness Change	1.45	-2.14	-0.27
MEDIUM: 25% ACETIC ACID @ 160°F/71°C			
% Weight Change	2.29	6.16	6.46
% Thickness Change	3.49	7.50	8.47
MEDIUM: 5% SODIUM HYDROXIDE @ 77°F/ 25°C			
% Weight Change	0.32	0.36	0.31
% Thickness Change	2.01	-0.26	-0.84
MEDIUM: 5% SODIUM HYDROXIDE @ 160°F/71°C			
% Weight Change	-0.29	-0.58	-0.07
% Thickness Change	-0.28	-0.62	-0.25
MEDIUM: DEMINERALIZED WATER @ 77°F/ 25°C			
% Weight Change	0.27	0.39	0.43
% Thickness Change	0.62	4.42	0.59
MEDIUM: DEMINERALIZED WATER @ 160°F/71°C			
% Weight Change	0.48	0.66	0.71
% Thickness Change	-0.96	0.36	-0.40
MEDIUM: 90% FUEL C & 10% METHANOL @ 77°F/ 25°C			
% Weight Change	2.92	4.94	7.40
% Thickness Change	4.80	7.67	9.22

Table 3C: Weight and Thickness Data for ST1 ATH System

MEDIUM: 15% HYDROCHLORIC ACID @ 160°F/71°C	MONTH 1	MONTH 3	MONTH 6
% Weight Change	-0.05	1.39	1.15
% Thickness Change	3.4	9.63	8.94
MEDIUM: 5% NITRIC ACID @ 77°F/ 25°C			
% Weight Change	0.02	-0.06	-0.56
% Thickness Change	0.11	0.05	0.92
MEDIUM: 25% ACETIC ACID @ 77°F/ 25°C			
% Weight Change	0.32	0.42	0.41
% Thickness Change	0.98	0.00	-1.83
MEDIUM: 25% ACETIC ACID @ 160°F/71°C			
% Weight Change	2.52	6.05	7.08
% Thickness Change	3.45	8.02	10.60
MEDIUM: 5% SODIUM HYDROXIDE @ 77°F/ 25°C			
% Weight Change	0.34	0.38	0.35
% Thickness Change	0.29	-0.64	3.23
MEDIUM: 5% SODIUM HYDROXIDE @ 160°F/71°C			
% Weight Change	-0.19	-.021	-0.15
% Thickness Change	1.23	0.01	-1.33
MEDIUM: DEMINERALIZED WATER @ 77°F/ 25°C			
% Weight Change	0.33	0.44	0.51
% Thickness Change	0.25	1.43	0.00
MEDIUM: DEMINERALIZED WATER @ 160°F/71°C			
% Weight Change	0.45	0.62	0.64
% Thickness Change	-0.91	0.00	-2.14
MEDIUM: 90% FUEL C & 10% METHANOL @ 77°F/ 25°C			
% Weight Change	2.62	4.06	5.35
% Thickness Change	2.04	4.70	8.75

DATA

Table 3D: Weight and Thickness Data for ST2 ATH System

MEDIUM: 15% HYDROCHLORIC ACID @ 160°F/71°C	MONTH 1	MONTH 3	MONTH 6
% Weight Change	1.81	4.29	1.94
% Thickness Change	6.45	9.85	10.50
MEDIUM: 5% NITRIC ACID @ 77°F/ 25°C			
% Weight Change	0.00	-0.65	-0.24
% Thickness Change	-0.73	0.52	0.00
MEDIUM: 25% ACETIC ACID @ 77°F/ 25°C			
% Weight Change	0.29	0.42	0.45
% Thickness Change	-1.49	-0.07	0.60
MEDIUM: 25% ACETIC ACID @ 160°F/71°C			
% Weight Change	1.96	4.38	6.02
% Thickness Change	2.13	7.36	7.74
MEDIUM: 5% SODIUM HYDROXIDE @ 77°F/ 25°C			
% Weight Change	0.33	0.40	0.26
% Thickness Change	0.00	0.50	-0.58
MEDIUM: 5% SODIUM HYDROXIDE @ 160°F/71°C			
% Weight Change	-0.21	-0.57	-0.15
% Thickness Change	-0.35	0.84	0.78
MEDIUM: DEMINERALIZED WATER @ 77°F/ 25°C			
% Weight Change	0.28	0.48	0.47
% Thickness Change	-0.10	2.66	-0.24
MEDIUM: DEMINERALIZED WATER @ 160°F/71°C			
% Weight Change	0.53	0.78	0.68
% Thickness Change	1.75	0.27	-0.01
MEDIUM: 90% FUEL C & 10% METHANOL @ 77°F/ 25°C			
% Weight Change	2.36	4.16	6.19
% Thickness Change	1.28	1.19	6.24

Table 4: Cone Calorimeter Test Results @ 35 kW/m<sup>2</sup> Heat Flux

	Unfilled Resin	Untreated ATH	ST1 ATH	ST2 ATH
Peak HRR (kW/m <sup>2</sup> )	276.21	193.60	215.57	174.00
Peak HRR (sec.)	92.81	106.14	139.45	126.13
Average HRR (kW/m <sup>2</sup> )	196.12	134.23	136.35	112.06
Total Heat Release (MJ/m <sup>2</sup> )	33.474	23.263	31.001	22.486
Average Effective Heat of Combination (MJ/kg)	13.096	15.612	12.997	11.267
Average Specific Extinction Area (m <sup>2</sup> /kg)	1918.6	1633.5	1410.8	1442.8
Average Mass Loss Rate (g/s•m <sup>2</sup> )	15.44	9.36	10.99	10.56
Average CO (kg/kg)	0.10215	0.10087	0.08065	0.06714
Average CO <sub>2</sub> (kg/kg)	0.92666	1.11640	0.92753	0.83354
Time to Ignition (sec.)	60.03	55.27	120.60	90.94

Table 5: ASTM E662 Smoke Chamber Test Results

NON-FLAMING MODE @ 2.5 W/cm<sup>2</sup> HEAT FLUX

	Unfilled Resin	Untreated ATH	ST1 ATH	ST2 ATH
Average Thickness (mm)	2.74	2.90	2.85	2.92
Average Weight (g)	20.01	25.79	24.12	25.64
Dm @ 1.5 minutes	0	1	1	0
Dm @ 4.0 minutes	37	6	7	6
Dm	415	206	230	208
Dm corr	402	202	225	205
90% of Time to Dm (minutes)	18.5	20.0	20.0	20.0

FLAMING MODE @ 2.5 W/cm<sup>2</sup> HEAT FLUX

	Unfilled Resin	Untreated ATH	ST1 ATH	ST2 ATH
Average Thickness (mm)	2.69	2.82	2.79	2.77
Average Weight (g)	27.06	25.08	24.46	24.29
Dm @ 1.5 min	355	59	27	42
Dm @ 4.0 min	>925	396	390	329
Dm	>925	440	491	464
Dm corr	>925	421	466	439
90% of Time to Dm (minutes)	3.0	5.8	7.2	6.3



INTERPLASTIC CORPORATION  
Thermoset Resins Division

1225 Willow Lake Blvd., St. Paul MN 55110-5145  
651.481.6860 800.736.5497 fax: 651.481.9836  
www.interplastic.com