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Using Instrumented Impact Testing as an Indicator of Resin Acrylic-Bonding-Potential for Tub and Shower Laminates

by

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Abstract

The ability of a highly-filled glass-reinforced resin to bond to an acrylic or ABS thermoformed shell is of significant interest to tub and shower manufacturers. There are a number of “internal” acrylic-adhesion test-methods manufacturers use that are subjective in nature and yield neither repeatable nor quantifiable nor interpretable results. One of the more established standardized test methods that can be used as a measure of tensile adhesion or bond-strength is ASTM C297. While this method is quantifiable and repeatable the correlation of the results to actual acrylic-bonding-resin field performance is not so apparent. This paper investigates whether instrumented impact testing can be used as a means of predicting acrylic-bonding-resin performance. Bond strength as determined by ASTM C297 is compared with impact results as derived from ASTM D3763.

Introduction

The methods typically used for testing the bonding potential of a resin to acrylic and ABS substrates are limited by the fact that they are not controlled, not standardized, and open to the interpretation of the tester. Although tensile adhesion ASTM C297 is quantifiable and repeatable, a closer examination of the method as applied to tub and shower laminates reveals its limitations. The data gathered from tensile adhesion is often just as open to interpretation as other production testing methods, and the results have limited success predicting bonding in the field. The object of our investigation into a new testing method, was to use ASTM D3763 impact testing to design a method that would: better represent the actual forces a tub unit may be subjected to in the field, have results that were not open to interpretation, give one quantifiable number from which the bond quality of a resin could be evaluated.

Limitations of Tensile Adhesion ASTM Method C297

The limitations of using ASTM method C297 Tensile Adhesion to predict bonding of tub and shower laminates are numerous. The most significant problem is the tensile or “pulling” forces placed on the sample do not correlate with the forces that tub units are normally subjected to during production, shipment, and installation. These forces are more similar to vibration from cutting tools, “impact” forces such as falls, and other straining forces from movement and installation. In tensile adhesion testing, the full straining force is not isolated to the bond between the laminate and the substrate, but is placed across the whole sample. The result of which is, that the failure often occurs not in the bond between the laminate and substrate, but most often in the laminate itself. This type of failure makes it hard to evaluate the actual bonding strength of the resin. Data gathered from tensile adhesion can also be open to interpretation, as samples that yield high numerical values often have mixed results bonding in the field. This leads to samples having to be evaluated for “failure mode” which adds yet another factor subject to interpretation. Other problems with using tensile strength to evaluate bonding include: complex sample prep, adhesive failure between the loading blocks and samples, and the small sample size of an actual tub unit that is tested.

Using Impact testing for tub and shower laminates

ASTM Method D 3763 is designed to test the puncture properties of plastics. The basics of the method involve raising a weighted plunger assembly to a set height, and dropping it so that it impacts the sample with a known velocity. The velocity at impact is measured by an optical sensor, and force placed on the plunger is recorded as a function of time by the load cell detector within the plunger. Knowing the forces on the weighted plunger, being gravity and the impact force imparted by the sample, the displacement of the plunger can be calculated as a function of time. Knowing the displacement and the force placed on the plunger from the sample, the energy can then be calculated by plotting force vs. displacement, and integrating the area under the this curve. This energy is the total amount of energy to cause the sample to fail or brake.

In order to measure the bonding potential in the case of a tub and shower laminate, the energy that we wanted to measure was not the energy needed to puncture the sample, but the energy needed to de-bond the laminate from the acrylic backing. In order to maximize the force being placed on the bond between the laminate and acrylic the samples were prepared in a very specific manner.

Sample Preparation

The samples tested were prepared in the lab. Laminates were constructed with 2 plies of 1.5oz chop strand mat, by hand, on top of the acrylic sheet. After curing over night, the 1ft x 1ft panel was cut into 3in x 3in square samples. On the laminate side of each sample a drill press with a hole saw was used to cut a ¾ inch diameter hole in the center of the sample. The depth of this hole was cut just to the edge of the laminate layer of the sample just until the acrylic became visible but not into the acrylic sheet. This left a ½ inch diameter circular piece of laminate unattached from the rest of the laminate but still bonded to the acrylic sheet. The sizing for the piece was chosen because it closely matched the size of the impact plunger used in the testing machine. On the side of the sample opposite the laminate side, the acrylic side, a 2 ¼ inch diameter hole was cut in a similar fashion, as seen in Fig-1. This hole was cut just to the edge of the acrylic layer until the laminate layer could be seen, but not into the laminate. Both sides of a fully prepared sample can be seen in Fig-2 and Fig-3. This sample design allows the force of the impact to be directed at the bond interface between the laminate and acrylic to a much greater degree than the traditional puncture test.

Testing

Sample testing is done exactly like normal impact puncture testing. Fig-4 and shows the testing equipment, and Fig-5 shows a closer view of the plunger. The sample is placed in the center of the impact clamp, and the impact plunger is lowered to ensure proper alignment. The plunger is lowered until it almost touches the top of the sample, and the optic sensor is set to this height, ensuring the impact velocity can be recorded precisely at the moment of impact. Once the sensor is set, the plunger is raised to the impact height. The height used in our experiment was 0.4 feet. The weight used was 11 pounds. Of primary importance when selecting the height and weight, is to ensure that the available energy for the impact is at least three times the absorbed energy at the peak load. This ensures the velocity slow down at impact is less then 20%, which is needed to get repeatable results. The impact energy can be calculated from the measured impact velocity by:

$$T = \frac{1}{2} mv^2 \qquad (1)$$

where T is the kinetic energy at impact, or impact energy, m is the mass of the weight, and v the velocity at impact. The theoretical impact velocity can by found from:

$$V = V_0 + gt \qquad (2)$$

where V is the velocity at time t, and g, the acceleration due to gravity, 32.17ft/s^2. V_0 is our initial velocity which in our case of a weight dropped from rest is zero. In order to find the time of impact use:

$$X = \frac{1}{2} gt^2 \qquad (3)$$

X is the height of weight, in our case 0.4 feet. Solving for t we find that the time it takes the weight to travel from our height to the time of plunger impact, t = .158 seconds or 158 milliseconds. Now using the time found from equation (3) and plugging it into equation (2) we find the theoretical impact velocity for our experiment is 5.08 ft/s. Plugging this velocity into equation (1), and using

$$W = mg \qquad (4)$$

to find the mass of our weight, where W = 11lb, we find the theoretical impact energy for our experiment is 4.41 ft lb. The load cell detector within the plunger allows us to calculate is the how much of this total impact energy is used to puncture or in our case "pop" the acrylic side off of the laminate. As the plunger falls and comes into contact with the sample, the load cell records the force placed on the plunger as a function of time. The resulting data is integrated to find the displacement as a function of time. By plotting the displacement of the plunger vs. force on plunger, amount of energy used to puncture the sample is calculated. The maximum load of a sample is the point at which the sample places the most resistance on the falling plunger, and it occurs just before the sample brakes. Our idea was that the energy used to bring a sample to its maximum load, call this energy "energy to max load," would be greater in samples where the bond was good, then in samples where the bond was poor.

Impact Results

Three different types of resin were used to construct the laminate samples. For sample set #1 we wanted to use a resin that we knew would not bond very well. We used a 100% DCPD resin known to have poor bonding to acrylic and filled it 50% with calcium sulfate, to simulate a tub and shower laminate. Sample set #2 was made with a 100% orthophthalic resin known to have good bonding on acrylic and it was filled with 50% with calcium sulfate. Sample set #3 was an unfilled 100% vinyl ester resin that is known to have the best bonding available of any resin. The fact that this resin was unfilled meant sample set #3 represented the best possible bonding we could achieve. The results from testing are shown in Tables-1-3.

Sample set #1 showed an average energy to max load of 0.7202 ft lb. The samples failed exactly as expected, with the acrylic piece "popping" off the back. The acrylic pieces upon examination showed the typical smooth interface associated with poor bonding, as seen in Fig-6. Sample set #2 showed an average energy to max load of 1.1135 ft lb. An increase of 0.3933 ft lb over sample set #1. As with sample set #1, the acrylic piece "popped" off the back. The acrylic pieces showed some etching but little fiber tare, as seen in Fig-7. Sample set #3 showed an average energy to max load of 1.9031 ft lb. An increase of 0.7896 ft lb over sample set #2 and an increase of 1.1829 fl lb over sample set #1. The samples did not show the "popping" acrylic piece failure of the other sample sets. On sample set #3 the samples the acrylic backing had shattered, but most of the acrylic stayed attached to the laminate, as seen in Fig-8. The samples showed etching and fiber tare similarly seen from other tests that demonstrate an excellent bond.

Tensile adhesion results

The three laminate samples where also tested using the tensile adhesion method C297. All the samples ether failed in the laminate side of the sample or in the adhesive as seen in Fig-9. The results from this testing are seen in Table-4. Samples set #2 and #3, came out close to one another, but sample set #1 came out almost 400 psi above the other samples. If we were to look at the tensile adhesion numbers alone, we would conclude that sample set #1 had the best bond, but we know from experience in the field and old traditional methods such as the "screwdriver test" that this is not the case.

Conclusion

It seems clear from the data gathered from this experiment, although limited to one type of laminate construction, that impact testing shows great promise in predicting resin bonding potential. The average energy to max load increased 35% from samples that show poor bonding to samples that show good bonding, and increased another 41% from samples that show good bonding to samples that show excellent bonding. The tensile adhesion testing failed to predict an accurate representation of the bonding potential of the resins. In the future we hope to expand this testing to different laminate constructions and tub and shower units from an actual production line.

Figure - 1: Cutting a sample with a drill press.

Figure - 2: The laminate side of the sample. The ¾ in cut is roughly equal to the size of the impact plunger.

Figure - 3: The acrylic side of the sample. This side is opposite the impact.

Figure - 4: The impact testing machine with the weight in the raised position.

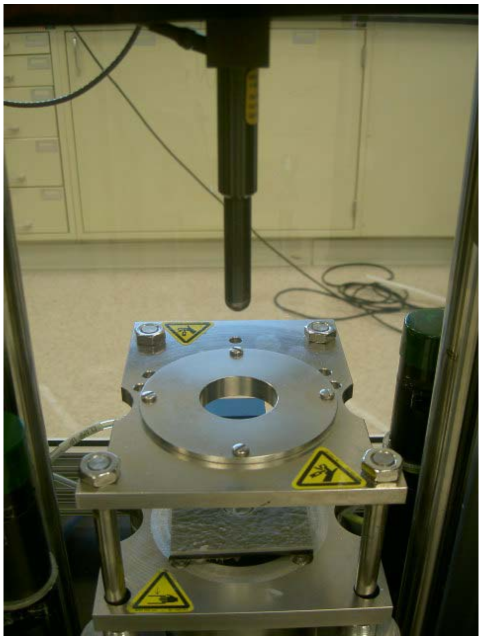

Figure - 5: A closer view of the impact plunger. During testing the top clamp comes down to secure the sample.

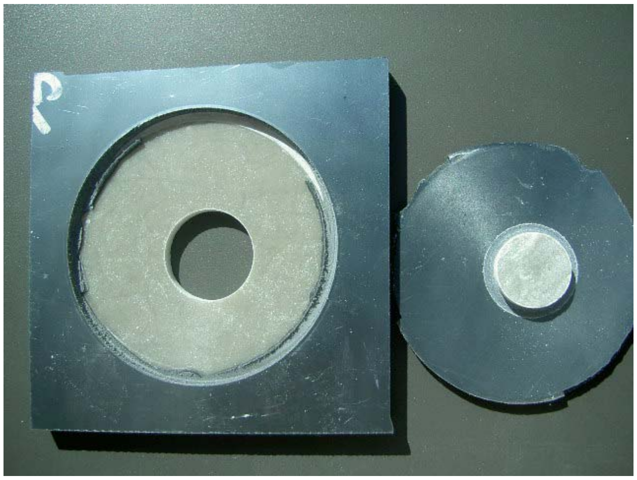

Figure - 6: A sample from sample Set #1. It shows a smooth surface associated with poor bonding.

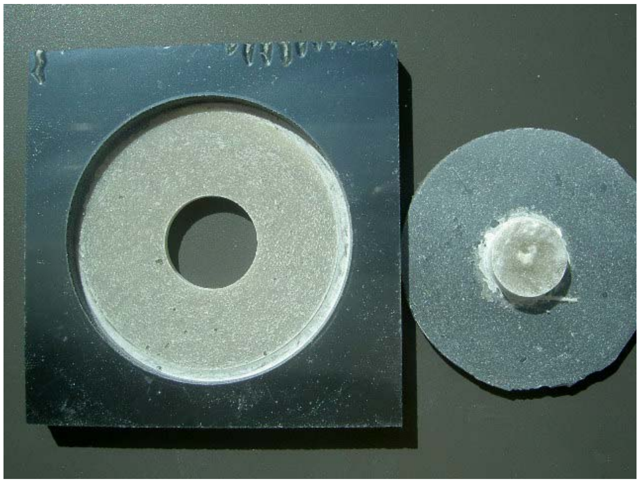

Figure - 7: A sample from sample Set #2. It shows a good etching but no fiber tare. In a field test I would consider this good bonding.

Figure -9: All of the tensile adhesion samples broke in the laminate side or adhesive, and not in the bond: just one of the many problems with this test.

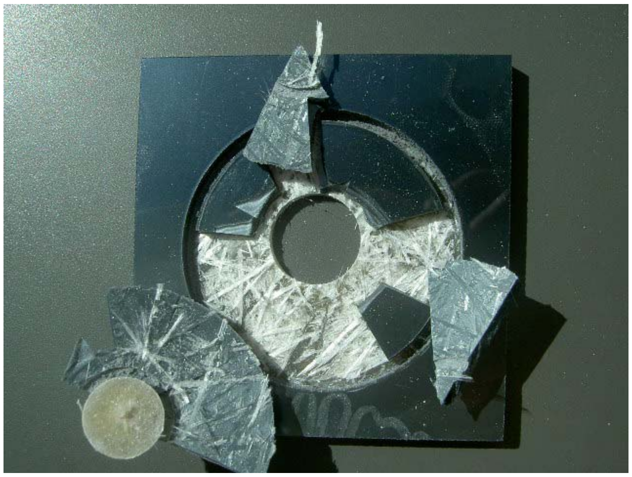

Figure - 8: A sample from sample Set #3. This sample shows the major difference from the other sample sets, the actual braking of the acrylic side. The broken pieces show fiber tare, generally considered to be an excellent bond.

Sample Set #1 DCPD Resin

Sample #	Impact Velocity (ft/s)	Velocity Slow down (%)	Maximum load (lb)	Deflection at max load (in)	Energy to max load (ft lb)	Impact energy (ft lb)
1	5.13	3.97	334.91	0.04	0.56	4.55
2	5.10	8.43	514.11	0.04	0.91	4.49
3	5.11	11.39	538.01	0.05	1.18	4.51
4	5.09	2.84	324.90	0.03	0.45	4.48
5	5.12	3.60	323.07	0.04	0.51	4.52
Average	5.1100	6.0470	406.9998	0.0395	**0.7202**	4.5105
Std. Dev.	0.0141	3.7034	109.1067	0.0078	0.3114	0.0249

Table - 1: Impact testing results from DCPD Resin: the average energy to max load was 0.7202 ft lb.

Sample Set #2 Orthophthalic

Sample #	Impact Velocity (ft/s)	Velocity Slow down (%)	Maximum load (lb)	Deflection at max load (in)	Energy to max load (ft lb)	Impact energy (ft lb)
1	5.10	17.14	610.56	0.06	1.67	4.50
2	5.12	8.97	505.22	0.05	1.03	4.54
3	5.11	9.25	473.67	0.05	1.07	4.52
4	5.11	4.87	422.61	0.04	0.69	4.51
5	5.13	10.80	500.46	0.06	1.19	4.55
6	5.09	4.44	468.53	0.03	0.60	4.47
7	5.11	15.91	669.18	0.05	1.55	4.51
Average	5.1097	10.1972	512.4591	0.0485	**1.1135**	4.5116
Std. Dev.	0.0141	4.9192	86.9102	0.0104	0.4009	0.0250

Table - 2: Impact testing results from the Orthophthalic Resin: the average energy to max load was 1.1135 ft lb.

Sample Set #3 Vinyl Ester Resin

Sample #	Impact Velocity (ft/s)	Velocity Slow down (%)	Maximum load (lb)	Deflection at max load (in)	Energy to max load (ft lb)	Impact energy (ft lb)
1	5.13	18.93	591.09	0.08	1.83	4.55
2	5.15	16.16	559.11	0.07	1.63	4.58
3	5.17	15.70	547.43	0.07	1.61	4.61
4	5.15	24.18	609.18	0.08	2.23	4.58
5	5.16	23.38	683.85	0.07	2.16	4.59
6	5.13	20.85	634.47	0.08	1.96	4.55
Average	5.1474	19.8671	604.1899	0.0750	**1.9031**	4.5783
Std. Dev.	0.0139	3.5752	50.4238	0.0055	0.2605	0.0248

Table - 3: Impact testing results from the Vinyl Ester Resin: the average energy to max load was 1.9031 ft lb.

Tensile Adhesion Testing

Property	**Units**	**#1 DCPD Resin**	**#2 Ortho Resin**	**#3 Vinyl Ester Resin**
Tensile Adhesion Strength	**psi**	**1,768**	**1,265**	**1,389**
Tensile Adhesion Modulus	**kpsi**	**52.6**	**52.2**	**51.4**
Failure of Laminate	**% (Mean)**	**0.0**	**62.5**	**99.3**
Failure of Facing	**% (Mean)**	**0.0**	**0.0**	**0.0**
Failure of Adhesive	**% (Mean)**	**100**	**37.5**	**0.7**

Table - 4: Tensile Adhesion testing of the three sample sets: even through we know Sample #1 does not bond well to acrylic it has the highest tensile adhesion strength.

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