EVALUATION OF NYLON AND POLYESTER PEEL PLYES USING THE RAPID ADHESION TEST

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ABSTRACT

Adequate surface preparation of composite parts for adhesive bonding by use of peel plies is highly desirable, yet it remains necessary to test each combination of composite resin system, peel ply, and adhesive for successful adhesion. Furthermore, failure in adhesion, as opposed to interlaminar or cohesive failure, is usually unacceptable for any application. The Rapid Adhesion Test (“RAT”) was developed as a simple, fast Mode I screening process for rejecting component combinations that fail in adhesion, taking advantage of the qualitative nature of this determination. Here, various combinations of 127 °C (260 °F) cure glass fiber reinforced polymer prepreg, nylon and polyester peel plies, and film adhesives were tested using the RAT. It was found that all of the samples prepared with nylon peel plies failed cohesively, whereas all of the samples prepared with polyester peel plies failed in adhesion at least to some degree. The topography of the surfaces to be bonded was characterized using optical and scanning electron microscopy. The surface energy of each surface to be bonded was measured using sessile drop contact angle measurements with at least 3 different fluids. The relationships between surface energy and bond quality are explored.

KEY WORDS: Adhesives/Adhesive Bonding, Surface Preparation Materials/Processes, Test Methods/Test Standardization

1. INTRODUCTION

In composite materials, there are many reasons to prefer the use of adhesives over mechanical fasteners. For one, a mechanical fastener such as a bolt that pierces a component introduces a stress concentration into the component; while this is not necessarily critical for metals, it can cause a dramatic degradation of the performance of a composite part in which the matrix material is more brittle. Adhesives, however, do not introduce such stress concentrations. Another reason for preferring adhesive bonding is that adhesives are often composed of viscoelastic polymers that are more resistant to fatigue than typical mechanical fasteners. For these reasons and others, adhesive bonding is commonly used in the fabrication of composite structures. However, implementing successful adhesion has special requirements, and all methods that facilitate adhesive bonding are highly desirable. Here, a brief discussion of adhesion will be followed by a discussion of peel plies as surface preparation and the Rapid Adhesion Test (“RAT”) as a mode I screening process for new adherend-adhesive-surface preparation combinations.
Practical adhesion is a term for the physical strength of an adhesive bond. The degree of practical adhesion between two surfaces may be broken down into several components, which are of varying significance in different cases: an electrostatic component, a diffusive component, a mechanical interlocking component, and a primary chemical bonding component. These components are affected by many interrelated variables, such as surface roughness, voids, pore penetration, wettability of surfaces, and acid-base interactions, among others [1].

One way of simultaneously measuring the effects of several of these variables on practical adhesion is by measuring the surface energies of the adhesive and adherends. A simplified view of the surface energy of a solid is that it is, essentially, a measure of its attractive force on other materials, due to unsatisfied chemical bonds, hydrogen bonds, and Van der Waals forces at its surface. In the case of liquids, this is the surface tension and is the reason that liquids tend to “bead up” into spherical shapes; they are minimizing their energy level by minimizing the amount of exposed surface area. Alternatively, the surface energy of a solid can be defined as being equal to the surface tension of a liquid that will just wet the solid, with a contact angle $\theta = 0$ [2]. The surface energy has units of force per distance, and the underlying relationship $\gamma_{lv} = \gamma_{s} + \gamma_{v} \cos \theta$, known as Young’s equation [3], is illustrated in Figure 1. In theory, a high-energy liquid should bead up on a low-energy solid surface, while a low-energy liquid should “wet out,” or form a thin layer, on a high-energy surface. Wetting out of the adhesive on adherends is generally recognized as a necessary, although not sufficient, requirement for creating a strong adhesive bond [4].

![Figure 1. Energy balance of contact angle of a liquid on a solid surface.](image)

The Owens and Wendt model [4] has two parameters for surface energy, giving it a “dispersive” and “polar” component, allowing a better prediction of wetting relationships. This relationship allows a two-dimensional “wetting envelope” to be constructed for any solid. The wetting envelope is the line on a plot of dispersive energy vs. polar energy that represents the breakeven energetic point for a liquid to wet out on that surface. Such a diagram should be useful, because in theory, adhesives that fall outside of the envelope for a given adherend should not function well due to lack of wetting [5].

Wetting on an adherend, and practical adhesion in general, may (and should) be increased by appropriate surface preparation. One way is by increasing roughness, which increases surface area and thereby surface energy, within limits [6]; another is by removing low-energy contaminants that can act as crack starters and in any case keep a good adhesive bond from forming. Without appropriate surface preparation, the practical adhesion of a bond may be severely compromised [7]. Even more insidiously, bad bonds can go undetected for a long time, apparently functioning as intended, before suddenly failing catastrophically. This makes it important to find good, consistent methods of preparing the surfaces of composites for bonding.
Grit blasting is widely considered the gold standard of surface preparation [8, 9], but, to the extent that they work, peel plies are an expedient and consistent alternative, making them an intriguing subject of study.

Given the wide range of variables that affect bond quality, successful approaches to the use of adhesives need to be based on both theoretical considerations and empirical results; that is, it is possible to predict how some adhesives and adherends will interact, but success cannot be guaranteed until it has been demonstrated in practice, with attention paid to all of the procedural details. One test for this purpose is the double cantilever beam (“DCB”) test, commonly used to screen new combinations of adhesive bond components, described in ASTM D5528-01 [10]. The DCB test measures both mode I fracture toughness ($G_{Ic}$) and gives a mode of failure, such as interlaminar or adhesion.

Unfortunately, the DCB test is expensive in terms of time and required machining accuracy, giving a motivation to find an easier method. The recently developed RAT [11] is a peel test patterned off the climbing drum peel test; it is intended to give a fast, easy way to qualitatively screen new adherend – surface preparation – adhesive combinations. The RAT takes advantage of the fact that there is a strong correlation between mode of failure and $G_{Ic}$, so merely determining the mode of failure already gives very important information. An undesirable failure mode in a specimen – namely, a failure in adhesion, with its much lower $G_{Ic}$ – does not require a quantitative measure of performance, because that combination would be rejected regardless. It has been shown that RAT results correlate to DCB results regarding the mode of failure [11].

Peel plies are often based on polyester or on nylon fibers, which have been shown to have differences in performance for various adhesives for one 176 deg °C (350 °F) cure system; in fact, nylon peel ply was shown to bond poorly in some cases [12], and the common failure of nylon peel plies to prepare surfaces has actually been referred to by Hart-Smith as a “curse” [9]. The goal of this research is to do initial testing on polyester and nylon peel plies with a selection of substrate-adhesive combinations with 127 °C (260 °F) cure systems. Furthermore, this research is intended to show applicability of the RAT as a fast evaluation tool for the purpose of screening such combinations.

2. EXPERIMENTAL

2.1 Materials All combinations of the following materials, using one each of substrate, peel ply, and adhesive, were evaluated:

- Three substrates, all glass fiber reinforced epoxy prepregs with a 0-90° plain weave and 127 °C (260 °F) cure cycle:
  - Hexcel 1581-F155
  - Yokohama F6986
  - Cytec Cycom MXB 7701/7781
- Two types of peel ply:
  - Nylon (Precision code 51789)
  - Polyester (Precision 60001)
Six epoxy film adhesives:
- 3M AF500
- 3M AF 163-2M
- Cytec FM 94
- Henkel Hysol EA 9696
- Cytec FM x209
- Henkel Hysol EA 9628

This resulted in a total of 36 bonded sample types; or, when only substrates and peel plies were evaluated, 6 sample types. All of the substrates and adhesives here are epoxy-based systems, each with different proprietary toughening systems and other unspecified contents.

For the RAT proper, two types of aluminum sheet were used per sample: a “thin” 0.051 cm (0.020 inch) piece of anodized 2024-T3 clad alloy, 22.9 cm x 10.2 cm (9 inch x 4 inch), and a “thick” 0.16 cm (0.063 inch) piece, also 22.9 cm x 10.2 cm (9 inch x 4 inch). Fluorinated ethylene propylene (FEP) was used as a crack starter material.

2.2 Sample Preparation
Characterization samples were laid up as flat squares approximately 7.6 cm x 7.6 cm (3 inch x 3 inch), with four aligned plies apiece and peel plies on both sides. These samples were vacuum-bagged and cured in an autoclave. The curing cycle for the prepregs (and, later, for the adhesives) was the following: ramp-up temperature of +4.4 °C (8.0 °F) / min and fast pressure ramp-up; holding pressure of 62 kPa (89 psi) for 90 minutes at 127 °C (260 °F); and cool-down of -2.8 °C (5.0 °F) / min to at least 60 °C (140 °F) and fast pressure release. Subsequent to cure, the characterization samples were cut and peeled as needed for scanning electron microscope (SEM) and contact angle measurements.

The RAT samples were prepared in two stages, in accordance with the test parameters described by Shelley and Van Voast [11]. Briefly, a single ply of substrate was placed directly a “thin” aluminum sheet as described previously, with the corresponding peel ply on top, and the assembly cured using a similar curing cycle, but in a hot press apparatus, with the peel ply on the tool side. Then a piece of the chosen adhesive was placed against a “thick” aluminum sheet (again, described previously), with a 2.5 cm (1 inch) wide piece of FEP placed across one end between the adhesive and the aluminum across the width of the specimen. This adhesive was then cured against the already-cured prepreg, after removing the peel ply. Figure 2 shows these steps.
After Stage 2 of RAT sample preparation was completed, the sides of each sheet were trimmed 1.3 cm (0.5 inch), perpendicular to the crack starter, and then cut into 22.9 cm x 2.5 cm (9 inch x 1 inch) test samples. A sampling of specimens were also inspected to verify a minimum acceptable bondline thickness.

### 2.3 Contact Angle procedure

Contact angle measurements were taken with a manual goniometer on each of the substrate-peel ply combinations (tool-side surfaces). The peel ply was removed immediately before measurements. At least 10 drops per fluid per surface were measured, and measurements were taken approximately 5-15 seconds after application of the fluid drop.

The method of generating wetting envelopes based on contact angle measurements was based on Owen and Wendt’s model [4] using the following relationship:

\[
\frac{\sigma_i (\cos \theta + 1)}{2 \sqrt{\sigma_i^d}} = \sqrt{\sigma_i^p \left( \frac{\sigma_i^p}{\sigma_i^d} \right)} + \sqrt{\sigma_i^s}
\]

where \( \sigma_i \) is the liquid surface tension, \( \sigma_s \) is the overall solid surface energy, and \( d \) and \( p \) refer to the polar and dispersive components of each. Given known test liquid values, this is an equation with two unknowns (\( \sigma_i^p \) and \( \sigma_i^d \)), requiring at least two test liquids in order to calculate values. Given more test liquids, a linear regression can be made of data points (a “Kaelble plot” [2, 5]) where

\[
y = \frac{\sigma_i (\cos \theta + 1)}{2 \sqrt{\sigma_i^d}}, \quad m = \sqrt{\sigma_i^p}, \quad x = \sqrt{\sigma_i^p}, \quad \text{and} \quad b = \sqrt{\sigma_i^s}.
\]

It should be noted that the alternate form of the relationship,

\[
\frac{\gamma_i (\cos \theta + 1)}{2 \sqrt{\gamma_i^d}} = \sqrt{\gamma_i^p \left( \frac{\gamma_i^p}{\gamma_i^d} \right)} + \sqrt{\gamma_i^s},
\]

while mathematically
equivalent, was found to be less useful in practice because while some test liquids have no polar element in their energy, rendering them incompatible with this latter version of the formula, the authors have found no test liquid that lacked a dispersive element.

After dispersive and polar elements were calculated for each test sample, a wetting envelope was generated from the quadratic roots of the relationship $\left(\sqrt{\gamma_{sv}}\right) - \sqrt{\gamma_{lv}} \left(\sqrt{\gamma_{lv}}\right) + \left[\gamma_{lv} - \sqrt{\gamma_{lv} \gamma_{sv}}\right] = 0$ [13]. The series of plotted points from this were generated by a computer program written by Clark for the purpose, based on another wetting envelope software utility by Tuttle [14].

**2.4 RAT Procedure** Once prepared, the RAT specimens were peeled as shown in Figure 3, as per Shelley and Van Voast [11]. The thin side of each sample where the crack starter lies was inserted into a 5.1 cm (2 inch) radius cylinder and the sample was peeled back by hand. When necessary, the thick side was held down by the use of clamps, and if there was difficulty in the peel getting started, the thin side was clamped to the cylinder. The peel rate was approximately 2.5 cm (1 inch) per second, for a distance of about 17.8 cm (7 inches), leaving the peeled part attached at one end.

![Figure 3. A RAT specimen being peeled (not from this set).](image)

After peeling, a mode of failure was determined for each specimen – cohesive (in the matrix of either the adhesive or adherend), adhesion failure on the bondline, or a significant mix of these. The method was to visually inspect the adherend and substrate, then to view under stereographic microscope as necessary, looking for peel ply patterns left in the fractured matrix. While
interlaminar failure was another possible failure mode in principle, the fact that the substrates were of woven fibers rather than a unidirectional tape made that outcome highly unlikely.

2.5 SEM Procedure Two separate sets of SEM samples were made. The first set was taken directly from the characterization samples, which were of the substrate surfaces after the peel ply had been removed (but without further curing or addition of adhesive). Edges of the characterization sample squares were trimmed approximately 0.5 cm (0.2 inch) on all sides before SEM specimens proper were cut. The second set of samples was taken from specimens after the RAT had been performed on them; these samples were used to view and confirm the difference in failure modes on the microscopic level. All SEM samples were sputter-coated with a layer of platinum shortly their surfaces were exposed.

3. RESULTS AND DISCUSSION

3.1 Surface Energies and Wetting Envelopes The measured contact angles are shown in Table I, Table II, and Table III. The use of diiodomethane requires some explanation: rather than being used as a standard test liquid to measure contact angles, it was simply observed whether diiodomethane “wet out” on each sample. This helped to confirm the validity of the calculated wetting envelopes shown in Figure 4 – if the envelopes were correct, then diiodomethane should wet out only on the specimens prepared with polyester peel ply, which it did.

Table I. Average contact angles $\theta$ for substrate-nylon peel ply (Precision code 51789) combinations.

<table>
<thead>
<tr>
<th>Test liquid</th>
<th>Substrate</th>
<th>Hexcel 1581-F155</th>
<th>Yokohama F6986</th>
<th>Cytec Cycom MXB 7701/7781</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\theta$</td>
<td>std dev</td>
<td>$\theta$</td>
<td>std dev</td>
</tr>
<tr>
<td>DI H2O</td>
<td>53.2</td>
<td>7.2</td>
<td>59.3</td>
<td>3.8</td>
</tr>
<tr>
<td>Ethylene Glycol</td>
<td>20.0</td>
<td>1.9</td>
<td>27.1</td>
<td>3.0</td>
</tr>
<tr>
<td>Formamide</td>
<td>39.4</td>
<td>3.5</td>
<td>41.7</td>
<td>4.9</td>
</tr>
<tr>
<td>Diiodomethane</td>
<td>not wet out</td>
<td>-</td>
<td>not wet out</td>
<td>-</td>
</tr>
</tbody>
</table>

Table II. Average contact angles $\theta$ for substrate-polyester peel ply (Precision 60001) combinations.

<table>
<thead>
<tr>
<th>Test liquid</th>
<th>Substrate</th>
<th>Hexcel 1581-F155</th>
<th>Yokohama F6986</th>
<th>Cytec Cycom MXB 7701/7781</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\theta$</td>
<td>std dev</td>
<td>$\theta$</td>
<td>std dev</td>
</tr>
<tr>
<td>DI H2O</td>
<td>78.3</td>
<td>7.8</td>
<td>78.9</td>
<td>6.5</td>
</tr>
<tr>
<td>Ethylene Glycol</td>
<td>3.9</td>
<td>0.9</td>
<td>9.8</td>
<td>4.3</td>
</tr>
<tr>
<td>Formamide</td>
<td>31.0</td>
<td>5.3</td>
<td>30.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Diiodomethane</td>
<td>wet out</td>
<td>-</td>
<td>wet out</td>
<td>-</td>
</tr>
<tr>
<td>Glycerol</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Table III. Average contact angles $\theta$ for selected uncured film adhesives.

<table>
<thead>
<tr>
<th>Liquid</th>
<th>$\theta$</th>
<th>std dev</th>
<th>$\theta$</th>
<th>std dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>DI H20</td>
<td>65.3</td>
<td>4.0</td>
<td>81.3</td>
<td>4.4</td>
</tr>
<tr>
<td>Ethylene Glycol</td>
<td>52.4</td>
<td>6.2</td>
<td>70.7</td>
<td>6.8</td>
</tr>
<tr>
<td>Formamide</td>
<td>62.3</td>
<td>4.3</td>
<td>61.4</td>
<td>4.7</td>
</tr>
</tbody>
</table>

The wetting envelopes generated from the data on these tables are shown in Figure 4. In theory, any liquids whose surface energy component coordinates within the envelopes should wet out on those surfaces. The two primary variables here are peel ply used and differences in matrix composition; the fact that the envelopes are similar per peel ply type means that differences in matrix composition make little difference.

According to the envelopes, ethylene glycol should have wet out on all three polyester-prepared surfaces, and the contact angles for formamide on the polyester-prepared surfaces should have been lower. There may have been some variation in the energy of the liquids, or this may be representative of acknowledged limitations of the Owens and Wendt model.

The data points from selected film adhesives are included to give some indication of how well the adhesives may tend to wet out on the substrates. While it is beyond the scope of this study to measure energy changes with heat and pressure, it is clear that even at room temperature, the adhesives have lower energies than the substrates; thus, they may be expected to wet out. This implies that any troubles with adhesion do not come from a lack of wetting, at least with these adhesives.
3.2 RAT Results

The results from the RAT are shown in Table IV and Table V, distinguished by peel ply. Even a casual inspection of the tables shows the dramatic difference: all of the specimens prepared with the nylon peel ply had a qualitatively desirable failure mode, cohesive in the adherend, while all of the specimens prepared with the polyester peel ply had the undesirable failure mode of adhesion failure or a mix between the two.

Table IV. RAT results for combinations using nylon (Precision code 51789) peel ply.

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Hexcel 1581-F155</th>
<th>Yokohama F6986</th>
<th>Cytec Cycom MXB 7701/7781</th>
</tr>
</thead>
<tbody>
<tr>
<td>3M AF500</td>
<td>COHESIVE</td>
<td>COHESIVE</td>
<td>COHESIVE</td>
</tr>
<tr>
<td>3M AF 163-2M</td>
<td>COHESIVE</td>
<td>COHESIVE</td>
<td>COHESIVE</td>
</tr>
<tr>
<td>Cytec FM 94</td>
<td>COHESIVE</td>
<td>COHESIVE</td>
<td>COHESIVE</td>
</tr>
<tr>
<td>Henkel Hysol EA 9696</td>
<td>COHESIVE</td>
<td>COHESIVE</td>
<td>COHESIVE</td>
</tr>
<tr>
<td>Cytec FM x209</td>
<td>COHESIVE</td>
<td>COHESIVE</td>
<td>COHESIVE</td>
</tr>
<tr>
<td>Henkel Hysol EA 9628</td>
<td>COHESIVE</td>
<td>COHESIVE</td>
<td>COHESIVE</td>
</tr>
</tbody>
</table>
Table V. RAT results for combinations using polyester (Precision 60001) peel ply.

<table>
<thead>
<tr>
<th>Adhesive</th>
<th>Hexcel 1581-F155</th>
<th>Yokohama F6986</th>
<th>Cytec Cycom MXB 7701/7781</th>
</tr>
</thead>
<tbody>
<tr>
<td>3M AF500</td>
<td>ADHESION</td>
<td>ADHESION</td>
<td>ADHESION</td>
</tr>
<tr>
<td>3M AF 163-2M</td>
<td>ADHESION</td>
<td>ADHESION</td>
<td>ADHESION</td>
</tr>
<tr>
<td>Cytec FM 94</td>
<td>ADHESION</td>
<td>ADHESION</td>
<td>ADHESION</td>
</tr>
<tr>
<td>Henkel Hysol EA 9696</td>
<td>ADHESION</td>
<td>ADHESION</td>
<td>ADHESION</td>
</tr>
<tr>
<td>Cytec FM x209</td>
<td>MIXED</td>
<td>MIXED</td>
<td>MIXED</td>
</tr>
<tr>
<td>Henkel Hysol EA 9628</td>
<td>ADHESION</td>
<td>ADHESION</td>
<td>ADHESION</td>
</tr>
</tbody>
</table>

There were other qualitative differences observed. First of all, the process of peeling the RAT specimens prepared with polyester peel ply was noticeably easier. This is consistent with a failure in adhesion because of the lower $G_{IC}$ values associated with this failure mode – it should take less energy to fracture. Secondly, the peeled specimens typically had a quite noticeable difference in their radii of curvature; this is shown in Figure 5. The specimens that failed cohesively – prepared with nylon peel ply – required more energy to fracture, resulting in more plastic deformation of the aluminum backing.

![Figure 5: Peeled RAT specimens, Cytec Cycom MXB 7701/7781 substrate with Henkel Hysol EA 9628 adhesive. The upper three, failures in adhesion, were prepared with the polyester peel ply; and the lower three, cohesive failure, with nylon.](image)

**3.3 SEM Results** The SEM results give important information about the morphology of the prepared surfaces and suggest a proximate cause for the RAT results. Figure 6 shows a representative substrate prepared with nylon peel ply; the surface is relatively clear of obvious
impurities. Figure 7, showing the same substrate at the same magnification but prepared with a polyester peel ply, reveals what is likely responsible for the fundamental difference in behavior between the two peel plies: tendrils of the polyester have pulled free from the peel ply and been left behind in the matrix at the surface, like a very fine fuzz. Closer examination showed that the tendrils were clearly embedded in the resin, not just surface debris; furthermore, the tapering shape of tendrils confirmed that they are ductile, and therefore not pieces of the matrix, which is brittle. It seems likely that these tendrils are the reason why the adhesives cannot bond effectively to the underlying substrates.

Although illustrations are given for only a single substrate here, these characteristics were found on all three substrates for each peel ply case.

![Figure 6. Cytec 7701/7781 with surface prepared using nylon peel ply.](image-url)
Figure 7. Cytec 7701/7781 with surface prepared using polyester peel ply. Note tendrils.

Pictures of the substrate surface from peeled RAT specimens are shown in Figure 8, Figure 9, and Figure 10. It is believed that the debris on the surface was introduced during execution of the RAT and is not relevant to the results.

Figure 8 shows the substrate from a specimen that failed in adhesion. The peel ply imprint is clearly left on the surface, showing that the specimen failed on the interface, and similar tendrils as seen in Figure 7 are still present.
Figure 8. Substrate Cytec 7701/7781 with surface prepared using polyester peel ply, after RAT – failure in adhesion (undesirable). Arrows indicate tendrils at fracture interface. Adhesive Henkel EA 9628.

Figure 9 shows a mixed failure mode. The picture is similar to Figure 8, but the circled area tells a different story; there, the fracture occurred in the substrate matrix resin near the glass fibers, rather than at the peel-ply-prepared layer. This is the reason why glass fibers are visible at that location. Typically, these desirable areas of cohesive failure were macroscopically large regions. It is not clear why the adhesive that caused substantial mixed-mode fracture, Cytec Fm x209, achieved these results.

Finally, Figure 10 illustrates a completely cohesive, desirable failure. In this case, practically all of the fracture occurred close to the glass fibers, as just described. The long lines visible are pieces of fractured glass fiber.
Figure 9. Substrate Cytec 7701/7781 with surface prepared using polyester peel ply, after RAT – mixed failure mode (still undesirable). Circled area indicates region of good bonding. Adhesive Cytec FM x209.

Figure 10 Substrate Cytec 7701/7781 with surface prepared using nylon peel ply, after RAT – cohesive failure mode (desirable). Adhesive Henkel EA 9628.
4. CONCLUSIONS
The most important result here is clear and unambiguous: the Precision 60001 polyester peel ply should not be relied on as the sole method of surface preparation for any of the tested fiberglass substrates with a 127 °C (260 °F) cure. Substantial numbers of ductile tendrils of the peel ply material are being left behind in the matrix, weakening the ability for the adhesive to bond successfully to the substrate. It is possible that some other substrate – adhesive combination could be made to work with the peel ply, but the uniformity of results across several substrate and adhesive combinations is discouraging.

On the other hand, the Precision code 51789 nylon peel ply showed a favorable mode of failure in all test cases, meaning that it is not automatically rejected on the basis of the RAT. The mode of failure implies a high fracture strength. More tests that are quantitative would be in order for these combinations of substrate, nylon peel ply, and adhesive. It is possible that the “curse” of nylon peel plies might be lifted.

5. ACKNOWLEDGEMENTS
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6. REFERENCES


