



# Technical

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## KEY FACTORS OF THE PEEL PLY SURFACE PREPARATION PROCESS

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### SUMMARY

This work sought to identify key characteristics of the peel ply process that influence the quality of subsequent adhesive bonds to composite surfaces. Currently, this method of creating a quality bondable surface lacks reliability. This work scope is focused on polyester fabrics. Key factors such as fabric openness, the time/temperature profile of the composite curing process and the impregnating resin crack toughness are critical to the quality of the ultimate adhesive bond. This work led to the development of a pre-impregnated peel ply material that optimizes these three variables leading to a reliable bonding surface.

### 1. INTRODUCTION

The use of a peel ply is an attractive route for the preparation of a composite bonding surface. Not only do considerable labor and capital savings result, but a surface consistent over its entire area is possible. However, industry experience has shown that this process lacks reliability with respect to the performance of the resulting adhesive bond.

Part of the reliability issue relates to contamination. Pocius and Wentz (ref. 1) found large performance reductions due to fluorocarbon residues transference from a "release" peel ply. Similarly, Hart-Smith, et. al. (ref. 2) found silicone contamination probably from weaving lubricants. Similar silicone contamination was also found in the author's work.

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Performance variation using polyester fabrics also occurs and cannot be explained with the above contamination theory. The reasons for this variability must be understood before a reliable peel ply process is available. Research was conducted to understand the effect of peel ply fabric characteristics and the corresponding composite cure schedule on the reliability of the peel ply process.

## 2. PROCESS MODEL

This work investigated variations in adhesive performance due to differences in peel ply construction and the toughness of the matrix resin. Resin adhesion was not considered because it is believed that epoxy resins do not wet well to clean polyester fiber. Effective wetting requires that the resin's surface tension ( $\gamma$ ) be less than the fiber's critical surface energy ( $\gamma_c$ ). Typical  $\gamma$  values for epoxy are in the 47 – 55 dynes/cm range while  $\gamma_c$  for a polyester fiber lies in the 42 – 43 dynes/cm area.

Preliminary work found that some polyester fibers are left on the bonding surface of the composite adherend and that the amount varied by fabric type. Because of the poor adhesion of epoxy resin to these residual fibers, bond performance is compromised which can be correlated to the residual fiber level. Figure 1 illustrates a typical level of retained polyester fiber on a bonding surface.

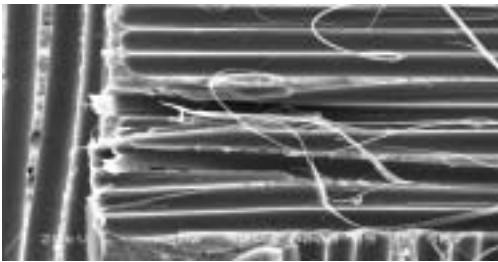


Figure 1: Residual polyester fiber on bonding

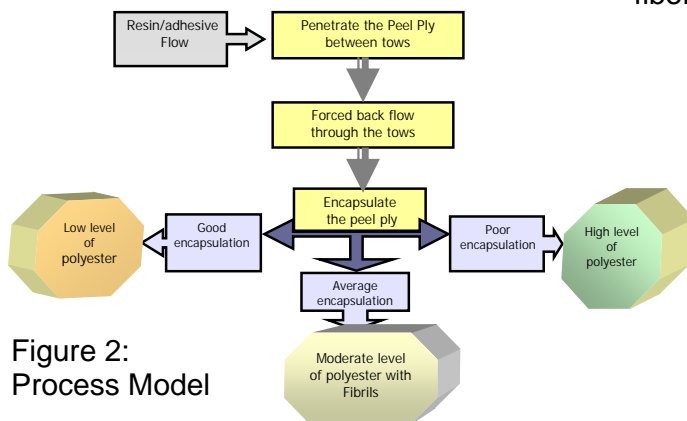
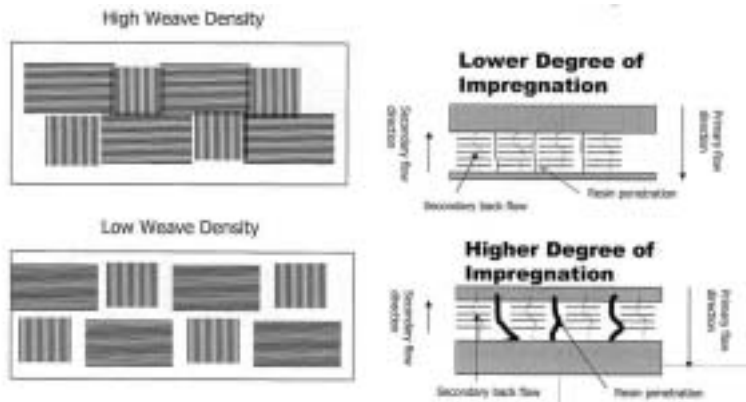


Figure 2: Process Model

A processing model (Figure 2) was developed to explain the variation in the amount of fiber left on the bonding surface, using a dry peel ply fabric.

The model illustrates that the amount of residual fiber is dependant upon the degree of resin encapsulation of the fabric. This is dependant upon not only weave density, but also the number of filaments per tow and the filament diameter. Additionally, variation in the composite cure schedule will change the resin viscosity profile. This will also produce variations in fabric encapsulation level.

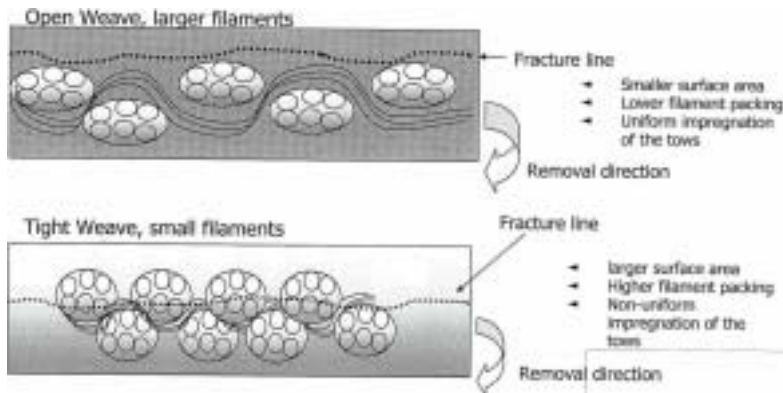


Resin encapsulates the fabric in two sequential steps: an initial flow through the fabric between the fiber tow bundles and a sequential “back” flow through the bundle itself. The influence of the fabric weave density can be seen in Figure 3.

Figure 3: Effect of weave density on resin flow

High density fabrics have more but smaller interstices producing lower levels of the initial type flow, reducing the amount of resin available for back flow. The small fiber diameter and high fiber count per tow retards back flow producing incomplete fabric encapsulation. Those fabrics with large diameter fibers and a lower tow count offer less resistance to back flow producing higher levels of encapsulation.

The amount of back flow also depends upon the viscosity profile of the composite resin system. As this resin reacts, its viscosity increases, increasing the time needed to completely encapsulate the fiber bundle. The ultimate level of fabric encapsulation then, varies with differences in resin reactivity or with an autoclave cure schedule that does not allow the resin to reach its minimum viscosity.



When peel ply layers with high levels of resin encapsulation are removed from the cured composite surface, the tendency is for fracture to occur in the resin, away from the fiber bundles (Figure 4). Incomplete fabric encapsulation leaves weakened areas within the fiber bundle itself. Fracture then occurs within the fiber, leaving residual fiber.

Figure 4: Impact of fabric density on fracture location

The final important variable is the fracture energetics of the encapsulating resin itself. Encapsulation with toughened prepreg resins accentuate the effects of poor fabric encapsulation by forcing fracture into the fiber bundle and generating residual peel ply fibers.



### 3. EXPERIMENTAL

Honeycomb peel and crack toughness tests were used to measure performance.

#### a) Honeycomb Peel

Adhesive: EA 9695, 0.05K, Prepreg: Cytec HTA/977-2, 2X2 Twill, 285 g/m<sup>2</sup>

Skins: [+45, 0, -45], pre-cured with peel ply on bonding surface

Honeycomb Core: Nomex HRH-10, 96 kg/m<sup>2</sup>, 4.76mm cell

Cure cycle: 2 hours @n 180°C, 5.9 bar (skins) & 3.1 bar (HC)

Test per EN2243

b) Adhesive bond durability was measured using both mode I and II ( $G_{Ic}$  and  $G_{IIc}$ ) crack toughness tests

AITM 1.0005 & 1.0006 respectively

### 4. RESULTS

#### 4.1. Dry Peel Ply

Six polyester fabrics from both European and U.S. sources were screened.

Comparison of the peel ply fabric surface after removal from the cured composite illustrates the impact of fabric density (Figure 5). The shredded fiber bundles of the moderate density fabric indicate that a significant amount of fiber was left on the bonding surface. The more complete bundles of the low-density fabric indicate that much less fiber remains on the bonding surface.

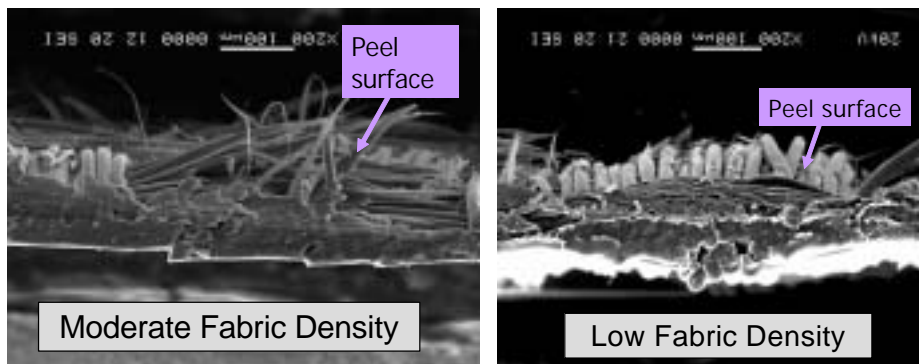


Figure 5:



The net impact on the bonding surface can be seen in Figure 6. The low density fabric leaves a much cleaner surface with little retained peel ply fiber. Considerable fiber can be seen on the bonding surface generated by removal of the tighter weave, smaller filament fabric.

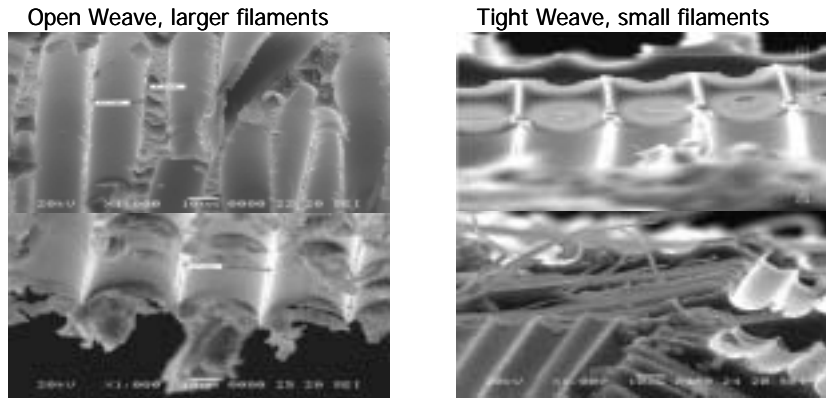


Figure 6: Bond surfaces generated high and low density fabrics

Re-examining the model, it can be seen that the fracture locus depends not only upon the degree of filling of the peel ply fabric but also upon the fracture resistance of the resin that fills the fabric. A high toughness resin system, such as the latest generation of prepreg resins, tends to drive the fracture location into the peel ply fabric even though it was completely filled. Controlling fracture location by regulating the toughness of the resin layer was the next area of improvement.

#### 4.2. Pre-Impregnated Peel Ply Systems, Wet Peel Ply

Hysol® EA 9895, containing an optimized impregnating resin, was developed to meet this need. Its reduced resin toughness directs the failure locus during peel ply removal, to the region between the peel ply and the outer layer of carbon fibers. The peel ply is easy to remove without damaging composite layers and without any residual peel ply fibers. This can be seen by comparing cross-sections of adhesive bonds surfaces prepared with toughened and optimized resins (Figure 7).

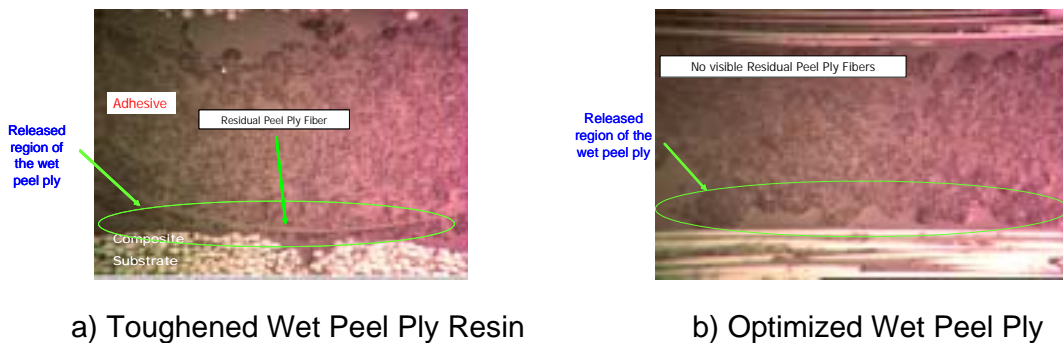
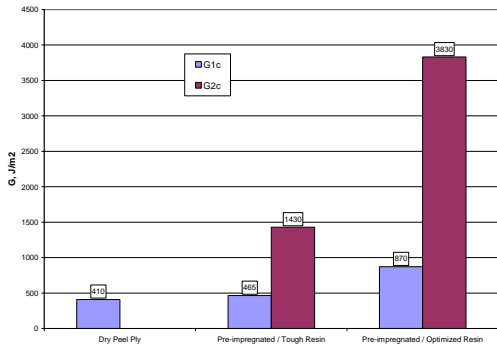


Figure 7: Effect of peel ply impregnation resin on retention of fiber in bond line



The lowered resin toughness of the peel ply resin does not negatively impact the toughness of the subsequent adhesive bond. This can be seen by comparing both the  $G_{Ic}$  and  $G_{IIc}$  properties of bonds made with various peel ply combinations (Figure 8).

Figure 8: Effect of Optimized Peel Ply on Adhesive Properties

The  $G_{Ic}$  performance of bonds made with either dry peel ply or that pre-impregnated with a tough resin system is less than one-half than that of the bond made using the Hysol® EA 9895 system. The  $G_{IIc}$  performance using Hysol® EA 9895 is three times that of bonds made using a tough resin impregnated peel ply. The choice of resin system also influenced the bond fracture location. Bonds made using a dry peel ply prepared surface failed at or very near the adhesive/composite interface. In contrast, bonds made using the optimized wet peel ply system, failed cohesively within the adhesive layer itself (Figure 9).

The use of Hysol® EA 9895 generates a very high energy bonding surface that appears to be compatible with all composite bonding epoxy adhesives.

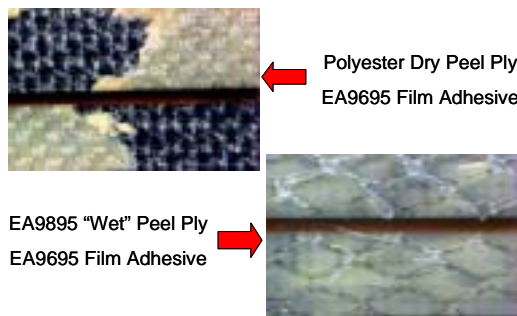


Figure 9:  $G_{Ic}$  Fracture Surfaces

## 5. CONCLUSIONS

Use of a peel ply produces significant labor and capital savings in the composite surface preparation process. However, the reliability and durability of the ultimate adhesive bond is strongly influenced by peel ply weave details and its encapsulation level during cured and also on the toughness of the impregnating resin system. Without optimization of these variables, peel ply fiber is left on the bonding surface producing variable and reduced adhesive bond properties. Maximizing fabric characteristics and optimizing composite cure cycles yields some performance improvements. However, selecting a peel ply impregnating resin that creates a residual fiber free surface is critical to achieving the desired bond reliability and durability.



Hysol® EA 9895, a pre-impregnated peel ply was developed to meet these needs. It generates a very bondable, fiber free surface that yields durable and reliable adhesive bonds. Bonds generated using surfaces made with this product have two- to three-fold higher levels of durability ( $G_{Ic}$  and  $G_{IIc}$ ) compared to use of a dry peel ply fabric. Correspondingly, an improved failure mode is obtained with Hysol® EA 9895.

## 6. REFERENCES

- [1] Pocius A.C., Wenz R.P., Mechanical Surface Preparation of Graphite-Epoxy Composite for Adhesive Bonding, 30<sup>th</sup> National SAMPE Symposium, March 19-21, 1985, pages 1073-1087
- [2] Hart-Smith L.J., Redmond G., and Davis M.J., The Curse of the Nylon Peel Ply, 41<sup>st</sup> International SAMPE Symposium, March 24-28, 1996, pages 303-317