

BONDING OF SANDWICH STRUCTURES - THE FACESHEET/HONEYCOMB INTERFACE - A PHENOMENOLOGICAL STUDY

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ABSTRACT

A predominant failure mechanism in sandwich structures is the de-bonding of the composite face-sheets from the core structures. In general, this type of de-bonding is initiated by impact damage on the surface and propagated by a flexural load where the damaged area is subjected to compression or cyclic fatigue. In case of core materials manufactured from Kevlar® N636 and Nomex®* T412 papers, guideline to improve this bond will be discussed. The surface preparation prior to bonding is critical, but differs in cases of metallic versus non-metallic cores. Strength of these types of bonds is generally measured by climbing drum peel test – which is inadequate to compare strength of adhesion between dissimilar (composite) materials. Morphological examination of the failed surface will be presented to provide routes to better adhesion and adhesion test.

KEY WORDS: Sandwich structures, Adhesive bonding, Testing/Evaluation

1. INTRODUCTION

In an aircraft, where the specific stiffness of a component is highly valued, the sandwich structure with honeycomb-core is of particular interest. Honeycomb core is ~90-98% air. Thus it provides a high in-plane bending stiffness with low weight. The sandwich structure consists of thin and stiff face-sheets made from either metal (aluminum alloys) or composite (such as carbon/epoxy, glass/epoxy, etc.), separated by light weight core. These face sheets are adhesively bonded to the core (honeycomb) through a secondary bonding process, where the components of the core do not flow. The honeycombs can be made from thin sheets of metal, usually aluminum, or strong papers (after resin impregnation) such as Kevlar®-N636. Honeycombs manufactured from organic materials, such as those based on aramid papers, provide greater degree of freedom

* Kevlar® and Nomex® are registered trademarks for aramids from E. I. DuPont de Nemours Co., Inc.

in design through low coefficient of thermal expansion, low electrical conductivity, dielectric properties, etc.

Due to change in modulus between face-sheets and the core (honeycomb wall material), there is a large amount of shear stress generated at the interface, while the structure is subjected to a bending load. Shear stress can peel the face-sheets off the honeycomb surface, when any flaw is introduced at the core/face-sheet interface. This flaw can be initiated by an impacting force, especially on the exterior structure.

The load bearing capacity of a sandwich structure is highly dependant on the quality of the adhesion between the core and the face-sheets. Delamination of face-sheets from the honeycomb can lead to catastrophic failure of the structure. Thus the nature and the quality of bonding between the face-sheet and the core is an important design criterion for sandwich-structures.

2. BONDING FACE-SHEETS ONTO HONEYCOMB

Composite face-sheets and honeycombs are bonded as two distinct solid-phases through a secondary bond. In general, a fully cured honeycomb is bonded to the composite face-sheets by either of the following two methods:

- An adhesive film is placed on the top and the bottom surfaces of the honeycomb, upon which cured/uncured prepregs are placed. This whole assembly is placed in an autoclave to cure the adhesive (resin). During curing process, the resin from the film plasticizes/melts. The resin flows and creates a bond between the prepregs and the honeycomb walls.
- Uncured prepregs are placed on the top and the bottom surfaces of the honeycomb. This whole assembly is cured in an autoclave. During curing, the resin from the prepreg flows and creates a bond between the prepregs and the honeycomb walls.

For a reliable bond to exist at the interface, the resin should flow from the prepreg (or adhesive sheet) and create a symmetric fillet on the honeycomb wall surrounding the interface between the honeycomb wall and the face-sheet (figure 1). In addition, the edge of the cell-wall of the honeycomb should be straight and sharp. It should slightly indent the face-sheet at the interface, creating distinct interfaces between the prepreg, resin and the cell-wall.

3. CLIMBING DRUM PEEL TEST AND ADHESION FAILURE

The quality of the face-sheet/honeycomb bond is often measured by the Climbing Drum Peel (CDP) test (ASTM D1781). This test is relatively simple, but requires a study of the failure pattern before the results are compared to decide on “relative” adhesion strength. This test actually measures the force required to impart enough energy to propagate the crack. Thus change in material, specimen configuration or test configuration can change the required force, making the comparison invalid.

The delamination of the face-sheet can occur by propagation of the crack in one or more of the following spaces:

1. Interface between the resin and fiber in the facesheet (prepregs)
2. Resin layers (between the prepreg and the honeycomb wall) formed during bonding.
3. Interface between the resin (from the prepreg/film) and the honeycomb cell-wall
4. Cell wall (failure in the core)

The first 3 sites of crack propagation can be grouped under the term “honeycomb/prepreg interface”. The fourth site is inside the honeycomb, away from the interface. For a relatively weak cell wall, the fracture may be confined to the core (case 4). In this case, the delamination force can be increased only by changing the honeycomb core-wall. However, a stronger paper may not increase the delamination force – if it changes the crack propagation site. For example, if the “stronger” paper is also stiffer, it may create a more severe stress concentration at the core/honeycomb interface – thus apparently requiring lower “load” to failure (where as the stress to failure is higher).

The stress distribution at the honeycomb/face-sheet interface (during CDP test) is schematically presented in figure 2. A relatively “flexible” core will distribute the load over larger area at the prepreg/core interface, thus creating less stress. For a “stiffer” core, the load is concentrated; hence the stress is much higher. Thus a higher delamination load in a flexible core system does not indicate higher adhesive strength compared to a stiffer-core system.

This problem becomes evident while comparing failure surfaces in cores manufactured from Nomex® and Kevlar®-N636 system. Their respective properties are listed in table 1. The flat-wise-tensile (FWT) strength (measured according to ASTM C297) shows that the Kevlar® N636 cores are twice as strong, compared to Nomex®-T412. The shear moduli give a measure of their relative stiffness (Kevlar® is about twice as stiff). However, Kevlar®-N636 has much lower CDP strength (30 N.m/m vs. 60 N.m/m). The surfaces of the fracture propagation are shown in figure 3. In the case of Nomex® cores, with relatively lower FWT strength, the fracture runs 100% through the core-walls. For Kevlar®, with stronger cell walls, the fracture runs 100% through the honeycomb/ prepreg interface. The morphologies of these two fracture surfaces are totally different – thus the CDP values cannot be compared directly.

4. QUALITY OF BOND AND HONEYCOMB SURFACE

The bonding surfaces of a honeycomb and the prepregs are distinct solid phases. Honeycomb does not flow or mix during the bonding process. Thus the surface quality of honeycomb plays a major part in determining the quality of the bond.

Kevlar® is difficult to cut. Standard procedures to cut Kevlar®-N636 core have been developed ^[1]. However, the quality of surface provided by different manufacturers at different occasions can be widely varied. In figure 4, three different types of core surfaces have been displayed. The first core (C1) had an extremely fuzzy surface. The second core (C2), from a different manufacturer, had a relatively cleaner surface. The third core (WS) was created from C1, by cleaning off the fuzz through wet-sanding.

For the extremely fuzzy surface(C1), the cell wall will over like a “paint-brush” at the contact point with the prepreg. This hinders the flow of adhesive and there is a weak-point in the fillet. During CDP, failure is initiated at these points. The crack propagates through by pulling off the damaged fibers in the “fuzz”. The SEM of the surface of the prepreg from C1 shows some amount of fibers and imprint of fibers on the resin. This type of surface is unacceptable, because full mechanical properties of the honeycomb have not been utilized.

For the moderately fuzzy surface(C2), the cell wall still bends over at the contact point. However, the amount of paint-brush-effect is relatively small and the epoxy fillet at the joint is relatively robust. The fracture surface SEM shows some amount short-fibers from the honeycomb being pulled out. The SEM also shows some of the fracture running through the fiber-resin interface of the prepreg (leaving weave pattern on the fracture surface). In this case, the mechanical properties of the honeycomb have been realized to a greater extent than those in C1.

When the honeycomb surface is completely cleaned through wet sanding (320 Grit sandpaper), the cell wall bond to the prepreg is ideal. These set of specimens are designated as WS. Upon bonding in autoclave, cell wall remains straight at the prepreg interface and symmetrical fillets are formed by the adhesive at the joint. In this case, SEM of the fracture surface shows total absence of fiber-pull-out from honeycomb. The fracture propagated through epoxy or epoxy fiber interface (prepreg). Since the fracture did not go through any part of the honeycomb interface, the mechanical properties of the honeycomb has been utilized to the fullest extent. In this structure now the weak point is the toughness of the prepreg resin or the fiber/resin interface of the prepreg. However, the CDP values of C1, C2 and WS cores are not significantly different because of the stress concentration due to stiff core.

We found that the clean surface on the Kevlar®-N636 honeycomb core can be achieved by machining. An ultrasonic cutter at a head-speed of 300 inch/min (AGFM US-350) can clean the core surface to compare favorably with wet-sanding by hand (figure 5).

Another factor that diminishes the bond quality in polymeric honeycomb structure – is the action of cleaning the core with strong solvents. An organic core contains oligomers with low molecular weight. Solvent cleaning will dissolve these oligomers and re-deposit those at the cell wall edges upon evaporation. This contaminant phase can severely interfere with the quality of bonding. Thus for organic cores, only cleaning with soap and water is recommended.

5. CONCLUSION

The quality of the bond between honeycomb core and the prepreg is significantly affected by the quality of the surface of the honeycomb, prior to bonding. The surface quality also affects the morphology of the fracture surface. A clean surface on a Kevlar®-N-636 core was achieved by wet sanding with 320 grit sandpaper. These clean cores displayed preferable morphology of the fracture surface indicating full utilization of the honeycomb mechanical properties.

The quality of the bond may also be affected by the nature of chemical cleaning of the organic core surface. Cleaning with aggressive solvents may leave a layer of oligomers at the cell wall surfaces, which will in turn interfere adversely with bond quality between the core and the face-sheets. For organic cores, it is recommended that only soap-and-water be employed for surface cleaning.

The climbing-drum-peel test is not a proper indicator of the relative bond quality between the core and the face-sheets when cores with different stiffness are compared. Stiffer cores create higher stress concentration at the core/face-sheet interface. Thus the CDP value of a stiff-core can be lower than that of a flexible core, irrespective of the bond quality. The CDP values can be used as a relative measure only when the morphologies of the fracture surfaces remain equivalent.

6. REFERENCES

1. L. Lapane, et al; *SAMPE J.*, **40** (3), 77 (2004).

Table 1 Typical properties of Honeycombs from aramid papers.

	Paper Thick μm	Cell size mm	HC Density kg/m ³	FWT Strength MPa	L-Shear Strength MPa	L-Shear Mod. MPa	W-Shear Strength MPa	W-Shear Mod. MPa	CDP N.m/m
1.8N636	45	3	48	4.6	1.8	138	1.0	76	30
2T412	56	3	48	2.3	1.2	58	0.7	26	60

Figure 1: Ideal Bonding between face-sheet and core

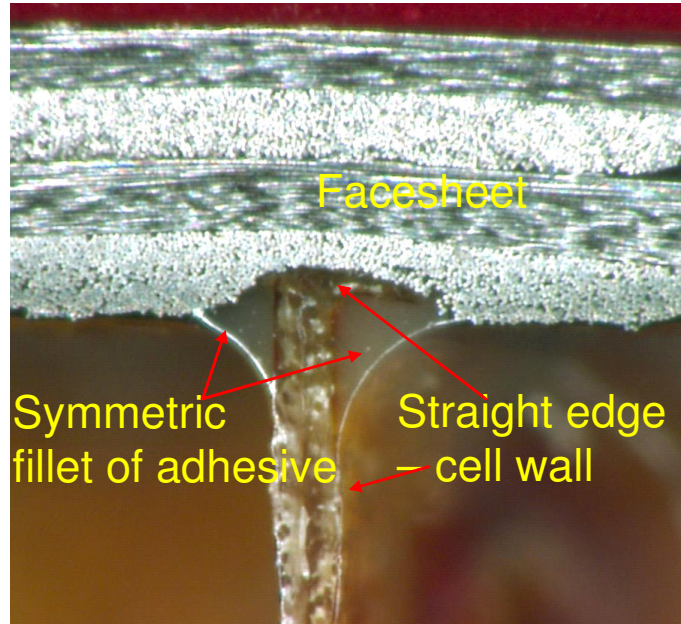


Figure 2: Schematic of Climbing-Drum-Peel test and stress distribution at the fracture.

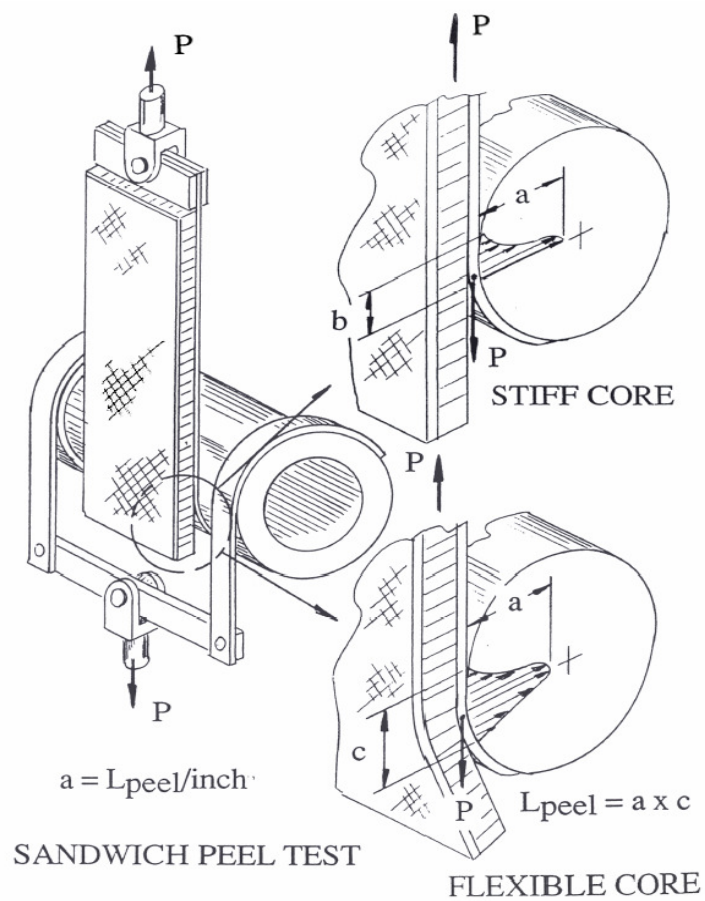


Figure 3: Comparison of fracture surfaces- CDP - Nomex® -2T412 and Kevlar®-N636

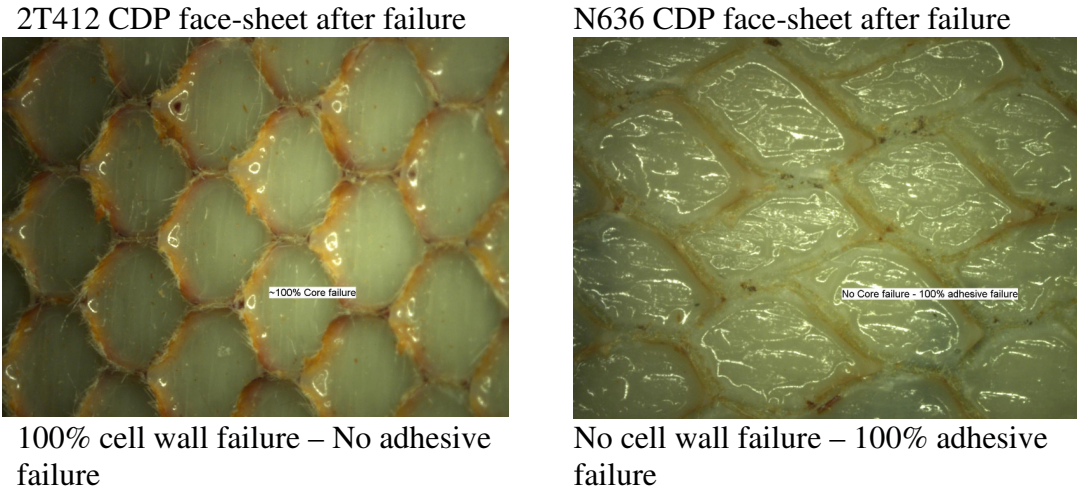


Figure 4 Comparison of core-surface with fracture surface and adhesive fillet at joint.

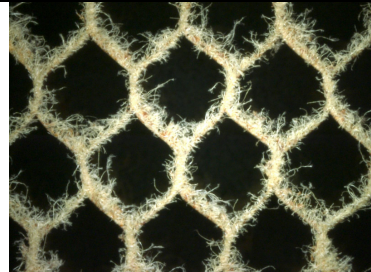
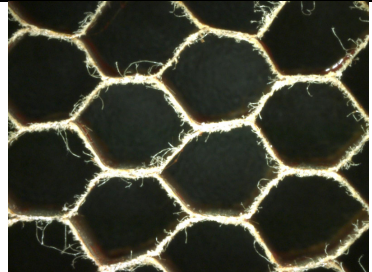
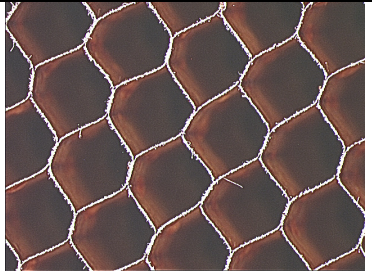
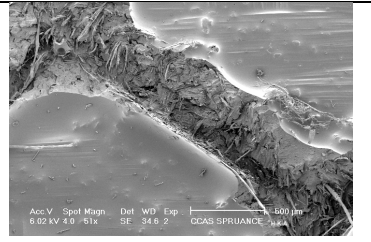
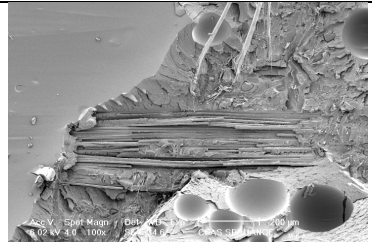
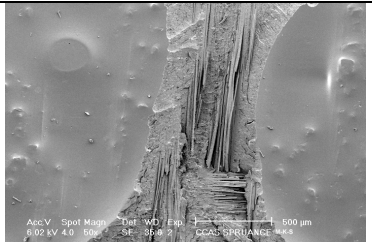
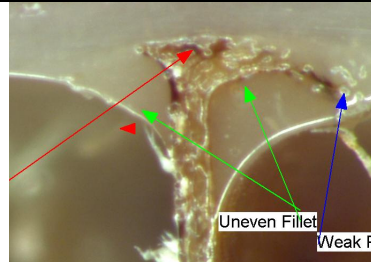
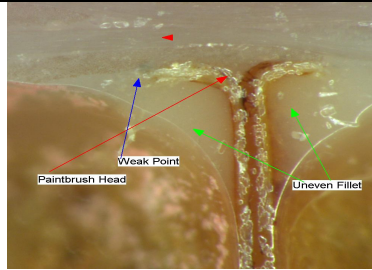
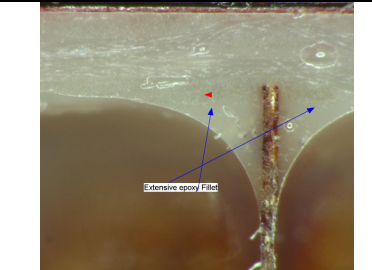
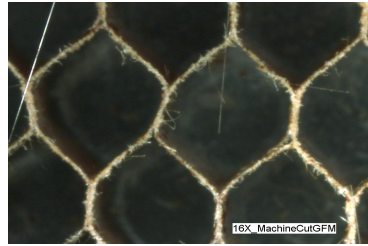
Core – 1 – as-is core surface	Core – 2 – as-is core surface	Wet-sanded (WS) core - core surface
		
Fracture surface (SEM) – C1	Fracture surface (SEM) – C2	Fracture surface (SEM) – WS
		
Paint-brush head Wall – C1	Paint-brush head Wall – C1	Straight head Wall – WS
		

Figure 5: Comparison of Core Cleaning – Ultrasonic cutter vs. wet-sanding

Core surface machined with ultrasonic cutter from AGFM at 300 ipm



Core surface Wet sanded with 320grit sandpaper

