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Experimental analysis and study on improving peel strength and its impact on flexural strength for non-metallic honeycomb sandwich panels

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Abstract

The role of sandwich structure in aerospace industry is inevitable. Scoring is a process of providing a passage or cutting the core/foam to certain depth to increase adhesion between core and face skin, thereby increasing the strength of sandwich structure. In this paper, the influence of change in width of cut on adhesion between core and skin is tested using Drum Peel Test. Long beam flexural test is also done in order to elucidate the impact of various widths of scoring on the strength of sandwich panels. Results after scoring gave improved peel strength and almost similar values for all width of cuts. Flexural strength of the panels was reduced by scoring and it was observed that the panels experience an early failure beyond a certain width of scoring.

The work had been presented *at an* international conference ***Fatigue Durability India 2015****, 28-30th May 2015, JN TATA AUDITORIUM, Indian Institute of Science, Bangalore.*

Introduction

The developments in Engineering always aimed to improve the efficiency. When it comes to the aerospace sector, composites are relevant in achieving efficiency. Composite parts are replacing predominant metallic parts in aerospace industry. Sandwich construction (skin bonded to a core) is an example of a highly efficient construction. Sandwich Structures have proven their ability in aerospace and automotive industry due to high stiffness, high strength to weight ratio and high flexural rigidity. Recent aircraft launch from Boeing (Boeing 787) has shown the usage of more than 50% composites by weight.

The strength and structural integrity of sandwich panels depends on the adhesion between skin and core/foam. Failure in adhesion may lead to drastic situations than metallic failure. Advanced composite uses prepregs (resin pre-impregnated fibrous material), metal skins (Aluminium) as skin, honeycomb core (Nomex, Aluminium) and foam as core for sandwich constructions. Prepreg resin, film adhesive or foam adhesive can be used for adhesion between skin and the core. The fillet formed between cell wall and skin holds the skin and core together, providing a good bond resulting high strength sandwich structures. The presence of impurities and voids in the fillet reduces the strength. Figure 1 shows the joining area of skin and core with fillet.

Factors to be considered in composites to meet the required strength and to avoid failures are higher when it’s compared to metals. Control over the parameters in composite manufacturing is sophisticated since it involves chemical reaction, vacuum pressure, temperature, heat up rate, dwell temperature, cooling rate which plays individual roles to produce good parts.
Volatiles are evolved during resin (from prepreg) curing. If these volatiles are not properly treated it will lead to improper bonding. Figure 1 shows the presence of voids in fillet. Providing a channel for venting the volatile gas is a solution to avoid the volatile entrapment. Scoring the core/foam is a method of creating channel on the surface of the core to a certain depth.

In this paper, Specimens without scoring and with various scoring width are tested and variations on peel strength and core shear strength are studied.

The effect of processing parameters like consolidation pressure, temperature cure cycle, temperature ramp rate and vacuum pressure application time on peel strength of Nomex honeycomb core/carbon fibre-epoxy skin sandwich panels was studied and it was observed that temperature cure cycle was the dominant parameter[1].

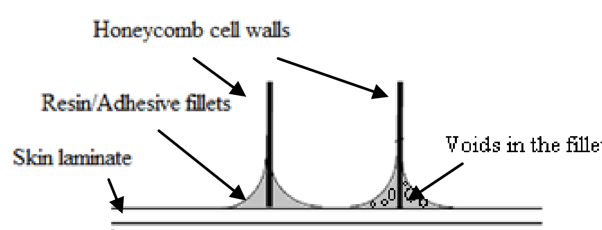

Figure 1 : Joining area between honeycomb core and skin bonded by fillet

The presence of moisture which is accumulated into the adhesively bonded composite structure and their bondline mechanical strengths were investigated through flatwise tension test and climbing drum peel test for dry, wet, wet and repair after wet specimens[2]. Initial pressure required inside the honeycomb core was found to be 40-70kPa by perforating the prepregs and adhesive speparately[3].Double vacuum bag process with designed cure cycle and careful selection of vacuum application point was considered to effectively manage the volatiles. It was found to have higher short beam shear strength, flexural strength, tensile and compressive strengths[4].Boeing company has patents on different pattern of indentation (scoring) on foams to provide effective removal of volatile gases and a method to vent the volatile gases using prescored foams[5].

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Material description, Testing Methods and procedure

Glass phenolic prepreg and aramid honeycomb core were used for sandwich constructions. Phenolic resins on curing at high temperature produce volatiles (water). At a temperature of 120˚C the percentage of volatile is ≤ 3.5%. Core thickness is 0.5 inches (12.7mm) and the cell size is 1/8 inches (3.175 mm). In order to find the peel strength of sandwich specimen, Drum Peel Test (DPT) was done. Long Beam Flexural Test (LBFT) was also done to find the flexural strength of sandwich panel. Cores were scored to various widths ranging from 0.1 mm to 4 mm. Layup of the sandwich panel was done as per the fabrication pattern for DPT and LBFT panels. The panels were cured in autoclave at a required temperature and pressure. DPT and LBFT specimens were cut from the respective panels. Peel strength and the flexural strength (four point bending test) were determined from DPT and LBFT test.

Core cutting, Scoring, Layup, Vacuum bagging and Curing

Glass phenolic prepreg (CYCOM 2290 Phenolic resin)) was cut keeping in mind the warp direction of the prepreg. Direction in which the fabric reinforcements run parallel along the length is the warp direction. Aramid honeycomb core of 0.5inch (12.7mm) was cut with longer dimensions of the specimen along the ribbon direction of the core. The cut core was air and acetone cleaned to remove the dust and other impurities. Honeycomb sandwich cores were scored to a depth of 2.5mm-3.00mm and varying width of cut. Variations in width of cut were 0.1mm, 0.45mm, 1mm, 2.4mm, and 4mm. Thus five cores of five different width of cut were prepared for DPT and LBFT. The layup tool was air cleaned, coated with one layer of MEK (Methyl ethyl ketone) and left for 15 minutes to evaporate. Three coats of Frekote 700 NC (a mould release agent) was applied within a gap of 15minutes. Sandwich panels of 480 mm X 360 mm and 480 mm X 660 mm dimensions were made to obtain DPT and LBFT specimens respectively. Drum peel test panel had one ply of glass phenolic prepregs on both sides of the core with the fill face of the prepreg against the core and warp direction of the prepreg perpendicular to core ribbon direction. Face of the prepreg where large numbers of yarns run perpendicular to the edge is the fill face. LBFT panels were fabricated similar to DPT panels with the exception of two plies on each side of the core. Resin in solid form is nearly 38 – 44 % which is sufficient to provide good bonding without any adhesives. Two thermocouples were placed on top of the skins to track the curing temperature. One layer of perforated release film followed by a breather layer (N10) was placed and then vacuum bagged. Vacuum of min 0.67bar was provided for compaction and the leak checked to a vacuum drop of 0.10 bar in 5min.

The Panels were cured in an autoclave at a heat up rate between 0.6°C/min – 1.38°C/min. During curing two dwells of 30-35min and 60-90 min were maintained at 65°C and 125°C respectively. Panel was then cooled at the rate of 3°C/min to a temperature of 40˚C. The practised cure cycle is shown in figure 2.

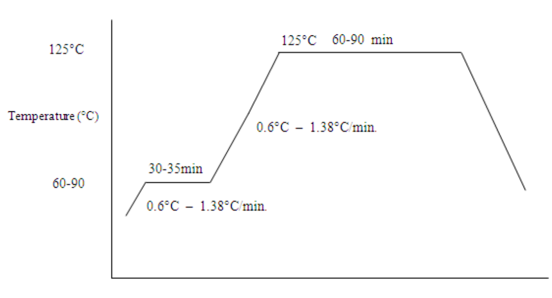


Figure 2 : Cure cycle

DPT specimens of 3” X 12” (76.2 mm X 304.8 mm) cut from the cured panels using a band saw, were 12” parallel to the warp of the prepreg. LBFT specimens of 3” X 24” (76.2 mm X 609.6 mm) were cut from the cured panel, with the long dimension parallel to the core ribbon direction . Figure 3 shows a typical drum peel specimen with dimensions.

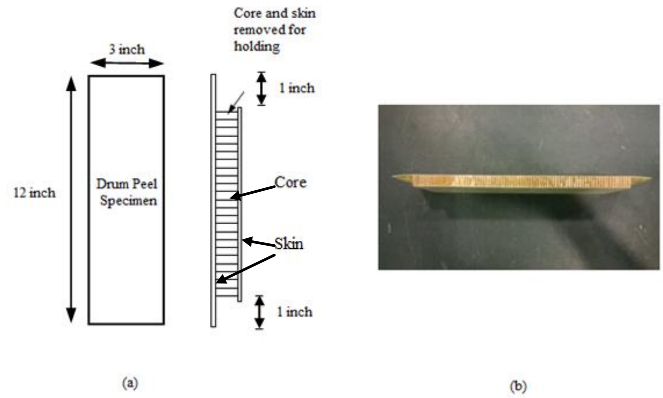


Figure 3 : Climbing drum peel test specimen

Experimental, Results and Discussion

Climbing drum peel test

Peel strength of sandwich structures are determined by peeling the face skin from the core around a circular drum following the ASTM D1781 standards [6]. One inch of the skin and core were removed from one side of the specimen to facilitate holding of the specimen on the drum peel setup. One end of the test specimens was clamped to the drum and the other end to the top clamp. Test was done with a cross head speed of 1 inch/min (25 mm) to a total length of 6 inch (152 mm). After the specimen facing was peeled, the cross head motion of the test machine was reversed and the crosshead returned to its starting position. Test was again repeated on the same specimen to find the average load required to rewind the peel skin back (F_o).The average load (F_p) required to peel the skin from the core is the average of five peaks and five troughs of the load deflection curve obtained during testing . The average peel torque (T) can be obtained from the equation [6] where, the radius of the flange plus one half the thickness of the loading straps (r_o) is 63.5mm and r_i represents the radius of the drum plus one half the thickness of the adherend being peeled which is 51.206mm.

$$T = [(r_o-r_i)(F_p-F_o)]/W \quad (1)$$

Figure below shows the process of loading, peeling and shows the peeled specimen after the test.

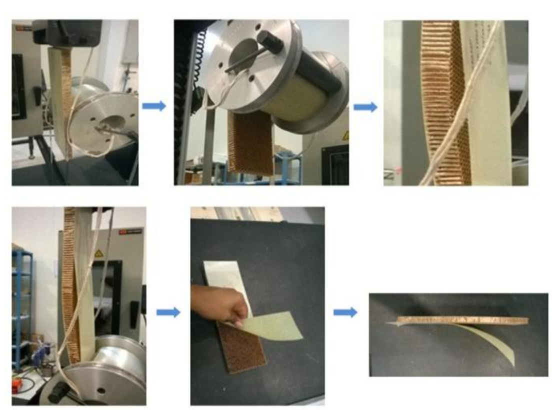


Figure 4 : Sequence of climbing drum peel testing

Specimens were tested for five widths of cut. Six specimens were tested for each condition and best three results were considered to find the average peel strength. Below shows the peel strength results of specimens without scoring and with varied scoring width.

Table 1 : Peel test results of unscored and scored specimens

	Results of Specimens Without Scoring		Results of Specimens With Scoring		
	Drum peel Strength (Nm/0.0254m)	Average Peel Strength (Nm/0.0254m)	Scoring Width (mm)	Drum peel Strength (Nm/0.0254m)	Average Peel Strength (Nm/0.0254m)
Climbing Drum Peel Test	1.75	1.35	0.10 mm	1.76	1.83
	1.10			1.87	
	1.19			1.87	
	1.07	1.13	0.45 mm	1.79	1.87
	1.13			1.83	
	1.19			2.00	
	1.55	1.43	1 mm	1.95	1.86
	1.41			1.82	
	1.33			1.81	
	1.33	1.32	2.4 mm	1.99	1.97
	1.30			1.94	
	1.33			2.00	
	1.05	1.25	4 mm	1.09	1.46
	1.29			1.72	
	1.42			1.58	

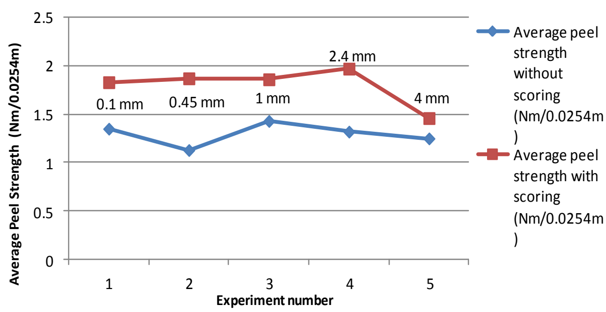
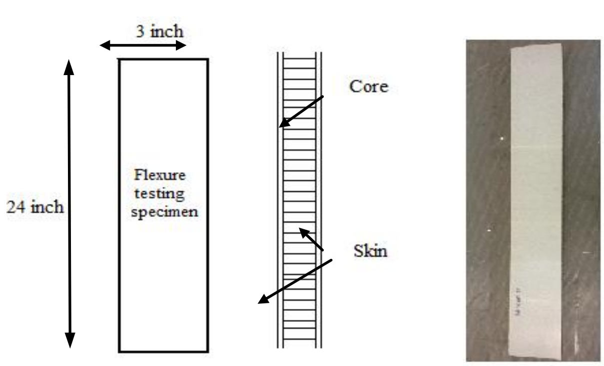


Figure 5 : Average peel strength of scored and unscored panels. Average peel strength decreases after 2.4 mm width of cut.

Long beam flexural Test (4 Point loading)

This test determines the flexural strength of flat sandwich panels. Specimens were visually checked for dimensional accuracy using a vernier calliper. Flat specimens were subjected to bending moment normal to plane of specimen.



(a) (b)

Figure 6 : Flexure test specimen

Four point bending test provides two support points and two loading points. Long beam flexural test fixture was placed on the Universal Testing machine (UTM). Along the 24 inch length, supports were provided with a span of 22 inch (558.8 mm) and the loading nose span length was 4 inches (101.6 mm). Marking lines were provided on the loading and supporting points to ensure the right type of loading for the defined span. Load was provided at a cross head speed of 0.25 in. /min (6 mm /min)[7] so as to produce a failure within 3-6 minutes. The load-deflection curve was monitored to find the maximum load of the specimen and also to detect any initial failure. Thus the maximum load of the specimen was noted down for various widths of scoring .Values of length, width, thickness and maximum load enable us to calculate the flexural strength according to[7]

$$F_S = P_{max} / ((d+c)\, b) \qquad (2)$$

Where F_S is the ultimate flexural strength, the maximum load before failure is (P_{max}), sandwich thickness is (d), thickness of the core is (c) and the sandwich width is (b). Specimens failing at some flaws were discarded and not considered for analysis.

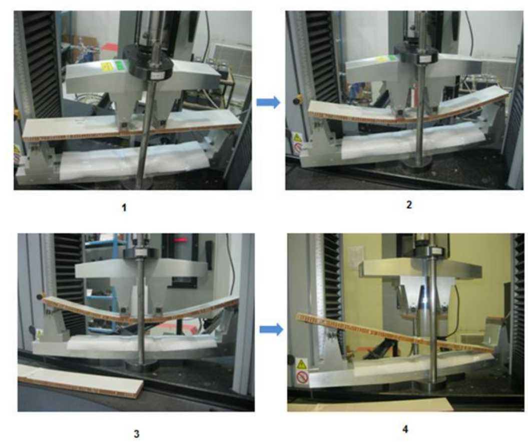


Figure 7 : Sequences of the long beam flexural test

Below table shows the flexural strength for various scoring widths.

Table 2 : Flexural strengths of unscored and scored specimens

	Results of Specimens Without Scoring		Results of Specimens With Scoring		
	Flexural Strength (MPa)	Average Flexural strength(MPa)	Scoring Width (mm)	Flexural Strength (MPa)	Average Flexural strength(MPa)
Long Beam Flexural Test	290.13	259.50	0.10 mm	254.83	243.21
	262.83			233.80	
	225.94			240.70	
	243.94			237.04	
	274.69			249.66	
	262.76	275.71	0.45 mm	244.21	246.38
	255.52			249.93	
	309.30			244.01	
	313.02			243.32	
	237.94			250.42	
	254.40	281.18	1 mm	242.07	242.23
	296.82			229.11	
	299.72			255.38	
	306.75			243.45	
	248.21			241.11	
	295.44	282.26	2.4 mm	242.07	245.38
	256.90			224.70	
	295.37			264.48	
	290.13			244.07	
	273.45			251.59	
	284.89	272.07	4 mm	206.22	198.79
	243.59			202.22	
	285.72			203.53	
	301.44			185.12	
	244.69			196.85	

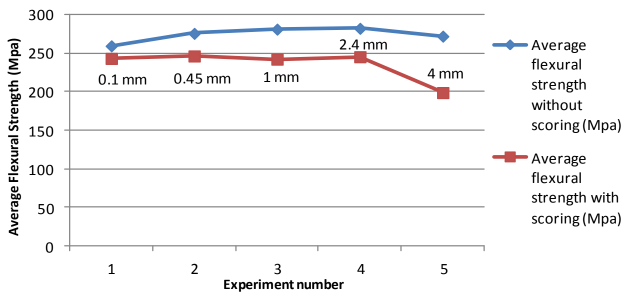


Figure 8 : Average flexural strength of scored and unscored panels. Scored panels show lower flexural strength than unscored panels. Failure after 2.4 mm width of scoring reduces flexural strength..

Conclusions

1. Drum peel test specimen results of the various scored specimens showed an improvement in the value of the drum peel strength (average improvement observed from(1.3 Nm/0.0254 m to 1.8 Nm/0.0254 m)over the unscored drum peel specimens.
2. Specimens having different scoring widths were tested and it was observed that the scoring width does not have a significant impact on the peel strength, up to a certain scoring width of 2.4 mm. After 2.4 mm, the test results showed a decrease in the peel strength values.
3. As expected and as it was observed, scoring reduces the flexural strength of the test specimens compared to non-scored specimens, as scoring reduces the surface area of adhesion between the core and prepregs . Flexural strength of the 4mm width scored specimens showed the least strength compared to other widths. Also, after a certain point of increasing the scoring width, the test values exhibited a decrease in flexural strength

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