EXPLORING THE FLEXURAL AND ADHESION BEHAVIOR OF COMPOSITE SANDWICH PANELS MADE OF RECYCLED FOAMED POLYPROPYLENE CORE AND GLASS/PP SKINS

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Abstract

Thermoplastic sandwich panels are gaining more attentions in automotive and construction applications since they can be readily formed into the light weight complex structures with high flexural rigidity. In this experimental study, the effect of using a solid-surface polymer foam as the core material on the mechanical and physical properties of composite sandwich panels was investigated and results were compared with a typical PP honeycomb sandwich panel with the same thickness. Recycled polypropylene (RPP) was foamed using an exothermic foaming agent through an extrusion process and sandwiched between two composite thermoplastic skins to make the sandwich panel. The core material is composed of recycled polypropylene and shreds of recycled Glass/PP. A commercial exothermic foaming agent was used to liberate gas inside the extruder and produce foam. Commingled E-Glass/polypropylene woven fabrics are used as the face sheets. Results of the flexural tests (3-point bending) indicate that the RPP foam sandwich panels show better flexural performance comparing with the honeycomb sandwich panels because of their high-stiffness core material. Also, results of the peel-off test show that the bonding strength between the core and face sheets of the honeycomb sandwich panel is slightly lower than that of the RPP foam sandwich panel due to the lattice structure of honeycomb core and less contact area between the core and face sheets.

1. Introduction

Composite sandwich panels are used in a wide range of application such as aircraft, aerospace, marine, automotive, and civil industries because of advantages such as high specific strengths. Typically, sandwich panels consist of two relatively high strength face sheets bonded to a relatively thick, low density and low strength core. Thus, the sandwich structure is characterized by a high flexural strength with reduced weight.

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Among the thermoplastic core materials for manufacturing sandwich panels, honeycombs are so popular due to their superior properties, such as light weight, rot resistance, recycling ability and thermal insulation. However, honeycombs are expensive materials requiring a sophisticated fabrication process. Moreover, honeycomb sandwich panels are more susceptible to delamination under the bending loads compared with the rigid core sandwich panels. Considered in most of experimental and numerical studies, debonding and delamination are the most important failure modes in composite sandwich panels [1-2]. The load carried by sandwich structures continues to increase after core yielding. Knowing that the core could not carry additional load after yield, this increasing load carrying capacity of post yield sandwich structure initiates the postulation that the additional shear load was transferred to the face sheets [3]. If the applied shear stress on the core material exceeds its ultimate shear strength, the sandwich structure will fail and is not able to carry the higher load. This is the case which commonly occurs in honeycomb sandwich panels since they are not strong materials under the shear stress. Solid-surface polymeric foams could be a good alternative since they have higher shear strength. Also, increasing the effective contact area to bond with thermoplastic skins makes this type of sandwich panels more resistant to delamination and provides higher adhesion strength [4-5]. In this experimental study, the flexural and adhesion behavior of RPP foam sandwich panels was compared with a typical polypropylene honeycomb sandwich panel based on the classical theory of sandwich panels [6-8] and the criteria for choosing a proper core material based on the application and panel thickness is represented.

2. Experimentation

The recycled polypropylene (RPP) foam sandwich panels were produced using our innovative in-line extrusion process described in our previous work [5]. In order to compare the mechanical performance of our recycled foam sandwich panels with honeycomb panels, a 3-point bending test was performed on two similar samples made of RPP foam sandwich panel and a typical honeycomb sandwich panel with same thickness of the core and facesheets. Also, a roll peeling test was carried out to determine the bonding strength between the core and skins for these two types of sandwich panels.

2.1. Materials

A recycled foam sandwich panel made of 6 mm thick PP foam extrudate and 1mm TWINTEX skin was compared with honeycomb sandwich panel. Honeycomb sandwich panel with the core thickness of 6 mm and skin thickness of 1 mm was produced using the innovated and fully automated machine in “AS Composite Inc.”. The core material is a polypropylene honeycomb with the nominal density of 80 kg/m^3 and cell size of 8 mm.

The RPP used in this study was a random copolymer grade of industrial recycled scraps. The density and melt index of this PP were 0.82 g/cm^3 and 11 g/10 min at 230 °C (ASTM D 1238), respectively. A high melt strength polypropylene (HMS-PP) was also added to enhance the stability of polymer melt and let the bubbles to grow and form the foam cells. A chemical foaming agent (CFA), Azodicarbonamide (EV AZ-3.0), was added into the PP pellets in 5wt%. So the starting material for extruding the RPP foam core is composed of 70/30 wt% PP/HMS and 5% CFA.

The commercial name of the thermoplastic skins we used is TWINTEX TPP Fabrics (Glass PP Natural, 60 %). TWINTEX is a roving made of commingled E-glass and polypropylene filaments.

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2.2. Experimental Procedure

Both honeycomb and RPP foam sandwich panels are fabricated under the same lamination temperature and pressure. The lamination process is done under a pressure applied by the squeezing rollers of the conveyor double belt press machine [5]. The vertical distance between the rollers is set 1 mm less than the total thickness of the core and skins so that it could squeeze the sandwich panel and apply enough pressure to bond the skin to core. The lamination temperature is around 150 °C for both of the above samples.

Figure 1 shows two similar samples made of RPP foam sandwich panel and honeycomb sandwich panel with same core and facesheet thickness under the 3-point bending test. This test was carried out based on the standard ASTM D790 [9]. A roll peeling test was also performed based on the standard ASTM D 3167 [10] to determine the bonding strength of these samples.

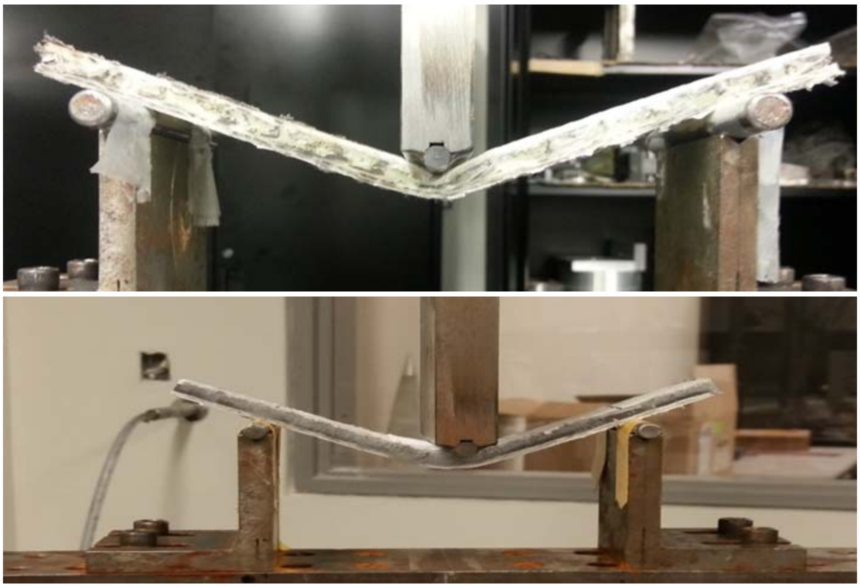

Figure 1. A view of honeycomb and RPP foam sandwich panels under the bending test

3. Results and Discussion

3.1 Flexural Behavior

Results of the 3-point bending test show that the mechanical behavior of recycled sandwich panel under 3-point bending test is completely different from the honeycomb sandwich panel. A drastic reduction in the applied force (stress) is evident in case of honeycomb while there is no such thing in case of recycled sandwich panels. It could be due to the skin delamination in honeycomb panel while there is no sign of fracture or delamination in RPP foam sandwich panels. In other words, honeycomb sandwich panel is more potential to be delaminated under the 3-point bending because of its lattice structure of hollow cells results in a poor bonding between skin and honeycomb. Unlike the honeycomb panels, the RPP foam sandwich panel is relatively strong in terms of core to skin bonding due to the high effective contact area between the core and skins. The most probable reason for flexural failure in RPP sandwich panels (if occurs) is due to the fracture in the core material not the skin delamination.

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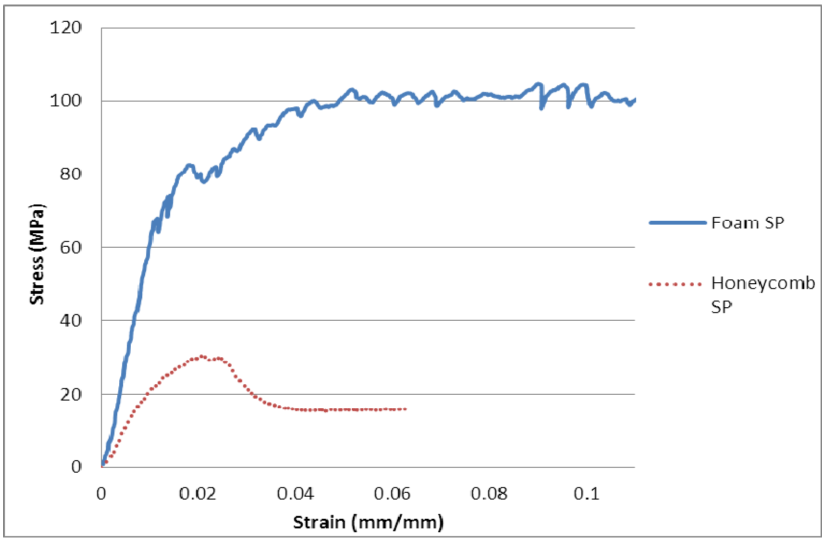

Figure 2. Stress-Strain curve for honeycomb and recycled PP foam sandwich

Table 1. Density and flexural properties of honeycomb and recycled foam sandwich panels

Sample	Bending Modulus E_{avg}(Gpa)	Bending Strength S_{avg}(Mpa)	Core Density (kg/m^3)	Panel Density (kg/m^3)	Specific Strength (10^3 m^{2}s^{-2})
Foam SP (8mm thick)	3.200	100	450	700	143
Honeycomb SP (8mm thick)	2.350	30	90	430	69

Results of the density and bending tests show that the flexural strength of RPP foam sandwich panels is about 3 times stronger than the honeycomb sandwich panel with the same dimensions but they are higher in weight compared to the honeycomb. The RPP foam core extrudate is about 5 times heavier than honeycomb core but when they are sandwiched with thermoplastic skins, for high skin-to-core thickness ratios (t/c>1/5), the skins' weight has a considerable effect on the total weight of the sandwich panel. Therefore, the RPP foam sandwich panel of 8 mm thickness is just 1.7 times heavier than the honeycomb sandwich panel with the same thickness. Altogether, the specific strength of RPP foam sandwich panel is about 2 times higher than that one for the honeycomb sandwich panel.

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However, for low-weight and high-thick sandwich panel applications, there is a remarkable difference between the weight of honeycomb and RPP foam sandwich panels and using honeycomb core is more recommended for t/c<1/10.

We have also calculated the maximum values of flexural and shear stress in the core and facesheet of honeycomb and RPP foam sandwich panels based on the theory of sandwich panels [6]. The amount of applied force and sample dimensions are obtained from the 3-point bending test. Figure 3 shows the specific strength of honeycomb and RPP foam sandwich panels for different skin to core thickness ratios. Also the results of stress distribution and panel density are represented for these two types of sandwich panels (Table 2).

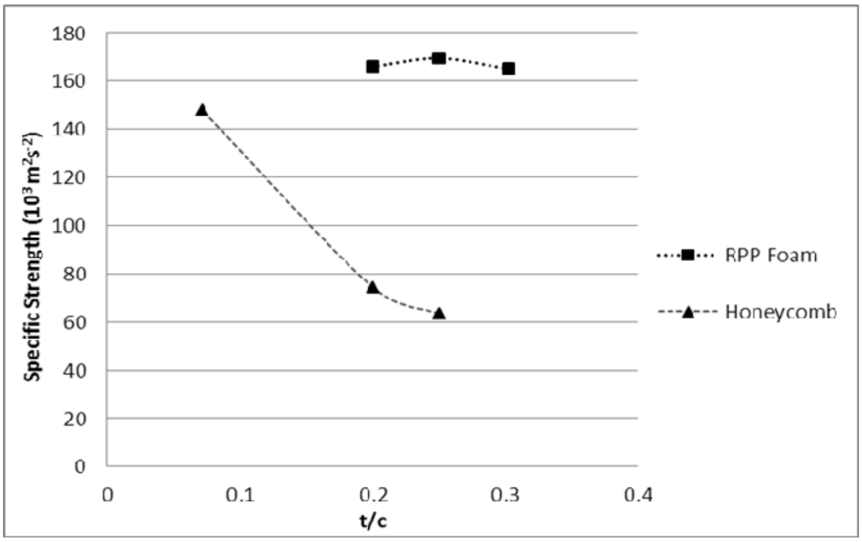

Figure 3. Specific strength of honeycomb and RPP foam sandwich panels

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Table 2. Effect of skin and core thickness on density and mechanical performance of honeycomb and recycled foam sandwich panels

Sample	Core (c) (mm)	Skin (t) (mm)	t/c	Density (kg/m^3)	$(\sigma_c)_{max}$ (MPa)	$(\sigma_f)_{max}$ (MPa)	$(\tau_c)_{max}$ (MPa)	Specific Strength (10^3 m^{2}s^{-2})
Honeycomb Sandwich panel	5	1	1/5	500	0	37.2	0.5	74.4
	6	1.5	1/4	550	0	34.9	1	63.5
	28	2	1/14	280	0	41.4	0.1	147.8
RPP Foam Sandwich Panel	5	1.5	1/3.3	825	6.2	136.0	3.5	165.0
	6	1	1/6	700	6.4	118.6	2.2	169.4
	7	1	1/7	670	5.9	111.2	2.0	166

The flexural modulus of honeycomb is assumed to be zero which is practically true compared to the skin material and the ultimate shear strength of the honeycomb we used is 0.5 MPa while this value is about 25 MPa for PP. Thus, as seen in Table 2, for low-thick sandwich panels (Sample 1 and 2), honeycomb will fail due to the exceeding shear stress in the core, so it is not able to undertake higher bending load. A failure in honeycomb core is evident in Figure 4 while there is no sign of fracture in RPP foam core. Moreover, the low-thick honeycomb panels are relatively high-density products since the skin effect will be dominant which results in low specific strength of the structure. For low-thick sandwich panel applications, RPP foam sandwich panels offer better mechanical performance with a specific strength of about 2.5 times more than honeycomb sandwich panels.

Figure 4. A view of honeycomb and RPP foam sandwich panels after the bending test

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3.2 Adhesion Behavior

A roll peel-off test was carried out to compare the bonding strength of skin-to-core for both the honeycomb and RPP foam sandwich panels and results are represented in Figures 5.

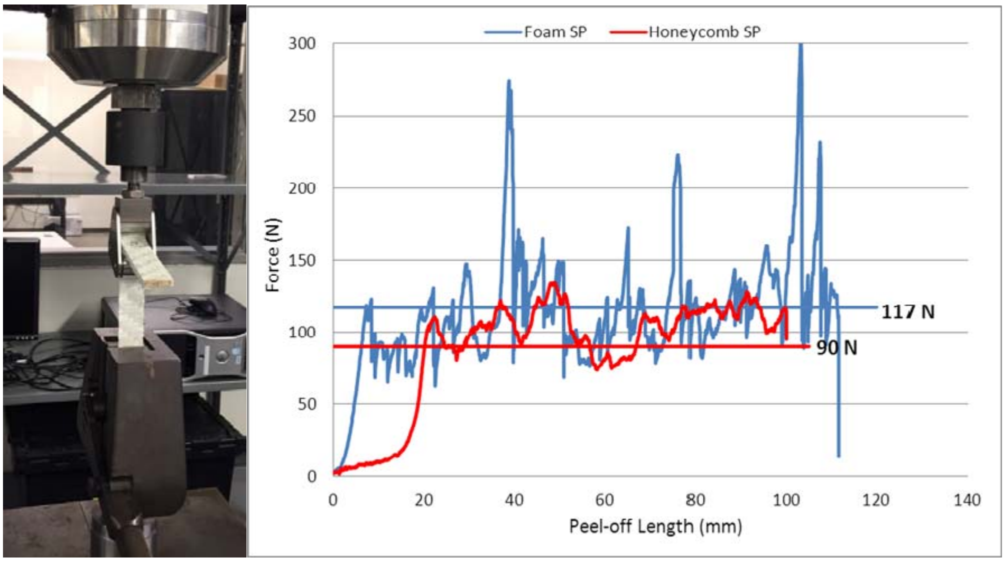

Figure 5. Results of the peel-off test for RPP foam and honeycomb sandwich panels

As seen in Figure 4, the applied force for peeling the skin of a honeycomb sandwich panel is less than that one for RPP foam sandwich panel. The average peeling force for honeycomb sandwich panel is about 77% of RPP foam sandwich panel. The reason is due to the lattice structure of honeycomb which creates a small contact area to bond with the skin. Figure 6 shows the honeycomb and RPP foam sandwich panels after the roll peel-off test. As illustrated in Figure 6, the effective contact area between the core and skin of honeycomb sandwich panel is much smaller than a solid-surface core material like our RPP foam extrudate.

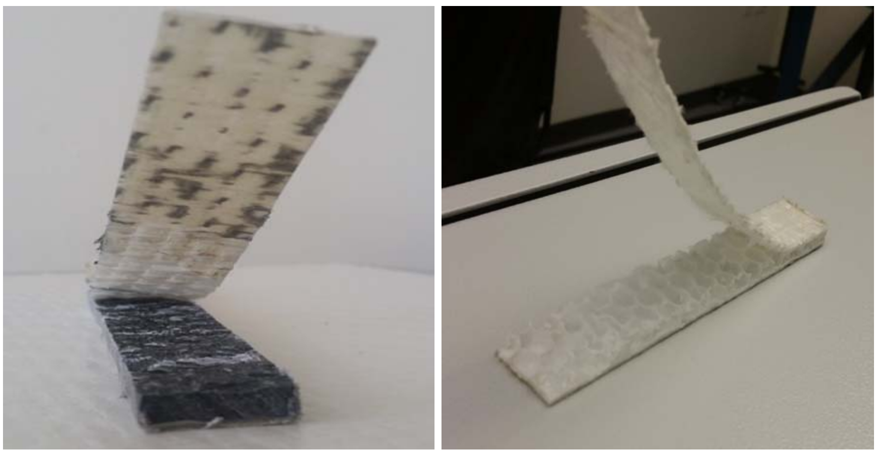

Figure 6. RPP foam extrudate (left) and honeycomb (right) sandwich panels used for peel-off test

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4. Conclusion

Comparing our low-density foam sandwich panel with a honeycomb sandwich panel of same thickness reveals that the RPP foam sandwich panels offer better flexural performance (higher specific strength) and higher adhesion strength. However, for low-weight and high-thick sandwich panel applications, there is a remarkable difference between the weight of honeycomb and RPP foam sandwich panels and using honeycomb core is more recommended for $t/c<1/10$.

The adhesive strength between the core and face sheets of the honeycomb sandwich panel is lower than that of the RPP foam sandwich panel due to the lattice structure of honeycomb core and less contact area between the core and face sheets.

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