

# THERMOPLASTIC COMPOSITE SANDWICH PANELS

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## **Abstract**

Thermoplastic composites are attractive for automotive applications since they can be rapidly formed into low cost complex structures with good impact strength and flexural rigidity. The properties of these composites can be enhanced while reducing basis weight through the use of sandwich structures. This paper will illustrate the extent of enhancement achieved through the use of thermoplastic composite skins combined with lower density thermoplastic cores. Glass mat reinforced polypropylene (GMT) with a thickness of 3.8 mm and a glass content of 40 wt % will be used as a baseline for assessing the performance of sandwich panels. Skins will include GMT as well as aligned fiber reinforced laminates. Both honeycomb and foam cores will be evaluated. Flexural rigidity will be presented and impact properties will be based on instrumented drop impact testing.

## **Introduction**

Composites are noted for providing weight savings in structural and impact applications compared to traditional materials. Thermoplastic composites offer further benefits since they can be processed easily by thermoforming and they can be recycled. By employing composites in sandwich panels further savings in weight may be realized

without sacrificing rigidity and toughness.

Thermoplastic composite sandwich panels are being considered for automotive applications. In his introduction to Venture's "SANDWIFORM" panels, Bradish(1) cited six examples: underbody load floors, engine shields, trunk panels, back rests, skid plates and bumpers. These applications require both rigidity and toughness.

In this paper the impact and flexural behavior of a variety of thermoplastic composite sandwich panels is presented. The properties of these sandwich panels are compared with equivalent properties for a baseline glass mat reinforced thermoplastic (GMT). Sandwich panel constructions are presented which have improved impact strength and flexural rigidity compared to GMT without increasing basis weight.

## **Materials**

A variety of skin and core materials have been evaluated. The baseline GMT is GCOMP<sup>®</sup> 40 produced by Georgia Composites, Inc.. Properties of a GCOMP<sup>®</sup> 40 laminate are shown in Table 1. The same material has been used for the face sheets for sandwich panels. In order to assess the effect of skin thickness on performance the basis weight of the GCOMP<sup>®</sup> 40 skins has

been varied from 500 to 1,500 g/sq. m.. In order to consider the effect of glass content GCOMP<sup>®</sup> skins with 40 and 50 % glass and the same basis weight of 1,000 g/sq.m. have been studied. In order to study the effect of glass fiber alignment skins containing consolidated Twintex<sup>®</sup> fabrics have been prepared. The properties of the Twintex<sup>®</sup> fabric are shown in Table 2.

Both honeycombs and foams have been evaluated as cores. Polypropylene honeycombs from Plascore, Inc, see Table 3, were studied extensively. This choice was based on the availability of these cores when this study began. The properties reported for the PP30-5-1 were provided by Plascore (2).

Descriptions of the other cores are presented in Table 4. The properties of these cores are not included in this paper but are available from the core suppliers (3). For these cores a range in densities, 1.7 to 6.9 pcf (lb/ft<sup>3</sup>), thicknesses, 0.24 in. to 0.59 in., structure and properties are evaluated to provide information for selecting cores to meet specific application requirements.

## **Experimental**

Most of the sandwiches were fabricated as 12 in. by 12 in. panels using two compression presses with 18 in. by 18 in. platens. The first press was used as a hot plate. A sheet of Teflon or Teflon coated glass fabric was placed on the hot platen with a consolidated skin on top. The platen temperature was set sufficiently high to melt the skin, usually 420 °F. Once hot the core Teflon and skin were moved to a cold press and immediately contacted with the core. The minimum force available for the 50

ton Wabash press was used to maintain a contact pressure between 5 and 10 psi. This process was repeated to bond the second face to the core.

The flexural testing was conducted in accord with ASTM D 790 for the solid samples and in accord with ASTM C 393 for the sandwich panels using an Instron 4466 mechanical testing machine. Three point bending was used. The crosshead movement was used to calculate deflection. A cut rubber tube was placed over the central loading nose to minimize localized crushing of the skins. The initial portion of the load-deflection curve was not considered in the analysis since it includes the deformation of the rubber. The span/depth ratio was set close to 20 to minimize crushing and excessive shear deformation. The testing rate was set at 0.1 in./min for the sandwich panels.

The impact testing was conducted according to ASTM D 3763 using an Instron Dynatup<sup>®</sup> 8250. The impact velocity was set at 11 ft/s (7.5 mph) and the impact energy was set at 61 ft-lb (83J), well in excess of the impact energies of the samples. The hardened steel impact tup was 0.5 in. in diameter.

## **Results and Discussion**

The first issue considered is the quality of the fabricated sandwich. If the skins separated from the cores easily by hand the sandwich was rejected. If too much heat reached the cores the cores would collapse. For the samples tested the average core thickness reductions are shown in Table 5. Some reduction is expected if the core starts to merge into the skins; however, more than 15 % thickness reduction tends to defeat the

purpose for creating a sandwich structure.

The baseline material is the solid GCOMP<sup>®</sup> 40 with the properties shown in Table 1. The properties in Table 1 is for a 0.142 in. thick sample. A thicker sample, 0.179 in thick, had a higher flexural strength (19,400 psi), virtually the same modulus (940,000 psi) and higher impact energy absorption (32 ft-lb). The flexural properties of solid samples should be independent of the sample dimensions, which is true for the modulus within experimental error. It is reasonable that the strength is somewhat lower in the thinner sample if there is no difference in flaw size. The impact energy absorption has not been corrected for sample thickness. It is expected to increase with thickness. This trend will be discussed later.

The flexural properties of the sandwich structures are difficult to report since modulus and strength values are not appropriate. The input and output information for sample PLAS1-S3-A is presented in Table 6. The maximum load is indicative of failure of the specimen. From this value the maximum shear stress in the core can be calculated as well as the maximum face stress. In this sample, as in most, the limiting shear stress in the core and the failure stress in the face are not reached. In accord with this behavior the first sign of failure noted is delamination at the face/core interface. This interface is usually the weakest link. The slope calculated at 10 pounds is indicative of the sample rigidity. From this slope the apparent rigidity of the sandwich can be calculated. For a solid sample this apparent rigidity is the product of the modulus of the sample times its moment

of inertia. For a sandwich panel it includes bending the face sheets, shearing the core and any interfacial slippage; hence, it is quite dependent on the specific sample. Assuming the modulus of the face sheets can be inferred from solid laminate properties of the same material, then the slope can be used to estimate the shear modulus of the core. In this case the estimate of 1,500 psi is reasonably close to the reported core shear modulus of 2,000 psi. It is reasonable that it is lower because there is some interfacial compliance which is not considered in the calculation of the shear modulus from the data.

Figure 1 illustrates how the experimental response compares with the elastic model used in ASTM C 393 with a core shear modulus of 1,500 psi. The model predicts a linear response; hence, there is significant deviation as the sample approaches its failure load. It is encouraging that the linear elastic model does represent a substantial portion of the load-deflection response of the panel. Thus, this model will be used later to adjust panel dimensions to permit comparisons among panels with reasonable dimensions.

It is interesting to note the differences in flexural rigidity of this sample, PLAS1-S3-A, compared to the solid GCOMP<sup>®</sup> 40 sample with a thickness of 0.142 in. The flexural rigidity has increased from 323 lb-in<sup>2</sup> to 1,323 lb-in<sup>2</sup> even though the basis weight has dropped from 4,400 g/m<sup>2</sup> to 3,700 g/m<sup>2</sup>. Both rigidities are based on 1 in wide samples. The benefit in rigidity is due to the increased thickness.

Table 7 summarizes the experimental shear moduli and shear stresses obtained from the sandwich panels tested. These values were obtained in the same manner as illustrated for sample PLAS1-S3-A. The core densities and thicknesses are prior to fabricating the panels. The core thickness reductions are reported in Table 5. The reduced core thicknesses lead to an increase in core density. In general the Plascore panels had relatively high shear moduli and reached relatively high shear stresses when the panels failed. In most cases these Plascore sandwiches failed by delamination at the interface. The panel with the thick core from Plascore exhibited some signs of crushing. Failure by core shearing was not observed.

The panels with the other types of cores have not been tested as extensively as the panels with cores from Plascore - the sample numbers are in Table 5. Therefore the results for these cores are only preliminary. The Nida-Core<sup>®</sup> and Wavecore<sup>®</sup> samples delaminated; hence, the properties reported aren't necessarily representative of the capabilities of these cores. The HEXWEB-ER<sup>®</sup> core exhibited progressive delamination for the one sample tested to date. One of the paper cores exhibited a relatively high apparent shear modulus, but the sample delaminated at a relatively low load. The results from the one Strandfoam<sup>®</sup> panel are promising; however, some core crushing occurred at failure. The urethane core exhibited the highest core thickness reduction, 74 %, during panel fabrication and the apparent core modulus is low. It failed by core crushing. An alternative urethane foam is being evaluated.

The impact properties for GCOMP<sup>®</sup> 40 laminates with different thicknesses are summarized in Figure 2. The energy absorbed up to the maximum load is primarily elastic deflection and crack initiation. The total energy includes crack propagation through the sample as well as the energy absorbed up to the maximum load. The difference between these two energies is primarily crack propagation. The crack propagation appears to vary linearly with thickness. The elastic deflection is expected to depend on the thickness cubed and the crack initiation should not depend on thickness. Therefore the energy up to the maximum load should have a nonlinear increase with thickness as shown in Figure 2.

The impact performance of the Plascore panels is shown in Table 8. The total energy absorption for the first panel is low, 5.17 ft-lb, in comparison to the GCOMP<sup>®</sup> 40 base sample with an impact energy of 22 ft-lb for a 0.145 inch thick laminate. If just the skins for sample 1 are considered the impact energy absorbed is less than what is expected based on the total energy curve versus thickness shown in Figure 2. If the total energy absorbed for sample 1 is normalized to match the basis weight of the base laminate, the normalized total energy is still well below the target of 22 ft-lb. One reason for the low performance of sample 1 is the 0.5 inch tup (impactor). If the tup contacts the skin where it is not supported by the honeycomb cell wall the failure process could initiate sooner and propagate with greater ease. Thicker skins and a larger diameter tup should lead to higher impact energies. Impacts with larger diameter tups will be explored.

Sample 2 exhibited better impact performance than sample 1 even though the basis weight of the skin is less. The glass content in the skin has been increased to 50 %. Also, this skin contains a glass veil in which the glass fibers are completely separated. Both these features could be contributing to the improved impact behavior.

Sample 3 is a sandwich panel which exhibits better impact energy absorption than the GCOMP<sup>®</sup> 40 base laminate as well as a slightly lower ( 2 %) basis weight. In addition to the GCOMP<sup>®</sup> 50, the skins have a Twintex<sup>®</sup> fabric. The extra glass and thicker skins clearly help improve the energy absorption.

Sample 4 is like sample 2 but has a thinner core. There is a slight improvement in energy absorption with the thinner core, but this change is within experimental error.

Sample 5 has skins somewhat similar to sample 3 but thinner. Also, the core is much thicker. The energy absorption in sample 5 is less than sample 3. Thus, there appears to be a threshold skin thickness or glass content that is needed in order to achieve an impact performance in these sandwich panels better than the base GCOMP<sup>®</sup> 40 panel. It is noteworthy that sample 3 did exceed the base in impact performance and also has a flexural rigidity 20 times greater than the base.

The influence of different types of cores on impact performance is shown in Tables 9 and 10. The cores in Table 9 are all honeycombs whereas the cores in Table 10 are foams. While there are differences in impact response among

these samples, a better comparison could be made with thicker skins.

## Conclusions

A wide range of thermoplastic composite sandwich panels have been fabricated and tested to assess their rigidity and toughness. Using a 0.145 inch thick recycled polypropylene laminate reinforced with 40 weight % random glass mat as a basis, substantial improvements in flexural rigidity have been achieved through the use of sandwich panels. The flexural response of the panels was represented well by an elastic deflection model with an "adjusted" core shear modulus. This adjustment is attributed to interfacial compliance between the core and skins. Most of the panels failed by delamination.

The impact response of most of the panels was less than the base laminate. One panel did perform better than the base laminate with no increase in weight. This panel had thicker skins and more glass content than any of the other panels. Also, this panel had a flexural rigidity 20 times greater than the base laminate.

At this time the comparison of the impact response of panels with different cores is not conclusive. Panels with thicker skins and higher glass contents will be studied. Also, the use of larger diameter tups will be evaluated.

## References

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Table 1  
Properties of GCOMP<sup>®</sup> 40

Source:	Georgia Composites, Inc.
Glass:	40 wt %, chopped mat, 2 inch length
Polypropylene:	recycled
Flexural Strength (ASTM D 790):	17,800 psi (123 MPa)
Flexural Modulus(ASTM D 790)::	935,000 psi (6.4 GPa)
Impact Energy(ASTM D 3973):	22 ft-lb (30 J)

Table 2  
Properties of Twintex<sup>®</sup> Fabric (4)

Source:	Saint-Gobain Vetrotex America, Inc.
Glass:	60 wt %, continuous, 2 X 2 twill weave
Polypropylene:	virgin
Flexural Strength:	43,500 psi (300 MPa)
Flexural Modulus:	1,740,000 psi (12 GPa)
Impact Energy:	74 ft-lb (100J)

Table 3  
Properties of Plascore<sup>®</sup> Polypropylene Honeycombs (2)

Identification:	PP30-5-1
Description:	0.30 in cell size, circular shape, no facings
Density:	5 pcf (lb/ft <sup>3</sup> )
Compression Strength.:	235 psi (1.62 MPa)
Compression Modulus.:	10,500 psi (72.3 MPa)
Shear Modulus.:	2,000 psi (13.8 MPa)
Tensile Strength.:	175 psi (1.21 MPa)
Cores used:	PLAS1: thickness = 0.32 in, density = 5.3 pcf PLAS2: thickness = 0.24 in, density = 5.4 pcf

Table 4  
Additional Cores

Honeycombs

NIDA1:	Nida-core <sup>®</sup> , PP, hexagonal, thickness = 0.51 in., density = 6.9 pcf
WAVE1:	Wavecore <sup>®</sup> , PP, rectangular, thickness = 0.32 in., density = 2.7 pcf
HEXL1:	HEXWEB-ER <sup>®</sup> , hexagonal, thickness = 0.32 in., density = 3.8 pcf
PAPR1:	Paper, hexagonal, thickness = 0.58 in., density = 2.2 pcf
PAPR2:	Paper, hexagonal, thickness = 0.39 in., density = 1.7 pcf

Foams

STRN1:	Strandfoam <sup>®</sup> , circular, thickness = 0.51 in, density = 3.8 pcf
UTHN1:	Urethane (Woodbridge <sup>®</sup> 2525, uniform, thickness = 0.32 in., density = 2.5 pcf

Table 5  
Core Thickness Reductions

Honeycombs

PLAS1:	8 % (6 samples) (range: 0 to 24 %)
PLAS2:	6 % (6 samples) (range: 0 to 17 %)
NIDA1:	18 % (3 samples)
WAVE1:	36 % (2 samples)
HEXL1:	6 % (1 sample)
PAPR1:	18 % ( 1 sample)
PAPR2:	12 % ( 1 sample)

Foams

STRN1:	5 % (1 sample)
UTHN1:	74 % (1 sample)

Table 6

Flexural Test of PLAS1-S3-A

Input

Skins:	GCOMP <sup>®</sup> 40, 1,500 g/ sq. m., thickness = 0.048 in., E= 935,000 psi
Core:	Plascore <sup>®</sup> PP 30-5-1, thickness = 0.313 in., Shear Mod = 2,000 psi Core thickness in panel = 0.277 in ( an 11 % reduction)
Sample:	thickness = 0.373 in, width = 2.99 in ., span = 8.0 in.

Output

Maximum Load:	118.1 lbs
Maximum slope:	371 lb/in (tangent at 10 lbs, load vs deflection)
Max shear stress:	61 psi (less than the 75 psi reported for the core)
Max face stress:	5,100 psi (less than the 17,800 psi reported for the face)
Failure mode:	Delamination
Panel bend stiff:	7,100 lb-in <sup>2</sup> (pure bending)
Panel shear rigidity:	2,300 lbs
Shear modulus:	1,500 psi ( less than the 2,000 psi reported for the core)
Apparent Rigidity:	1,300 lb-in <sup>2</sup>

Table 7

## Effect of Flexural Testing on Apparent Core Properties

Core	Density pcf	Thickness in.	Shear	Properties
			Modulus psi	Stress psi
Plascore <sup>®</sup>	5.4	0.24	1,251	59
Plascore <sup>®</sup>	5.3	0.32	1,587	61
Plascore <sup>®</sup>		0.87	1,229	58
Nida-Core <sup>®</sup>	6.9	0.51	1,061	27
Wavecore <sup>®</sup>	2.7	0.32	737	42
HEXWEB-ER <sup>®</sup>	3.8	0.32	598	17
Paper	1.7	0.39	808	13
Paper	2.2	0.58	1,774	17
Strandfoam <sup>®</sup>	3.8	0.51	1,518	33
Urethane	2.5	0.32	187	48

Table 8

Impact Response of Plascore<sup>®</sup> Sandwich Panels

Sample Number	1	2	3	4	5
<u>Skin</u>					
GCOMP <sup>®</sup> 40, g/m <sup>2</sup>	1,500				500
GCOMP <sup>®</sup> 50, g/m <sup>2</sup>		1,000	1,000	1,000	
Twintex <sup>®</sup> fabric, g/m <sup>2</sup>			745		745
Skin thickness, in.	0.048	0.029	0.090	0.029	0.077
Sandwich thickness, in.	0.370	0.373	0.497	0.258	0.974
Basis weight, g/m <sup>2</sup>	3,800	2,900	4,300	2,700	7,000
<u>Impact Response</u>					
Max Load, lb	203	284	640	398	460
Energy at max., ft-lb	3.38	4.50	13.84	7.13	10.00
total energy, ft-lb	5.17	10.65	24.92	10.78	17.28
Relative Basis Weight	0.86	0.66	0.98	0.61	1.59
Normalized total E, ft-lb	6.0	16.2	25.5	17.6	10.9

Table 9

Impact Response of GCOMP<sup>®</sup> Panels with Different Cores

Sample Number	6	7	8	9	10
<u>Skin</u>					
GCOMP <sup>®</sup> 40, g/m <sup>2</sup>		1,000			
GCOMP <sup>®</sup> 50, g/m <sup>2</sup>	1,000		1,000	1,000	1,000
Core	Nida-Core <sup>®</sup>	Wavecore <sup>®</sup>	Hexweb-ER <sup>®</sup>	Paper	Paper
Skin thickness, in.	0.029	0.320	0.029	0.029	0.029
Sandwich thickness, in.	0.543	0.289	0.351	0.404	0.625
Basis weight, g/m <sup>2</sup>	3,500	2,400	2,700	2,400	2,700
<u>Impact Response</u>					
Max Load, lb	234	188	244	194	205
Energy at max., ft-lb	2.60	3.13	4.62	2.51	3.35
total energy, ft-lb	8.72	4.81	10.78	9.23	6.58
Relative Basis Weight	0.80	0.55	0.61	0.55	0.61
Normalized total E, ft-lb	11.0	8.8	17.6	16.9	10.7

Table 10

Impact Response of GCOMP<sup>®</sup> Panels with Foam Cores

Sample Number	11	12
<u>Skin</u>		
GCOMP <sup>®</sup> 50, g/m <sup>2</sup>	1,000	1,000
Core	Strandfoam <sup>®</sup>	Urethane
Skin thickness, in.	0.029	0.320
Sandwich thickness, in.	0.566	0.289
Basis weight, g/m <sup>2</sup>	3,100	2,400
<u>Impact Response</u>		
Max Load, lb	228	386
Energy at max., ft-lb	1.56	4.64
total energy, ft-lb	9.05	10.94
Relative Basis Weight	0.70	0.55
Normalized total E, ft-lb	12.8	20.1

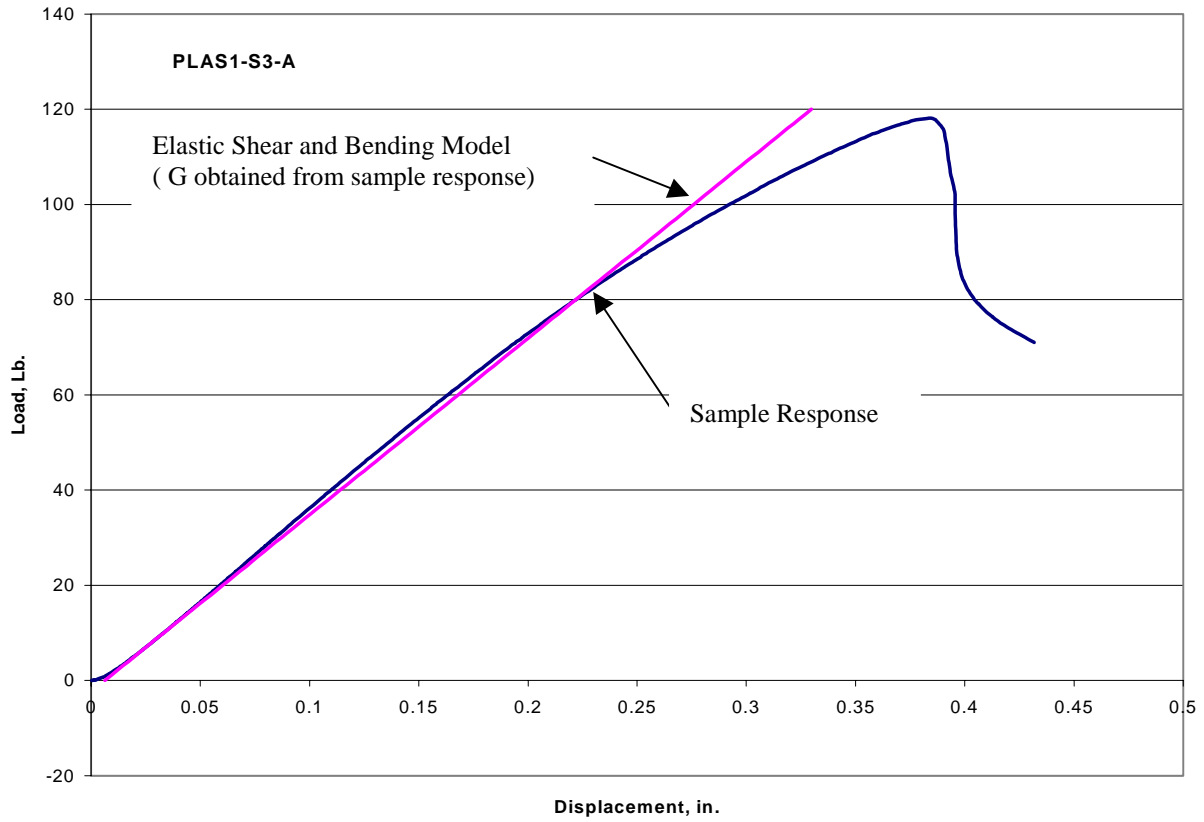


Figure 1 Load-Deflection Response of Sample PLAS1-S3-A in 3-Point Bending.

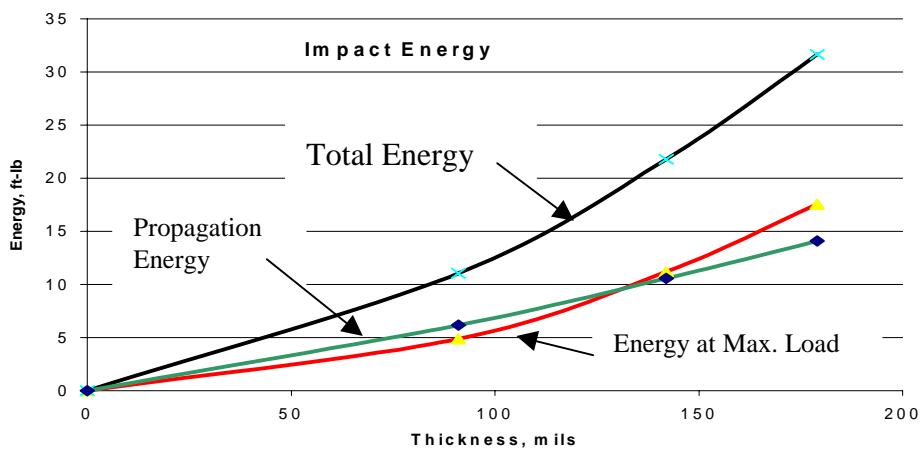


Figure 2 Impact Response of GCOMP<sup>®</sup> 40 Laminates