PROPERTIES AND APPLICATIONS OF SANDWICH PANELS BASED ON PET FOAMS

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Abstract

PET foams of variable densities, (1 g/cc to 0.2 g/cc), based on virgin and recycled material were produced by extrusion with physical or chemical blowing agents and evaluated as low density core in sandwich panels having M/F impregnated paper or flame retardant mineral reinforced PET as skin faces. Flexural and shear stiffness of the laminates were determined by variable span three point bending. Panels were also tested for thermal and moisture stability and compared with competitive sandwich constructions based on PVC foam, flake board, particleboard and plywood. Potential applications of the PET based laminates in building and construction are presented.

Introduction

The development of extruded polyethylene terephthalate (PET) foam products has been prompted by the favorable cost/performance characteristics, good mechanical properties, high temperature stability and recyclability of the semicrystalline resin. The lack of widespread use of PET foams, however, has been mostly related to difficulties arising from the required high processing temperatures, limited process stability, high initial density (approx. 1.4 g/cc), unfavorable rheology as a result of the low MW and narrow MWD of common PET resins, and slow crystallization.

Significant developmental work has been conducted over the past twenty years by resin producers and converters to develop suitable resins and foam extrusion processes, particularly for low density foaming. Medium-high density (>0.5 g/cc) foams are mostly produced in single extruder lines with chemical blowing agents (CBA's), but also with Physical Blowing Agents (PBA's) in equipment with long L:D. The process is relatively sensitive to resin rheology (1). Low-medium density foams (<0.5 g/cc) are produced in single or tandem lines equipped with ports for injection of PBA's - atmospheric gases, VOC's, HFC's, HCFC's. Since the process is particularly sensitive to resin rheology, chemical modification by chain extension/branching with multifunctional additives is often used to enhance foamability (2-4). Modified resins are characterized by high overall melt viscosity, virtual absence of a Newtonian region in their shear viscosity/shear rate curve, high shear sensitivity, and high melt "elasticity/strength" from criteria such as extrudate swell, G', extensional viscosity, melt tension (1,5,6).

Current applications of extruded foamed PET include thermoformable thin sheets intended for food packaging. Potential applications could include the use of PET foam in panels for building/construction, furniture and/or transportation. PET foams of different densities used as core in sandwich structures could compete with traditional foamed PVC, PS, PUR, P/F or honeycomb cores to produce stiff, strong, and lightweight structures. Such structures could also compete with the widely used structural plywood products for both indoor and outdoor applications. In sandwich construction a suitable core is characterized by its ability to withstand the shear stresses set up by the external forces and stabilize the facings against wrinkling and buckling.

The data reported in this article are part of a multiyear R&D project funded by the NJ Commission on Science and Technology and industrial partners. Specific activities during the first phase of the study, reported in our earlier presentations/publications, (1, 5-9), were aimed at:

- Relating the melt rheology of a variety of PET resins, (including virgin materials for comparison, recycled and post-reactor modified), to their extrusion foaming characteristics with PBA's and CBA's,
- Producing foam core PET sheets of variable densities that would be laminated in sandwich structures

In this paper we report on the fabrication of sandwich laminates containing recycled and virgin foamed PET core and present data on the bending characteristics and dimensional stability of prototypes as compared with competitive materials including other commercial polymeric foams and wood panels.

Experimental

PET Extrusion Foaming

PET foams were prepared from a variety of materials including neat resins of different intrinsic viscosities and recycled materials that had been chemically modified for enhanced foamability. Details on the experimental procedures may be found in Refs. (5,7,8). Commercially available foams were also used.

High density (>0.8 g/cc) foamed sheets (up to 1.5 mm thick) were extruded in flat sheet dies. Foams from recycled low IV (0.6-0.7) resins, capped with a very thin unfoamed layer were produced in a Welex co-extrusion line. 1-3 phr CBA (Safoam RPC-40, Reedy Intern. or Expandex 5PT, Uniroyal Chem.) and 10-15 phr rheology modifiers, (reactive ethylene copolymers e.g. Lotader, Atochem, or chain extended/branched PET resins, e.g. Cobitech, Sinco Eng.), were used.

Low-medium density (0.8-0.2 g/cc) sheets (up to 1.5 mm thick) were produced in a segmented 32 mm dia. single screw extruder (Killion) by injecting atmospheric gases (carbon dioxide, argon or nitrogen). High IV (>0.9) resins were used including linear polymers and branched resins, the latter based on recycled materials after chemical modification. In addition, commercially available foamed sheets (Petlite, Shell) were also used.

Very low-density (<0.2 g/cc) boards up to 25 mm thick were also used for comparison. They were prepared by Sinco Engineering from chemically modified high IV resin, through PBA injection.

Lamination/Testing

Sandwich laminates (up to about 25 mm thick) having a foamed core and thin layers of commercially available impregnated M/F paper or extruded sheets of glass reinforced flame retardant PET grades as facings were prepared by press or oven lamination at about 150°C. A dry thin adhesive film (Dribond, Eastman Chemical Co.), was used to bond the facings to the core.

Foamed cores included multilayered and single layered PET of different densities, a single layered commercial PVC board (Polyboard), a semirigid bilayered commercial polyisocyanurate (PIC) foam (Celotex) after removing the aluminum foil faces and a commercially available monolayer polystyrene (PS) foam (Owens Corning). A variety of commercially available wood panels (CDX FIR plywood, Oriented strand, industrial flakeboard, MD. fiberboard, particle board) were also used as core materials for comparison.

Preparation of the multilayered PET foamed core involved the use of several thin sheets pressed for different time periods, (depending on the type of material), under low pressure to build the required thickness. Samples were then slowly cooled under pressure. For extruded sheets with crystallinity exceeding 10%, lamination was assisted by incorporating the dry thin adhesive film within the layers. Additional crystallization during lamination resulted in samples with final crystallinity of 25-30%.

Flexural properties of the laminates were determined by three point bending of samples about 1.2 cm wide at fixed and variable span to depth ratios ranging from 6:1 up to 16:1. Stress at failure was calculated from the tensile and interlaminar shear, ILS, (when applicable) formulae for isotropic beams. Dimensional stability was determined from density changes after a) immersion in water for 4 days and b) following heat treatment at 150°C (2 hrs) with and without load.

Results and Discussion

Table 1 shows preliminary results of flexural testing of various panels at short span to depth ratios ranging from 6/1 to 8/1. In cases where it was not possible to have exact thickness of 25 mm, the force values are normalized based on a sample thickness of 25 mm. Apparent modulus values were calculated using the ASTM D-790 procedure for an isotropic beam and relative deflections are based on the material with the highest modulus. Normalized force at failure is reported since all but the monolayer PET and PS core structures failed by ILS at these short span to depth ratios. It is shown that the higher density PET multilayer structures have properties similar to those of the high-density particle board. In the low-density core region (<0.085 g/cc) modulus decreases with decreasing density regardless of the type of core; an exception is the 0.214 g/cc core where lower deflections would be expected.

Table 2 shows data obtained at a higher span to depth ratio of 14:1 still assuming isotropic beam behavior. Panels of different foam core densities are compared with equivalent wood panels. Strength values were calculated based on tensile failure and interlaminar shear failure. It is of interest to note that all wood panels failed by this latter mode whereas all foam panels failed in tension, including the PET multilayer core. The results indicate that in terms of specific modulus and specific strength values, (properties divided by specific gravity), both PET and PVC foam core laminates are overall comparable to the wood panels.

Experimental verification of the flexural and shear stiffness of new sandwich constructions involves three point bending at variable span to depth ratios (10). For a point load at midspan of a simply supported beam the overall deflection including bending and shear is

$$\Delta = PL^3/48D + PL/4N$$

where D is flexural rigidity, (EI), primarily a function of modulus of facings, beam width, and thickness of facings and core, and N is shear stiffness of core, a function of core shear modulus, G_c, beam width, b, and distance between centers of faces.

D and N can be determined by measuring deflection Δ at variable span L for load P and plotting Δ/PL vs. L^2 or Δ/PL^3 vs. $1/L^2$ after recasting the above equation. Table 3 shows results obtained by this method for the panels tested at fixed span to depth ratio in Table 2. The high-density multilayer PET panels have similar flexural rigidity to the wood panels. With respect to shear stiffness, with the exception of the low-density PET single layer panel, all shear stiffness values appear to be very similar.

The shear modulus of the foam core, (an important parameter in bending and edgewise compressive loading) may be calculated from the shear stiffness values by using the following equation (11):

$$N = G_c b s$$

The results shown in Table 4 for the rigid PET and PVC foams confirm the expected shear modulus/specific gravity dependence and indicate that similar specific modulus values are obtained regardless of density or type of foam.

Fig. 1 shows a comparison of dimensional stability of PET and wood laminates after prolonged exposure in water and heat. The significant increase in specific gravity of the wood panels, (as high as 40%), after conditioning in water is contrasted by the dimensionally stable PET foam panels; this suggests their potential in exterior applications.

Conclusions

Sandwich laminates from high-density PET foams (virgin and post-consumer), have bending properties close to those of wood panels, superior water resistance and good thermal stability. Lower density sandwich laminates are competitive to alternate rigid foam products in terms of their specific modulus and strength. The calculated shear moduli of PET foams used in this work compare favorably with those of a commercial rigid PVC foam of similar density. In addition to further panel characterization for freeze-thaw resistance and flame retardancy, work is underway to determine manufacturing costs in order to determine applications and benchmark performance of alternate products.

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References

1. M. Xanthos, Q. Zhang, SK. Dey, Y. Li, U. Yilmazer and M. O'Shea, J. Cell. Plastics, 34, 6, 495 (1998)

2. L.C. Muschiatti, US 5,229,432 (1992)

3. H. Al-Ghatta, S. Severini and L. Astarita, US 5,422,381 (1995)

4. M. Hayashi, N. Amano, T. Taki and T. Hirai, US 5,000,991 (1991)

5. M. Xanthos, U. Yilmazer, SK. Dey, and J. Quintans "Melt Viscoelasticity of Polyethylene Terephthalate Resins for Low Density Extrusion Foaming", Polym. Eng. Sci. (in press)

6. J. Quintans, M. Xanthos and U. Yilmazer, "Rheological Characterization of Unmodified and Chemically Modified PET resins", PPS North American Meeting, August 17-19, 1998, Toronto, Ont.

7. M. Xanthos, SK. Dey, Q. Zhang and J. Quintans, Proc. 57th SPE ANTEC, 45, 2109 (1999)

8. M. Xanthos, SK. Dey and Q. Zhang, 1998 TAPPI Polymers, Laminations and Coatings Conference, pp. 645-650, TAPPI Press, Atlanta 1998

9. M. Xanthos, SK. Dey and U. Yilmazer, Proc. Foams 99 SPE Conference, p 55, Parsippany, NJ, October 1999.

10. R. Nicholls, "Composite Construction Materials Handbook", Chapter 12, Prentice-Hall, Inc. Englewood Cliffs, NJ, 1976

11. AG. H. Dietz ed., "Composite Engineering Laminates", Chapter 8, The MIT Press, Cambridge, Mass, 1969

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Table 1. FLEXURAL PROPERTIES OF SANDWICH PANELS

(span to depth 6/1 to 8/1),
Formica facings, isotropic beam assumption

Core type	Core Spec. Gr.	Force at Failure* (N)	App. Modulus (MPa)	Relative Deflection***
PET Multilayer	0.957 (CBA)	1308**	2606	1.00
PET Multilayer	0.84 (PBA)	349**	896	2.88
Particle Board	0.72 Commercial (no facings)	195**	1647	1.58
PET Multilayer	0.214 (PBA)	166**	69.6	37.5
PET Single Layer	0.085 (PBA)	124	206	12.6
PIC Bilayer	0.036 Commercial	62**	83.4	31.4
PS Single Layer	0.035 Commercial	51	105	24.6

* Normalized to 25 mm thickness
** ILS failure
*** From ratio of App. Moduli

Table 2. FLEXURAL PROPERTIES OF SANDWICH PANELS

(span to depth 14/1),
Formica facings, isotropic beam assumption

Core type	Panel Spec. Grav.	Modulus (MPa)	Specific Modulus (MPa)	Strength (MPa)	Specific Strength (MPa)
Foams					
PET single layer	0.26	1937	7452	11.9	46
PVC single layer	0.62	3164	5094	36.6	59
PET multilayer	0.84	4440	5281	34.9	41
Wood panels					
CDX FIR Plywood	0.53	5949	11230	41.9* 1.57 ILS	79
Oriented strand	0.69	4198	6087	39.8* 1.5 ILS	58
Industrial flakeboard	0.76	4577	6025	42.3* 1.5 ILS	56
M.D. fiberboard	0.84	5253	6253	57.2* 2.18 ILS	68

- Calculated for tensile failure: actual failure by interlaminar shear

Table 3. STIFFNESS OF SANDWICH PANELS (Variable span 3-point bending, span to depth 16/1 to 10/:1, aver. thickness 19 mm, Formica facings)

Core type	Panel Specific Gravity	Flexural rigidity, D (N m^2)	Shear stiffness, N (N)
Foams			
PET single layer	0.26	46	5789
PVC single layer	0.62	75	38552
PET multilayer	0.84	123	53746
Wood panels			
CDX FIR Plywood	0.53	172	45811
Oriented strand	0.69	113	45789
Industrial flakeboard	0.76	122	44653
M.D. fiberboard	0.84	144	51326

Table 4. CALCULATED SHEAR MODULUS OF CORE FOAMS

Core Type	Aver. Specific gravity	Calculated shear modulus, (MPa)	Specific modulus, (MPa)
PET single layer (Sinco Eng.-extruded board)	0.10	13.7	137.6
PVC single layer (Sintra-Polyboard)	0.53	79.5	151.1
PET multilayer (Shell Petlite™ laminated)	0.78	107.9	138.9

Figure 1. NORMALIZED DENSITY OF SANDWICH PANELS (FORMICA FACINGS) AFTER CONDITIONING