Investigation of the Compression and Bending Strength of Veneer-Polyurethane Foam Composites

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Abstract

Lightweight sandwich panels have been widely used for structural applications in the building and furniture industry. The advantages of using these materials comprise their high stiffness- and strength-to-weight ratios. A large variety of applied materials and a wide assortment of developed manufacturing methods allow a purposeful design tailoring of sandwich components and a usage of different materials and geometries. Fixture developments in the furniture industry allow lightweight panels to be used without stiles, rails and internal blocking, making them more cost competitive with particleboard and medium density fiberboard panels.
This poster presents an alternative concept for the production of lightweight sandwich panels using preformed hardwood veneer residues/polyurethane foam core and different wood veneers as face layers. Mechanical properties of the panels including compression and bending strength were tested in two directions, parallel and perpendicular to the strand alignment. A two-level factorial design was employed in order to establish the effect of resin spread, pressure and resin setting temperature on the compression strength. The veneer clippings used as reinforcements in the core gave the panel more rigidity and increased compression strength. The obtained results demonstrate the viability of the newly developed panels for both structural and non-structural applications.

Keywords: veneer residues, polyurethane foam, sandwich panel, mechanical properties, design of experiments

Introduction

During the last decades the increasing need for construction materials coupled with the decreasing quality and quantity of available raw materials triggered innovations and research works to meet challenges of demand and supply. Composite sandwich products are playing an increasingly important role to meet these demands because of there high stiffness-to-weight and strength-to-weight ratios. Sandwich construction has broad application in diverse industries where lightweight, stiff panel construction is required, from marine industry to aircraft structures, from building sidewalls to furniture panels. The high specific strength and stiffness of fiber-reinforced polymer-matrix composite materials have made them attractive for use in sandwich construction, and their environmental durability and corrosion resistance offer superior serviceability in many applications compared to metals, wood, concrete, and other more traditional materials. Sandwich beams/panels are basically formed from two thin and stiff sheets, so called faces separated by a thick, light and weaker core where the stiff faces are effective in withstanding the bending loads applied to the panel/shell, whilst the core offers a high resistance to the shear loads. Commonly used non-metallic face materials include wood, cement and fiber composites while the cores can be divided into four main groups: corrugated panels, honeycomb, balsa wood (*Ochroma pyramidale*) and foams. The latter core material offers greater shear strength- and stiffness-to-weight ratios of the composite sandwich (Zenkert, 1997) than of honeycombs.

This poster focuses on the two mechanical properties of a newly developed veneer/polyurethane foam composite panel products where decorative veneer clippings were used as reinforcing material. Presently, this high quality wood "residues" are incinerated primarily to eliminate their storage and handling problems while producing some energy. Previous researches conducted at Division of Forestry, West Virginia University (Lang et Denes, 2007) and Institute of Product Development, University of Western Hungary proved that these clippings could be converted into high-performance composite panels and structural materials with outstanding load-carrying capacity using traditional wood composite consolidation technologies (Denes et al., 2006). The developed prototype products demonstrated superior mechanical properties compared to structural panels and structural composite lumber currently available on the market. Based on prior results the utilization of these strand type material from decorative veneer manufacturing can be extended forming sandwich panels. The new panel type products could represent an alternative to other lightweight panels currently available on the market.

The objective of this research part was to investigate the viability of using veneer clipping residues in composite panel formulation while testing to important mechanical properties. This poster presents the compression and bending behavior of the new sandwich panels determined parallel and perpendicular to strand alignment.

Materials and Methods

A mix of three dominant North American species for decorative veneer production was used as furnishes material for all panel types. These included about 60% black cherry

(*Prunus serotina*), 35% red oak (*Quercus rubra*) and 5% maple (*Acer spp*.). The composite panels consist of a blend of side clippings comprising the fiber and commercially available moisture-curing one-component polyurethane foam as a matrix material to formulate the core. The fully set polymeric diisocyanate –based foam is semi-rigid and predominantly close celled with good adhesion to wood. **Table 1.** lists the principal physical and mechanical properties of the cured polyurethane foam.

TABLE 1. *Physical properties of the applied foam.*

Density	kg m^{-3}	23
Dimensional stability	%	≤10
Tensile strength	kPa	70
Compressive strength	kPa	60
Shear strength	kPa	40

Foam application to the veneer surface took place in a metal roller coater with adjustable distance between the rollers. A multilayered veneer/foam mat was formed in a 78 cm x 45.5 mm forming box with parallel alignment of the side clippings. After the full foam setting specimens with near cubical shape were cut from the panels and tested in compression. All mechanical tests were performed on an MTS servo-hydraulic universal machine, equipped with a 10 kN ± 1 N load cell. Compression load application occurred through a self-aligning block placed on bottom of the specimens **Figure 1**.

FIGURE 1. *Test set-up for compression tests (a), specimen buckling (b), and back spring after load release (c).*

Due to the complex deformation, i.e. buckling torsion and compression no strain gauge was attached to the samples. Testing procedures included the determination of compression strength parallel and perpendicular to the strand alignment. The back spring phenomenon after the load release can be attributed to the foam semi-rigidity and veneer elasticity. The effect of foam spread, pressure and temperature on the panel's compression strength was investigated adopting a two level factorial design with three center points added. **Table 2.** summarizes the factor's setting levels.

TABLE 2. – *Experimental factors and their levels.*

Factors			Factor levels	
Symbol	**Description**	**Unit**	**1**	**2**
A	Resin content	g m^{-2}	100	170
B	Pressure	kPa	6.9	55.2
C	Temperature	°C	25	80

The veneer/polyurethane panels produced in the previous research phase were further processed to create new types of lightweight panel products. Equal width slabs were cut out from panels then rotated with 90° and re-bonded with the same polyurethane foam to form a continuous mat. This core material was veneered on both sides using different wood species and veneer thicknesses. To increase the dimensional stability of the panels in some cases cross banded veneer layers were applied on both surfaces. Some of the panels were reinforced with solid wood rails at the edges. **Figure 2**. shows several panel types.

FIGURE 2. *Sandwich panels with veneer faces and veneer residue - polyurethane foam composite core.*

A total of 10 tests were conducted on the sandwich panels to determine the bending strength according to the ASTM D1037 standard. Five specimens had reinforced foam core with strand alignment perpendicular to the panel surface the rest was oriented parallel to the surface. The specimens were rectangular in cross-section with a depth of 50 mm and span of 711 mm. The test setup is shown in **Figure 3**.

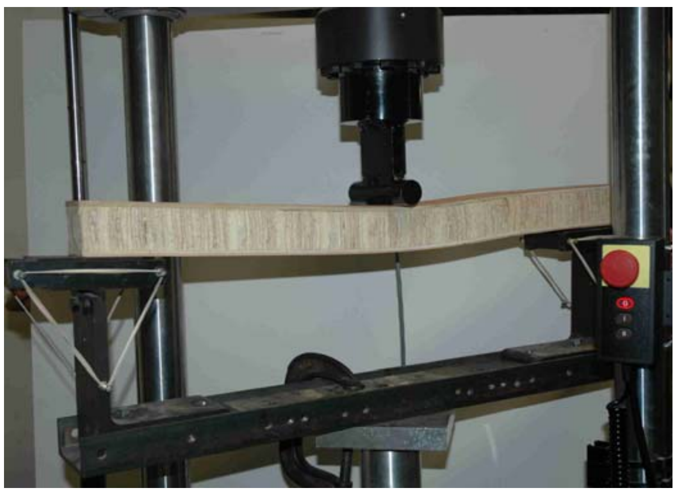

FIGURE 3. *Flexural test setup using a single concentrated load.*

Results and Discussion

Table 3. summarizes the compression strength properties of veneer/polyurethane core panels by factor-level combinations. Both specimen types having parallel and perpendicular strand alignment demonstrated significantly higher strength values than the pure polyurethane foam (**Table 1.**). This confirms that veneer strand reinforcements contribute significantly to the compression strength increase of porous foam materials. High variations experienced in several experimental runs are attributable to the presence of noise factors such as alignment imperfections, uneven distribution of resin, strand etc. However, the factors effect is reflected in the relevant differences between the runs.

TABLE 3. *Summary statistics of the experimental test results by factor/level combinations.*

	Factors and	Density	Compression strength

Run number	**Levels**			**n**			**parallel alignment**		**perpendic. alignment**	
	A	**B**	**C**		$\bar{y}$ (kg m^{-3})	CV[a] (%)	$\bar{y}$ (kPa)	CV (%)	$\bar{y}$ (kPa)	CV (%)
1	-1	-1	-1	6	197	3,8	1388	20	346	8
2	-1	-1	+1	5	174	3,1	983	23	207	10
3	-1	+1	-1	6	253	2,4	1836	25	574	7
4	-1	+1	+1	6	256	2,5	1103	23	288	6
5	+1	-1	-1	6	101	3,2	499	7	115	18
6	+1	-1	+1	6	115	2	587	17	95	12
7	+1	+1	-1	5	207	3,4	1898	37	395	7
8	+1	+1	+1	6	219	4,2	955	21	184	18
9	0	0	0	6	168	4,7	909	28	167	20
10	0	0	0	6	162	3,5	825	37	170	7
11	0	0	0	6	194	2,3	1349	9	291	22
Overall average values:					**183**	**--**	**1121**	**--**	**257**	**--**

[a] – coefficient of variation

Figure 4. represents the relationship between the panel's density and compression strengths. Specimens demonstrated a linear correlation with an acceptable coefficient of determination when the strands were aligned perpendicular to the load direction. However, specimens with parallel strand alignment slightly correlate with the density especially in the upper region. Elevated deviations can be attributed to the noise factors mentioned above. From the figure we can distinguish the individual runs which indicate that the selected factors have an influence both on density and compression properties.

FIGURE 4. *Relationship of compression strength to panel density.*

Analysis of Variance (ANOVA) at significance level of $\alpha = 0.05$ confirmed the occurrence of statistical differences between the selected factors on the flexural properties. Analyzing individually the marginal effects of factors (**Figure 5**), it does appear that adhesive content in the selected range play an insignificant role when the panels were compressed parallel to the strand alignment while pressure has a positive linear effect and temperature a negative one. Perpendicular to the strand alignment, all factors have a significant effect with the same influence on the strength. The high variation is reflected in the wide confidence intervals of the mean represented by dashed lines.

FIGURE 5. *Effect of factors on the compression strength.*

Figure 5. reveals also that the highest compression strength values are obtained when the pressure is set to the upper level (55.2 kPa) and the temperature at the lower level (25˘C)

This corresponds to the experimental runs 3 and 7 as far as the resin spread in this range has a negligible effect.
The bending strength of the sandwich panels (**Table 4.**) using a veneer/polyurethane foam core are remarkably higher than of honeycomb panels made of 8 mm particleboard skins and 36 mm thick expanded paper honeycomb core (Barboutis and Vassiliou, 2005) and comparable to the through-the-thickness stitched plain weave glass fabric/polyurethane foam/epoxy composites (Lee et al., 2003).

TABLE 4. *Flexural properties of the sandwich panels.*

Strand align.	No. of spec. n	Density kg m^{-3}	MOR MPa
Parallel	5	270 (6)	4.57 (0.34)
Perpendicular	5	277 (7)	3.38 (0.30)

Summary and Conclusions

The effect of resin spread, pressure and curing temperature on the compression strength of veneer/polyurethane foam panels were investigated. The applied pressure during the foam set has a positive linear effect on the compression strength while the temperature has a negative effect by contributing to the moisture elimination from the system needed for resin foam cure.
The compression strength of polyurethane foam core sandwich panels will increase significantly using sliced veneer clippings as reinforcements. The aligned veneer strands give the panels more rigidity, crush strength and structural integrity than the common used honeycombs.

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