VINYLTEC 2000

Rigid PVC in the New Millennium
Innovations, Applications, Properties

October 11-12, 2000

Wyndham Franklin Plaza
Philadelphia, PA

Sponsored by Vinyl Division-SPE and Philadelphia Section

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***-** *Note: This paper not available at time of going to press.*

New Opportunities With Wood Flour Foamed PVC

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Introduction

Wood-plastics composites represent a relatively small, but rapidly growing industry. These composites were first introduced to the market quite some time ago, and its only recently that they have become more widely accepted especially in the decking market. In the decking market, these composites compete predominantly with pressure-treated lumber. Now some of the wood-plastic composites are starting to compete with vinyl and aluminum in various profile applications, such as windows and doors. Composites of wood flour and/or fiber with polyethylene (PE), polypropylene (PP), and polyvinylchloride (PVC) are starting to be seen throughout the building products industry. The industry estimates that the total production of wood-plastic composites in 1999 was approximately 460 million pounds up from 100 million pounds just two years earlier. A breakdown by thermoplastic resin is shown in Figure 1. Polyethylene currently represents the largest portion of the wood-plastic composites market with most of the materials going into decking.

Wood-plastics composites represent an emerging class of materials that combines the favorable performance and cost attributes of both wood and thermoplastics. The forest-products companies see plastics as a way to make new construction materials with attributes that wood doesn't have, such as moisture and insect resistance. Plastics processors see wood as a readily available, relatively inexpensive filler that can lower their resin costs, add stiffness, and increase profile extrusion rates because wood cools faster than plastics. Most all wood-plastic composites can be fastened, sanded, stained, and machined in the same way that wood can without the need to invest in new equipment.

Despite some similarities, not all wood-plastic composite materials are the same. Most of the important differences come with the selection of the thermoplastic resin that is used and the level and species of wood flour that goes into the formulation. Most wood-plastic composites use either polyethylene or PVC as the thermoplastic. Both thermoplastics offer performance characteristics making them more desirable for certain applications. Polyethylene-based wood composites reportedly offer higher heat resistance with a heat distortion temperature of about 180 degF at 264psi. They may also be somewhat less expensive than PVC formulations. The key advantage of PVC-based wood composites is their stain or paintability. Little, if any, treatment is needed to make the stain or paint stick to the PVC-wood composite. A comparison of the properties of HDPE/wood and the PVC/wood composites with rigid PVC and pressure-treated lumber is shown in Table1.

One of the problems in producing the wood-plastics composites is compatibility. Plastics and wood do not always mix easily. Some polymers, however, are more compatible than others. PVC, for example, which is polar like wood, bonds fairly well to the filler without the need for a coupling agents. Polyolefins, on the other hand, adhere less well to wood, so they are more likely to need modification or compatibilization.

Wood selection

Commercial wood flour is available in a range of mesh sizes from 20 to 200 mesh, but we have found that for most thermoplastics applications the 40 to 80 mesh range is the easiest to work with. The basic difference between a wood fiber and a wood flour is that the wood fiber has an aspect ratio (length/diameter) of 10:1 or 20:1 while wood flour generally has an aspect ratio of 1:1 to 4:1. The longer wood fibers adds stiffness, but seems to hurt impact strength and they are definitely trickier to process. The fine-mesh wood flour seems to contribute some stiffness and lighter weight and may have less of an effect on toughness. Besides mesh size and particle size distribution, the species of wood flour or fibers that is used can also make a difference. Some common species that are available include maple, oak, spruce, cedar, Southern yellow pine, and Ponderosa pine. Prices for the wood fibers/flours range from $0.06 a lb for the coarse grades to $0.25 a lb for the finest grades (200 mesh). American Wood Fibers offers 15 grades based on hardwood or pine. PJ Murphy Forrest Products offers materials from pine, spruce, hemlock, maple, oak, and birch.

Much of the initial work that we have done is with PVC and wood flour so the remainder of this paper will focus on the PVC-based wood composites and the production of cellular products with that combination.

Processing PVC / wood composites

The development activity in the PVC-wood composites area is impressive considering the technical difficulties that are involved in the handling and processing of PVC and wood flour productively. Typically when high loadings of wood flour are blended with the PVC resin, the resulting compound exhibits a high moisture content, poor powder handling properties (poor powder flow and low bulk density), some degree of thermal sensitivity, poor melt flow and melt strength, and the finished part tends to have a rough surface, and possibly some edge tearing.

One of the major difficulties in working with wood flour is that it is hydroscopic and since most conventional plastics processes have little or no tolerance for water, much of the wood flour is pre-dried. Without the drying step, and at normal processing conditions, any water will turn to steam and expand causing the plastic to foam. The problem with this foaming is the irregular cell structure that is obtained and this results in low mechanical properties, poor surface quality, and voids. The moisture is also said to disrupt the compatibility required in the wood polymer coupling. We have found that for both cellular and solid PVC-wood composites, the moisture content should be kept in the 0.5-1.0 % range. At these levels, a vented extruder can remove the remaining moisture.

PVC-wood composites producers have overcome the moisture problems by pre-drying either the wood flour or the compound before pelletization and/or extrusion. There are also some new extruders or other equipment on the market that allow you to pre-dry the wood before introducing it to a polymer melt.

Wood flour is also thermally sensitive. Wood flours have a tendency to burn at temperatures required for processing many thermoplastics. As a rule of thumb, if the melt temperatures are kept below 200 degC and processing times kept to a reasonable limit, degradation of the wood flour should not occur.

The wood flour has a lower bulk density than many of the commonly used inorganic fillers. This can seriously affect the compounds ability to be fed into the extruder and the resultant throughput can be quite low. A common strategy in the industry to overcome this is to install crammer-type feeders on the processing equipment, but this can be expensive and throughput can still be compromised.

One of the outcomes of our development work with PVC-wood composites is a process that allows high loadings of wood flour (40% or more) to be added to a PVC compound. Pre-drying of the wood is eliminated and the PVC-wood compound can be extruded directly from powder without the need to pelletize. The compound exhibits good hot melt strength and the resulting extruded product has good surface and edge quality. The process was considered to be so unique that a patent application has been filed covering certain aspects of this PVC-wood composite technology.

Foaming PVC / wood flour composites

PVC -wood composites offer many advantages over conventional lumber. One of the major disadvantages, however, is the heavier weight. A PVC-wood composite has a specific gravity of about 1.3 g/cc. One way to reduce that weight is to make a foamed product. We have been able to produce a PVC-wood flour composite with densities down to about 0.6 g/cc.

When producing a cellular PVC -wood flour composite, density reduction can be achieved with either an azodicarbonamide, or sodium bicarbonate blowing agent system. In our work, however, the sodium bicarbonate system appears to give lower densities than we were able to achieve with an azodicarbonamide.

We extruded PVC/wood composite samples on a KMDL 25 mm conical twin screw extruder looking at both blowing agent systems In these studies we looked at various wood flour levels and species. The physical properties that will be presented in the next section have been determined on PVC/wood flour all containing 40% of an 80 mesh hardwood from AWF.

Performance properties

We have been able to produce both cellular and non-cellular wood composites. These were tested by the ASTM standards for specific gravity, tensile and flexural properties, Izod impact, DTUFL at 264 psi, water absorption, and coefficient of thermal expansion. The results shown in Table 2 compare the non-cellular PVC-wood composite with rigid PVC. As you can see, both the flexural and tensile modulus values for the wood composite are higher than the rigid PVC. We also saw a higher DTUFL (73 vs 61degC) and a lower COTE.

In Table 3, we compare the properties of a moderately foamed PVC compound with the PVC-wood composite with approximately the same density (approximately 1.0 g/cc). This was done to eliminate the effect of density on physical properties. Again the modulus numbers for the PVC-wood composite are higher. In this case the DTUFL shows no difference, but the COTE is again significantly lower. Water absorption, as you might expect, increases with decreasing density.

At the lowest density of approximately 0.6 g/cc (Table 4), we see similar performance difference comparing a foamed PVC with the PVC-wood composite. In this case, the tensile modulus numbers are almost the same, but there still appears to be a higher flexural modulus for the composite. In this set, the DTUFL was again higher at 67 degC for the PVC-wood composite versus 59 degC for our foamed PVC sample. The COTE was, however, still significantly lower.

One of the main attributes of the PVC-wood composites is aesthetics. They have the look and feel of wood. We have taken some of the foamed samples that we produced, and even at the lower density, we were able to nail and screw them without splitting or cracking. We applied a variety of stains and weatherable coatings to the samples and achieved very attractive finishes. With embossed samples, the stains actually highlight the embossing leaving a pronounced wood-grain effect. We have coextruded the PVC-wood composites leaving a PVC-wood composite over a solid PVC substrate. Both the foamed PVC-wood composites and the coextruded parts have been thermoformed, and even with a deep draw, have not shown any signs of stress-whitening.

In Table 5 we compared the economics of the three PVC-wood composites at densities of 1.31, 1.00 and 0.60 g/cc with a cellular PVC profile that also has a density of 0.60 g/cc. The costs were determined for the production of a 5 ½ x 1 inch board. The cost calculations show that the cellular PVC board is less expensive to produce that the PVC-wood composites when there is little or no foaming. But, as the density of the PVC-wood composites is dropped, the economics then favor the composite material. The total cost of the foamed PVC board is $0.75 per foot versus $0.60 for the PVC-wood composite.

Conclusions

Overall the PVC-wood composites offer a wide variety of possible applications. Although the non-cellular PVC-wood composite has a relatively high specific gravity (1.3 g/cc) compared to many wood products, it can be foamed to produce a product that has a density of about 0.6 g/cc, and for many applications, it offers properties that are adequate. The stiffness and COTE are definitely improved with the addition of wood flour. Foaming a PVC-wood composite can also greatly improve the economics of some profile parts even when compared to a cellular PVC product with the same specific gravity.

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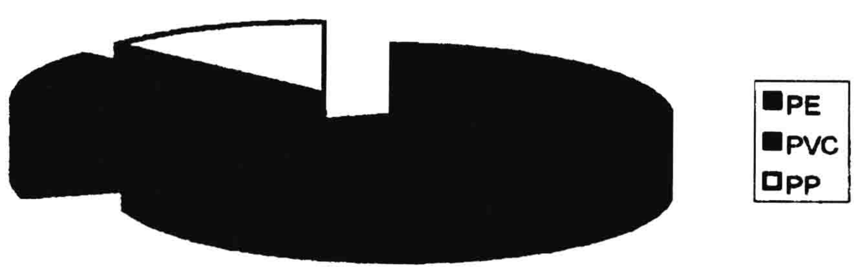
Figure 1 : Plastics - Wood Composites Market In North America

460 MM Lbs Total



PE	**322 MM lbs**
PVC	**76 MM lbs**
PP	**61 MM lbs**

Table 1 :
Comparison of Wood Composites Properties with PVC and Ponderosa Pine

Test	ASTM Method	HDPE/wood	PVC/wood	Rigid PVC	Pressure-treated pine
Specific gravity	D143	1.1	1.36	1.45	0.4-0.6
Water absorption (%)	D1037	0.7	1.2	0.07-0.4	17.2
COTE $x10^{-5}$(in/in/°F)	D696	1.6	1.74	3.5	2.5
Tensile strength (psi)	D198	1204	2818	630	420
Modulus of elasticity (psi)	D790	505	948	425	1290
Modulus of rupture (psi)	D790	2105	5350	N/A	9400
HDT at 264 psi (°F)	****	180	180	160	268
Nail withdrawal	D1761	97	N/A	N/A	51
Screw withdrawal	D1761	438	N/A	N/A	163
Hardness (lb)	D143	1288	****	790	460

Table 2 :
Property Comparison of PVC and PVC/Wood Flour Composite

	Rigid PVC	PVC/WF composite
Specific gravity (g/cc)	1.42	1.31
Tensile strength (psi)	5,620	4,020
Tensile modulus (psi)	390,700	517,000
Flexural strength (psi)	13,300	7,210
Flexural modulus (psi)	496,000	560,000
Izod impact (in.lbs/ft)	1.0	0.4
Dynatup impact (in-lbs)	39.0	N/A
DTUFL at 264 psi (°C)	61	73
Water absorption (%)	0.04	2.4
COTEx10-5 (in/in/°C)	5.7	4.0

Table 3 :
Property Comparison of PVC and PVC/Wood Flour Composite (Foamed)

	Foamed PVC	Foamed PVC/WF composite
Specific gravity (g/cc)	0.98	1.01
Tensile strength (psi)	4720	4110
Tensile modulus (psi)	216800	243000
Flexural strength (psi)	7040	2270
Flexural modulus (psi)	216800	306000
Izod impact (in.lbs/ft)	0.4	0.3
Dynatup impact (in-lbs)	1.8	N/A
DTUFL at 264 psi (ºC)	61	60
Water absorption (%)	0.21	7.2
COTEx10-5 (in/in/ºC)	5.7	4.2

Table 4 :
Property Comparison of PVC and PVC/Wood Flour Composite (Foamed)

	Foamed PVC	Foamed PVC/WF composite
Specific gravity (g/cc)	0.57	0.60
Tensile strength (psi)	2490	N/A
Tensile modulus (psi)	122000	116000
Flexural strength (psi)	3610	N/A
Flexural modulus (psi)	152600	182000
Izod impact (in.lbs/ft)	0.3	0.2
Dynatup impact (in-lbs)	0.9	N/A
DTUFL at 264 psi (°C)	59	67
Water absorption (%)	0.65	9.2
COTEx10-5 (in/in/°C)	5.7	4.0

Table 5 : Cellular PVC-Wood Composite Economics for a 5 1/2 x 1 inch board

	Solid PVC/WF	Cellular PVC/WF	Cellular PVC/WF	Cellular PVC
Specific gravity	1.31	1.00	0.60	0.60
Weight / ft	3.124	2.384	1.431	1.431
Output (ft/hr) *	256	336	559	559
RM cost ($/ft)	0.9895	0.7768	0.4773	0.6320
Mfg cost ($/ft)	0.2640	0.2016	0.1209	0.1209
TOTAL cost ($/ft)	1.2535	0.9783	0.5982	0.7530

NOTE : Assumes extruder output rate of 800 lbs/ hour

PVC Wood ; A New Look in Construction

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Introduction

With the increasing environmental concern for forest protection, wood is likely become even more protected resulting in rising costs and less availability. There is increasing demands of rigid PVC and PVC wood as an alternative construction materials. In this paper shows that PVC wood, which includes rigid PVC foam and PVC/wood composite, is an interesting alternative to wood and wood - like products. Since it can be nailed, screwed, sawed and glued like wood by conventional tools without any special skills required. Moreover, the advantages of PVC wood are light weight, better thermal insulation and water resistance. Hence, PVC wood demonstrates an excellent alternative products for wood replacement in many building applications.

Experiment

PVC wood is a mixture of PVC resin with wood flour, blowing agents and other additives. All ingredients are mixed by a high intensity mixer at the appropriate temperature. The mixture is extruded into a formed profile through an extrusion die and calibrator. The evaluated properties are termite resistance, weathering aging, bending strength, moisture absorption, glue line shear, nail withdrawal, direct screw withdrawal and installation.

Result and Discussion

Termite resistance was evaluated by Thai Royal Forest Standard of wood testing as shown in Figure 1. Termite species, *Coptotermes gestroi*, is well known to cause the most damage to wood in Thailand. Teng and Sya wood were chosen for testing due to their hard wood properties which are high-load bearing and termite resistance.

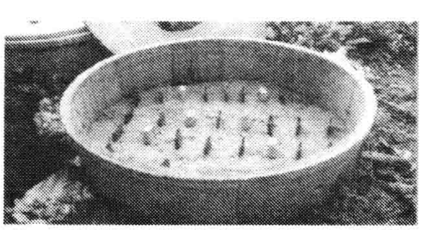
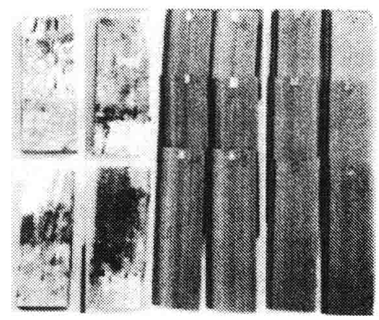


Figure 1 Standard termite resistance test.

From Figure 2, it can be obviously seen that termite start to attack standard rubber wood after 2 weeks but do not damage PVC wood products within 6 months period. This may be due to the wood flour surface was surrounded by PVC matrix.



A B

Figure 2 Standard rubber wood (A) and PVC wood (B) after termite resistance test for 6 months.

Color change was determined by outdoor aging of PVC wood and natural wood products, measured by color sensor device, in terms of color different (ΔE) and yellow index (ΔYI). As shown in Figure 3 and 4, ΔE and ΔYI of PVC wood products are less than Teng and Sya wood. These indicates that PVC wood give less changed in color after aging for 12 months.

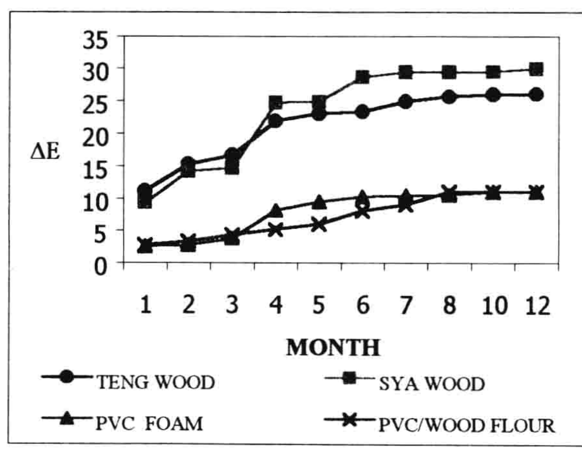


Figure 3 Color different (ΔE) from weathering test.

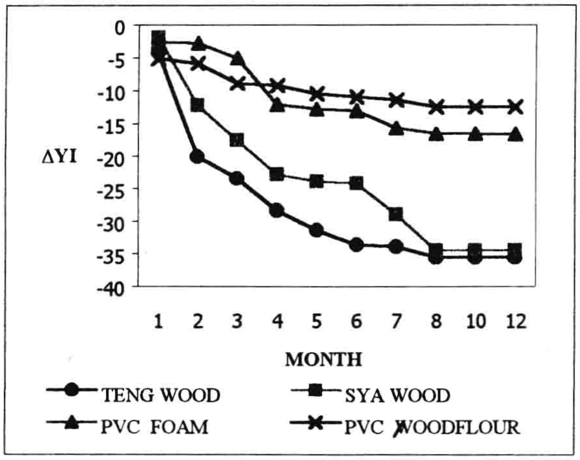


Figure 4 Yellow index (ΔYI) from weathering test.

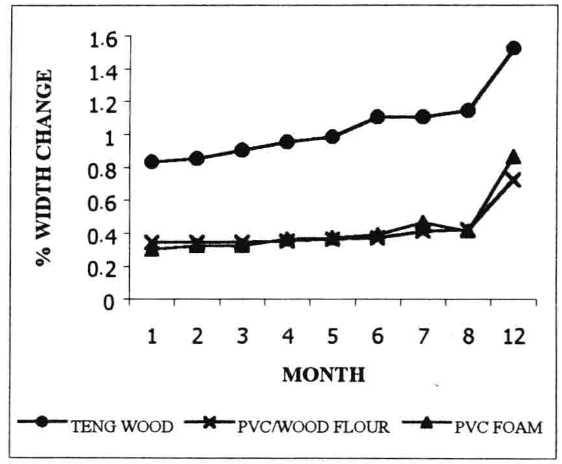


Figure 6 Width change from weathering test.

Dimensional stability was tested by sunlight aging and periodically measured products' dimension. The specimen, four meters in length, were placed on 7 supports. The distance of each support is 50 cm. Figure 5 and 6 show that dimensional stability of PVC/wood flour, after aging for 12 months, is much better than wood.

From these two experiments indicated that PVC wood outperforms wood in color change and dimensional stability.

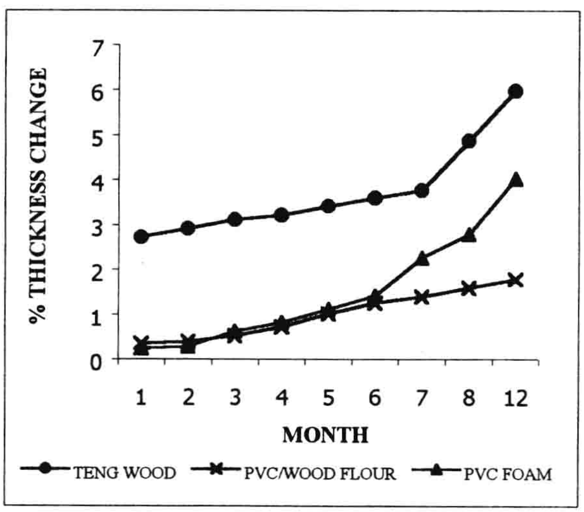


Figure 5 Thickness change from weathering test.

Bending strength was measured according to ASTM D790 by extensometer. From Table 1, it is obviously seen that bending strength of PVC wood is much lower than wood. This result suggests that PVC wood should not be used for high load-bearing applications like building column. However, it can be fulfilled for decorative applications.

Table 1 Compare bending strength of PVC wood, Rubber wood and Teak wood.

Type	Bending strength (kg/cm^2)
PVC wood : Rigid PVC Foam	290*
PVC wood : PVC / Wood composite	470*
Rubber wood	880**
Teak wood	1,000**

Remark : * Length = 30 cm, ** Length = 100 cm

Moisture absorption was measured according to ASTM D570. Table 2 shows that PVC wood has lower moisture absorption than three types of wood. These indicated that PVC wood should have less effect from moisture–related problems, i.e. warping, bowing, and decay.

Table 2 Moisture absorption test.

Type	Moisture Absorption (%)
Teak wood,Pradu wood	12
Rubber wood	13
Teng wood	13.6
PVC wood : PVC Foam	0.65
PVC wood : PVC / Wood composite	1.42