COMPOSITE FLOORING
for North American Van Trailers
A technical paper of Havco Wood Products LLC
Featured at the 2007 Land Transport Forum in Paris, France

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The Next Generation of Composite Floors
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Acknowledgements
Havco Wood Products LLC acknowledges the extensive testing of composite flooring and product qualification efforts of trailer manufacturers in North America.
Preface

This study was originally presented on April 5th, 2007 at the JEC Composite Forums in Paris, France. The audience was made up of select professionals within the land transport and composite materials industries. The research was conducted by Gopal Padmanabhan, vice president of product engineering and Bruce Bader, president of Havco Wood Products, LLC.

Abstract

Laminated oak flooring has been successfully used in dry van trailers for more than four decades. Due to its natural properties like high strength, resistance to decay, ability to nail, wear resistance and plentiful availability, oak is the preferred hardwood for van trailer flooring [1-3]. The lifetime of van trailers is normally estimated to be about seven years. In recent times, there is an effort in the industry to engineer trailers so that the lifetime of trailers can be extended to ten years or more. Further, weight reduction of trailers has become necessary due to the high cost of fuel. Many fleets are willing to bear a higher upfront cost for durable and lighter trailers since there are tangible benefits during road service and a higher trade-in value for these trailers. Several new products and innovations are being offered to accomplish this goal for doors, walls, roofs, wheels, tires, wall liners and flooring. Our commercially available flooring innovation is a composite of oak and glass fiber reinforced epoxy panel. This product has been field tested and proven in road service of trailers for more than ten years. It has been commercially produced since the year 2000. Composite flooring offers higher strength, resistance to fatigue, moisture protection, longer life, and weight savings compared to conventional wood flooring. In this paper, we present the evidence for superior performance of composite flooring and also provide an estimate of the benefits in US dollars over a ten year lifetime of the flooring.
Conventional Hardwood Flooring

Van trailers can be up to 53 feet in length and they are a popular choice for transporting freight in North America. These trailers are designed and manufactured for both specific applications like transporting paper goods, automotive parts, beverage, etc., and also for hauling general freight. About 90% or more of van trailers are constructed with laminated hardwood flooring and about 80% of hardwood floors for van trailers are made of oak. Laminated wood flooring in van trailers is typically comprised of about eight individual floorboards. Each floorboard is composed of several sticks of wood, each with a random length between 1 to 6 feet, which are edge-glued to make a unitary floorboard. The ends of sticks form mechanical joints without any adhesive and therefore they do not support load. These joints are distributed throughout the flooring. Each floorboard is about 12 inches wide and up to 50 feet long. The floorboards are laid next to one another and fastened to steel I-beams or cross-members of trailers. The cross-members are in turn attached to the bottom of the sidewalls or siderails of the trailer. The floor system consisting of wood flooring and cross-members is an important structural part of the trailer.
Service Requirements

Van trailers in North America are typically loaded and unloaded by fork lift trucks and clamp lift trucks. A lift truck carrying a cargo laden pallet runs in and out of each trailer many thousands of times during the lifetime of the trailers. A typical unit of cargo can weigh about 2,000 to 8,000 pounds. The heavier pieces of cargo are usually paper rolls, which are handled by clamp trucks. Lift trucks can weigh about 10,000 to 16,000 pounds. Thus, the combined weight of the cargo and lift truck can be between 12,000 to 24,000 pounds. The heavier loads cause the common trailer floor to deflect up to 1.5 inch at the center of the cross-members. The trailer flooring is subjected to fatigue load cycles due to the repetitive nature of operation of lift trucks on the floor at the trailer docks. Depending upon the type of transportation operation, a trailer can be subjected to 500 to 2,000 fatigue cycles in a year. Clearly, fatigue resistant flooring is needed to reduce floor maintenance.

Mechanical strength characteristics of wood flooring normally show significant variations due to the natural variations inherent in the components of wood that make up the floorboards. The average length of wood components and the placement of end-joints of the components also play a role in these variations. High strength properties of flooring with improved consistency are desirable.

The underside of the trailer flooring is exposed to the road side environment. Water spray from the roads can have a degrading effect on the glue bonds of laminated wood over the long term. The continual cycles of expansion of wood due to absorption of water and the consequent shrinkage of wood upon its drying during road service can lead to the deterioration of glue bonds of flooring. An improved protective coating for wood flooring at the bottom side can help to provide longer life of flooring.
The importance of lower weight of the trailer is critical at times when the price of fuel is high. Some applications such as the transportation of heavy paper rolls, automotive parts, glass plates, carpet rolls, etc., require a heavy-duty floor system. The lift trucks that are used to load trailers with this type of freight apply front-axle loads in the range of 20,000 to 24,000 pounds on the trailer floor. To obtain a higher rating with conventional wood flooring, the trailer floor system is typically built with additional cross-member supports, thus incurring a significant weight penalty and higher cost. Ideally, many fleets prefer a lightweight, water resistant, high-strength, and durable trailer floor system capable of transporting a variety of freight including heavy paper rolls.

**Design of Composite Flooring**

To address the needs of the trucking industry, we embarked on a research program in 1993. Based on several years of our research work, composite flooring for van trailers was developed using laminated oak boards and glass fiber reinforced epoxy composite. This flooring has a thin layer of composite panel adhesively bonded to the bottom side of each laminated oak floorboard [4, 5]. The composite floor boards are installed in trailers just as the conventional oak floorboards. The top side of each composite floor board is composed of laminated oak as in conventional wood flooring. Surface characteristics of wood, appearance, ability to nail, method of installation etc., are preserved while the high strength, environmental resistance and fatigue resistance of glass/epoxy panel are additionally incorporated into the flooring. The mechanical strength properties of the composite flooring are significantly higher than those of the conventional wood flooring. This aspect allows the use of thinner composite boards leading to weight savings in trailers and also saves wood.

*Figure 3 » A composite floor board*
**Composite Panel**

The glass/epoxy panel used to make composite flooring is produced by a continuous lamination process. Continuous rovings of E-glass fibers are used along with woven glass as the reinforcement. The continuous rovings provide longitudinal strength and stiffness to the floor boards while the woven glass rovings provide transverse strength properties and resistance to splitting of board. About 49 oz/yrd² of continuous rovings are used in the warp direction along with 4 oz/yrd² of weft fibers to make the composite panel. The glass content of the composite panel is about 75% by weight. To enhance bonding of the panel to wood, one side of the panel is lightly sanded. The glass reinforced panel has a tensile strength of about 130 Ksi and a tensile modulus of 5.8 Msi. The nominal thickness of the panel is about 0.050 inch. The same thickness of composite panel is used on all composite floors irrespective of their overall thickness. By varying the thickness of the wood layer in the composite floor, higher structural properties are obtained at the lowest additional cost. The overall thickness of the composite floor is determined by the desired floor rating. Typical thicknesses of composite flooring are 1.06, 1.12 and 1.19 inch. The most common thicknesses of conventional wood flooring are 1.31 and 1.38 inch. Conventional wood flooring at the higher thickness of 1.5 inch is sometimes used in certain applications. Reduction in thickness of composite flooring compared to conventional wood flooring is made possible due to the higher strength of composite flooring. Typically, composite flooring saves about 0.25 inch of wood thickness while providing comparable or better performance than conventional wood flooring.

**Method of Manufacturing Composite Flooring**

The first step of manufacturing of composite flooring is the production of conventional oak floorboards. Green lumber is dried under controlled environment to average moisture content of 8%. Each board of lumber is sawed into several sticks. The sticks are sanded on two sides. Each stick of lumber is then carefully examined and defects such as knots, wormholes, shakes, checks, etc., are removed to form usable sticks. Any wood component with a length less than 12 inches is discarded. The remaining usable sticks are edge-glued with a urea-melamine adhesive to form a rough panel. The panel is sawn into four rough boards of length up to 50 feet. The rough boards are planed and machined to form a finished wood board. The planed wood boards are lightly sanded on the bottom side. The sanded surface of board is coated with a polyurethane reactive hotmelt adhesive. The glass/epoxy panel is also coated with the hotmelt adhesive. The coated panel is laid over the coated board in a continuous manner and nip rolled. The corners of the boards are trimmed to remove excess glass fibers. The finished boards are assembled into kits of eight boards and shipped on flatbed trailers to trailer manufacturers.

**Three Point Bending Test**

Three point bending tests were independently conducted by a trailer manufacturer on both the conventional oak and composite floor boards. Boards with a width of 12 inches were subjected to static bending at a span of 18 inches. The load versus deflection curves of all tested samples are shown in Figure 4. The composite floorboards at the thickness of 1.06 inch is about 20% stronger than the standard 1.31 inch oak floorboards based on maximum load sustained. The bending properties of the floorboards are shown in Table 1. The material strength of composite flooring is nearly two times as that of laminated oak. Mode of failure of the conventional oak floorboards is by fracture and pop-out of end-joints of wood components at the bottom side of boards. The composite boards fail by compression damage of wood at the top side of boards followed by tensile fracture of wood and composite panel at the bottom side.
Offset Bending Test

The offset bend test as specified by the Fruehauf Corporation Quality Standard [6], has been in use for several decades in the flooring industry for routine production quality control of flooring. In this test, specimens of floorboards with nominal size of 36 inches x 12 inches are used. Each specimen is supported at a span of 30 inches as shown in Figure 5. A hard rubber block is placed along one edge of the specimen at mid-span. Load is applied on the rubber block until failure of the board occurs. The maximum load sustained by the specimen is recorded as the bending strength. The average test results for various thicknesses of floorboards are shown in Table 2. The composite flooring significantly outperforms the standard oak flooring in this test.
Static Testing of Floor System

This test was conducted by a trailer manufacturer according to the procedure of TTMA RP37-94 [7]. In this test, eight floorboards were fastened to standard cross-members spaced at 12 inches to simulate a trailer floor system. Standard cross-members are 4 inches high steel I-beams weighing 3.2 lbs/ft with the steel having a yield strength of 80 Ksi. The third board or sixth board starting from any one side of the eight-board system typically happens to be in the track of a lift truck running along the center-line of a trailer. The load is positioned on the track boards between two adjacent cross-members. A rubber block measuring 42.5 square inches representing the footprint of the tire of a lift truck is used to transfer the load to each board. The load is increased at least until a floorboard is no longer able to carry additional load. The maximum load sustained is recorded. The 1.31 inch conventional oak floorboard failed at the load of 36,500 pounds. The 1.06 and the 1.12 inch composite floors, each sustained 50,000 pounds without damage to the boards. Loading of the composite floors was not continued beyond 50,000 pounds. This test demonstrated the superior strength of the composite floorboard over the conventional floorboard in a floor system. The results of this test cannot be used to provide load ratings for floor systems. However, this test indicates that composite flooring has a higher load rating than conventional wood flooring.
Fatigue Test

Rolling load fatigue test is necessary to qualify a floor system and for providing ratings. This test can be conducted by simply driving a load carrying lift truck in and out of a trailer and completing the required number of load cycles. The entry of a lift truck into the trailer, its forward and reverse movements and exit from the trailer constitutes a load cycle. The composite floor has been fatigue tested by the application of cyclic rolling loads according to TTMA RP37-94 and RP37-02 [7] by several trailer manufacturers. TTMA RP37-02 requires the application of 4,000 center load cycles on the floor when testing at 20,000 pounds of front axle load. In the center load cycles, the lift truck tires are usually on the third and sixth boards of floor. In order to pass the fatigue test, the trailer flooring needs to maintain its structural integrity allowing the fork truck to complete the required load cycles. Further, the permanent deformation of cross-members cannot exceed 0.25 inch.
Conventional floorboards usually show damage to the bottom side during the rolling load fatigue tests. The reasons for the damage include the natural variations in the structural properties of the wood sticks of the floorboards, frequency of end-joints of wood components and the fact that these end-joints do not carry significant load. The damage is normally seen at the bottom side of boards in the form of wood fracture, cracks, pop-out of end-joints and sometimes splits along the length of the board. Since composite flooring is much stronger, they require far more number of load cycles to cause visible damage to the floorboards. In one test, the 1.19 inch thick composite board split after 27,000 load cycles. The number of load cycles can carry different levels of importance to different transportation companies. Some fleets may load a trailer once a week and other fleets may load more frequently. As a result, over its lifetime, a trailer may be subjected to as few as 4,000 load cycles and as high as 16,000 load cycles. Further, a typical trailer may experience a variety of loads depending on the size of lift trucks and weight of cargo. Generally, automotive applications require a load rating of 20,000 or 24,000 pounds for the trailer floor [8]. Paper haulers require a load rating of 24,000 pounds or even higher. Large truckload carriers transport a variety of goods and they normally require a floor rating of 20,000 pounds. Table 3 lists nominal load ratings and weight savings of equivalent floors systems with standard steel cross-members at 12 inch spacing. The ratings are based on several fatigue tests. The 1.12 inch composite flooring is typically used as an equivalent to 1.38 inch standard oak flooring. The 1.19 inch composite flooring

<table>
<thead>
<tr>
<th>Thickness (Inch) of Equivalent Floors</th>
<th>Load Ratings (Pounds)</th>
<th>Unit Weight (Pounds per Square foot)</th>
<th>Floor Weight (Pounds)</th>
<th>Trailer Weight Savings (Pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.31 (1 5/16), Oak</td>
<td>16,000</td>
<td>5.1</td>
<td>1,938</td>
<td>228</td>
</tr>
<tr>
<td>1.06 (1 1/16), Composite</td>
<td>16,000</td>
<td>4.5</td>
<td>1,710</td>
<td></td>
</tr>
<tr>
<td>1.38 (1 3/8), Oak</td>
<td>17,000</td>
<td>5.35</td>
<td>2,033</td>
<td>228</td>
</tr>
<tr>
<td>1.12 (1 1/8), Composite</td>
<td>18,000</td>
<td>4.75</td>
<td>1,805</td>
<td></td>
</tr>
<tr>
<td>1.5  (1 1/2), Oak</td>
<td>20,000</td>
<td>5.85</td>
<td>2,223</td>
<td>323</td>
</tr>
<tr>
<td>1.19 (1 3/16), Composite</td>
<td>20,000</td>
<td>5.0</td>
<td>1,900</td>
<td></td>
</tr>
</tbody>
</table>
is normally used by fleets that require 20,000 and 24,000 pounds of load rating at a higher number of fatigue cycles than the minimum test requirement. The higher load rating of 24,000 pounds is obtained by using cross-members at 8 inch spacing.

**Water Soak and Drying Test**

Trailer floors experience water spray on their bottom side during road service. Further, the top side of the flooring can get wet when trailer doors are kept open during rain, from leaks in the trailer or by other means. Expansion and shrinkage of wood components of flooring due to the wet and dry cycles can cause delamination to occur. In the case of the composite floor, the composite panel prevents absorption of water by wood at the bottom side of flooring.

The water soak and drying test causes accelerated aging of boards. In this test, floorboards of size 36 inches x12 inches were fastened to steel cross-members using floor screws. Three screws were used at each cross-member. The floorboards on cross-members represent a small section of a trailer floor system. The boards on cross-members were immersed in a tub of water for 7 days and then dried in a kiln at about 1400 F for 2 days. The boards were then subjected to an additional soak and dry cycle. After the second drying period, the boards were removed from the cross-members and subjected to the offset bending test. The results of this test are shown in Table 4. Both the conventional oak floor and composite floor showed loss of strength after being subjected to the wet/dry cycles. However, the artificially aged composite floor was found to be stronger than the equivalent new conventional wood floor. Further, the composite panel showed little or no debonding from the wood boards.

<table>
<thead>
<tr>
<th>Floor Type and Thickness (Inch)</th>
<th>Failure Load of New Floor Boards (Pounds)</th>
<th>Failure Load of Aged Floor Boards (Pounds)</th>
<th>Reduction in Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Oak, 1 5/16</td>
<td>5,100</td>
<td>3,748</td>
<td>27%</td>
</tr>
<tr>
<td>Composite, 1 1/16</td>
<td>6,768</td>
<td>5,685</td>
<td>16%</td>
</tr>
<tr>
<td>Composite, 1 1/8</td>
<td>7,618</td>
<td>6,766</td>
<td>11%</td>
</tr>
<tr>
<td>Composite, 1 3/16</td>
<td>9,054</td>
<td>7,594</td>
<td>16%</td>
</tr>
</tbody>
</table>

**Figure 9 »** Composite boards after soak/dry test show good bonding of composite panel to wood.
Effects of Nailing the Composite Flooring

It is quite common in some operations of trailer fleets to nail blocks into the flooring to prevent the shifting of cargo during transportation. Composite flooring can be nailed like standard wood flooring. The transverse fibers in the composite panel help to prevent potential splitting of the floor board. By its very nature, oak is resistant to splitting more than other common hardwoods [1]. Nailing into composite flooring is not known to cause gross delamination of the composite panel in dry or wet state. In one test conducted by a trailer manufacturer, a 6 inch wide composite board was nailed two times. The board was immersed in water for six months and then allowed to dry for six more months. Around the nail holes, the color of the laminate turned black due to leaching of wood, however, the composite panel maintained its bonding to oak with little or no delamination.

Figure 10 » Bottom side of composite board with nail holes after soaking in water

Figure 11 » End section of composite board with nail holes after soaking in water for 6 months
10 Years of Field Testing

During the early stages of the research and development of the composite flooring, many of the advantages of this product were recognized based on laboratory testing. To ensure that the composite flooring would perform as expected, field testing was undertaken in 1995. About a dozen kits of composite flooring were fabricated using a fifty foot long hot press. The materials used included woven glass fabrics and epoxy resin. These test kits were installed in trailers belonging to various fleets. After 10 years of field testing, one trailer was brought back for observations in 2005. The aged composite flooring was found to be in good condition without any visible sign of debonding of the composite panel. The floor boards were flat with no sign of warping. The top side showed signs of wear and tear from the dragging of objects and lift truck operation. At the rear section near the doors, the wood components showed partial debonding at the top side. This was caused by water ingress into the wood from the top side of flooring. The bottom side showed good bonding of the composite panel to wood. Some of the aged composite boards were removed for offset bend testing. The 1.19 inch field tested composite floor board showed a 22% loss of strength from 7,883 pounds when newly installed to 6,166 pounds after 10 years of service. The results showed that the ten year old composite floor board is stronger than a new 1.31 or 1.38 inch standard oak floor board.
Figure 14 » Underside of 10 year old composite flooring in a trailer

Figure 15 » Cross-section of 10 year old composite flooring away from the rear doors of trailer

Figure 16 » Cross-section of 10 year old composite flooring near the rear doors of trailer
Figure 17 » Three point bending test of 10 year old composite flooring

Figure 18 » Offset bending test of 10 year old composite flooring
Lifetime Benefits Analysis of Composite Flooring

The total cost of composite flooring includes the cost of the wood board, the composite panel, reactive hotmelt adhesive and labor for the composite bonding operation. The saving encountered with the manufacture of composite flooring comes from the use of a thinner layer of wood since a thinner composite flooring is equivalent to thicker conventional oak flooring. The net cost of the composite flooring is higher than the cost of the equivalent oak flooring and accordingly, the initial purchase price of the composite flooring is also higher. In general, price of flooring to transportation companies is subject to the market conditions and several other uncontrollable factors. For the sake of simplicity, an effort is made here to quantify the economic benefits of composite flooring based on available data for the value of weight savings [9] and personal communications with trailer dealers and sales professionals in the USA. The economic benefits of the composite flooring are derived as follows:

1) Lower overall trailer weight – This weight saving is the result of the reduced weight of the composite flooring and in some cases the elimination of the threshold plate. Reduced weight increases fuel efficiency and the payload that the trailer can legally transport thus resulting in higher revenue.

2) Reduced repair costs – Composite flooring has established a record of reduced repairs in service thus resulting in savings of the cost of repair and reduced downtime.

3) Elimination of the threshold plate – Some users find that the composite floor eliminates the need for a threshold plate. This reduces the cost of manufacture of trailer and has the potential of reducing the initial acquisition cost of the trailer.

4) Improved resale value – Trailers with composite flooring are estimated to receive a higher trade-in value at the time of trade-in.

The table below attempts to quantify the economic benefits of the above advantages using estimates from various government and industry sources. By its very nature, the table below is an estimate and the actual benefits to any single transportation company could vary. Each fleet will normally make such an evaluation based upon its own criteria and estimates. For example, the benefits from the elimination of threshold plate may not apply to those fleets which do not normally use such a plate or if they use a trailer where the flooring does not extend to the rear door frame. Table 5 illustrates the estimated total gross benefit over a ten year period as well as an estimate of the net present value of those benefits assuming a discount rate of 7%. All amounts are in US dollars.

<table>
<thead>
<tr>
<th>Type of Benefit</th>
<th>Total Gross Benefit</th>
<th>Net Present Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Savings</td>
<td>$1,330</td>
<td>$934</td>
</tr>
<tr>
<td>Repair Cost</td>
<td>$150</td>
<td>$105</td>
</tr>
<tr>
<td>Reduced Downtime</td>
<td>$200</td>
<td>$140</td>
</tr>
<tr>
<td>Elimination of Threshold Plate</td>
<td>$170</td>
<td>$170</td>
</tr>
<tr>
<td>Improved Resale/Trade-In Value</td>
<td>$250</td>
<td>$127</td>
</tr>
<tr>
<td>Additional Payload Revenue</td>
<td>$100</td>
<td>$70</td>
</tr>
<tr>
<td>Total</td>
<td>$2,200</td>
<td>$1,546</td>
</tr>
</tbody>
</table>

*This table reflects 2007 pricing.*
Commercial scale production and sales of the composite flooring for van trailers began in 2000. During the first five years, dedicated trucking companies engaged in the transportation of paper rolls, beverage, carpet, architectural glass plates and automotive parts were the primary customers. Due to specific issues related to the nature of these types of transportation operations, it was relatively easier to justify the need for composite flooring. The justifications for choosing composite flooring over conventional flooring were one or more of the following reasons: weight savings, high number of load cycles, need for moisture protection, heavy lift truck loads and occasionally, even narrow tire widths of lift trucks. In the recent times, large fleets are considering composite flooring with the goal of extending the lifetime of the trailer to more than seven years before trade-in of trailer. The potential higher trade-in value of a trailer with composite flooring provides further motivation. Market demand for composite flooring has consistently grown for the past six years. About 25,000 van trailers having composite flooring are currently in operation all over North America. One such trailer was exhibited at the American Composite Manufacturers Association tradeshow at St. Louis, Missouri in 2006. This trailer belongs to a relatively new category of operation for composite flooring, namely the large truckload carriers who are typically involved in the transportation of industrial goods of all kinds. In this type of operation, the number of load cycles on the floor is a not a major consideration due to relatively low frequency of loading and unloading of trailers, however, reduced maintenance, longevity of flooring and weight savings are significant considerations.

Figure 19 » Trailer with composite flooring exhibited at the ACMA tradeshow in 2006
Composite Flooring for North American Van Trailers

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and
Bruce Bader, President
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