Comparative study of four adhesives used as binder in engineered wood parquet flooring

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Abstract

Engineered Wood Parquet Flooring (EWF) is gaining popularity since it appeared in Europe in the 1970s. In 1999, two-thirds of the wood parquet installed in Europe was EWF; in the United States it was one third. Even though EWF has captured these market shares, knowledge of the product and its behavior is very limited. Relative humidity variations occurring between summer and winter conditions in North America can induce hygro-mechanical deformation and permanent fatigue in composite material, which results in a decrease of the mechanical performance of the glue line. The objective of this study was to evaluate the glue line shear strength lost in EWF over cycles of summer and winter conditions. Four adhesives, polyvinyl acetate (PVA), urea formaldehyde (UF), melamine urea formaldehyde (MUF), and polyurethane (PUR) were tested following nine cycles of accelerated aging. In accordance with the manufacturing parameter in this study, the best adhesive to bond the EWF layer was found to be the PUR adhesive for the stability of its glue line strength following aging cycles. UF and MUF showed similar behavior with a shear strength decreasing with the number of aging cycles. PVA was not expected to be an appropriate adhesive for EWF and this was confirmed in the study.

Engineered wood parquet flooring (EWF) increases its global market share every year. Irland (1990) and Lamy (1997) note that EWF is proving to be very popular, and that wood parquet in general has made a remarkable come-back since the early 1980s. Rapid growth in the market share appears to be related mostly to the repair and remodeling sector and to consumers’ desire for a healthier indoor environment. Total shipments of EWF have been growing at a faster rate than the total flooring material footage area (Anonymous 1998, Irland 1990) and there is no reason to suspect that this trend might change over the next few years. Beauregard (1998) notes that, in Western Europe, in 1996, wood parquet flooring material made 4.6 percent of the total flooring material. In Europe again, multilayer wood parquet accounted for two-thirds of the total wood flooring products. Floor Covering Weekly (Anonymous 2000a) reports that carpets have been losing market share to wood products because homeowners are converting to healthier products. Like other wood flooring products, EWF allows no hiding place for dust and airborne EWF provides an alternative to traditional solid hardwood parquet without compromising its warm appearance. Installation is easy and is within the handyman’s capabilities. Installation is hence cheaper than other types of wood flooring material (Anonymous 2000b).

Knowledge of EWF is limited and generally held privately by the product developer. Previous work has defined the performance criteria and the behavior of this wood composite product (Lefebvre et al. 2001). Cupping deformation can be very important following hygrometric condition changes. In fact,

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*Forest Products Society Member.
†Forest Products Society 2003.

Forest Prod. J. 53(1):89-93
an important turnover in relative humidity (RH) occurs between the summer and winter conditions in North America over a 1-year period. The working hypothesis for this work was that hygromechanical deformation could induce permanent fatigue in the composite material that can result in a decrease of the mechanical performance of the glue line. In this case, an EWF product, generally sold with a 25-year warranty by the manufacturer, is at risk of not performing well for its entire service life.

The purpose of this study was to evaluate the strength loss in the glue line of EWF due to cyclic hygromechanical deformation in the composite material following changes in the environment conditions.

**Materials and methods**

Four adhesives were investigated: polyvinyl acetate (PVA), urea formaldehyde (UF), melamine urea formaldehyde (MUF), and polyurethane (PUR). PVA type III (single component) was chosen to validate the method used to age the samples. This PVA behavior was known as not appropriate under highly variable conditions of temperature and humidity and this is why this adhesive was chosen. A PVA type I (cross-linked) might have been more appropriate to bond this product in an industrial setting, but our aim was to obtain contrast in comparing the various adhesives. Usually, the PVA adhesive used in this study is not used in EWF. UF, MUF, and PUR are more commonly used by the EWF industry to bind the face and core layers together.

The UF- and MUF-bonded EWF strips were cured in a hot-press according to the adhesive supplier specifications for this kind of application. PVA-bonded strips were also pressed according to the supplier-suggested conditions in a cold-press. Finally, PUR was cold-pressed with an infrared wood heater on an adhesive application system at an industrial EWF line, also under the recommendations of the adhesive supplier. Table 1 gives an overview of the gluing conditions used in this study.

The adhesives were used to bond a 4-mm-thick, 65-mm-wide, and 600-mm-long sugar maple wear layer over a set of cross-grain 8-mm thick, 22-mm width, and 65-mm-long sticks (Fig. 1).

As suggested by the working hypothesis, the fatigue in the glue line can induce hygromechanical deformation. To
evaluate glueine fatigue, 2-layer EWF samples were fabricated. The resulting parquet is as shown in Figure 1. The samples were built with sugar maple in accordance with the ASTM standard D 905-94 (ASTM 1994), standard test method for strength properties of adhesive bonds in shear by compression loading. Based on this standard, a methodology was developed to test EWF. Because of the crossed-grain layers, the surface layer tends to buckle during the compression loading as shown in Figure 2. To avoid this deformation and maintain the stress in shear during the compression test, a metal plate was glued to the surface of the sample as suggested by Lang et al. (2000). This situation is illustrated in Figure 3. The metal plate was bonded to the sample with hot melt adhesive.

Kinloch (1987) discussed simulation of environmental attack, such as water vapor, for adhesive in service. He suggested controlling the aging schedule as much as possible to be sure that the degradation of the adhesive is representative of the in-service degradation. He also suggested accentuating the real conditions. The accelerated aging test chosen in this study consisted of alternating conditioning cycles, the conditions being selected according to the products at test and the purpose of the test. In this case, two chambers were used: one replicating a dry and warm climate (49°C, 25% RH), the other replicating a low temperate, humid climate (20°C, 80% RH) as described in ASTM D 1183-96 (ASTM 1996) and EN 29142 (AFNOR 1993) testing methods. Cycle duration was 1 week, with conditions alternating according to a predetermined schedule shown in Figure 4. Climate cycling increases hygroscopic exchanges and wood moisture content gradient, which amplifies wood shrinkage and expansion. Hygromechanical movements of the wood components induce glue-joint fatigue.

The EWF strip, edge, and bottom face, were isolated with a silicon sealant and aluminum foil. This was done to limit the water vapor movement through these surfaces of the strip and reproduce the behavior of EWF in service. The following strips were prepared for each adhesive: 60 strips, 600 mm long, to ensure 10 shear block samples (50 mm by 50 mm) as shown in Figure 5. The first series of blocks were used for the initial shear strength measurement immediately after manufacturing. The nine others were cut one after each of the nine aging cycles performed on the EWF strips.

Results were analyzed with the Statistical Analysis System (SAS®): analysis of variance (ANOVA), regression, and Duncan multiple comparison tests. Table 2 shows the experimental design. In this table, dependent variables are the type of adhesive and the number of conditioning cycles performed. Interaction between these variables was also considered in the model.

**Results and discussion**

Table 3 presents the results by adhesive after each aging cycle. The results are also illustrated in Figure 6. It is important to note that cycle 1 was not considered in the statistical analysis and is not presented in Figure 6, because of an equipment malfunction, which increased the time period between the end of the first cycle and the moment of testing. This situation had modified the hy-

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**Table 2.** Experimental design used for the ANOVA in this study.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
</tr>
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<tbody>
<tr>
<td>Adhesive type</td>
<td>3</td>
</tr>
<tr>
<td>Cycle no.</td>
<td>9</td>
</tr>
<tr>
<td>Replication</td>
<td>15</td>
</tr>
<tr>
<td>Interaction cycle no.</td>
<td>adhesives type</td>
</tr>
<tr>
<td>Error term</td>
<td>585</td>
</tr>
<tr>
<td>Total</td>
<td>639</td>
</tr>
</tbody>
</table>

**Table 3.** Average shear test value by adhesive following aging cycles.

<table>
<thead>
<tr>
<th>No. of conditioning cycles</th>
<th>PVA</th>
<th>PUR</th>
<th>MUF</th>
<th>UF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(MPa)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>4.3</td>
<td>5.0</td>
<td>6.0</td>
<td>5.9</td>
</tr>
<tr>
<td>2</td>
<td>4.1</td>
<td>5.3</td>
<td>4.2</td>
<td>4.9</td>
</tr>
<tr>
<td>3</td>
<td>2.7</td>
<td>5.6</td>
<td>4.6</td>
<td>4.2</td>
</tr>
<tr>
<td>4</td>
<td>3.1</td>
<td>5.4</td>
<td>4.2</td>
<td>4.3</td>
</tr>
<tr>
<td>5</td>
<td>2.2</td>
<td>5.2</td>
<td>4.1</td>
<td>4.2</td>
</tr>
<tr>
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<td>2.2</td>
<td>5.2</td>
<td>4.2</td>
<td>4.2</td>
</tr>
<tr>
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<td>5.1</td>
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<td>8</td>
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<td>3.3</td>
<td>3.1</td>
</tr>
<tr>
<td>9</td>
<td>1.8</td>
<td>5.7</td>
<td>3.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>

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Figure 4. Aging cycle used in this study adapted from ASTM D 1183-96 and EN 29142:1993.
grososcopic equilibrium of the samples and it was not possible to compare them with the other conditioning cycles.

The adhesives evaluated in this study showed different initial shear strength. A Duncan multiple comparison test \( (\alpha = 0.05) \) was done on the shear value immediately after manufacturing. This test was made to determine the initial shear strength ranking. Table 4 shows these rankings. PVA and PUR showed a comparable performance, as did UF, MUF, and PUR. However, PVA was statistically different from UF and MUF.

In Figure 6, three trends can be observed. PVA, UF/MUF, and PUR appeared to have different behaviors from each other. The statistical analysis confirmed these differences with a significant \( (\alpha = 0.01) \) interaction between the type of adhesive and the aging cycle on the shear strength.

PVA behaved as expected. A significant decreasing relation \( (\alpha = 0.01) \) was observed, showing a linear loss of shear strength in the glue line. An 86 percent \( r^2 \) was obtained for this linear regression (Fig. 6). It is clear that each cycle increased the fatigue in the glue line and decreased its strength. It is also possible that moisture attacked the glue line because the PVA is swellable and this may have affected the glue line strength negatively. In fact, PVA single component is a single-part thermoplastic-based emulsion adhesive, and as such, is not cross-linked. That is why it was swelled by water and had a lower performance. PVA was used to confirm the sensitivity of the accelerated-aging method since Type III PVA is known not to be appropriate to use in EWF.

Both formaldehyde-based adhesives had a behavior similar to the PVA adhesive, except for the initial shear strength value. The shear strength slopes for PVA, UF, and MUF were not significantly different but initial shear strength was found to be significantly different. Initial values computed for MUF/UF regression were 40 percent higher than that of PVA (4.3 kPa). This indicates an overall weaker performance for PVA when compared to the UF/MUF. For PVA and UF/MUF, shear strength linearly decreased with the number of aging cycles. The relationships between the adhesives and the aging cycles were significant \( (\alpha = 0.01) \) with an \( r^2 \) of 91 percent for the UF and 84 percent for the MUF. River et al.
(1991) obtained similar trends in their evaluation of various adhesives. A study done by Northcott and Hancock (1966) showed a difference of behavior between UF and MUF with the time when the adhesive was submitted to direct water immersion at 22°C. In that case, MUF was more efficient. Another study made by Chang et al. (1997) on the glueline moisture contact with water immersion again showed a decrease of the shear strength when the adhesive was hydrolyzed. In the present study, the moisture attack was done by water vapor diffusion in the composite material. Since the UF resin had an identical behavior to the MUF, it is believed that water vapor in the sample did not hydrolyze the glueline. The shear strength decrease appears to be more attributable to fatigue due to EWF repeated deformation following the condition change during the aging cycle. The polyurethane adhesive did not show any shear performance decrease over the aging cycle (Fig. 6). This means that over the span of those nine aging cycles, this adhesive had a better performance than others to RH variation and to fatigue due to movement of layers in the composite parquet. Absence of performance deterioration was confirmed by ANOVA.

Duncan test results (α = 0.05) on the shear value after nine aging cycles are given in Table 4. This confirms the different behaviors of each adhesive as illustrated in Figure 6. From Table 4, it is clear that PUR was the strongest after nine aging cycles and PVA was the weakest.

The molecular reaction between the isocyanate groups in the PUR adhesive and the moisture in wood can explain these results. Functional groups cross-link to produce a glueline with all the characteristics of thermosetting products. The results of this process are to impart to the glueline a high resistance to water and water vapor (Bandel 1995). That is not the case with PVA and UF, which are hydrolysable adhesives. Furthermore, the PUR used in this study had a 700 percent elongation, at break, a property that allows the parquet to deform without sacrificing bond performance, PVA, UF; and MUF do not allow elongation as PUR does.

**Conclusion**

Only limited knowledge on EWF is available even though this product has steadily gained market share in recent years and was 60 percent of the wood flooring market in Europe and 30 percent of wood flooring market in the United States. It is an innovative product, which maximizes recovery from high value wood species by limiting their use to the face layer, while cheaper wood products can serve as support material. The purpose of this study was to shed some light on time-related problems and focus on the specific issue of glueline aging. Four adhesives (PVA, PUR, MUF, and UF) were tested following nine cycles of accelerated aging.

Hygromechanical movements of the wood induce glue-joint fatigue. Climate cycling increases hygroscopic exchanges, which amplifies wood shrinkage and expansion. After each aging cycle, the joints were tested for shear strength of the glueline and the results showed that the four adhesives could be classified into three main groups, PVA, MUF/UF, and PUR, on the basis of their chemical composition and performance. Shear strength differences between the PUR and PVA adhesives were not statistically significant at the beginning of the aging cycles. This was also the case between PUR and MUF/UF. On the other hand, significant differences were initially found between PVA and MUF/UF. At the end of the nine cycles, differences between the three groups were statistically significant. PUR came out as the strongest, followed by MUF/UF; PVA was the weakest. The tests revealed that, with PVA and MUF/UF, the shear strength of the glueline declined gradually through testing. On the contrary, the performance of the PUR adhesive was constant throughout the nine aging cycles. A classification of these adhesives would therefore be that PVA is the least resistant to moisture conditioning, followed by MUF/UF, with the PUR exhibiting the highest and most consistent performance. Actually, the PUR bond showed no sign of deterioration over the nine-cycle test, suggesting that its higher cost is well justified.

It would be interesting to pursue this study beyond nine cycles to evaluate the performance of the four adhesives, particularly the PUR. Assuming that the ultimate shear strength of PUR would eventually deteriorate, the test would provide an evaluation of the behavior's magnitude difference between PUR and the other adhesives.

**Literature cited**


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