CHARACTERISTICS OF DELAMINATED EXTERIOR HARDWOOD PLYWOOD

Project F-918
by
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CONCLUSIONS

1. Kapur is not the only species group that delaminates. Just as many failures were found with keruing/apitong veneers, and occasional failures occurred with meranti/lauan veneer.

2. When delamination had started in a glueline, the "sound" areas of that glueline could be knifed readily with little wood failure.

3. Insufficient adhesive spread was either the major cause of or a contributor to the delamination of half of the panels studied.

4. Excessive shrinking and swelling of face veneers was not the ultimate cause of the delamination, although it likely hastened delamination.

5. Even when ample adhesive was present, keruing and kapur were not penetrated by the phenolic adhesive. These unanchored gluelines failed without fracturing either the adhesive or the wood.

6. Two of the three durian gluelines failed because the adhesive overpenetrated the face veneer, starving the glueline.
INTRODUCTION

Shortly after United States plywood manufacturers began producing exterior siding panels with South East Asian hardwood faces, sporadic delaminations began to appear in panels in use. Much speculation followed as to the causes for these field failures.

Some speculated that delamination resulted from excessive shrinking and swelling of the dense face veneers, causing inordinate stress on the glueline. Some suggested that a combination of high veneer dryer temperature and high extractive content created veneer surfaces that were difficult to wet with phenolic adhesives. In fact many believed that the adhesive might bond only to a layer of extractives, never reaching the woody cell wall. Others speculated that delamination occurred because the extractives interfered with the cure of the phenolic resin.

In response to this problem, the School of Forestry at Oregon State University initiated a research project to establish bases for segregating troublesome South East Asian hardwood veneers and to determine the causes for poor bonding of these veneers. The results reported here are the first study in that project. This study had the objective of thoroughly analyzing a random assortment of field delaminations in order to make preliminary decisions about the causes for delamination.

STUDY METHODS

Sixty-two delaminating exterior plywood panels, or parts of panels were obtained from the various manufacturers. Each panel represented a different installation. Every veneer was identified as to species group and its general condition was noted. Every glueline in each panel was knifed, and observed under the microscope, estimating the % wood failure and the extent of adhesive
flow, transfer and penetration. Depth of penetration was estimated under the microscope in two ways: by gently probing into the face of a veneer, lifting fibers until unpenetrated cells were reached, and by examining the cut edges of gluelines with reflected light. Adhesive spread was assumed to be adequate only if the adhesive had flowed horizontally and vertically to fill the voids on the hardwood face veneer. Selected gluelines were also studied with the scanning electron microscope to confirm the light microscopy.

HARDWOOD SPECIES OCCURRING IN DELAMINATED PLYWOOD

Kapur (Dryobalanops spp.) and apitong or keruing (Dipterocarpus spp.) were the predominant veneers that delaminated. Table 1 shows that these two groups of woods were encountered in about equal numbers, with a limited number of lauan/meranti (Shorea, Parashorea, and Pentacme spp.), durian (Durio spp.) and nyatoh (Sapotaceae) veneers also being found.

GENERAL DESCRIPTION OF GLUELINES

1. Back/Core

The back to core gluelines were all Douglas-fir or cottonwood bonded to Douglas-fir. Every one of these gluelines knifed with difficulty, resulting in 100% wood failure. Adhesive had penetrated deeply into the backs, often as much as 6-8 cells deep, and these cells appeared to be thoroughly impregnated by adhesive. This same appearance occurred even when the other gluelines in the panels appeared dried out.

2. Center/Core

The center/core gluelines were all South East Asian hardwood bonded to Douglas-fir cores. Their appearance was identical to the face/center gluelines discussed next, except that the center/core gluelines were degraded less than the face/core gluelines. As seen in Table 1 five (5) panels delaminated only in the center. These centers were durian (2), meranti (1), and keruing (2).
Those durian and meranti gluelines were obviously starved because of over-penetration of the center, whereas the keruing gluelines were against extremely rough lower cores.

The remaining 17 five-ply panels all had face delamination, but only 9 of those were delaminated in the center. The center delaminations were much less extensive than the face delaminations, and generally occurred adjacent to grooving in the panel. As can be seen from Table 2, however, once a center started delaminating it could be knifed with very low wood failure in comparison to those centers with no delamination.

3. **Face/Core**

The face/core gluelines were uniformly poor bonds. As can be seen in Table 2, when those gluelines were knifed back into "sound" areas, the % wood failure averaged 10%. Occasionally, knifing across edge bonded face strips revealed a difference in bond quality between the two face strips, even though they were from the same species group.

The face/core gluelines could be divided into three categories based on appearance: insufficient spread, unanchored, and starved. The occurrence of these difficulties was, in part, species related, so each is discussed separately.

1. **Insufficient spread**—Low spread coupled with dry out and rough core was the single most important production difficulty encountered. This can be seen in Table 3. We have no knowledge of the actual spread levels used for the panels studied, but we do know that most manufacturers have increased both the amount of adhesive spread and the % resin solids in the adhesive in comparison to those used earlier for production of hardwood plywood siding.
The necessity for high spreads is obvious from Figures 1-4, microtome sections of wood from the species groups studied. Photograph "a" in each pair is the cross section or end grain of the wood. This is analogous to looking at the end of a veneer strip. Thus, the upper edge of the photographed wood is like a profile of a veneer surface (without lathe checks). In Figure 1, Douglas-fir has a moderately smooth profile which adhesive must be pressed against to form a continuous glueline. Figures 2, 3, and 4 show that the surface profile for meranti, keruing and durian is considerably more irregular because of the large open pores in these woods. Kapur is not pictured because it is so similar to keruing. Thus adhesive spread must be increased on all of these woods to fill the large pores.

In addition, adhesive penetrates into the wood rays. The wood rays appear as lens-shaped groups of cells on the tangential surface (photograph "b" in each set. The tangential surface is the surface of a sheet of veneer). These ray cells penetrate about 3-5 thousandths of an inch into the thickness of a veneer, or about 1/4 to 1/2 as deep as the large pores are wide. Even though the ray cells penetrate only a short distance, they do represent a cavity that must be filled to form a continuous glueline. Note that the area occupied by ray cells in Douglas-fir is considerably less than the ray area for the hardwoods.

When such open textured woods as these hardwoods are bonded to roughly peeled, or severely lathe checked Douglas-fir, the adhesive requirements become even greater.
2. **Unanchored gluelines**—Table 3 shows that unanchored gluelines were the major difficulty with both keruing and kapur. We use this term "unanchored" to describe a condition seldom seen in Douglas-fir plywood. When a panel with either keruing or kapur face veneer was knifed or had delaminated, the adhesive and the wood separated almost perfectly at the interface between them. Neither the adhesive fractured nor did the wood fail. The adhesive must have been fluid during pressing, and the spread must have been ample because the adhesive flowed to completely fill the pores and lathe checks of the hardwood face veneer. But we could find little evidence for adhesive penetration beyond this surface. When the panel failed, the ridges of adhesive filling the pores and lathe checks separated from the wood leaving the adhesive as an almost perfect moulding of the hardwood surface.

A scanning electron micrograph of an unanchored glue film from a delaminated glueline is pictured in Figure 5. The ridges seen there are the phenolic resin that cured in the pore structure of the wood and then separated from it. There is little evidence for wood failure even in the valleys where wood fiber was obviously pressed against the adhesive. Figure 6 is a scanning electron micrograph of a keruing face that separated from the adhesive. There are no plugs of adhesive left in the pores of the wood, verifying the cleanness of the separation.

These "unanchored" gluelines in keruing and kapur were even partially evident when the adhesive spread was low. Thus this condition seems to describe the generally occurring difficulty with those species.

Several factors could cause such unanchored gluelines. They would result if the adhesive failed to wet and penetrate the wood, and they
would also occur if the adhesive bonded to a thin layer of extractives that later leached from the glueline. From these observations we cannot say which of these causes is involved. Unanchored gluelines might also occur if the extractives at the wood surface dissolved into the adhesive and either accelerated its cure or made it too viscous to penetrate the wood structure.

One fact does emerge from these observations. Shrinking and swelling of the wood veneer could not have been the major cause of delamination. If it were the major cause, and if a good adhesive bond existed initially, more wood failure should have occurred. We observed almost none in any of the panels described as "unanchored".

The "unanchored" kapur gluelines differed from keruing in one significant way. When the kapur separated from the adhesive, the wood surface was invariably blackened, even though the adhesive separated cleanly. At high magnification only small amounts of adhesive could be seen beyond this thin blackened surface layer. Possibly this layer is extractive material, but it could not be completely removed with 1% sodium hydroxide.

Two lauan/meranti gluelines were "unanchored", and otherwise resembled the keruing gluelines. The face veneer peeled from such a glueline is pictured in Figure 7. Most lauan/meranti gluelines broke with wood failure as pictured in Figure 8, if the spread was adequate. And even when the spread was low, wood failure occurred on the ridges of the roll spreader pattern.

3. Starved gluelines—Although only three durian gluelines were examined in detail, two of them appeared substantially different from any other gluelines examined. These two gluelines were obviously starved because
of overpenetration of resin into the durian. A scanning electron micrograph of one of the durian faces, Figure 9, shows the plugs of adhesive in the pore structure. And at very high magnification adhesive plugs could be seen in the open ends of ray cells, Figure 10. This excessive penetration was readily obvious even with the light microscope. Whether or not excessive penetration is a general problem with durian cannot be concluded from only three observations.
Table 1. Hardwood species occurring in delaminated plywood.

<table>
<thead>
<tr>
<th>Species Group</th>
<th>Face* Delaminated</th>
<th>Center Delaminated</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Kapur</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>Apitong/Keruing</td>
<td>27</td>
<td>0</td>
</tr>
<tr>
<td>Lauan/Meranti</td>
<td>7</td>
<td>5</td>
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<tr>
<td>Durian</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Nyatoh</td>
<td>0</td>
<td>0</td>
</tr>
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</table>

*based on 25 samples of face veneer only, 15 samples of 3 ply, and 22 samples of 5 ply plywood.

Table 2. % wood failure in knifed glue-lines from delaminated panels.

<table>
<thead>
<tr>
<th>Species Group</th>
<th>Face Delaminated</th>
<th>Center Delaminated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Kapur</td>
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<td>--</td>
</tr>
<tr>
<td>Apitong/Keruing</td>
<td>10</td>
<td>--</td>
</tr>
<tr>
<td>Lauan/Meranti</td>
<td>15</td>
<td>55</td>
</tr>
<tr>
<td>Durian</td>
<td>10</td>
<td>--</td>
</tr>
<tr>
<td>Nyatoh</td>
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Table 3. Probable causes of field delaminations

<table>
<thead>
<tr>
<th>Species Group</th>
<th>Low Spread</th>
<th>Over-penetration</th>
<th>Unanchored</th>
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<tbody>
<tr>
<td></td>
<td>Dryout</td>
<td>Rough Core</td>
<td>Starved</td>
</tr>
<tr>
<td>Kapur</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Apitong/ Keruing</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Lauan/ Meranti</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Durian</td>
<td></td>
<td>2</td>
<td>2</td>
</tr>
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</table>
Figure 1. Anatomy of Douglas-fir wood.  a, cross section; b, tangential section. Magnification 50X.
Figure 2. Anatomy of meranti (Shorea spp.) wood. a, cross section; b, tangential section. Magnification 50X.
Figure 3. Anatomy of keruing (Dipterocarpus spp.) wood. a, cross section; b, tangential section. Magnification 50X.
Figure 4. Anatomy of durian (Durio spp.) wood. a, cross section; b, tangential section. Magnification 50X.
Figure 5. Phenolic glueline after delaminating from keruing face. Magnification 100X.
Figure 6. Keruing face after delaminating from phenolic glue line. Magnification 50X.
Figure 7. Meranti face after delaminating from phenolic glue line. Magnification 50X.
Figure 8. Durable glueline of meranti (upper layer) on Douglas-fir (lower layer). Magnification 50X.
Figure 9. Durian face after delaminating from phenolic glueline. Magnification 50X.
Figure 10. Ray cell plugged with phenolic resin on durian face. Magnification 1000X.