Strength of Screws in Wood Composites

As a Function of Specific Gravity

Face Holding Strength in Particleboard

Particleboard is widely used in furniture construction, primarily as core stock material for table and counter tops, for case sides, and for such applications as doors and drawer fronts. It is also used to a limited extent to fabricate structural members in furniture such as the front rail on certain types of sofas. Screws are most frequently used in conjunction with particleboard to attach various types of hardware such as brackets and hinges to the particleboard itself.

The average ultimate withdrawal strength of screws embedded in the face surface of a sheet of particleboard may be predicted by means of the expression

\[ F_{\text{face}} = 2.655 \times D^{1/2} \times (L - D/3)^{5/4} \times G_x^2 \] (6-22)

where

- \( F_{\text{face}} \) = withdrawal strength from the face of particleboard, in;
- \( G_x \) = specific gravity based on weight when dry and volume at current moisture content;
- \( L \) = depth of penetration of the screw, in.

For convenience a number of values of the quantity \( 2.655 \times D^{1/2}(L - D/3)^{5/4} \) have been calculated and are given in Table 6-17. It should be noted that this expression is based upon the specific gravity of the particleboard at current moisture content rather than on density which is commonly used. According to this formula withdrawal strength is proportional to the square root of the diameter of the screw. This is in contrast to the case with solid wood in which withdrawal strength is directly proportional to the diameter of the screw. A simple example serves to illustrate the use of the above equation.

**Example:** Calculate the withdrawal strength of a number 10 sheet metal type screw that is embedded 3/4 of an inch in the face of a piece of particleboard that has a density of 50 pounds per cubic foot at a moisture content of 10 percent.

In order to solve this problem we first calculate the specific gravity of the particleboard by utilizing the relationship

\[ G_x = W_x \times (1 - mc/100) / 62.4 \] (6-23)

where

- \( W_x \) = the density of the board, lbs/ft³;
- \( mc \) = moisture content in percent.

Substituting the appropriate values into this expression gives

\[ G_x = 50 \times (1 - 10/100) / 62.4 = 45 / 62.4 = 0.72 \]

Referring to Table 6-17 we see that the appropriate length-diameter factor for a number 10 screw embedded 3/4 inches in the face of particleboard is 723.4. Also, from Table 6-18 we see that \( G_x^2 \), that is, 0.72 squared is 0.518. Substituting these values into equation 6-22 gives

\[ F_{\text{face}} = 723.4 \times 0.518 = 374.7 \text{ lbs}. \]
Table 6-17.  Length diameter factors for screw withdrawal from the face of particle-board.  These factors are calculated values of the quantity \(2655D^{1/2}(L-d/3)^{5/4}\) and are to be used in equation (6-22) of the text.

<table>
<thead>
<tr>
<th>Depth of Penetration – Inches</th>
<th>Screw Gage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1/4</td>
</tr>
<tr>
<td></td>
<td>111.6</td>
</tr>
<tr>
<td>2</td>
<td>118.2</td>
</tr>
<tr>
<td>3</td>
<td>123.7</td>
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<td>13</td>
<td>136.6</td>
</tr>
<tr>
<td>14</td>
<td>132.5</td>
</tr>
</tbody>
</table>

Edge Holding Strength in Particleboard

The withdrawal strength of screws embedded in the edge of particleboard can be predicted by means of the expression

\[ F_{\text{edge}} = 2055 \times D^{1/2} \times (L - D/3)^{5/4} \times G_x^2 \]  

(6-24)

where \(F = \) withdrawal strength from the edge of the particleboard in pounds and the other symbols have the same meanings defined for face withdrawal.  Since all of the relationships expressed here are identical to those for face withdrawal, edge withdrawal strength can be expressed as a fraction of face withdrawal; namely

\[ F_{\text{edge}} = \frac{2055}{2655} \times F_{\text{face}} = 0.774 \times F_{\text{face}} \]

or, rounding this value for convenience in using Table 6-17,

\[ F_{\text{edge}} = \frac{3}{4} \times F_{\text{face}} \]  

(6-25)

To demonstrate the use of equation 6-25, consider the following example.

Example: Find the withdrawal strength of a number 8 screw that is embedded 7/8 inches in the edge of a piece of particleboard which has a density of 40 lbs/ft³ at a 10 percent moisture content level.

From equation (6-23) we see that the specific gravity of the particleboard is

\[ G_x = 40 \times (1 - 10/100) / 62.4 = 0.58 \]

and from Table 6-18, \( G_x^2 = 0.336 \).  Since \( F_{\text{edge}} = 3/4 \times F_{\text{face}} \), we can calculate the appropriate length diameter factor by finding the corresponding factor for face withdrawal in Table 6-17 and multiplying it by 3/4.  Carrying out these operations and making the appropriate substitutions in equation 6-25 gives
Face Holding Strength in Medium Density Fiberboard

Tests carried out by the author (Eckelman, 1973) indicate that the withdrawal strength of screws from hardwood fiberboard is somewhat greater than from particleboard. In particular it was found that the withdrawal strength of a screw from the face of a homogeneous hardwood medium density fiberboard could be predicted by the relationship

\[ F(\text{face}) = 3700 \times D^{\frac{3}{2}} \times \left( L - \frac{D}{3} \right)^{\frac{3}{2}} \times G_x^2 \]  

6-26

Because this expression is of the same form as equation 6-22, the withdrawal strength of screws from fiberboard can be expressed as a multiple of that for particleboard; namely

\[ F(\text{face, fiberboard}) = \frac{3700}{2655} \times F(\text{face, pbd}) = 1.394 \times F(\text{face, pbd}) \]

According to this expression, therefore, the withdrawal strength of screws from the face of hardwood fiberboard may be taken as 40 percent greater than the withdrawal strength of screws from softwood particleboard of the same density. For convenience in using Table 6-17, equation 6-26 can be rewritten as

\[ F(\text{face, fiberboard}) = 1.4 \times F(\text{face, pbd}) \]  

(6-27)

Table 6-18. Specific gravity values raised to various powers.

<table>
<thead>
<tr>
<th>Specific Gravity Values</th>
<th>Specific Gravity Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>( G_x ) ( G_x^{3/2} ) ( G_x^{7/4} ) ( G_x^2 ) ( G_x^{5/2} )</td>
<td>( G_x ) ( G_x^{3/2} ) ( G_x^{7/4} ) ( G_x^2 ) ( G_x^{5/2} )</td>
</tr>
</tbody>
</table>
| \hline
| .360 | .216 | .167 | .130 | .078 | .690 | .573 | .522 | .476 | .435 |
| .370 | .225 | .176 | .137 | .083 | .700 | .586 | .536 | .490 | .440 |
| .380 | .234 | .184 | .144 | .089 | .710 | .598 | .549 | .504 | .425 |
| .390 | .244 | .192 | .152 | .095 | .720 | .611 | .563 | .518 | .440 |
| .400 | .253 | .201 | .160 | .101 | .730 | .624 | .577 | .533 | .455 |
| .420 | .272 | .219 | .176 | .114 | .750 | .650 | .604 | .563 | .487 |
| .430 | .282 | .228 | .185 | .121 | .760 | .663 | .619 | .578 | .504 |
| .440 | .292 | .238 | .194 | .128 | .770 | .676 | .633 | .593 | .520 |
| .450 | .302 | .247 | .202 | .136 | .780 | .689 | .647 | .608 | .537 |
| .460 | .312 | .257 | .212 | .144 | .790 | .702 | .662 | .624 | .555 |
| .470 | .322 | .267 | .221 | .151 | .800 | .716 | .677 | .640 | .572 |
| .480 | .332 | .277 | .230 | .160 | .810 | .729 | .692 | .656 | .590 |
| .490 | .343 | .287 | .240 | .168 | .820 | .743 | .707 | .672 | .609 |
| .500 | .354 | .297 | .250 | .177 | .830 | .756 | .722 | .689 | .628 |
| .520 | .375 | .318 | .270 | .195 | .850 | .784 | .752 | .722 | .666 |
| .530 | .386 | .329 | .281 | .204 | .860 | .798 | .768 | .740 | .686 |
| .540 | .397 | .340 | .292 | .214 | .870 | .811 | .784 | .757 | .706 |
| .550 | .408 | .351 | .302 | .224 | .880 | .826 | .800 | .774 | .726 |
| .560 | .419 | .363 | .314 | .235 | .890 | .840 | .816 | .792 | .747 |
| .570 | .430 | .374 | .325 | .245 | .900 | .854 | .832 | .810 | .768 |
Holding Strength as a Function of Internal Bond Strength

Face Withdrawal Strength

The holding strength of #4 through #16 screws in the face of MDF and PBd may be predicted by means of the expression

\[ F(\text{face}) = 39 \times (IB)^{0.85} \times D^{0.5} \times (L - D/3)^{1.25} \text{ lb} \]  

(6-28)

where \( F \) refers to the withdrawal strength of the screw, lbs.; \( D \) is the diameter of the screw, in.; \( L \) is the depth of embedment of the screw, in.; and \( IB \) refers to the internal bond strength of the board, psi.

Edge Withdrawal Strength

Similarly, the holding strength of screws in the edge of MDF may be predicted by means of the expression

\[ F(\text{edge}) = 18.4 \times (IB)^{0.85} \times D^{0.5} \times (L - D/3)^{1.25} \text{ lb} \]  

(6-29)

where the symbols have the same meanings previously defined. It should be noted that this second expression does not hold for particleboard with a coarse core and overall stratified structure. It should be noted, however, that an analysis of the results obtained in a study carried out by Winistorfer and Moschler (1989) on edge withdrawal strength in boards which measured 1.5 inches thick with internal bond strengths of 111, 126, and 60 psi indicated that withdrawal strength was related to IB raised to the 0.466 power rather than the 0.85 power.

These expressions indicate that holding strength is only weakly associated with screw diameter; i.e., it is proportional to the square root of the diameter of a screw. The ratio of the holding strength of a number 12 screw compared to that of a number 8 screw, for example, amounts to \((0.216/0.164)^{0.5}\), or, 1.15 where 0.215 and 0.164 are the diameters of number 12 and 8 screws, respectively. Thus, the holding strength of a number 12 screw would be expected to be only 15 percent greater than a number 8 screw even though its shank diameter is 0.216/0.164, or, 1.32 times greater. On the other hand, the expression indicates that holding strength is proportional to depth of embedment raised to the 1.25 power (after a slight allowance is made for the reduced holding strength of the tip). The holding strength of a screw embedded 1 inch, accordingly, would be expected to be \((1/0.667)^{1.25}\), or, 1.67 times as great as a screw embedded to only 2/3 of an inch.

Importantly, these expressions indicate that holding strength is closely related to the IB strength of the board. To demonstrate the importance of high IB strength to the holding strength of screws, let us calculate the holding strength of a number 10 sheet metal screw embedded 1/2 inch in the face of an MDF board which has an IB strength of 150 psi. Substituting the appropriate values into the first of the two above expressions gives

\[ F(\text{face}) = 39 \times (150)^{0.85} \times (0.190)^{0.5} \times (0.5 - 0.190/3)^{1.25} = 427 \text{ lbs.} \]
Had this screw been inserted in a board with a much lower IB strength such as 60 psi, on the other hand, its withdrawal strength would have been only $(60/150)^{0.83} \times 427$, or, 196 lbs. The board with the lower IB strength, therefore, had a holding strength less than 50 percent as great as that of the board with the IB of 150 psi.

Product Engineering Considerations

When design options exist, it is important to consider whether it is more cost effective to use a longer or a larger diameter screw. Realistically, however, the diameter and length of a screw used in a given application usually cannot be varied over a wide range, whereas boards with a wide range of IB strength could potentially be used. In general, therefore, optimum holding strength is not likely to be obtained through the choice of a specific fastener but rather through the choice of boards with high IB strengths.

Effect of Adhesives

Englesson (1972) found that use of an adhesive in the pilot hole increases withdrawal strength of the wood screws (included in his tests) by 45 percent. Presumably, adhesive is forced from the hole into the surrounding layers by hydraulic action when the screw is turned into the hole.

Improved Screws

Several types of “improved” screws are offered on the market today which presumably have superior holding strength in PBd and MDF. Tests carried out by the author indicate that there may be little difference in holding strength between so-called particleboard screws and simple sheet metal screws. The difference in cost between the various types of screws offered, however, can be very significant. It is important that a product engineer carry out tests to determine the actual holding strength of the various screws being used to determine the types best suited to his needs.

Screw Dimensions

In general, it must be assumed that the specific geometry of a screw will influence its withdrawal strength - at least to some extent. The number of threads per inch of Type A and Type AB sheet metal screws are given in Table 6-19a. Outside and root diameters for these types are given in Table 6-19b. The outside and the root diameters of type A and type AB sheet metal screws may be calculated by means of the expressions.

**Type A:**

- Outside diameter: $D = 0.06 + 0.013 \cdot N$
- Root diameter: $d = 0.04265 + 0.00952 \cdot N$

**Type AB:**

- Outside diameter: $D = 0.0609 + 0.0127 \cdot N$
- Root diameter: $d = 0.04489 + 0.00947 \cdot N$
where $D$ refers to the outside diameter and $d$ to the root diameter of the screw, inches, and $N$ refers to the gage of the screw. The $R^2$ value for the root expressions $= 0.98$. The expressions for outside diameter give exact values.

Additional Information

For additional information concerning the holding strength of screws in particleboard and medium density fiberboard to:


Withdrawal Strength of Lag Bolts and Anchor Bolts

In Solid Wood

Withdrawal of Anchor and Lag Bolts from Side Grain

There is a tendency to overestimate the holding strength of lag screws in wood. Actually, there is no reason to expect their strength to be greater than that of common screws and it may, in fact be less. As an example, the average withdrawal strength of seventeen 0.25-inch diameter lag screws from yellow-poplar was found to be 538.6 pounds.

By way of comparison, the average withdrawal strength of eighteen number 10 Type A sheet metal screws from the face grain of yellow-poplar specimens cut from the same parent material amounted to 553.9 pounds (Eckelman, unpublished). In this case, the #10 screws (0.190 inch diameter) had greater holding strength than the 1/4-inch diameter lag screws.

Anchor Bolt with Corner Block Joints

Information on the strength of table joints constructed with corner block and anchor bolt joints is found in the following reference.

Withdrawal of Anchor Bolts from End Grain of Wood

A common method of attaching wooden legs to mounting plates is by means of an anchor screw which is threaded into the end of the leg. The exposed end of the screw is threaded. Frequently, the mounting plate itself is threaded so that the anchor screw (and the leg in which it is embedded) can be threaded into the plate, Figure 6-50. In other cases, however, the exposed end of the screw passes through a hole in the mounting plate and is secured in place by a nut. This type of construction is widely used in certain types of furniture construction where strength requirements are limited. The mounting plates themselves are constructed of 14 or 16 gage metal so that the strength of the connection is often limited by the bending moment resistance of the plate.

Relatively high strength connections can be made with anchor screws driven into the ends of legs, however. Strength of the joint will depend on screw length and diameter, the cross sectional dimensions of the leg, and the bending moment resistance of the plate. Tests carried out by the author indicate that a leg to plate connection made with a 3/8 inch diameter anchor screw embedded 2 inches deep in the end of the leg should develop a bending moment resistance of about 4,400 lb-in. Similar joints made with anchor screws 3/8 inches in diameter embedded 2-3/4 inches developed bending moment resistances of about 5,400 in-lb. Presumably two anchor screws could be driven into the ends of the legs in order to develop even higher bending moment resistances, but splitting of the end of the leg could be a problem.

Withdrawal Strength of Lag Bolts From Particleboard

Because of their size and appearance, there is often a tendency to credit lag screws or bolts with greater holding strength than they actually possess. Presumably, the holding strength of lag screws can be predicted by the same formula used to predict the holding strength of screws. In general, however, lag screws are somewhat coarser in construction than screws, and withdrawal strengths may be less. As an example, the average withdrawal strength of eighteen 1/4-inch diameter lag bolts embedded 0.75 inches in particleboard was found to be only 250.7 pounds (Eckelman, unpublished). The particleboard used in these tests was of a type commonly used for furniture core construction.
Withdrawal Strength of Metal and Plastic Inserts

Withdrawal from Solid Wood

Threaded Screw-In Types

The holding strength of straight-shank fasteners with a uniform relatively coarse thread may be predicted (Eckelman and Cassens, 1984) by means of the expression

\[ F = 1.188 \times D^{0.25} \times L^{1.25} \times S_x \]  \hspace{1cm} (6-30)

where \( F \) is the withdrawal strength of the insert, lbs.; \( D \) is its diameter, in.; \( L \) is its length, in.; and \( S_x \) is the shear strength of the wood parallel to the grain at current moisture content, psi.

Fasteners with coarse or unusual thread or with tapered shanks may have less holding power than is predicted by the above expression. Wedge type and knock in types should be expected to have much less strength than threaded types and to be quite variable in holding strength. Fasteners with fine threads which have a clean cutting action may have greater strength.

Holding strength in end grain is variable. Values may be expected to range from 40 to 50 percent of those for face holding strength.

Withdrawal from Particleboard and MDF

The relatively large size of metal and plastic inserts, Figure 6-51, gives an impression of holding strength that tends to exceed realized values.

Tests have shown (Cassens and Eckelman, 1984) that the withdrawal strength of threaded metal inserts in PBd and MDF may be predicted by means of the expression

\[ F = 121.5 \times (IB)^{0.5} \times D^{0.5} \times L \]  \hspace{1cm} (6-31)

where \( F \) refers to the withdrawal strength of the insert, pounds; \( IB \) is the internal bond strength of the board, psi; \( D \) is the root diameter of the insert, inches, and \( L \) is the depth of embedment of the insert, inches.

This expression indicates that withdrawal strength is directly related to the internal bond strength of the PBd and MDF. Clearly, therefore, it is important to use those boards with high internal bond strengths in order to obtain high holding strengths with these fasteners. This factor is particularly important because even the same producer may offer supposedly equivalent boards produced at different plants in which the internal bond strength may vary by a factor of two to one. Simply changing from one supplier to another may result in a doubling of holding strength without affecting costs.
The above expression also indicates that withdrawal strength is directly related to depth of embedment but only weakly related to diameter. Hence, it is more cost efficient to obtain desired withdrawal strengths through the use of inserts of greater length rather than greater diameter.

Knock-In Inserts

The withdrawal strength of coarse-surfaced knock-in inserts may be predicted by means of the expression

\[ F_{2}(\text{coarse surface}) = 42.5 \times (IB)^{0.5} \times D^{0.5} \times L \]  

(6-32)

Similarly, the holding strength of fine-surfaced knock-in type inserts may be predicted by means of the expression

\[ F_2(\text{fine surface}) = 66.8 \cdot (IB)^{0.5} \cdot D^{0.5} \cdot L \]  

(6-33)

These expressions may also be restated in terms of the face withdrawal of threaded metal inserts as

\[ F(\text{fine surface}) = 0.55 \cdot F(\text{threaded}) \]  

(6-34)

and

\[ F(\text{coarse surface}) = 0.35 \cdot F(\text{threaded}) \]  

(6-35)

These expressions simply indicate that the withdrawal strength of finely surfaced knock-in type inserts is about 55 percent as great as the values predicted by the previous equation for threaded inserts; similarly, the withdrawal strength of coarsely surfaced knock-in inserts is about 35 percent as great.

Pilot Hole Diameter

Technical information (Murakoshi) indicates that highest values are obtained with zero pilot - hole clearance.

Placement Near an Edge

Placement of a bushing in a part also has a significant effect on withdrawal strength. In samples in which the bushings were placed near the edge of the sample (Technical information, Murakoshi) in a manner similar to what would occur in making a corner joint, withdrawal values were 25 percent less than when the bushings were inserted away from the edge of the board.

Plastic Inserts

Bachmann and Hassler (1975) found that pressed-in and glued plastic bushings or inserts gave better withdrawal values than metal inserts. On the average, the pressed-in and glued plastic inserts gave strength values about 35 percent higher than the metal inserts.

Thread Effects

Preliminary tests also indicate that finely threaded inserts may give higher holding strengths than comparable coarsely threaded inserts.
More tests are needed, however, to draw definitive conclusions with respect to the effect of thread geometry on holding strength.

**Product Engineering Considerations**

The increase in strength gained by an increase in diameter is quite limited. Consider, for example, the withdrawal strengths of 7/16 inch diameter and 3/4-inch diameter inserts, both of which are 1/2 inch long, from the face of a piece of PBd or MDF which has an internal bond strength of 120 psi. The withdrawal strength of the 7/16 inch diameter insert would be:

\[
F_1 = 121.5 \cdot (10.95) \cdot (0.661) \cdot (0.5) = 440 \text{ lbs.}
\]

Similarly, the withdrawal strength of the 3/4 inch diameter insert would be:

\[
F_2 = 121.5 \cdot (10.95) \cdot (0.866) \cdot (0.5) = 576 \text{ lbs.}
\]

This amounts to an increase in strength of 31 percent, but at a substantial increase in fastener cost. By way of comparison, the withdrawal strength of the 7/16 inch diameter fastener could have been increased to 550 pounds, i.e., essentially equal to that of the 3/4-inch diameter insert and at a much lower cost, simply by increasing its length to 5/8 inches.

It is also important to consider the effect of internal bond strength of the board on withdrawal strength. Had a board with an internal bond strength of 60 psi been used—which is not uncommon—the withdrawal strength of the 7/16-inch by 1/2-inch and the 3/4-inch by 1/2-inch inserts would have been reduced to 311 and 405 pounds, respectively. This result clearly demonstrates the importance of internal bond strength to the holding strength of threaded inserts in PBd and MDF.

**Figure 6-51.**

Corner Joints in Cases - Particleboard

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Several investigations have been made of the joints used to connect panels together to form cases. Englesson (Sept., 1973) investigated the strength of five different corner connectors including butt dowel joints, a mitered joint with an included plastic angle, a mitered joint with dowels, a simple miter joint, and a miter joint with spline, Figure 6-52. Of the joints tested, the mitered joint with spline gave the best results followed closely by the doweled miter. The boards used were 16 and 19 mm thick (0.630 and 0.748 in.). Bending moment resistances for the splined joints constructed from 19 mm particleboard amounted to about 115 in-lb per inch of joint width when the joint was loaded in compression and about double that amount when the joint was loaded in compression.

The greatest problem in constructing joints of particleboard is the tendency of edges of the particleboard to delaminate. This is particularly true when butt type joints are constructed. In tests carried out by Bachmann and Hassler (1975), delamination of the free edge of the one panel was the principal source of failure with demountable connectors which utilized metal and plastic inserts. Values obtained with screws which passed through the panel were nearly double those for the demountable fittings. Dowel construction gave values better than those for demountable hardware but less than for the fitting in which the screw passed entirely through the external panel. When the edge of the exposed panel was covered with mahogany veneer, however, the bending moment resistance of the doweled construction was 43 percent greater than that of the through screw connection. The results of their tests serve to point out the importance of taking the natural characteristics of the material into account when designing with particleboard. In particular, it is necessary to design the joints in such a way that the tendency of the board to delaminate is minimized.

In general, the connections between side walls and shelves or tops and bottoms in cases can presumably be analyzed in much the manner as dowel joints in flatwise bending. If a particleboard shelf were joined to a particleboard side wall by a single screw, for example, the bending moment resistance of this connection should be equal to the withdrawal strength of the screw multiplied by the internal resisting moment arm. For the case cited, if the particleboard is 3/4 inches thick and if it is further assumed that the screw used has a withdrawal strength of say 250 pounds from the edge grain of the particleboard, then as a first approximation, the bending moment resistance of this joint, Figure 6-53 might be expected to be 250 lb \times 0.375 \text{ in.} = 93.8 \text{ lb-in.} Here, the internal moment arm has simply been taken as the distance from the longitudinal axis of the screw to the lower or outer edge of the particleboard.

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The principle consideration in the design of these joints is the withdrawal strength of the fastener from the end grain surface (edge). This statement holds whether inserts, screws or dowels are used. Furthermore, because of the tendency of the side wall to delaminate, these joints are stronger if the shelf is not glued to the side wall.

Lower strengths are achieved when tops or bottoms are attached to the side wall (at the edges) because of the tendency of the exposed edge of the wall to delaminate. Performance of this type of joint can be improved considerably when metal fasteners are used if the fastener passes entirely through the side wall and into the end of the top or bottom so that the wall cannot delaminate. Greatly improved performance can be achieved in the case of doweled joints if the exposed edge of the side wall is covered with wood veneer which again prevents the edge from delaminating.

Additional Information

Additional information concerning the strength of corner joints may be found in the following publications.


