Effects of curing time and end pressure on the tensile strength of finger-joined black spruce lumber

Cecilia Bustos
Mohammad Mohammad
Roger E. Hernández
Robert Beauregard

Abstract
Finger-joined black spruce (Picea mariana (Mill.) B.S.P) specimens from eastern Canada were prepared to assess the effect of curing time and end pressure on the tensile strength of the joints. An isocyanate adhesive cured at room temperature and a feather joint configuration were used for this purpose. The joints were machined at a 18.3 m/min. (60 ft./min) feed rate, 3500 rpm rotation speed, and 0.86 mm (0.034 in.) feed per knife (chip load). A single-face glueline application was used at a spread rate of 110 g/m². Four curing times (1, 2, 5, and 24 hr.) and six end pressures ranging from 1.38 MPa to 4.82 MPa (200 to 700 psi) applied for 20 seconds were tested. The results showed that curing time and end pressure have a statistically significant influence on the performance of structural finger-joints. After 5 hours of curing time, finger-joints made with isocyanate can achieve more than 90 percent of the reference ultimate tensile strength based on 24 hours of curing time. Analysis also indicated that finger-joined black spruce has the best performance at an end pressure of 3.43 MPa (498 psi). Lower or higher end pressure can result in a lower tensile strength.

Finger-joints are commonly used to produce engineered wood products from short pieces of lumber. Such joints must have excellent mechanical performance. To be suitable for structural uses, a joint must be subjected to a proper end pressure following machining and adhesive application. To produce acceptable products, technical parameters, such as machining and gluing processes must be optimized. The conditions of curing time and the pressure applied during joining play a major role in the gluing process and the final strength of the assemblies (CTBA 1973).

Isocyanate-based adhesives such as polyurethane (PUR) are a viable alternative for wood finger-jointing applications. They are gaining acceptance in North America for a variety of structural applications (Verreault 1999, Chen 2000, Lange et al. 2000). PUR adhesives develop a high strength and cure at ambient conditions. Hot-pressing or radio-frequency treatments can be used to accelerate the curing process. Studies by Pagel and Luckman (1983, 1984) have shown that PUR-bonded joints did not fail in creep and had good water resistance. King and Chen (2001) investigated the performance of a two-part PUR adhesive for finger-joint application and for I-joist assembly using various curing times. They tested black spruce among other species. Results showed that the adhesive cured in a relatively short time, which makes it suitable for finger-joint processing. However, no information is available on the influence of end pressure using this type of adhesive for finger-joining black spruce. Thus, end pressure and curing time need to be further investigated for
finger-joined black spruce made with isocyanate in order to determine optimum conditions for the production of finger-joints for structural applications.

The main function of the pressure is to bring the mating surfaces so close together that the glue forms a thin and continuous film between them. This pressure also allows a uniform distribution of the adhesive and creates an optimum glueline thickness. Several authors have investigated the effect of the glueline thickness on the strength of finger-joints (Ebewele et al. 1979, Sandoz 1984, Groom and Leitch 1994, River 1994). They indicated that it is necessary to control the glueline thickness to produce strong joints. Thin gluelines lead to starved joints. Above the optimum glueline thickness, stress concentration develops in the adhesive layer due to cure-shrinkage. The pressure must be applied to force fingers together to form an interlocking connection, giving a certain immediate handling strength (Raknes 1980). The increase of the end pressure up to a certain point gives a better contact of the finger to obtain strong joints. However, cell damage or splitting of the finger root can be induced by excessive pressure (Jokerst 1981, Marra 1984, Kutscha and Caster 1987).

Several opinions exist regarding the amount of pressure needed to produce high-strength finger-joints. The German standard Deutsches Institut fuer Normung (DIN) 68-140 (1971) specifies minimum acceptable values for the different lengths of fingers, for example, 11.77 MPa (1707 psi) for 10-mm (0.4-in.) fingers and 1.96 MPa (284 psi) for 60-mm (2.4-in.) fingers. The German standard also establishes that a minimum pressure of 0.98 MPa (142 psi) must be applied (DIN 1971). Strickler (1980) stated that an end pressure of about 2.76 MPa (400 psi) is near optimum for most softwood species. With an increase in end pressure, a better contact between the sides of the finger is obtained and the gap between fingertip and root reduced. Thus, as a higher pressure is applied, more locking efficiency and performance can be obtained up to the point where damage to the tips of fingers or splitting of the wood occur (Dawe 1965). Madsen and Littleford (1962) used end pressures between 0 and 4.14 MPa (600 psi) with casein and phenol-resorcinol adhesives. Their results showed that 2.76 MPa (400 psi) end pressure was adequate to facilitate curing and to develop optimum tensile strength. Juvonen (1980) also studied the effects of end pressure on joint strength but considering the geometry and size of the finger. The end pressure had a relatively small effect on the long fingers; therefore, adequate joints could be obtained with a relatively low end pressure. However, with shorter fingers, the effect of end pressure in the low range was greater. As a result, a certain minimum pressure is required depending on the size of finger. Recently Ayarkwa et al. (2000) tested three end pressures on finger-joined African hardwoods. Results showed no significance of this parameter on modulus of rupture and modulus of elasticity in flexion. On the other hand, Sandoz (1984) noted that a “back pressure” can be obtained during the phase of relaxation of the pressure, which can cause separations and lead to adhesive-free gaps at the end of the finger.

In most of the cited studies, with different species, information is lacking about wood machining parameters, wood conditions, and finger-joint configuration. Therefore, the literature does not provide a comprehensive understanding of relationships between the various factors and end pressure for any particular species.

The final stage in manufacturing finger-joined wood products is the curing of the adhesive. Most of the adhesives commonly used require long periods to set, which is inconvenient and interferes with production. The adhesives in general must be heated to reduce the curing time either before or after application of the adhesive using a radio-frequency or conventional oven. The level and variation of moisture content in the wood is very important because water absorbs energy and it interferes with the heating process. Also, the heating equipment required is expensive to buy, operate, and maintain.

The effect of curing time and end pressure on the performance of finger-joints of black spruce is important in the finger-jointing process. In this investigation, we studied the structural performance of finger-joined black spruce wood glued with an isocyanate adhesive, cured at four curing times and six end pressure levels.
or end pressure as independent variables (SAS-NLIN procedure) (SAS Institute 1998). Data points for curing time were fitted with a segmented model that included two sections, one quadratic and one linear; while data for end pressure effect was fitted with a quadratic equation.

### Results and discussion

A summary of test results showing the influence of curing time on UTS is given in Table 1. The wood specimens built up enough strength to be handled after 1 hour of curing time, averaging above 26 MPa (3771 psi) of UTS. The ANOVA indicated that statistically significant differences existed among the four curing times studied; however, there were no significant differences between 1 and 2 hours or between 5 and 24 hours. But 1 and 2 hours yielded different results than 5 and 24 hours of curing time (Table 1). Results at 1 hour of curing time do not agree with those reported by King and Chen (2001) who studied the performance of a two-part PUR adhesive, ISOSET UX-100, for finger-joint application on 38- by 64-mm (nominal 2- by 3-in.) studs of black spruce. The UTS determined by King and Chen (2001) was considerably lower than the UTS determined by King and Chen (2001) who studied the application on 38- by 64-mm (nominal 2- by 3-in.) studs of black spruce. The UTS of the wood specimens built up enough strength to be handled after 1 hour of curing time, averaging above 26 MPa (3771 psi) of UTS. The ANOVA indicated that the curing time had an influence on the UTS between 1 and 5 hours. King and Chen (2001) indicated that it took about 3 hours for black spruce joined lumber to reach full cure at room temperature. In our case, after 5 hours of curing time, the performance in tensile strength still increases, but slightly, until it stabilizes. The segmented regression model estimates that the maximum UTS could be already reached at 10 hours of curing time. Given the variability of results obtained,

### Table 1. — Ultimate tensile strength (UTS) of finger-joined black spruce wood as determined from tension tests with different curing times.

<table>
<thead>
<tr>
<th>Statistical parameter</th>
<th>1 hr.</th>
<th>2 hr.</th>
<th>5 hr.</th>
<th>24 hr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (MPa)</td>
<td>25.9 A</td>
<td>26.9 A</td>
<td>32.5 B</td>
<td>35.2 B</td>
</tr>
<tr>
<td>SD (MPa)</td>
<td>3.3</td>
<td>2.4</td>
<td>3.5</td>
<td>3.8</td>
</tr>
<tr>
<td>Sample size</td>
<td>15</td>
<td>14</td>
<td>12</td>
<td>16</td>
</tr>
</tbody>
</table>

a Means within a row followed by the same capital letter are not significantly different at the 5 percent probability level.
b SD = standard deviation.

### Table 2. — Ultimate tensile strength (UTS) of finger-joined black spruce wood as determined from tension tests with different end pressure levels.

<table>
<thead>
<tr>
<th>end pressure (MPa)</th>
<th>1.3</th>
<th>2.2</th>
<th>2.8</th>
<th>3.7</th>
<th>4.0</th>
<th>4.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (MPa)</td>
<td>26.6 C</td>
<td>31.1 ABC</td>
<td>30.4 ABC</td>
<td>35.2 A</td>
<td>33.6 AB</td>
<td>29.2 BC</td>
</tr>
<tr>
<td>SD (MPa)</td>
<td>5.0</td>
<td>4.2</td>
<td>5.7</td>
<td>3.8</td>
<td>4.6</td>
<td>4.4</td>
</tr>
<tr>
<td>Sample size</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>16</td>
<td>14</td>
<td>14</td>
</tr>
</tbody>
</table>

a Means within a row followed by the same capital letter are not significantly different at the 5 percent probability level.
b SD = standard deviation.
A summary of results on the influence of end pressure on UTS is given in Table 2. The strength of the finger-joint in tension appears to be related to the amount of end pressure applied. The ANOVA indicated statistically significant differences among the six pressure levels ($p < 0.0001$) (Table 2). A second-degree polynomial was fitted to all data for the six pressures (Fig. 2). The coefficient of determination was found to be low ($r^2 = 0.22$) even though the relationship was statistically significant ($p < 0.0001$). The UTS increased slightly from 1.35 MPa (196 psi) end pressure, reached a maximum value at 3.43 MPa (498 psi), and then it decreased as the end pressure increased (Fig. 2). This result is not far from the optimum value of 2.76 MPa (400 psi) found by Strickler (1980) for softwood species. Pressure in excess of 3.43 MPa (498 psi) will likely cause a reduction of the UTS, provoking splitting due to compression load at the finger root, even without the tips of fingers reaching the roots of the opposite fingers. On the other hand, an end pressure of 1.35 MPa (196 psi) was enough for the joined wood to be handled, even though it represented the lowest performance on the structural properties. The mean strength value in all tension tests was higher than those specified in SPS 1-2000 (NLGA 2000b) for spruce-pine-fir, grade No. 2 and better for finger-joined structural lumber (Table 2).

The quality of the glueline was also evaluated by the percent wood failure developed in the finger-joint according to ASTM D 4688-97 (ASTM 1997b). Generally, wood failure was high. More than 80 percent of specimens failed in modes number 3 and 4. Failure mode number 3 is mostly along the joint profile but with some failure at the finger roots, while mode 4 is with tensile wood failure occurring at the joint roots and with high overall wood failure. These modes of failure are usually associated with good gluing in structural finger-joined material. No glue failure was observed, which confirms that the gluing process was adequate. The high performance among the different curing times and end pressures of finger-joints studied is an indication of the good bonding quality of the isocyanate adhesive used in this study.

**Conclusion**

Black spruce has a good potential in the finger-jointing with isocyanate adhesive for structural applications. The curing time and end pressure of structural finger-joints have a significant influence on ultimate tensile strength. The maximum curing time effect takes place between 2 and 5 hours at room temperature. After 1 or 2 hours of curing time at room temperature, finger-joints could reach more than 70 percent of reference strength achieved at 24 hours of curing time. After 5 hours of curing time, finger-joints achieve the same level as the reference ultimate tensile strength. On the other hand, an end pressure of 3.43 MPa (498 psi) was found to be the

---

**Figure 1.** — Effect of curing time on the ultimate tensile strength (UTS) of finger joined black spruce wood assembled at 3.75 MPa (544 psi) of end pressure.

**Figure 2.** — Effect of end pressure on the ultimate tensile strength (UTS) of finger-joined black spruce wood tested after 24 hours of curing time.
optimum condition for assembling finger-jointed black spruce with isocyanate adhesive. The tensile strength of all finger-joints fabricated using various curing times and end pressure treatments met the tensile strength requirements outlined in the SPS 1-2000 (NLGA 2000b) for structural lumber. The results have also shown that finger-joints of high tensile performance can be produced using the type of isocyanate adhesive studied.

Literature cited


Corporate research and technology innovation dept., Ashland Specialty Chemical Co., Ajax, Ontario, Canada.


give city and country for DIN


9497 P&P: This study demonstrates the influence of curing time and end pressure on the tensile strength performance of finger-jointed black spruce. The information obtained will help the industry develop an in-depth understanding of its main species, including its processing characteristics, which should contribute to the development of secondary processing and improved wood products.