# EFFECT OF GEOMETRIC PARAMETERS OF FINGER JOINT PROFILE ON ULTIMATE TENSILE STRENGTH OF SINGLE FINGER-JOINED BOARDS

*Shuzhan Rao*

Graduate Research Assistant
E-mail: shuzhan.rao@unb.ca

*Meng Gong**†

Research Scientist
E-mail: mgong@unb.ca

*Y. H. Chui*†

Professor
Wood Science and Technology Centre
Faculty of Forestry and Environmental Management
University of New Brunswick
Fredericton, New Brunswick, Canada E3C 2G6
E-mail: yhc@unb.ca

*Mohammad Mohammad*†

Group Leader and Research Scientist
FPInnovations
Quebec, QC, Canada G1P 4R4
E-mail: Mohammad.Mohammad@fpinnovations.ca

(Received November 2011)

**Abstract.** The feasibility of adopting a short finger profile for structural finger-joined lumber was studied by investigating the effect of geometric parameters of a finger joint profile on ultimate tensile strength (UTS) of single finger-joined boards. Six finger joint profiles were designed with three finger lengths (28.27, 15.88, and 12.70 mm). A commonly used finger profile was included as a control. Eastern white pine (*Pinus strobus*) lumber was used to fabricate single finger-joined boards that were joined using a polyvinyl acetate adhesive. Analysis of variance showed that the finger joint profile had a statistically significant influence on UTS of single finger-joined boards. Finger profile P2 showed the highest UTS value and had the shortest finger length among seven groups. With decreasing profile slope, UTS increased. Slope of 1:12 appeared to be the optimized value for finger jointing. UTS decreased with increasing tip width. It can be concluded that with the proper design of finger profile, a finger joint with short finger lengths can be used to fabricate finger-joined structural lumber without any loss of tensile strength compared with the finger length commonly used by the wood industry.

***Keywords:*** Joint profile, slope, tip thickness, joint length, ultimate tensile strength, single finger-joined board.

## INTRODUCTION

### Background

Finger-joined products are manufactured by taking pieces of quality kiln-dried wood, machining a "finger" profile in each end of the short-length pieces, applying an adhesive, pressing the pieces together, and curing (normally through radio-frequency on a production line in a mill) to make a longer piece. Finger joining is an economic way to transform low-grade short pieces of wood to produce high-quality lumber of any length (Strickler 1980). It offers the best way of

* Corresponding author
† SWST member

splicing wood endwise because it provides high-strength materials, recovers good-quality wood, and can be manufactured at a high production rate (Mohammad 2004). Finger-joined lumber is now widely used for glued-laminated timber, wood I-joists, and wall studs. Currently, the Canadian engineered wood products industry uses a joint length of 22-29 mm, which is longer than that used in some countries (ie typically about 9.5-13 mm). If joint length could be decreased, a considerable volume of good-quality wood fiber could be saved. Walford (2000) evaluated the effect of finger length on tensile strength of radiata pine (*Pinus radiata*) lumber intended for both nonstructural and structural applications. Finger length in his study ranged from 3.5-16 mm. He indicated that shorter joints were slightly stronger than longer ones but required greater precision in manufacturing. Gong et al (2009) examined characteristic ultimate tensile strength (UTS) and mean modulus of elasticity of finger-joined black spruce (*Picea mariana*) lumber containing 29- and 16-mm-long finger joints and unjoined sawn lumber. They found that there was no statistical difference in UTS of finger-joined lumber between two selected joint lengths. The previous studies were in general agreement that finger length was not a critical geometric parameter in determining joint strength. This finding suggested a potential to shorten the structural finger joint by properly modifying the finger profile with a minimal influence on joint strength. Very limited studies on this topic have been conducted in Canada.

The overall objective of this study was to examine the feasibility of adopting a short finger profile for manufacturing structural finger-joined lumber. The specific goal was to investigate the effect of geometric parameters of a finger joint profile on UTS of single finger-joined boards.

## Geometric Parameters of Finger Joint Profile

Jokerst (1981) indicated that the geometry of a finger joint largely dictates potential strength of a joint. Geometric parameters of a joint include finger length ($L$), finger pitch ($p$), tip thickness ($t$), and slope ($S = \tan \alpha$) (Fig 1). They are related to each other, therefore changing any one parameter changes the others. This interrelationship among parameters of a joint complicates investigation of the effect of any single parameter on strength (Jokerst 1981). Eq 1 defines such a geometric relationship among the four parameters:

$$S = \tan \alpha = \frac{\frac{1}{2}p\text{-}t}{L} \qquad (1)$$

Considerable research has been done on the influence of each geometric parameter on joint strength. As mentioned previously, finger length ($L$) affected joint strength significantly only when it was decreased to approximately the length of a single wood fiber (Pavlov 1955). As with finger length, Strickler (1980) stated that pitch ($p$) had very little or no effect on joint strength.

Tip thickness ($t$) and slope ($S$) have more significant influences on joint strength. Finger tips are essentially a series of butt joints that decrease effectiveness of finger joints as well as creating sources of stress concentration (Strickler 1980). Thus, thin finger tips are required to obtain maximum joint strength (Selbo 1963). A thickness of 0.4-0.8 mm is about the practical minimum value for machining tips. For structural finger joints, tip thickness must be no greater than 0.8 mm (FPL 1999).

Plain scarf joints were used for many years in structural applications. This type of joint is formed by cutting a slope, or incline, usually through wood thickness, thus exposing wood that approaches side grain (Jokerst 1981). When a finger joint is tested in tension, stress at the bonded area consists of a shear and a tensile stress component, similar to a scarf joint. The shear component becomes more dominant as the joint slope is decreased, leading to a stronger joint overall.

Tests on scarf joints have shown that, within certain limits, UTS generally increased with a decrease in slope (Selbo 1963). Strickler (1980) concluded that finger slope had approximately

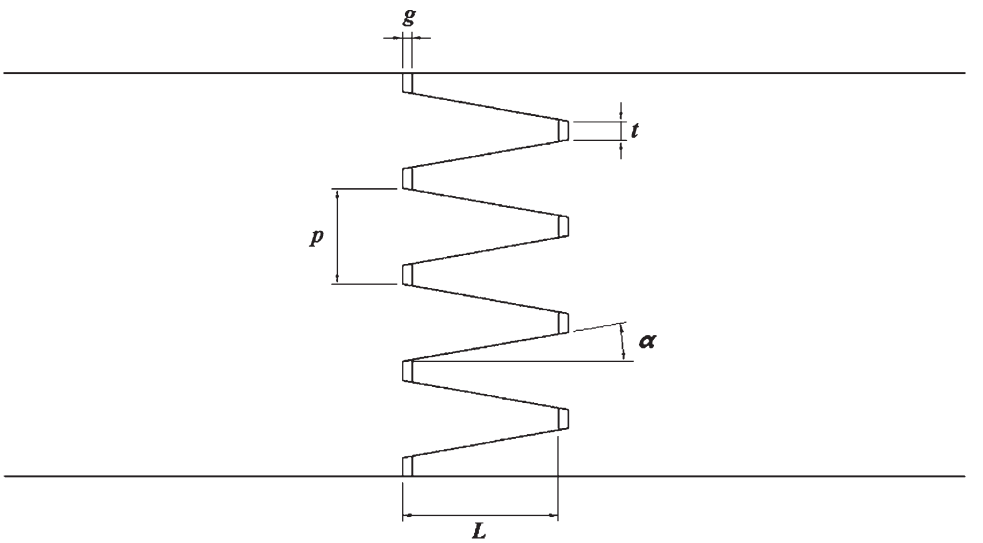


Figure 1. Geometric parameters of a finger joint.

the same effect on joint strength as the slope of scarf joints. Flat slopes of 1:16 to 1:20 produced joint strength closely approaching 100% of clear wood when they were properly bonded. However, Selbo (1963) indicated that both very steep slopes and very flat slopes adversely affected joint strength. He examined the effect of joint geometry on UTS of finger joints across a wide range of joint dimensions for two softwoods, sitka spruce (*Picea sitchensis*) and Douglas-fir (*Pseudotsuga menziesii*), and one dense hardwood, white oak (*Quercus alba*). In his study, UTS of finger joints increased with decreasing finger slope but the rate of increase decreased as the slope decreased. Gain in strength was generally very small as the slope decreased from 1:12 to 1:16. Selbo (1963) found that a joint with a slope of 1:14 showed the highest UTS. DIN (1998) recommends that the angle between the faces of fingers and the axis of a joint should not be greater than 7.1° (slope of 1:8) for finger lengths greater than 10 mm.

Walford (2000) indicated that a small tip gap ($g$) improved joint strength. German specifications (DIN 1998) require a tip gap of 0.03-0.05 of finger length for finger lengths greater than 10 mm after the end pressure has been applied. SPS1 (NLGA 2006a) requires that tip gap not exceed 1.6 mm. DIN (1998) also specifies maximum taper ($t/p$) should be 0.18 for structural finger joints.

In summary, neither length nor pitch of a finger significantly affects finger joint strength. However, tip thickness and slope govern joint strength to some degree. A high-strength finger joint can be achieved by designing and adopting relatively flat slopes and sharp tips. A proper tip gap can improve mechanical performance of a finger joint.

## MATERIALS AND METHODS

### Design of Joint Profiles

Based on the discussion and analysis given in the previous literature review and consultation with finger-joined lumber manufacturers, six finger profiles were designed with three selected finger lengths for fabricating finger-joined boards of a single joint (Table 1). The logic was that the same glue-joint area of finger joints could produce the same bonding strength. The three selected finger lengths were 28.27, 15.88, and 12.70 mm. A commonly used finger profile in Canadian engineered wood products was used as a control (P6).

Table 1. Design of finger joint profiles.

| Finger profile/group | Finger length ($L$) (mm) | Pitch ($p$) (mm) | Tip thickness ($t$) (mm) | Gap ($g = 0.03L$) | Glue-joint length (mm) | Slope of fingers ($K$) | Angle of fingers ($\alpha$) (°) | Effective glue-joint area ($2L/p$) | Taper ($t/p$) |
|---|---|---|---|---|---|---|---|---|---|
| P1 | 12.70 | 3.02 | 0.34 | 0.38 | 25.51 | 1:10.88 | 5.26 | 8.40 | 0.11 |
| P2 | 12.70 | 3.02 | 0.45 | 0.38 | 25.49 | 1:12 | 4.76 | 8.40 | 0.15 |
| P3 | 15.88 | 3.78 | 0.45 | 0.48 | 31.88 | 1:11 | 5.19 | 8.40 | 0.12 |
| P4 | 15.88 | 4.42 | 0.45 | 0.48 | 31.95 | 1:9 | 6.34 | 7.18 | 0.10 |
| P5 | 28.27 | 6.21 | 0.50 | 0.85 | 56.78 | 1:10.88 | 5.26 | 9.11 | 0.08 |
| P6 | 28.27 | 6.73 | 0.76 | 0.85 | 56.78 | 1:10.88 | 5.26 | 8.40 | 0.11 |
| P7 | 15.88 | 3.78 | 0.43 | 0.48 | 31.88 | 1:10.88 | 5.26 | 8.40 | 0.11 |

## Preparation of Wood Material

Samples of 2.4-m-long (cross-sectional size 38 × 89 mm) kiln-dried eastern white pine lumber was purchased from a local wood products manufacturer in New Brunswick, Canada. These lumber pieces were cross-cut and planed to make boards of 419 × 46 × 5 mm. A total of 296 pieces of flat-sawn boards without any visible defects such as knots were selected. The boards were stored for at least 1 mo in a conditioning chamber at 65% RH and 20°C prior to testing. The mean and standard deviation of moisture content of boards at testing were about 8.33 and 1.81%, respectively.

## Matching and Grouping of Wood Boards

After conditioning, density of each piece of board was determined by its mass and volume. Afterward, a total of 288 pieces of flat-sawn boards were selected by eliminating those pieces of extreme density values. The boards selected were thereafter matched into pairs according to their density values. The boards were sorted from lowest to highest density into 12 sets, each of which had 24 pieces of boards. Among each set, 24 pieces of boards were randomly matched into pairs, forming 12 pairs of boards for finger joining. The main purpose for density matching between groups was to eliminate the influence of density on results. This was achieved by ensuring that mean value and standard deviation of density of each group were similar. The mean and standard deviation of density were 396 and 28 kg/m$^3$, respectively.

## Preparation of Finger-Joined Specimens

Seven groups of flat-sawn boards were used to fabricate single finger-joined specimens (groups P1-P7).

***Finger profile cutting.*** A computer numerical controlled (CNC) machine (HAAS TM-1 Tool Room Mill) available at the University of New Brunswick was used to make the single finger profile. Because of the dimensional limitation of the CNC machine, the dimensions of designed finger profiles were scaled up five times. A 1.5-mm-diameter cutter was rotated by a spindle to profile fingers on the boards.

***Application of adhesive for finger joining.*** A polyvinyl acetate adhesive was used to bond the male and female ends of joints. Adhesive was evenly applied manually on both sloping sides of a finger joint at room temperature using a brush. An end pressure of 0.9 N/mm$^2$ was used during the bonding process according to DIN (1998), which was applied by an Instron (Norwood, MA) universal testing machine from 0-0.9 N/mm$^2$ at a load rate of 1 mm/min, kept for 2 s, and then released. Because of their relatively long length compared with width, a side pressure needed to be applied to group P5 and P6 specimens for 1 min during specimen preparation to prevent lateral movement and ensure close contact between gluing surfaces. However, because of improper operation in the fabrication procedure, this pressure was not applied to group P5, and its impact will be subsequently discussed.

Finger-joined specimens were cured at 20 ± 2°C for more than 24 h according to the manufacturer's instructions. Extruded adhesive during joining was removed by sanding prior to further processing. Both ends of specimens were reinforced by gluing with maple veneer pieces to prevent any potential damage caused by the grips during tension testing. Length of a joined specimen varied from 655-740 mm with a cross-section of 46 × 5 mm depending on finger joint length.

### Test Method

Each specimen was tested in tension to determine UTS using a Material Test System (Model 810, Eden Prairie, MN). A load cell of 1 kN was used. Finger-joined specimens were held by hydraulic grips. The clear distance between grips was from 560-648 mm depending on finger joint length. The finger joint was located within the span and as close to the center as possible. Loading rate was controlled to ensure that failure occurred within about 2 min. After testing, the failure mode of each specimen was recorded.

## RESULTS AND DISCUSSION

Table 2 shows that mean density and standard deviation of each group were very similar. This suggests that the density matching was successful and that any difference in mean UTS values among the groups could have been caused by inherent differences in wood density.

NLGA SPS4 classifies failure of finger-joined specimens into six modes (NLGA 2006b). Mode 1 is related to low-quality glue bonding, presenting poor wood failure. Modes 2, 3, 4, and 5 show a high, or even 100%, wood failure, indicating good adhesive bonding. Mode 6 fails away from a joint. This kind of failure is not influenced by the joint. Therefore, data of specimens with failure mode 6 should be excluded from statistical analysis. However, in this study, no specimens failed in mode 6. Therefore, all test data were used for analysis except nine outliers (Table 3).

A summary of statistical results on UTS of single finger-joined boards of the seven finger profiles is given in Table 3. Mean UTS of the seven finger profiles ranged from 28.07-41.28 MPa. Group P2, with the shortest finger length of 12.70 mm, exhibited the highest mean UTS (41.28 MPa). Conversely, group P5, which had the longest finger length (28.27 mm), showed the lowest mean UTS of 28.07 MPa. The unexpected low UTS of group P5 might be attributed to the lack of side pressure during gluing, which led to poor bond quality. Without side pressure, some specimens in group P5 split along glue lines during curing. Except for P5 and P7, UTS values of other groups exceeded UTS of group P6 (control), which was 32.07 MPa. UTS of group P2 was 29% higher than that of group P6. This suggests that joint profiles (P1, P2, P3, and P4) with short finger lengths (12.70 and 15.88 mm) can produce similar or higher UTS values than commonly used finger length (P6) if the finger profile is properly designed. This also suggests a great potential for adopting a profile shorter than 28.27 mm for manufacturing structural finger-joined lumber.

Table 4 gives analysis of variance statistics on mean UTS, which indicates that there is a statistically significant difference ($P = 0.0002 < 0.05$) at a confidence level of 95% among the groups

Table 2. Density values of wood boards of different finger profiles.

| | | Finger profile/group | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | P1 | P2 | P3 | P4 | P5 | P6 | P7 |
| Count (pairs) | | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Density (kg/m$^3$) | Mean | 396 | 398 | 396 | 396 | 396 | 397 | 396 |
| | Standard deviation | 28 | 31 | 29 | 28 | 27 | 29 | 28 |

Table 3. Ultimate tensile strength summary statistics of single finger-joined boards of different finger profiles.

| Profile/group | P1 | P2 | P3 | P4 | P5 | P6 | P7 |
|---|---|---|---|---|---|---|---|
| Count (pairs) | 12 | 8 | 11 | 11 | 12 | 11 | 10 |
| Mean (MPa) | 35.15 | 41.28 | 33.21 | 34.13 | 28.07 | 32.07 | 29.83 |
| Standard deviation (MPa) | 6.63 | 4.41 | 4.14 | 4.07 | 8.78 | 4.70 | 3.48 |

Table 4. Analyses of variance on mean ultimate tensile strength (UTS).

| Source | *SS* | *Df* | *MS* | *F* | *P* value |
|---|---|---|---|---|---|
| Profiles | 1020.29 | 6 | 170.05 | 5.42 | 0.0001 |
| Error | 2134.63 | 68 | 31.39 | | |
| Total | 3154.92 | 74 | | | |

Post hoc analysis on $P$ values for pairwise $t$ tests

| | | Profile | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | P5 | P7 | P6 | P3 | P4 | P1 | P2 |
| | UTS (MPa) | 28.07 | 29.83 | 32.07 | 33.21 | 34.13 | 35.15 | 41.28 |
| P5 | 28.07 | | | | | | | |
| P7 | 29.83 | 0.4636 | | | | | | |
| P6 | 32.07 | 0.0917 | 0.3649 | | | | | |
| P3 | 33.21 | 0.0313 | 0.1725 | 0.6342 | | | | |
| P4 | 34.13 | 0.0117 | 0.0841 | 0.3918 | 0.7023 | | | |
| P1 | 35.15 | 0.0028 | 0.0299 | 0.1912 | 0.4084 | 0.6615 | | |
| P2 | 41.28 | 0.00000 | 0.0001 | 0.0007 | 0.0028 | 0.0077 | 0.0193 | |

tested. The post hoc analysis further points out that mean UTS of group P2 is statistically different ($P < 0.05$) from the other five groups and from the control (P6). The post hoc also showed that no statistically significant difference in mean UTS existed among groups P1, P3, P4, P6, and P7 (only group P7 statistically differed from P1, $P = 0.03 < 0.05$). These results further showed profile P2 could be an excellent candidate for decreasing finger joint length.

It is generally logical to assume that tensile strength of a finger joint is highly related to the effective glue-joint area (EGA). EGA is defined as the surface area of a side-grain joint because the end-grain area at the tip of a finger may not always make proper contact with the end-grain areas at the base of fingers (Selbo 1963). Selbo (1963) and Raknes (1982) indicated that to obtain high joint strength, fingers must be sufficiently long and slope must be sufficiently low, therefore an EGA would provide adequate total shear strength to withstand the tensile strength of the corresponding uncut section. It was recommended that EGA should be at least 10 times greater than the corresponding cross-sectional area (the projected cross-sectional area after subtracting end-grain area of finger tips), because wood is approximately 10 times stronger in tension than in shear (FPL 1999). EGA($A_j$) can be calculated using Eq 2 (Selbo 1963; Jokerst 1980; Ayarkwa et al 2000):

$$Aj \rightarrow \frac{2L}{p} \tag{2}$$

According to Eq 2, $A_j$ could be recommended to be 8-10 or more (DIN 1998). Groups P5 and P4 given in Table 1 had the highest (9.11) and the lowest (7.18) EGA, respectively. The other groups (P1, P2, P3, P7) had the exact same EGA (8.40) as the control (P6). However, despite the highest EGA, P5 had the lowest UTS. This can probably be attributed to the aforementioned lack of side pressure during curing, which led to poor bond quality. The mean UTS of single finger-joined boards with EGA of 7.18 and 8.40 was almost the same (Fig 2). Among the groups with EGA of 8.4 (groups P1, P2, P3, P7, and P6), except group P2, no statistically significant difference existed (Table 4). The mean UTS of group P2 showed a statistically significant difference from other groups. It may be reasonable to say that the highest UTS of group P2 might be related to its flattest slope in addition to the relatively higher EGA (8.4). Nevertheless, the range of EGA (7.18-8.4) appeared adequate for single finger-joined white pine boards.

Figure 2 shows that UTS increased with decreasing slope. A slope of 1:12 (group P2) showed the highest UTS among seven groups

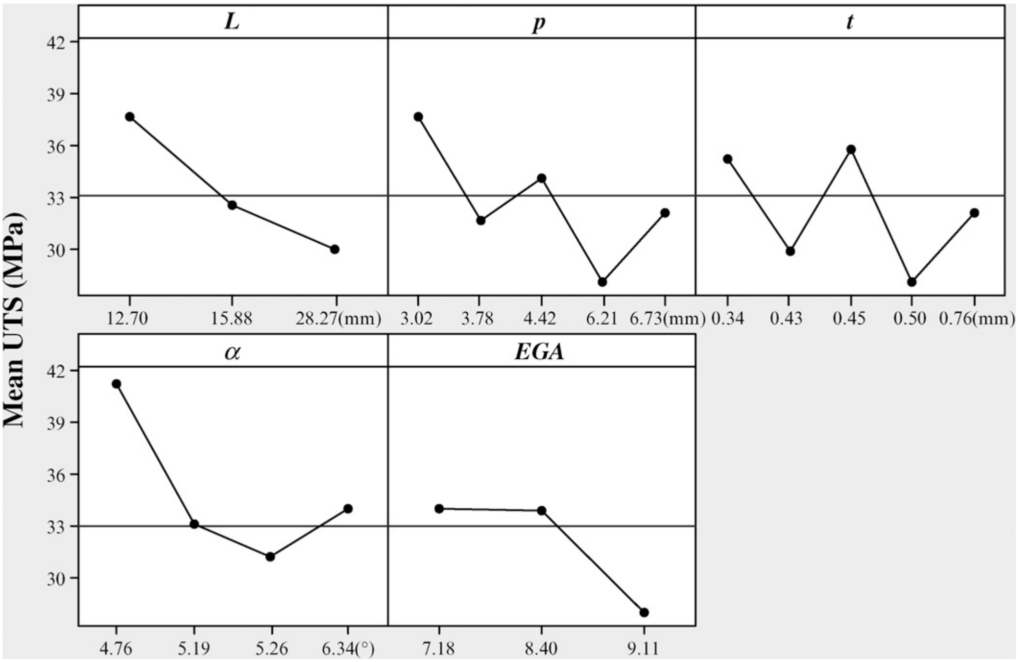


Figure 2. Main effects plot for ultimate tensile strength (UTS) vs each single geometric parameter.

(Table 4). This is in agreement with Selbo (1963) who discovered that a decreasing slope usually produced an increased UTS of a joint, but the rate of increase decreased as the slope decreased. Figure 2 also shows that UTS goes down with increasing tip thickness, further confirming the findings of Selbo (1963) and Strickler (1980), and UTS increases with decreasing finger length. This is consistent with Walford (2000). He stated that shorter joints were slightly stronger than longer ones but required greater precision in fabrication.

## CONCLUSIONS

The previous results and discussion suggest that the range of geometric parameters used in this study appears to be adequate for white pine single finger-joined boards. Finger profile P2 showed the highest UTS and had the shortest finger length among seven groups. Finger profile had a statistically significant influence on UTS of single finger-joined boards. With decreasing slope, UTS increased. A slope of 1:12 appeared to be the optimized value for finger jointing. UTS decreased with increasing tip thickness. A high-strength finger joint could be made when the fingers had relatively flat slopes and sharp tips. It can be concluded that with a proper design of finger profile, the finger joint with a length of 12.70 mm, which is 55% shorter than the current industrial practice (28.27 mm), is possible to produce finger-joined lumber without any decrease in UTS. This suggests a potential for adopting finger profile (P2) of a short joint length to fabricate finger-joined lumber for structural applications. Future work will be focused on fabricating cutters of the joint profile developed in this study, manufacturing finger-joined lumber, and examining its mechanical properties.

## ACKNOWLEDGMENTS

We extend our sincere gratitude for the financial support from Natural Resources Canada under its Value-to-Wood Program and New Brunswick Innovation Foundation under its

Research Assistantship Initiative Program and for the technical support from Mr. Dean McCarthy and Mr. Scott Fairbairn of Faculty of Forestry and Environmental Management, University of New Brunswick.

## REFERENCES

Ayarkwa J, Hirashima Y, Sasaki Y (2000) Effect of finger geometry and end pressure on the flexural properties of finger-jointed tropical African hardwoods. Forest Prod J 50(11/12):53-63.

DIN (1998) DIN 68140-1. Finger joints in wood. Part 1: Finger-jointed structural timber (softwood). Deutsches Institut für Normung (the German Institute for Standardization), Berlin, Germany.

FPL (1999) Wood handbook: Wood as an engineering material. Gen Tech Rep FPL-GTR-113 USDA For Serv Forest Prod Lab, Madison, WI. 463 pp.

Gong M, Delahunty S, Chui YH (2009) Development of a material-efficient finger-joint profile for structural finger-joined lumber. Final Report (UNB043). Wood Science and Technology Centre, University of New Brunswick, Fredericton, New Brunswick, Canada.

Jokerst RW (1980) The effect of geometry on the performance of structural finger-joints. Pages 169-180 *in* CFL Prins, ed. Proc Production, Marketing and Use of Finger-Jointed Sawnwood, 15-19 September 1980, Timber Committee of the UN Economic Commission for Europe. Martinus Nijhof/Dr. W. Junk Publishers, The Hauge, The Netherlands.

Jokerst RW (1981) Finger-jointed wood products. Res Pap FPL-RP-382. USDA For Serv Forest Prod Lab, Madison, WI.

Mohammad M (2004) Finger-joint process and products quality. Report #4016. FPInnovations–Forintek Division, St-Foy, Quebec, Canada.

NLGA (2006a) SPS 1. Special products standard for fingerjoined structural lumber. National Lumber Grades Authority, Westminster, British Columbia, Canada.

NLGA (2006b) SPS 4. Special products standard for fingerjoined flange stock lumber. National Lumber Grades Authority, Westminster, British Columbia, Canada.

Pavlov VP (1955) Joining wood longitudinally with toothed tenons. Translation No. 2705 of Australian CSIRO. Translated from. Derev Prom 3(10):5-8.

Raknes E (1982) The influence of production conditions on the strength of fingerjoints. Pages 154-168 *in* CFL Prins, ed. Proc Production, Marketing and Use of Fingerjointed Sawnwood, United Nations Economic Commission for Europe. Martinus Nijhof/Dr. W. Junk Publishers, The Hague, The Netherlands.

Selbo ML (1963) Effect of joint geometry on tensile strength of finger-joints. Forest Prod J 13(9):390-400.

Strickler MD (1980) Finger-jointed dimensioned lumber: Past, present and future. Forest Prod J 30(9):51-56.

Walford BG (2000) Effect of finger length on fingerjoint strength in radiata pine. Paper 3-5-2 *in* Proc 6th World Conference on Timber Engineering, University of British Columbia, Whistler, British Columbia, Canada.