BENDING STRENGTH OF FINGER JOINTS

Jürgen Ehlbeck and François Colling
Lehrstuhl für Ingenieurholzbau und Baukonstruktionen
Universität Karlsruhe

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by

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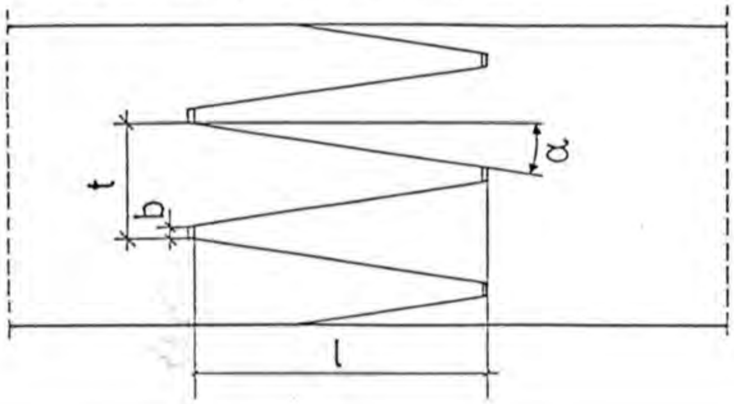
1 General

The strength of finger joints has been the subject of numerous investigations in the past. The first investigations dealt with the effect of joint geometry (Selbo 1963, Strickler 1980, Radovic/Rohlfing 1986). These investigations found the tip thickness b and the ratio $\varphi = 2l/t$ to be the most strength determining factors: decreasing tip thickness and increasing φ lead to higher strength values of finger joints. The ratio φ is a measure for the glued area available per unit of width. *Fig. 1* shows a finger joint with the notations of DIN 68140.



l = length of fingers
t = pitch
b = tip thickness
α = slope angle

Figure 1: Finger joint

Other investigations found that the strength of finger joints is also governed by wood properties such as density and MOE of the jointed boards (Egner/Dorn 1962, Madsen/Littleford 1962, Larsen 1980, Moody 1970, Johansson 1983 and 1986, Eby 1968, Ehlbeck et al. 1985).

Ehlbeck, Colling and Wenz 1989 investigated the bending strength of structural finger joints depending on both wood properties and joint geometry. The results are presented in this paper.

2 Test results and discussion

2.1 Sampling and testing

A total of 900 finger - jointed laminations (white spruce, picea abies) were randomly selected during production in 30 German glulam factories.

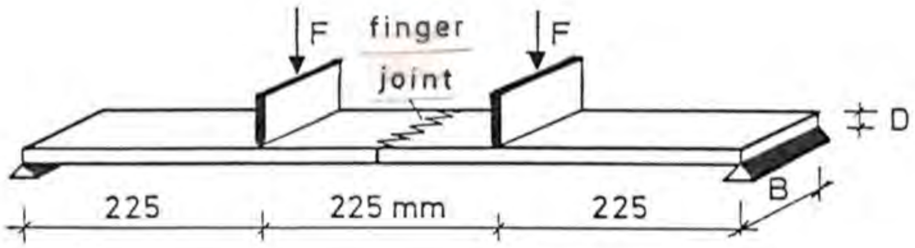


Figure 2: Test set-up

Test set-up is shown in *fig. 2* and bending strength was calculated according to

$$f_B = 1350 \frac{F_u}{BD^2} \quad \text{in N/mm}^2 \qquad (1)$$

where

F_u = ultimate load in N,
B = width of the test specimen in mm,
D = depth of the test specimen in mm.

From each test specimen the following parameters were determined:

- density of both jointed boards,
- dynamic MOE of each board determined according to Görlacher 1984,
- greatest annual ring width of each board,
- greatest early wood portion within each board,

- if pith did occur in a board (yes/no),
- kind of glue,
- failure mode (bending failure near the tips or shear failure along the fingers),
- location of failure,
- actual joint geometry.

A total of 55 test specimen were not considered during evaluation of test results. Reasons for this were:

- bad gluing (shear failure within the glue line) ;
- bad finger joints (crashed fingers);
- knots in the area of the finger joint;
- wood failure outside the finger joint area.

2.2 Test results

2.2.1 Effect of failure mode

Taking into account the remaining 845 test specimen, the bending strength of finger joints was found to be 50,6 N/mm^2 on average with a standard deviation of 8,7 N/mm^2 (coefficient of variation = 17%).

Furthermore it was differentiated between joints with a predominant wood failure and joints with a predominant finger joint failure.

A predominant wood failure was defined as a bending failure (in the area of tips) over at least 80% of the board width (see *fig. 3*). In the further course of this paper, this group will be noted as 80% WF.

In analogy to this, a predominant finger joint failure was identified as a shear failure along the fingers over at least 80% of the width of the test specimen (see *fig. 4*). This group will be noted as 80% FJF.

If neither a predominant wood failure nor a predominant finger joint failure could be detected, the failure mode was considered as mixed failure, noted as MF (see *fig. 5*).

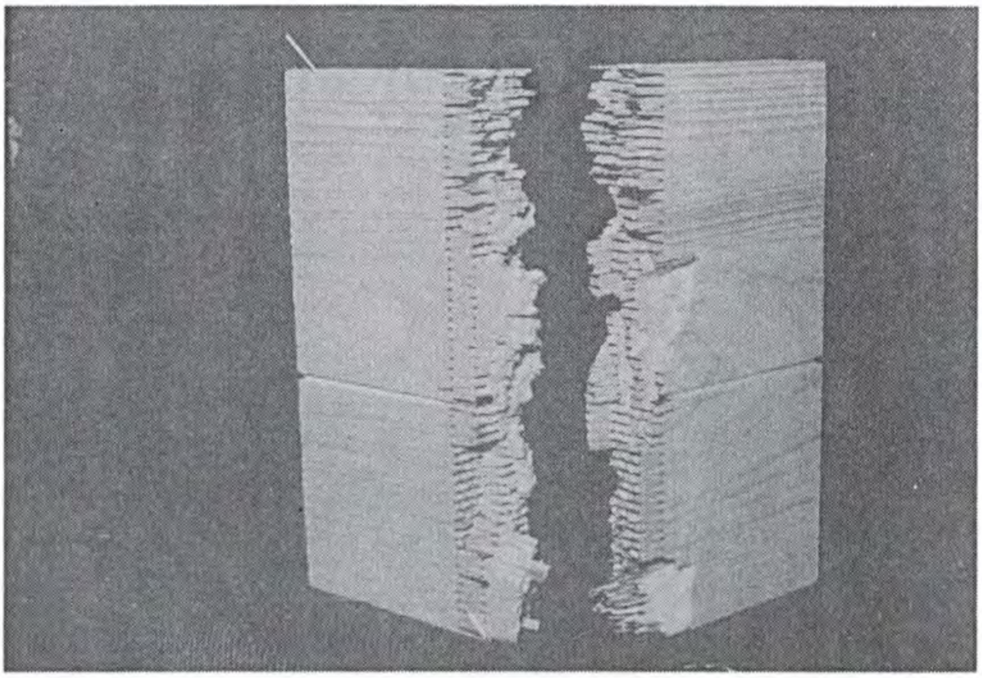


Figure 3: Finger joint with predominant wood failure (80% WF)

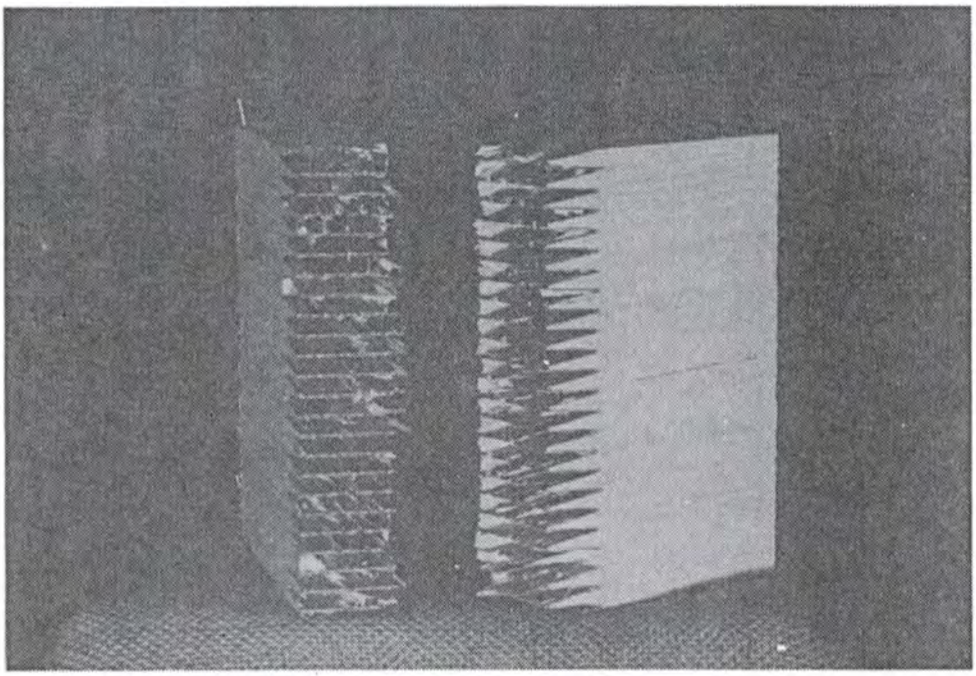


Figure 4: Finger joint with predominant finger joint failure (80% FJF)

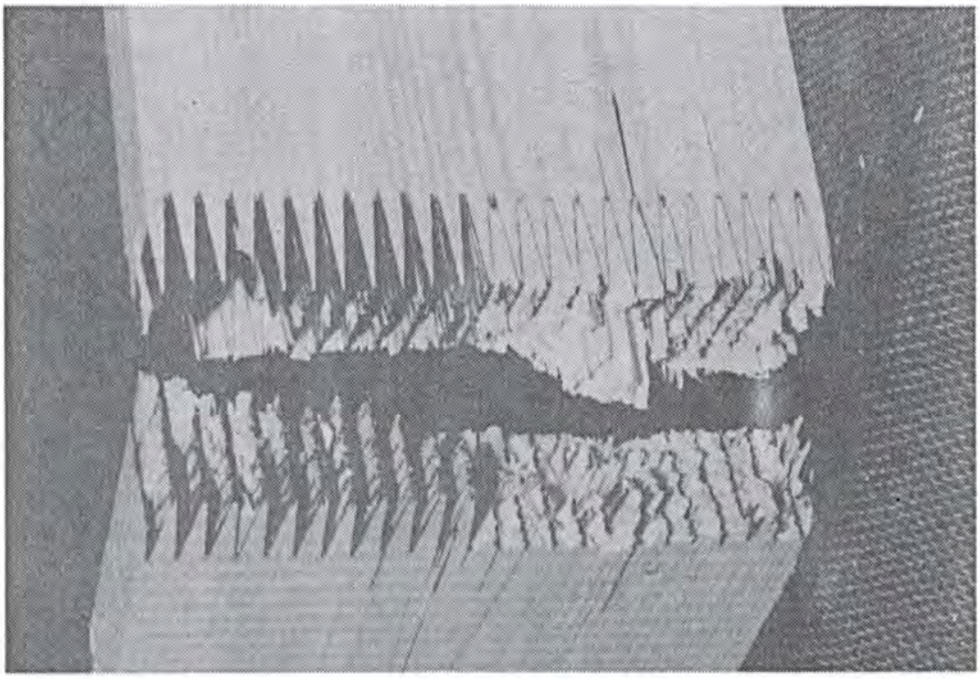


Figure 5: Finger joint with mixed failure (MF)

For each group the test results are given in *table 1*.

Table 1: Bending strength of finger joints

group	N	mean value	stand. dev. N/mm^2	coeff. of variation N/mm^2 -
All	845	50,6	8,7	0,17
80% FJF	258	53,0	9,5	0,18
80% WF	185	46,9	7,6	0,16
MF	402	50,9	8,0	0,16

This table shows that a shear failure along the fingers must not necessarily be equivalent to a poor quality of the joint: the bending strength of finger joints with predominant finger joint failure was 13%, on average, higher than the corresponding value of the test specimen with predominant wood failure. This tendency can be explained by the influence of the wood properties, as shown later.

2.2.2 Effect of wood properties

Tests confirmed former investigations of Moody 1970, Ehlbeck et al. 1985, Samson 1985, indicating that the strength of a finger joint is controlled by the "weaker" part (board) of the joint: approximately 2/3 of the test specimen failed in the board having the poorer wood properties.

For the remaining test specimens, differences between wood properties were low so that a failure in the better part of the joint was quite possible.

Therefore, the bending strength of each finger joint was evaluated by using the lower values of wood properties of the two jointed boards.

In *table 2* mean bending strength values and wood properties are summarized for each failure mode.

Table 2: Test results; mean values

group	f_B N/mm^2	E_{min} N/mm^2	ρ_{min} kg/m^3	max ARW mm	max EWP %
All	50,6	12340	444	4,33	84
80% FJF	53,0	13470	455	3,79	83
80 WF	46,9	11130	433	4,93	85
MF	50,9	12140	442	4,40	85

where

f_B = bending strength,
E_{min} = lower MOE - value of the jointed boards,
ρ_{min} = lower density of the jointed boards,
max ARW = greatest annual ring width,
max EWP = greatest early wood portion,
FJF = finger joint failure,
WF = wood failure,
MF = mixed failure.

It is evident, that the lower strength values of the test specimen with predominant wood failure may be explained by the poorer wood properties of this group.

Hence, these test results indicate that bending strength increases more than shear strength with increasing wood properties, so that in case of high quality boards a shear failure along the fingers may be expected.

In *fig. 6 - 9* bending strength of finger joints depending on the strength determining factors of *table 2* is shown for all test specimen. The dotted lines represent the 5th-percentile and the 95%-percentile, resp., so that in the area between these lines 90% of the test values are expected.

In these figures rather close dependencies with coefficients of correlation up to R = 0,50 in case of ρ_{min} and E_{min} may be seen.

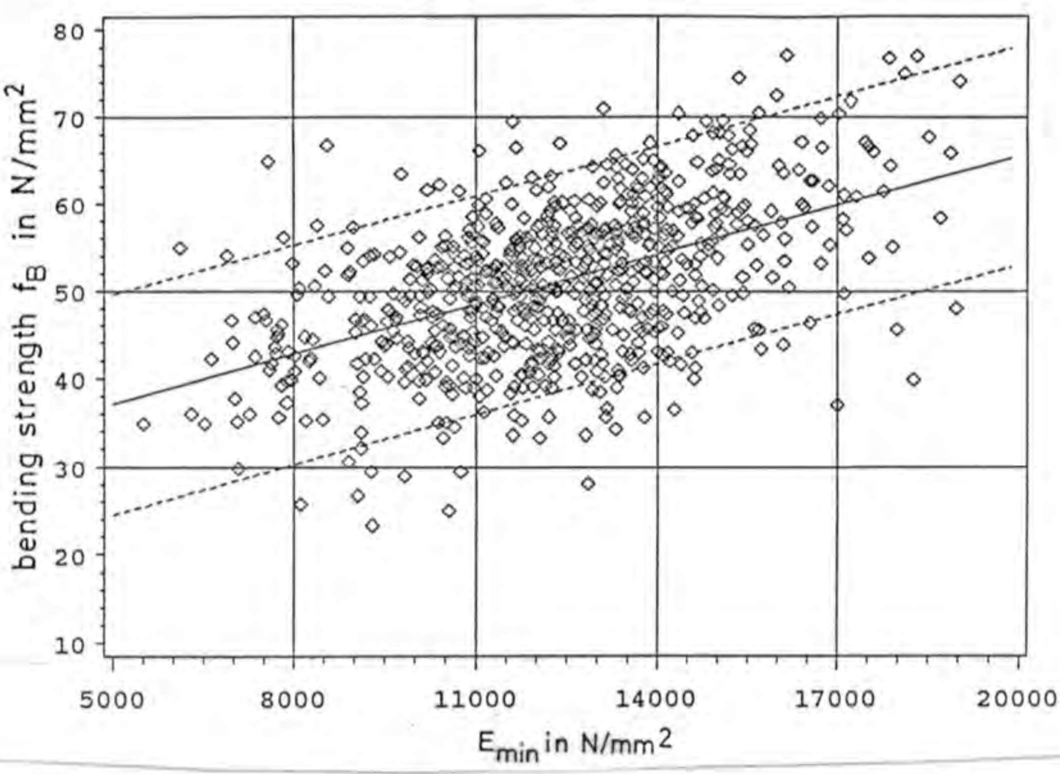


Figure 6: bending strength of finger joints depending on E_{min}; all finger joints

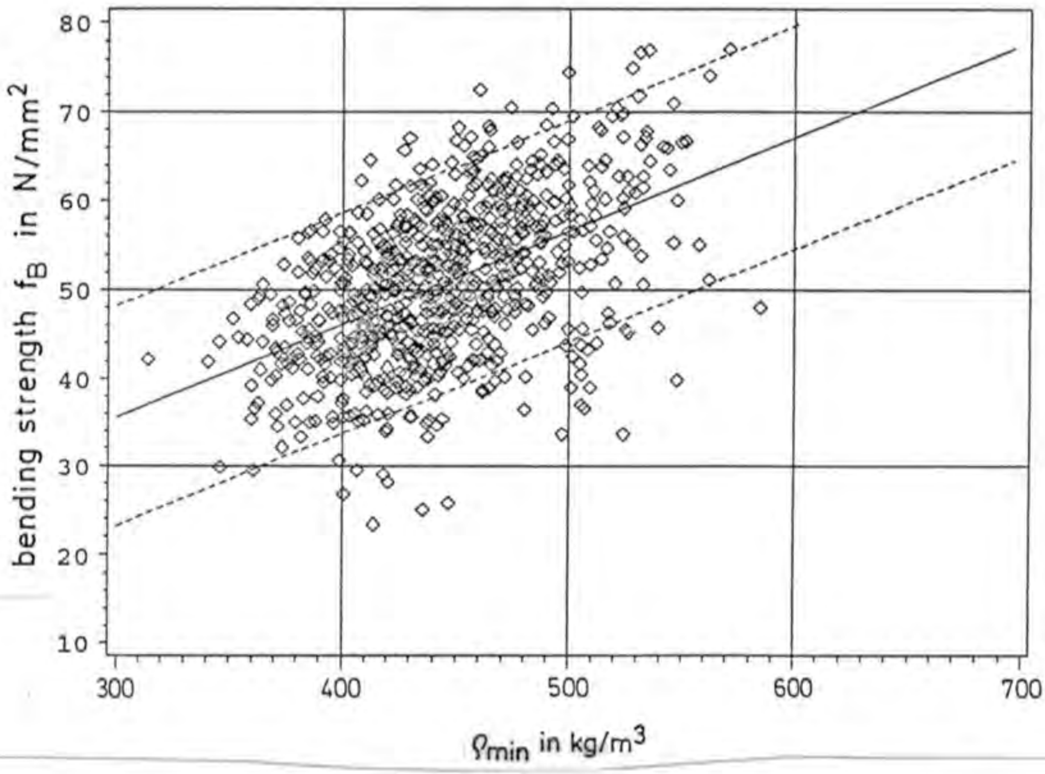


Figure 7: bending strength of finger joints depending on ρ_{min}; all finger joints

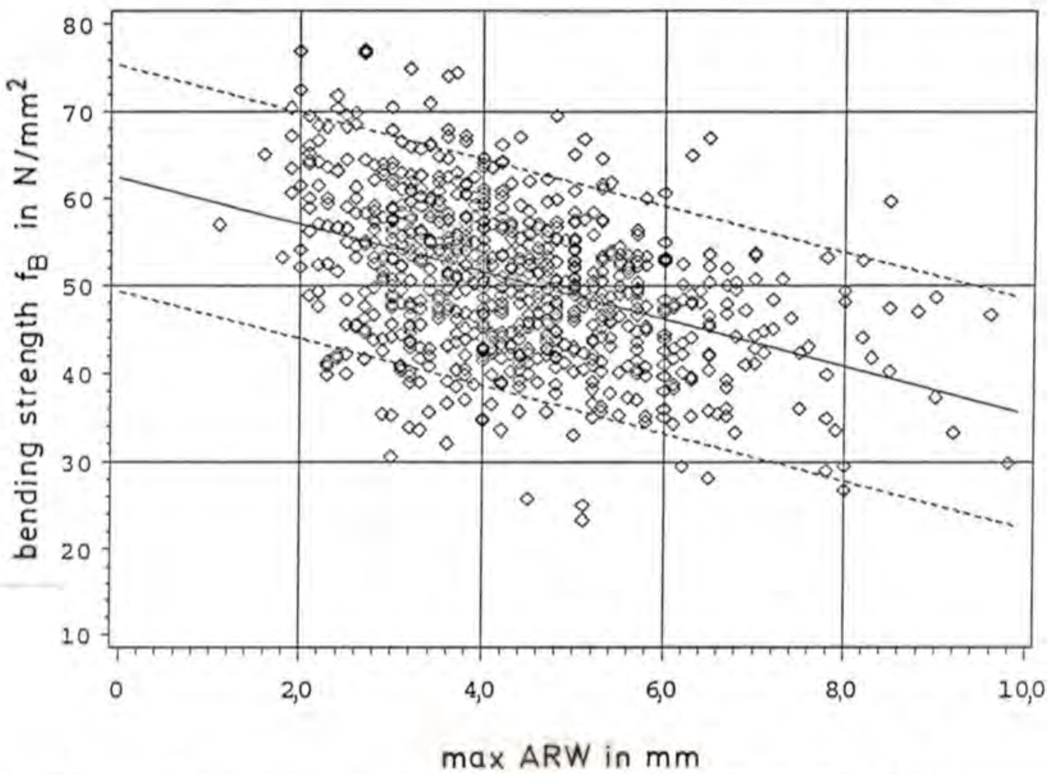


Figure 8: bending strength of finger joints depending on max ARW; all finger joints

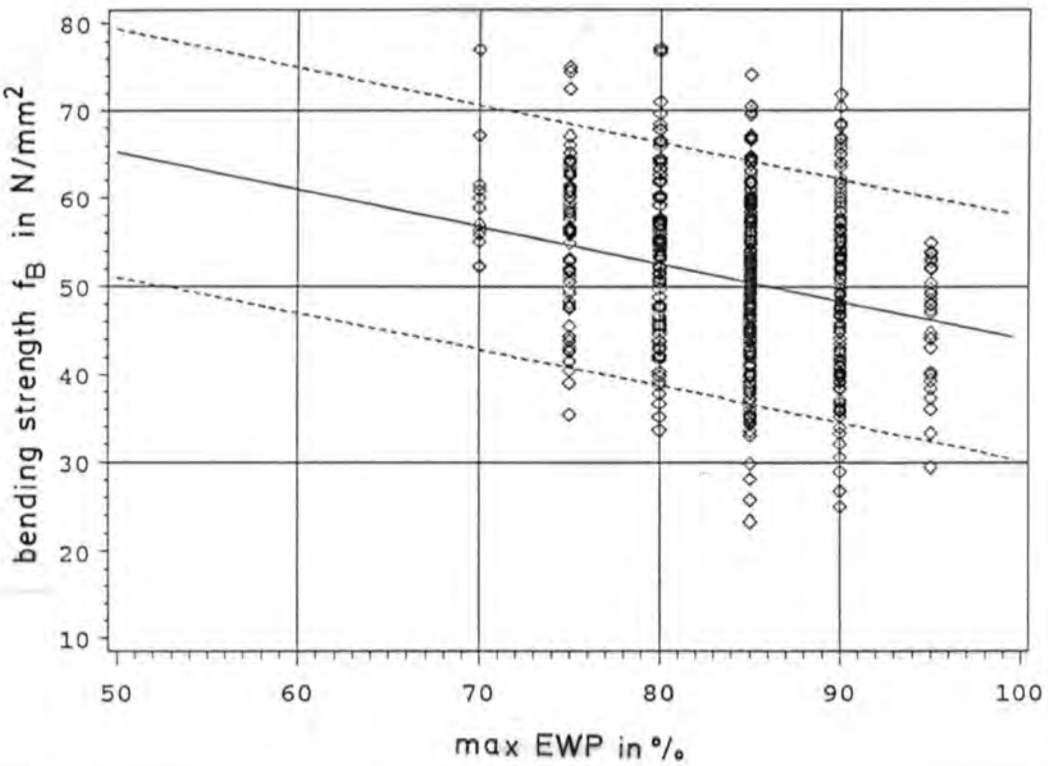


Figure 9: bending strength of finger joints depending on max EWP; all finger joints

As mentioned before, the strength of finger joints is governed by the "weaker" part of the joint. *Figures 6 - 9* indicate that it will be possible to obtain equivalent strength properties of the jointed boards by means of either a machine grading on the basis of MOE and/or density or a visual grading on the basis of annual ring width or early wood portion.

But taking into account the lower coefficients of correlation in case of max ARW (R = -0,424) and max EWP (R = -0,253) and the fact that a visual grading is based on a subjective judgement of the grading person an effective strength grading of finger joints seems only be possible by machine grading.

2.2.3 Effect of pith

Tension tests of Moody 1970 showed that the strength of finger joints is affected by the occurence of pith associated wood. Therefore it was proved if pith did occur in one or both halves of the test specimen. In approximately 1/6 of all cases pith was detected in at least one part of the test specimens and the strength of this group was found to be 6-7%

on average lower than the corresponding strength of finger joints without pith.

Taking into account that pith associated (juvenile) wood was found in nearly every jointed board, these tests show that a pith in one board affects significantly the strength of finger joints.

2.2.4 Effect of joint geometry

A total of 640 finger joints had a profile l/b/t = 20/1,1/6,3 mm, whereas the remaining 205 had a profile l/b/t = 15/0,7/3,8mm.

In *table 3* test results are given for both profiles.

Table 3: Test results; mean values

		f_B N/mm²	E_{min} N/mm²	ρ_{min} kg/m³	max ARW mm	max EWP %
15 mm-profile	All	53,6	12420	446	4,28	84
	80% FJF	59,7	14580	466	3,40	82
	80% WF	48,2	10640	431	5,10	85
	MF	53,7	12080	442	4,25	84
20 mm-profile	All	49,7	12320	443	4,34	85
	80% FJF	51,1	13170	452	3,89	84
	80% WF	46,3	11330	433	4,84	85
	MF	50,2	12160	441	4,44	85

This table shows that finger joints having a nominal length of 15 mm have higher strength values than finger joints with a 20 mm-profile, irrespective of the failure mode. This tendency is explained by the more favourable joint geometry of the 15 mm-profile: tip thickness b is lower (0,7 mm in comparison to 1,1 mm) and ratio φ = 2l/t is higher (7,9 in comparison to 6,3) than in case of the 20 mm-profile.

Regression analysis, however, showed that the influence of joint geometry normally is governed by the effect of the wood properties. The comparatively low coefficients of correlation are given in *table 4*.

Table 4: Coefficients of correlation

	b	φ
All	-0,147	0,235
80% FJF	-0,275	0,308
80% WF	-0,094	0,249
MF	-0,153	0,268

Table 4 shows a significant joint geometry effect only in case of a predominant finger joint failure. For this group the relation between bending strength and ratio $\varphi = 2l/t$ is shown in *fig. 10*.

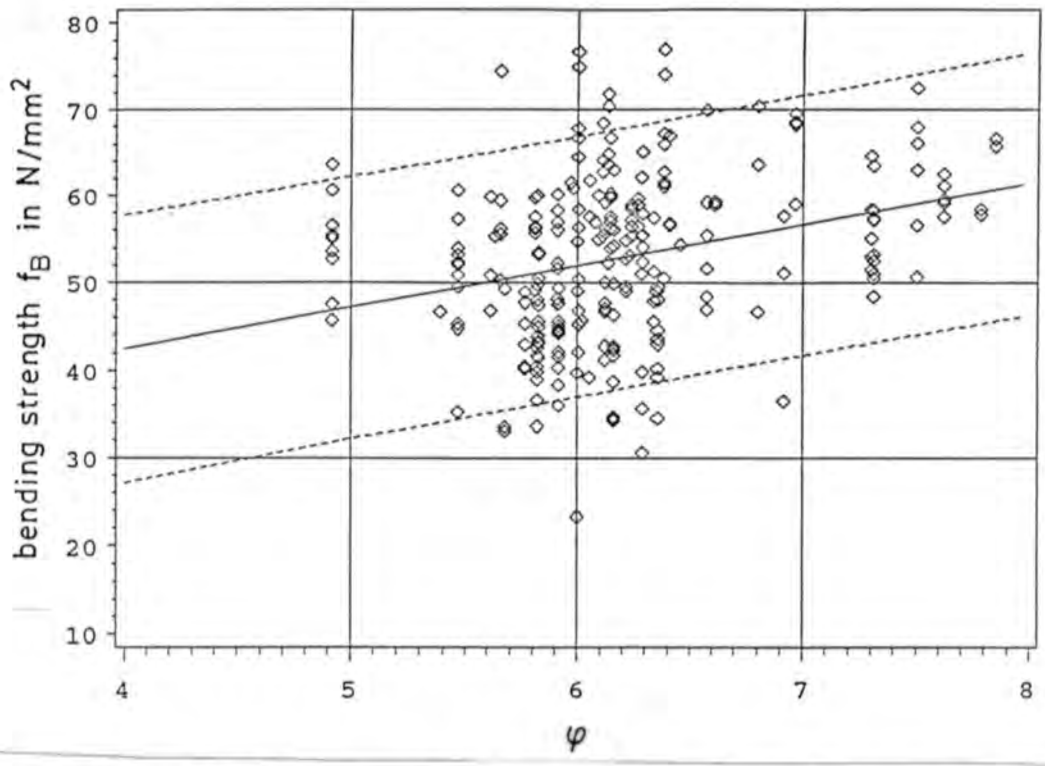


Figure 10: bending strength of finger joints depending on ratio $\varphi = 2l/t$; 80% FJF

Thus, the tests indicate that the effect of joint geometry will increase with increasing wood properties and a shear failure along the fingers is forced. In case of poor wood properties, finger joints mostly show a bending failure so that joint geometry is of minor importance.

3 Summary

Bending tests with 900 finger joints exhibited the following tendencies:

- the strength of a finger joint is governed by the "weaker" member of the joint, i.e. failure normally occurs in the board with the poorer wood properties;
- the strength of finger joints increases with increasing MOE and density and decreasing annual ring widths and early wood portions of the boards;
- the probability of a shear failure along the fingers increases with increasing wood properties. Hence a predominant finger joint failure must not necessarily indicate a poor quality of the joint;
- a pith in at least one board affects the strength of finger joints;
- the strength of finger joints increases with decreasing tip thickness b and increasing ratio φ = 2l/t;
- the effect of joint geometry is less than the effect of wood properties.

Thus, some important tendencies could be determined on the basis of which it should be possible to achieve high strength finger joints.

Due to insufficient data, a satisfactory investigation of the effect of production dependent factors was not possible.

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