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FACTORS INFLUENCING THE FINGER JOINT STRENGTH IN DOUBLE LAMINATED BEECH GLULAM

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ABSTRACT: Previous research on high strength glulam produced using *Fagus sylvatica* (European Beech) showed that the finger joints are governing the bending strength of structural sized specimens. In single laminated glulam each finger joint represents a possible weak spot of the lamella over the whole width. In case of a double laminated glulam this can be avoided and depending on the quality and the number of laminations, the influence of the finger joint on the tension strength can be reduced significantly. The aim of the presented research is to investigate parameters that influence the finger joint strength in double laminated glulam produced using *Fagus sylvatica.* The results showed that the strength of the finger joints is increasing at least over the first four weeks after production and that the arrangement of finger joints in a double laminated glulam influences the strength of the lamellas.

KEYWORDS: double laminated glulam, finger joint strength, beech*,* time dependency

1 – INTRODUCTION

In central Europe especially in Switzerland *Picea abies* (Norway Spruce) is a limited resource and since in non-alpine regions hardwoods are native the availability of softwood on the marked will decrease dramatically [3]. Furthermore, this process is facilitated by the politics and the climate change. Hardwoods and especially *Fagus sylvatica* (Beech) have superior strength and stiffness properties than the widely used spruce timber. However, due to the challenges producing glulam using hardwood the price is significantly higher than for softwood glulam according to EN 14080 [7]. Furthermore, in Europa the production and requirement standard for hardwood glulam and the standards considering structural hardwood bonding are still under development. In Switzerland hardwood glulam (single and double laminated) is commercially available and a national guideline [1] is regulating the production requirements and process. Despite the characteristic strength of beech and ash glulam is significantly higher that the strength of softwood glulam the market share of hardwood is marginal in Switzerland.

2 – BACKGROUND

Frese et al. investigated the influence of visual and machine grading on the bending strength of finger joints in beech boards and concluded that beech glulam with a characteristic bending strength of 48 MPa can be produced [11]. Lehmann et al. investigated the bond quality and finger joint strength of 20 mm thick beech lamellas. They showed that industrially produced finger joints can reach depending on the wood quality characteristic tension strength of up to 52.2 MPa. The characteristic bending strength was independent of the strength grades of the lamellas around 66 MPa [14]. Grando Sanzovo qualified the influence of slope of grain on the bending and tension strength of finger joints in beech lamellas and concluded that slope of grain is critical for high strength finger joints [12]. Erhard et al. investigated the production process and mechanical properties of beech glulam and concluded that characteristic bending strength of up to 55 MPa can be achieved for beach glulam. The presented four point bending tests of various cross sections showed that failure started predominantly in the finger joints of the 20 mm thick lamellas [10]. Lehmann et al. investigated the production of double laminated beech glulam and aimed to reach higher bending strength than for single laminated glulam [13]. In 2021 the commercial production of double laminated beech glulam started in Switzerland, however the declared characteristic bending strength is not higher than for single laminated beech glulam [2]. Even in double laminated glulam the finger joint strength of the single battens is governing the bending strength. Preliminary investigations showed that the tension strength of finger joints strongly depends on the

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waiting time between production and the testing. To a certain degree this can be explained with the curing of the adhesive however the results indicated that the duration of this increase is much longer hat one would expect.

3 – MATERIAL AND METHODS

As mentioned above waiting time between production and testing seems to have a significant influence on the tension strength of finger joints produced using beech lamellas and MUF adhesive. In the first series a total of 240 specimens were produced using beech lamellas with a cross section of 40 mm by 95 mm and a grade of T 42. The grading was done using MOE measurement and visual criteria. However, the finger joints were placed in visually clear wood as specified in [1]. All specimens were produced on an industrial finger jointer at the same time using identic production parameters. The waiting time between the production of the finger joints and the cutting of the specimen was set to two hours as it is required by the adhesive producer for an industrial production process. The Specimens were randomly divided in eight different samples each containing 30 specimens. Seven samples were selected for tension tests according to EN 408:2010+A1:2012 [6]. For the tension test a GZU 850 from Zumwald was used. The distance between the clamps was set to ten times the height of the specimen (40 mm), this compiles with the standard as EN 408 requests at least 9 times the smaller side of the cross section. To investigate the influence of the waiting time between the production and testing on the tension strength seven different waiting times were defined (Table 1). One sample was tested in bending for this the waiting time was set to one week. The four point bending tests were done according to EN 408:2010+A1:2012 [6]. For the bending tests a Zwick Z50 was used. The specimen were tested flatwise as recommended in EN 14080:2013 [7] for finger joint testing in lamellas. The span was set to 18 times the height (780 mm), the load was applied in the third points and the finger joint was placed at midspan.

For the finger joints tested in tension the fibre angle at the location of failure was measured and the influence of the fibre angle on the tension strength was investigated for each waiting time separately. For the evaluation of the influence of the waiting time on the tension strength the specimens with failure out of the finger joints and with a large influence of the fibre angle were excluded.

Before the strength testing, the density of all specimens was measured and the moister content of each specimen was measured according to EN 13183-2:2002 [5] on both sides of the finger joint using a Hydromette M 4050 of Gann. The values stated in this publication represents the average of both measurements of one specimen.

Table 1: Samples as selected for the testing

Sample	Waiting time	Density [kg/m^3]	MC [%]	Test
1	1 Day	703	7.3	tension
2	2 Day	692	7.3	tension
3	3 Day	703	7.7	tension
4	1 Week	709	7.8	tension
5	2 Week	706	7.6	tension
6	3 Week	709	8.1	tension
7	4 Week	680	8.3	tension
8	1 Week	689	7.8	bending

In a second series the influence of the positioning of the finger joints within one lamella on the tension strength was investigated. Two different arrangements were tested (Figure 2):

- All finger joints in one row
- The finger joints were staggered at 10 times the width of the battens

The tension tests on the lamellas were done according to the EN 408:2010+A1:2012 [6]. The clear span between the was set to 10 times the width of the lamella to allow a distance of 200 millimetres between the last finger joint and the clamping zone (Figure 2). The setup was kept equal for both arrangements. The finger joints in the lamellas were produced using the same parameters as for series 1. 30 lamellas of each arrangement were produced and tested. For each specimen the density was determined before the tension test and three moister content measurements in different battens were taken for each lamella. The measurements were done according to EN 13183-2:2002 [5] using a Hydromette M 4050 of Gann, the values stated in this publication represents the average value of the measurements done on each lamella. The waiting time between the production of the finger joints and the testing was set to four weeks. In addition to the single lamellas 16 specimens containing two lamellas and all finger joints at the same position were produced. The final cross section of the double laminated beach glulam was 80 millimetres by 160 millimetres (Figure 1). The testing setup was the same as for the single lamellas.

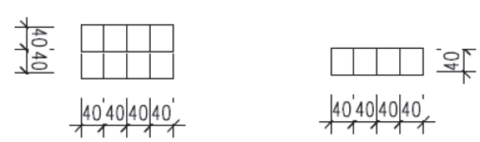

Figure 1: Left: Cross section of a double laminated specimen; right: cross section of a single lamella

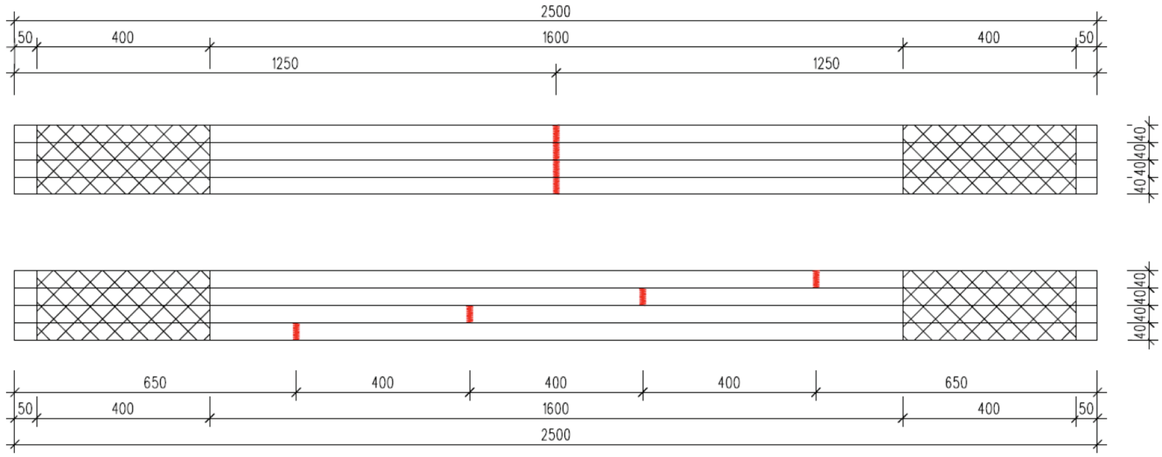

Figure 2: Arrangement of the finger joints within one lamination for the tension tests to investigate the influence of the arrangement the cross-hatched area represents the clamping zone.

4 – RESULTS

Some of the specimens did fail due to slope of grain or not in the finger joint, these results were excluded for the evaluation of the influence of the waiting time between production and tension tests. This measure allowed to exclude the influence of slope of grain on the evaluation. As specially as slope of grain has a negative influence on the tension strength of finger joints in beech [4, 12, 14] and occurred mainly in the samples with a longer waiting period. Table 2 shows an overview of the results of the tension tests and the number of specimens considered for the evaluation. Figure 3 shows the boxplots of the considered results and visualises the variation between and within the samples.

Table 2: Overview of the results used for the evaluation of the influence of the waiting period between production and testing on the tension strength of the finger joints.

Sample	**Waiting time**	**Number of Specimens**	**tension strength [MPa]**	**characteristic value [MPa]**
1	1 Day	30	31.1	24.8
2	2 Day	30	39.3	28.0
3	3 Day	25	38.8	29.1
4	1 Week	26	45.8	35.4
5	2 Week	27	46.3	32.6
6	3 Week	26	50.1	37.5
7	4 Week	24	51.1	38.4

Table 3 shows the results of the bending tests done one week after the production. All specimens failed in the finger joint.

Table 3: Overview of the bending test results

Sample	**Waiting time**	**number**	**bending strength [MPa]**	**characteristic value [MPa]**
8	1 Week	30	71.7	60.9

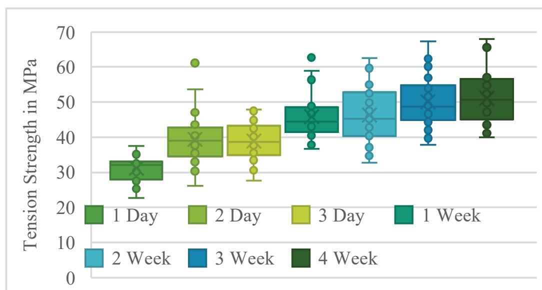

Figure 3: Boxplots of the results considered for the evaluation of the influence of the waiting period on the tension strength

The results of the tension tests on single finger joints clearly show a significant influence of the waiting period on the tension strength (Figure 3). The influence could be seen on the average value (Figure 4) as well as on the characteristic value, which represents the 5% percentile calculated according to EN 14358:2016 [8] assuming a log-normal distribution (Figure 5). The tested samples and the logarithmic trend lines indicate that the maximum strength may not be reached after four weeks. An extrapolation based on the presented data is regarded as not appropriate to estimate the strength after a longer waiting period.

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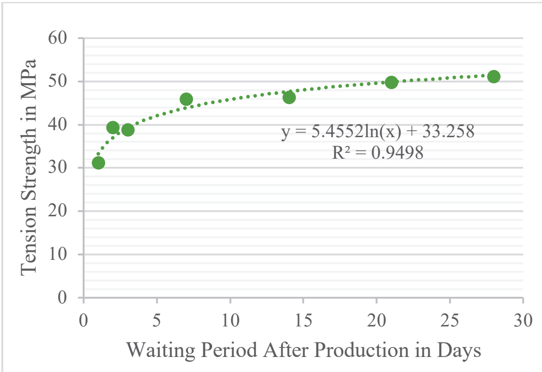

Figure 4: Average tension strength of finger joints as a function of the waiting time between production and tension test.

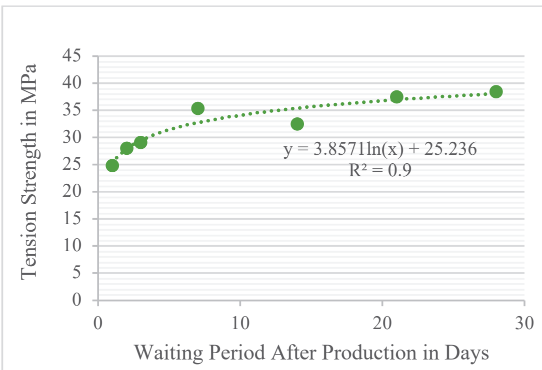

Figure 5: *Characteristic tension strength of finger joints as a function of the waiting time between production and tension test*

Slope of grain (Figure 6) had a negative influence on the tension strength of the finger joints. An analyse of all specimens independent of the waiting time between production and tension test resulted in total 45 specimen were a slope of grain larger than 5° in the failure at the finger joint could be detected. Thees 45 specimens were divided in three groups to investigate the influence of slope of grain on the strength. The number of specimens and the range of the angle of lope of grain can be seen in Table 4. There was no clear trend visible between group B and C. However, the average tension strength of group A is about 20 % higher than the one of Group B and C. The results indicate that a there is a threshold and above this the slope of grain has a negative influence on the strength.

Table 4: Range of slope of grain detected in the finger joints over all samples

	Angle	Number of specimens	Tension Strength [MPa]
Range A	5-9°	16	49.5
Range B	10-14°	15	40.0
Range C	15-18°	14	40.5

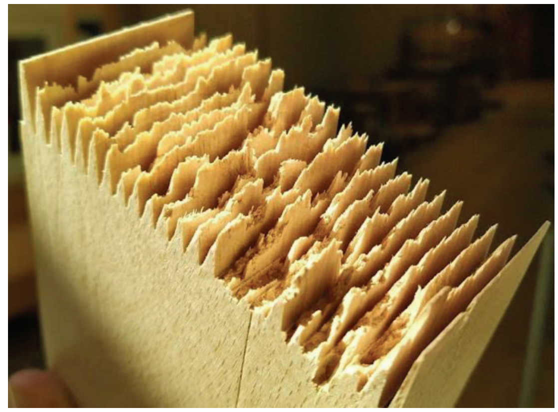

Figure 6: Specimen after tension test with clearly visible slope of grain in the finger joint and its influence on the failure behaviour [4].

The specimens tested four weeks after production were evaluated separately for the influence of slope of grain on the tension strength of the finger joints. For this analyse all specimens with an angle above 8° were considered as specimen with slope of grain. The threshold of 8° was chosen based in the work done by Grando Sanzovo [12]. In Table 5 the influence of the slope of grain on the tension strength of the finer joints can clearly be seen.

Table 5: Influence of slope of grain on the tension strength of the finger joints in sample 7

	Tension Strength [MPa]	CoV
no slope of grain	51.8	14.5%
with slope of grain	42.8	14.8%

As one would expect the bending strength tested after one week is significantly higher than the tension strength for the same waiting time. This is well known and already considered in EN 14080:2013 [7] the European glulam standard for softwood. Previous research [9, 14] indicate that the factor of 1.4 used in EN 14080:2013 to convert bending strength requirements of finger joints in tension strength is not valid for beech and furthermore the factor is depending of on the timber properties. The results presented in this paper indicate a factor of 1.56 for the average strength and a factor of 1.72 for the characteristic value.

The test to investigate the influence of a staggered arrangement compared to an alignment of all finger joints in the centre of the lamella (Figure 2) showed that the laminations with a staggered arrangement of the finger joints had a higher tension strength than the one with all joints aligned in one line at the centre. This difference was more pronounced for the 5% percentile as for the

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mean values (Table 6). A staggered arrangement also leaded to a lower coefficient of variation.

Table 6: Test results of the tension test of lamellas with different arrangements of the finger joints

	Number of Speci-mens	tension strength [MPa]	CoV	characteristic value [MPa]
central	28	53.1	18.7%	35.7
staggered	31	55.3	14.9%	40.2

Table 7 shows the results of the tension test on the beams containing two lamellas and all finger joints arranged in one line.

Table 7: Test results of the tension test on beams with all finger joints aligned in one line in the centre of the specimen

	Number of Speci-mens	tension strength [MPa]	CoV	characteristic value [MPa]
beams	15	57.0	11.0%	44.9

Figure 7 clearly shows that for the staggered arrangement some battens fail in the timber and not in the finger joint in lamellas with all finger joints arranged in one line the failure usually happen at the finger joint only.

Figure 7: Typical failure of a lamella with a staggered arrangement of the finger joints

Figure 8 clearly shows that the tension strength of a beam with two lamellas is significantly higher than the one of one lamella produced using the same parameters and resource. The beams with a centred arrangement reached the highest strength and also the lowest coefficient of variation. These results indicate a positive volume effect for the tension strength of the finger joints for the specimen with four and eight finger joints in one line. However, this effect is not confirmed for the specimen with on single finger joint (sample 7) and the lamellas. However, it needs to be considered that the specimens for testing the influence of the arrangements of the finger joints and the specimens for evaluating the influence on the waiting period between production and testing were produced on different dates and using a different timber resource furthermore the battens used in the lamellas and for the tests on single finger joints did not have the same geometry.

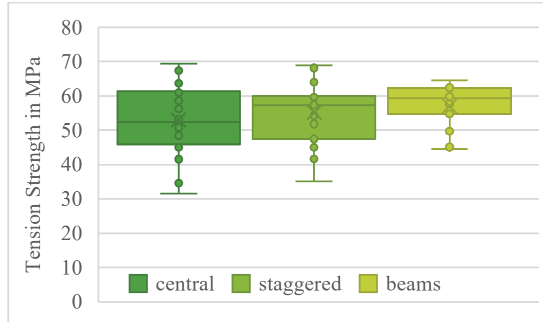

Figure 8: Boxplots of the results of the tension tests on lamellas with different finger joint arrangement and beams containing two lamellas with all finger joints arranged in one line

Figure 9 shows a bema specimen with a typical failure initiated in the area of the finger joints. All beam specimens failed to a great proportion in the finger joints and showed a verry brittle failure. The alignment in one line prevented a load redistribution after the first crack initiation to the other battens as this happened in the lamellas with a staggered arrangement. This indicates that a staggered arrangement of the finger joints in a beam would lead to higher tension strength and therefore should be used in a production of double laminated glulam.

Figure 9: Beam specimen after tension test with high proportion of failure in the finger joints

5 – CONCLUSIONS

The investigations clearly show an influence of the waiting period between testing and production on the strength of finger joints. This finding needs to be verified using different adhesives, production parameters and also different hardwood species. For future investigations on the influence of the waiting time on the tension strength additional series with 8 weeks and 6 month waiting time are recommend, this would probably allow the determination of the final tension strength of the finger joints. In case

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the findings are confirmed it should be considered in the quality control of (double laminated) glulam produced using European beech.

7 – ACKNOWLEDGEMENTS

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