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A METHOD FOR GLUE BOND QUALITY TESTING OF FLANGE/WEB ADHESIVE CONNECTIONS OF WOODEN I-BEAMS

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Title:

A method for glue bond quality testing of flange/web adhesive connections of wooden I-beams

Abstract:

A test method for assessing the quality of glue bonds in the web-flange joint of I-beams has been developed. The method is based on a shear test of small pieces cut from the beam. The investigation has included shear tests on different specimen sizes, including the influence of the wood density, the wood moisture content and the influence of different pre-treatments (boiling) in order to detect possible gluing errors. A limited finite element analysis was also performed. The main conclusion is that pre-treatment of the specimen by boiling is necessary in order to detect gluing errors. Another confirmation is that the wood failure percentage can be used as a good indicator of the bond quality. Finally, a draft test method for a possible standard is given.

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Contents

Preface

This report was prepared as the final project report for the Nordtest project 1583-02 "Träbaserade lättbalkar. Utveckling av metod för bestämning av limfogskvalitet" (Wood I-beams. Development of a method for the determination of adhesive bond line quality").

The project has been performed as a co-operation by SP – Swedish National Testing and Research Institute, VTT –Technical Research Centre of Finland and NTI – Norwegian Institute for Wood Technology. SP has had the responsibility of the final compilation of the results and editing of this report.

Borås, October 2003

Erik Serrano

Summary

An important aspect of the production of wooden I-beams is the control of the quality of the adhesive joint that bonds the web to the flange. A test method needs to be developed, since the existing ones as described, for example in EN 392 (Anon.1995), cannot be used due to the geometry of the joint. The development of such a test method is the aim of the current project.

The work reported here has included different investigations in order to establish a reliable test method. The influence of the test piece thickness was studied in order to obtain a test specimen size of appropriate dimensions. The influence of the moisture content and of different pre-conditioning climates was also investigated. Finally, in order to be able to detect less severe gluing errors, the influence of boiling the specimens prior to testing was investigated. In total 800 individual shear tests have been performed, each being evaluated at least in terms of shear strength and wood failure percentage.

Based on the findings, it is recommended that a test method based on a compressive shear test of the bond between web and flange (push-through) be used. It is recommended that the test pieces should be 20 mm in thickness, which was found to be a good compromise between the strive for a large enough specimen in order not to cause to much damage when cutting it and the strive for small specimens resulting in lesser load levels and more uniform stress distribution.

It is furthermore recommended that the testing be preceded by repeated boiling of the specimens in water. This pre-treatment has shown to be enough to predict the most severe gluing errors. An alternative pre-treatment to use is boiling the specimens only once, but to use a stricter pass/fail criterion.

When evaluating the test results, it is recommend that the wood failure percentage be used as a pass/fail criterion in combination with a minimum shear strength criterion. The level for the wood failure percentage is set to 70% for repeated boiling as a pre-treatment. This means that, in order to accept the quality of the bond line, the wood failure percentage should be 70% or more. For the alternative pre-treatment of boiling only once, the level is set to 80% wood failure. The reference shear strength value to be met, should be determined at the products initial type testing.

A test method, which can be used as starting point for future standardisation, can be found in Appendix A.

1 Introduction

1.1 Background

Different types of engineered wood products (EWP) have gained importance in recent years. A large part of these EWP are I-beams, where the web is adhesively bonded into grooves machined into the flanges. Other EWP include such products like oriented strand board (OSB) and Laminated Veneer Lumber (LVL).

In the US the increased use of I-beams is evident from the increase in number of producers, which is fast growing. During the 1990's, the number of plants producing Ibeams increased in number from 16 to 43 (Zylkowski 2000). The use of I-beams has, to a large extent, replaced the use of solid timber for floor and roof structures.

1.2 Aim

A test method for the web/flange connection of I-beams needs to be developed, since the existing test methods for glue bonds, as described for example in EN 392 (Anon.1995), cannot be used due to the geometry of the joint. Typically the web is bonded into a slightly wedge-shaped groove, see Figure 1. The development of such a test method is the aim of the current project.

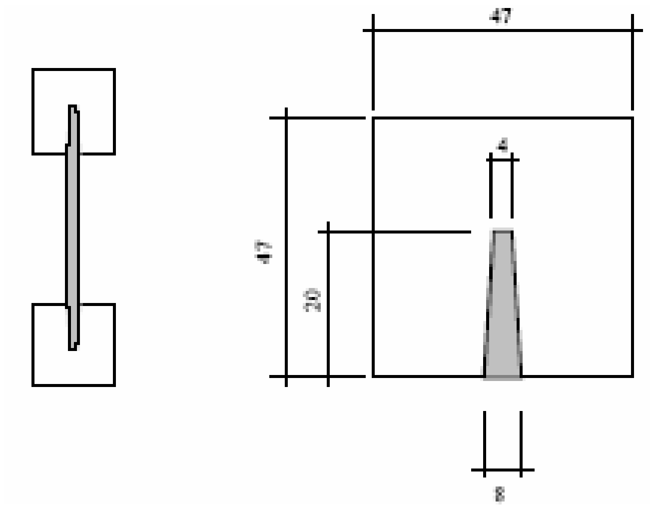

Figure 1. Example of web-to-flange geometry of a wood I-beam.

1.3 Current method used by a manufacturer

At the present, one manufacturer uses an in-house method to determine whether the adhesive bond has an acceptable quality. The method is based on a shear test of a thin slice of the complete I-beam cross-section. A loading device applies a compressive force on the web material, as indicated in Figure 2. This method has served as a starting point for further development within the present project.

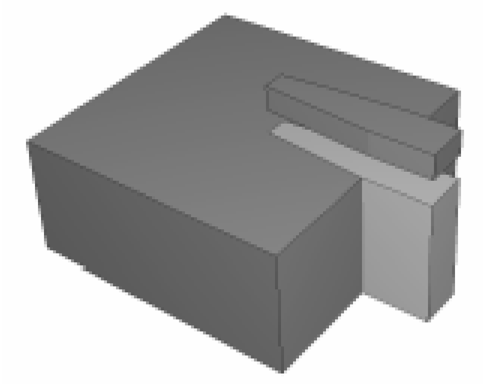

Figure 2. A steel plate is used to push through the web material in shear. Only part of the cross-section and the loading device is shown.

1.4 Work content and disposition of the report

The project has been divided into a number of tasks, of which Tasks 2, 3 and 4 relate to testing and evaluation of tests using a proposed test method. The work contents of these tasks are described below.

- Task 2
  - The influence of the test piece thickness. Normally, size effects should be investigated for any kind of material or structural test. A finite element study was also conducted in this task.
- Task 3
  - The influence of the moisture content. Different pre-conditioning climates are used in order to investigate their effect on the glue bond quality.
- Task 4
  - The influence of pre-treatment (boiling) of the specimens prior to testing in order to detect any problems with glue bond quality.

Chapter 2 gives a general description of the materials and methods used for the respective tasks. Chapters 3-5 describe the results from the tests performed in tasks 2-4 and the FE-simulations performed in task 2. Chapter 6 gives a general discussion on the project results and includes some final remarks and recommendations. Appendix A, finally, presents the draft test method as proposed by the project partners.

2 Materials and methods

2.1 Beam materials

For this project it was decided to use two different beam types, manufactured in Sweden and in Norway. The Swedish beam is manufactured by Masonite Beams AB. The Norwegian beam is manufactured by Forestia AS and is sold under the commercial name “Rantibjelken”. The two beams are based on the same principles of an I-beam, but differing in their material composition and geometrical shape of the web-to-flange joint. In Figure 3 is shown two cross-sectional views of the beam types investigated.

The beams from Masonite AB are made from an 8 mm thick HDF-board (K40) and 47×47 mm^2 solid timber flanges (K24 or K30). The Rantibeam consists of a 10 mm thick chipboard of structural class and 47×47 mm^2 solid timber flanges of an especially graded class. Both products are subject to technical approvals in their respective countries. The Masonite beam has a web-to-flange joint that is wedge shaped, while the Rantibeam has a V-shaped groove in the edge of the web, and a corresponding shape in the flange, see Figure 3.

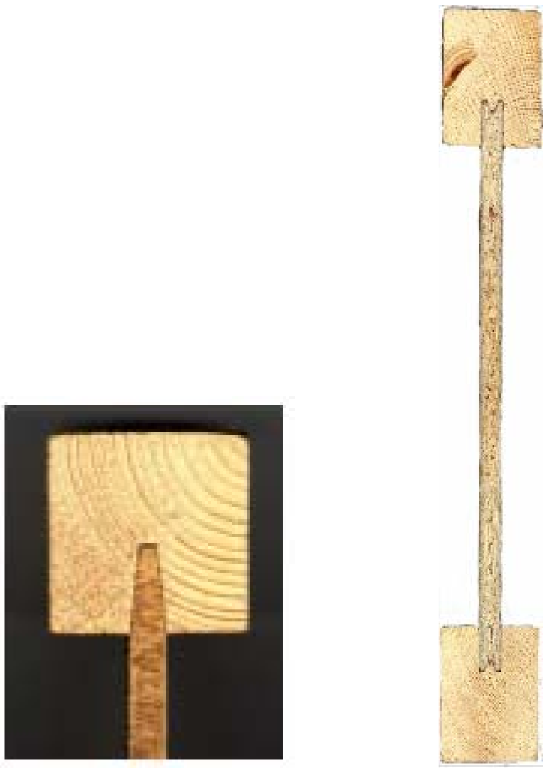

Figure 3. The Masonite beam (left) and the Rantibeam (right).

Since the parameters to be studied included the density of the wood flanges, the beams where selected in order to obtain different density groups (high-medium-low). Another parameter studied was the influence of gluing errors and the possibility to detect them. Therefore, a number of beams were produced were the mixing of the adhesive was deliberately wrong (the recommended adhesive/hardener mixing ratio was altered) and also a series were the amount of glue applied differed from the amount recommended by the manufacturer.

2.2 Test set-ups

Due to the fact that the different beams have differently shaped web-to-flange joints, the test setups must be adapted correspondingly. The main principle remains the same, however. A loading device is used to push through the web material from its connection to the flange. The test piece is placed on a self-aligning steel plate, which has a cut shaped as the web-to-flange joint. A loading device with a corresponding shape is used to push through the web material. The precise geometry of the loading device and the cut in the supporting plate is determined such that the distance between the bond line (i.e. the intended shear plane) and the loading device is 0.5-1 mm. The parts used in obtaining this test set-up are shown schematically in Figure 4.

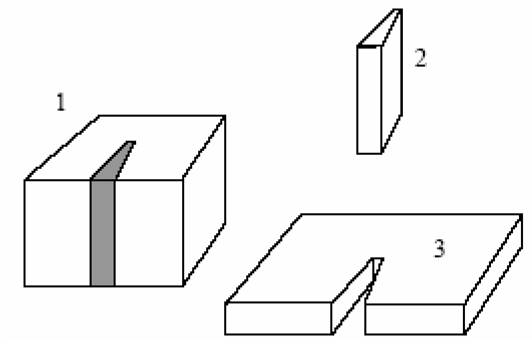

Figure 4. Schematic of test set-ups used with test specimen (1), loading device (2) and support plate (3). The support plate must be self-aligning.

3 Task 2 – Influence of specimen thickness

3.1 General remarks

The basic idea behind this task is to investigate any possible size effect. The original idea was to use the same thickness as that used in EN 392 (75 mm), it turns out, however, that this is not possible due to the crushing strength of the web materials. It was therefore decided to test three different specimen thicknesses (in the beam axis direction): 10, 20 and 30 mm. The outcome from this task establishes the reference thickness to be used in the rest of the project tasks. The tests performed included the two beam types, different densities and a deliberately induced gluing error.

In addition to the original test plan, a limited finite element study was performed. This study is presented in section 3.4.

3.2 Test programme

Task 2 included the tests as indicated in Table 1. A total of 450 individual tests were included in this task.

Table 1. Test programme for task 2.

Description	RH (%)	Thickness (mm)	Number of specimens	Tested by
MB-1, Low density, thickness 1	65	10	30	SP
MB-1, Low density, thickness 2	65	20	30	SP
MB-1, Low density, thickness 3	65	30	30	SP
MB-2, High density, thickness 1	65	10	30	SP
MB-2, High density, thickness 2	65	20	30	SP
MB-2, High density, thickness 3	65	30	30	SP
RB-B1, Low density, thickness 1	65	10	30	NTI
RB-B1, Low density, thickness 2	65	20	30	NTI
RB-B1, Low density, thickness 3	65	30	30	NTI
RB-A1, High density, thickness 1	65	10	30	NTI
RB-A1, High density, thickness 2	65	20	30	NTI
RB-A1, High density, thickness 3	65	30	30	NTI
RB-C1, Gluing error, thickness 1	65	10	30	NTI
RB-C1, Gluing error, thickness 2	65	20	30	NTI
RB-C1, Gluing error, thickness 3	65	30	30	NTI

3.3 Test results

The test results from the tests are summarised in Table 2 and Table 3 for the Ranti beam and the Masonite beam respectively. The density and the moisture content were measured on specimens cut from the vicinity of the specimens used for the shear tests (Ranti) or from the 30 mm thick specimen (Masonite).

Table 2. Shear test results. Ranti-beam.

Thickness (mm)	Shear strength (MPa)		Wood failure (%)		Density (kg/m^3)		Moisture content (%)	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Low density								
10	9.00	0.88	92	7				
20	7.30	0.59	90	8	493	6.4	13.0	0.13
30	6.35	0.48	91	6				
High density								
10	8.71	1.21	90	13				
20	7.78	0.71	86	11	576	13.4	13.6	0.13
30	6.55	0.54	86	16				
50% hardener								
10	9.52	2.17	83	18				
20	7.66	1.28	81	21	470	24.7	13.1	0.13
30	6.60	1.00	83	20				

Table 3. Shear test results. Masonite beam.

Thickness (mm)	Shear strength MPa		Wood failure %		Web material failure, %		Density kg/m^3		Moisture content, %	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Low density										
10	4.85	1.04	99	3	67	24	-	-	-	-
20	5.13	0.70	100	1	57	17	-	-	-	-
30	5.44	0.33	100	2	52	15	350	11	11.7	0.6
High density										
10	5.78	0.72	98	4	68	21	-	-	-	-
20	5.99	0.63	99	3	65	20	-	-	-	-
30	4.89	0.39	100	2	71	23	398	7	11.7	0.5

3.4 Finite element study

3.4.1 FE-model

The geometries of the specimens were modelled using the nominal dimensions as provided by the manufacturers. The cut in the flange and the corresponding part of the web were modelled with the same dimensions, giving a perfect fit. However, since the bond line thickness is finite, there will be a mismatch between the two parts. The adhesive bond lines were assumed to be of 0.1 mm thickness. Details of the two specimens are shown in Figure 5 and in Figure 6. The loading devices were modelled with rigid plates.

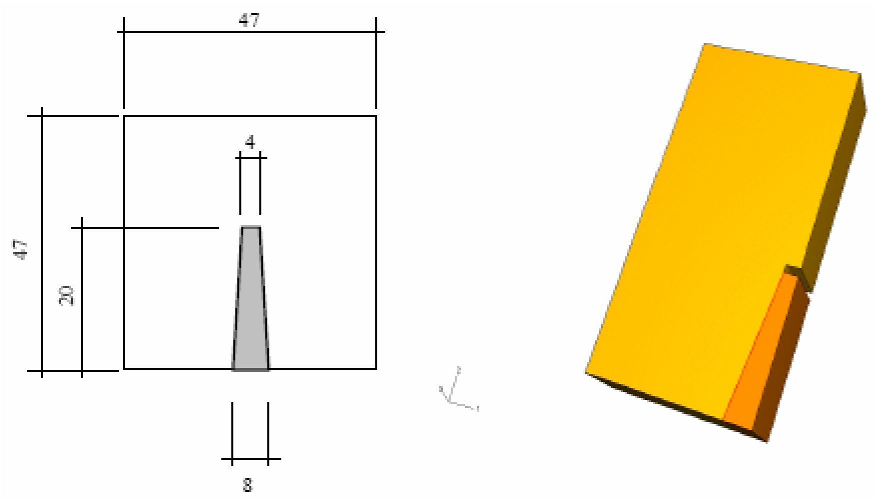

Figure 5. Nominal geometry and solid model of the Masonite specimen (symmetric half).

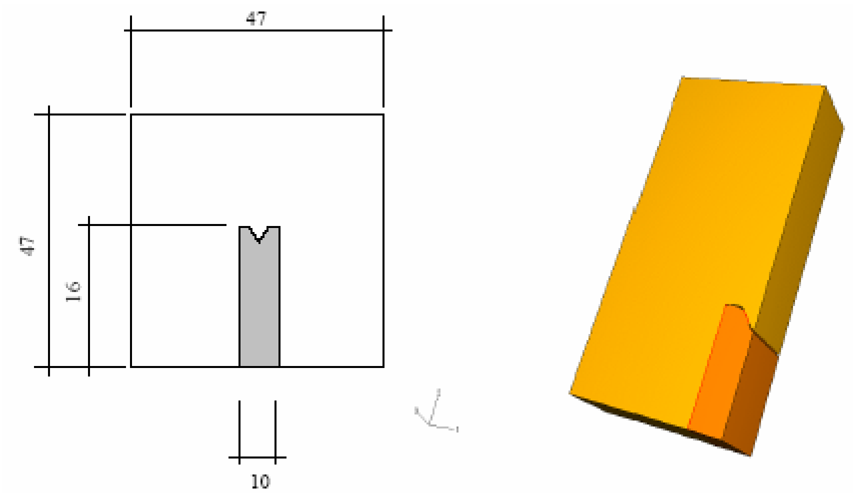

Figure 6. Nominal geometry and solid model of the Ranti specimen (symmetric half).

The test specimens were modelled using linear elastic materials for the flanges and the webs and with a nonlinear fracture-softening model for the adhesive bond line. For the bond line one must define both fracture energy and strength, for both pure shear and for pure normal deformation (peel stress). The adhesive layer is characterised not only by its shear properties, but also by its strength and fracture energy perpendicular to the bond line. When acting in a combined state of deformation including both shear and normal deformation, the bond line model accounts for different strength and fracture energy as compared to the values for uni-axial states. The local strength and fracture energy of the adhesive layer was set to 18 MPa and 1250 J/m^2, respectively, which correspond to a brittle adhesive, such as a phenolic resorcinol. The bond line thickness was set to 0.1 mm. The specific elastic constants used in the simulations are summarised in Table 4 and in Table 5.

Table 4. Material parameters used in the finite element study.

Beam	E_{web} (MPa)	G_{web} (MPa)	$E_{flange,0}$ (MPa)	$E_{flange,90}$ (MPa)	$G_{flange,0/90}$ (Mpa)
Masonite	5000	2100	12000	400	800
Ranti	3000	1300	13000	430	810

Table 5. Material parameters used in the finite element study.

Shear strength (MPa)	Peel strength (MPa)	Fracture energy, $G_{f,I}$ (J/m^2)	Fracture energy, $G_{f,II}$ (J/m^2)
18	6	550	1250

The loading was applied by the use of rigid surfaces and the contact modelling capabilities of the software used (ABAQUS 6.3). The flange piece was assumed to interact with a rigid surface, which is constrained in all directions. The loading piece was modelled with a rigid surface interacting with the web part. The loading piece was prescribed to move in the loading direction while constraining all other directions. The coefficient of friction was set to $\mu = 0.6$ for all cases.

3.4.2 FE-Results

The results from the FE-simulations are summarised in Table 6, which gives calculated load-bearing capacities and corresponding nominal shear strengths. Figure 7 givas, as an example the deformation of the Masonite specimens. The load-deformation curves for the two specimens are shown in Figure 8.

Table 6. Results from FE-simulations. Loads and areas are for the symmetric half.

Beam-Length	Max load, P_{max} (N)	Shear area, A (mm^2)	Shear strength, f_v (MPa)	Compressive stress (MPa)[1]
MB-10 mm	2533	191	13.3	42
MB-20 mm	2802	382	7.3	47
MB-30 mm	3226	573	5.6	54
RB-10 mm	1944	179	10.9	26
RB-20 mm	2449	358	6.9	33
RB-30 mm	2822	536	5.3	38

[1] Calculated under the assumption that the applied load is uniformly distributed over the web material. The areas were set to 60 mm2 and 75 mm2 for the symmetric halves of the Masonite- and Ranti- beam, respectively

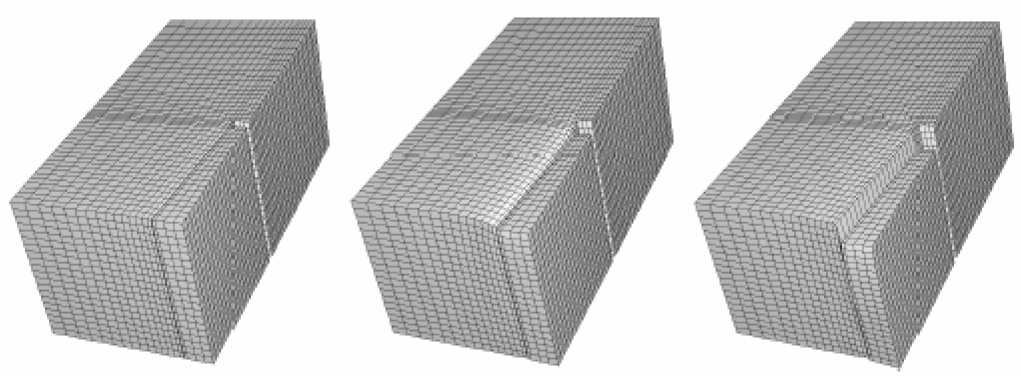

Figure 7. The deformation during the course of loading of the Masonite beam. The deformations are scaled a factor of 20, for clarity.

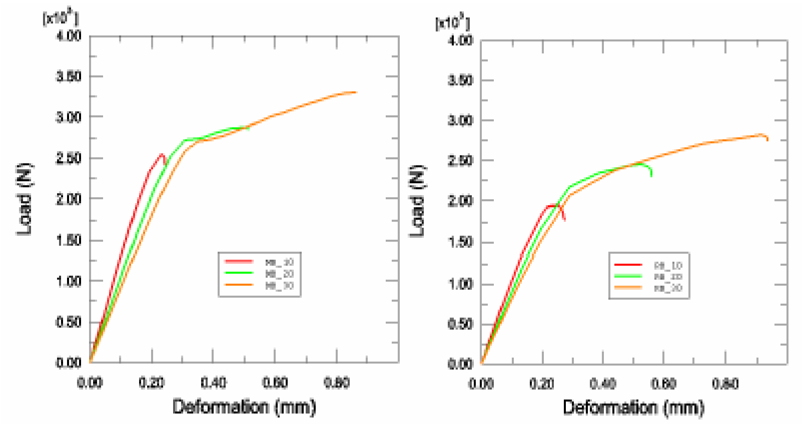

Figure 8. Load-deformation from nonlinear FE-analyses. Masonite-beam (left) and Rantibeam (right).

3.5 Conclusions – Task 2

The test results from the tests with the Ranti beam show a clear trend: thicker test specimens tend to give a lower shear strength prediction. The results from the tests with the Masonite beam, however, are more inconclusive. The wood failure percentages are higher for these than for the Ranti beam tests. Also, the web material failure percentage is high when the failure is outside the bond line, as can be seen in Table 3. This is interesting in terms of the design of the test method. Possibly, the Masonite-beam has had a larger amount of web material failure, and thus the influence of the bond specimen thickness is not as obvious. The failure of the web material could be a compressive failure, but the state of stress at testing is complex and the tensile strength of the material perpendicular to the web plane could also play a role here.

The tests with the Ranti beam included a series whit only 50% of the recommended amount of hardener being used. The resulting shear strength of the bond line was not affected by this gluing error. However, the wood failure percentage was slightly lower for the specimens with gluing error.

The FE-analyses have shown that it is possible to predict a size effect, similar to the one seen in the Ranti-beam tests. The FE-analyses were performed using material data, which have not been calibrated to the present test material. Therefore, the results can only be used for a qualitative comparison. The FE-analyses have also shown that the influence of bending of the test specimen is of no importance, and therefore cannot explain any influence of specimen size.

The specimen should be more than 10 mm thick, in order to avoid that a large fraction of the bond line is damaged when cut from the beam. However, the specimen thickness should not exceed approximately 20 mm, in order to avoid failure of the web material.

As a result from this task it was decided that the specimen thickness should be 20 mm, for the remaining tests.

4 Task 3 – Influence of moisture content

4.1 General remarks

This task relates to the influence of pre-conditioning at different relative humidity levels, resulting in different moisture contents. The levels of air relative humidity chosen were:

45%: room-climate, dry specimens

65%: standard climate, reference

85%: humid climate, wet specimens

All specimens tested were 20 mm in thickness, as decided from the outcome of task 2.

4.2 Test programme

The tests in this task are summarised in Table 7. A total of 45 specimens, each 20 mm in thickness, were included in this task. The specimens were uniformly distributed, such that each beam of three different beams used was represented by 5 specimens. The tests were performed by VTT.

Table 7. Test programme for task 3.

Description	RH	No of specimens	Tested by
MB-3-45, dry	45%	15	VTT
MB-3-65, reference	65%	15	VTT
MB-3-85, wet	85%	15	VTT

4.3 Test results

The density and the moisture content were determined for 5 specimens from each beam. Both the mass and the density were measured at the moisture content indicated together with the results in Table 8.

Table 8. Test results – density and moisture content (MC)

Beam	Density		MC	
	Mean kg/m^3	Std. dev. kg/m^3	Mean %	Std. dev. %
MB-3-1	486	4	14.8	0.1
MB-3-2	465	3	14.7	0.1
MB-3-3	475	6	14.8	0.0

The results from the shear tests are given in Table 9. Two results from series 65% RH were excluded due to the presence of a knot.

The glue line for the beams was without any flaws, which is indicated by the high woodfailure percentage – above 90%. The failure was mainly in the web material. The web material shear strength is higher at 45% RH than at 65% RH, as expected.

Table 9. Shear test results, influence of moisture content.

Series	Shear strength		Wood failure		Web failure	
	Mean	Std. dev	Mean	Std. dev	Mean	Std. dev
	MPa	MPa	%	%	%	%
MB-3-45	6.65	0.45	98	3	90	10
MB-3-65	5.51	0.53	92	11	79	11
MB-3-85	5.50	0.29	98	4	86	9

5 Task 4 – Influence of pre-treatment

5.1 General remarks

This task relates to the effect of different pre-treatments (boiling) of the test specimens. The tests in this task were all performed with the specimen thickness 20 mm. The tests have been performed using three different pre-treatments and with two types of gluing error, with the following notations:

65%:	standard 20°C / 65% climate, used for reference
100%:	boiling for two hours followed by storage in 20°C water for two hours, and
100+100%:	boiling for four hours + drying for 18 hours (60°C) + boiling for four hours+ storage in 20°C water for two hours. This pre-treatment is required for LVL according to prEN 14374.
Error 1:	Adhesive to hardener ratio 100/2, a large gluing error (Masonite beams).
Error 2:	Adhesive to hardener ratio 100/4, a small gluing error (Masonite beams).
Error 3:	50% of the recommended amount of glue used (Ranti beams).
Error 4:	50% of the recommended amount of hardener, a large gluing error (Ranti beams).

5.2 Test programme

This task included the test series indicate in Table 10, making a total of 305 individual tests. Tests were performed at VTT and SP.

A total of 270 specimens were manufactured from 15 Masonite beams. All specimens were 20 mm in thickness. Five of the beams (three for series MB-5 and two for series MB-8) were without any deliberately induced gluing errors, which means that the adhesive/hardener ratio was 100/15. Five of the beams (three for series MB-6 and two for series MB-9) were manufactured with a mixing ratio of 100/4, and the last five (three for series MB-7 and two for series MB-10) had a ratio of 100/2. The specimens were distributed in the following test series:

MB-5 (3 series): No gluing error, mixing ratio 100/15, reference, 3 x 15 specimens
MB-6 (3 series): Gluing error, mixing ratio 100/4, 3 x 15 specimens
MB-7 (3 series): Gluing error, mixing ratio 100/2, 3 x 15 specimens
MB-8 (3 series): No gluing error, mixing ratio 100/15, reference, 3 x 15 specimens
MB-9 (3 series): Gluing error, mixing ratio 100/4, 3 x 15 specimens
MB-10 (3 series): Gluing error, mixing ratio 100/2, 3 x 15 specimens

A total of 135 specimens were manufactured from 3 Ranti beams. All specimens were 20 mm in thickness. One of the beams (RB-A3) was without any deliberately induced gluing error. One of the beams (RB-C2) was manufactured with a correct mixing ratio but with a too small amount of mixed glue (50%). The last beam (RB-C3) had a mixing ratio with a reduced amount of hardener (50%). The specimens were distributed in the following 9 test series:

RB-A3 (3 series): No gluing error, reference, 3 x 15 specimens
RB-C2 (3 series): Gluing error, 50% of glue amount, correct mixing ratio
RB-C3 (3 series): Gluing error, 50% of hardener, correct amount of mixed glue

Table 10. Test programme for task 4.

Description	RH	Number of tests	Tested by
MB-5, reference	65%	15	VTT
MB-5, boiling	100%	15	VTT
MB-5, 2×boiling	100+100%	15	VTT
MB-6, gluing error 1, reference	65%	15	VTT
MB-6, gluing error 1, boiling	100%	15	VTT
MB-6, gluing error 1, 2×boiling	100+100%	15	VTT
MB-7, gluing error 2, reference	65%	15	VTT
MB-7, gluing error 2, boiling	100%	15	VTT
MB-7, gluing error 2, 2×boiling	100+100%	15	VTT
RB-A3, reference	65%	15	VTT
RB-A3, boiling	100%	15	VTT
RB-A3, 2×boiling	100+100%	15	VTT
RB-C2, gluing error 3, reference	65%	15	VTT
RB-C2, gluing error 3, boiling	100%	15	VTT
RB-C2, gluing error 3, 2×boiling	100+100%	15	VTT
RB-C3, gluing error 4, reference	65%	15	VTT
RB-C3, gluing error 4, boiling	100%	15	VTT
RB-C3, gluing error 4, 2×boiling	100+100%	15	VTT
MB-8, Reference	65%	15	SP
MB-8, Boiling	100%	15	SP
MB-8, 2×boiling	100+100%	15	SP
MB-9, Gluing error 1, reference	65%	15	SP
MB-9, Gluing error 1, boiling	100%	15	SP
MB-9, Gluing error 1, 2×boiling	100+100%	15	SP
MB-10, Gluing error 2, reference	65%	15	SP
MB-10, Gluing error 2, boiling	100%	15	SP
MB-10, Gluing error 2, 2×boiling	100+100%	15	SP

5.3 Test results

The densities and the moisture contents were determined from 5 specimens from each Masonite beam and from 15 specimens from each Ranti beam. The mass and the volume of the specimens were determined at the moisture content indicated. The results are given in Table 11.

Table 11. Test results, density and moisture content.

Series	Density		MC	
	Mean kg/m^3	Std. dev. kg/m^3	Mean %	Std. dev. %
MB-5	475	10	14.8	0.1
MB-6	442	30	14.0	0.1
MB-7	451	32	14.1	0.1
MB-8	483	16.7	13.7	0.7
MB-9	396	17.6	13.9	0.8
MB-10	381	16.1	14.4	0.8
RB-A3	396	7	13.7	0.1
RB-C2	515	9	13.9	0.1
RB-C3	478	5	13.8	0.1

The shear strength results are indicated in Table 12 - Table 14. One result was excluded from series R-1 of Table 12 and two results from series R-1 of Table 13 due to the presence of knots.

Table 12. Test results, influence of gluing error. 20/65.

Series	Shear strength		Wood failure		Web failure	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
	MPa	MPa	%	%	%	%
MB-5	5.51	0.53	92	11	79	11
MB-6	6.52	0.68	93	5	19	8
MB-7	5.61	0.56	84	7	11	12
MB-8	4.61	0.77	96	4	84	12
MB-9	3.46	0.84	52	27	46	36
MB-10	4.90	0.93	93	1	24	25
RB-A2	8.80	2.51	88	28	16	29
RB-C2	3.51	0.38	50	4	50	6
RB-C3	8.14	2.69	90	19	15	17

Table 13. Test results, influence of gluing errors, Boiling 2 h + storage in 20° water for 2 h.

Series	Shear strength		Wood failure		Web failure	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
	MPa	MPa	%	%	%	%
MB-5	1.83	0.24	96	2	81	10
MB-6	1.78	0.24	75	16	39	13
MB-7	1.40	0.24	39	16	15	9
MB-8	2.04	0.12	100	1	99	3
MB-9	1.50	0.28	30	16	100	0
MB-10	1.61	0.25	66	17	69	21
RB-A2	3.10	0.62	90	20	82	23
RB-C2	1.77	0.21	48	12	94	9
RB-C3	3.01	0.46	91	10	47	4

Table 14. Test results, influence of gluing error, Boiling 2 h + drying in 60°C for 18 h + boiling 4 h + storage in 20°C water for 2 h.

Series	Shear strength		Wood failure		Web failure	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
	MPa	MPa	%	%	%	%
MB-5	1.72	0.27	94	8	91	8
MB-6	1.30	0.12	64	9	50	11
MB-7	0.91	0.22	41	14	26	11
MB-8	1.36	0.17	100	0	95	9
MB-9	0.78	0.15	50.0	19	73	23
MB-10	1.15	0.18	77	13	53	21
RB-A2	2.35	0.23	93	8	92	8
RB-C2	1.44	0.21	49	2	92	15
RB-C3	2.61	0.46	94	10	67	22

The beam used for the series without gluing error in series MB-8, was taken from beams previously sent to SP for production control. It turned out that this beam, unfortunately, had a significantly higher wood density, as can be seen in Figure 9, showing the lengthwise density variation. As additional examples of the lengthwise variation of the properties measured the results from series MB-8, MB-9 and MB-10 are shown in Figure 10, Figure 11 and Figure 12 for the three pre-treatments investigated.

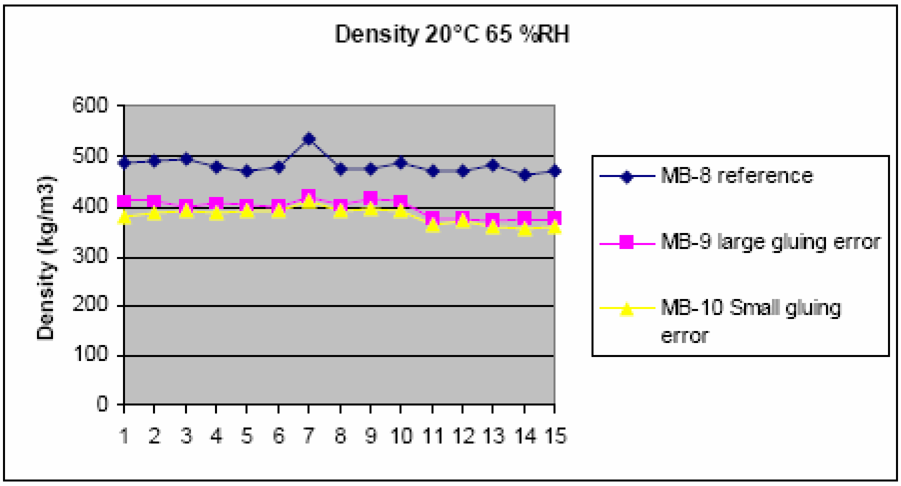

Figure 9. Dry densities for test series MB-8 – MB-10, all for testing without prior boiling. The peak value for the MB-5 series was due to a specimen containing a knot.

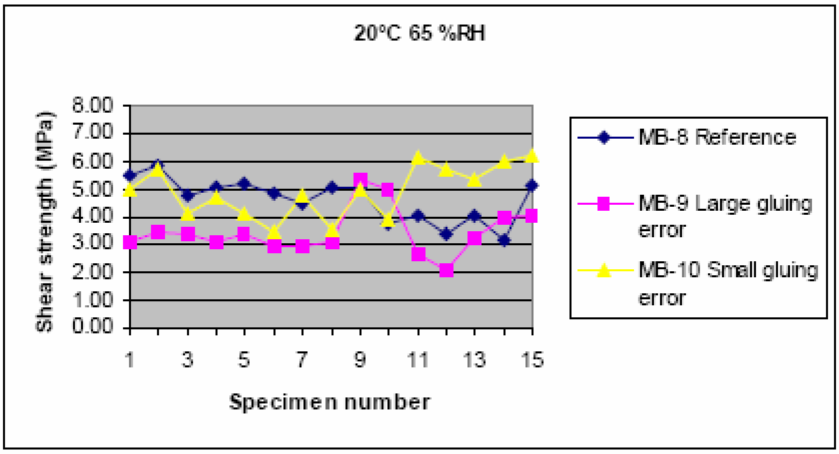

Figure 10. Shear strength after pre-conditioning at 20/65.

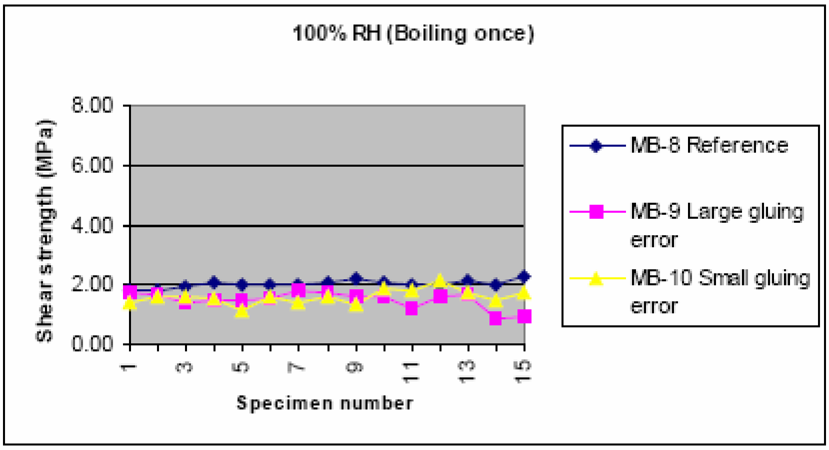

Figure 11. Shear strength after boiling once.

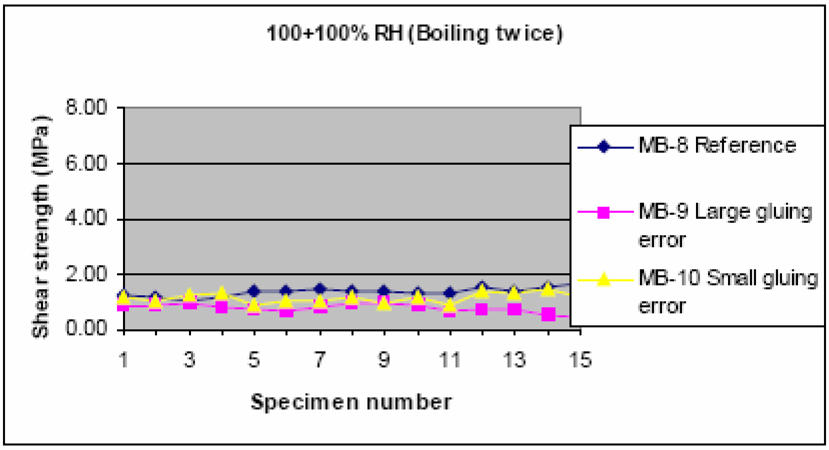

Figure 12. Shear strength after boiling twice.

6 Discussion and conclusions

6.1 Gluing errors

The aim of this investigation has been to develop a test method for detecting possible gluing errors. Thus, it is of course important to define the precise meaning of a gluing error. Obviously, applying only half the recommended amount of the mixed adhesive is an error. Likewise it is to be regarded as an error if only a small fraction of the hardener amount as recommended by the adhesive manufacturer is used. Both these gluing errors have been used here. However, the amount of hardener to use as specified by the adhesive manufacturer is often given with wide safety margins, such that in some cases using only half the recommended amount can still give acceptable strength. On the other hand, *if* an amount of hardener distinctively different from the one recommended by the manufacturer is used, then the adhesive is not the same as the one, which has passed the various criteria necessary for structural adhesives.

6.2 Detecting errors

6.2.1 General

The shear tests performed have shown that:

1. Often, there is no significant difference between the average shear strength of the reference specimens and the ones with a small gluing error, for the case of no boiling prior to testing.
2. For many cases, when using boiling as a pre-treatment, there is a significant difference in average shear strength.
3. Generally, the wood failure percentage is not a good indicator for gluing errors for the case without boiling. Small gluing errors cannot be detected in this way. After boiling, however, it is possible to detect also small gluing errors. The wood failure percentage typically drops to approximately 70-80% from almost 100% in the reference pieces.
4. The method of boiling twice is a very sensitive method for detecting the large gluing errors. The difference in average shear strength is much easier to detect after boiling twice as compared to only boiling once.

6.2.2 Without pre-treatment

It is a general conclusion from this study that, apart from extremely serious gluing errors, *it is difficult to detect gluing errors without prior pre-treatment*. Two exceptions though: for the Ranti-beam both the shear strength and the wood failure percentages are low for series RB-C2, 50% of adhesive amount, and also for the series MB-9 (13% of correct hardener amount) it was possible to detect the defect. No other gluing errors were detectable.

6.2.3 With pre-treatment (boiling)

As to what errors are detectable with boiling prior to testing. Of course, the errors that were detected without boiling are generally also detectable after boiling. For the Rantibeam it has not been possible to detect the error with 50% hardener, which could indicate large safety margins from the adhesive manufacturer in terms of mixing ratio. It is generally possible to detect the remaining gluing errors for the Ranti and the Masonite beam, especially if the wood failure percentage is taken into account.

For some cases it is enough to boil only once, such as for the test series RB-C2 and MB-7. It is however interesting to note that after boiling only once, in the tests of series MB-8 and MB-9 the gluing error with a low hardener content was detected, but this is not the case for the nominally equal tests of series MB-6.

Boiling only once is probably a useable method, if combined with repeated boiling for those cases where a low wood-failure percentage is detected.

6.2.4 Decision based on shear strength or wood failure percentage

Although the amount of wood failure is a somewhat subjective measure, it is still better to use than the shear strength. Firstly, the main interest here lies in asserting that the adhesive strength is good enough, which means better than the wood material. Secondly, it is difficult to decide on a shear strength value to be used for every combination of wood-based materials and adhesive. A generally acceptable wood failure percentage could be 70% and above if repeated boiling is used. As an alternative, an 80% level of wood failure could be used in combination with boiling only once. Finally, the use of the wood failure percentage as a decision- making criterion makes the use of a loadmeasuring device unnecessary. Of course, it could be of interest to use both a shear strength minimum value *and* the wood failure percentage as criteria. However, in cases where the shear strength is tested in another way it should suffice with using only the wood failure percentage.

References

Anon. (1987). NT Build 327 Light weight beams of wood: Load bearing capacity and rigidity.

Anon. (1995). EN 392 Glued laminated timber – Shear test of glue lines

Anon. (2001). EOTA Guide line 011

Anon. (2003). prEN 14374 Timber structures - Structural laminated veneer lumber - Requirements.

Axelsson, M., Johansson, C.-J.(2000). *Light composite wood based beams. Nordic Round Robin test.*

Fonselius, M., Johansson, C.-J., Solli, K. (1994). *Dimensionering av träkonstruktioner genom provning.* SP Rapport 1994:60.

Zylkowski, S. (2000). *Engineered wood products in North America.* Presentation to COST Action E13

Appendix A: NT BUILD 512

The approved method **NT BUILD 512 Wooden I-beams – Test method for evaluation of flange/web glue bond quality** can be downloaded at
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