Evaluation of glulam beams after 6 years exposure to outdoor climate

Project leader: Birte Pitzner, Arne Rambøl and Per Lind,
Norsk Treteknisk Institutt
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Summary

Glulam used in outdoor structures is in danger of developing cracks, with the following threat of water uptake and is therefore highly endangered of rot. If glued structure elements are used in these kinds of surroundings, it has to be assured that the protection against uptake of water is sufficient.

The aim of this project is to evaluate the condition of glulam beams after they have been exposed to outdoor climate for six years. They were installed with a 45° angle facing south, on the roof of Moelven Limtre Agder in southern Norway in 1997.

Based on the investigations and the test results, it can be said that the various impregnation methods and surface treatments have a great influence on the long-time behavior (6 years) of glued laminated timber.

Some treatments were positive for the glue line but negative for the development of wood cracks in the lamellae. Others had a positive influence on the wood but a negative influence on the glue line bonding.

Stikkord: Limtrebjelker, beskyttelse, væreksponering
Keywords: *Glulam beams, protection, exposure to weather*

Preface

This TEFT-project is a continuation of an earlier project supported by TEFT. The original idea was to see whether glulam could be used for the design of a roof construction covering a fish farm. The aim was to explore the durability of glulam using different methods of protection. The project was divided into a constructive and a rot protecting segment.

Participants in the first project were Agder Limtre AS, Marnar Bruk AS and the Norwegian Institute of Wood Technology (NTI). The first report where the rot protection segment was discussed theoretically was written by Eirik Raknes (NTI). The conclusion was that glulam should be produced using impregnated lamellae and that the beams should be treated with the Royal process afterwards. Field exposure was recommended to prove the theoretical results.

After this initial part, the project changed its character since the fish farming segment was pulled out. Following a proposal from NTI, the concept was changed somewhat. The decision was made to focus on glulam in general and its protection against outdoor exposure.

NTI-report no. 359507-2 describes the manufacture of the test beams and the placing of those on the roof of Moelven Agder Limtre in 1997.

The present TEFT-project deals with the evaluation of the beams after six years of outdoor exposure. Participants in this project are Moelven Limtre AS – Agder, Moelven Limtre AS – Splitkon and Marnar Bruk AS.

Contents

1 Introduction

Glulam used in outdoor structures is in danger of developing cracks with the following threat of water uptake and is therefore highly endangered of rot. When glued structure elements are used in these kinds of surroundings, it must be assured that the protection against the uptake of water is sufficient.

Even if a glulam beam is protected by a surface treatment, the wood will react with the air humidity and change its form. If the reaction is quick, the risk of developing cracks is high. Especially endangered are large dimension cross-sections with a poor protection against humidity.

To reduce the risk of cracking, the beam has to be protected sufficiently against the uptake of water. It also has to be assured that the stress differences do not develop between the inner and outer parts of the beam in a too large extend. This can be done with constructive protection, which is a physical method to protect the construction against direct water contact. Another method is to use chemical substances. Such substances will restrict the uptake of water and will therefore reduce the development of great stress gradients.

One way to produce impregnated glulam beams is by gluing CCA-impregnated lamellae together. In this case the beams are protected against rot but not against water uptake. Another disadvantage with this production method is that both the impregnated lamellae and the beams are planed. This will often result in the exposure of heartwood with an increase of the risk for rot attacks.

A stable cross-section can not be reached solely with a surface treatment. The glulam beam has to be made water resistant in large portions of the cross section. Unfortunately it is difficult to glue lamellae treated with water protection solutions satisfactorily. In case such a treatment is required, it should be applied after the gluing process. One way to prevent water uptake is to impregnate glulam with creosote (for special areas of application). However, the oil sweating during the summer period is a problem when using this method.

Two investigations on this topic were performed by the Norwegian Institute of Wood Technology (NTI) earlier and documented in two reports.

Part 1

The first investigation discussed the protection against rot and gave a theoretical evaluation concerning the climatic conditions such a construction is expected to be exposed to. Suggestions concerning chemical treatments were also given in that report.

One conclusion of part 1 is that the Royal process could be defined as a good or promising treatment for glulam beams. The Royal process in general includes the impregnation of wood with salts based on copper and then the treatment with a warm oil with a "drying effect" that contains pigments. The wood receives a rot protection along with a water protecting shell.

Part 2

The main objective of part 2 was to manufacture glulam treated with the full Royal process. These were to be observed and examined during part 3 of the project, concerning the delamination of the glue lines, cracks in the wood as well as rot. To be able to compare the beams treated with the Royal process, other beams were manufactured with several different treatments of the wood and/or beams, two different wood species and two glue types.

Part 3

The aim of this part of the project is to evaluate the condition of the glulam beams after they have been exposed to outdoor climate for six years. They were placed with a 45° angle facing south on the roof of Moelven Limtre AS-Agder in southern Norway in 1997.

2 Material and methods

22 beams were taken down from the roof on the 30th of September 2003. They were stored indoors until the 7th of October 2003. (Ø = Mean Value)

No:	Ø	Wood species	Glue type	Treatment Lamellae	Treatment Beams
1A	Ø1	Pine	PRF	ACQ	Full Royal process
1B					
2A	Ø2				
2B					
3A	Ø3		MUF		
3B					
4A	Ø4		PRF	CCA	Full Royal process
4B					
5A	Ø5				
5B					
6A	Ø6			None	Full Royal process
6B					
7A	Ø7				
7B					
8A	Ø8	Norway spruce		Same as beam no. 6 and 7	
8B					
9A	Ø9		MUF	None	Stained grey- black
9B					
10A	Ø10	Pine	PRF	CCA	Un-stained
10B					
11A	Ø11			CCA	Stained grey-black
11B					

The original 11 beams were produced in 1997 and cut in two halves (beam A and beam B) before they were placed on the roof. Beam A had the pith sides (internal face) upwards and beam B had the pith sides downwards.

The 22 beams are divided in seven groups according to their surface and/or impregnation treatment as well as the wood species. Except for beams 8A+B and 9A+B, all beams were made of pine lamellae. Group I includes the beams where the lamellae were impregnated with ACQ (Kenwood ACQ 1900, based on copper), glued with Phenol-Resorcinol-Formaldehyde -PRF- (1A+B, 2A+B) and Melamine-Urea-Formaldehyde -MUF- (3A+B) and treated afterwards with the full Royal process. Group II consists of the beams 4A+B, 5A+B. These beams were impregnated with CCA (Copper-Chrome-Arsenic), glued with PRF and afterwards treated with the full Royal process as well. Group III contains beams 6A+B, 7A+B which were glued with PRF and treated only with the full Royal process. Groups IV and V include beams 8A+B, 9A+B which were manufactured of spruce lamellae and glued with PRF (8A+B) and MUF (9A+B) respectively. Beams 8A+B were treated with the full Royal process and beams 9A+B were only treated with a grey-black oil based stain. Groups VI and VII consist of the beams 10A+B, 11A+B manufactured of pine. They were impregnated with CCA and glued with PRF. Beams 11A+B were additionally treated with a grey-black oil-based stain.

Each beam was divided into three parts and marked: left, middle and right, as seen from the weather exposed side. The left and right part had a length of 600 mm.

Figure 2.1 Sketch of a beam divided in three parts

The length of delamination in the glue lines on the exposed long side of each beam was marked, measured and recorded. With these numbers the delamination percentage for the entire long side was calculated (chapter 4.1). The deepest opening of each glue line was also measured and recorded.

Figure 2.2 Left part of beam 4B with glue line openings

One beam in each group had the length of cracks in the wood in the left section marked, measured and recorded. Only those cracks that had a minimum width of 0,2 mm and a depth of at least 1 mm were recorded.

Figure 2.3 Left part of beam 10B with wood cracks

Pictures were taken of each of the three sections and of the entire beam. Afterwards the right sections of the beams were cut off and sent to NTI for delamination and shear testing.

Figure 2.4 Enlarged section of beam 10B with markings

The right side of the remaining shorter beams received a fresh surface treatment, except for beams 10A and B. The beam sections were painted with two layers of oil-based stain in different colors:

1. Butinox I, 527 Antikkbrun

2. Butinox I, 561 Blodbøk

Figure 2.5 Surface treatment of the right beam sections with two different stains

The cross cut ends were sealed with silicone. The 22 now shorter beams were lifted back up on the roof to be tested again on a later occasion.

Figure 2.6 Sealed cross cut ends, beams 10A + 10B

3 Test methods

3.1 Delamination test EN 391, method B

The delamination test method EN 391, method B is a test method during which glulam test pieces are placed in a pressure vessel to be impregnated with water over the fiber saturation point after a preceding vacuum phase and then dried with a sharp climate in a drying duct. This method is used to test the quality of the glue lines. The introduced moisture gradient, provoked by first the swelling and followed by the shrinkage of the test pieces, causes great stresses perpendicular to the glue lines. In case of an inadequate bonding quality in the glue lines, delamination will occur. The sum of those openings in relation to the sum of the glue line lengths on the two end-grain surfaces of each test piece gives the total delamination percentage. This is considered to be the measurement of the glue line quality.

This test method is supposed to give a statement about the durability and steadiness of glulam, especially for the outside use. That means, this testing method simulates the practical use of glulam over a longer period of time. The method is described in detail in the appendix.

Figure 3.1 Pressure vessel

According to EN 386 the maximum value to pass the testing method is 4 % total delamination in the first testing cycle. In case the maximum value lies above 4 %, an extra cycle is required with the new maximum value of 8 % total delamination.

Figure 3.2 Delamination test pieces from beam 1A

3.2 Shear Test according to EN 392

The test method according to EN 392 is a procedure for measuring the shear strength of the glue line parallel to the grain direction. This test is applicable in the field of continuous quality control of the glue line. The main principle is to apply shear stress to the glue line until a failure occurs.

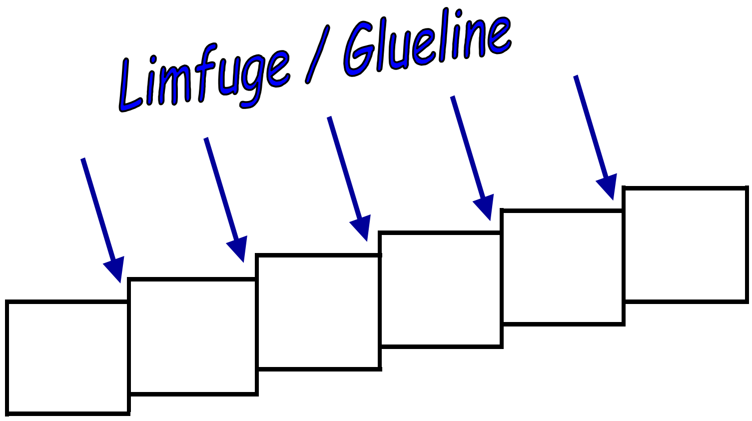


Figure 3.3 Prepared test piece – EN 392

The test pieces shall be conditioned to equilibrium moisture content in the standard climate 20 °C/65 % RH.

The dimensions of the test pieces have to be measured to the nearest 0,5 mm. The loading has to be in the direction of the grain. The distance between the shearing tool and the glue line may not exceed 1 mm. The applying of shear stress has to be undertaken at a constant rate and in that way, that the failure occurs after at least 20 seconds. Additional to the shear strength, the wood failure percentage has to be estimated to the nearest figure divisible by 5.

The shear strength f_v is determined with the following equation:

$$f_v = k \cdot \frac{F_u}{A} \qquad [\text{N/mm}^2]$$

With

A	Shear area $A = b*t$
t	Thickness in mm
b	Width in mm
F_u	Ultimate load in N
k	Modification factor: $k = 0{,}78 + 0{,}0044t$

Note: Factor k modifies the shear strength for test pieces where the thickness in the grain direction of the sheared area is less than 50 mm

For documentation, a test report has to be written with all relevant data.

4 Results

In this chapter the results of the investigations and tests are shown in various diagrams.

4.1 Glue line openings on the long side

The visual inspection of the beam surface included the measurement of the glue line openings on the long side (Figure 4.1).

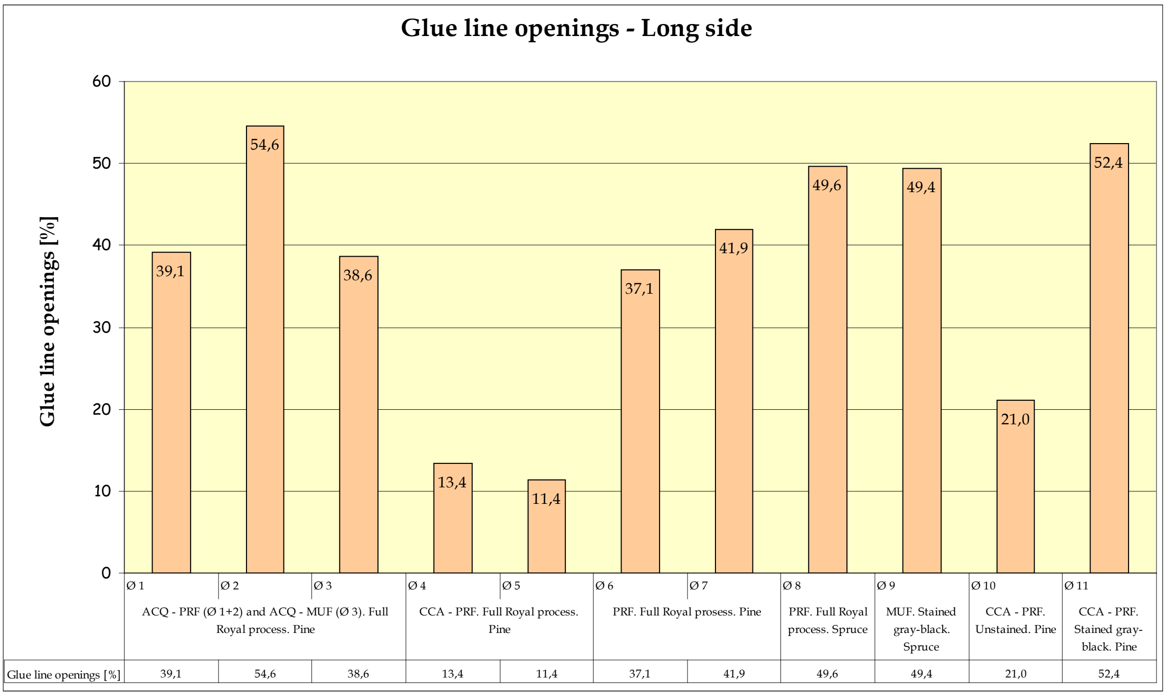


Figure 4.1 Results - Glue line openings – Long side

The opening percentages were calculated in relation to the total length of the glue lines. Beam A and B were placed together in average values (Ø). The percentage values of the glue line openings vary between 11,4 % and 54,6 %. The beams 4 and 5 had the lowest amount of openings. The lamellae were impregnated with CCA before the beams were treated with the full Royal Process. The percentages differ only between 11,4 % and 13,4 %. The beams manufactured of ACQ-impregnated lamellae, which were afterwards treated with the full Royal Process (beams 1, 2 and 3), and the beams manufactured of untreated lamellae but treated with the full Royal Process (beams 6 and 7) did not show great differences in the amount of the openings, but the percentages were definitely higher than those of the beams manufactured of CCA- impregnated lamellae.

Another interesting result is shown in the last two columns. Beams 10 and 11 were both impregnated with CCA, like beams 4 and 5, but not treated with the full Royal process. Beam 10 was left without any surface treatment and beam 11 was stained with a grey-black oil-based stain. Between these two treatments it became obvious that the dark surface treatment had a negative influence on the glue lines. The comparison of all the beams impregnated with CCA shows that the best results concerning the glue line openings on the long side were reached by the beams which were also treated with the full Royal process (beams 4 and 5).

Figure 4.2 Glue line openings – Beam 5A (12,6 %)

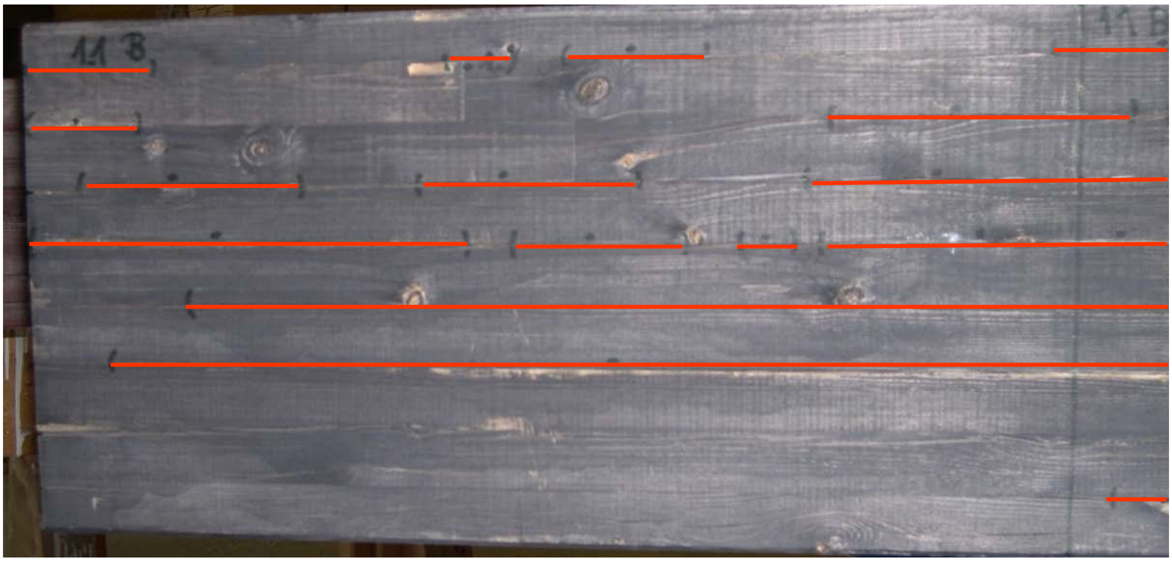


Figure 4.3 Glue line openings – Beam 11B (53 %)

4.2 Relation between glue line openings and cracks in the wood

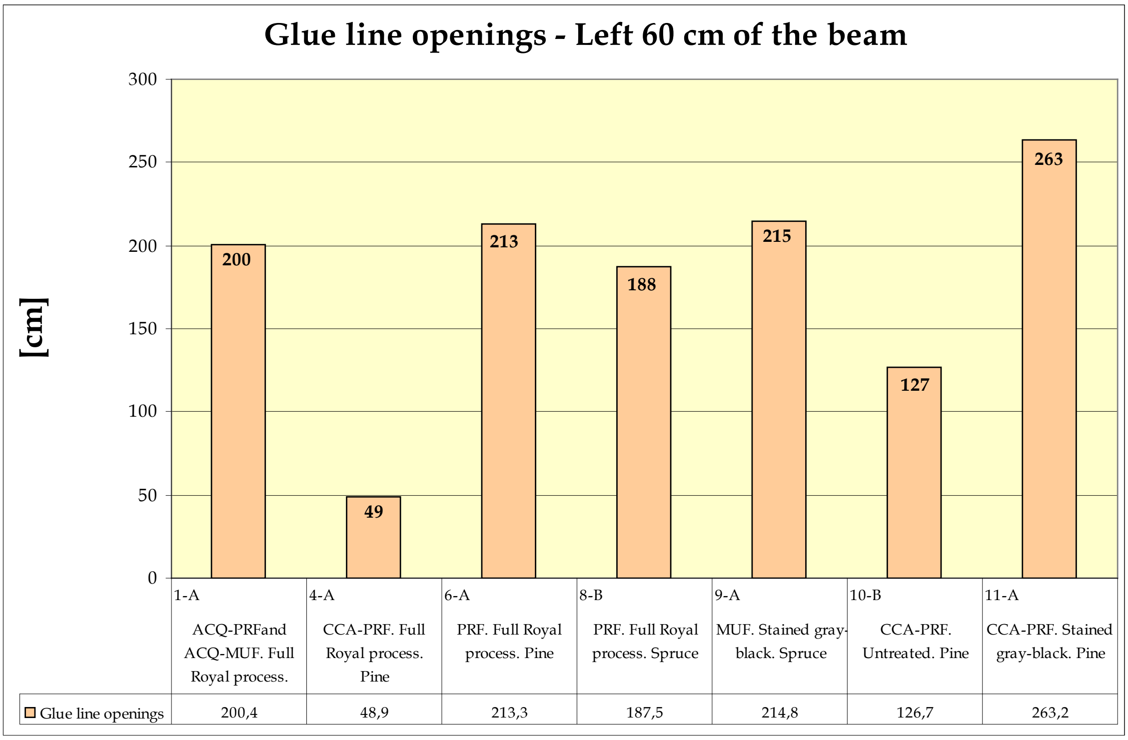


Figure 4.4 Glue line openings - Left 60 cm of the beam

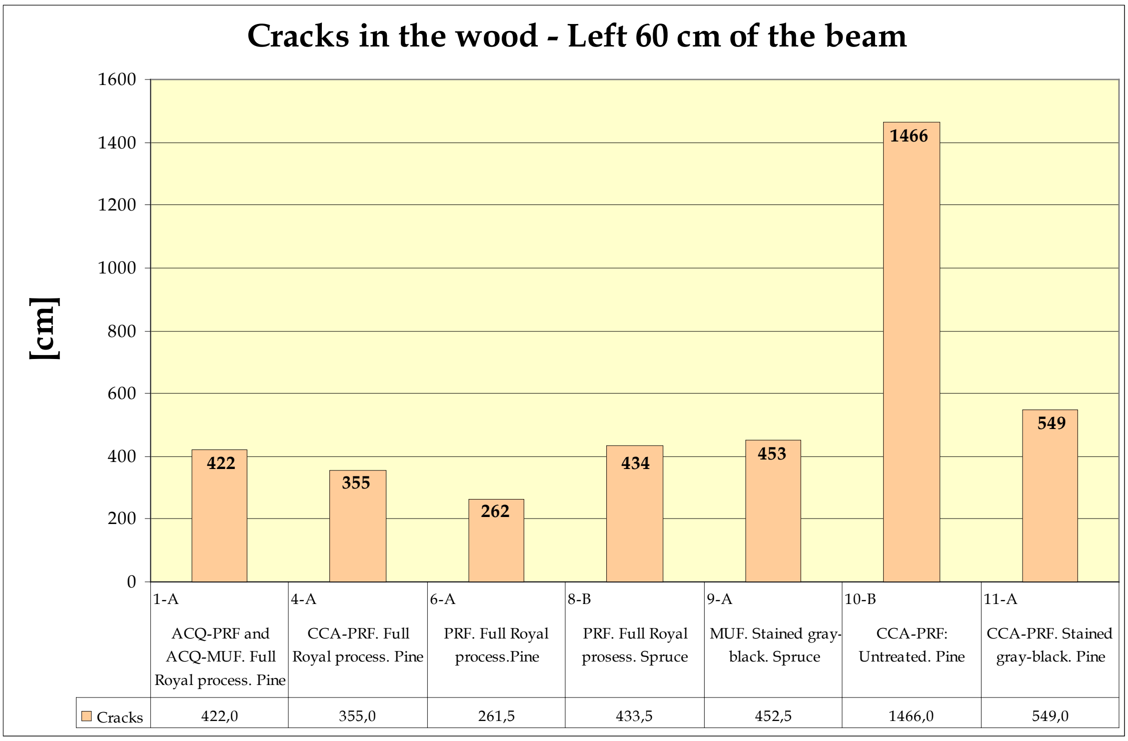


Figure 4.5 Cracks in the wood - Left 60 cm of the beam

The two figures (figure 4.4 and 4.5) show the relation between the openings in the glue lines on the long side of the beams and the occurrence of cracks in the wood. One beam was selected from each group and the openings in the left 60 cm were measured and recorded.

The three beams impregnated with CCA (4A, 10B and 11A) show noticeable differences to the others. These three beams make it obvious that the surface treatment has a great influence on the development of glue line openings and cracks in the wood. Beam 4A (Full Royal process) developed less glue line openings than all the other beams but on the other hand the amount of cracks was on the same level as the others were, except for beam 10B. Beam 10B (no further treatment after the impregnation with CCA) also had less glue line openings, but the highest amount of cracks in the wood. The last of the CCA-beams (11A) was treated with a dark grey-black oil-based stain and showed the highest amount of glue line openings of all the beams. On the other hand the wood crack amount was on the same level as the majority of the beams.

Figure 4.6 Beam 4A. Glue line openings and cracks

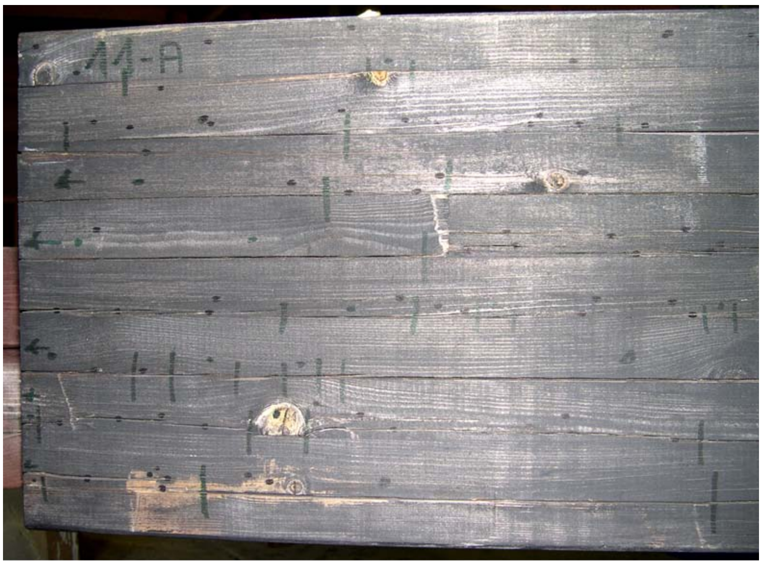


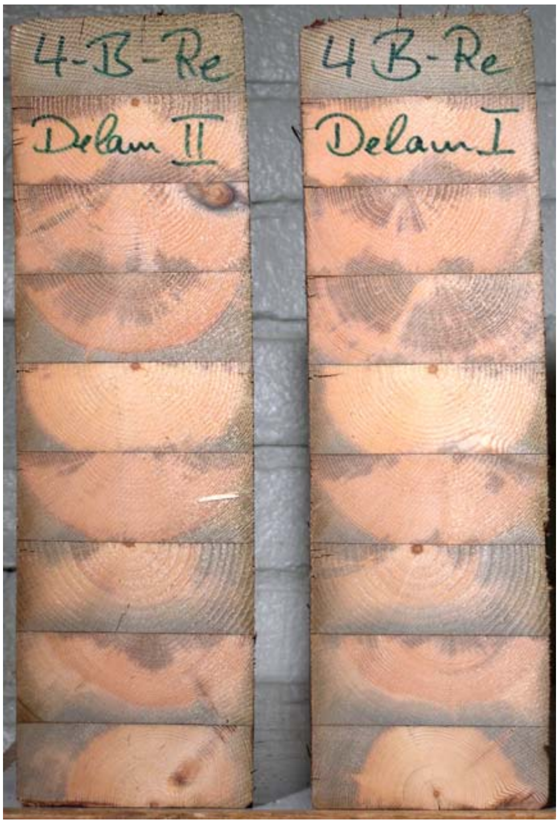
Figure 4.7 Beam 11A. Glue line openings and cracks

4.3 Delamination test EN 391, method B

Figure A-2.1 in the appendix shows the results of the delamination test according to EN 391-B, which include the previous openings of the glue lines caused by the natural climate changes outdoors.

The figure also shows that the results are not always on one level within one beam. An example of large differences can be found in beam 1. The delamination percentage varies between 4,5 % and 13,5 %. All in all, it has to be taken into consideration that the climate influenced openings are included in this evaluation.

The second diagram in the appendix (figure A-2.2) only shows the delamination percentages that were caused by the delamination test EN 391, method B. Only one test cycle has been carried out.



Again the results show differences within the same beam. On one hand there are no real tendencies to be seen in this figure but on the other hand it has to be remembered that the delamination test method B requires a delamination percentage lower or equal to 4 % after the first cycle. Seven test pieces of twenty-two reached values which were just above the 4 % value (highest value: 6,7 %)

The only obvious observation is to be seen in group one (beams 1, 2 and 3). There is a difference in the results to be seen between the test pieces taken from the beams glued with PRF and MUF. The test pieces glued with PRF show a higher delamination percentage than those glued with MUF. The mean values of all test pieces in group one still fulfill the 4 % requirement.

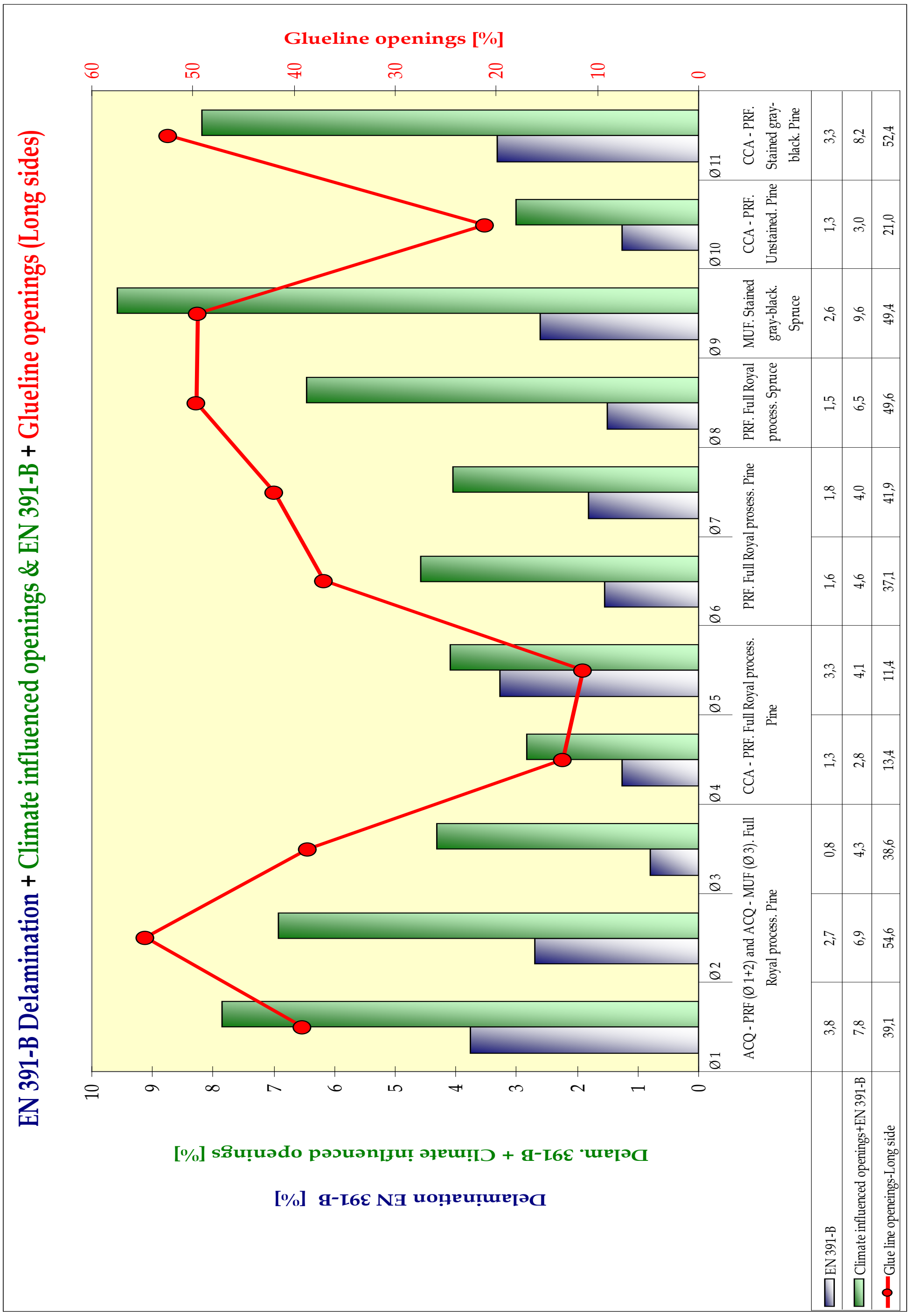
Figure 4.8 Delamination Test pieces from beam 4B

4.4 Relation between the delamination test EN 391-B, climate influenced openings in the test pieces and total glue line openings on the long side

The following figure shows the relation between the results of the previous examinations. All single values of the beams were calculated to mean values (Ø).

Figure 4.9 Relation between EN 391-B, EN 391-B + climate influenced previous openings in the test pieces and glue line openings on the long side

It is obvious that there is a relation between the glue line openings on the long side and the delamination percentages (with and without previous openings) on the crosscut ends. All results of the three examinations follow the same pattern.

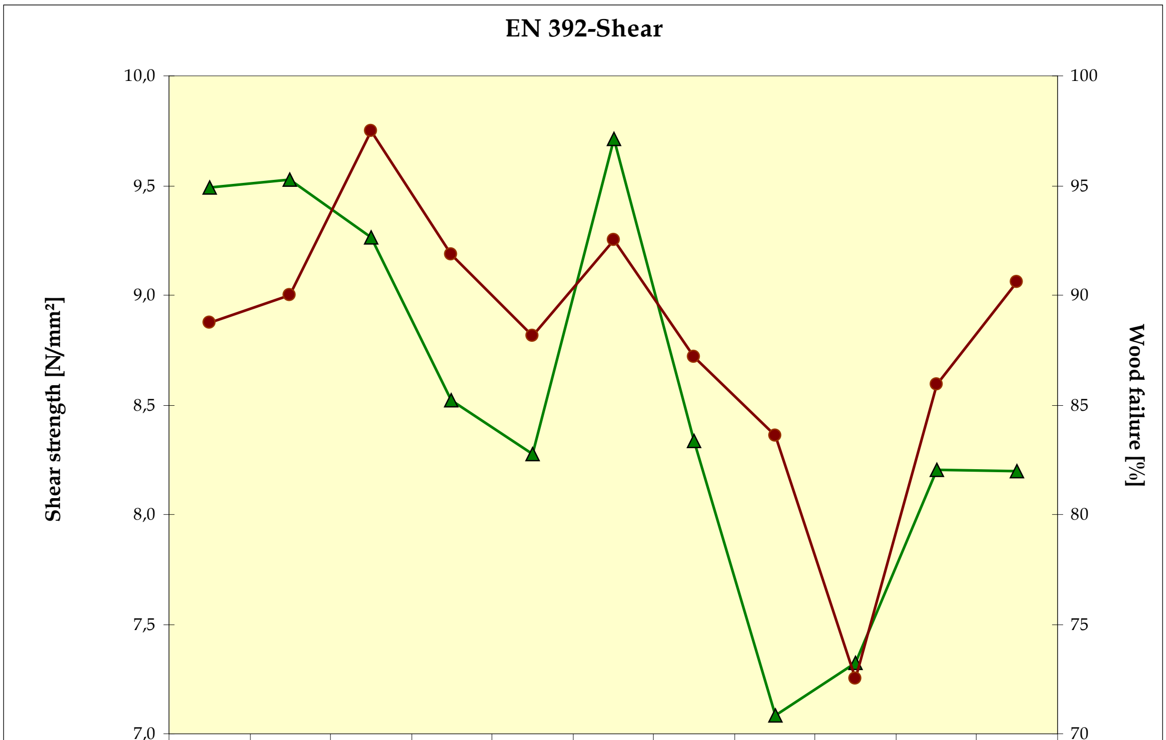


4.5 Shear Test according to EN 392

Figure 4.10 Shear test EN 392 - Mean values of the beams

Figures 4.10 and 4.11 show the results of the shear test according to EN 392. Figure 4.10 shows the mean values of the originally whole beams (Ø1=1A+1B, Ø=2A+2B,…). The green columns represent the shear strength value and the red-brown line represents the wood failure percentage.

Figure A-3.1 in the appendix shows the mean values of the test results in the single beams (1A, 1B,….).



	1	2	3	4	5	6	7	8	9	10	11
Shear [N/mm²]	9,5	9,5	9,3	8,5	8,3	9,7	8,3	7,1	7,3	8,2	8,2
Wood failure [%]	89	90	98	92	88	93	87	84	73	86	91

Figure 4.11 Relation between shear strength and wood failure percentage

This figure (figure 4.11) shows the relation between the shear strength results (green line) and the wood failure percentages (red-brown line) with another scale as the previous figures. A similar pattern between the two lines is recognizable.

The results from the test pieces are all on a similar level. It is not possible to conclude on better or worse results because of impregnation or surface treatments.

5 Conclusions

Based on the investigations and the test results it can be concluded that the various impregnation methods and surface treatments have a great influence on the long-time behavior (6 years) of glued laminated timber exposed outdoors. An other important observation is that there was not found any evidence of rot in any of the beams (only visual inspection).

Some treatments were positive for the glue line but negative for the development of wood cracks in the lamellae. Others had a positive influence on the wood but a negative influence on the glue line bonding.

The most obvious conclusion is that the treatment of glulam with dark oil-based stains is negative for the glue lines, but the oil prevented that the wood developed cracks. On the other hand, the beams behave the opposite way when not treated with a protective stain. This was observed on the beams where the lamellae were impregnated with CCA and either treated with an oil-based dark-grey stain or left without surface treatment. These observations were repeated with the delamination test according to 391-B.

The test results show that it is very important to avoid dark colors in the finishing treatment. Dark colors generate a higher surface temperature of the wood and create quick moisture changes which result in cracks in the wood surface.

The results of the shear test according to EN 392 do not show great variations and do not seem to influence the examination results of the above described tests and observations.

Looking at the results from the delamination test according to EN 391-B, the CCA-impregnated lamellae glued with PRF show the best results. This applies for all beams that were treated with the Royal process, as well as for the beams that were not treated at all.

The beams composed of CCA-impregnated lamellae, glued with PRF and finally treated with the Royal process reached the best results after being exposed for six years to outdoor climate.

It is planned to observe the longtime behavior of the surface especially of the beams treated with the Royal process. For that reason the right 60 cm of all beams (except beams 10A and 10B) were treated with a pigmented oil-based stain before they were again placed on the roof. This is supposed to give an answer to the question of maintenance intervals concerning appearance, cracks in the wood as well as rot.

Appendix

A-1 Delamination Test – EN 391-B

(European Standard EN 391:2001 E, CEN Brussels, October 2001)

For the delamination test EN 391-B the following equipment is needed:

- Pressure vessel
- Drying duct
- Balance capable of determining mass to an accuracy of 5 g
- Metal wedge and wooden hammer capable of splitting open glue lines

The test piece is cut from the complete cross section of a glulam element perpendicular to the fiber angle with a sharp tool. The test pieces are 75 ± 5 mm in length (along the grain).

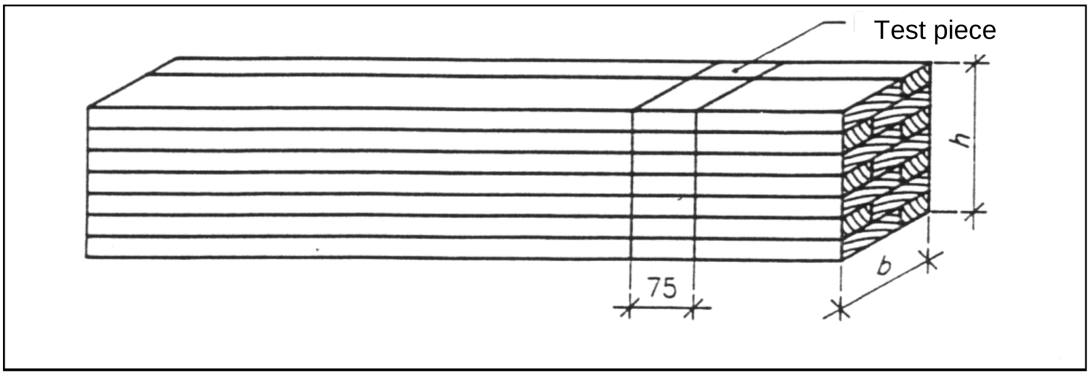
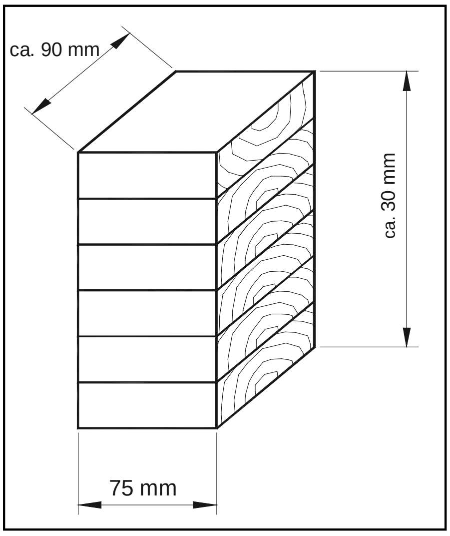


Figure A-1.1 Method to take a test piece – Delamination test EN 391-B

The mass of each test piece has to be documented before starting the test cycle.

The pieces in the pressure vessel have to be completely submerged in water with a temperature of 10° to 20 °C. A vacuum of 15 kPa to 30 kPa absolute pressure at sea level has to be drawn and held for 30 min. Afterwards, a pressure of 600 kPa to 700 kPa absolute pressure has to be applied for 2 hours.



Subsequently, the test pieces will be dried in an oven with a temperature from 65 °C to 75 °C with a relative humidity of 8 % to 10 % at an air circulation velocity of 2 m/s to 3 m/s. The test pieces shall be placed with at least 50 mm intervals with the end-grain surfaces parallel to the stream of air.

Figure A-1.2 Test piece – EN 391-B

The test pieces stay in the oven until the mass of the pieces has returned to within 100 to 110 % of their original mass. At that point the amount of delamination has to be assessed and documented.

Isolated glue line openings which are less than 2,5 mm long and more than 5 mm away from the nearest delamination do not count as delamination, neither do openings in the glue line that are found along knots or resin pockets which border the glue line or are caused by hidden knots in the glue line. To be sure that an opening is not caused by a hidden knot, the glue line will be opened with a wedge and hammer and inspected for hidden knots. A solid wood failure is also not regarded as a delamination.

Finally, the delamination percentages have to be calculated after the following formulae:

Total delamination: $$100 \cdot \frac{l_{tot,delam}}{l_{tot,glue\ line}}$$ [%]

Maximum delamination: $$100 \cdot \frac{l_{max,delam}}{2 l_{glueline}}$$ [%]

With

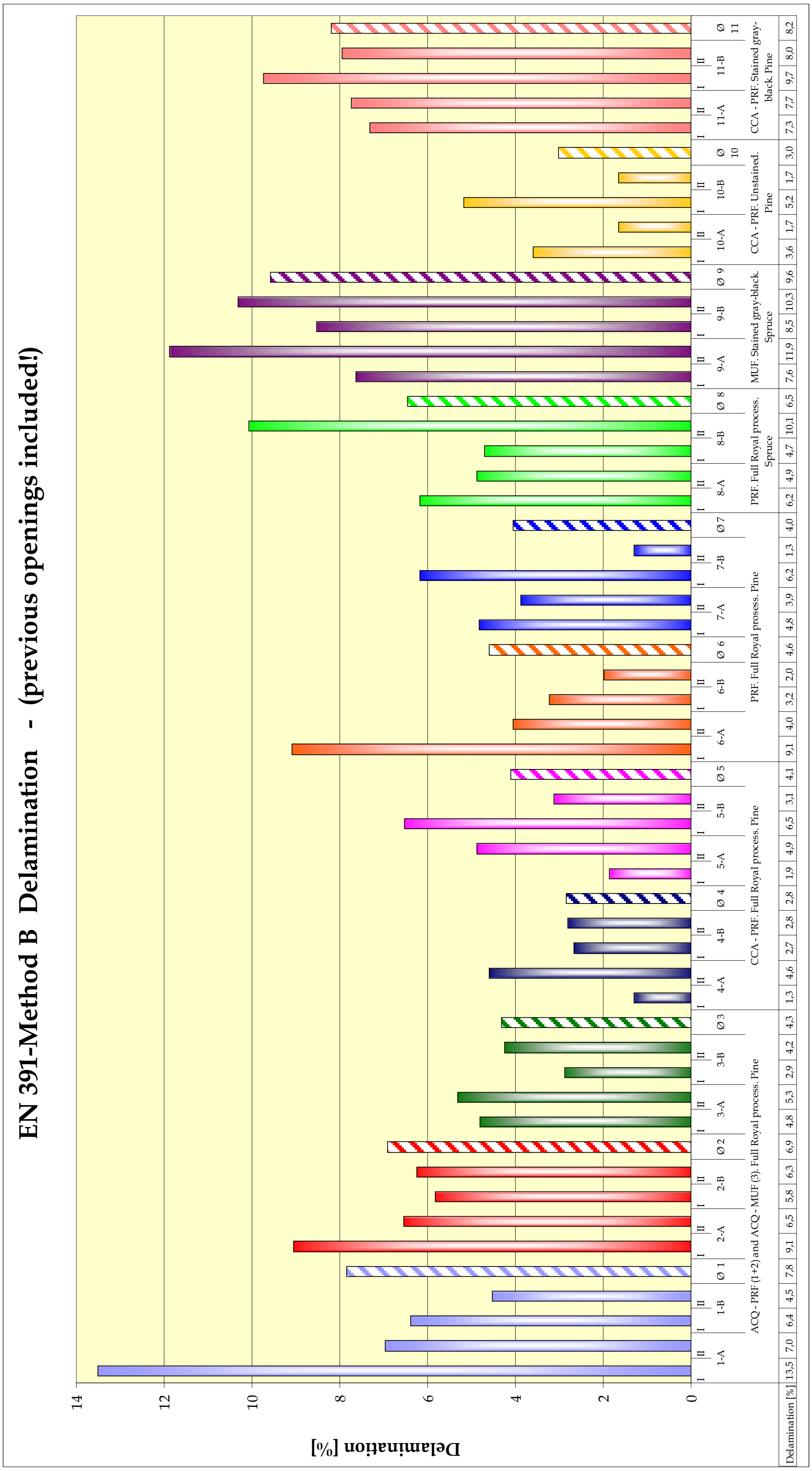
$l_{tot,\ delam}$	delamination length of all glue lines in the test piece [mm]
$l_{tot,\ glue\ line}$	entire length of glue lines on the two end-grain surfaces of each test piece [mm]
$l_{max,\ delam}$	maximum delamination length of one glue line in the test piece [mm]
$l_{glue\ line}$	length of one glue line [mm]

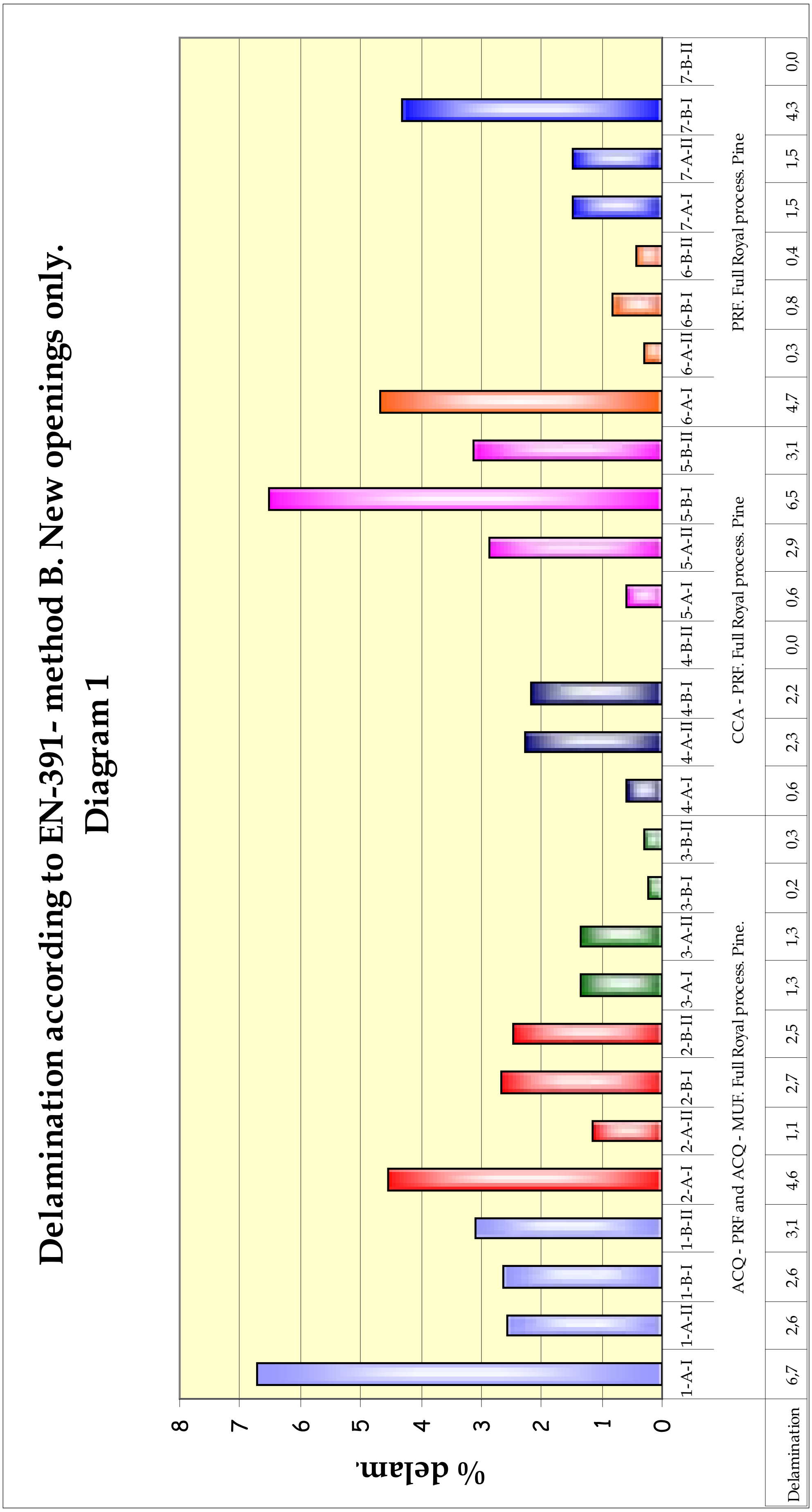
For documentation, a test report with all the relevant data has to be written.

A-2 Results – Delamination test and glue line openings

Figure A-2.1 *(see p. 25)**: EN 391-B (previous openings included)*

Figure A-2.2 *(see p. 26+27)**: EN 391-B – Delamination percentages*


EN 391-Method B Delamination - (previous openings included!)
Delamination [%]
0
2
4
6
8
10
12
14
ACQ - PRF (1+2) and ACQ - MUF (3). Full Royal process. Pine
CCA - PRF. Full Royal process. Pine
PRF. Full Royal prosess. Pine
PRF. Full Royal process. Spruce
MUF. Stained gray-black. Spruce
CCA - PRF. Unstained. Pine
CCA - PRF. Stained gray-black. Pine
Delamination [%]
13,5 7,0 6,4 4,5 7,8 9,1 6,5 5,8 6,3 6,9 4,8 5,3 2,9 4,2 4,3 1,3 4,6 2,7 2,8 2,8 1,9 4,9 6,5 3,1 4,1 9,1 4,0 3,2 2,0 4,6 4,8 3,9 6,2 1,3 4,0 6,2 4,9 4,7 10,1 6,5 7,6 11,9 8,5 10,3 9,6 3,6 1,7 5,2 1,7 3,0 7,3 7,7 9,7 8,0 8,2


Delamination according to EN-391- method B. New openings only.
Diagram 1
% delam.
0
1
2
3
4
5
6
7
8
1-A-I
1-A-II
1-B-I
1-B-II
2-A-I
2-A-II
2-B-I
2-B-II
3-A-I
3-A-II
3-B-I
3-B-II
4-A-I
4-A-II
4-B-I
4-B-II
5-A-I
5-A-II
5-B-I
5-B-II
6-A-I
6-A-II
6-B-I
6-B-II
7-A-I
7-A-II
7-B-I
7-B-II
ACQ - PRF and ACQ - MUF. Full Royal process. Pine.
CCA - PRF. Full Royal process. Pine
PRF. Full Royal process. Pine
Delamination
6,7
2,6
2,6
3,1
4,6
1,1
2,7
2,5
1,3
1,3
0,2
0,3
0,6
2,3
2,2
0,0
0,6
2,9
6,5
3,1
4,7
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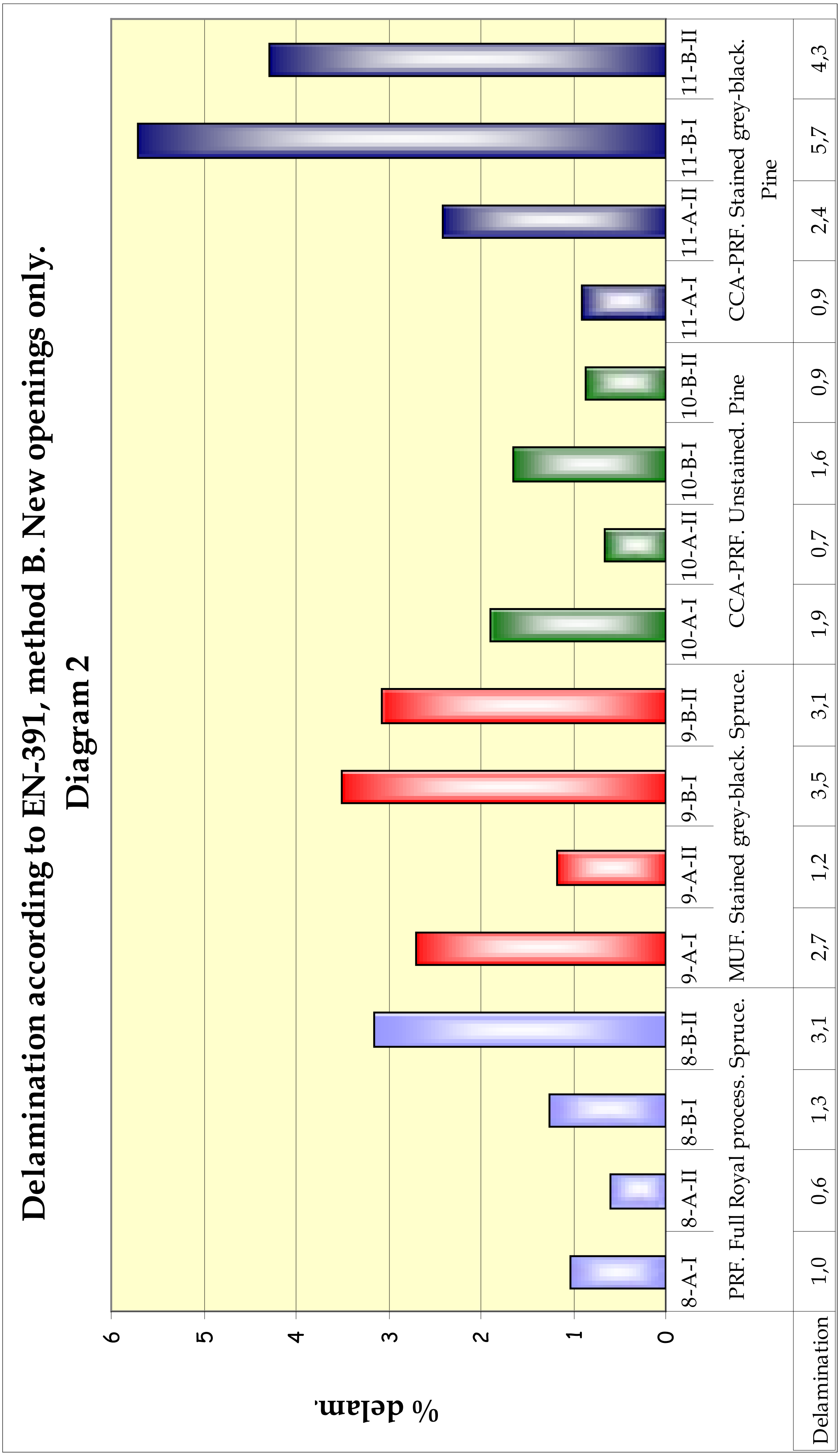
0,8
0,4
1,5
1,5
4,3
0,0


Delamination according to EN-391, method B. New openings only.
Diagram 2
% delam.
0
1
2
3
4
5
6
8-A-I
8-A-II
8-B-I
8-B-II
9-A-I
9-A-II
9-B-I
9-B-II
10-A-I
10-A-II
10-B-I
10-B-II
11-A-I
11-A-II
11-B-I
11-B-II
PRF. Full Royal process. Spruce.
MUF. Stained grey-black. Spruce.
CCA-PRF. Unstained. Pine
CCA-PRF. Stained grey-black. Pine
Delamination
1,0
0,6
1,3
3,1
2,7
1,2
3,5
3,1
1,9
0,7
1,6
0,9
0,9
2,4
5,7
4,3

A-3 Results - Shear Test EN 392

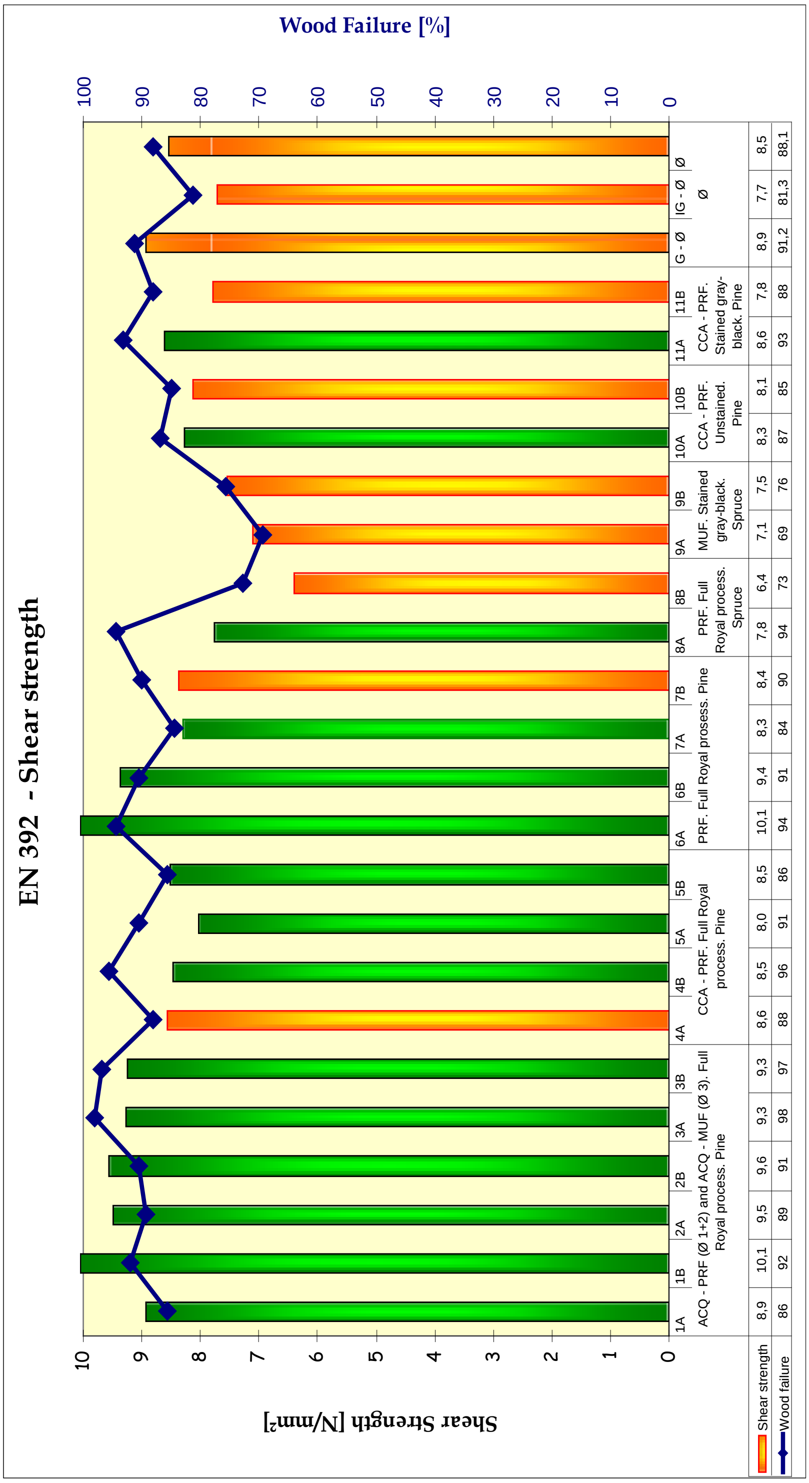


Figure A-3.1 Shear test EN 392. Single results of the beams

The green columns stand for accepted test results, whereas the orange columns stand for the beams which did not pass the test. The blue line on top of the columns represents the wood breakage percentages.