# Delamination performed on glulam according to prEN 391-method B, January 2001, final draft.

## Bestemmelse av delaminering i bjelker i henhold til prEN 391-method B, January 2001, final draft.

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*Project number:* 320561

## 1. Summary

The aim of this proposal is to perform round-robin tests carried out with EN 391 (method B) to improve the evaluation with glulam material manufactured with MUF adhesives. This can improve the reproducibility of the test results of EN 391-B within the Nordic test institutes, as well as in the glulam industry, which uses this important production standard on a daily basis.

After the first round of tests, the results were analysed, and after suggested modifications of the test method, a second round-robin test with a more precise evaluation definition was carried out. The results provide the basis for a more reliable EN 391-B. Results can also improve the evaluation results of EN 302-2, which also deals with delamination and classifies the adhesive performance.

Suggestions for improving the present wording of the standard are also given.

*Stikkord:* Delaminering, EN 391, limtre, testmetode, produksjonskontroll
*Keywords*: Delamination, EN 391, glulam, test method, production control

# 2. Preface

This project has been jointly co-ordinated by NTI (N) and Casco Products (S). Partners include DTI (DK), Late-Rakenteet Oy (SF), Limträ Danmark A/S (DK), Martinsons Trä (S), Moelven (N), SFS-Sertifiointi Oy (SF), and SP (S). Both FMPA (D) and Holzforschung Austria (A) have also participated in the round robin testing.

The statistical and numerical compilation was carried out by Per Lind, and the report written and compiled by Martin Kemmsies.

This project has been financed by contributions from Nordtest and by the participating industry and institutes.

Stockholm Oslo

Martin Kemmsies Per Lind

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# 3. Introduction

## 3.1. Background

EN 391 – Method B (Glued laminated timber – Delamination test of glue lines) is a glulam production standard, which determines if the product is "up to standard". It is used daily in the control of Scandinavia's annual 340.000 $m^3$ (year 2000) of glulam production (out of ca. 1.6 mio. $m^3$ produced in Europe), and is by far the most accepted tool to evaluate the quality of glulam, both in Scandinavia and in Europe.

This test method measures the delamination of glue lines after a treatment consisting of soaking in water followed by fast drying at a high temperature - that is, in effect, an accelerated ageing test method. Stresses in the wood perpendicular to the glue line put a strain on the joint, which either fails in the glue line (causing a delamination), or creates cracks in the wood. If the delamination value after treatment is low (< 4 % after one cycle, or < 8 % after 2 cycles using Method B, which is the most common treatment method), the bonding is seen as being successful, and the product can go to the market.

In the last decade, MUF (melamine-urea-formaldehyde), a light-coloured adhesive, has made a place for itself, and represents about 60 % of the Scandinavian adhesive market for glulam (the remaining 40 % being made up of PRF, phenol-resorcinol-formaldehyde). One problem with light-coloured glue lines is the difficulty in evaluating a delamination, as it is hard to distinguish light-coloured softwood from the adhesive - this is much easier with PRF, which has a dark colour. An additional difficulty is a tendency with MUF to, at times, result in unique failures called "thin-fibre-failure" – here it is difficult to distinguish if the failure was an adhesive failure or a wood failure, whereupon the light colour of the adhesive strongly hinders a clear evaluation. These two MUF-specific problems can lead to evaluations that have very different final results, at times an "accept", at times a "reject".

With the upcoming harmonised standard for glulam prEN 14080, which will allow for CE-marking, this means that much of the responsibility of routine testing the glulam quality through EN 391 will be carried out by the glulam producer. It is therefore imperative that before this happens uniform evaluation guidelines are created, and that the notified bodies of the respective countries pass these guidelines onto the glulam producers, to ensure the same minimum product quality is guaranteed.

## 3.2. Aim

The above mentioned problem makes for a situation where some subjectivity during the delamination evaluation might come into play, an undesirable aspect in any test standard. It is this issue that was addressed in this project. Through round robin testing involving the Scandinavian industry and institutes, it is expected that a more unified basis for evaluation be achieved, and that all parties working with the standard, work towards common evaluation rules. This experience will flow into EN standardisation, both concerning EN 391 (glulam production standard), as well as EN 302-2 (classification of adhesives for use in glulam, which also uses the same delamination test method).

A similar round robin test involving PRF has been carried out in 1994, regarding the delamination test method: based on the results of this Nordic round robin test, a better reproducibility was assured. Nordtest also contributed to this topic in Nordtest project no. 1089-93 (Delamination test of glue lines according to EN 391) – results [1] were directly used to remedy and revise both EN 391 and EN 302-2.

## 3.3. Participants

All in all, there were 11 participants in this Nordtest project, two of which were non-Scandinavian:

*Industry*

Late-Rakenteet Oy (SF), glulam producer

Limträ Danmark A/S (DK), glulam producer

Martinsons Trä (S), glulam producer

Moelven (N), glulam producer

Casco Products (S), adhesives producer

*Testing houses/institutes*

DTI (DK)

FMPA (D)

Holzforschung Austria (A)

NTI (N)

SFS-Sertifiointi Oy (SF)

SP (S)

# 4. Material

Five glulam beams were produced for the project at Moelven, in Moelv, Norway. One normal beam was a beam made according to Casco's adhesive specifications, while the remaining beams had the following mistakes built in during manufacturing, so that delamination of different degrees would be evident.

*Table 1 Production parameters of the beams produced*

| Beam no. | Failure type | Total assembly time (min) | Glue spread (g/m²) | Pressure (N/mm²) |
|---|---|---|---|---|
| 1 | Very long assembly time (closed) | 80 min | 365 g/m² | 6 N/mm² |
| 2 | Normal | 3 min | 365 g/m² | 6 N/mm² |
| 3 | Low glue spread | 3 min | 150 g/m² | 6 N/mm² |
| 4 | Low pressure | 5 min | 365 g/m² | 3 N/mm² |
| 5 | Long assembly time (closed) | 55 min | 365 g/m² | 6 N/mm² |

The spruce beams were 12 m long, 150 mm wide (and planed down to 140 mm afterwards), and contained 5 lamellae per beam. The adhesive used was Casco Products MUF Cascomin resin 1241 with hardener 2542. Enough after-curing time was ensured for full cure at room temperature.

After the first 30 cm was removed and discarded from the beam, the test pieces from each beam were cut into pieces 75 mm wide (as stated in EN 391). The specimens were distributed in a recurrent order. These were packed in plastic, marked, and sent off to the partners to be tested within two weeks of each other. Each partner received 4 samples from each beam, or 20 samples per test round, for a total of 40 samples.

The partners had identification letters allocated to them, as follows:

| Identification | Partner´s name |
|---|---|
| A | Martinsons Trä |
| B | DTI |
| C | NTI |
| F | Moelven |
| I | SFS-Sertifionti |
| J | Holzforschung Austria |
| K | Limträ Danmark |
| L | Casco Products |
| M | Late-Rakenteet |
| N | SP |
| O | FMPA |

# 5. Test Round 1 results

## 5.1. Directions

The partners received the following instructions:

- Only half of the specimens sent should be tested.
- The most recent version of prEN 391 – method B, January 2001 should be followed, a copy of this standard being supplied to all.
- The cause for delamination of a given beam should also be guessed.

## 5.2. Results

The results were recorded on special Excel forms prepared in advance. The filled out forms were then returned to the co-ordinators for evaluation and comparison.

A summary of the mean delamination results for each beam and institute are given below:

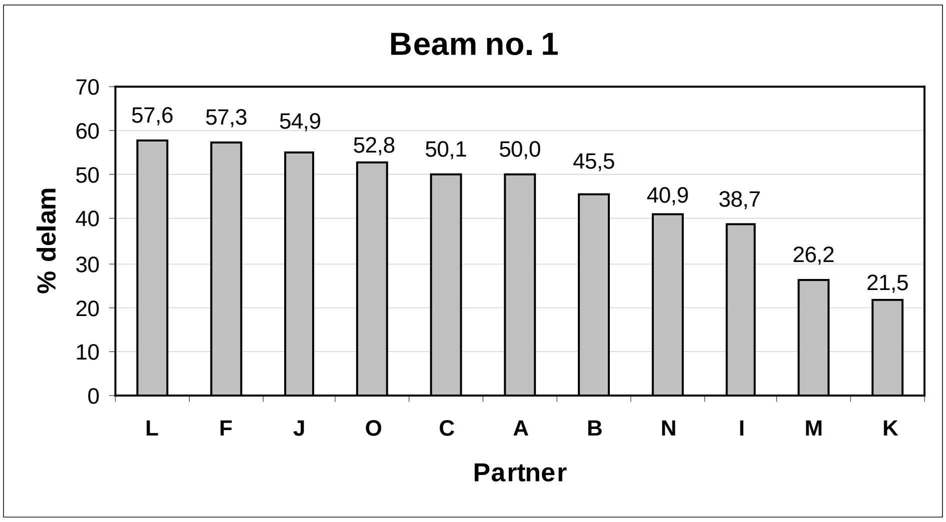


**Figure 5.1** *Mean delamination for beam 1 (very long closed assembly time, 80 min)*

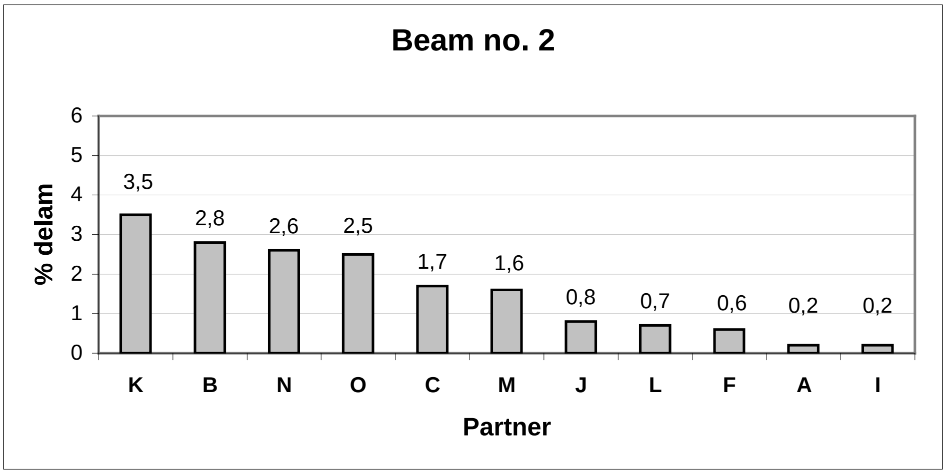


***Figure 5.2*** *Mean delamination for beam 2 (normal conditions)*

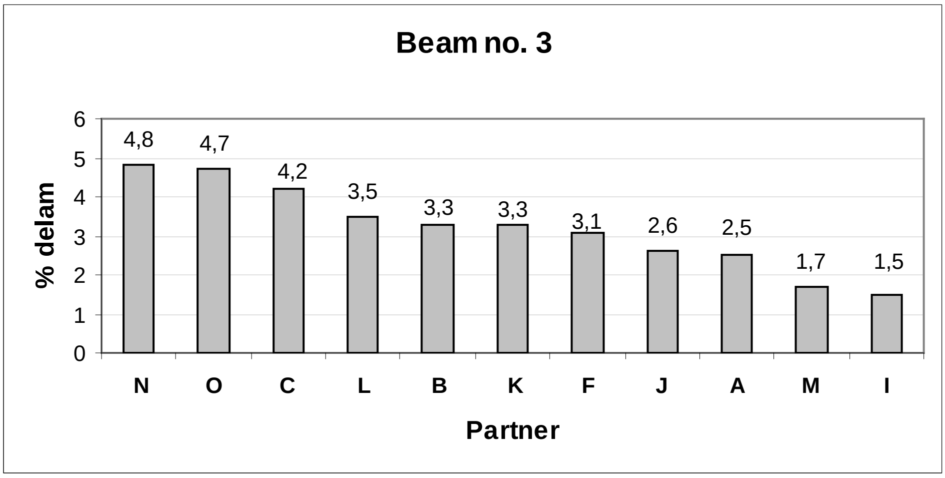


***Figure 5.3*** *Mean delamination for beam 3 (low glue spread)*

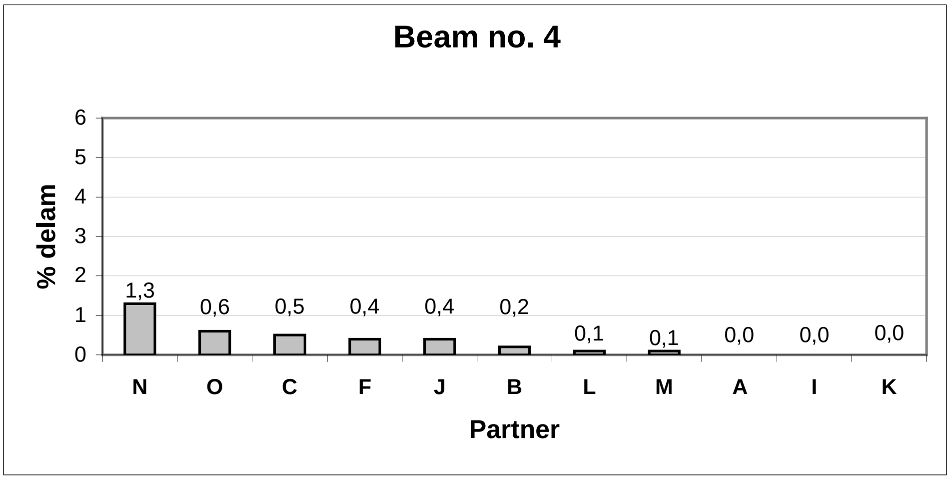


***Figure 5.4*** *Mean delamination for beam 4 (low pressure)*

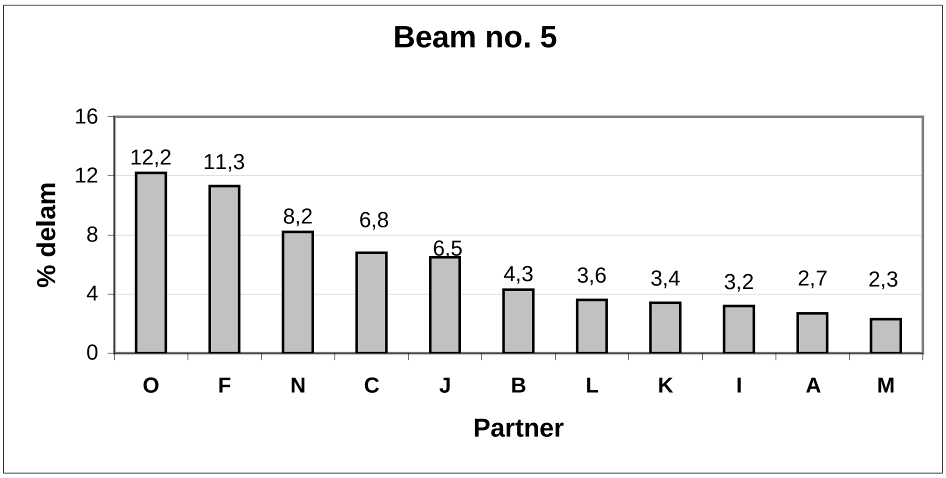


***Figure 5.5*** *Mean delamination for beam 5*
*(long closed assembly time, 55 min)*

With beams number 1 to 4 there were concordance between the partners on whether the beams should be “accepts” (below 4 % or 8 %) or “rejects”. The judgement for beam no. 5 was not unanimous, as some partners had results above 8 % while others had results between 4-8 %, and yet others had results below the critical 4 % level.

Interesting were also “placement”, or ranking, when considering the mean delamination of all results for each partner and each beam (Figure 5.6). Figure 5.7 also shows the mean delamination for all beams for each partner, and also ranks them from highest to lowest according to how the delamination was evaluated.

**Colour Code**

| | | |
|---|---|---|
| Red | I | SFS |
| Magenta | M | Late |
| Pink | K | Limträ Danmark |
| Blue | J | Holzforschung Austria |
| Cyan | C | NTI |
| Light cyan | A | Martinsons |
| Dark green | O | FMPA |
| Green | N | SP |
| Yellow | B | DTI |
| Lilac | L | Casco Products |
| Grey | F | Moelven |

| **Beam** | Highest ranked partners (highest delam.) | | | | | | Lowest ranked partners (lowest delam.) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 57,6 | 57,3 | 54,9 | 52,8 | 50,1 | 50,0 | 45,5 | 40,9 | 38,7 | 26,2 | 21,5 |
| **2** | 3,5 | 2,8 | 2,6 | 2,5 | 1,7 | 1,6 | 0,8 | 0,7 | 0,6 | 0,2 | 0,2 |
| **3** | 4,8 | 4,7 | 4,2 | 3,5 | 3,3 | 3,3 | 3,1 | 2,6 | 2,5 | 1,7 | 1,5 |
| **4** | 1,3 | 0,6 | 0,5 | 0,4 | 0,4 | 0,2 | 0,1 | 0,1 | 0,0 | 0,0 | 0,0 |
| **5** | 12,2 | 11,3 | 8,2 | 6,8 | 6,5 | 4,3 | 3,6 | 3,4 | 3,2 | 2,7 | 2,3 |

**Figure 5.6** *Ranking for each partner and each beam, from the highest delamination (on the left side) to the lowest delamination (on the right side).*

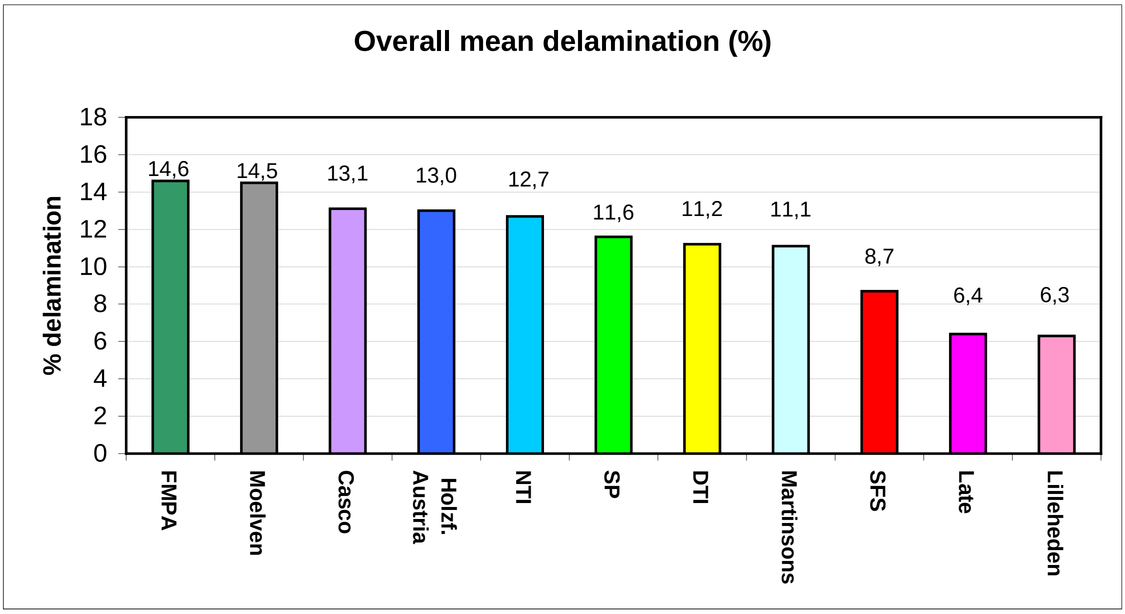


**Figure 5.7** *Ranking for each partner and all beams, from the highest delamination (on the left side) to the lowest delamination (on the right side).*

Figure 5.8 shows the process parameters during testing, and also states what process parameters should be used in EN 391 Method B. Here we can also see some reasons for some of the discrepancies in results.

| Partner | Code | Autoclave | | Climate chamber | | | Test samples | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Vacuum kPa | Pressure kPa | Air speed m/s | Temperature °C | RH % | Level of drying % | Water absorption % | Drying time h |
| Martinsons | A | 80 | 580 | - | 72 | 8 | 6,6 | 114 | 18-22 |
| DTI | B | 73 | 550 | 2.0 | 69 | 8 | 11,4 | 118 | 12 |
| NTI | C | 25-28 | 670 | 2,1 | 68 | 19-7 * | 6,5 | 107 | 15,5-23,5 |
| Moelven | F | 20 | 800 | 2.3-2.8 | 68 | - | 1,5 | 98 | 10 |
| SFS | I | 60 | 600 | 3,0 | 70 | 20-5 * | 0,5 | 108 | 16,5 |
| Holzf. Austria | J | 80 | 580 | 2-3 | 70 | 9 | 5,1 | 109 | 13,5-14,5 |
| Limträ Danmark | K | 70-80 | 600-700 | 2-3 | 65-69 | 10-11 | 18,2 | 126 | 14-17 |
| Casco | L | 30 | 637-688 | 1.15-1.30 | 70 | 11 | 3,8 | 84 | 20,75 |
| Late | M | 80 | 560 | 3,0 | 72 | 20-5 * | -2,9 | 104 | - |
| SP | N | 70-85 | 500-600 | 2-3 | 70 | 8-10 | 2,2 | - | 16 |
| FMPA | O | 25 | 600 | 2,5-3,0 | 65 | <10 | 1,8 | 96 | 15-16 |

*****: Highest value at the beginning, lowest at the end.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **EN 391 norms** | | 70-85 | 500-600 | **2-3** | **65-75** | **8-10** | **0-10** | | **10-15** |
| | Absolute pressure | **15-30** | **600-700** | | | | | | Approximately |

***Figure 5.8*** *Process parameters results for all partners*

The generally lower delamination results for Partner K are due to the low level of drying, which was 18,2 % higher than the original sample weight (when it should have been between 0-10 % above the original weight).

Partner M generally over dried the samples, making the delamination hard to identify due to the closing of the glue lines. Both phenomena have been identified in [1], and it was previously known that these conditions should be avoided. Percentage water absorption was also somewhat higher than other partners.

Some confusion in the interpretation of what vacuum should be drawn was also noted in the results sent in by some partners.

# 6. Meeting after round 1 to discuss results

After the results from the first round were over, an analysis was made and a meeting held to discuss them. From this meeting, some technical points were highlighted as being important to modify or to better specify. Based on these suggestions, the EN 391 wording was modified for the purposes of more precise testing in Round 2. The additions to the wording are highlighted in **bold**:

*Change 1*

We were uncertain as to whether the equipment had been calibrated recently, making the demand of a calibration date necessary. The size of the climate chambers also was to be documented, as no size is prescribed in the norm.

"**6.2 in prEN 391, Apparatus**

**Recommendation: calibrate drying chamber and autoclave before performing Round 2. If not possible, indicate when the machinery was last calibrated!**

**Measure and record your cabinet dimensions: depth, length and width (cm), and the shape (send in a digital photo of it if possible).**"

*Change 2*

Some partners opened the delaminated glue lines to check for knots, and some did not. It was decided that this was always to be carried out in Round 2, if the delamination level was above 4 %.

"**6.4.2.1 in prEN 391** The delamination measurement and the evaluation of the test pieces shall take place no later than 1 hour after the final drying treatment. The total glue line delamination on both end-grain surfaces of the test pieces shall be measured in millimeters.

**All samples which have a delamination of > 4 % shall be analyzed for hidden knots by opening the glue lines with a wedge and hammer.**"

*Change 3*

To avoid the confusing level of vacuum that was to be drawn in the first phase of water impregnation, a clearer wording was given, along with an example of where the manometer pointer should be pointing, indicating the correct vacuum.

In order to always achieve the same air speed conditions in the climate chamber, it was decided that dry dummies should be used to always fill the entire cross section of the chamber (in air flow direction).

"**6.4.4.1 in prEN 391** Weigh and record to the nearest 5 g, the mass of each test piece. Place the test pieces in the pressure vessel and weigh them down. Admit water at a temperature of 10 ˚C to 20 ˚C in sufficient quantity, so that the pieces are completely submerged. Separate the test pieces by stickers, wire screens, or other means in such a manner that all end-grain surfaces are freely exposed to the water.

Draw a vacuum of 70 to 85 kPa (absolute pressure 15 to 30 kPa) and hold it for 30 min. **An example on how correct vacuum shall be measured is shown in photo 1 (100 kPa = 1 bar).**

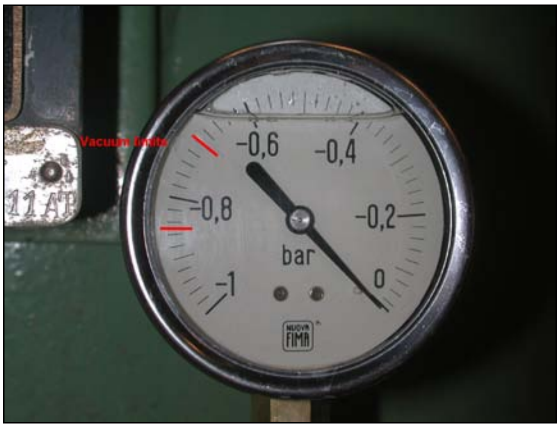


***Photo 1: With this meter, the vacuum to be drawn shall lie between –0,70 and –0,85 bar (0 is atmospheric pressure, -1 is absolute vacuum).***

Release the vacuum and apply an absolute pressure of 600 to 700 kPa for 2 h.

**Dry dummies will be used in Round 2 to fill up the chamber, and should be placed in the same way, with the same volume, every time the test is performed. They may be colored in a separate color to facilitate identification. Dummies shall be placed on the outer parts of the pile, while the samples to be dried are placed in towards the middle of the pile (see photo 2). Samples are always placed above each other in rows, so that a 5 cm space between rows is always present.**

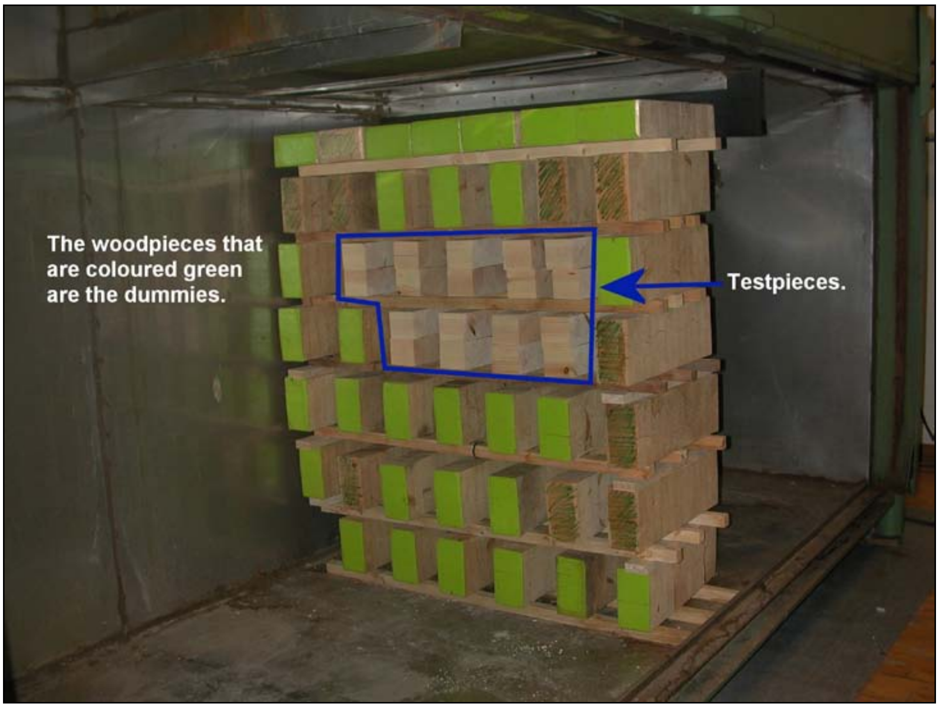


***Photo 2: Wet samples should be placed in the middle of the sample pile. Samples consisting of dry dummies and wet samples should fill out the whole of the drying chamber's cross-section. Samples shall always be placed above each other and stand in a row, so that a corridor of 5 cm between samples is present. The air speed shall be measured in the middle of the pile in between the samples, with a closed chamber door.***"

*Change 4*

The placing of the anemometer in the climate chamber to measure the air speed is crucial for a correct air speed reading. It was determined to place it in the spatial middle of the chamber, between the rows of samples, and with a closed door!

"**6.4.4.2 in prEN 391** Dry the test pieces for a period of approximately 10 h to 15 h in air at 70±5 ˚C and a relative humidity of 8 % to 10 % and circulating at a velocity of 2 m/s to 3 m/s. **The air speed shall be measured (not estimated!) in the spatial middle of the drying chamber (see Photo 2): not on the sides of the chamber, not in front or the back of the chamber, but between the rows of samples in the middle of the pile. Air speed is to be measured with a closed door.**

**Control the air RH (%) in the drying chamber after 5 min, 60 min and at the end of the drying period.** During drying the test pieces shall be placed at least 50 mm apart with the end-grain surfaces parallel to the stream of air."

*Change 5*

It was attempted to further limit what the weight of the samples should be at the time of evaluation, reducing the limit from 100-110 % to 105-110 % of the original weight. It was expected that the delamination would also be at its highest at this level. The total drying time for each sample was also recorded, and a mean was built.

"**6.4.4.3 in prEN 391** The actual time in the drying duct shall be controlled by the mass of the test pieces. Delamination shall be observed and recorded when the mass of the test pieces has returned to within **105 %-110 % of the original mass. Record the total drying time for each individual sample.**"

A half-hour session was held to compare what some considered a true delamination, and what was a mere opening. This was considered very useful by many, as it gives a common basis for agreement on what can sometimes be a subjective evaluation.

# 7. Test Round 2 results

Samples from the same beams were then tested with the new EN 391 wording and conditions.

A summary of the mean delamination results for each beam and institute are given below:

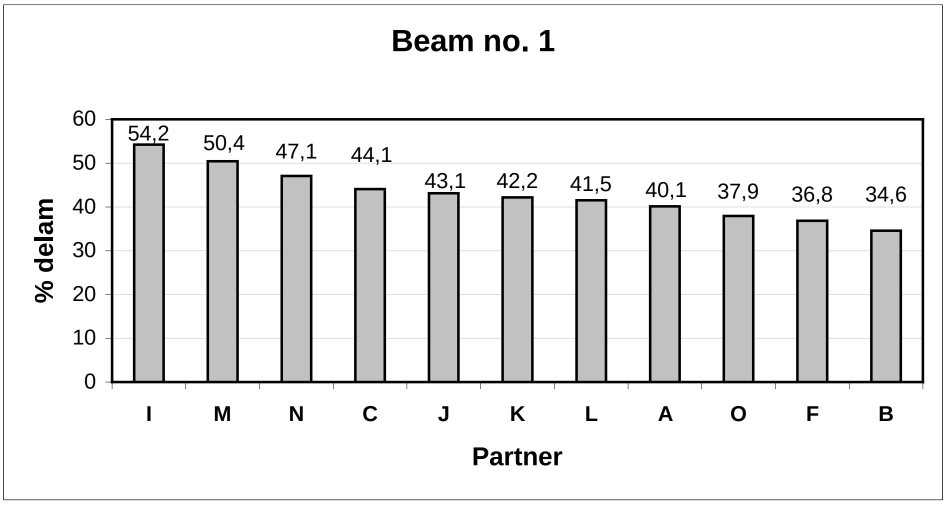


***Figure 7.1*** *Mean delamination for beam 1 (very long assembly time, 80 min)*

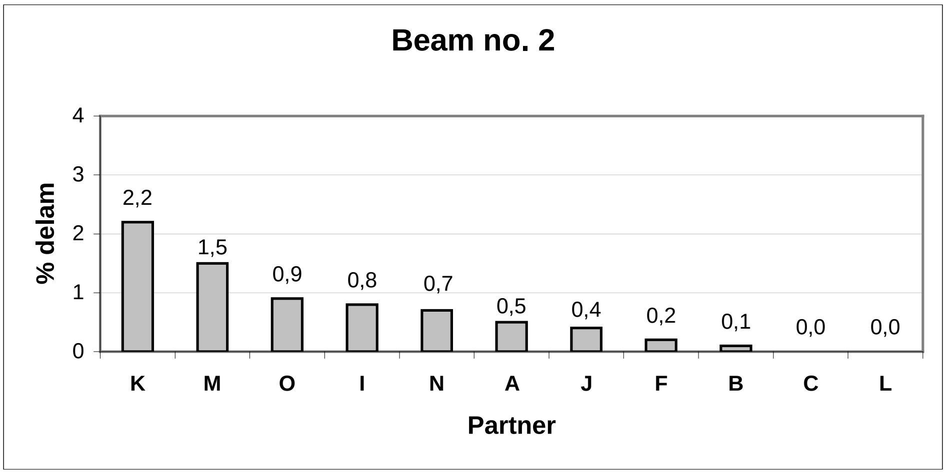


***Figure 7.2*** *Mean delamination for beam 2 (normal conditions)*

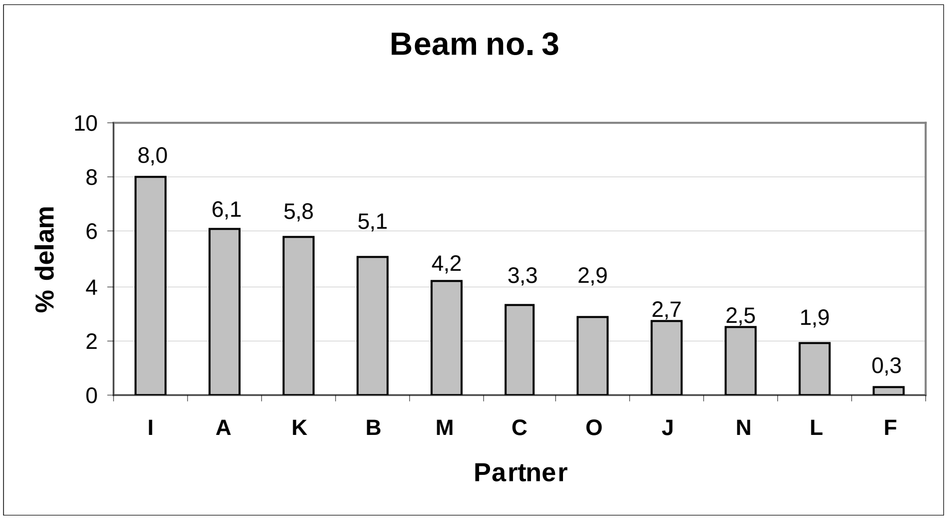


***Figure 7.3*** *Mean delamination for beam 3 (low glue spread)*

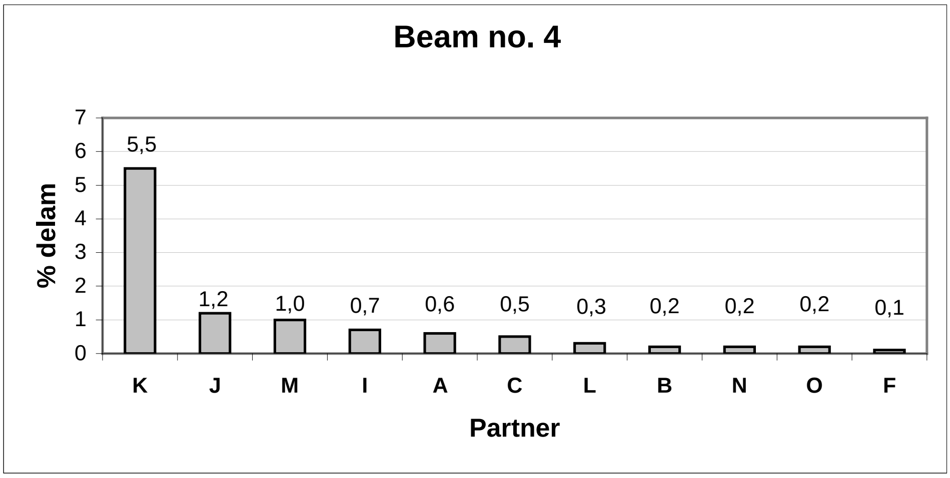


***Figure 7.4*** *Mean delamination for beam 4 (low pressure)*

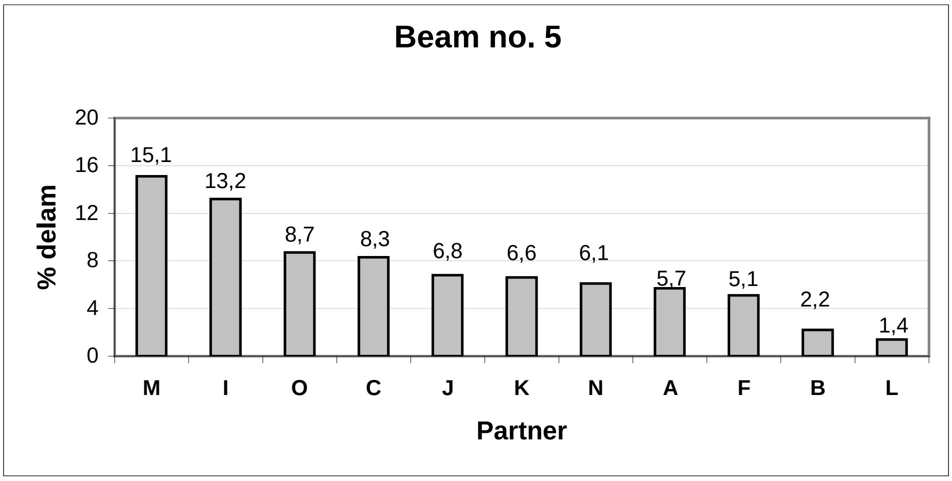


***Figure 7.5*** *Mean delamination for beam 5 (long assembly time, 55 min)*

As in Test Round 1, beams number 1 to 4 all gave the same "accept" results, that is there was general concordance between the partners on whether the beams should be "accepts" (below 4 % or 8 %) or "rejects". A clear judgement for beam no. 5 (long assembly time) was once again not unanimous, as some partners had results above 8 % while others had results between 4-8 % and yet others again had results below the critical 4 % level. Very possibly this could be due to having certain areas along the lamellae having dried out or pre-cured, while others were not as affected yet, leading to differential delamination evaluations, which were not as clear-cut as in beams 1-4.

A ranking was again carried out, when considering the mean delamination of all results for each partner and each beam (Figure 7.6). Figure 7.7 also shows the mean delamination for all beams for each partner, and also ranks them from highest to lowest according to how the delamination was evaluated.

**Colour code**

| | | |
|---|---|---|
| | I | SFS |
| | M | Late |
| | K | Lilleheden |
| | J | Holzf. Austria |
| | C | NTI |
| | A | Martinsons |
| | O | FMPA |
| | N | SP |
| | B | DTI |
| | L | Casco |
| | F | Moelven |

| **Beam** | Highest ranked partners (highest delam.) | | | | | | Lowest ranked partners (lowest delam.) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 54,2 | 50,4 | 47,1 | 44,1 | 43,1 | 42,2 | 41,5 | 40,1 | 37,9 | 36,8 | 34,6 |
| 2 | 2,2 | 1,5 | 0,9 | 0,8 | 0,7 | 0,5 | 0,4 | 0,2 | 0,1 | 0,0 | 0,0 |
| 3 | 8,0 | 6,1 | 5,8 | 5,1 | 4,2 | 3,3 | 2,9 | 2,7 | 2,5 | 1,9 | 0,3 |
| 4 | 5,5 | 1,2 | 1,0 | 0,7 | 0,6 | 0,5 | 0,3 | 0,2 | 0,2 | 0,2 | 0,1 |
| 5 | 15,1 | 13,2 | 8,7 | 8,3 | 6,8 | 6,6 | 6,1 | 5,1 | 5,7 | 2,2 | 1,4 |

***Figure 7.6*** *Ranking for each partner and each beam, from the highest delamination (on the left side) to the lowest delamination (on the right side).*

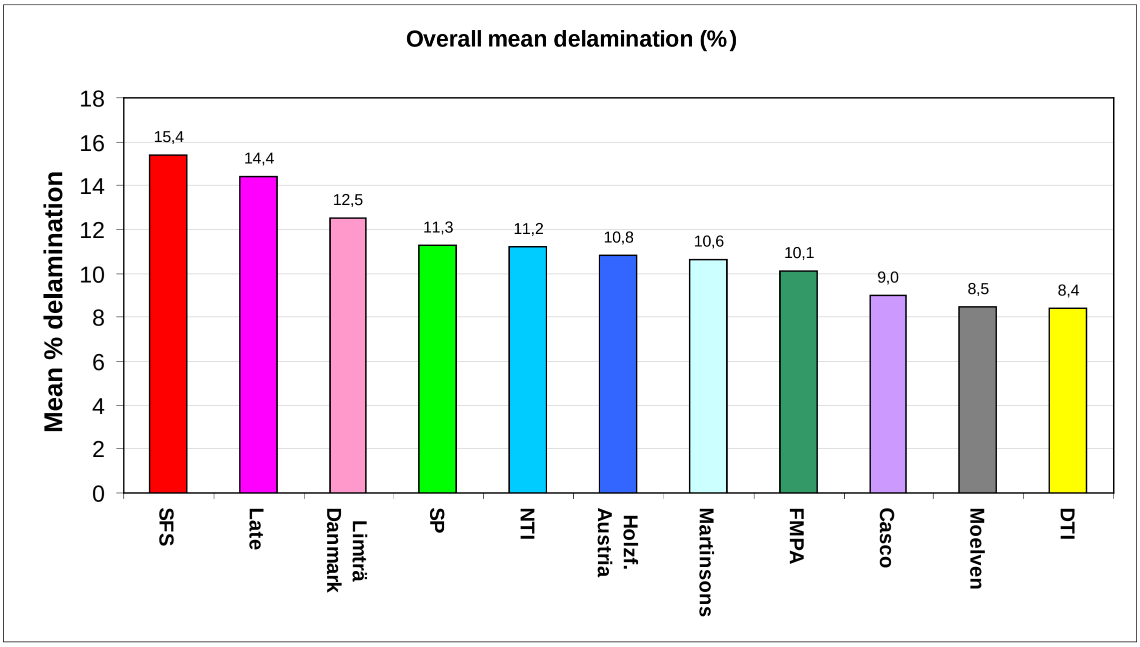


***Figure 7.7*** *Ranking for each partner and all beams, from the highest delamination (on the left side) to the lowest delamination (on the right side).*

| Partner | Code | Autoclave | | Climate chamber | | | Test samples | | | Chamber size | Calibration date |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Vacuum kPa | Pressure kPa | Air speed m/s | Temperature °C | RH* % | Level of drying % | Water absorption % | Drying time h | WxLxH (cm) | |
| **Martinssons** | A | 30 | 500 | 1,2-1,5 | 71/73 | 52/57-15/20 | 7,8 | 117 | 20-23 | 61x63x122 | 14.12.01 |
| **DTI** | B | (-) 78 | 680 | 2,3 | 68 | 51-9 | 7,5 | 137 | 21-24 | 120x200x120 | 01.11.01 |
| **NTI** | C | 25-28 | 650 | 2,25 | 68 | 51-9 | 6,2 | 105 | 15-23 | 82x80x85 | 31.07.01 |
| **Moelven** | F | 20 | 800 | 2,3-2,8 | 68 | - | 0,9 | 85 | 10 | 60x60x140 | - |
| **SFS** | I | 0,77 | 650 (abs) | 2,5 | 70 | 33-8 | 5,9 | 103 | 11-13,5 | 70x70x110 | 01.02.02 |
| **Holzf. Austria** | J | 80 | 580 | 3-4,5 | 71,6 | 72-10,2 | 5,1 | 107 | 12-13 | 60x120x52 | 24.09.01 |
| **Limträ Danmark** | K | 70-80 | 600-700 | 2-3 | 71 | 45-10 | 6,2 | 128 | 18-20 | 63x290x82 | 13.11.01 |
| **Casco** | L | 70 | 637-687 | 0,07-0,97 | 70 | 16,4-10,2 | 6,1 | 101 | 27,5-35 | 80x83x86 | 05.12.01 |
| **Late** | M | 76-78 | 500-600 | 2,5 | 70 | 50-8 | 5,3 | 104 | 12-13,5 | 70x70x110 | 01.02.02 |
| **SP** | N | 70 | 550 | 2-3 | 70 | 8-10 | 6,9 | 114 | 17 | - | - |
| **FMPA** | O | 25 | 600 | 2,7 | 65 | 14-6 | 8,2 | 102 | 14-16,5 | 90x131x32 | - |

*****: Highest value at the beginning, lowest at the end.

**EN 391 norms**

| | Vacuum kPa | Pressure kPa | Air speed m/s | Temperature °C | RH* % | Level of drying % | Drying time h |
|---|---|---|---|---|---|---|---|
| | 70-85 | 500-600 | 2-3 | 65-75 | 8-10 | 0-10 | 10-15 |
| Absolute pressure | **15-30** | **600-700** | | | | | Approximately |

***Figure 7.8*** *Process parameters results for all partners*

Figure 7.8 shows the process parameters during testing, and also what EN 391 Method B states should be used. Here we can see some more reasons for some of the discrepancies in results.

The generally low delamination results for Partner L is clearly due to a malfunctioning fan in the climate chamber (0,1 –1,0 m/s).

Time to reach the 106 % of original weight lay around 30 h, or twice as long as other partners. Delamination results also dropped from the previous 13 % level to 9 % - basically, the stress perpendicular to the glue line imposed was not as tough as it should have been, with kinder delamination results.

Partner F also dried its samples to just over 100 % of the original weight instead of the required 105-110 %.

Additional statistics are given in appendix 3. Important information gained from the test results can be seen in appendix 4.

# 8. Discussions and conclusions

In general, there was accordance as to the evaluation of the delamination testing in 4 out of 5 beams, Beam 5 (long closed assembly time, 55 min) being the exception to the rule. When there are 12 m long lamellae, which are sometimes not plane, there are various degrees of curing occuring along the beam, with some areas being strongly pre-cured or dried, while other areas are still useable despite the assembly time being exceeded. The case of Beam 1, which had a *very* long assembly time of 80 min, was much more clear-cut, with very high delaminations and which left no doubt at all of the poor quality of the glue lines, as they were way above the 8 % “accept” level.

Some mistakes performed by some partners during the testing, demonstrated clearly that the test method must be followed closely to reach reasonable results. Some recommendations are listed below:

**Apparatus**

Test apparatus *must* be checked and calibrated regularly, something which possibly test institutes are better at than the industry. Proper functioning and reading of the manometer when drawing vacuum must be paid attention to (a less ambiguous wording for this must be devised in the present norm), as must the proper pressure. Notified bodies checking the quality of the apparatus used by the industry must be aware of this.

**Air speed**

The slower the air speed is, the slower the drying will be, and the lower the delamination results. The air speed of 2-3 m/s is reasonable, and gives reproducible results. It is also very important to measure the true air speed in the chamber in a uniform manner, preferably in the spatial centre of the chamber in between the samples – a better wording for this must be found in EN 391, such as where to measure the air speed. Climate chamber doors shall be closed when measuring air speed.

Airflow of 2-3 m/s is also of vital importance here. Samples must be placed so that the air can flow between them without impediment, and not in interspersed rows as some partners have done, which breaks the airflow. To allow a constant airflow, it is advisable to always have the same amount of samples placed in the chamber, in the same order, to ensure the same airflow from test to test. This can be achieved by the use of dry dummies.

**Final weight of sample in relation to original weight**

Both too low and too high drying can cause low delamination results. The present drying level of 100-110 % of the original weight, has been in use for some years now. A further tightening of this level to 105-110 % is not seen as necessary, as it means a more onerous and time consuming control of the samples during drying.

However, the wording in the norm should be "105 ± 5 %" instead of "100-110 %" to indicate more clearly that 105 % over the original weight should be aimed for.

**Opening of glue lines**

These should *always* be opened if delamination of any samples is greater than 4 %, as this removes any doubt that the delamination is truly due to intrinsic bond line failure and not to knots.

The most important point to realise after this round-robin testing, is that small errors are cumulative. If the whole test method is performed as described, results will be repeatable, reproducible and credible. It must be realised that the aim of EN 391 is to create a perpendicular stress to the glue line that depends on artificial aging in the form of pumping a certain amount of water into a piece of wood, and then drying the water out in a uniform way. The importance of the combination of heat and airflow on the delamination evaluation seems to have been underrated.

Despite the discrepancies between partners on the methodology of the norm, it is remarkable that even so there was good agreement on what beams could be considered an "accept" and which ones a "reject". The round-robin has proven that it is a dependable test method for the industry, and that with even further tightening of the wording in EN 391 and EN 302-2, even better glulam quality estimates can be made in a relatively short period of time.

# 9. References

1. Johansson, CJ; Buchter, J; Lind, P; Saarelainen, U (1994): Delamination test of glue lines according to EN 391. Nordtest project 1089-93. SP report 1994:67, Borås, Sweden.

2. EN 301 (July 2001): Adhesives for load-bearing timber structures. Polycondensation adhesives of the phenolic and aminoplatsic type. Classification and performance requirements. Europe Committee for Standardization.

3. EN 302-2 (Feb 2001): Adhesives for load-bearing structures. Polycondensation adhesives of the phenolic and aminoplatsic type. Test methods. Part 2: Determination of resistance to delamination. Europe Committee for Standardization.

# 10. Appendixes

## 10.1. Appendix 1 -Test results

Results for all partners in **Test Round 1**

| Beam no. | Partner | Delam. % | Level of drying % | Water absorption % | *Mean drying level* % deviation from starting point | *Mean water absorption* % of starting weight |
|---|---|---|---|---|---|---|
| | | | | | | |
| 1 | A | 50,0 | 4,9 | 108 | | |
| 2 | A | 0,2 | 6,8 | 119 | | |
| 3 | A | 2,5 | 4,3 | 101 | | |
| 4 | A | 0,0 | 8,4 | 120 | | |
| 5 | A | 2,7 | 8,7 | 122 | 6,6 | 114 |
| 1 | B | 45,5 | 9,6 | 111 | | |
| 2 | B | 2,8 | 12,6 | 132 | | |
| 3 | B | 3,3 | 8,4 | 111 | | |
| 4 | B | 0,2 | 11,6 | 116 | | |
| 5 | B | 4,3 | 14,7 | 121 | 11,4 | 118 |
| 1 | F | 57,3 | 1,2 | 93 | | |
| 2 | F | 0,6 | 0,9 | 106 | | |
| 3 | F | 3,1 | 1,1 | 94 | | |
| 4 | F | 0,4 | 1,3 | 97 | | |
| 5 | F | 11,3 | 2,9 | 101 | 1,5 | 98 |
| 1 | I | 38,7 | -2,5 | 97 | | |
| 2 | I | 0,2 | 1,3 | 122 | | |
| 3 | I | 1,5 | 1,9 | 100 | | |
| 4 | I | 0,0 | 1,7 | 103 | | |
| 5 | I | 3,2 | -0,1 | 117 | 0,5 | 108 |
| 1 | N | 40,9 | -0,8 | | | |
| 2 | N | 2,6 | 5,3 | | | |
| 3 | N | 4,8 | -1,2 | | | |
| 4 | N | 1,3 | 2,5 | | | |
| 5 | N | 8,2 | 5,1 | | 2,2 | - |
| 1 | K | 21,5 | 19,4 | 122 | | |
| 2 | K | 3,5 | 16,8 | 128 | | |
| 3 | K | 3,3 | 18,1 | 122 | | |
| 4 | K | 0,0 | 18,9 | 127 | | |
| 5 | K | 3,4 | 17,7 | 131 | 18,2 | 126 |
| 1 | L | 57,6 | 4,0 | 77 | | |
| 2 | L | 0,7 | 3,2 | 92 | | |
| 3 | L | 3,5 | 1,5 | 79 | | |
| 4 | L | 0,1 | 4,2 | 83 | | |
| 5 | L | 3,6 | 5,9 | 90 | 3,8 | 84 |
| 1 | C | 50,1 | 5,6 | 95 | | |
| 2 | C | 1,7 | 7,7 | 122 | | |
| 3 | C | 4,2 | 5,9 | 101 | | |
| 4 | C | 0,5 | 7,3 | 102 | | |
| 5 | C | 6,8 | 5,8 | 116 | 6,5 | 107 |
| 1 | O | 52,8 | 1,9 | 89 | | |

| Beam no. | Partner | Delam. % | Level of drying % | Water absorption % | ***Mean drying level*** % deviation from starting point | ***Mean water absorption*** % of starting weight |
|---|---|---|---|---|---|---|
| | | | | | | |
| 2 | O | 2,5 | 4,9 | 106 | | |
| 3 | O | 4,7 | 0,6 | 90 | | |
| 4 | O | 0,6 | 2,1 | 96 | | |
| 5 | O | 12,2 | -0,5 | 101 | 1,8 | 96 |
| 1 | J | 54,9 | 4,9 | 97 | | |
| 2 | J | 0,8 | 5,4 | 119 | | |
| 3 | J | 2,6 | 5,3 | 103 | | |
| 4 | J | 0,4 | 6,1 | 102 | | |
| 5 | J | 6,5 | 4,1 | 122 | 5,1 | 109 |
| 1 | M | 26,2 | -3,8 | 92 | | |
| 2 | M | 1,6 | -0,5 | 114 | | |
| 3 | M | 1,7 | -3,0 | 95 | | |
| 4 | M | 0,1 | -3,4 | 104 | | |
| 5 | M | 2,3 | -4,1 | 116 | -2,9 | 104 |

Results for all partners in **Test Round 2**

| Beam no. | Partner | Delamination % | Level of drying % | Water absorption % | ***Mean level of drying*** % deviation from starting point | ***Mean water absorption*** % of starting weight |
|---|---|---|---|---|---|---|
| | | | | | | |
| 1 | A | 40,1 | 6,6 | 111 | | |
| 2 | A | 0,5 | 9,2 | 121 | | |
| 3 | A | 6,1 | 5,8 | 99 | | |
| 4 | A | 0,6 | 8,5 | 132 | | |
| 5 | A | 5,7 | 9,0 | 120 | 7,8 | 117 |
| 1 | B | 34,6 | 5,5 | 133 | | |
| 2 | B | 0,1 | 9,4 | 135 | | |
| 3 | B | 5,1 | 5,8 | 125 | | |
| 4 | B | 0,2 | 8,4 | 147 | | |
| 5 | B | 2,2 | 8,2 | 143 | 7,5 | 137 |
| 1 | C | 44,1 | 4,8 | 98 | | |
| 2 | C | 0,0 | 8,0 | 111 | | |
| 3 | C | 3,3 | 4,8 | 92 | | |
| 4 | C | 0,5 | 7,7 | 116 | | |
| 5 | C | 8,3 | 5,6 | 110 | 6,2 | 105 |
| 1 | F | 36,8 | 0,5 | 88 | | |
| 2 | F | 0,2 | 1,2 | 81 | | |
| 3 | F | 0,3 | 1,1 | 79 | | |
| 4 | F | 0,1 | 0,8 | 89 | | |
| 5 | F | 5,1 | 0,9 | 90 | 0,9 | 85 |
| 1 | I | 54,2 | 4,7 | 98 | | |
| 2 | I | 0,8 | 6,1 | 101 | | |
| 3 | I | 8,0 | 6,3 | 103 | | |
| 4 | I | 0,7 | 6,0 | 108 | | |

| **Beam no.** | **Partner** | **Delamination** % | **Level of drying** % | **Water absorption** % | ***Mean level of drying*** % deviation from starting point | ***Mean water absorption*** % of starting weight |
|---|---|---|---|---|---|---|
| | | | | | | |
| 5 | I | 13,2 | 6,3 | 103 | 5,9 | 103 |
| 1 | J | 43,1 | 4,2 | 103 | | |
| 2 | J | 0,4 | 4,1 | 110 | | |
| 3 | J | 2,7 | 2,5 | 92 | | |
| 4 | J | 1,2 | 7,9 | 122 | | |
| 5 | J | 6,8 | 6,6 | 108 | 5,1 | 107 |
| 1 | K | 42,2 | 6,3 | 122 | | |
| 2 | K | 2,2 | 6,7 | 130 | | |
| 3 | K | 5,8 | 6,2 | 115 | | |
| 4 | K | 5,5 | 6,6 | 137 | | |
| 5 | K | 6,6 | 5,2 | 134 | 6,2 | 128 |
| 1 | L | 41,5 | 5,9 | 96 | | |
| 2 | L | 0,0 | 6,3 | 104 | | |
| 3 | L | 1,9 | 5,1 | 92 | | |
| 4 | L | 0,3 | 6,6 | 113 | | |
| 5 | L | 1,4 | 6,7 | 98 | 6,1 | 101 |
| 1 | M | 50,4 | 5,0 | 101 | | |
| 2 | M | 1,5 | 5,3 | 108 | | |
| 3 | M | 4,2 | 4,9 | 96 | | |
| 4 | M | 1,0 | 6,7 | 109 | | |
| 5 | M | 15,1 | 4,8 | 107 | 5,3 | 104 |
| 1 | N | 47,1 | 9,3 | 108 | | |
| 2 | N | 0,7 | 8,8 | 119 | | |
| 3 | N | 2,5 | 6,9 | 99 | | |
| 4 | N | 0,2 | 8,5 | 129 | | |
| 5 | N | 6,1 | 1,1 | 115 | 6,9 | 114 |
| 1 | O | 37,9 | 5,8 | 93 | | |
| 2 | O | 0,9 | 9,3 | 106 | | |
| 3 | O | 2,9 | 6,6 | 87 | | |
| 4 | O | 0,2 | 11,2 | 119 | | |
| 5 | O | 8,7 | 8,2 | 105 | 8,2 | 102 |

Questionnaire as to whether partners opened delaminations

| **Partner** | **Round 1** | **Round 2** |
|---|---|---|
| Late-Rakenteet | Yes, some large delaminations, randomly. | Yes, when delamination >4 %. |
| Limträ Danmark | Yes | Yes |
| Martinsons Trä | Yes | Yes and no, only gluelines that could contain knots and those who was difficult to see if there were fiber in glueline, were opened in round 2 |
| Moelven | Yes | Yes |
| DTI | No | Yes |
| FMPA | Opening of the glue lines for evaluation was only done for samples in case it was not clear if it was a valid delamination or not, and only for samples with a delamination of more than 4 %. This means that not all samples with more than 4 % delamination were opened. | Splitting open of the glue lines was done for all samples with a delamination of more than 4 % |
| Holzforschung Austria | Yes | Yes |
| NTI | Yes, if over 4 % | Yes, if over 4 % |
| SFS | Samples not opened for delamination (we opened 2-3 pieces because we saw there may be some interesting knots in). | We opened all test pieces that was 4 % or more delaminated. |
| Casco | Yes | Yes |
| SP | Yes | Yes |

## 10.2 Appendix 2 - prEN 391 Final Draft - January 2001

**CEN/TC 124**

**prEN 391**

CEN/TC 124

Secretariat: DS

# Glued laminated timber - Delamination test of glue lines

**Brettschichtsholz – Delaminierungsprüfung von Leimfugen**

**Bois lamellé collé – Essai de délamination des joints de collage**

ICS : 79.060.00

Descriptors : Wood, laminated boards, gluing, quality control, tests, peeling

Document type :
Document subtype :
Document stage :
Document language :

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**Contents** **Page**

## Foreword

This European Standard has been prepared by Technical Committee CEN/TC 124 "Timber structures", the secretariat of which is held by DS.

This document is currently submitted to the Unique Acceptance Procedure.

This European Standard supersedes EN 391:1995.

> NOTE It is considered desirable to maintain the same clause numbers consistently throughout this series of standards. Consequently, some clauses are void in this edition of this standard, but it is envisaged that future editions may need to include text in the clauses.

## Introduction

Two delamination methods called A and B are suitable for adhesives of type I as defined in EN 301, and one method called C is suitable for adhesives of type II as defined in EN 301.

The two methods A and B have a duration of two days and a half day respectively, and method C requires four days. All are suitable for every day quality control.

# 1 Scope

This standard specifies three delamination methods for continuous quality control of the glue line integrity of glued laminated timber.

# 2 Normative references

None.

# 3 Terms and definitions

For the purposes of this European Standard the following definitions apply:

## 3.1 delamination length

The sum of the lengths of delaminated glue lines on both end-grain surfaces of each test piece.

## 3.2 glued laminated timber (glulam)

Structural member formed by bonding together timber laminations with the grain essentially parallel.

# 4 Symbols

$b$ width of cross section, in millimetres;

$h$ depth of cross section, in millimetres;

$l_{max,delam}$ maximum delamination length of one glue line in the test piece, in millimetres;

$l_{glueline}$ length of one glue line, normally the width $b$ shown in figure 1, in millimetres;

$l_{tot,delam}$ delamination length of all glue lines in the test piece, in millimetres;

$l_{tot,glueline}$ entire length of glue lines on the two end-grain surfaces of each test piece, in millimetres.

# 5 Requirements

None.

# 6 Delamination test of glue lines

## 6.1 Principle

A gradient is introduced in the moisture content of the wood to build up internal stresses. This will result in tensile stresses perpendicular to the glue lines so that inadequate bonding quality will result in delamination of the glue lines.

## 6.2 Apparatus

### 6.2.1 Pressure vessel

A pressure vessel designed to withstand safely a pressure of at least 600 kPa (700 kPa absolute pressure) and a vacuum of at least 85 kPa (15 kPa absolute pressure), and equipped with pumps or similar device capable of giving a pressure of at least 600 kPa (700 kPa absolute pressure) and of drawing a vacuum of at least 85 kPa (15 kPa absolute pressure).

### 6.2.2 Drying duct

A drying duct where air is circulating at a velocity of 2 m/s to 3 m/s, and at a temperature and a relative humidity as given in table 1.

**Table 1 – Climate in the drying duct for the different methods**

| | Method: | | |
|---|---|---|---|
| | A | B | C |
| Temperature °C | 60 to 70 | 65 to 75 | 25 to 30 |
| Relative humidity % | < 15 | 8 to 10 | 25 to 35 |

#### 6.2.3 Balance

A balance capable of determining mass to an accuracy of 5 g.

#### 6.2.4 Metal wedge and wooden hammer

Metal wedge and wooden hammer capable of splitting open glue lines.

### 6.3 Preparation of test pieces

The test pieces shall be prepared or selected in such a manner that they are representative of the production run.

Each test piece shall be taken from a full cross section of the laminated member to be tested, prepared by cutting perpendicular to the grain of the wood. It shall be (75 ± 5) mm in length (along the grain). The end-grain surfaces of the test piece shall be cut with a sharp saw or tool that produces a smooth surface.

If the width *b* of the cross section is greater than 300 mm the test piece may be split into two or more test pieces each at least 130 mm wide. If the depth *h* is greater than 600 mm the test piece(s) may be cut into two or more pieces each with a depth of at least 300 mm, see figure 1.

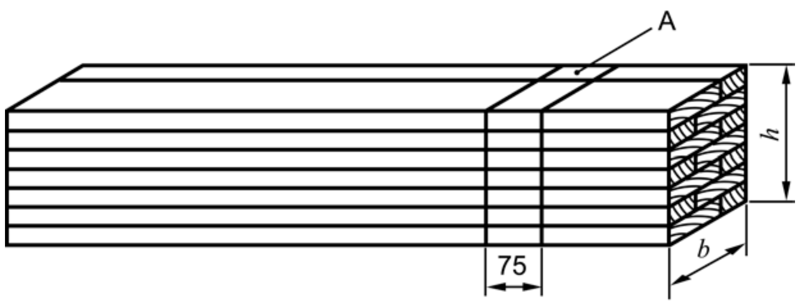



**Figure 1 - Test piece cut from a glulam member**
Key: A Test piece Dimensions in millimeters

## 6.4 Procedures

### 6.4.1 General

Before subjecting the test pieces to the test cycles, measure the total length in millimetres of glue lines on the end-grain surfaces of the test pieces.

Subject the test pieces to the appropriate test cycle described in 6.4.2, 6.4.3 or 6.4.4. The number of test cycles shall be as given in table 2.

**Table 2 - Number of test cycles to be used in the different test methods.**

| | Method: | | |
|---|---|---|---|
| | A | B | C |
| Number of initial cycles | 2 | 1 | 1 |
| Number of extra cycles | 1 | 1 | 0 |

An extra test cycle need only be carried out if the total delamination percentage according to 6.5.2 is larger than the prescribed maximum value.

### 6.4.2 Measurement and evaluation of delamination

**6.4.2.1** The delamination measurement and the evaluation of the test pieces shall take place not later than 1 hour after the final drying treatment. The total glue line delamination on both end-grain surfaces of the test pieces shall be measured in millimetres.

NOTE 1 The use of a magnifying glass with a magnification of ca. 10 X and strong lighting are recommended to determine whether the opening in the glue line is a valid delamination or not.

NOTE 2 A feeler gauge of 0,08 mm - 0,10 mm thick is convenient for probing into the joint to determine if separation in the glue line actually exists.

**6.4.2.2** Consider the following glue line openings as being valid delaminations:

a) a cohesive crack within the adhesive layer.

b) a failure of the glue line precisely between the adhesive layer and the wood substrate. No wood fibres are left attached to the adhesive layer.

c) a wood failure which is invariably within the first one or two layers of cells beyond the adhesive layer, in which the fracture path is not influenced by the grain angle and the growth-ring structure. It is characterized by a fine, woolly appearance of the wood fibres, which border the interface between the wood surface and the adhesive layer.

**6.4.2.3** Do not regard the following glue line opening as delaminations:

a) a solid wood failure which is invariably more than two cell layers away from the adhesive layer, in which the fracture path is strongly influenced by the grain angle and the growth-ring structure.

b) isolated openings in the glue line which are less than 2,5 mm long and more than 5 mm away from the nearest delamination

c) openings in the glue line which are found along knots or resin pockets which border the glue line, or openings in the glue line which are caused by hidden knots in the glue line. When the cause of an opening in the glue line due to the presence of a knot is suspected, the glue line shall be opened with a wedge and hammer and be inspected for the presence of a concealed knot. Should the cause of the glue line opening be due to a concealed knot, the opening shall not be considered a delamination.

### 6.4.3 Test cycle for method A

**6.4.3.1** Place the test pieces in the pressure vessel and weigh them down. Admit water at a temperature of 10 °C to 20 °C in sufficient quantity so that the pieces are completely submerged. Separate the test pieces by stickers, wire screens, or other means in such a manner that all end-grain surfaces are freely exposed to the water. Draw a vacuum of 70 kPa to 85 kPa (i.e. an absolute pressure of 15 kPa to 30 kPa at sea level) and hold it for 5 min. Then release the vacuum and apply a pressure of 500 kPa to 600 kPa (600 kPa to 700 kPa absolute pressure) for 1 h. Whilst the test pieces are still completely immersed, repeat this vacuum pressure cycle making a two-cycle impregnating period requiring a total of 130 min.

**6.4.3.2** Dry the test pieces for a period of between 21 h and 22 h in air at 60 °C to 70 °C and a relative humidity not greater than 15 %, and circulating at a velocity of 2 m/s to 3 m/s. During drying, the test pieces shall be placed at least 50 mm apart with the end-grain surfaces parallel to the stream of air.

### 6.4.4 Test cycle for method B

**6.4.4.1** Weigh and record to the nearest 5 g the mass of each test piece. Place the test pieces in the pressure vessel and weigh them down. Admit water, at a temperature of 10 °C to 20 °C in sufficient quantity so that the pieces are completely submerged. Separate the test pieces by stickers, wire screens, or other means in such a manner that all end-grain surfaces are freely exposed to the water.

Draw a vacuum of 70 kPa to 85 kPa (i.e. an absolute pressure of 15 kPa to 30 kPa at sea level) and hold it for 30 min. Release the vacuum and apply a pressure of 500 kPa to 600 kPa (600 kPa to 700 kPa absolute pressure) for 2 h.

**6.4.4.2** Dry the test pieces for a period of approximately 10 h to 15 h in air at 65 °C to 75 °C and a relative humidity of 8 % to 10 % and circulating at a velocity of 2 m/s to 3 m/s. During drying the test pieces shall be placed at least 50 mm apart with the end-grain surfaces parallel to the stream of air.

**6.4.4.3** The actual time in the drying duct shall be controlled by the mass of the test pieces. Delamination shall be observed and recorded when the mass of the test pieces has returned to within 100 %-110 % of the original mass. Record the total drying time.

### 6.4.5 Test cycle for method C

**6.4.5.1** Place the test pieces in the pressure vessel and weigh them down. Admit water at a temperature of 10 °C to 20 °C in sufficient quantity so that the pieces are completely submerged. Separate the test pieces by stickers, wire screens, or other means in such a manner that all end-grain surfaces are freely exposed to the water. Draw a vacuum of 70 kPa to 85 kPa (i.e. an absolute pressure of 15 kPa to 30 kPa at sea level) and hold it for 30 min. Then release the vacuum and apply a pressure of 500 kPa to 600 kPa (600 kPa to 700 kPa absolute pressure) for 2 h. Whilst the test pieces are still completely immersed, repeat this vacuum pressure cycle giving a two-cycle impregnating period requiring a total of 5 h.

**6.4.5.2** Dry the test pieces for a period of 90 h in air at 25 °C to 30 °C and a relative humidity in the range of 25 % to 35 %, and circulating at a velocity of 2 m/s to 3 m/s. During drying, the test pieces shall be placed at least 50 mm apart with the end-grain surfaces parallel to the stream of air.

## 6.5 Results

### 6.5.1 General

For each test piece the delamination percentages shall be calculated. If an extra cycle is performed calculate the results before and after the extra cycle.

### 6.5.2 Total delamination

The total delamination percentage of a test piece shall be calculated from the following formula:

$$100 \, \frac{l_{\mathrm{tot,delam}}}{l_{\mathrm{tot,glueline}}}$$

### 6.5.3 Maximum delamination

The maximum delamination percentage for a single glue line in a test piece shall be calculated from the following formula:

$$100 \frac{l_{\text{max,delam}}}{2 \; l_{\text{glueline}}}$$

## 6.6 Test report

The test report shall include the following items:

a) date of the test;

b) identification of test pieces and members from which they have been cut. Any other relevant information, e.g. about preconditioning;

c) species of timber;

d) type of adhesive;

e) test method; (A, B or C)

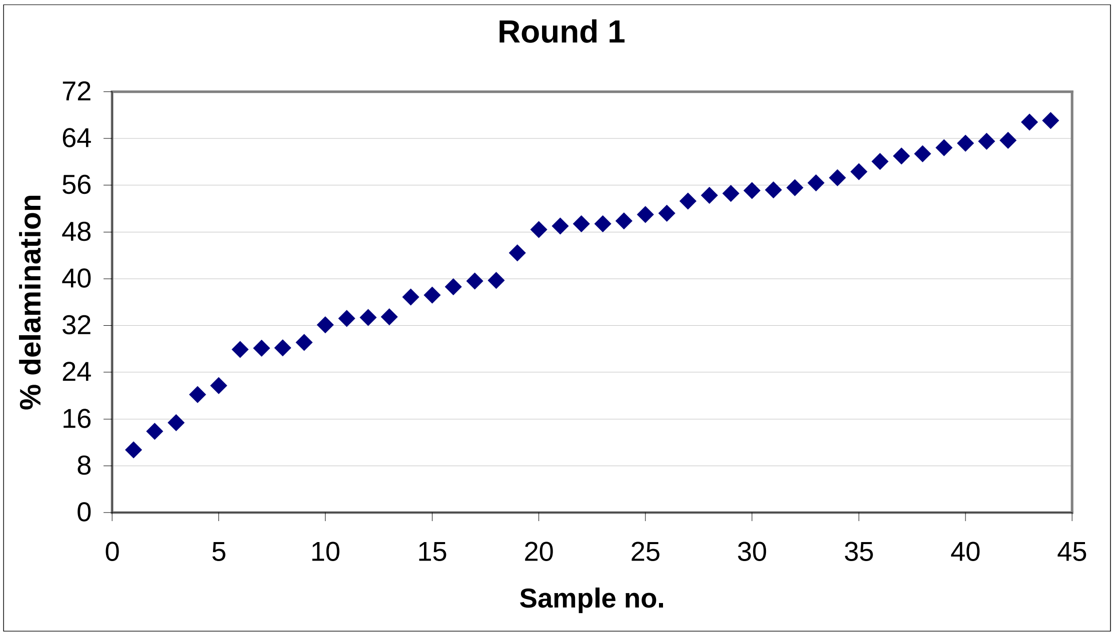
f) the total delamination percentage and the maximum delamination percentage after the prescribed number of cycles and any additional cycle that may be necessary;

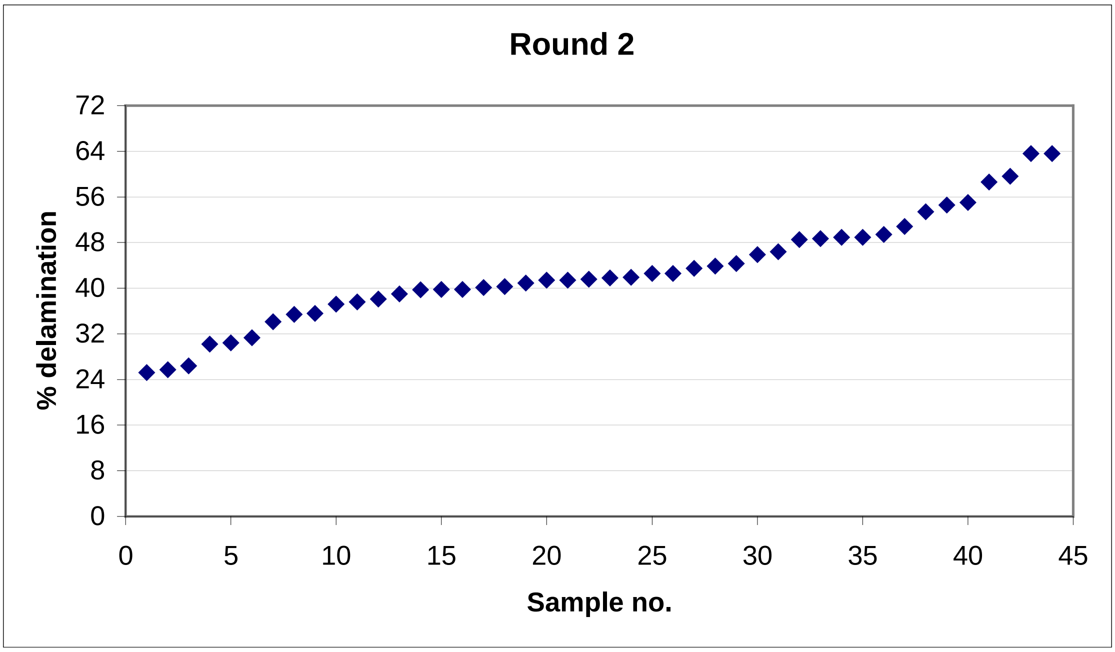
g) any relevant observation made during or after testing;

h) signature of the person responsible for the testing.

## 10.3 Appendix 3 - additional statistics

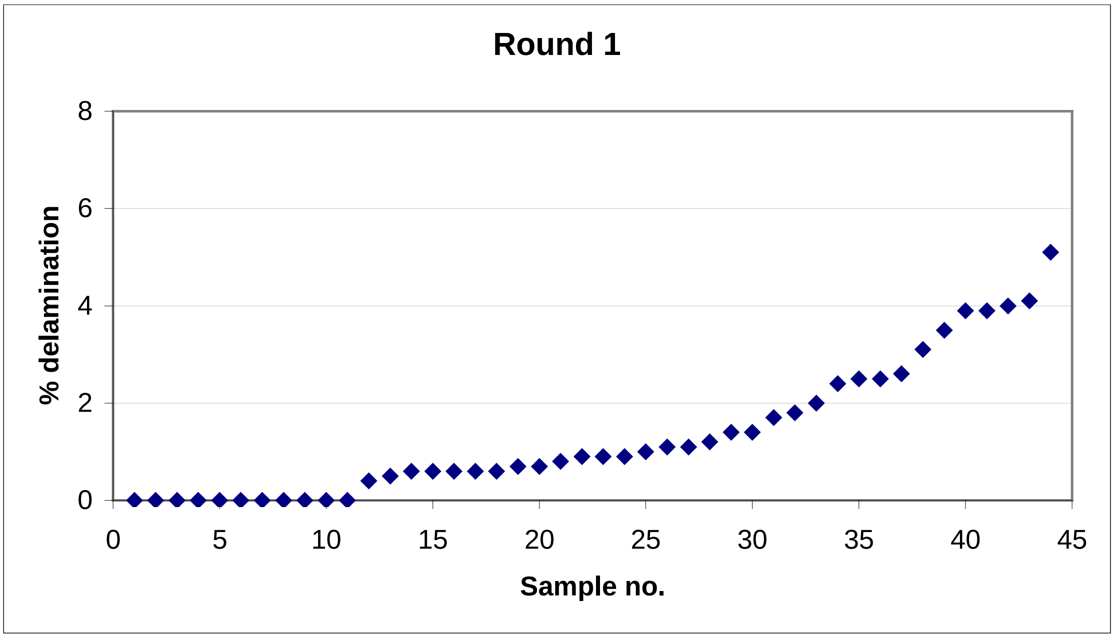
Beam 1 - 80 min. closed assembly time
All obtained values are ranked from the lowest to the highest

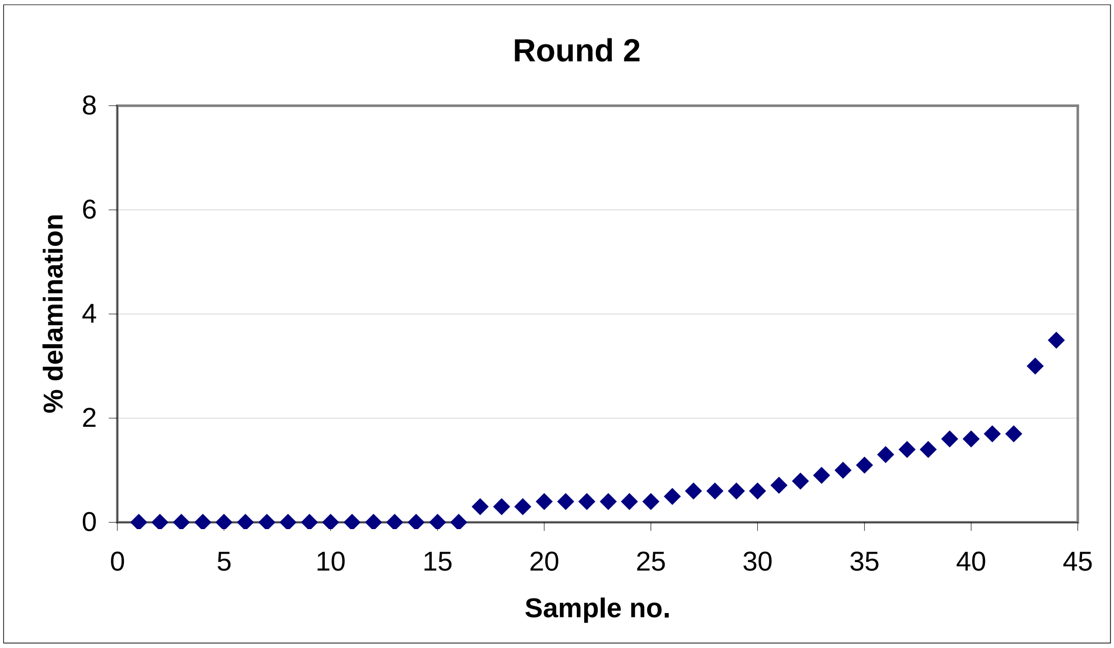


## Beam 2 – normal conditions

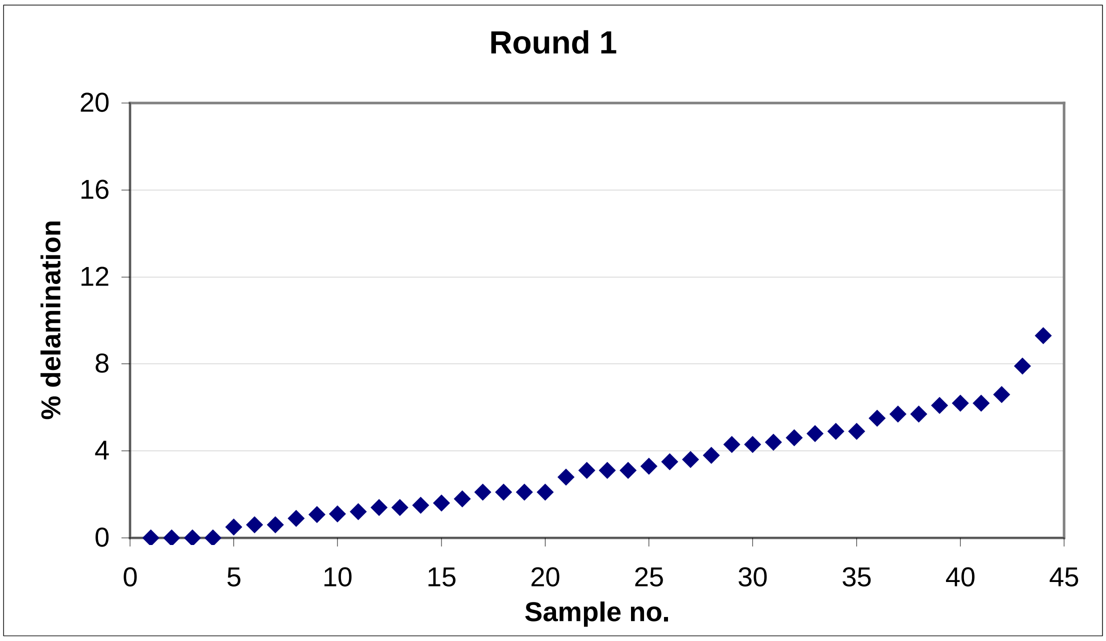
All obtained values are ranked from the lowest to the highest

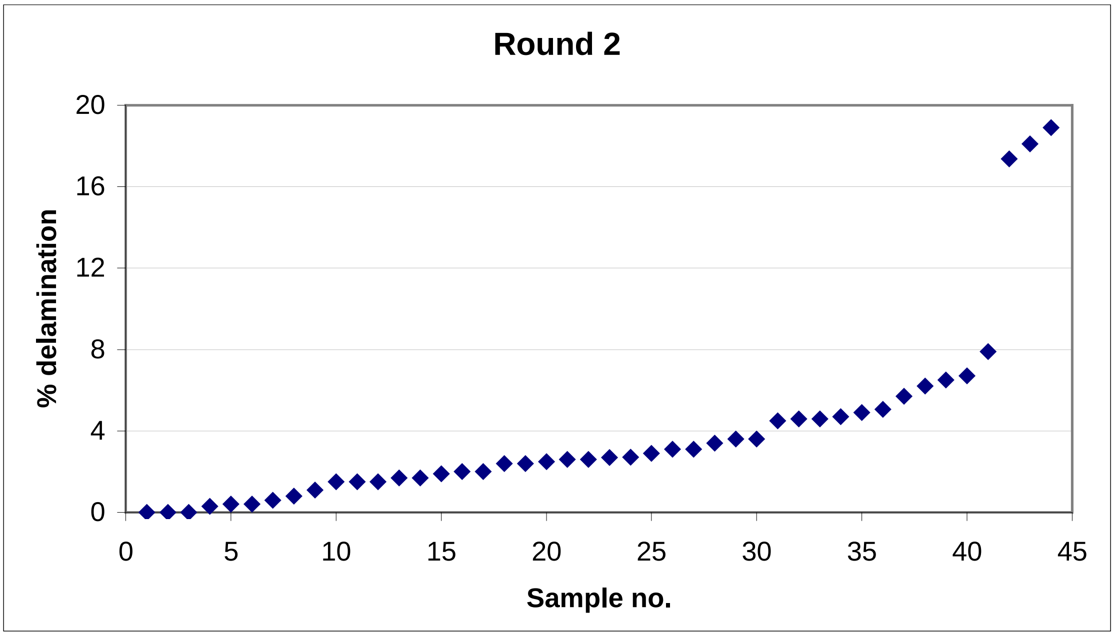


## Beam 3 – low glue spread (150 g/m²)

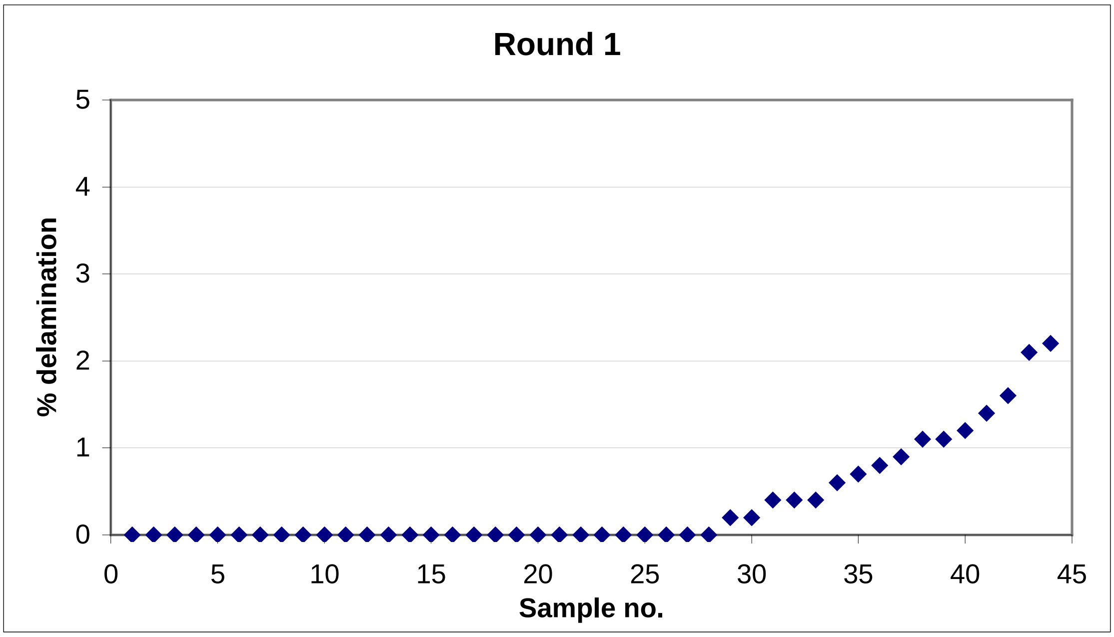
All obtained values are ranked from the lowest to the highest

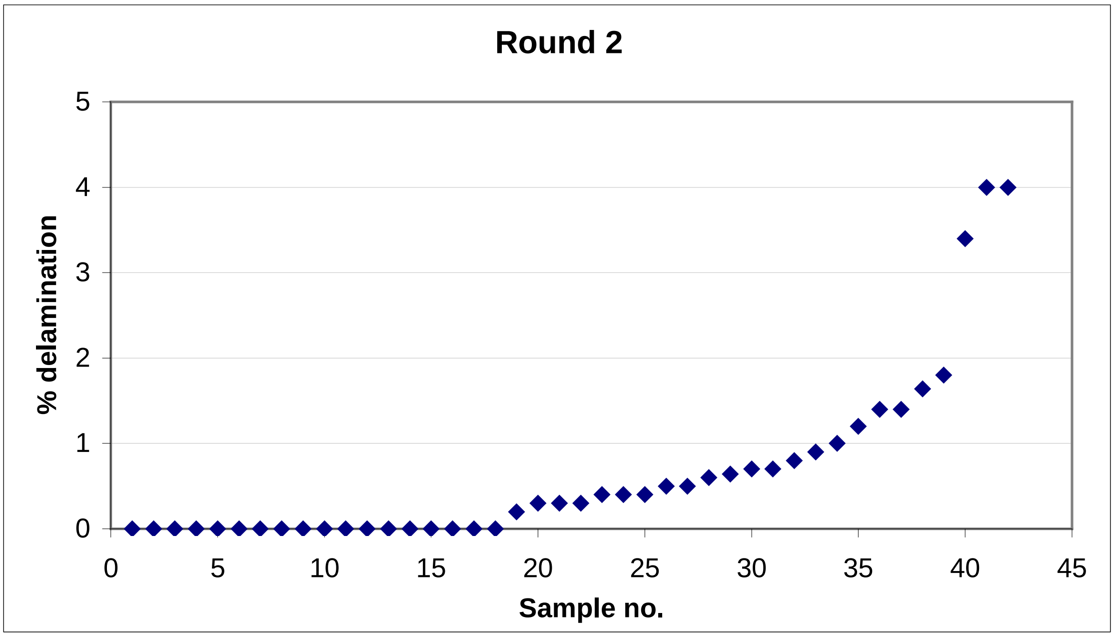


## Beam 4 – low pressure (3,0 N/mm²)

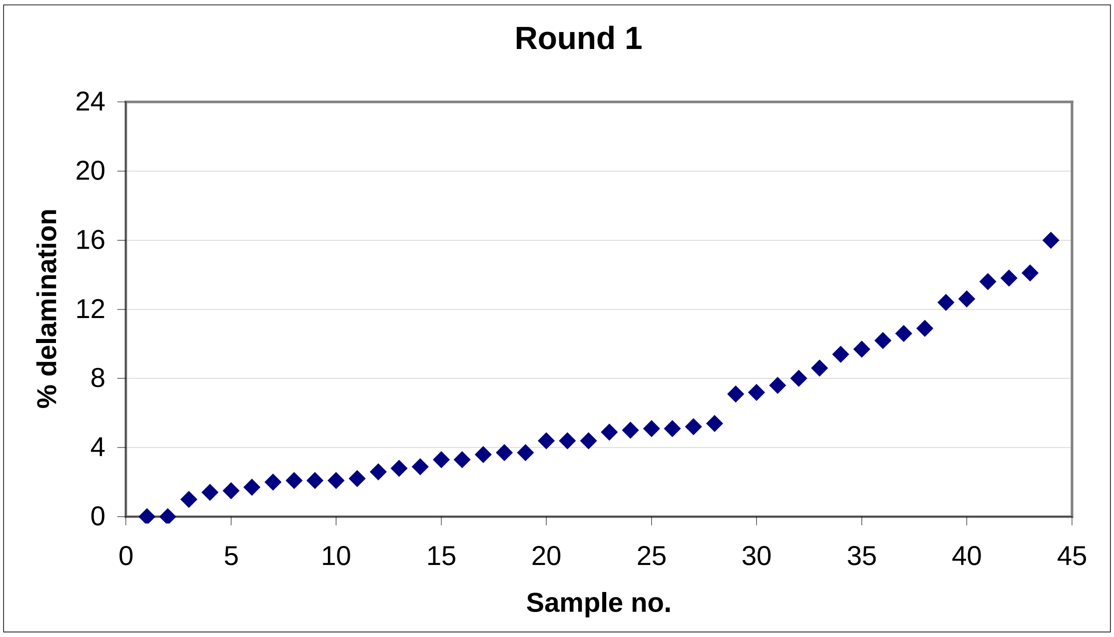
All obtained values are ranked from the lowest to the highest

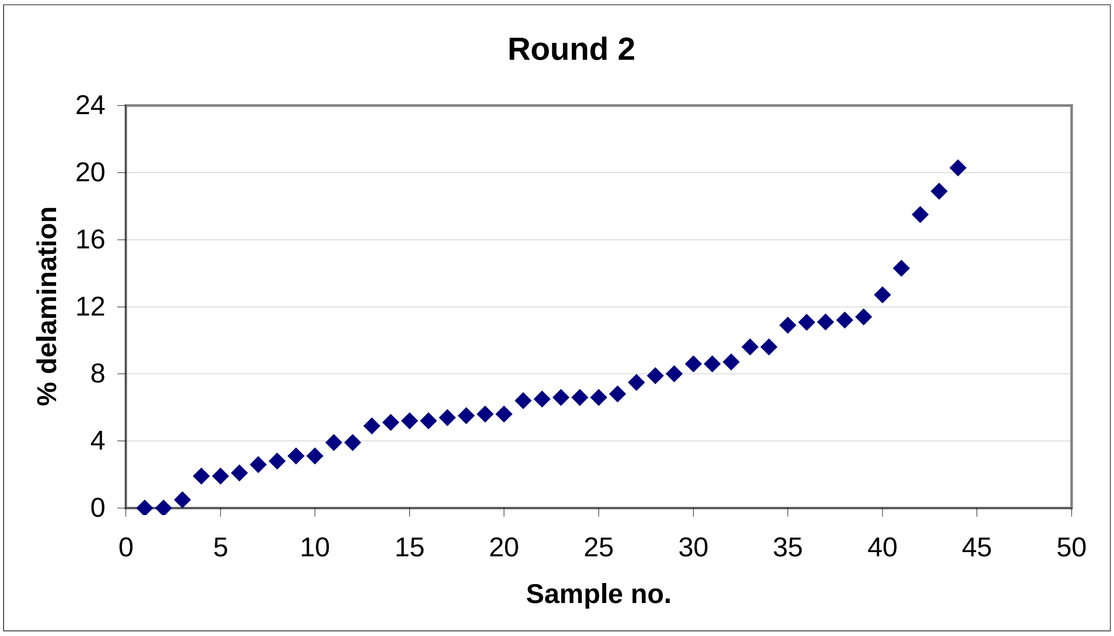


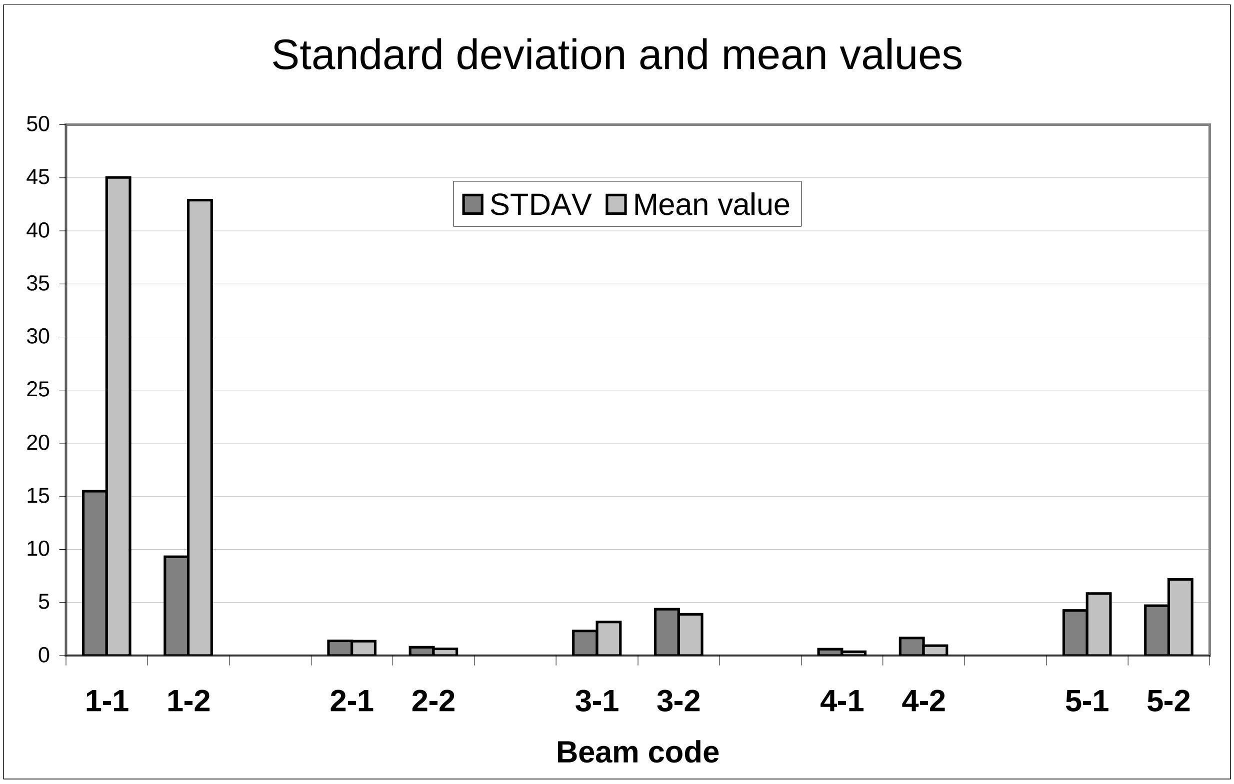



## Beam 5 – 55 min. closed assembly time

All obtained values are ranked from the lowest to the highest






Beam codes
1-1: beam 1 in round 1
1-2: beam 1 in round 2

## 10.4 Appendix 4 – important observations

The 3 partners with lowest overall mean value from round 1
SFS have used the testing equipment at Late.

| Partner | % delam (overall mean) | Level of drying | Comments |
|---|---|---|---|
| Limtre Danmark (K) | 6,3 | 18,2 | High water absorption<br>15 h drying time |
| Late (M) | 6,4 | - 2,9 | Over dried<br>Unknown drying time |
| SFS (I) | 8,7 | 0,5 | Low drying level |

The 3 partners with lowest overall mean value from round 2

| Partner | % delam (overall mean) | Level of drying | Comments |
|---|---|---|---|
| DTI (B) | 8,4 | 7,5 | Very high water absorption<br>24 h drying time |
| Moelven (F) | 8,5 | 0,9 | Low water absorption<br>10 h drying time |
| Casco (L) | 9,0 | 6,1 | Low air speed<br>30 h drying time |

The 3 lowest from round 1 are the 3 highest in round 2
SFS have used the testing equipment at Late.

| Partner | % delam (overall mean) | Level of drying | Comments |
|---|---|---|---|
| SFS (I) | 15,4 | 5,9 | 13 h drying time |
| Late (M) | 14,4 | 5,3 | 13 h drying time |
| Limtre Danmark (K) | 12,5 | 6,2 | High water absorption<br>20 h drying time |