Gluing of Norway spruce and Scots pine with an EPI-adhesive (emulsion polymer isocyanate)
- An activity in the SSFF-project

Laminering av gran og furu med lim av type EPI (emulsjonspolymerisert isocyanat)
- En aktivitet i SSFF-prosjektet

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Summary

Part 1: In part 1, the influence of the length of the closed assembly time, as well as the surface condition regarding a sawn or planed surface of the lamellae before gluing, was investigated.

Norway spruce lamellae were glued with an EPI-adhesive system from Dynea ASA, Lillestrøm, Norway. Delamination and shear tests were carried out.

The results of part 1 lead to the implication that the used EPI-glue system is very sensitive to the accurate observance of the time limit for the length of the closed assembly time and the amount of glue given by the producer.
The outcome of gluing of just sawn and unplaned lamellae is not satisfactory.
All test results from the planed lamellae pieces with the short closed assembly time passed the tests and fulfilled all requirements given in EN 386 "Glued laminated timber – Performance requirements and minimum production requirements" of the delamination test (EN 391-C) and shear test (EN 392).

An additional delamination test with the longer closed assembly time was carried out on request by Dynea ASA, because the test results from the first delamination test with the longer closed assembly time were not satisfactory. A new batch of the adhesive system was used to glue planed lamellae and produce test pieces similar to the previously glued test pieces. The annual ring orientation and the dimensions were different to those in the first test series. Afterwards, the same test method (EN 391-C) was applied. The new results passed the requirements, contrary to the first results.

Stikkord: Limtre, temperatur, fuktighet, EPI, lim
Keywords*:* Glulam, temperature, moisture content, EPI, adhesive

Part 2: In part 2, the influence of the parameters' temperature and moisture content of the wood on the gluing results were closely investigated.

Norway spruce and Scots pine lamellae were glued into beams with the same glue system from Dynea ASA. Delamination and shear tests were carried out.

All test pieces of Norway spruce and Scots pine tested in part 2 fulfil the requirements given in EN 386 "Glued laminated timber – Performance requirements and minimum production requirements" of the delamination test (EN 391-B) and shear test (EN 392) for all combinations of moisture content and temperature.

Sammendrag

Del 1: I del 1 ble innflytelsen av lengden på lukket limingstid samt overflateforhold i form av saget og høvlet lamellflate undersøkt.

Granlameller (Norway spruce) ble limt med et godkjent EPI-system fra Dynea ASA, Lillestrøm, Norge. Tester ble utført med hensyn på motstand mot delaminering og bestemmelse av skjærfasthet.

Resultatene fra del 1 konkluderer med at det benyttede limsystemet er sensitivt med hensyn til overholdelse av limprodusentens oppgitte lukkede limingstid. Det samme gjelder for påført limmengde.

Testresultatene vedrørende liming av sagede lamelloverflater er ikke tilfredsstillende.

Samtlige testresultater vedrørende liming av høvlede lamelloverflater der kort lukket limingstid er benyttet, tilfredsstiller alle kravene i EN 386 "Limtre – Ytelseskrav og minstekrav til produksjon". Prøvene er testet i henhold til EN 391-Metode C (motstand mot delaminering) og EN 392 (bestemmelse av skjærfasthet).

På forespørsel fra Dynea ASA ble det utført en tilleggstest på delaminasjon med den lengste lukketiden, fordi testresultatene fra den første delamineringstesten ikke var tilfredsstillende. En ny batch av limsystemet ble brukt til å lime høvlede lameller og produsere teststykker lignende de tidligere limte teststykkene. Orienteringen på årringene og dimensjonene var forskjellig fra den første testserien, men den samme testmetoden (EN 391-C) ble benyttet. De nye resultatene oppfylte kravene, i motsetning til de første resultatene.

Del 2: Her ble parametrene lamelltemperatur og trefuktighet og deres innvirkning på limeresultatet studert nøye.

Gran (Norway spruce) og furulameller (Scots pine) ble limt til prøvebjelker ved hjelp av det samme limsystemet som angitt i rapportens del 1. Også her ble prøving utført i henhold til EN 391 (metode B) og EN 392.

Alle prøvestykkene av gran og furu testet i del 2 oppfyller kravene gitt i EN 386 med hensyn til EN 391, metode B og EN 392 for alle kombinasjoner av trefuktighet og temperatur.

Preface

The SSFF-project ″Norwegian timber as raw material – added value and industrial possibilities” is initiated by SSFF (Research Association for Forestry and Forest Industry). This is a competence project with user involvement.

The SSFF-project includes an activity regarding lamination as well. The main objective has been to examine critical conditions surrounding lamination with EPI-glue.

The SSFF-project is financed by *Norges forskningsråd* (Research Council of Norway), *Skogtiltaksfondet*, the *Norwegian wood working industry* and *Fondet for treteknisk forskning* at NTI. Additionally, several persons from the forestry and forestry based industry have contributed with considerable work effort.

We would like to extend our thanks to H-Profil AS for their contribution in Part 1 and Dynea ASA for their contribution in Part 2. Additionally, Dynea ASA provided the EPI-glue system Prefere 6151/6651 for both parts of the project.

Contents

1. Introduction

”Section Wood” in the SSFF-project consists of several activities, where lamination is one. This section has a bipartite aim.

First of all, the aim is to achieve methods for upgrading timber unsuited for production of solid wood products. Through splitting/sorting and subsequent gluing, one will be able to achieve high value materials for use for several purposes. Secondly, one wishes to achieve production techniques that both technically and financially can simplify the gluing process itself.

The project group has chosen to use an EPI-glue from Dynea ASA (emulsion polymer isocyanate), a type of glue that is relatively unknown in the Nordic countries, as well as in the rest of Europe. The system has for a while been used in gluing of non-bearing products, and has recently been approved by the Nordic Glulam Committee (NLN) for use in load bearing glulam constructions in service class 1 and 2 (indoors and outdoors under roof).

The advantage of the EPI-glues is that they have a short pressing time of ca. 30 minutes at 20 °C. This means that the pressing equipment itself can be simplified, depending on the desired production volume. The glue system is a two-component system, where the glue base is emulsified in water and the hardener is an isocyanate.

The focus of the project was on the properties of the EPI-glue concerning material temperature, different moisture levels and gluing for planed and sawn surfaces. For now, the focus will be on gluing of Norway spruce *(Picea abies)* and Scots pine *(Pinus sylvestris)*.

The hope is that the results will lead to an increased interest in using gluing techniques as a tool for upgrading ”inferior” timber, as well as focus on the good and versatile properties of the EPI-glue concerning gluing of wood.

2. Test methods

In parts 1 and 2, two delamination methods (part 1: EN 391-Method C, part 2: EN 391-Method B) and one shear test method (EN 392) were used.

Detailed information about the test methods can be found in the Annex.

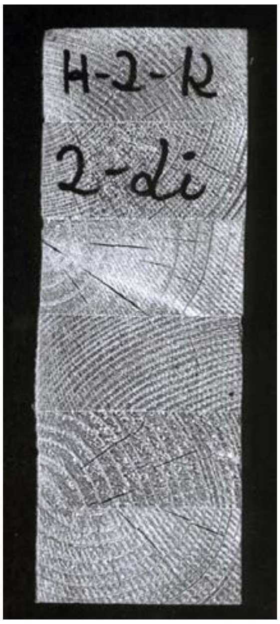


Figure 2.1. Part 1: Test piece EN 391-C.

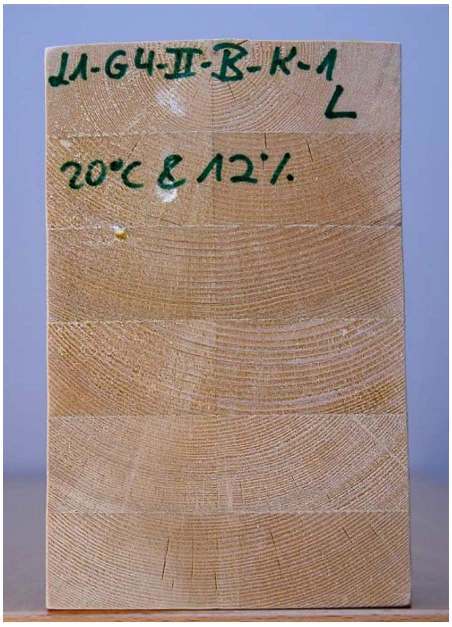


Figure 2.2. Part 2: Test piece EN 391-B.

3. Gluing of sawn and planed Norway spruce lamellae with an EPI-adhesive - Part 1

3.1. Material and methods

In part 1, the main focus is on the surface quality, sawn or planed surface, and the closed assembly time with a short (5 min) and a longer (15 min) time span. All lamellae had the same moisture content, density range and wood temperature (see Table 3.1). All test pieces were glued with the system "Prefere 6151/6651", a two-component emulsion polymer isocyanate (EPI) from Dynea ASA.

Table 3.1. Test overview - Part 1.

	Surface quality	**Closed assembly time** [min]	**Moisture content** [%]	**Wood temperature** [°C]	**Density** [g/cm^3]	**Annual ring orientation**	**Heartwood/ sapwood distribution**	**No. of repetitions**
Spruce	Sawn	Short **(5 min)**	12	20	400 - 500	defined	at random	**5**
		Long **(15 min)**						**5**
	Planed	Short **(5 min)**	12	20	400 - 500	defined	at random	**5**
		Long **(15 min)**						**5**

The lamellae for the beams with the short and long assembly time, as well as with the sawn and planed surfaces, were cut from the same boards to obtain lamellae with similar wood properties. Each of the six lamellae in each beam originates from a different plank.
The distribution of heart- and sapwood was random. The annual ring orientation on the other hand, was defined as shown in Figure 3.1.

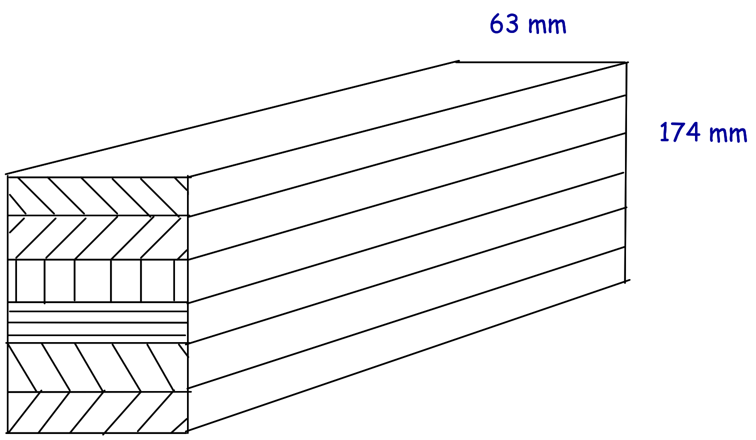


Figure 3.1. Annual ring orientation.

This defined composition was chosen to examine the influences of the different wood properties on the use of EPI-adhesive.

The dimensions of the lamellae were: 500 mm x 63 mm x 29 mm.

The glue system was mixed for each beam separately, with a mixing ratio of 100 parts glue and 15 parts hardener. The glue was applied two-sided with a spatula. In each gluing, one beam with a long closed assembly time and one beam with a short closed assembly time were pressed at the same time. The open assembly time was always short (< one minute).

The applying of glue and assembling the beam took 2 to max. 3 minutes. The beams composed of sawn lamellae were pressed with a higher pressure of 0,85 N/mm² and a higher glue amount of 280 g/m². The planed lamellae were pressed with the usual pressure of 0,6 N/mm² and the lower glue amount of 260 g/m². The pressing time was 2 hours. The post curing time was 14 days for all beams.

Two pieces (D-I, D-II) for the delamination test, EN 391-Method C, and two pieces (S-I, S-II) for the shear test, EN 392, were cut from each beam. The sampling was carried out after the set-up shown in Figure 3.2.

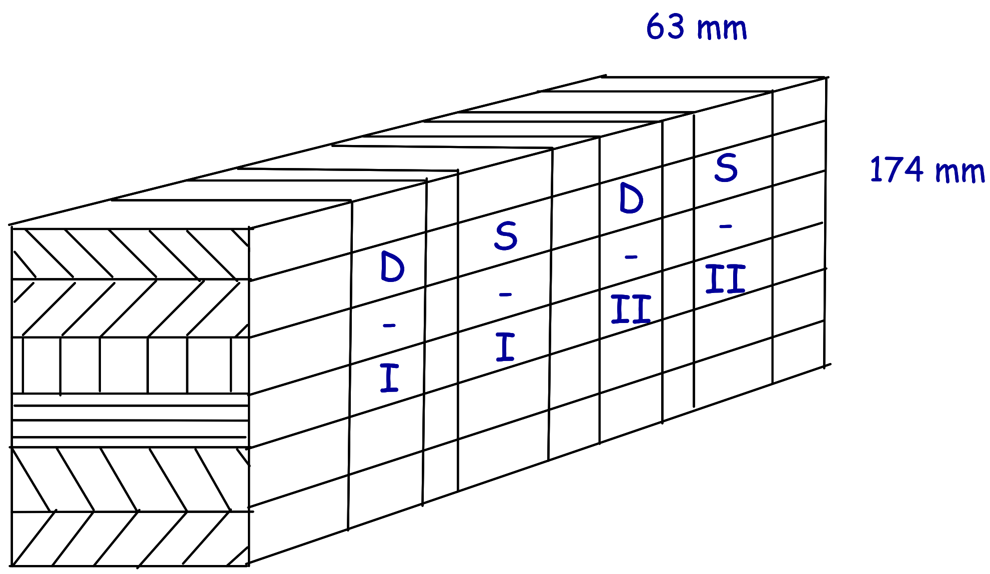


Figure 3.2. Sampling set-up.

The tests were carried out, and the results were recorded and evaluated.

3.2. Results – Part 1

The marking of the test pieces gives information about the surface of the wood before gluing and the length of the closed assembly time:

- S ⇨ Sawn surface
- P ⇨ Planed surface
- K ⇨ Short closed assembly time (5 min)
- L ⇨ Long closed assembly time (15 min)

This code is also used in all diagrams which describe the results in this chapter.

3.2.1. Delamination test EN 391-Method C

Figures 3.3 and 3.4 show the results of the delamination test according to EN 391-C.

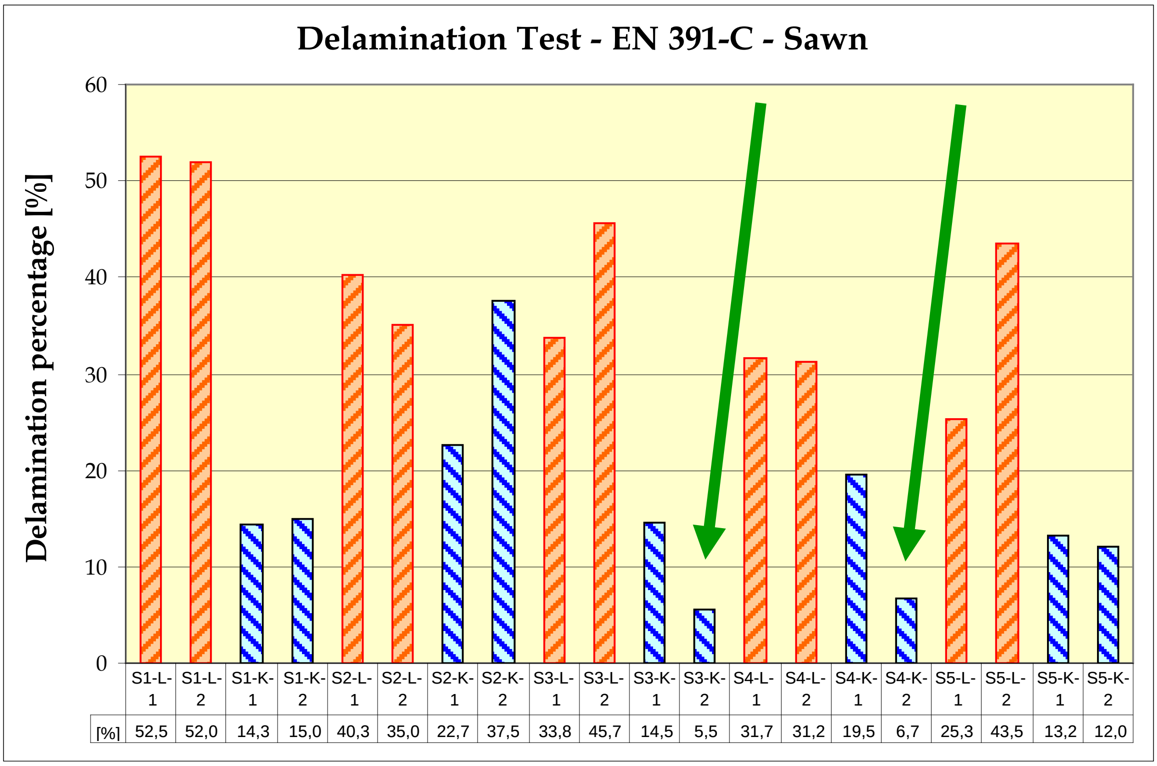


Figure 3.3. Delamination test – Sawn surface.

Figure 3.3 illustrates the results of the test pieces that were taken out of beams made with sawn lamellae. The test pieces with the shorter closed assembly time (blue columns) reached better results than those with the longer assembly time.

Still, only two test pieces (green arrows) fulfilled the requirements of EN 386 with the maximum value of 10 % delamination.

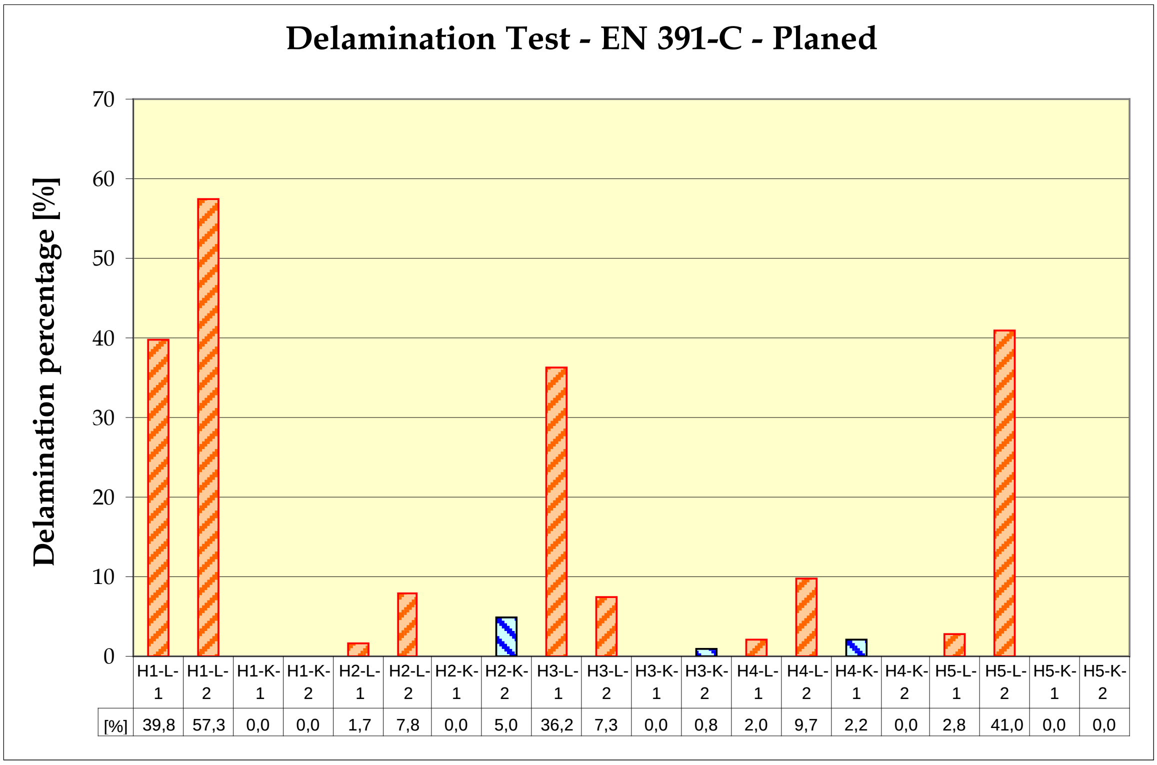
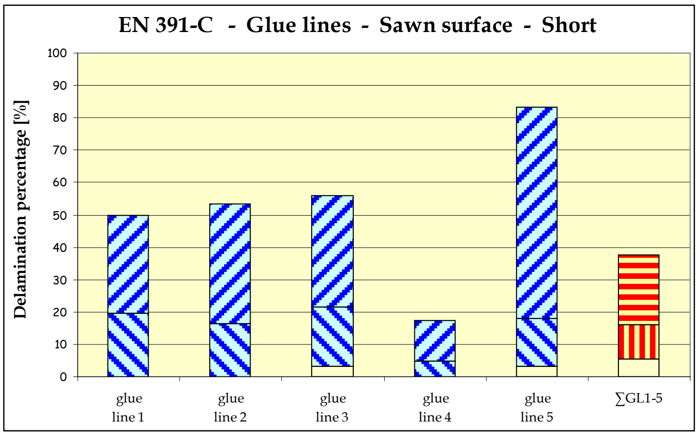


Figure 3.4. Delamination test – Planed surface.

Figure 3.4 illustrates the results of the test pieces that were taken from beams of planed lamellae. The delamination percentages of the test pieces with the shorter assembly time (blue columns) are lower than of those with the longer assembly time (orange-red columns). All test pieces with the short assembly time fulfil the requirements of the standard EN 386 with the maximum value of 10 % delamination. Six test pieces of the ten test pieces with the long assembly time pass the test.

3.2.2. Influence of the annual ring orientation

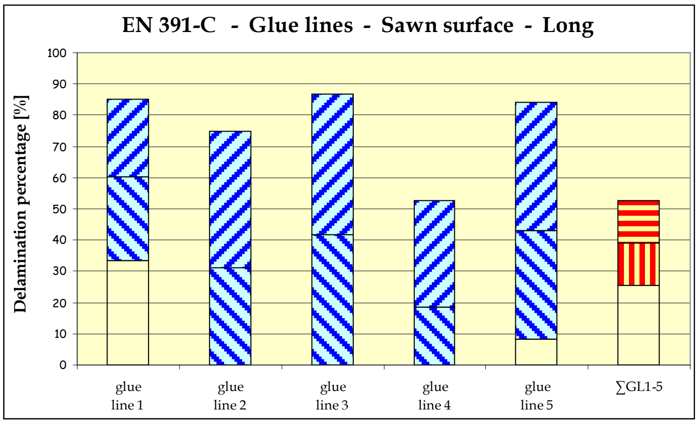


	glue line 1	glue line 2	glue line 3	glue line 4	glue line 5	∑GL1-5
Delam.-Min.	0,0	0,0	3,3	0,0	3,3	**5,5**
Delam.-Max.	50,0	53,3	55,8	17,5	83,3	**37,5**
Delam.-Mean value ⌀	19,8	16,4	21,4	4,8	18,1	**16,1**

Figure 3.5. Influence of the annual ring orientation. Sawn surface - short assembly time.

Figures 3.5 and 3.6 show the influence of the annual ring orientation on the results of the delamination test EN 391-C on test pieces with a sawn surface. The configuration of the annual ring orientation is described in Figure 3.1.

Figure 3.5 illustrates the influence on the pieces glued with the short assembly time, whereas the test pieces in Figure 3.6 were glued with the long assembly time.

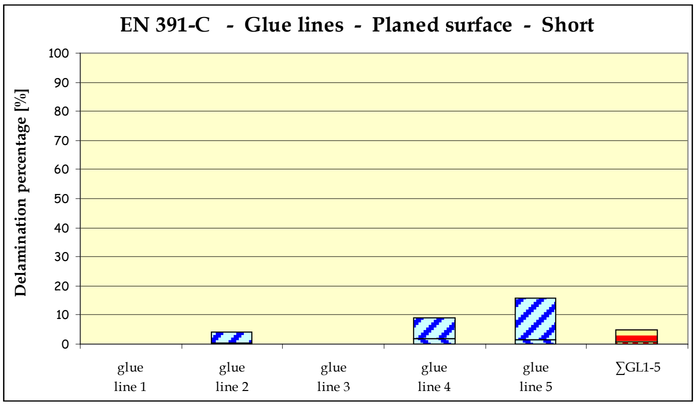


	glue line 1	glue line 2	glue line 3	glue line 4	glue line 5	∑GL1-5
Delam.-Min.	33,3	0,0	0,0	0,0	8,3	**25,3**
Delam.-Max.	85,0	75,0	86,7	52,5	84,2	**52,5**
Delam.-Mean value ⌀	60,2	31,3	41,7	18,5	43,0	**38,9**

Figure 3.6. Influence of the annual ring orientation. Sawn surface - long assembly time.

Generally, it can be said that the delamination percentage is lower with the shorter assembly time. In both test series, glue line 4 reached the best results.

Unfortunately, since the amount of test pieces was limited, no precise conclusions could be reached.

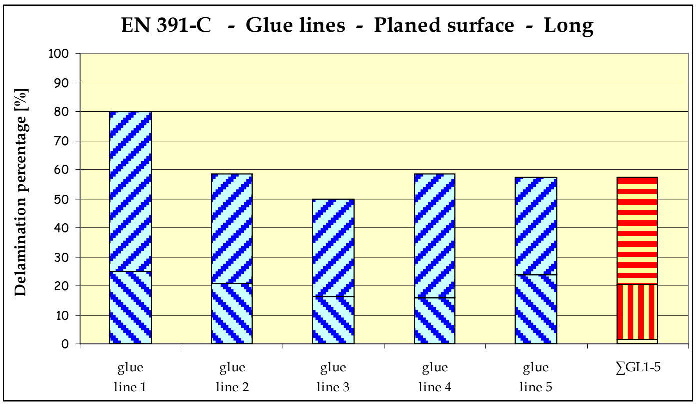


	glue line 1	glue line 2	glue line 3	glue line 4	glue line 5	∑GL1-5
Delam.-Min.	0,0	0,0	0,0	0,0	0,0	**0,0**
Delam.-Max.	0,0	4,2	0,0	9,2	15,8	**5,0**
Delam.-Mean value ⌀	0,0	0,4	0,0	2,0	1,6	**0,8**

Figure 3.7. Influence of the annual ring orientation. Planed surface - short assembly time.

Figures 3.7 and 3.8 show the influence of the annual ring orientation on the results of the delamination test EN 391-C on test pieces with a planed surface. The configuration of the annual ring orientation is described in Figure 3.1.

Figure 3.7 illustrates the influence on the pieces glued with the short assembly time, whereas the test pieces in Figure 3.8 were glued with the long assembly time.



	glue line 1	glue line 2	glue line 3	glue line 4	glue line 5	$\sum_{GL1-5}$
Delam.-Min.	0,0	0,0	0,0	0,0	0,0	**1,7**
Delam.-Max.	80,0	58,3	50,0	58,3	57,5	**57,3**
Delam.-Mean value ⌀	25,0	20,7	16,3	15,8	23,7	**20,3**

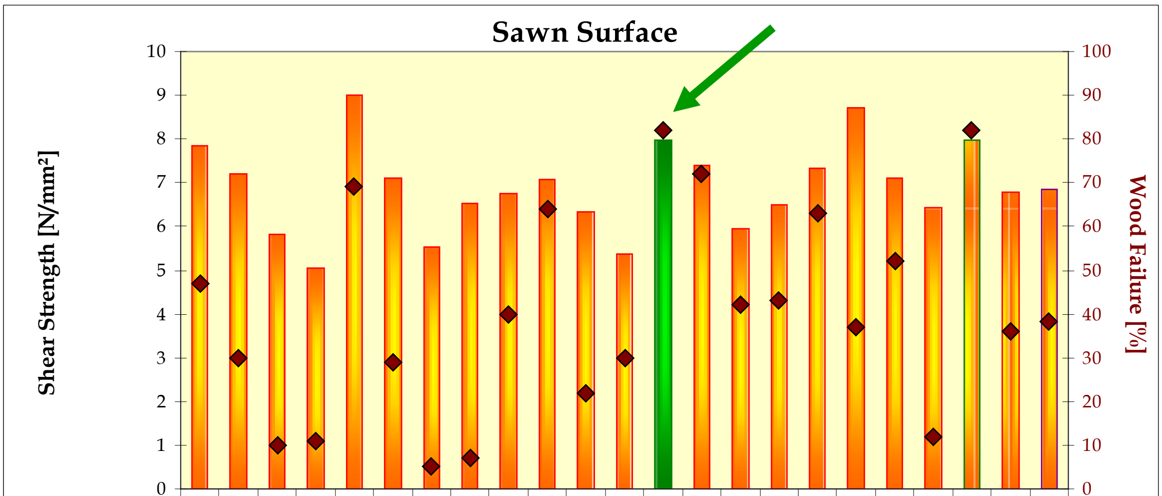
Figure 3.8. Influence of the annual ring orientation. Planed surface - short assembly time.

Generally, it can be said that the delamination percentage is definitely lower with the shorter assembly time.

Unfortunately, since the amount of test pieces was limited, no precise conclusions regarding the annual ring orientation could be reached.

3.2.3. Shear test EN 392

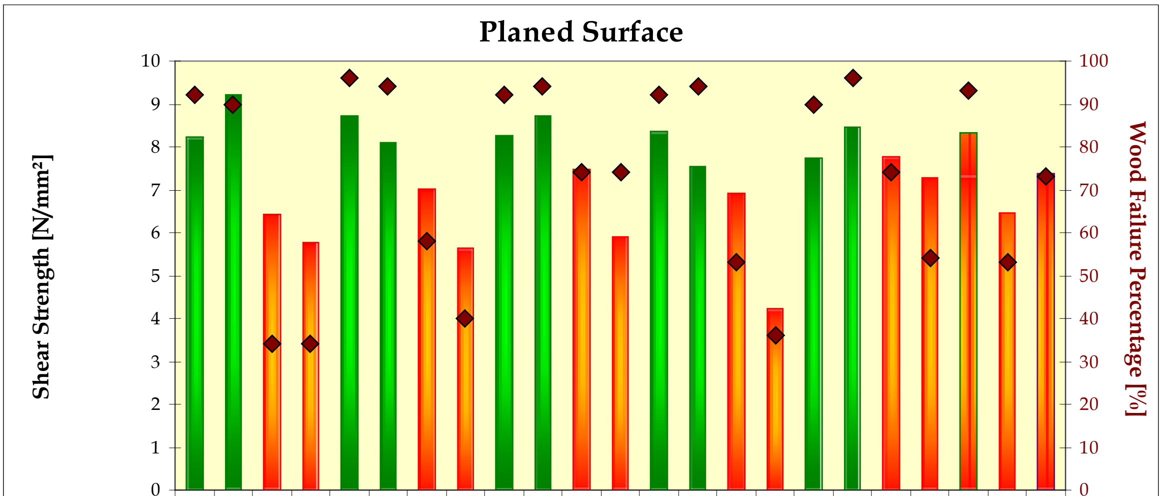
Figures 3.9 and 3.10 show the results of the shear test according to EN 392. The columns illustrate the shear strength. The green columns represent the results of the test pieces which passed the test. The orange-red columns stand for the results of the test pieces which failed the test. The striped columns represent the mean values of the passed (green) and accordingly the failed results (orange-red) of the test pieces. The last column (pink) on the right side of the diagrams shows the mean value of all test pieces. The red-brown squares represent the wood failure percentage. Each value for the shear strength and the wood failure percentage equals the mean value of one test piece with five tested glue lines.



	S1 - K-I	S1 - K-II	S1 - L-I	S1 - L-II	S2 - K-I	S2 - K-II	S2 - L-I	S2 - L-II	S3 - K-I	S3 - K-II	S3 - L-I	S3 - L-II	S4 - K-I	S4 - K-II	S4 - L-I	S4 - L-II	S5 - K-I	S5 - K-II	S5 - L-I	S5 - L-II	G - Ø	IG - Ø	Ø
N/mm²	7,9	7,2	5,8	5,1	9,0	7,1	5,5	6,5	6,8	7,1	6,3	5,4	8,0	7,4	6,0	6,5	7,3	8,7	7,1	6,4	8,0	6,8	6,8
Wood failure [%]	47	30	10	11	69	29	5	7	40	64	22	30	82	72	42	43	63	37	52	12	82,0	36,1	38,4

Figure 3.9. Shear test EN 392 – Sawn surface.

Figure 3.9 shows the results of the shear test of glued sawn lamellae. Only one test piece (S4-K-I, with the green arrow) fulfilled the requirements of the standard. These results point out very clearly that gluing sawn and unplaned lamellae is ineffective. The second conclusion is that the test pieces with the shorter closed assembly time gave better results.



	H1- K-I	H1 - K-II	H1 - L-I	H1 - L-II	H2 - K-I	H2 - K-II	H2 - L-I	H2 - L-II	H3 - K-I	H3 - K-II	H3 - L-I	H3 - L-II	H4 - K-I	H4 - K-II	H4 - L-I	H4 - L-II	H5 - K-I	H5 - K-II	H5 - L-I	H5 - L-II	K - Ø	L - Ø	Ø
N/mm²	8,2	9,2	6,4	5,8	8,7	8,1	7,0	5,6	8,3	8,7	7,5	5,9	8,4	7,5	6,9	4,2	7,7	8,5	7,8	7,3	8,3	6,4	7,4
Wood failure [%]	92	90	34	34	96	94	58	40	92	94	74	74	92	94	53	36	90	96	74	54	93,0	53,1	73,1

Figure 3.10. Shear test EN 392 – Planed surface.

Figure 3.10 illustrates the results of the shear test of glued planed lamellae. All test pieces with the short assembly time (green columns) passed the requirements of EN 386 regarding shear strength and wood failure percentage (EN 392). No test piece taken out of the beams with the longer assembly time passed the shear test. The striped columns describe the mean values of the passed and failed test pieces. The shear strength mean values differ from 6,4 N/mm^2 (failed test pieces) to 8,3 N/mm^2 (passed test pieces). The mean values for the wood failure percentage differ between 53,1 % (failed test pieces) and 93 % (passed test pieces).

3.3. Conclusions - Part 1

Part 1 of this project displays three conclusions very clearly.

Conclusion 1: There are great differences in the test results after gluing sawn and planed surfaces with EPI-glue into beams. This conclusion relates to both test methods, the delamination test EN 391-C and the shear test EN 392. These results point out that gluing sawn and unplaned lamellae is ineffective.

Conclusion 2: The test pieces with the shorter closed assembly time (5 min) reached better results than the test pieces with the longer assembly time (15 min). This conclusion also relates to both test methods, the delamination test EN 391-C and the shear test EN 392.

Conclusion 3: All test results from the planed lamellae pieces with the short closed assembly time passed the tests and fulfilled all requirements given in EN 386.

Generally, it is known that gluing of sawn surfaces tends to result in a reduced glue line strength, irrespective of the tested adhesive type. Difficult wood species or surface qualities have an influence on the required glue amount and pressure.

The results lead to the implication that the used EPI-glue system is sensitive to the accurate observance of time limits (e.g. lengths of open or closed assembly time) and the amount of glue given by the producer.

3.4. Additional delamination test

An additional delamination test with the longer closed assembly time (13-15 min) was carried out on request by Dynea ASA, because the test results from the first delamination test with the longer closed assembly time were not satisfactory. A new batch of the adhesive system Prefere 6151/6651 with the mixing ratio 100:15 was used to glue planed lamellae with an adhesive amount of 260 g/m^2 to produce test pieces similar to the previously glued test pieces. The annual ring orientation and the dimensions were different to those in the first test series. The annual rings were not arranged as in the previous test, since no direct influence could be ascertained. The dimensions were: 410 mm x 121 mm x 30 mm. The mean value of the lamellae density was 0,508 g/m^3. The open assembly time was 1-2 min. Pressure in the press was 0,6 N/mm^2 and was applied for 3 hours.

Afterwards, the same test method (EN 391-C) was applied. The new results passed the requirements, contrary to the first results (see Annex A-3).

4. Gluing of Norway spruce and Scots pine with an EPI-adhesive - Part 2

In part 2 of the gluing section, 20 beams were produced of Norway spruce and 5 beams of Scots pine. As in Part 1, all 25 beams were glued with the EPI-system "Prefere 6151/6651" from Dynea ASA.

4.1. Material and methods

Prior to the climatic treatment and gluing, the lamellae for the beams were taken out of planks after a certain system and assembled to beams with six lamellae each. Each of the six lamellae in each beam originates from a different plank.

Table 4.1. Test overview - Part 1.

Wood species	Spruce	Spruce	Spruce	Spruce	Spruce	Spruce	Pine
Combination no.	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**	**F4**
Climate conditions of the lamellae until gluing	**6 % 4 °C**	**6 % 20 °C**	**12 % 4 °C**	**12 % 20 °C**	**18 % 4 °C**	**18 % 20 °C**	**12 % 20 °C**
Number of beams	**3**	**3**	**3**	**5**	**3**	**3**	**5**

The lamellae of the assembled beams were stored in three different climate chambers (20 °C/65 % RH, 20 °C/85 % RH, 30 °C/30 % RH) until a stable moisture content was reached. The day before gluing, the lamellae, which had to be cooled down to 4 °C, were planed, put in plastic bags and vacuum-packed. It was of interest to investigate the influence of a low wood temperature on the bonding quality. It was decided to use NTI's cooling chamber, which operates with 4 °C. The other lamellae were planed right before the gluing process. Accurate measurements and weight were recorded.

Dimensions of the lamellae: 410 mm x 124 mm x 30 mm.

The glue system was mixed with a mixing ratio of 100 parts glue and 15 parts hardener. The glue was applied two-sided with a spatula. Since always two beams were glued and pressed at the same time, two persons glued synchronically.

The open assembly time was always short (maximum one minute). The closed assembly time varies inside the beam because of the gluing technique (3-5 minutes closed assembly time).

The glue amount was 260 g/mm². The time between applying the glue on both sides of the lamellae and closing of the press did not exceed 6 minutes. The beams were pressed with a pressure of 0,6 N/mm². The press was closed until the next day to ensure that the pressing time did not influence the results.

After at least 14 days post curing time, the test pieces for the shear and delamination tests were prepared. For each test method, two test pieces were taken out of each beam. The outer 100 mm of the beams were not used for testing.

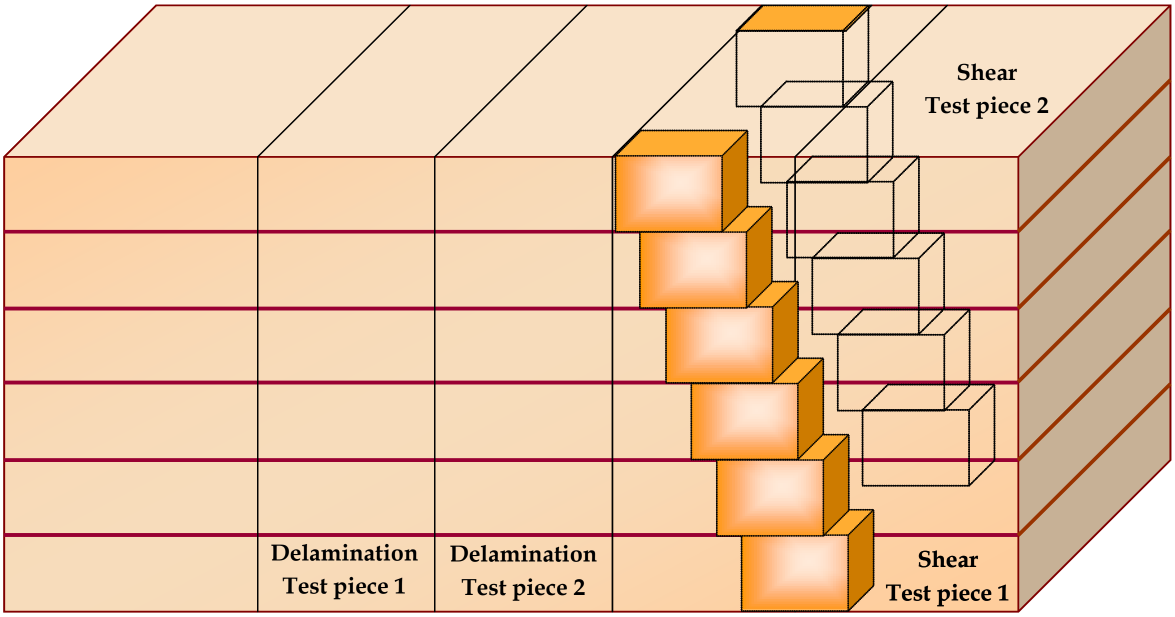


Figure 4.1. Preparing of the test pieces.

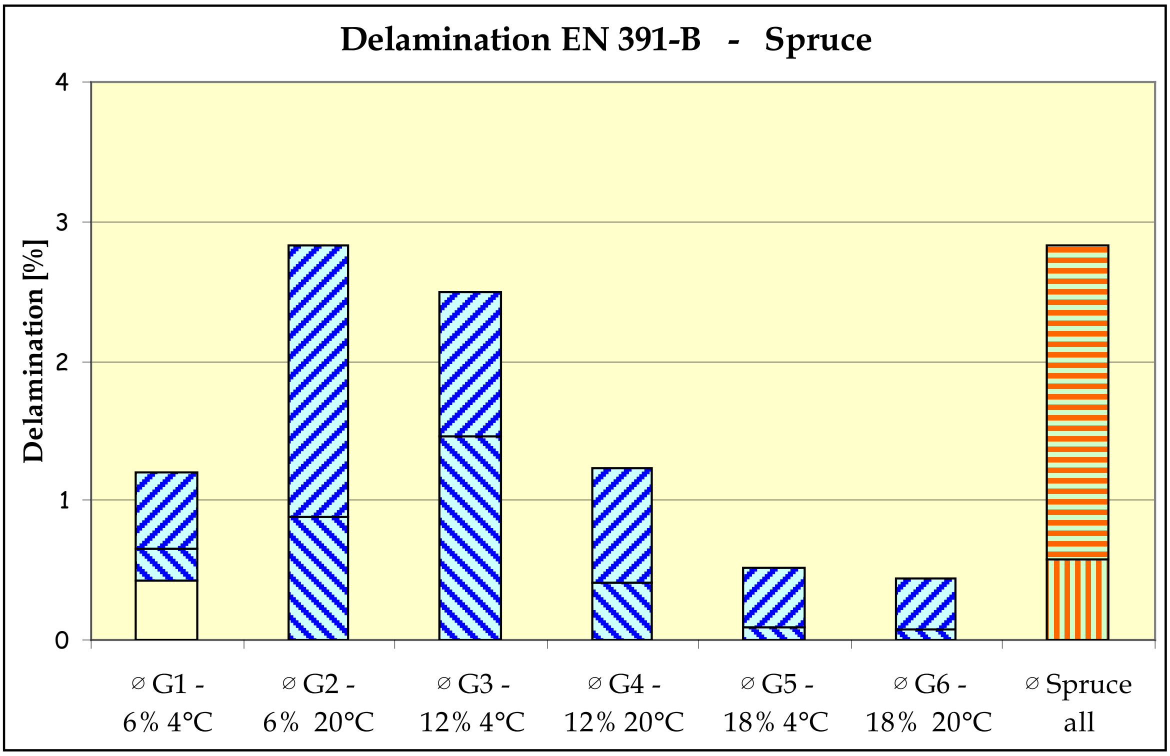
The test pieces were tested according to EN 391-B, delamination test and EN 392, shear test (see Annex A-1 and A-2).

4.2. Results – Part 2

In this chapter, the results of the tests are shown in various figures.

4.2.1. Delamination test EN 391-Method B

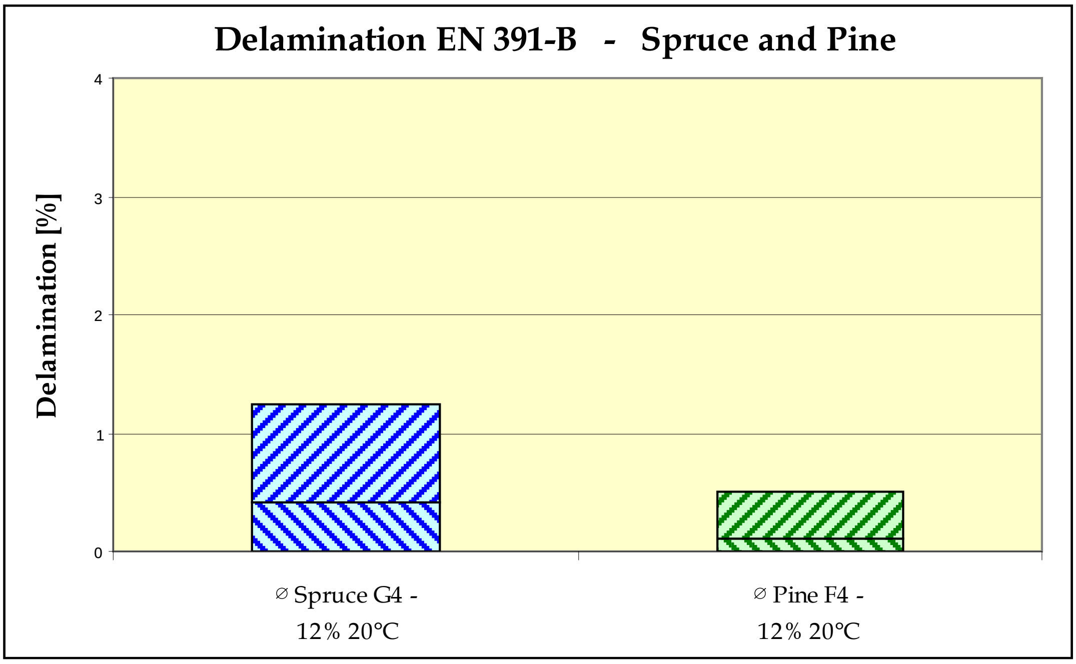
Figure 4.2 shows the results of the delamination test EN 391-Method B. The columns show the minimum, maximum and mean values (Ø) of the different test series. Each series consists of 6 test pieces taken from 3 beams with one exception: The series glued under normal conditions consists of 10 pieces taken out of 5 beams. The right column shows the mean value (Ø) of all spruce test pieces. All test pieces fall below the required maximum value of 4 % delamination (EN 386).



	⌀ Spruce G1 6% 4°C	⌀ Spruce G2 6% 20°C	⌀ Spruce G3 12% 4°C	⌀ Spruce G4 12% 20°C	⌀ Spruce G5 18% 4°C	⌀ Spruce G6 18% 20°C	⌀ Spruce all
Delam.-Min.	0,4	0,0	0,0	0,0	0,0	0,0	**0,0**
Delam.-Max.	1,2	2,8	2,5	1,2	0,5	0,4	**2,8**
Delam.-Mean value ⌀	0,6	0,9	1,5	0,4	0,1	0,1	**0,6**

Figure 4.2. Delamination test – Spruce.

Figure 4.3 shows the results of the test pieces made of spruce and pine respectively that were glued in the normal climate 20 °C and 65 % RH.



	∅ Spruce G4 12% 20°C	∅ Pine F4 12% 20°C
Delam.-Min.	0,0	0,0
Delam.-Max.	1,2	0,5
Delam.-Mean value ∅	0,4	0,1

Figure 4.3. Delamination test – Spruce and pine 20 °C, 65 % RH.

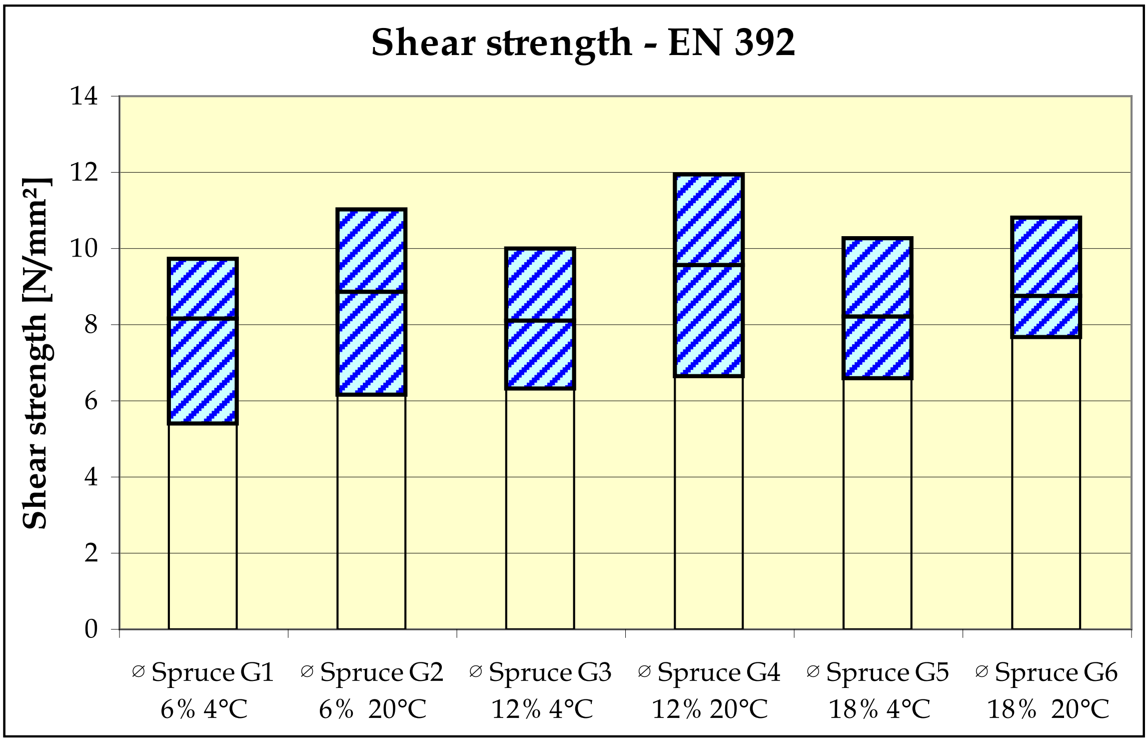
Again, all test pieces, in each case 10 pieces taken from 5 beams, passed the required maximum value of 4 % delamination according to EN 386.

Due to the properties of the delamination data (lack of normal distribution), it is not practical to do any statistical analysis of these.

4.2.2. Shear test EN 392

The results of the shear test according to EN 392 are described in the following figures. The first two figures show the shear strength, respectively the wood failure percentage with the minimum, maximum and mean values. The columns show the minimum, maximum and mean values (Ø) of the different test series.

Each series consists of 6 test pieces taken from 3 beams with one exception: The series glued under normal conditions (20 °C/65 % RH) consists of 10 pieces taken out of 5 beams. Each test piece gives 5 values, one for each glue line.



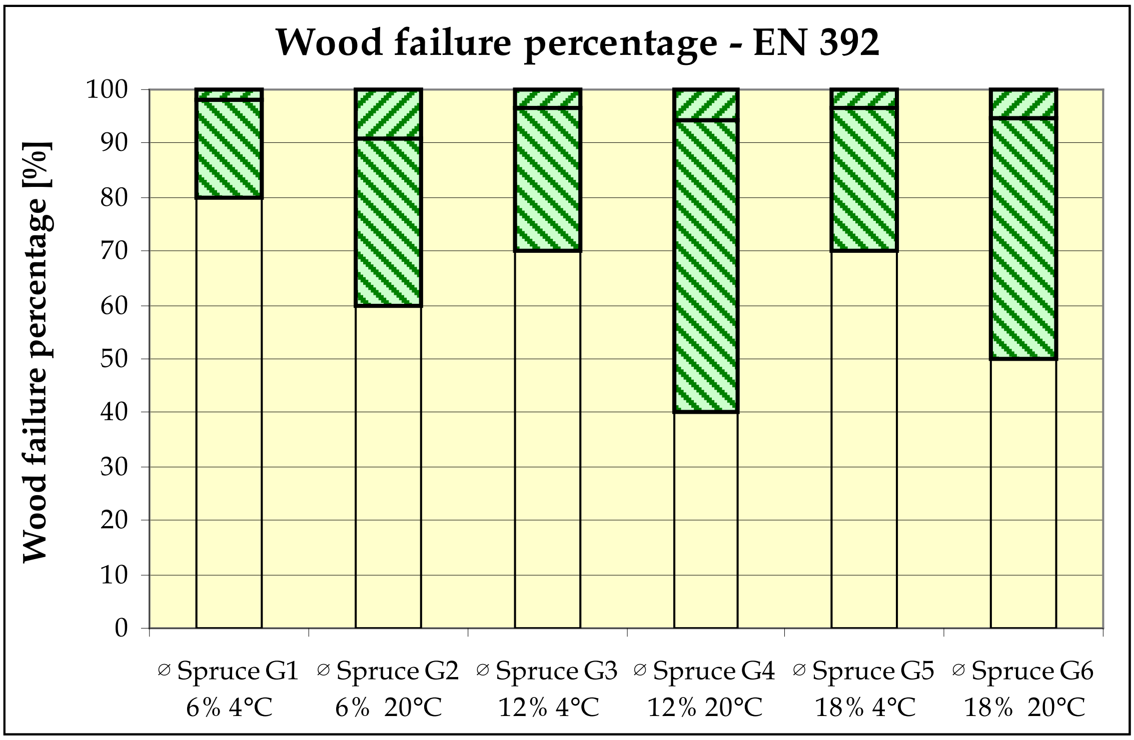
	∅ **Spruce G1 6% 4°C**	∅ **Spruce G2 6% 20°C**	∅ **Spruce G3 12% 4°C**	∅ **Spruce G4 12% 20°C**	∅ **Spruce G5 18% 4°C**	∅ **Spruce G6 18% 20°C**
Min.	5,4	6,2	6,3	6,6	6,6	7,7
Max.	9,7	11,0	10,0	11,9	10,3	10,8
∅ Mean value	8,2	8,9	8,1	9,6	8,2	8,7

Figure 4.4. Shear test - Strength – Spruce.

The one-way ANOVA-test shows that there is a significant difference between the various combinations (F=10,0, Prob>F <0,0001, DF=5-172). A further multiple comparison analysis (Tukey-Kramer) shows that the moisture contents of 6 % and 12 % at 20 °C are significantly higher than the other combinations. There is no significant difference between the various moisture contents at 4 °C.

Another one-way ANOVA-test, where only the effect of temperature is tested, shows that the 20 °C wood temperature gives a significant higher shear strength value than at 4 °C wood temperature (F=34,9, Prob>F <0,0001, DF=1-176).

Figure 4.5 shows the wood failure percentage.



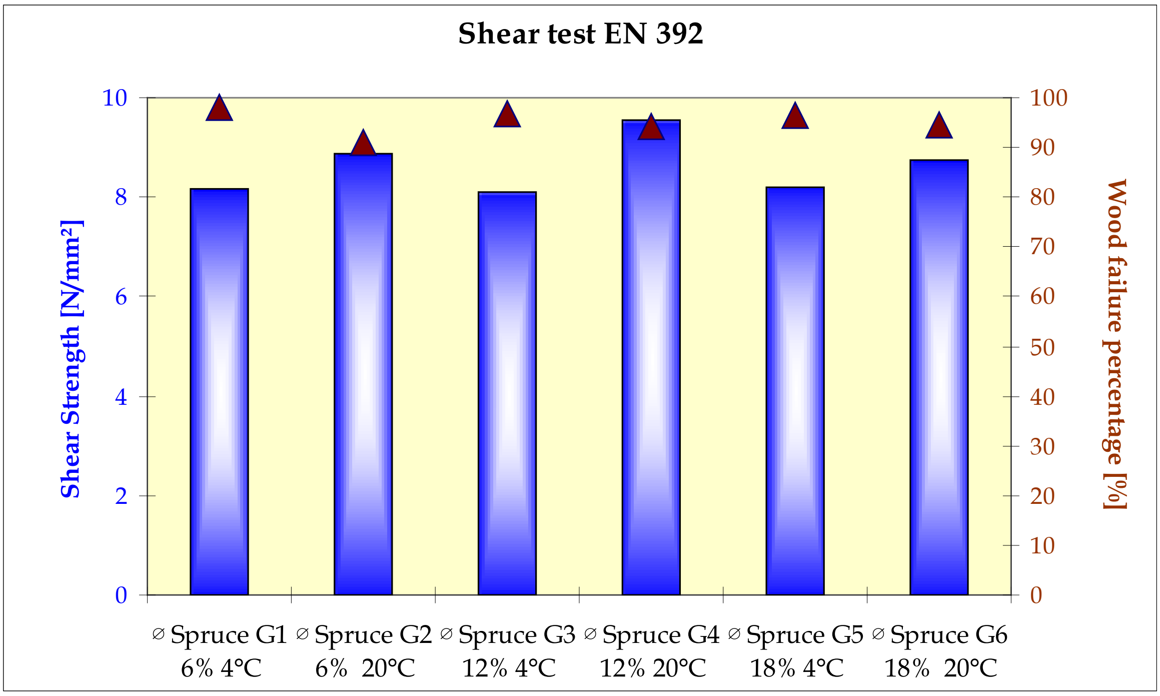
	⌀ Spruce G1 6% 4°C	**⌀ Spruce G2 6% 20°C**	**⌀ Spruce G3 12% 4°C**	**⌀ Spruce G4 12% 20°C**	**⌀ Spruce G5 18% 4°C**	**⌀ Spruce G6 18% 20°C**
Min.	80,0	60,0	70,0	40,0	70,0	50,0
Max.	100,0	100,0	100,0	100,0	100,0	100,0
⌀ Mean value	98,0	91,0	96,7	94,3	96,6	94,7

Figure 4.5. Shear test - Wood failure percentage.

All test pieces pass the test with the requirements given in EN 386.

Due to the properties of the data concerning the wood failure percentage (lack of normal distribution), it is not practical to do any statistical analysis of these.

Figure 4.6 describes the relation between the shear strength and the wood failure percentage. The columns and the triangles represent the mean values (Ø) of the different test series. Each series consists of 6 test pieces taken from three beams with one exception: The series glued under normal conditions (20 C/65 % RH) consists of 10 pieces taken out of 5 beams. Each test piece gives 5 values, one for each glue line.

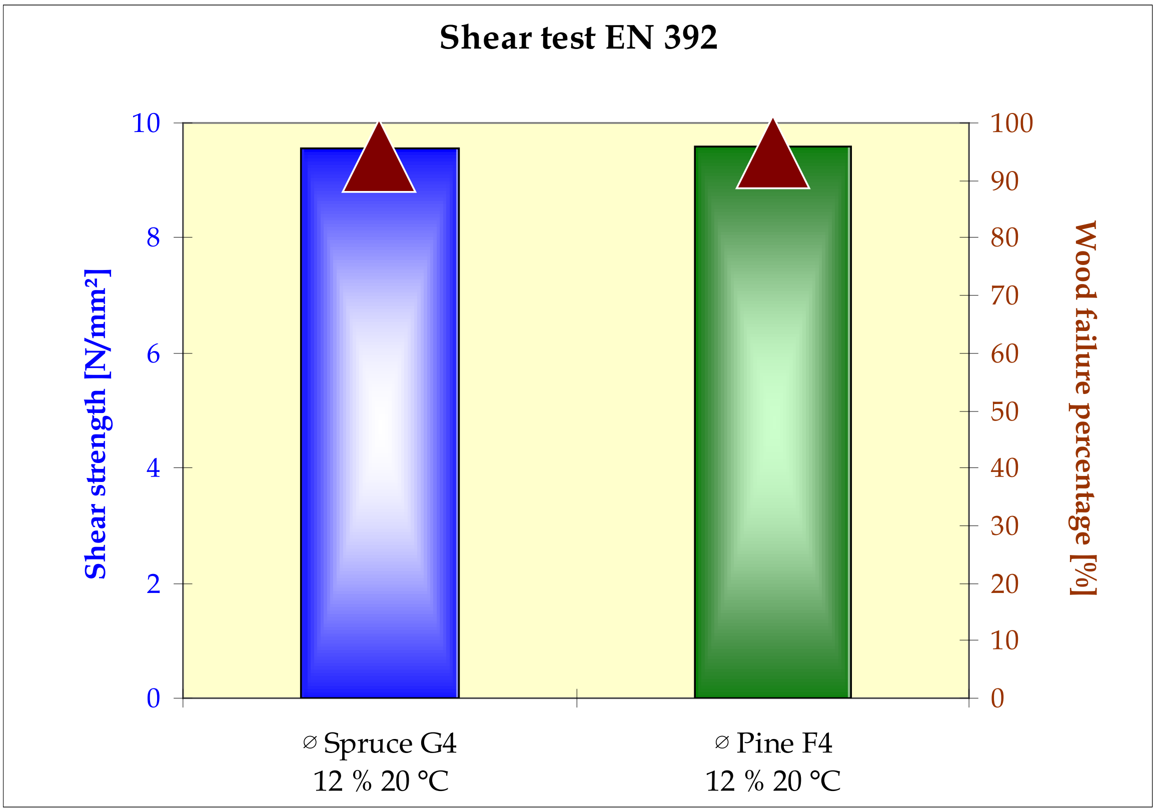


	ø Spruce G1 6% 4°C	ø Spruce G2 6% 20°C	ø Spruce G3 12% 4°C	ø Spruce G4 12% 20°C	ø Spruce G5 18% 4°C	ø Spruce G6 18% 20°C
Shear strength [N/mm²]	8,2	8,9	8,1	9,6	8,2	8,7
Wood failure [%]	98	91	97	94	97	95

Figure 4.6. Shear test – Relation between shear strength and wood failure percentage.

Figure 4.6 clearly shows the higher mean values of the test pieces glued with a 20 °C wood temperature.

Figure 4.7 compares the shear strength of the test pieces produced with spruce and pine, respectively.



	⌀ **Spruce G4** **12% 20°C**	⌀ **Pine F4** **12% 20°C**
Shear strength [N/mm²]	9,6	9,6
Wood failure [%]	94	95

Figure 4.7. Shear test – Spruce and pine.

The results of the test pieces produced of two different wood species under the same normal conditions (20 °C/65 % RH) were approximately the same.

4.3. Conclusions - Part 2

All test pieces of Norway spruce and Scots pine glued with EPI fulfil the requirements given in EN 386 "Glued laminated timber – Performance requirements and minimum production requirements" of the delamination test (EN 391-B) and shear test (EN 392) for all combinations of moisture content and temperature.

The differences in the test results between the various conditions of the wood (low (4 °C) and normal (20 °C) temperature, high (18 %), normal (12 %) and low (6 %) moisture content) before gluing are small, and for the delamination tests it is difficult to make any conclusions concerning the “best” combination. The results of the shear test pieces glued with a wood temperature of 20 °C are significantly higher than of the test pieces glued with a wood temperature of 4 °C, and the highest results are found for the combination 12 % moisture content and 20 °C wood temperature.

The tests also show that the test results of glued Norway spruce and Scots pine with a moisture content of 12 % and a temperature of 20 °C with EPI only differ marginally.

Annex

A-1. Delamination test EN 391

The delamination test method EN 391, is a test method in which glulam test pieces are placed in a pressure vessel to be impregnated with water above the fibre 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 these 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 outdoor use (method B). Meaning, this testing method tries to simulate the practical use of glulam over a longer period of time.

Figure A-1.1 Pressure vessel.

For the delamination test EN 391, 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 fibre angle with a sharp tool. The test pieces are 75 ± 5 mm in length (along the grain).

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

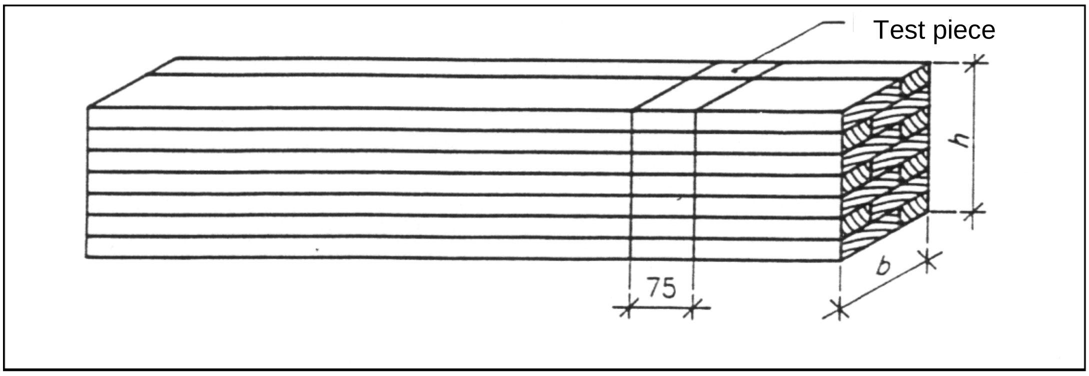


Figure A-1.2. Method to take a test piece – Delamination test EN 391.

Method B

The pieces in the pressure vessel have to be completely submerged in water with a temperature of 10 °C 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.

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.

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.

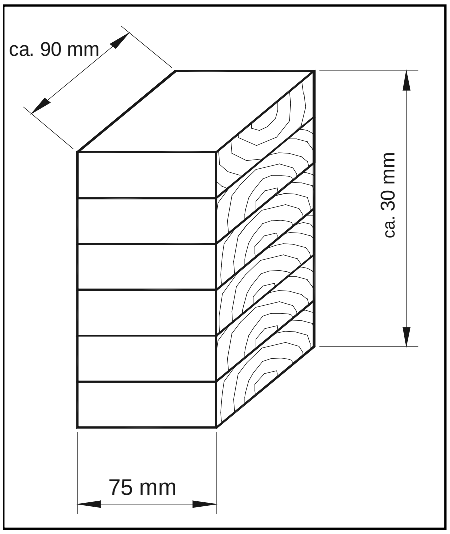
Method C

The pieces in the pressure vessel have to be completely submerged in water with a temperature of 10 °C 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. This vacuum pressure cycle will be repeated to have a total impregnation period of 5 hours.

Subsequently, the test pieces will be dried in an oven with a temperature from 25 °C to 30 °C with a relative humidity between 25 % and 35 % 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.

According to EN 391-Method C, the test pieces are supposed to be dried for 90 hours. Deviant from the standard, in this project the test pieces stay in the oven until the mass of the pieces has returned to within 100 to 110 % of their original mass (as in method B). At that point, the amount of delamination will be assessed and documented.

Method C: According to EN 386, the maximum value to pass the testing method is 10 % total delamination after the test cycle.



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.

Figure A-1.3. Test piece – EN 391.

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: $$100 \cdot \frac{l_{max,delam}}{2l_{glue\ line}}$$ [%]

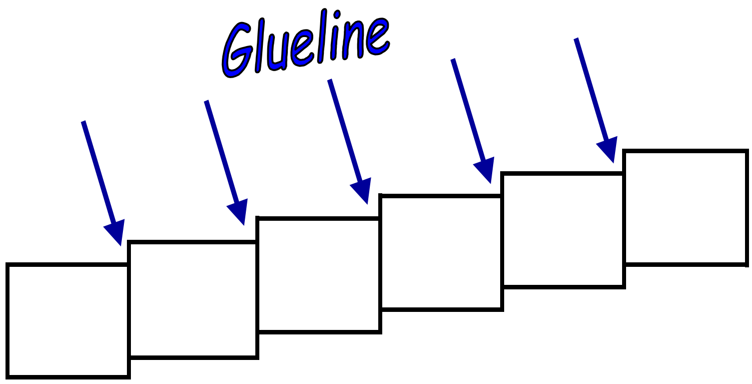
With

$l_{tot,\ delam}$	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. Shear Test 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.



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

Figure A-1.4. Prepared test piece – EN 392.

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 such a 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:

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

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.

The given requirements in EN 386 "Glued laminated timber – Performance requirements and minimum production requirements" have to be fulfilled.

A-3. Results of additional delamination test

Norsk Treteknisk Institutt **PM 507-01**
Mekanisk prøvelaboratorium

PM 507 Resultat- og rapporteringsskjema
Motstand mot delaminering iht. NS-EN 391, 2 utgave 2002

Utgave: 6 *Gyldig fra: 2004-10-01* *Utarbeidet av: PL* *Godkjent av: PL* *Filnavn: PM 507-01.xls*

Produsent: NTI Dynea-SSFF
Prosjekt nr: 310225
Bilag nr: A-3

	Antall	Dato	Sign.
Uttatt/besøkt:	-		
Mottatt:	-		
Testet:	4	2005-03-09	KL

Ordinær limtrekontroll:	
Ekstrakontroll-limtre:	
Ordinært oppdrag:	x

Lim av klasse:	2
Delammetode:	C

Parametre angitt i standarden

Tilnærmet tørketid [timer]:	90
Tørketemperatur [°C]:	25-30
Rel. luftfuktighet [% RH]:	25-30

Koding av prøver
Gran (G), Furu (F), Impregnert furu (IF)
Bjørk (B). Annet: -

Limtypen angis som
PRF, MUF, MF eller EPI
Annet: -

Beskrivelse av prøvestykkene						Syklus 1				Syklus -			
						Kun 1 syklus		Undermåler: > 10,0 %					
Prøve nr.	Treslag	Limtype	Fuge-bredde [mm]	Antall fuger	Total fugelengde [mm]	Total delaminering		Fuge med høyest delaminering		Total delaminering		Fuge med høyest delaminering	
						[mm]	[%]	[mm]	[%]	[mm]	[%]	[mm]	[%]
1-1	G	EPI	120	5	1200	0	0,0	0	0,0				
1-2	G	EPI	120	5	1200	38	3,2	28	11,7				
2-1	G	EPI	120	5	1200	0	0,0	0	0,0				
2-2	G	EPI	120	5	1200	0	0,0	0	0,0				

Total middelverdi:	0,79
Totalt standardavvik:	1,58
Antall undermålere:	0
Antall til Syklus -:	0
Serien er:	**Godkjent**

Kommentarer: