In: Proceedings, 25th meeting of International Council
for Building Structures; 1992 August 24–27; Ahus, Sweden.
Ahus, Sweden: CIB - W18; 1992. 8 p.

THE STRENGTH OF NORWEGIAN GLUED LAMINATED BEAMS

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This paper focuses on the characterization and the performance of glued laminated (glulam) timber beams manufactured from machine stress graded Norwegian spruce in comparison to developing CEN standards. Material property testing indicated that the supplied laminating timber can be represented by two CEN strength classes, C37-14E and C30-12E, with about 50% yield in each class. Beams constructed from these grades exhibited strength and stiffness meeting the requirements of CEN combinations LH35, LH40 and LC38.

INTRODUCTION

This paper reports on research performed in Norway by Robert H. Falk in close cooperation with The Norwegian Institute of Wood Technology.

The study was performed during the period from September 1990 until September 1991, and was linked to the draft CEN standards applicable in 1990, as shown in the appendix of this paper.

The research was sponsored by Royal Norwegian Council for Scientific and Industrial Research, Norwegian Glulam Producers Association and The Norwegian Instutute of Wood Technology.

OBJECTIVES

The basic objective of this research is to characterize the performance of glulam beams manufactured from machine stress graded Norwegian spuce relative to the developing CEN standards. This study involves the strength and stiffness testing of Norwegian spruce timber for the establishment of lamination grades meeting CEN standards, testing of finger joints and testing of full size beams in bending .

Specific objectives are to:

1. Characterize the mechanical properties of lamination timber and determine the yield of laminating grades meeting CEN standards.

2. Evaluate the performance of full size glulam beams constructed from the established lamination grades.

3. Quantify the relationship between the bending and tensile strength of the finger joints and lamination material and the required performance of these elements on the tension side of the beam.

This paper will focus on objective 2. A complete report from the research are beeing finalized and will be published this year.

MATERIAL DESCRIPTION

The Norway spruce (*Picea abies*) lamination timber utilized in this study was visually graded by the manufacturer to meet the requirements of the Norwegian glulam industry visual grades LT20 and LT30. 5602 laminations, nominally 40 mm x 95 mm in cross section, were provided in random lengths. The lengths varied from 2.20 m to 5.65 m, with an average length of about 4.30 m.

Each lamination was run through a Computermatic MK-IV machine stress grader. Specialized data acquisition equipment developed for this study was used to record deflection (bit) values at 150 mm intervals along each lamination.

MATERIAL TESTING

Using the machine stress grader data, the parent population of laminations was ranked according to MOE_{mac} and specimens were selected from throughout this ranking for material property testing. These material property tests provided the information necessary to establish lamination grades meeting CEN requirements.

The lamination property tests performed were ; (1) bending stiffness (including flatwise and edgewise bending), (2) bending strength (edgewise), (3) tension strength and (4) average density. Laminations to be tested were selected in such a way that the stiffness distribution of each material property test group matched as closely as possible the stiffness distribution (MOE_{mac}) of the parent population of laminations. All tests were performed on specimens 38 mm x 90 mm in cross section. Specimen length varied depending on the specific test performed and the requirements of the test standard ISO 8375. All MOE test data were corrected to 12% moisture content in accordance with CEN standards.

LAMINATING GRADES

To determine the laminating grades representative of the parent population of supplied laminations, the results of the machine stress grading, bending stiffness and strength testing, and tension tests were statistically analyzed. Laminating grades meeting the requirements of EN TC 124.203 including C37-14E, C30-12E, C24-11E and C21-10E, were targeted.

The results of this procedure indicated that 48% fall into the C37-14E grade and 50% into the C30-12E grade. The balance of the laminations fall into the C24-11E grade.

Table 1 summerizes the distribution estimates of the lamination bending strength. Note that the bending strength data have been adjusted to the reference depth of 200 mm.

<u>Table 1</u>
Summary of distribution estimates of lamination bending strength.

GRADE		PERCENTILE ESTIMATES *) MPa 50th	5th	COV (%)
C30-12E	Nonparametric	44,2	30,4	-
	Distributional	44,5	29,7	20
C37-14E	Nonparametric	55,9	38,4	-
	Distributional	56,3	36,9	20,9

*) Adjusted to reference depth of 200 mm

Table 2 summerizes the distribution estimates of the bending stiffness.

<u>Table 2</u>
Summary of distribution estimates of bending stiffness

GRADE		PERCENTILE ESTIMATES MPa 50th	5th	COV (%)
C30-12E	Nonparametric	12802	8522	-
	Distributional	12505	8965	15,9
C37-14E	Nonparametric	15102	11550	-
	Distributional	15180	11865	14,7

BEAM PRODUCTION

The balance of the laminations not utilized in the material property and finger joint tests were sorted into the established C30-12E and C37-14E grades and three different beam combinations were produced, two homogeneous (LH35 and LH40) and one combined (LC38*). Since the combined combination utilized C37-14E/C30-12E and not C37-14E/C24-11E as specified in the CEN standard, this layup is referred to as LC38*.

All beams were constructed of nine laminations 33 mm in thickness and resulted in test beams 300 mm in depth and 90 mm in width. Figure 1 indicates the beam combinations. A total of 312 beams were manufactured: 104 LH35, 112 LH40, and 96 LC38*. The beams were manufactured by a commercial laminator in 24 m length using phenol-resorcinol resin. Four 6 m test beams were cut from each full length beam.

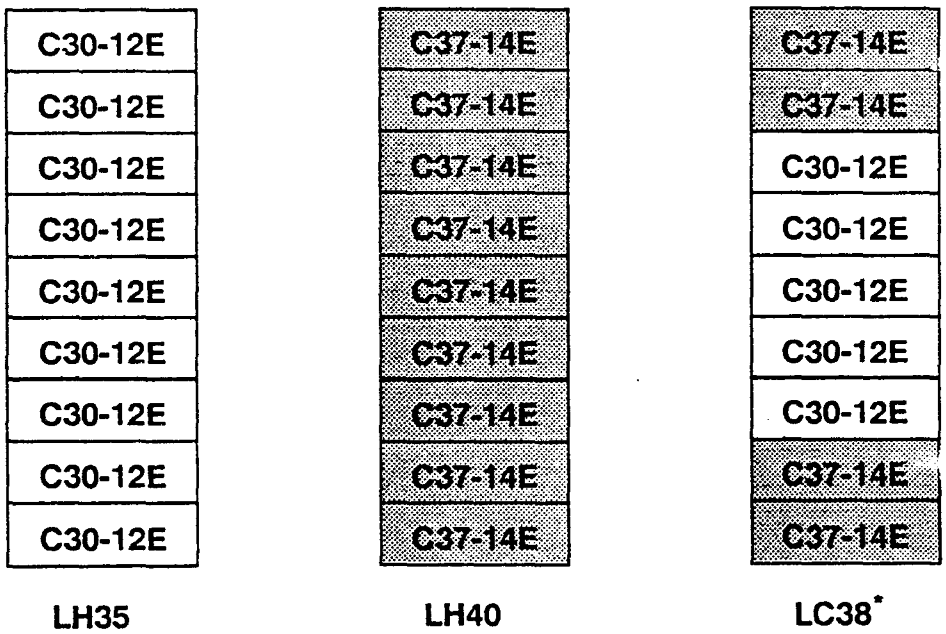

Figure 1
Beam combinations manufactured and tested

BEAM TESTING

The beams were tested according to ISO 8375 over a 5.40 m span with 1.80 m between the load heads. The MOE was measured in the shear free zone between the load heads over a 1.50 m span using an electronic trancducer. Moisture content readings were taken on each glulam beam and the MOE was adjusted to standard conditions (12% MC).

The location of all finger joints in each beam were noted before testing as well as the identifying number of each lamination.

BEAM TEST RESULTS

In general, the 312 glulam beams tested in this study failed as expected, that is, in tension in the outer lamination.

Table 3 summarizes the distribution estimates of the beam bending strength. Note that there was no depth effect adjustment applied to the data. The distribution estimates for bending stiffness is shown in Table 4.

Table 3
Summary of distribution estimates of beam bending strength.

BEAM GROUP		PERCENTILE ESTIMATES MPa 50th	5th	COV (%)
LH35	Nonparametric	44,3	32,8	-
	Distributional	44,1	34,3	12,6
LH40	Nonparametric	52,5	39,4	-
	Distributional	52,3	39,4	14,6
LC38*	Nonparametric	47,7	37,9	-
	Distributional	48,6	39,2	13,4

Table 4
Summary of distribution estimates of beam MOE

BEAM GROUP		PERCENTILE ESTIMATES MPa 50th	5th	COV (%)
LH35	Nonparametric	13073	11305	-
	Distributional	13000	11242	7,5
LH40	Nonparametric	15395	13421	-
	Distributional	15362	13409	7,2
LC38*	Nonparametric	14618	12928	-
	Distributional	14596	13049	6

It is seen that all the beam combinations meet or exceed the CEN stiffness requirements. The LH40 beam combination has a slightly higher stiffness than the LC38* combination due to the uniform use of the higher stiffness C37-14E lamination grade.

For the LC38* combination the CEN standards are exceeded also in bending. The 5th percentile estimates of beam strength are seen to be within two percent of the CEN requirements for the LH35 and LH40 beam combinations.

Note that the LC38* combination had a characteristic bending strength equal to the LH40 combination though the LC38* combination uses 55% less high grade laminations. This indicates the material efficiencies realized through the use of the combined glulam layup.

CONCLUSION

In general, the results of this study show that high yields of two machine stress rated Norwegian spruce laminating grades meeting the requirements of the draft CEN standards, C37-14E and C30-12E, can be generated from the supplied laminating timber. Futhermore, glulam beams manufactured from these grades can meet or exceed the strength and stiffness requirements of CEN beam combinations LH35, LH40 and LC38.

CONCLUDING REMARKS

The data from this project are still beeing analyzed. The data are used as input to the "Karlsruhe Model" and to the American "PROLAM-model", and the results from these simulations will be reported at a later stage.

REFERENCES

1. Draft Standard EN TC 124.203 "Structural Timber - Strength Classes", August 1990

2. Draft Standard EN TC 124.207 "Glued Laminated Timber - Strength Classes and Determination of Characteristic Properties", January 1990

3. International Organization for Standardization, ISO 8375 "Solid Timber in Structural Sizes - Determination of Some Physical and Mechanical Properties", 1985

Appendix: Extract from EN TC 124.203 (1990) and EN TC 124.207 (1990)

APPENDIX

Extract from EN TC 124.203 and EN TC 124.207

Table A.1
Strength classes.

Strength classes			C13-7E	C15-8E	C15-11E	C18-9E	C21-10E	C21-13E	C24-11E	C30-12E	C30-15E	C37-14E	C48-20E	C60-22E
Strength properties in MPa														
BENDING	$f_{m,k}$		13	15	15	18	21	21	24	30	30	37	48	60
TENSION PARALLEL	$f_{t,o,k}$		8	9	9	11	13	13	14	18	18	22	29	36
TENSION PERPENDICULAR	$f_{t,90,k}$		0,3	0,3	0,3	0,3	0,4	0,4	0,4	0,4	0,4	0,4	0,6	0,7
COMPRESSION PARALLEL	$f_{c,o,k}$		16	17	17	19	20	20	21	24	24	28	35	40
COMPRESSION PERPENDICULAR	$f_{c,90,k}$		4,8	4,8	5,2	5,2	5,4	5,7	5,7	6,3	6,7	6,7	9,0	10,5
SHEAR	$f_{v,k}$		1,6	1,7	1,7	1,8	2,1	2,1	2,4	3,0	3,0	3,7	4,8	6,0
Stiffness properties in MPa														
MOE MEAN PARALLEL	$E_{o,mean}$		7000	8000	11000	9000	10000	13000	11000	12000	15000	14000	20000	22000
MOE MINIMUM PARALLEL	$E_{o,min}$		4900	5500	7400	6500	7000	8700	7400	8500	10300	10000	14000	15000
MOE MEAN PERPENDICULAR	$E_{90,mean}$	S'Woods	230	270	370	300	330	430	370	400	500	450	-	-
		H'Woods	470	530	730	600	670	860	730	800	1000	900	1300	1500
SHEAR MODULUS MEAN	G_{mean}		440	500	690	560	630	800	690	750	900	800	1250	1400
Density in kg/m³														
DENSITY	ρ_k		290	300	450	320	350	480	380	410	520	450	600	700

Table A.2
Classification of glulam.

Strength classes for homogeneous glulam	LB25	LB28	LB30	LB35	LB40
Required lamination strength class	C18-9E	C21-10E	C24-11E	C30-12E	C37-14E
Strength classes for combined glulam	LC24	LC26	LC28	LC33	LC38
Required strength class of:					
Outer laminations	C18-9E	C21-10E	C24-11E	C30-12E	C37-14E
Inner laminations	C13-7E	C15-8E	C18-9E	C21-10E	C24-11E

<u>Table A.3</u>

Characteristic strength of homogeneous glulam.

Strength class		LH25	LH28	LH30	LH35	LH40
Bending	$f_{m,k,g}$	25	28	30	35	40
Tension						
- par.	$f_{t,0,k,g}$	20	23	25	28	32
- perp.	$f_{t,90,k,g}$	0.3	0.4	0.4	0.4	0.4
Compression						
- par.	$f_{c,0,k,g}$	25	26	27	29	33
- perp.	$f_{c,90,k,g}$	5.7	5.9	6.3	6.9	7.4
Shear	$f_{v,k,g}$	2.7	2.9	3.1	3.5	4.0
Modulus of Elasticity par.						
+ bending	$E_{mean,m,g}$	10000	11000	11500	12500	13000
+ axial	$E_{mean,a,g}$	10000	11000	11500	12500	13000
Density	kg/m³	320	350	380	410	450

<u>Table A.4</u>

Characteristic strength of combined glulam. p

Strength class		LC24	LC26	LC28	LC33	LC38
Bending	$f_{m,k,g}$	24	26	28	33	38
Tension						
- par.	$f_{t,0,k,g}$	17	19	21	24	26
- perp.	$f_{t,90,k,g}$	0.3	0.3	0.3	0.4	0.4
Compression						
- par.	$f_{c,0,k,g}$	22	23	25	27	30
- perp.	$f_{c,90,k,g}$	5.7	5.9	6.3	6.9	7.4
Shear	$f_{v,k,g}$	2.5	2.6	2.7	2.9	3.1
Modulus of Elasticity par.						
+ bending	$E_{mean,m,g}$	9500	10500	11000	12000	13000
+ axial	$E_{mean,a,g}$	8500	9500	10500	11500	12000
Density	kg/m³	250	300	320	350	380