Strength and Stiffness of Edge-Loaded Plywood

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STRENGTH AND STIFFNESS OF EDGE-LOADED PLYWOOD
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EUROPEAN STANDARD **EN 112.411** CEN/TC112/WG4 N186
First Draft November 1994

Wood based panels - Determination of edgewise bending properties

CEN
European Committee for Standardization
Comité Européen de Normalisation
Europäisches Komitee für Normung

Central Secretariat: rue de Stassart 36, B-1050 Brussels

Foreword

This European Standard was prepared by Working Group 4 'Test methods' (Secretariat: UK) of Technical Committee CEN/TC 112 'Wood-based panels' (Secretariat: Germany).

This standard is one of a series specifying methods of test for determining the properties of wood based panels.

No existing European Standard is superseded.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by xxxxx, and conflicting national standards shall be withdrawn at the latest by xxxxx.

In accordance with the CEN/CENELEC Internal Regulations, the following countries are bound to implement this European Standard:

Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom.

Contents

1 Scope

This European Standard specifies a method for the determination of edgewise bending properties of wood-based panels.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the last edition of the publication referred to applies.

EN 310 Wood-based panels
Determination of modulus of elasticity in bending and of bending strength

EN 325 Wood-based panels
Determination of dimensions of test pieces

EN 789 Wood-based panels
Test methods for the determination of mechanical properties for structural purposes

EN 1156 Wood-based panels
Determination of duration of load and creep factors

EN 326-1 Wood-based panels
Sampling, cutting and inspection
Part 1: Sampling and cutting of test pieces and expression of test results

3 Principle

The bending properties are determined on test pieces prepared with panel strips, edgewise glued together forming a test piece which can be tested according to the test standards for flatwise bending.

4 Test pieces

4.1 Number of test pieces
The sampling and number of test pieces required is given in each relevant test standard. Since this method to produce test pieces implies that the result from the test is always a mean value of the stripes used, the number of test pieces can be reduced to the required number of test pieces in each standard divided by the number of stripes used in each glued test piece, rounded up to the nearest integer value.

4.2 Small size test pieces
Prepare stripes with a length of 500 mm and a width of 30 mm. Glue the stripes together to a test piece with the dimensions 500 x 30 x (appr 50) mm. Use a glue which is proven not to increase the stiffness and strength of the test piece. Cut the test piece to length 490 mm and thickness 22 mm. The width of the test piece is dependent to the thickness of the stripes (see figure 1).

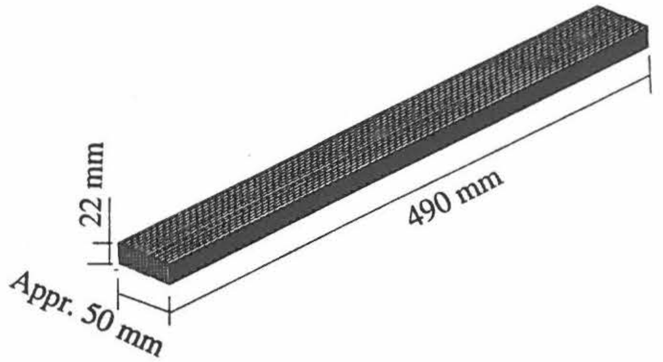

Figure 1 Small size test piece for edgewise bending

4.3 Medium size test pieces
Prepare stripes with a length of 1000 mm and a width of 30 mm. Glue the stripes together to a test piece with the dimensions 1020 x 30 x (appr 300) mm. Use a glue which is proven not to increase the stiffness and strength of the test piece. Cut the test piece to length 1000 mm and thickness 22 mm. The width of the test piece is dependent to the thickness of the stripes (see figure 2).

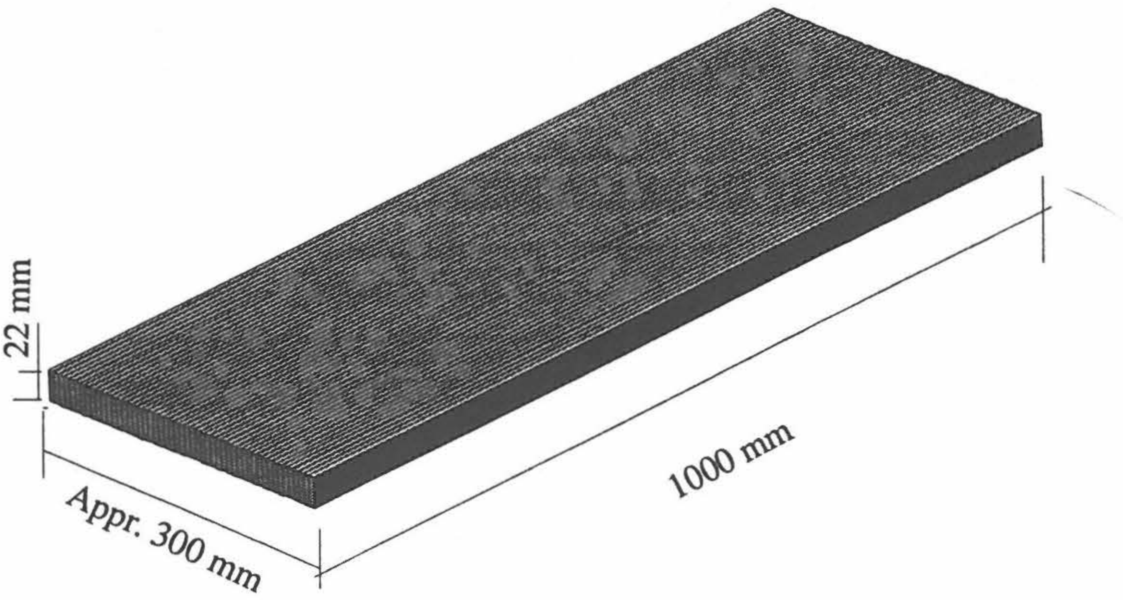

Figure 2 Medium size test piece for edgewise bending

4.4 Test pieces for duration of load and creep test
Prepare stripes with a length of 550 mm and a width of 30 mm. Glue the stripes together to a test piece with the dimensions 550 x 30 x (appr 50) mm. Use a glue which is proven not to increase the stiffness and strength of the test piece. Cut the test piece to length 530 mm and thickness 22 mm. The width of the test piece is dependent to the thickness of the stripes (see figure 3).

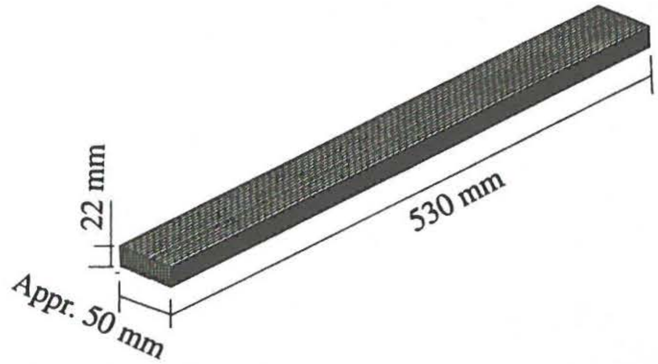

Figure 3 Test pieces for duration of load and creep test for edgewise bending

5 Conditioning

Before testing, the test pieces shall be conditioned to constant mass in accordance to the rules in the chosen test standard below.

6 Procedure

6.1 Small size test pieces
Carry out the test in accordance with EN 310

6.2 Medium size test pieces
Carry out the test in accordance with EN 789

6.3 Test pieces for duration of load and creep test
Carry out the test in accordance with EN 1156

7 Test report
According to the test standards used above.

Acknowledgements

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Oversøisk Træimport, Europly, Esbjerg
Kaukas A/S, Farum
Anco Træ A/S, Herlev
Det Danske Trælastkompagni, København
Oscar Peschardt & Co. A/S, København

Summary

Objectives
The objectives of the test programme described in this report were to compare bending strength and stiffness of edge-loaded plywood with the corresponding properties of members subjected to tension and to evaluate the effect of the build-up on the results.

Test programme
Six different plywood types were tested. For each type the following tests were performed:

In-plane bending test of 125 mm deep double members
In-plane bending test of 200 mm deep double members
Tensile test of 125 mm wide single members
Tensile test of 125 mm wide double members
Tensile test of 200 mm wide single members
Tensile test of 200 mm wide double members

For one of the plywoods these tests were supplemented by bending tests performed on 125 mm deep single members.

Test specimens
The test specimens were prepared from panels (1200 × 2400 mm) cut into 125 mm and 200 mm wide specimens parallel to the longitudinal direction of the panels giving a span-over-depth ratio of 18 and 11 respectively for the bending tests.

Ideally, the test specimens for in-plane bending as well as for tension should consist of single members, but since they created stability problems when subjected to in-plane bending it was decided to increase the lateral stability of the bending members by gluing together two adjacent strips. Furthermore, to increase the lateral stability the test apparatus was equipped with lateral supports along the compression zone of the test specimens. Since the bending tests were performed on double members it was decided to test double members in tension as well so that the strength properties would be comparable.

And in order to assess the effect on the strength properties, when two specimens are glued together, also single members were tested in tension.

Results
The test results indicate that the in-plane bending strength of plywood exceeds

the tensile strength by 20-50% dependent on the build-up of the cross-section.

The test results did not give a clear picture of the effect of gluing together two strips before testing. The strength seems to remain unchanged or to increase compared with that of the single members.

The difference in depth of the specimens tested did not seem to influence the test results. There seemed, however, to be a tendency towards increasing spread with decreasing depth.

Based on the test results this report also includes a suggestion on how the in-plane bending strength can be determined on the basis of test results from double members. As an alternative it is suggested to develop a test apparatus for testing single members in in-plane bending.

Introduction

Strength and stiffness properties of plywood for structural purposes may be determined in accordance with existing standards. However, the standards do not include determination of in-plane bending strength and stiffness (properties).

These properties may be needed e.g. in cases where the sheathing material form part of a cross-section as in I and box beams built up with plywood webs.

If in the design the strength of the web material is taken into consideration there is no alternative to applying the tensile and compressive strength and the modulus of elasticity in tension of the plywood. This may cause inaccuracy in the design.

Preliminary results from a pilot programme conducted at the University of Aalborg indicated that the in-plane bending strength exceeds the strength in tension. A result to be expected according to the Weibull brittleness theory.

It was therefore decided to carry out a more comprehensive test programme.

The objectives were to determine in-plane bending strength and stiffness properties of a variety of plywood panel types and to gain experience with respect to test set-up, testing procedure and to build-up and size of the test specimens.

Definitions

n_0 The tensile strength of an h mm deep specimen subjected to an axial tensile force parallel to the longitudinal direction of the panel. n_0 is found as

$$n_0 = P_{ult}/h \text{ [Nmm}^{-1}\text{]}, \text{ see figure 1}$$

n_m The bending strength of an h mm deep specimen subjected to in-plane bending. n_m is found as

$$n_m = 6M_{ult}/h^2 \text{ [Nmm}^{-1}\text{]}, \text{ see figure 2}$$

E_0 Modulus of elasticity in tension e.g. corresponding to n_0.

E_m Modulus of elasticity in bending e.g. corresponding to n_m.

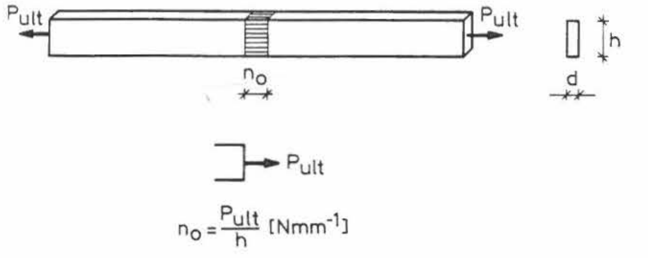


Figure 1. Tensile strength.

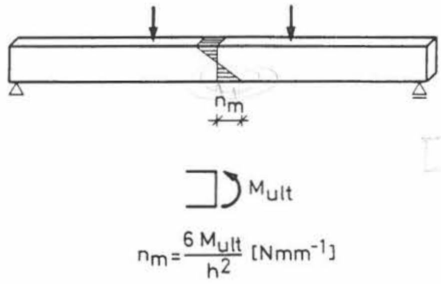


Figure 2. Bending strength.

Materials

The plywood tested were American, Canadian and European of different thickness and build up.

A total of 180 panels were included in the test programme.

The test specimens were conditioned before testing at a temperature of 20±2°C and a relative humidity of 65±5%.

Test programme

The panels tested were divided into six series.

Series

1 12,5 mm Canadian CSP, sheathing
2 16 mm USA DFP, sheathing, A-C
3 15 mm Finnish Combi
4 15,5 mm Canadian CSP, sheathing
5 12,5 mm Swedish Vänerply, P30
6 16 mm Polish Europly Birch/pine

The plywood build-ups are shown in figure 3.

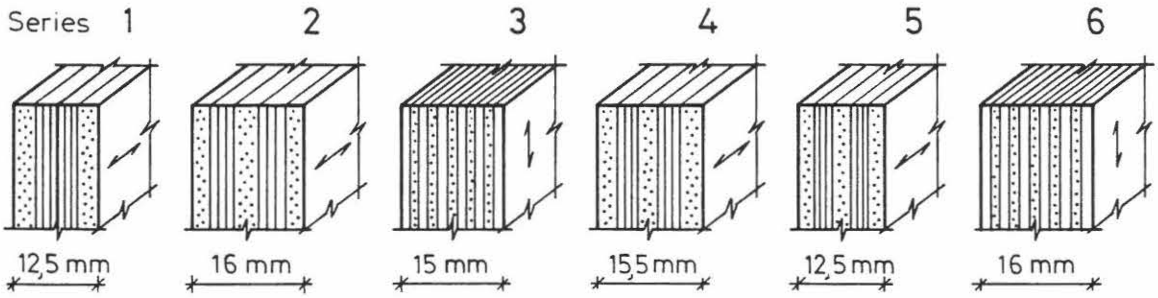


Figure 3. Plywoods tested.

The test specimens were cut parallel to the length of the panels in strips of 125 mm and 200 mm depth giving a span-over-depth ratio of 18 and 11, respectively.

The cutting diagram is shown in principle in figure 4. The position of the deep and slim specimens was varied from panel to panel.

In order to prevent the test specimens subjected to bending from buckling the width of these specimens was doubled by gluing together two adjacent members. The common edge was placed in tension in order to reduce lamination effect, if any.

The same stability problem did not occur for the members in tension but in order to eliminate the lamination effect, if any, on the result when comparing bending and tensile strength, the tensile strength was found also by testing members produced by gluing together two single members as for members in bending.

In order to evaluate the lamination effect, if any, single members were tested also in tension, and the strength were compared with the strength of double members.

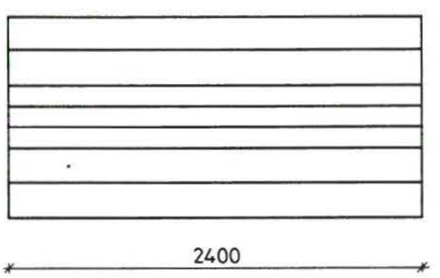
The test specimens for testing in tension and bending were selected as shown in principle in figure 5.

The symbol ↔○ in figure 5 indicates the following:

↔① evaluating the influence of size on strength properties

↔② evaluating lamination effect on strength properties

↔③ comparing tensile and bending strength



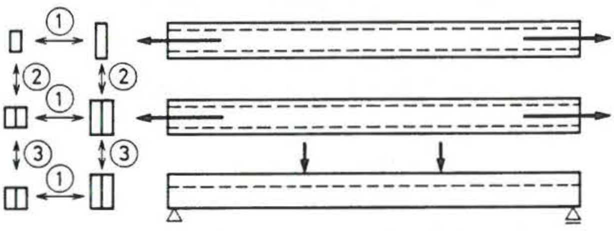


Figure 4. Cutting diagram. Dimensions in mm.

Figure 5. Test specimens.

Testing

Tensile tests were performed using a tensile test machine for testing boards, planks etc. The apparatus allows testing of cross-sections up to 50 × 200 mm and a test length between the testing machine clamps up to 3.70 m. The length of grips is 0.80 m.

The load is applied through the grips by means of a 1 MN manually operated hydraulic press, cylinder LUCAS, type HP100/200. The load is measured by two load cells HBM, C3H2, 200 kN.

When applying the load the grips will apply a translatory movement parallel to the length of the test specimens.

Deformations were measured over a 400 mm gauge length. Two extensiometers were used, HBM, type DO1. They were attached to the test specimen along the centreline at the two opposite wider faces.

Corresponding values of load and deformation were recorded and stored in a HP 9845 computer.

The ultimate load was reached within 300±120 secs.

The test set-up is shown in principle in figure 6.

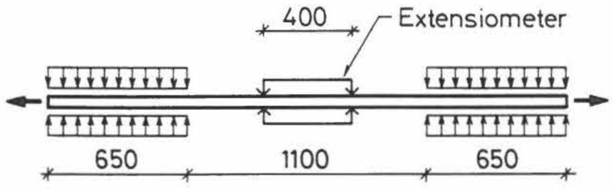


Figure 6. Tensilte test. Dimensions in mm.

The bending tests were performed using a bending test apparatus designed for testing of slim specimens. The test set-up is shown in figure 7. The test specimens were simply supported on bearings supported by long struts providing free support conditions. Lateral restraint was provided by steel wheels on roller bearings supported by the main test frame. The wheels are adjustable horizontally and vertically. Prior to testing they were equally spaced in the length direction of the test specimen and adjusted to support the compression zone. In order to provide a smooth surface for the supporting steel wheels and thus reducing friction when the specimens deflected, steel rails were mounted on the specimens at each wheel. The specimens were loaded in bending at two points dividing the length into thirds over a span of 11 times the depth for the 200 mm deep specimens and over a span of 18 times the depth for the 125 mm specimens.

The load was applied by means of a manually operated 50 kN hydraulic press, LUCAS, type HP5/150.

In order to record the loss of friction, if any, caused by the lateral restraint the supports were provided with load cells, HBM, C3, 10 kN.

Deflections were measured at three points on the mid third of the specimen (at the zone subjected to a constant bending moment). The displacement transducers were spaced 300 mm, HBM, type WTK20.

Corresponding values of load, reactions and deflections were recorded and stored in a HP 9845 computer.

The ultimate load was reached within 300±120 secs.

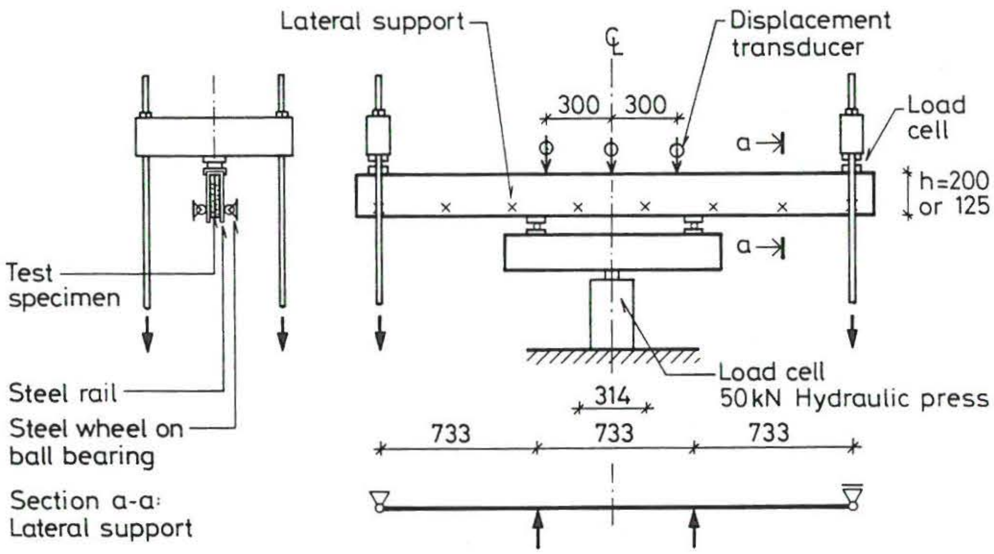


Figure 7. Bending test. Dimensions in mm.

Test results

Moisture content and density

After testing the moisture content and density were determined from 50 mm wide samples cut close to the section of failure. The mean values and coefficients of variation as well as the number of test specimens in each series are shown in table 1.

Strength properties

The bending strength n_m in Nmm^{-1} corresponding to the thickness of one panel was calculated from

$$n_m = \frac{6M_u}{h^2}$$

where

M_u is the bending moment at failure and

h is the depth of the specimen.

The tensile strength n_o in Nmm^{-1} corresponding to the thickness of one panel was calculated from

$$n_o = \frac{P_u}{h}$$

where

P_u is the load at failure and

h is the width of the specimen.

The calculated values of the strength capacities n_m and n_o are shown in table 1 and compared in table 3.

Stiffness properties
Loads and deformations/deflections were recorded at intervals corresponding to 0.1-0.2 times the ultimate load.

In series 4-6 the values were stored for stiffness calculation.

The modulus of elasticity in bending was calculated from

$$E_m = \frac{a \cdot l_1^2 \cdot \Delta F}{16 \cdot I \cdot \Delta W}$$

where

a is the distance between a load point and the adjacent support, i.e. 1/3 = 733 mm

l_1 is the gauge length i.e. 600 mm

I is the second moment of area. It was calculated on basis of the actual depth and the nominal thickness

ΔF is an increment of load below the proportional limit i.e. below 0.5 F_u

ΔW is the deflection under the increment of load ΔF.

The modulus of elasticity in tension was determined from

$$E_o = \frac{l_1 \cdot \Delta F}{A \cdot \Delta W}$$

where

l_1 is the gauge length i.e. 400 mm

ΔF as described above

A is the area of the cross-section. It was determined from the actual width and the nominal thickness

ΔW as described above

The calculated values of E_m og E_o are shown in table 2.

Table 1. Strength properties, moisture content and density (mean values and coeff. of var.). Number of test specimens.

Series	Specimen / Depth in mm		Tension				Bending	
			125 ▯	125 ◫	200 ▯	200 ◫	125 ◫	200 ◫
1	Strength [Nmm^{-1}]	n_0 or n_m	204	229	208	266	316	314
	Coeff. of var.	v_n	0.18	0.23	0.22	0.17	0.15	0.09
	Moisture content %	w	9.3	9.6	8.9	9.5	8.9	9.0
	Coeff. of var.	v_w	0.08	0.05	0.05	0.05	0.04	0.05
	Density kg/m^3	ρ	430	406	426	399	433	410
	Coeff. of var.	v_p	0.07	0.10	0.07	0.05	0.08	0.08
	No. of specimens	n	14	15	19	15	15	21
2	Strength [Nmm^{-1}]	n_0 or n_m	239	247	225	259	391	357
	Coeff. of var.	v_n	0.33	0.19	0.19	0.22	0.17	0.14
	Moisture content %	w	8.6	8.6	8.6	8.8	8.4	8.9
	Coeff. of var.	v_w	0.05	0.04	0.04	0.02	0.04	0.05
	Density kg/m^3	ρ	442	447	428	443	459	447
	Coeff. of var.	v_p	0.05	0.05	0.07	0.06	0.06	0.04
	No. of specimens	n	18	18	17	18	21	20
3	Strength [Nmm^{-1}]	n_0 or n_m	527	538	537	522	620	627
	Coeff. of var.	v_n	0.12	0.11	0.10	0.09	0.08	0.08
	Moisture content %	w	9.9	9.5	9.8	9.7	9.6	9.7
	Coeff. of var.	v_w	0.02	0.04	0.04	0.05	0.03	0.03
	Density kg/m^3	ρ	562	572	567	574	578	574
	Coeff. of var.	v_p	0.02	0.03	0.02	0.02	0.03	0.03
	No. of specimens	n	15	15	16	18	15	18
4	Strength [Nmm^{-1}]	n_0 or n_m	386	387	360	422	543	501
	Coeff. of var.	v_n	0.17	0.18	0.17	0.16	0.12	0.13
	Moisture content %	w	10.2	10.3	9.6	10.3	9.6	9.4
	Coeff. of var.	v_w	0.02	0.03	0.03	0.03	0.03	0.03
	Density kg/m^3	ρ	425	423	421	430	436	431
	Coeff. of var.	v_p	0.05	0.04	0.05	0.04	0.05	0.05
	No. of specimens	n	21	22	28	23	24	28
5	Strength [Nmm^{-1}]	n_0 or n_m	196	243	220	236	331	315
	Coeff. of var.	v_n	0.19	0.19	0.17	0.10	0.17	0.13
	Moisture content %	w	9.5	9.8	9.2	9.3	8.7	9.6
	Coeff. of var.	v_w	0.05	0.05	0.03	0.04	0.06	0.05
	Density kg/m^3	ρ	472	473	467	475	466	479
	Coeff. of var.	v_p	0.04	0.05	0.06	0.03	0.04	0.04
	No. of specimens	n	21	19	20	18	18	19
6	Strength [Nmm^{-1}]	n_0 or n_m	425	442	411	421	600	554
	Coeff. of var.	v_n	0.19	0.19	0.15	0.20	0.20	0.15
	Moisture content %	w	9.1	9.4	8.6	8.5	8.4	8.3
	Coeff. of var.	v_w	0.03	0.03	0.03	0.05	0.04	0.04
	Density kg/m^3	ρ	587	597	594	590	591	592
	Coeff. of var.	v_p	0.03	0.03	0.04	0.03	0.03	0.04
	No. of specimens	n	22	18	20	18	18	19

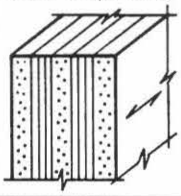
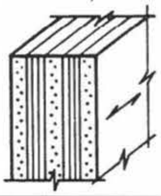
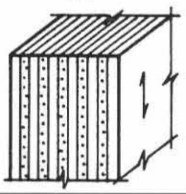
Evaluation of test results

Stiffness properties

It is seen from table 2 that the ratio between the modulus of elasticity in in-plane bending E_m and the modulus of elasticity in tension E_o gives the value $\frac{E_m}{E_o} \sim$ 1,0-1,1.

A statistical evaluation of the test results confirms that the difference between E_m and E_o is not significant (significance level $\alpha = 1\%$) assuming normal distributions with the same variance.

Table 2. Modulus of elasticity in bending and tension, mean values, coeff. of var.

Series	Specimen		Depth in mm 125 ▯	125 ◫	200 ▯	200 ◫
4	Canadian sheathing CSP 15,5 mm 	E_0[Nmm^{-2}]	7194	7200	7123	7471
		v	0.09	0.07	0.08	0.08
		E_m[Nmm^{-2}]		7858		7832
		v		0.10		0.10
		E_m/E_0		1.1		1.0
5	Swedish Vänerply P30 12,5 mm 	E_0[Nmm^{-2}]	7064	7232	7312	7000
		v	0.09	0.13	0.14	0.10
		E_m[Nmm^{-2}]		7424		7376
		v		0.10		0.09
		E_m/E_0		1.0		1.1
6	Polish Europly Birch/pine 16 mm 	E_0[Nmm^{-2}]	7106	7369	7031	7150
		v	0.14	0.13	0.09	0.09
		E_m[Nmm^{-2}]		7678		7713
		v		0.15		0.13
		E_m/E_0		1.0		1.1

Strength properties

As regards the strength properties it is seen from table 3 that the ratio between the bending strength n_m and the tensile strength n_o, $\frac{n_m}{n_o}$, gives values ranging from 1.2 (average) for high grade Finnish Kombi with 11 veneer layers (series 3) to 1.5 (average) for a lower grade American Plywood with 5 veneer layers (series 2).

A statistical evaluation of the test results confirms that in all series the bending strength n_m exceeds the tensile strength n_o significantly (significance level $\alpha =$ 1%) assuming normal distributions with the same variance.

As mentioned earlier the effect of friction on the test results, if any, resulting from the lateral restraint of the members subjected to bending was determined by recording the corresponding values of the applied load and reactions.

In none of the series the average friction caused by the lateral supports exceeded 1% of the average load at failure. The friction is therefore negligible.

Lamination effect
The influence on the tensile strength of gluing together two members before testing was evaluated in each series by testing single and double members in tension.

In table 3 the tensile strength of double members are compared with the tensile strength of single members ($\frac{n_b}{n_a}$, $\frac{n_d}{n_c}$).

It was expected that the lamination effect, if any, would be more significant for the plywood built up of fewest veneer layers, i.e. series 1, 2 4 and 5. To a certain extent this was true, since the ratio between the strength of double members and the strength of single members varied between 1.0-1.3 in these series, whilst the same ratio in series 3 and 6 each having 11 veneer layers gave the value 1.0. However, no clear picture was obtained, since the ratio also varied within the same series.

The influence on the bending strength of gluing together two members before testing was only evaluated in series 4 where 125 mm deep single members were tested in bending in addition to the ordinary programme.

Testing of single members created some stability problems, some members tended to buckle before rupture, and this may have contributed to reducing the average bending strength obtained.

However, it appears from table 3 that the influence on the bending strength of gluing together two members is not significantly different from the influence on the tensile strength (ratio 1.1 in bending and 1.0, 1.2 in tension).

It seems reasonable to assume that this will also be true for other plywood types.

Assuming normal distributions with the same variance a statistical evaluation shows that gluing together two members before testing increased the strength in four tests, while the difference between the strength of double members and single members was insignificant in the remaining nine tests (significance level $\alpha = 1$).

Size effect
The influence of the depth of the test specimen on the strength was not evaluated in detail. Two different sizes only were tested, specimens having a depth of 125 mm and specimens having a depth of 200 mm.

The results are shown in table 3. The ratio between the tensile strength of 200 mm wide members and 125 mm wide members varies between 0.9-1.2. In series 3 and 6 the ratio was 1.0.

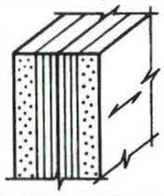
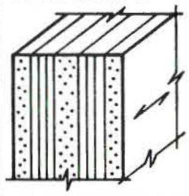
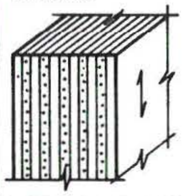
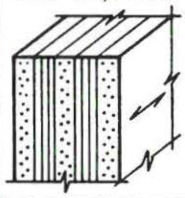
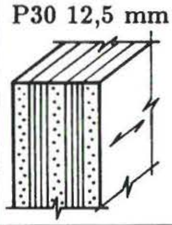
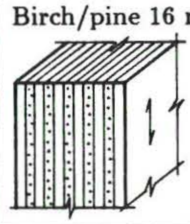
Regarding the influence of the depth of the test specimens on the bending strength the ratio between the bending strength of 200 mm deep members and that of 125 mm deep members was found to be $\frac{n_d}{n_b} \sim$ 0.9-1.0. In no case the ratio exceeded

1.0 as was the case for members in tension.

This is due to the fact that the 200 mm deep specimens in some tests tended to buckle between the lateral supports before failure.

A statistical evaluation of the test results shows that the strength in bending as well as in tension of the 125 mm members does not differ significantly from the corresponding strength properties of 200 mm members, assuming normal distributions of same variance (significance level $\alpha = 1\%$).

Table 3. Comparison between bending and tensile strength, n_m and n_0, (mean values) and evaluation of lamination effect and size of specimens on results. Values indicated in brackets, see next paragraph.

Series	Specimen		Depth in mm: 125 a	125 b	200 c	200 d	Lamination effect: n_b/n_a	n_d/n_c	Size effect: n_c/n_a	n_d/n_b
1	Canadian sheathing CSP 12,5 mm 	$n_0[Nmm^{-1}]$	204	229	208	266	1.1	1.3	1.0	1.2
		v	0.18	0.23	0.22	0.17				
		$n_m[Nmm^{-1}]$		316	(246)	314				1.0
		v		0.15		0.09				
		n_m/n_0		1.4		1.2				
2	USA sheathing 16 mm A-C 	$n_0[Nmm^{-1}]$	239	247	225	259	1.0	1.2	0.9	1.0
		v	0.33	0.19	0.19	0.22				
		$n_m[Nmm^{-1}]$		391	(310)	357				0.9
		v		0.17		0.14				
		n_m/n_0		1.6		1.4				
3	Finnish kombi 15 mm 	$n_0[Nmm^{-1}]$	527	538	537	522	1.0	1.0	1.0	1.0
		v	0.12	0.11	0.10	0.09				
		$n_m[Nmm^{-1}]$		620	(645)	627				1.0
		v		0.08		0.08				
		n_m/n_0		1.2		1.2				
4	Canadian sheathing CSP 15,5 mm 	$n_0[Nmm^{-1}]$	386	387	360	422	1.0	1.2	0.9	1.1
		v	0.17	0.18	0.17	0.16				
		$n_m[Nmm^{-1}]$	485	543	(427)	501	1.1			0.9
		v	0.11	0.12		0.13				
		n_m/n_0	1.3	1.4		1.2				
5	Swedish Vänerply P30 12,5 mm 	$n_0[Nmm^{-1}]$	196	243	220	236	1.2	1.1	1.1	1.0
		v	0.19	0.19	0.17	0.10				
		$n_m[Nmm^{-1}]$		331	(294)	315				1.0
		v		0.17		0.13				
		n_m/n_0		1.4		1.3				
6	Polish Europly Birch/pine 16 mm 	$n_0[Nmm^{-1}]$	425	442	411	421	1.0	1.0	1.0	1.0
		v	0.19	0.17	0.15	0.20				
		$n_m[Nmm^{-1}]$		600	(541)	554				0.9
		v		0.20		0.15				
		n_m/n_0		1.4		1.3				

Determination of bending strength

Testing of double members

As it appears from table 3 gluing together two members have no effect on the strength for plywoods built up of many veneer layers as is the case for series 3 and 6 each having 11 layers.

The bending strength found by testing double members as has been done in this programme therefore also apply to single members in this case. As regards plywoods built up of fewer veneer layers, 4-5, as is the case for series 1, 2, 4 and 5 it appears that gluing together two members before testing tends to increase the strength and the bending strength found by using double members does therefore not apply to single members.

The results suggest that the bending strength should be reduced about 20% in this case in order to obtain the bending strength of a single member.

The bending strength may be determined more accurately by supplementing the in-plane bending tests performed on double members by supplementing these tests with tensile tests performed on double and single members (as in this test programme).

The in-plane bending strength may then be found from the tensile strength of single members, n_o, multiplied by the ratio between the in-plane bending strength and tensile strength of double members $\frac{n_{m,double}}{n_{o,double}}$

$$n_m = \frac{n_{m,double}}{n_{o,double}} \cdot n_o$$

Using the results for 200 mm deep specimens the values of n_m indicated in brackets in table 3 are found.

Testing of single members

As an alternative to testing double members a test apparatus for testing single members could be developed. The test apparatus used in this test programme will be applicable to testing 125 mm deep members but it will require an increase of lateral supports. Testing of 200 mm members will require more comprehensive changes.

Evaluation of the bending test apparatus

The test apparatus was originally designed to test slim I-beams with wooden flanges and webs of wood based panels. However, the apparatus was used without modification when testing the in-plane bending as described above.

The lateral stability of the compression zone is a major problem when testing slim members. The lateral support by steel wheels on roller bearings proved to be satisfactory since no noticeable loss of friction was recorded.

It was noticed that a limited number of the specimens of the highest strength tended to buckle before failure, indicating that the number of lateral supports should be increased.

Conclusion

Strength and stiffness properties

The tests show that the in-plane bending strength of all plywoods tested exceeds the tensile strength significantly, i.e. by 20-50%. The smallest strength increase was found for the plywoods having the highest number of veneer layers. The modulus of elasticity in in-plane bending is found not to be different from the modulus of elasticity in tension.

Test specimens

Regarding the size of the test specimens to be used for determining the in-plane bending strength the test results show no significant difference between the strength of 125 mm deep members and 200 mm deep members, however the coefficient of variation tended to increase with smaller depth.

Regarding the effect of gluing together two members before testing the test results showed that this will result in unchanged or increased strength compared to that of single members.

For plywoods built up of many layers the strength seems to remain unchanged and the strength found is therefore applicable to single members as well.

For plywoods built up of few veneer layers the strength seems to remain unchanged or to increase. However, the test programme does not give a clear picture of the lamination effect.

Therefore, the in-plane bending strength determined from double members may include a lamination effect and it is therefore not applicable to single members in this case. However, double members may still be used if the lamination effect is eliminated by supplementing the in-plane bending tests with tensile tests performed on double and single members (as in this test programme).

The in-plane bending strength may then be found from the tensile strength of single members (determined in accordance with standards) multiplied by the ratio between the in-plane bending strength and tensile strength of double members.

As an alternative to testing double members in bending a test apparatus for testing single members could be developed. The test apparatus used in this test programme will be applicable to testing of 125 mm deep single members if the number of lateral supports are increased. Testing of 200 mm single members will require more comprehensive changes.

APPENDIX

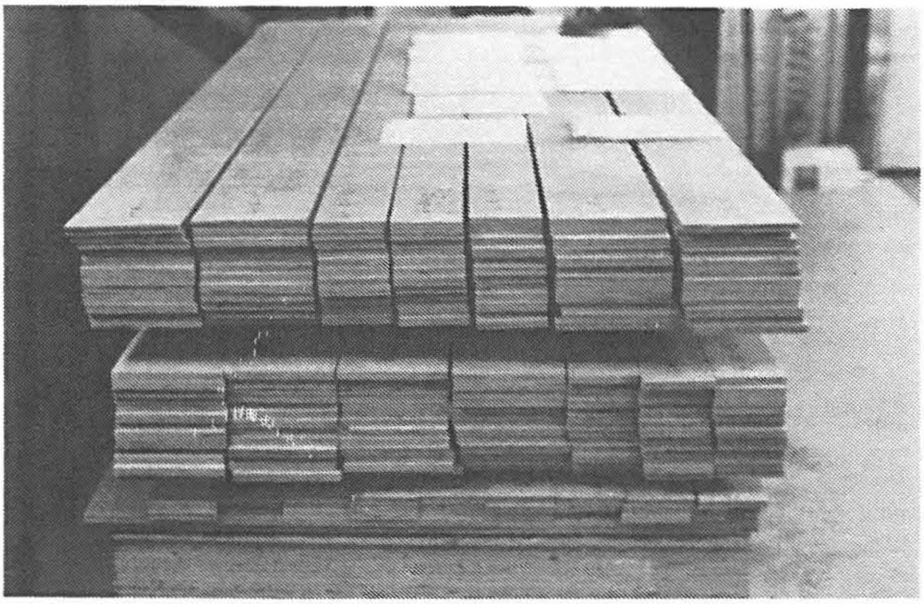


Figure A1.
Panels cut
into 125 mm
and 200 mm
samples.

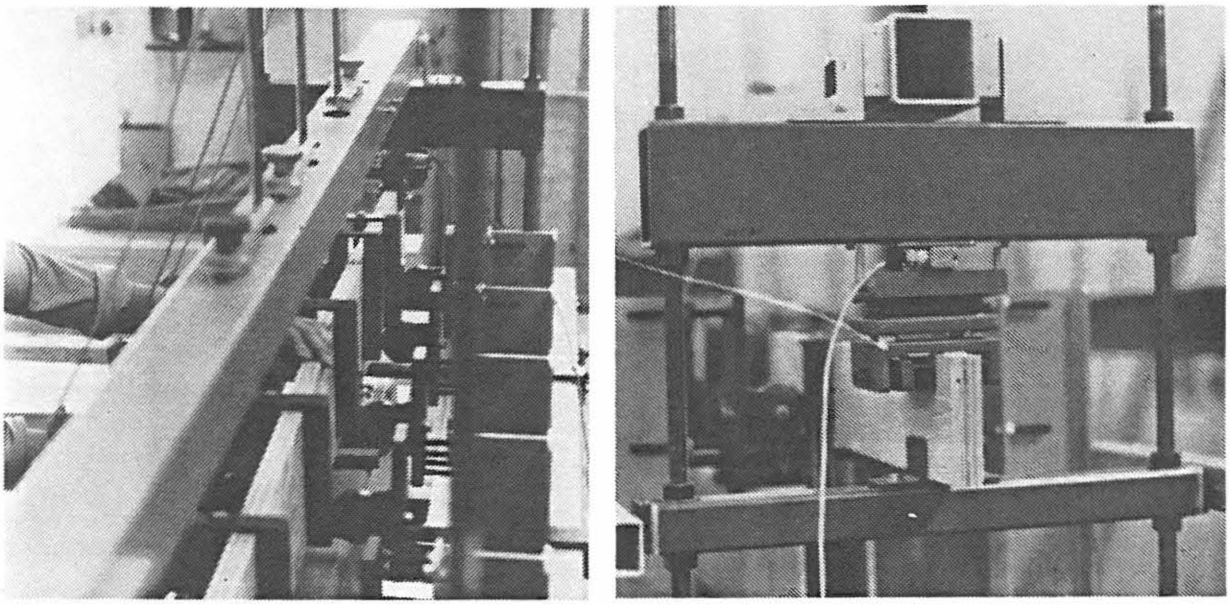


Figure A2. Bending test. Lateral supports and end support.

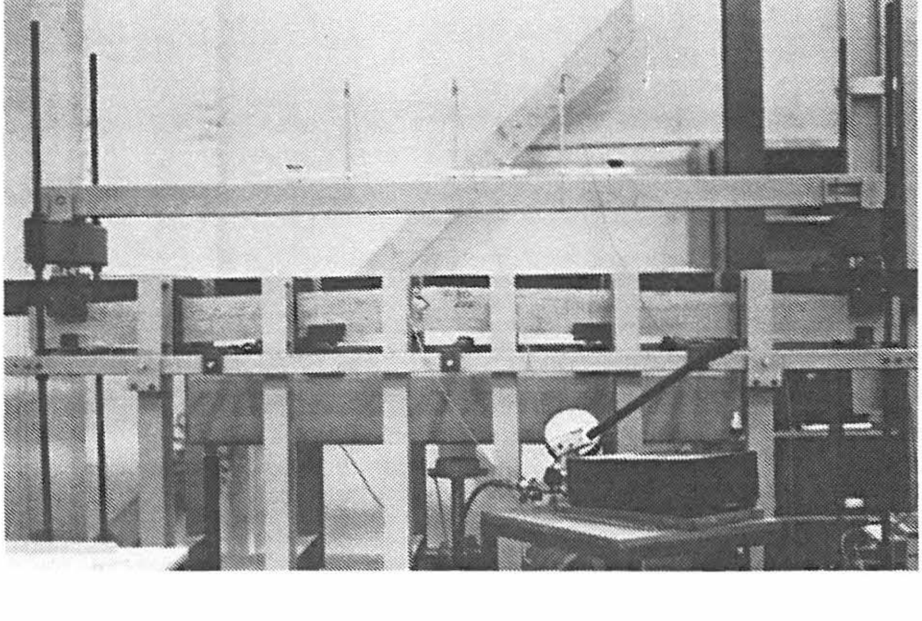


Figure A3.
Bending test.
Side view.

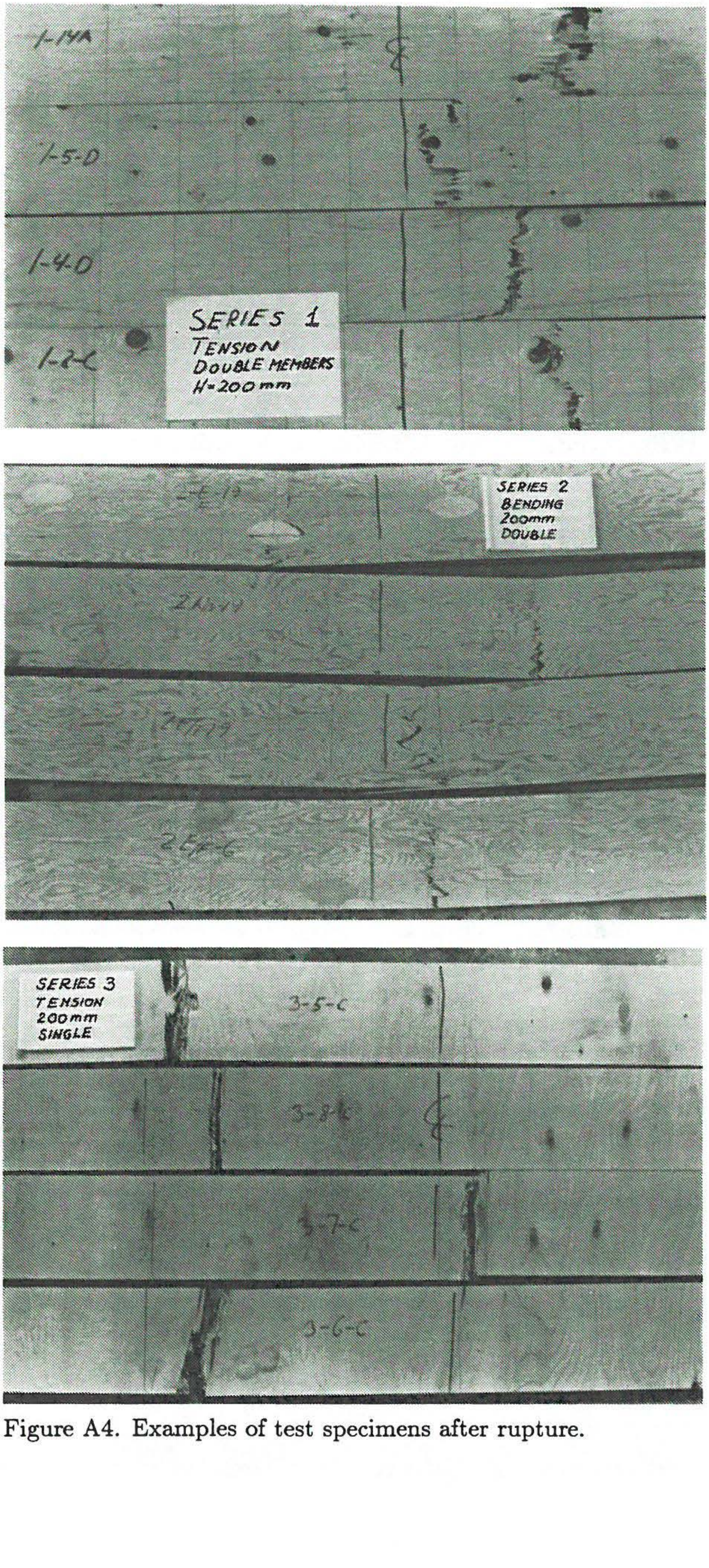


Figure A4. Examples of test specimens after rupture.