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A STUDY OF NAIL-GLUED TIMBER TRUSS JOINTS

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Wood Working and Wood Technology

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Sammendrag.

Denne artikkelen beskriver en eksperimentell undersøkelse av spikerlimte fagverkknutepunkters styrke og varighet. Undersøkelsen er utført som en samarbeidsoppgave mellom Norges byggforskningsinstitutt og Norsk Treteknisk Institutt med midler stillet til disposisjon av Norges Teknisk-Naturvitenskapelige Forskningsråd.

I alt ble ca. 150 prøvestykker av spikerlimte fagverkforbindelser i full målestokk belastet til brudd. Prøvestykkene ble fremstillet av lufttørket, høvlet granvirke, vanlig firkantstift og kaseinlim. Halvparten av prøvestykkene hadde finér knuteplater, se figurene 3—8. Prøvene representerer tre typiske forbindelser i et fagverk, slik som vist i figur 9.

Prøvene ble utsatt for varierende klimatiske betingelser før belastningsforsøket. Figurene 14 a og 14 b gir frekvensdiagrammer over de oppnådde skjærspenninger i fugene. I artikkelen vurderes resultatene, og forslag til tillatte spenninger antydes.

A study of nail-glued timber truss joints

SUMMARY

JOHANNES MOE, DR. TECHN. CIV. ENG., THE NORWEGIAN INSTITUTE OF WOOD WORKING AND WOOD TECHNOLOGY

Approximately 150 full size nail-glued timber truss joints have been tested to failure in order to determine the strength and the durability.

The specimens were made of air-seasoned Norway spruce and 50 per cent of the specimens had gussett plates of unsanded pine plywood. Common square nails and casein glue was used.

Three types of specimen representing typical truss joints were tested under different climatic conditions prior to the load test.

The paper presents the test results and also discusses allowable stresses and precautions which should be taken during the fabrication.

Etude de joints de ferme en bois cloué-collé

SOMMAIRE

JOHANNES MOE, INSTITUT NORVÉGIEN DU TRAVAIL DU BOIS ET DE LA TECHNIQUE DU BOIS

Environ 150 joints de ferme de bois cloués-collés de grande taille ont été essayés jusqu'au point de rupture en vue de déterminer la résistance et la durabilité.

Les spécimens étaient de sapin norvégien séché à l'air et 50 % des spécimens avaient des plaques d'éclissage de pin. On s'était servi de clous carrés ordinaires et de la colle caséine.

Trois sortes de spécimens représentants des joints de fermes typiques furent mis à l'essai dans des conditions climatiques différentes, antérieurement à l'essai de charge.

Le rapport présente les résultats des essais et discute des tensions permises et des précautions à prendre pendant la fabrication.

Eine Studie nagel-geleimter Fachwerkknotenpunkten

INHALTSANGABE

JOHANNES MOE, NORWEGISCHES INSTITUT FÜR HOLZARBEITEN UND HOLZTECHNOLOGIE

Ungefähr 150 nagel-geleimter Fachwerkknotenpunkten in ganzer Größe sind auf Versagen geprüft worden, um die Stärke und Dauerhaftigkeit festzustellen.

Die Probeexemplare wurden aus luftgetrocknetem Fichtenholz hergestellt und 50 % der Probeexemplare hatten Eckplatten aus ungesandetem, mehrschichtigen Tannenholz. Es wurden gebräuchliche viereckige Nägel und Kaseinleim benutzt.

Drei Probeexemplare, die typisch für die gängigen Knotenpunkten sind, wurden unter verschiedenen klimatischen Verhältnissen – vor dem Belastungsversuch – geprüft.

Der Bericht stellt die Prüfungsergebnisse und zulässige Spannungen dar, und während der Fabrikation zu treffende Vorsichtsmaßregeln werden besprochen.

Изучение гвозде-клеевых сращиваний в деревянных стропильных фермах

СВОДКА ДОКЛАДА

ЙОХАННЕС МЁ, Норвежский Институт Технологии и Обработки Дерева

Для определения их прочности и стойкости в работе были испытаны под нагрузкой до их разрушения окого 150 полноразмерных гвозде-клеевых стыков в деревянных стропильных фермах.

Эти образцы были изготовлены из норвежской ели воздушной сушки и 50% из них были снабжены косынками из сосновой нешлифованной фанеры. Для этих скреплений были применены обыкновенные квадратные гвозди и казеиновый клей.

Перед испытаниями под нагрузкой образцы трех сортов, представляющих из себя типовые стропильные скрепления, были испытаны в различных климатических условиях.

В докладе приводятся результаты этих испытаний, а также дискутируются допустимые нагрузки и предосторожности, которые следует принимать в течение процесса изготовления сращиваний.

A study of nail-glued timber truss joints

JOHANNES MOE, DR. TECHN. CIV. ENG.,

THE NORWEGIAN INSTITUTE OF WOOD WORKING AND WOOD TECHNOLOGY

1 Introduction

The application of glued connections in timber structures has been rapidly increasing during the recent years. Most notable are the developments of glued laminated and end jointed products. Through the application of high curing pressures and well controlled conditions of production, strong and reliable glue joints are obtained.

In some cases it may, however, be a considerable inconvenience that this production requires relatively heavy and expensive equipment that is only found in sizeable plants. The question then arises whether it is possible to develop a sufficient gluing pressure by means of nails. This problem has received considerable interest by several investigators.

Giese et. al. (1, 2) studied the strength of nail-glued shear block specimens made from materials of relatively low moisture contents (7–12 per cent). Casein glues or resorcinol resins were used. Some of the specimens were subjected to cyclic variations in moisture content. In joints where the grain directions of the connected members were at right angles, the variations in the moisture content tended to impair the glue line strength. This was especially true for relatively thick (2 in.) and wide (6–8 in.) members. Average shear strengths as low as 7 kg/cm.^{2} (100 p.s.i.) were observed, with extreme lows at 3·5 kg/cm.^{2} (50 p.s.i.) with resorcinol resins.

Radcliffe and *Granum*(3) investigated the effect of the nailing pattern and the surface conditions on the shear strength. The specimens were made of Douglas Fir of 12 per cent moisture content and of plywood. A casein glue was used. An allowable shear stress of 6·3 kg/cm.^{2} (90 p.s.i.) in the plane of the glue line was suggested for plywood gusset plates.

Radcliffe and *Granum*(4) also tested full-scale roof trusses with plywood gusset plates and nail-glued connections.

Kolb(4) reports on interesting studies of the gluing pressure obtained by means of nails. According to these tests a gluing pressure of approximately 1 kg/cm.^{2} (14 p.s.i.) was probably obtained with the nailing pattern which was used in the tests described in the present report.

Kolb found large variations in the shear strength of nail-glued joints. When testing joints with parallel grain directions in the members more than 30 kg/cm.^{2} (425 p.s.i.) in shear strength was always found. Small shear block specimens were used.

2 Object of investigation

The purpose of the experimental investigation which is reported here was to find whether reliable nail-glued joints can be produced from air-seasoned materials of approximately 20 per cent moisture content. Moreover, it was emphasised that the method of production ought to be relatively simple. In the case of success it might become possible to introduce nail-gluing as a means of connecting various types of elements at the building site.

3 Factors effecting the glue line strength

The successful application of nail-gluing depends on a great number of factors which will be discussed in the following. Some of these factors are of major importance also when sufficient gluing pressure is secured, but a number of special problems arise due to the low pressure obtained by nails.

3.1 TYPE OF GLUE

The type of glue should be selected with due consideration of the conditions of production as well as of service. Due to the low gluing pressure obtained in nail-gluing, it will not always be possible to bring the surfaces into close contact. A glue with good gap-filling qualities should therefore be used.

Casein glue is well suited in this respect, and besides, is relatively simple in use. Casein glue is cold setting and adheres to wood of fairly high moisture content. It was, therefore, chosen for the present investigation. Its relatively low moisture resistance is sometimes an important disadvantage.

Cold setting phenolic glues also possess many of the advantageous properties of the casein glue, and besides, are water resistant to a considerable degree. They are, however, more difficult to handle.

Urea glues are sensitive to high moisture contents in the wood at the moment of gluing, and resorcinol resins require fairly high curing pressures. These glues, therefore, require well-controlled conditions of curing.

3.2 TYPE OF NAILS

The main purpose of the nails is to produce sufficient pressure in the glue line during the period of curing. In the present investigation it was decided to use nails of square cross-section, as shown in Fig. 1. These nails are commonly used in Norway.

It is realised that round nails generally are considered to have higher withdrawal resistance and would therefore probably also give better curing pressure than the square ones.

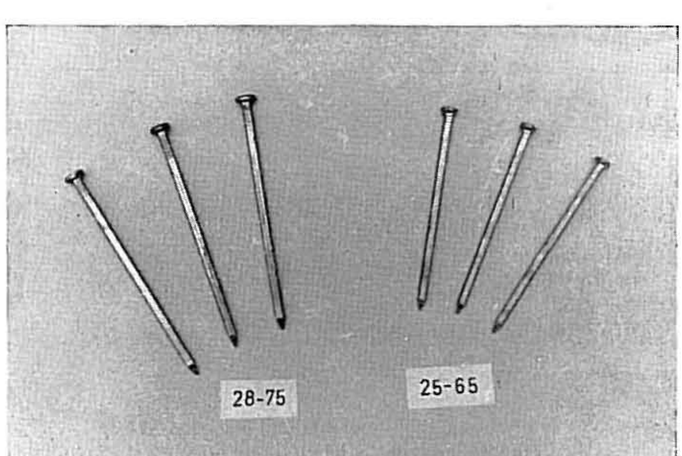

Fig. 1 Square nails for nail-gluing

The American types of improved nails, such as Screwtite, Stronghold, etc., are likely to give considerably better pressures than the other types.(6)

3.3 WOOD SPECIES

In the present investigation Norway spruce was used in all the solid wood members. Gusset plates were made from unsanded pine plywood of commercial grade glued with urea resin.

3.4 GLUING PRESSURE AND SURFACE CONDITIONS

Earlier investigations as well as preliminary tests by the author seem to indicate that it is possible to produce strong glue bonds with very low pressure if only the surfaces of the materials are perfectly plane. In practice the surfaces will always be more or less rough and in the laminating industry it is therefore usually found necessary to prescribe a pressure of 7–10 kg/cm.^{2} (100–150 p.s.i.) in order to secure close contact between the surfaces.

In the main test series of the present investigation it was decided to use dressed surfaces. The planing operation was, however, carried out while the materials were green. During the subsequent air-seasoning the materials tended to shrink to a variable extent which resulted in materials of slightly varying thicknesses. Some cupping was also found. The surfaces to be glued therefore deviated considerably from the plane. It was believed that this deviation could be compensated for in some degree by the application of relatively large amounts of glue. Throughout the main series of tests 400 g/m.^{2} (80 lb. per 1,000 sq. ft.) was used. The glue was spread on one of the pieces only. It should be realised that the use of glue lines which are too thick may result in impaired strength and durability of the joint.

3.5 MOISTURE CONTENT

Earlier studies of the moisture content of air-seasoned Norway spruce seem to indicate that well-seasoned materials contain 18–20 per cent of moisture. All of the materials for the present investigation were therefore stored in a climate corresponding to 20 per cent moisture content in the materials for several weeks before the gluing.

When the casein glue sets, most of the water which has been added to the casein powder prior to the gluing operation must somehow escape from the glue line. Uusally this water is absorbed by the wood. It is obvious that if the moisture content of the wood gets close to the point of fibre saturation, the rate of absorption slows down. Great difficulties should therefore be expected when gluing materials of moisture contents above, say, 25 per cent with casein glue. At 20 per cent moisture content the test results have been encouraging.

3.6 GRAIN DIRECTIONS

The influence of the relative grain directions on the strength of glued joints has been studied at Forest Products Laboratory in Madison.(7) On average the shear strength of a joint with an angle of 90 deg. between the grain directions was approximately 50 per cent of the value obtained with parallel grains. For angles between 0 deg. and 90 deg. the Hankinson formula was found to apply. These results were found when testing small shear block specimens of varying shapes.

When non-parallel structural members are joined with glue, the cupping of the materials may become a serious problem. If the materials are relatively thick it may be very difficult to obtain sufficient gluing pressure over the total surface even if clamps are used. When producing the pressure by means of nails the problem is still more serious.

Such connections are also the most problematic as far as durability is concerned. Variations in the moisture content of the wood impose large internal stresses in the joints due to the different amounts of shrinkage and swelling of wood in the various directions.

In joints between planks and plywood gusset plates internal stresses are developed due to changes in moisture content even if the grain direction of the face ply of the plywood is parallel with the grain direction of the plank.

Tensile stresses across the joint may develop if the materials tend to cup. In the present investigation the boards were always placed with the face side turning out, as indicated in Fig. 2.

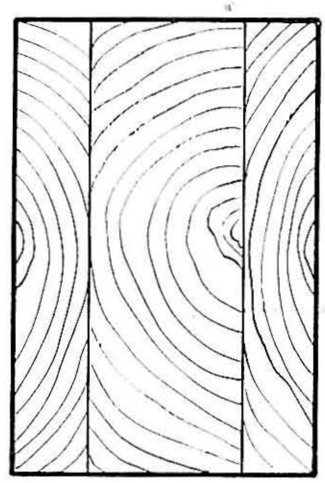

Fig. 2 Section through specimen of type I

3.7 CLIMATIC CONDITIONS

It has already been pointed out that variations in the moisture content of the materials may cause considerable internal stresses. While the moisture content of air-seasoned materials averages approximately 20 per cent, observations carried out in some Norwegian residential houses(8) showed that the moisture content after a couple of years had decreased to 11 per cent. Seasonal variations of as much as 7 per cent were observed. It is believed that, under extreme circumstances, the moisture content may go down to 8 per cent.

3.8 SIZE OF SPECIMENS

The magnitude of the internal stresses caused by changes in the moisture content of the materials is greatly dependent upon the size of the specimen. It was therefore decided to test full-size models of the joints under consideration.

Earlier investigations(9) have clearly demonstrated that the size of the specimens influences the average shear strength even when internal stresses are believed to have been of minor importance. When the area of the glued joint is large, heavy stress concentrations are likely to occur in some parts of the joint, thus causing collapse long before the average shear stress has reached a value which compares with the shear strength as observed on shear block specimens of the standard type.

Also the effects of cupping are most easily covered by means of full-size specimens.

On the other hand it is quite clear that the joints of the main series described below were not subjected to pure shear. Tensile and compressive stresses perpendicular to the planes of the joints obviously to some extent influenced the results. This will also be the case in practice.

4 Outline of tests

This report describes one major test series (Series I) and two supplementary investigations (Series II and III).

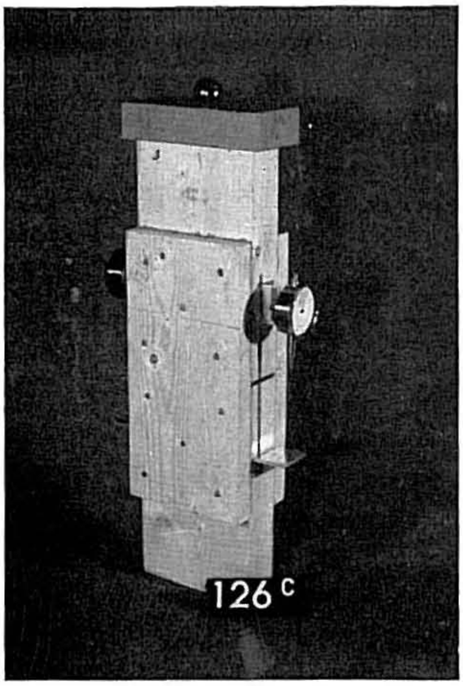

Fig. 3 Specimen of type 1

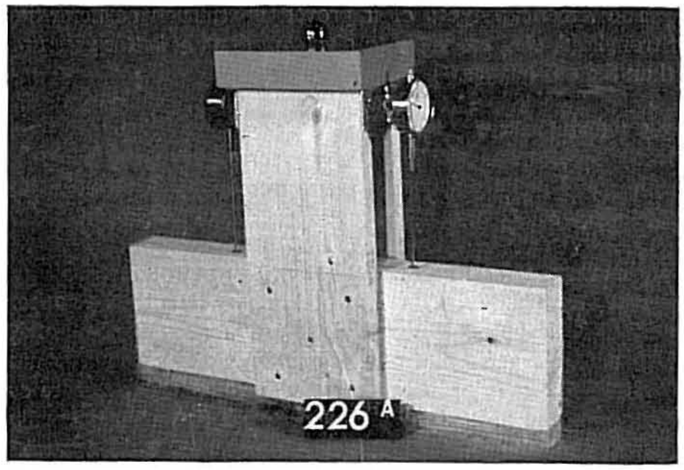

Fig. 4 Specimen of type 2

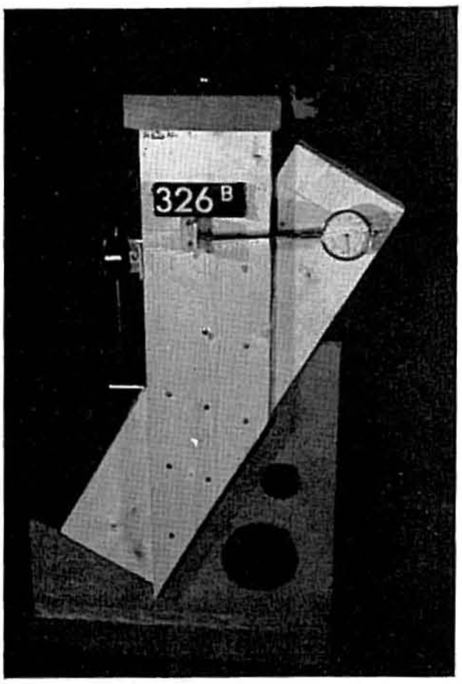

Fig. 5 Specimen of type 3

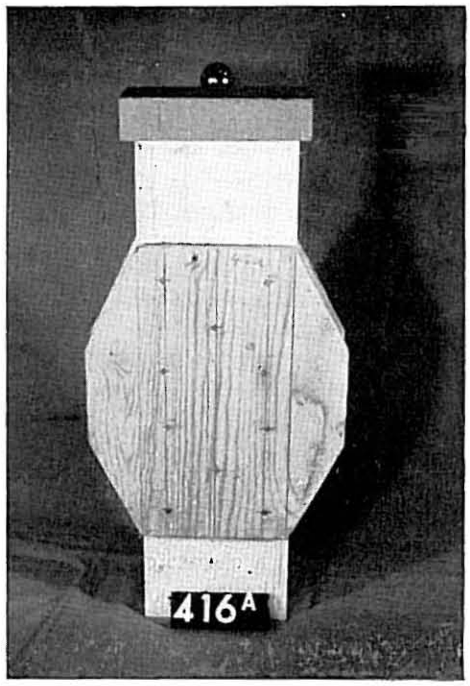

Fig. 6 Specimen of type 4

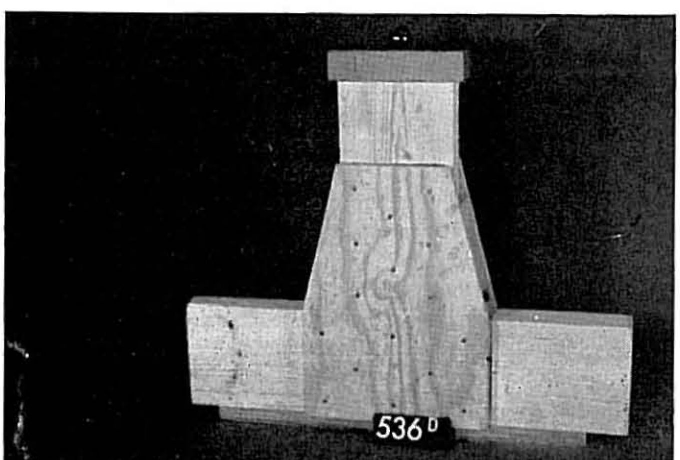

Fig. 7 Specimen of type 5

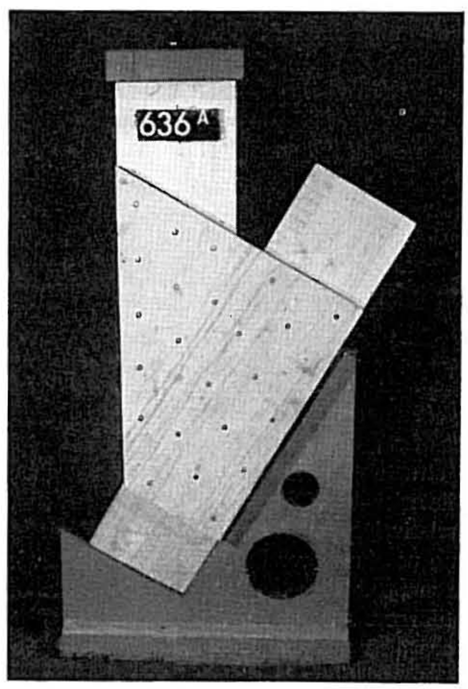

Fig. 8 Specimen of type 6

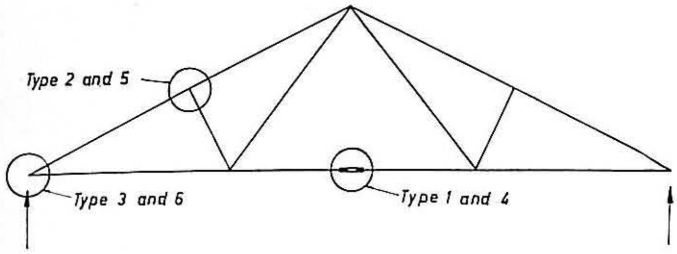

Fig. 9 Types of joints investigated

4.1 SERIES I

This main series included tests of 120 specimens, twenty of each of the six different types indicated in Figs. 3–8. All of the specimens represented typical truss joints, as indicated in Fig. 9. Each group of twenty specimens was subdivided into four groups which were given different conditions of gluing, curing and testing, as indicated in Table I. Of each sub-group of five specimens four were nail-glued while the fifth, which was cured under a pressure of 10 kg/cm.[2] (140 p.s.i.), served as a control. The numbers identifying each specimen are listed in Table I. The four nail-glued companion specimens in each sub-group are identified by the letters *a–d*.

The specimens of types 1–3 were produced from 1 in. × 6 in. boards and 2 in. × 6 in. planks. Specimens of types 4–6 were produced from 2 in. × 6 in. planks and 12 mm. or 18 mm. thick plywood of 7 and 11 plies, respectively.

For each type of specimen the materials were selected on a statistical basis, so as to minimise the effects of random variations in the quality of the material.

The principle of selection is illustrated below for specimens of type 1:

Plank *a*	116*a*	126*a*	136*a*	146*a*	156*a*
,, *b*	156*b*	116*b*	126*b*	136*b*	146*b*
,, *c*	146*c*	156*c*	116*c*	126*c*	136*c*
,, *d*	136*d*	146*d*	156*d*	116*d*	126*d*

The sequence of production was arranged correspondingly.

4.2 SERIES II

This series was designed to study the contribution of the nails to the load carrying capacity of nail-glued connections. Two specimens of each of the six types of joints were studied. One of each type was nail-glued and the other was only nailed. The same number of nails was used in both of the specimens.

4.3 SERIES III

Consisted of eight specimens, four of type 1 and four of type 4 While the two pieces of 2 in. plank in each specimen of types 1, 4 and 6 of Series I were taken from one and the same dimension, the two pieces to be connected were in Series III selected from different planks in order to study the effect of differences in the thicknesses.

5 Design and fabrication of specimens

The dimensions were chosen on the basis of preliminary tests and were designed to give glue line failures.

In order to avoid wood failures it was necesssary to make the joints of types 1 and 4 too short for practical conditions. The gusset plates of types 5 and 6 are also small. In the case of type 6 it was necessary to use plywood of 18 mm. thickness in order to avoid shear failure in the gusset plates.

TABLE I *Outline of tests, Series I*

Test Conditions		A	B	C	D	Remarks
Moisture content at gluing		Plank 20% Board and Plywood 20%	Plank 20% Board and Plywood 20%	Plank 20% Board and Plywood 20%	Plank 20% Board and Plywood 12%	
Moisture content at curing		20%	20% ↓ 12%	20% wv↘ 12%	20% ↓ 12%	
Moisture content at testing		20%	12%	12%	12%	
Designation of specimens type	1	116 *a–d* 156 *a*	126 *a–d* 156 *b*	136 *a–d* 156 *c*	146 *a–d* 156 *d*	Nail-glued Clamped, pressure: 10 kg/cm.[2]
	2	216 *a–d* 256 *a*	226 *a–d* 256 *b*	236 *a–d* 256 *c*	246 *a–d* 256 *d*	Nail-glued Clamped, pressure: 10 kg/cm.[2]
	3	316 *a–d* 356 *a*	326 *a–d* 356 *b*	336 *a–d* 356 *c*	346 *a–d* 356 *d*	Nail-glued Clamped, pressure: 10 kg/cm.[2]
	4	416 *a–d* 456 *a*	426 *a–d* 456 *b*	436 *a–d* 456 *c*	446 *a–d* 456 *d*	Nail-glued Clamped, pressure: 10 kg/cm.[2]
	5	516 *a–d* 556 *a*	526 *a–d* 556 *b*	536 *a–d* 556 *c*	546 *a–d* 556 *d*	Nail-glued Clamped, pressure: 10 kg/cm.[2]
	6	616 *a–b* 656 *a*	626 *a–d* 656 *b*	636 *a–d* 656 *c*	646 *a–d* 656 *d*	Nail glued Clamped, pressure: 10 kg/cm.[2]

In specimens of types 4 and 5 square nails No. 25/65 were used, while nails No. 28/75 were used in all other types, see Fig. 1. The nails were driven by hammer from both sides. In specimens of type 6 one nail was provided for each 35 cm.[2] of glue line area. In all other specimens the corresponding area was approximately 45 cm.[2]

The moisture content and the cupping of the material was determined immediately prior to the fabrication, see Tables III–VIII.

The casein glue was mixed in accordance with the instructions of the manufacturer and two parts of water were added to each part of glue powder (by weight). The amount of glue applied to each specimen was measured by weight and corresponded to 400 grams per sq. m. of glue line, which was applied in a single spread.

All the specimens of one particular type were fabricated on one and the same day and from the same batch of glue.

The specimens were cured at a temperature of 20° C. and a relative humidity of 85 per cent for at least seven days before testing or drying.

The control specimens were cured under a pressure of approximately 10 kg/cm.[2] glue line for two hours.

6 Test procedures and test results

6.1 TEST PROCEDURES

The specimens were loaded to failure in a testing machine of 50 tons capacity which was equipped with an Amsler pendulum manometer, see Fig. 10. The load was increased continuously up to failure, at a rate of approximately 500 kg. per minute for specimens of types 2 and 5, and 1,000 kg. per minute for all other types.

In the specimens of types 2 and 5 the vertical reaction introduced fairly large compressive stresses perpendicular to the grain direction in the horizontal 2 in. × 6 in. A thin rubber pad was placed under the 2 in. × 6 in. on each side of the joint in order to reduce the pressure under the joint. Fairly large deformations of the 2 in. × 6 in. were, however, recorded on several occasions, notably on specimens of type 5. These deformations are believed to have introduced secondary tensile stresses in the glue lines, thus reducing the strengths of the joints.

Deformations in the joints, measured as shown in Figs. 3–5 were recorded at 10 to 20 different levels of the load for each specimen.

Moisture content and specific gravity were determined for each group of specimens, and the percentage of wood failure was recorded for each specimen.

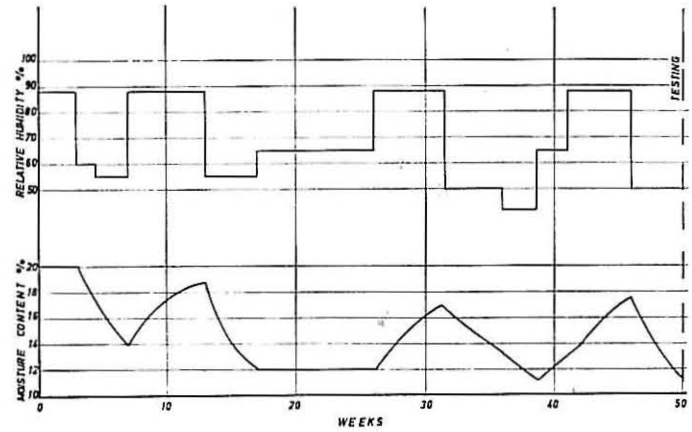

Fig. 11 Variations in moisture content and relative humidity-test condition C

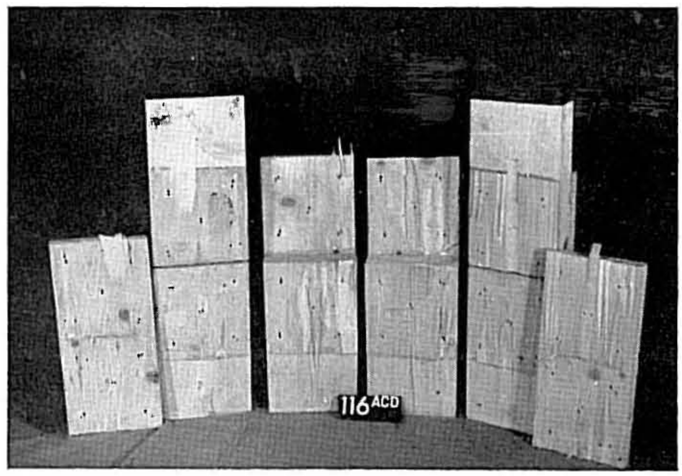

Fig. 12 Broken specimens of type 1

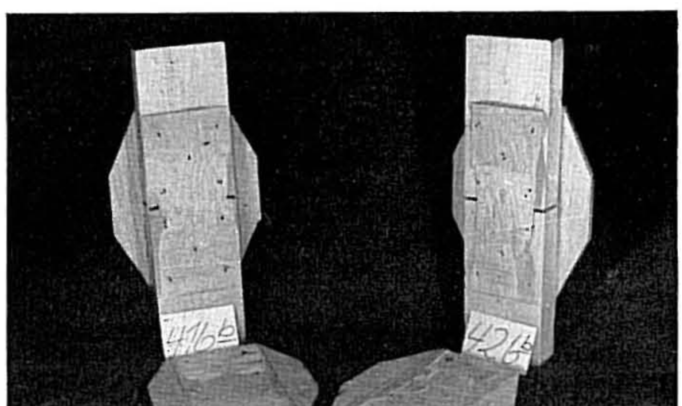

Fig. 13 Broken specimens of type 2

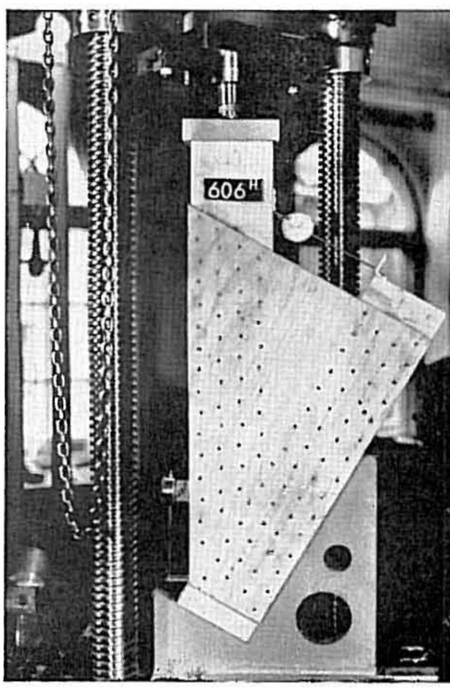

Fig. 10 Specimen in testing machine

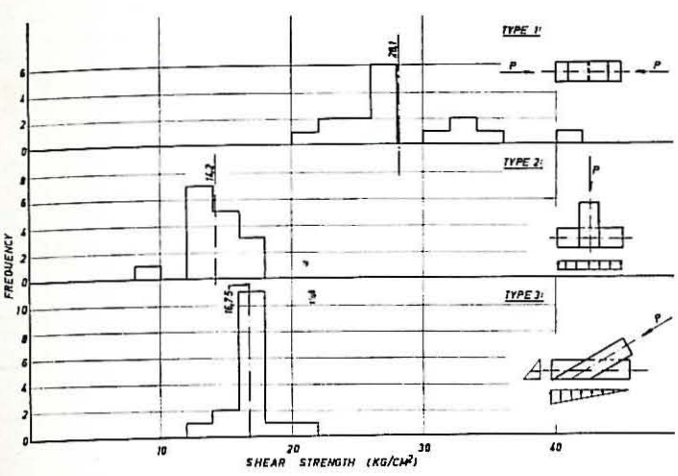

Fig. 14*a* Frequency distributions of shear strength, specimens 1–3

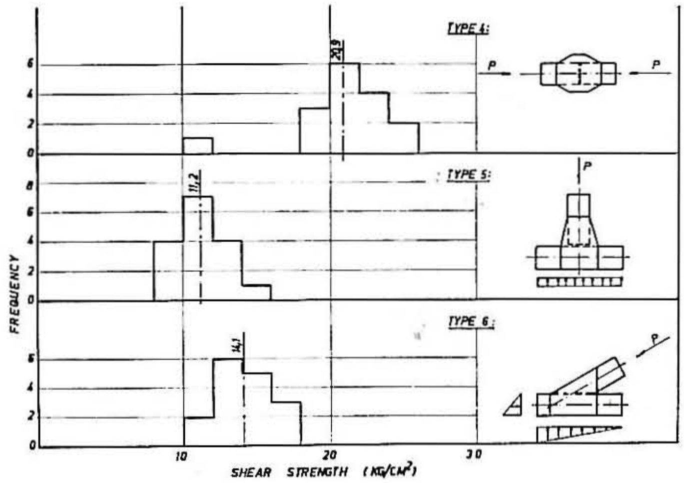

Fig. 14*b* Frequency distributions of shear strength, specimens type 4–6

Test condition C consisted of four cycles of climatic variations prior to the load test. The variations in the climatic conditions as well as in the moisture content of the specimens are plotted in Fig. 11. The load test of these specimens took place approximately one year after the production.

6.2 TEST RESULTS, SERIES I

A summary of the shearing strengths obtained is given in Table II, and additional data for each of the specimens are presented in Tables III to VIII. Some broken specimens are shown in Fig. 12.

Table II shows that the variations in the shearing strengths of specimens of the same type were relatively small. No significant difference was found between test conditions A, B and D (see Table I). An analysis of variance showed that test condition C (cyclic variations in climate) resulted in a significant reduction in strength of the specimens of type 2 – at the 5 per cent level of significance. No such significant reduction was, however, found for any of the other types of specimens.

The strengths of the joints with plywood gusset-plates were consistenty lower than those of the corresponding joints with board. The difference on the average amounted to approximately 20 per cent. The difference is probably to a large extent due to the tendency of the plywood to fail in shear in the plane of the first interior ply.

Specimen No. 426*b* failed in shear at a shearing stress of only 11·3 kg/cm.² which is about 50 per cent of the average value for the specimens of type 4. The failure took place partly in the glue line and partly in the first interior ply of the gusset-plate. The 2 in. × 6 in. plank used in this specimen had relatively large cupping. Fig. 13 clearly shows that the 2 in. × 6 in. was not properly covered with glue, but a local weakness in the plywood is believed to have played an important role in the early collapse.

In Table II all numbers in the parentheses indicate specimens which did not fail in the glue line. The values in the parentheses therefore indicate lower limits of the strengths of the pertinent glue lines.

It is interesting to note that some of the control specimens which were cured under a pressure of approximately 10 kg/cm.², failed in the glue lines at loads which were comparable to, or even below, those of the nail-glued specimens.

The average shear strengths of the specimens in which failure was caused by a collapse of the glue line are listed in Table IX. The standard deviations and the coefficients of variance which are also given in Table IX indicate a satisfactory consistency in the results. Specimen No. 426*b*, as was mentioned above, somewhat disturbs the picture for the specimens of type 4.

Figs. 14A and B present frequency distributions of the shearing strengths. These figures include all of the specimens belonging to series I.

The strength ratios shown near the bottom of Table IX indicate that the Hankinson formula does not apply. It would predict a strength ratio of approximately 0·8 for specimens with an angle of 30 deg. between the grain directions (types 3 and 6) while the tests indicated a strength ratio of only 2/3 for these specimens.

The values of the 'allowable' shear stresses given in Table IX are calculated on the basis of the following formula.

$$\nu_{\text{allow}} = \frac{2}{3} \cdot \frac{9}{16} (\nu_{\text{average}} - 2s)$$

where: ν_{allow} = allowable shear stress

ν_{average} = average shear strength

s = standard deviation

$\frac{9}{16}$ = factor accounting for long duration of loading

$\frac{3}{2}$ = factor of safety

A further discussion on the allowable shear stresses is given in Section 7.

Figs. 15A and 15B show some average curves of deformations. The variations in stiffness were, with a few exceptions, relatively moderate within the same type of specimen but varied considerably between different types. The deformations shown in Figs. 15A and 15B include some deformation of the wood, especially in the case of specimens of types 2 and 5.

6.3 TEST RESULTS, SERIES II

This series of tests clearly demonstrated that the contribution of the nails to the load carrying capacity of a nail-glued connection is negligible. Fig. 16, which pertains to the specimens of type 1, demonstrates increase in stiffness obtained by the introduction of glue into the joints. Comparable effects were obtained with the other types of joints.

6.4 TEST RESULTS, SERIES III

Tests results and other data pertaining to this series are shown in Table X. Specimens No. 166*b* and 466*b* are unfortunately of little value since the first by a mistake was nailed on one side only, while data on cupping and thickness variations are lacking for the second.

Of the remaining six specimens only No. 466*d* is lower in

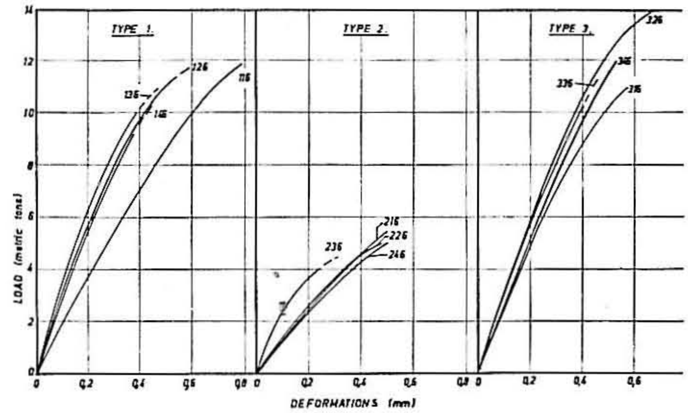

Fig. 15*a* Average deformations

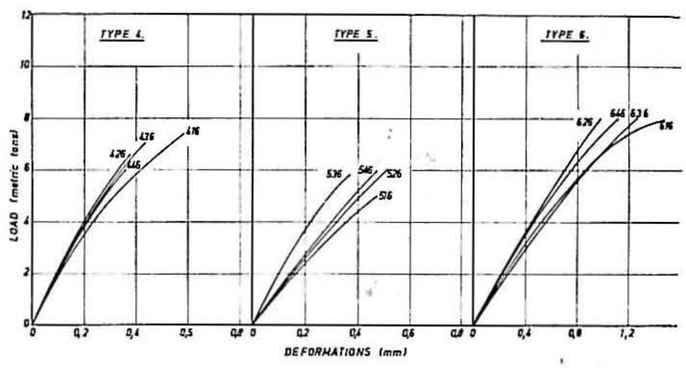

Fig. 15*b* Average deformations

strength than the average value of the corresponding specimens of Series I. The low shear strength of 16·4 kg/cm.² is probably due to the large cupping (2·25 mm.) as well as the relatively large difference in thickness between the two planks (2·1 mm.).

Additional tests should be carried out in order to establish safe limits on the permissible amount of cupping and variation in thickness.

7 Conclusions

A successful application of the technique of nail-gluing depends in a decisive degree on conscientious execution of the job. Great care should be taken to avoid materials of excessively high moisture contents. Materials with excessive cupping or twisting and large variations in thickness should also be rejected.

The surfaces to be glued together should be clean. Double spread of glue is recommended, and it is probably wise to apply a somewhat larger amount of glue than used in the present investigation, say 500 grams per sq. m.

Care should also be exercised in order to ensure that all the nails are properly driven.

Considering all these requirements with respect to high standards of production, it seems to the author that the application of nail-gluing is particularly well suited for products that are prefabricated in plants under controlled conditions and with skilled workmen.

Under such conditions the following allowable stresses seem to be safe for joints of the same size as those tested by the author:

Specimen type 1 – 7 kg/cm.² (100 p.s.i.)
,, ,, 2 – 4 ,, (56 ,,)
,, ,, 3 – 5 ,, (70 ,,)
,, ,, 4 – 5 ,, (70 ,,)
,, ,, 5 – 3 ,, (42 ,,)
,, ,, 6 – 4 ,, (56 ,,)

It should be noted, however, that secondary bending moments are introduced into the nail-glued joints of trusses due to their great stiffness. These moments may cause important secondary stresses. Tests on complete trusses should be executed in order to study these effects.

It may be wise to provide the joints with a sufficient number of nails to avoid complete collapse in the case of glue line failure.

The nails which were used in the present investigation would probably carry a lateral load of approximately 90 kg. each at a deformation of 5 mm. in the joints. The allowable lateral load for nails No. 28/75 is approximately 30 kg.

In order to provide the specimens of the present investigation with enough nails to carry the entire allowable load at a deformation of 5 mm., it would be necessary to increase the number of nails by the following percentages:

Specimen type 1 – 230 per cent
,, ,, 2 – 90 ,,
,, ,, 3 – 170 ,,
,, ,, 4 – 140 ,,
,, ,, 5 – 50 ,,
,, ,, 6 – 55 ,,

For all the specimens this extra safety would be obtained with approximately one-third of the number of nails required to take the same load in a purely nailed connection.

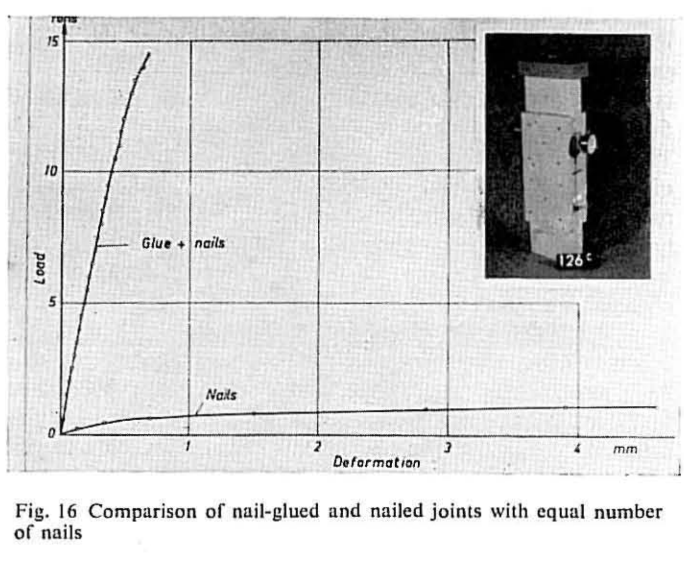

Fig. 16 Comparison of nail-glued and nailed joints with equal number of nails

8 Acknowledgments

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TABLE II *Summary of test results, Series I Shear strength in kg/cm.*^{2}

Specimen		Nail-glued specimens						Control speci-men
Type	No.	*a*	*b*	*c*	*d*	Average*	Average†	
	116	20·8	27·6	26·4	26·7	25·4	25·4	(31·8)
	126	26·5	26·6	(32·4)	22·5	25·2	(27·0)	27·0
1	136	30·9	(35·1)	27·0	25·5	27·8	(29·6)	(24·8)
	146	(32·7)	(40·5)	23·7	24·9	24·3	(30·5)	(29·0)
	216	14·0	15·6	17·0	14·3	15·2	15·2	13·7
	226	17·4	14·5	15·7	13·7	15·3	15·3	11·9
2	236	13·6	12·1	9·9	12·4	12·0	12·0	11·8
	246	16·1	13·7	13·2	13·6	14·2	14·2	(15·0)
	316	13·4	(17·5)	(17·1)	16·3	14·9	(16·1)	15·5
	326	16·5	(21·5)	(16·5)	16·6	16·6	(17·8)	22·3
3	336	14·0	(16·2)	(16·3)	17·6	15·8	(16·0)	(19·5)
	346	17·2	(19·5)	(15·0)	16·8	17·0	(17·1)	(18·2)
	416	24·2	21·4	(18·9)	20·9	22·2	(21·4)	(25·5)
	426	23·0	11·3	(21·5)	20·5	18·3	(19·1)	(25·3)
4	436	(22·2)	18·5	(22·4)	21·2	19·9	(21·1)	(22·0)
	446	19·5	23·2	20·4	24·9	22·0	22·0	26·2
	516	10·4	11·1	10·0	12·0	10·9	10·9	(10·7)
	526	10·4	12·5	9·6	14·0	11·6	11·6	10·5
5	536	11·3	9·9	9·7	10·4	10·3	10·3	7·8
	546	12·7	11·4	9·5	13·9	11·9	11·9	11·2
	616	14·2	13·6	13·6	15·7	14·3	14·3	17·1
	626	14·4	10·2	16·7	13·2	13·6	13·6	15·9
6	636	16·8	11·9	13·5	13·3	13·9	13·9	16·8
	646	16·1	14·3	13·2	14·9	14·6	14·6	(17·8)

* Includes only glue line failures. † Includes all four specimens.

TABLE III *Test results, Series I. Specimens of type* 1

Speci-men No.	Cup*		Moisture content at production		Moisture content at testing		Ulti-mate load	Av. shear str.	Wood failure	Type of failure
	Face side mm.	Core side mm.	Plank %	Board %	Plank %	Board %	kg.	kg/cm.²	%	
116*a*	+0·04 —0·28	+0·18 +0·16	21·1	20·2			8,950	20·8	5	Glue line
b	—0·35 +0·04	+0·66 +0·07	21·0	20·0			11,900	27·6	50	,,
c	—0·21 —0·12	+0·56 +0·15	21·1	19·8	18·4	20·6	11,350	26·4	20	,,
d	—0·04 —0·16	+0·20 +0·24	20·6	19·9			11,500	26·7	70	,,
156*a*	—0·02 —0·16	+0·29 +0·16	21·1	20·2			13,700	31·8	100	2 in. × 6 in. split
126*a*	0 —0·22	+0·33 —0·01	21·1	20·2			11,400	26·5	40	Glue line
b	—0·18 +0·12	+0·47 +0·07	21·0	20·0			11,450	26·6	30	,,
c	—0·24 +0·08	+0·51 0	21·1	19·8	13·4	11·7	13,960	32·4	100	2 in. × 6 in. split
d	+0·04 —0·28	+0·31 +0·34	20·6	19·9			9,700	22·5	30	Glue line and 2 in. × 6 in.
156*b*	—0·29 +0·09	+0·60 —0·05	21·0	20·0			11,650	27·0	100	2 in. × 6 in. split
136*a*	—0·08 +0·01	+0·40 —0·10	21·1	20·2			13,300	30·9	35	Glue line and 2 in. × 6 in.
b	—0·10 +0·12	+0·42 +0·05	21·0	20·0			15,150	35·1	80	2 in. × 6 in. split
c	—0·27 +0·01	+0·63 +0·12	21·1	19·8	12·0	12·0	11,650	27·0	60	Glue line and 2 in. × 6 in.
d	+0·02 —0·15	+0·78 +0·19	20·6	19·9			11,000	25·5	15	,,
156*c*	—0·20 —0·10	+0·45 +0·16	21·1	19·8			10,700	24·8	100	2 in. × 6. in split
146*a*	+0·11 —0·65	+0·17	21·1	14·0			14,100	32·7	100	,,
b	—0·29 —0·77	+0·51	21·0	13·7			17,460	40·5	100	,,
c	—0·20 —0·90	+0·55	21·1	13·9	13·2	11·7	10,200	23·7	100	Glue line
d	0 —0·20	+0·85	20·6	13·9			10,720	24·9	40	,,
156*d*	—0·06 —0·45	+0·27 +0·19	20·6	13·9			12,500	29·0	100	2 in. × 6 in. split

* First lines: planks.
Second lines: boards

Area of glue line: 430 cm.²
No. of nails: 10.

TABLE IV *Test results, Series I Specimens of type 2*

Specimen No.	Cup* Face side mm.	Cup* Core side mm.	Moisture content at production Plank %	Moisture content at production Board %	Moisture content at testing Plank %	Moisture content at testing Board %	Ultimate load kg.	Av. shear str. kg/cm.²	Wood failure %	Type of failure
	—0·10	+0·44								
216*a*	—0·28	+0·47	20·8	20·4			5,950	14·0	5	Glue line
	—0·42	+0·58								
b	—0·32	+0·21	21·1	20·3			6,650	15·6	10	,,
	—0·20	+0·29								
c	—0·09	+0·22	21·1	20·4	19·7	20·4	7,250	17·0	40	,,
	—0·15	+0·14								
d	—0·15	+0·21	21·1	20·4			6,100	14·3	30	,,
	—0·10	+0·60								
256*a*	+0·30	—0·26	20·8	20·4			5,850	13·7	50	,,
	—0·05	+0·28								
226*a*	+0·17	—0·16	20·8	20·4			7,430	17·4	30	,,
	—0·36	+0·51								
b	—0·31	+0·27	21·1	20·3			6,200	14·5	20	,,
	—0·04	+0·17								
c	—0·13	+0·27	21·1	20·4	12·8	11·7	6,700	15·7	20	,,
	—0·11	+0·29								
d	—0·19	+0·30	21·1	20·4			5,850	13·7	50	,,
	—0·47	+0·68								
256*b*	—0·13	+0·10	21·1	20·3			5,060	11·9	10	,, violent
	—0·02	+0·22								
236*a*	+0·12	—0·02	20·8	20·4			5,800	13·6	10	Glue line
	—0·42	+0·65								
b	—0·31	+0·34	21·1	20·3			5,150	12·1	30	,,
	—0·17	+0·29								
c	—0·14	+0·37	21·1	20·4	11·6	11·6	4,200	9·9	20	,,
	—0·16	+0·32								
d	—0·19	+0·30	21·1	20·4			5,280	12·4	30	,,
	—0·25	+0·32								
256*c*	—0·06	+0·26	21·1	20·4			5,030	11·8	100	In 1 in. × 6 in. board
	+0·12	+0·27								
246*a*	—0·21		20·8	13·8			6,850	16·1	80	Glue line
	—0·60	+1·05								
b	—0·83		21·1	13·9			5,850	13·7	30	,,
	—0·18	+0·34								
c	—0·94		21·1	13·8	12·9	11·8	5,630	13·2	20	,,
	—0·51	+0·67								
d	—0·90		21·1	13·9			5,800	13·6	10	,,
	—0·10	+0·30								
256*d*	—0·42		21·1	13·9			6,380	15·0	70	Failure in plank

* First lines: planks.
Second lines: boards.

Area of glue line: 426 cm.²
No. of nails: 10.

TABLE V *Test results, Series I Specimens of type 3*

Speci-men No.	Cup* Face side mm.	Cup* Core side mm.	Moisture content at production Plank %	Moisture content at production Board %	Moisture content at testing Plank %	Moisture content at testing Board %	Ultimate load kg.	Av. shear str. kg/cm.²	Wood failure %	Type of failure
	—0·19	+0·30								
316*a*	—0·15	+0·10	21·2	19·3			11,450	13·4	15	Glue line
	—0·50	+0·58								
b	—0·27	+0·18	(20·8)	18·8			14,950	17·5	100	Failure in 1 in. × 6 in.
	0	+0·06								
c	—0·49	+0·37	20·2	20·0	19·6	20·5	14,600	17·1	100	,,
	—0·06	+0·09								
d	—0·09	+0·05	20·9	(19·5)			13,900	16·3	20	Glue line
	—0·09	+0·08								
356*a*	—0·05	+0·11	21·2	19·3			13,200	15·5	100	Failure in 1 in. × 6 in.
	—0·08	+0·09								
326*a*	—0·14	+0·16	21·2	19·3			14,050	16·5	90	Glue line
	—0·09	+0·14								
b	—0·36	+0·33	(20·8)	18·8			18,350	21·5	100	Failure in 1 in. × 6 in.
	—0·37	+0·30								
c			20·2	20·0	12·8	11·7	14,050	16·5	100	,,
	—0·10	+0·31								
d	+0·08	+0·09	20·9	(19·5)			14,130	16·6	50	Glue line
	—0·32	+0·48								
356*b*	+0·07	—0·12	(20·8)	18·8			18,980	22·3	30	,,
	—0·23	+0·27								
336*a*	—0·30	+0·34	21·2	19·3			11,900	14·0	20	Glue line
	—0·60	+0·80								
b	—0·08	+0·06	(20·8)	18·8			13,830	16·2	100	Failure in 1 in. × 6 in.
	—0·73	+0·69								
c	—0·04	+0·04	20·2	20·0	11·1	11·1	13,900	16·3	100	,,
	0	+0·02								
d	—0·06	+0·14	20·9	(19·5)			15,000	17·6	25	Glue line
	—0·30	+0·09								
356*c*	—0·60	+0·70	20·2	20·0			16,630	19·5	100	Failure in 1 in. × 6 in.
	—0·90									
346*a*			21·2	(13·1)			14,700	17·2	50	Glue line
	—0·70									
b			(20·8)	(13·1)			16,580	19·5	50	,,
	—0·25									
c			20·2	(13·1)	12·5	12·7	12,820	15·0	50	Failure in 1 in. × 6 in.
d	—0·55		20·9	13·1			14,300	16·8	20	Glue line
	—0·02	+0·03								
356*d*	+0·03	+0·08	20·9	(13·1)			15,530	18·2	100	Failure in 1 in. × 6 in.

* First lines: planks.
Second lines: boards.

Area of glue line: 853 cm.²
No. of nails: 18.

TABLE VI *Test results, Series I. Specimens of type* 4

Specimen No.	Cup* Face side mm.	Cup* Core side mm.	Moisture content at production Plank %	Moisture content at production Plywood %	Moisture content at testing Plank %	Moisture content at testing Plywood %	Ultimate load kg.	Av. shear str. kg/cm.²	Wood failure %	Type of failure
	—0·08	+0·41								
416*a*	+0·78	+0·18	20·5	20·1			10,440	24·2	60	Glue line
	—0·38	+1·31								
b	+0·51	+1·20	19·6	20·1			9,200	21·4	90	,,
	+0·01	+0·64								
c	+0·12	+0·65	20·0	20·1	22·9	21·3	8,130	18·9	40	Eccentric load
	—0·16	+0·38								
d	—0·12	+0·79	20·1	20·1			9,000	20·9	90	Glue line
	—0·11	+0·44								
456*a*	+0·09	+0·32	20·5	20·1			11,000	25·5	100	Plywood buckled
	—0·14	+0·48								
426*a*	—0·12	+0·42	20·5	20·1			9,900	23·0	80	Glue line
	—0·44	+1·10								
b	—0·52	+1·10	19·6	20·1			4,880	11·3	50	,,
	+0·19	+0·61								
c	—0·30	+0·81	20·0	20·1	13·2	14·1	9,240	21·5	100	Splitting of 2 in. × 6 in.
	—0·54	+0·20								
d	—0·15	+0·71	20·1	20·1			8,820	20·5		Glue line
	—0·36	+0·12								
456*b*	—0·32	+0·89	19·6	20·1			10,900	25·3	100	Splitting of 2 in. × 6 in.
	—0·07	+0·48								
436*a*	—0·10	+0·48	20·5	20·1			9,580	22·2	80	Splitting of 2 in. × 6 in.
	+0·57	+1·08								
b	—0·35	+1·05	19·6	20·1			7,950	18·5	20	Glue line
	+0·28	+0·51								
c	+0·48	+0·41	20·0	20·1	11·2	11·2	9,650	22·4	90	Splitting of 2 in. × 6 in.
	+0·14	+0·35								
d	+0·31	+0·23	20·1	20·1			9,150	21·2	90	Glue line
	+0·06	+0·65								
456*c*	+0·10	+0·59	20·0	20·1			9,450	22·0	100	Splitting of 2 in. × 6 in.
	—0·15	+0·41								
446*a*	—0·06	+0·41	20·5	14·0			8,400	19·5	50	Glue line
	—0·45	+0·95								
b	—0·36	+1·00	19·6	14·0			10,000	23·2	80	,,
	—0·02	+0·74								
c	+0·04	+0·61	20·0	14·0	13·2	14·1	8,800	20·4	80	,,
	+0·12	+0·34								
d	+0·09	+0·40	20·1	14·0			10,710	24·9	90	Splitting of 2 in. × 6 in.
	+0·07	+0·57								
446*d*	—0·22	+0·77	20·1	14·0			11,300	26·2	100	Glue line

* First lines: planks.
Second lines: plywood.

Area of glue line: 430 cm.²
No. of nails: 10.

TABLE VII *Test results, Series I Specimens of type 5*

Specimen No.	Cup* Face side mm.	Cup* Core side mm.	Moisture content at production Plank %	Moisture content at production Plywood %	Moisture content at testing Plank %	Moisture content at testing Plywood %	Ultimate load kg.	Av. shear str. kg/cm.²	Wood failure %	Type of failure
	−0·26	+0·44								
516*a*	−0·14	+0·45	19·7	20·1			7,620	10·4	20	Glue line
	+0·14	+0·14								
b	−0·01	+0·26	19·4	20·1			8,130	11·1	5	,,
	+0·40	+1·05								
c	−0·23	+0·73	19·7	20·1	21·0	21·3	7,300	10·0	50	,,
	+0·17	+0·50								
d	−0·05	+0·49	19·4	20·1			8,780	12·0	20	,,
	−0·15	+0·28								
556*a*	−0·01	+0·27	19·7	20·1			7,800	10·7	30	,,
	−0·10	+0·48								
526*a*	−0·09	+0·35	19·7	20·1			7,625	10·4	10	,,
	−0·10	+0·36								
b	−0·11	+0·35	19·4	20·1			9,160	12·5	10	,,
	−0·25	+1·08								
c	−0·25	+0·89	19·7	20·1	13·2	12·6	7,000	9·6	20	,,
	+0·16	+0·11								
d	+0·16	+0·51	19·4	20·1			10,200	14·0	100	,,
	−0·07	+0·71								
556*b*	+0·11	+0·32	19·4	20·1			7,700	10·5	40	,,
	−0·20	+0·48								
536*a*	−0·10	+0·66	19·7	20·1			8,250	11·3	30	,,
	−0·10	+0·38								
b	−0·16	+0·26	19·4	20·1			7,240	9·9	50	,,
	−0·42	+1·07								
c	−0·28	+1·05	19·7	20·1	11·3	11·3	7,070	9·7	50	,,
	+0·48	+0·24								
d	+0·06	+0·60	19·4	20·1			7,580	10·4	30	,,
	−0·06	+0·72								
556*c*	−0·19	+0·60	19·7	20·1			5,700	7·8	40	,,
	−0·13	+0·27								
546*a*	+0·68	+0·65	19·7	14·0			9,250	12·7	50	,,
	−0·07	+0·61								
b	−0·02	+0·35	19·4	14·0			8,320	11·4	10	,,
	−0·48	+1·28								
c	−0·36	+1·10	19·7	14·0	13·2	12·6	6,950	9·5	15	,,
	+0·05	+0·45								
d	+0·09	+0·34	19·4	14·0			10,150	13·9	60	,,
	+0·09	+0·53								
556*d*	−0·12	+0·83	19·4	14·0			8,200	11·2	90	,,

* First lines: planks.
Second lines: plywood.

Area of glue line: 730 cm.²
No. of nails: 16.

TABLE VIII *Test results, Series I Specimens of type 6*

Speci-men No.	Cup* Face side mm.	Cup* Core side mm.	Moisture content at production Plank %	Moisture content at production Ply-wood %	Moisture content at testing Plank %	Moisture content at testing Ply-wood %	Ulti-mate load kg.	Av. shear str. kg/cm.^{2}	Wood failure %	Type of failure
	+0·18	+0·10								
616*a*	+0·13	+0·21	20·4	20·1			10,600	14·2	30	Glue line
	—0·05	+0·38								
b	—0·43	+1·29	20·1	20·1			10,100	13·6	60	,,
	—0·06	+0·46								
c	—0·15	+0·90	18·6	20·1	20·4	21·3	10,100	13·6	40/70	,,
	+0·18	+0·10								
d	+0·08	+0·37	19·4	20·1			11,650	15·7	5	,,
	+0·06	+0·04								
656*a*	+0·09	+0·06	20·4	20·1			12,700	17·1	100	,,
	+0·12	+0·21								
626*a*	+0·03	+0·28	20·4	20·1			10,700	14·4	50	,,
	—0·04	+0·90								
b	—0·42	+1·14	20·1	20·1			7,600	10·2	20	,,
	+0·01	+0·32								
c	+0·53	+0·10	18·6	20·1	12·9	12·0	12,460	16·7	60	,,
	+0·16	+0·14								
d	+0·10	+0·30	19·4	20·1			9,840	13·2	20	,,
	—0·78	+1·40								
656*b*	—0·50	+1·37	20·1	20·1			11,800	15·9	80	,,
	+0·36	+0·05								
636*a*	+0·01	+0·21	20·4	20·1			12,550	16·8	60	,,
	—0·14	+0·70								
b	—0·36	+1·00	20·1	20·1			8,850	11·9	10	,,
	+0·24	+0·21								
c	+0·17	+0·16	18·6	20·1	11·3	11·3	10,050	13·5	10	,,
	+0·05	+0·42								
d	+0·24	+0·50	19·4	20·1			9,950	13·3	15	,,
	—0·35	+1·07								
656*c*	—0·10	+0·56	18·6	20·1			12,500	16·8	80	,,
	+0·09	+0·04								
646*a*	+0·10	+0·16	20·4	14·0			11,960	16·1	20	,,
	—0·38	+0·55								
b	—0·28	+0·57	20·1	14·0			10,680	14·3	60	,,
	+0·11	+0·54								
c	—0·37	+0·86	18·6	14·0	12·9	11·9	9,800	13·2	30	,,
	+0·17	+0·42								
d	+0·05	+0·62	19·4	14·0			11,060	14·9	30	,,
	—0·05	+0·58								
656*d*	+0·15	+0·56	19·4	14·0			13,260	17·8	100	Compression, 2 in. × 6 in.

* First lines: planks.
Second lines: plywood.

Area of glue line: 744 cm.^{2}
No. of nails: 20.

TABLE IX *Ultimate and 'allowable' shear stresses*

	Specimen type					
	1	2	3	4	5	6
Number of glue line failures	12	16	8	12	16	16
Average shear strength (kg/cm.^{2})	25·8	14·2	16·1	20·8	11·2	14·1
Standard deviation (kg/cm.^{2})	2·78	1·90	1·51	3·52	1·47	1·72
Coefficient of variance (%)	10·7	13·4	9·4	17·0	13·1	12·2
'Allowable' shear stresses (kg/cm.^{2})	7·6	3·9	4·9	5·1	3·1	4·0
Strength ratio	1·0	0·55	0·62	1·0	0·56	0·68
Strength of control specimens (kg/cm.^{2})	27·0	12·5	22·3	26·2	9·8	16·6

TABLE X *Test results, Series III*

Speci-men No.	Cup*		Thickness		Ultimate load	Average shear strength	Wood failure	Type of failure
	Face side mm.	Core side mm.	Plank 1 mm.	Plank 2 mm.	kg.	kg/cm.^{2}	%	
	−0·05	+0·01						
166*a*	−1·19	+2·44	47·1	46·1	11,030	25·6	80	Glue line
	−0·10	+0·22						
b	−0·26	+0·48	47·1	47·8	(4,530)	(10·5)	0	,,
	−0·11	+0·89						
c	−0·19	+0·44	47·9	47·7	13,600	31·6	100	Splitting of 2 in. × 6 in.
	−1·38	+2·37						
d	−0·05	+0·34	46·4	47·9	11,250	26·1	100	,,
	−0·07	+0·24						
466*a*	−1·11	+2·39	47·0	46·4	9,580	22·2	80	,,
b					8,330	19·3		Glue line
	−0·24	+0·51						
c	−0·12	+0·45	48·0	47·7	9,800	22·8	70	,,
	−1·11	+2·25						
d	−0·05	+0·19	46·0	48·1	7,080	16·4	70	,,

* First lines: planks.
Second lines: boards.

Area of glue line: 430 cm.^{2}
No of nails: 10.

Mosture content at production: planks 21·0 per cent, boards 21·0 per cent
Moisture content at testing: planks 15·0 per cent, boards 15·0 per cent

WILLIAMS, LEA AND COMPANY, LIMITED, WORSHIP STREET, E.C.2

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