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Mechanics of stripped CLT panels with numerical validity testing

Md. Zahid Hasan[a,*], Sabhasachi Saha[b], Souvik Roy[c], Md. Sazid Rahman[d]

Department of Industrial & Production Engineering, Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh

[a-d]E-mail address: zahidipe13@gmail.com , sabha.showmo@gmail.com , souvikroyksd@gmail.com , sazidrahmanipe@gmail.com

*Corresponding author: zahidipe13@gmail.com

ABSTRACT

Cross-laminated timber (CLT) is a board molded designed wood item, amassed of cross-wise situated layers of lamellas. Subsequently, anticipating the particular conduct of such boards requires exact data about their twisting and shear quality and additionally their flexible properties. Directions with respect to the inference of execution qualities, assessment of similarity and stamping of wood-based boards for use in development are given in EN 13986. As per this standard bowing quality and stiffness of CLT must be evaluated following the system in EN 789. The last requires 4-point twisting trial of strip-formed examples with a width of 300 mm, remove the CLT boards. The traverse must be taken as 300 mm + 32 t, t being the ostensible thickness of the CLT board. By looking at aftereffects of bowing tests on strip-formed examples and on full boards it is appeared, that neither quality nor stiffness properties determined by testing strip-molded boards are suitable to survey the separate properties of the first boards. Moreover a check via doing static twisting tests (diversion estimations) under various stacking circumstances appeared, that the general stiffness properties (versatile parameters of the stiffness network) can, on the other hand to EN 789 tests or estimations with the compound hypothesis, be determined straightforwardly by a modular investigation of full-measure CLT boards.

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***Keywords*:** Cross-laminated solid timber, CLT, bending strength / stiffness, failure mode, EN 789, rolling shear, NDE, modal analysis, production control, variation of mechanical properties

1. INTRODUCTION

Cross-laminated timber (CLT) is a board formed designed wood item (EWP), amassed of cross-wise arranged layers of lamellas (for the most part softwood) which contrasted with the crude material advantages from homogenized mechanical properties. As opposed to other board formed EWP, CLT isn't just utilized as part of auxiliary components, but instead for stack bearing plates and shear boards itself. Concerning other load bearing auxiliary components too, the plan of CLT requires check of adequate quality and serviceability. Since practically speaking the outline of plates stacked opposite to the plane is frequently administered by serviceability models like maximal diversion and vibration helplessness, foreseeing the satisfactory conduct of such boards must be founded on precise data about their flexible properties other than their twisting and shear quality.

Controls with respect to the deduction of execution qualities, assessment of similarity and (CE-) stamping of wood-based boards for use in developments are given in EN 13986 [1]. There CLT is called "Strong Wood Panel" (SWP) and as to inferring the alleged "execution attributes" bowing quality and bowing stiffness reference is made to the standard EN 789 [2]. EN 789 requests 4-point twisting trial of strip-formed examples with a width of 300 ±5 mm cut from the CLT boards. The traverse must be taken as 300 mm ±32 t, t being the ostensible thickness of the CLT board.

As per EN 789 inspecting needs to ensure satisfactory thought of inconstancy inside the creation of the EWP by following certain cutting plans of the crude plates. The standard EN 13353 [3] being important for the necessities on SWP permits this particular test an incentive to be taken as the mean estimation of the entire board and for utilizing this incentive for every single factual computation where the mean esteem and the variety of the mean estimations of the boards are utilized.

It is however said that "the variety inside a board and the concurring estimations is impossible" which implies that e.g. trademark esteems can't be doled out to SWP in light of the strategy depicted previously. As indicated by EN 789 computation of trademark 5-percentile esteems and examining needs to take after the tenets of EN 14358 [4]. Clearly getting mechanical properties from one single test isn't sufficiently solid. In any case, over the span of generation control such tests are helpful to check e.g. adequate nature of holding and would thus be able to fill in as a sort of "red light caution". In logical investigations, trial of strip-formed examples may serve to check suppositions (e.g. Poisson's proportions, shear moduli, and so on.).

When outlining CLT boards to be utilized as plates, bowing and shear quality and also moduli of flexibility (MOE) parallel and opposite to the grain bearing of the face layers together with shear moduli are required. These qualities are typically determined on base of the mechanical properties of the crude material (layers) utilizing the compound hypothesis [5] [6]. Stiffness properties can likewise be surveyed by non-dangerous testing of the CLT board e. g. by a mix of hypothetical and trial modular examination [7] as will be clarified in more detail in 3.1.

Bowing trial of strip - formed boards cut from entire plates is another method for assessing quality and stiffness properties of CLT. Such tests, be that as it may, experience the ill effects of being damaging, dreary and not in all cases a dependable marker of the CLT's genuine mechanical execution [8] [9]. By looking at aftereffects of twisting trial of strip-molded CLT examples with properties of full boards the exhibited examine planned to assess, if bowing quality and flexural stiffness properties of CLT boards can be dependably inferred by testing strip-formed examples.

2. MATERIAL

2. 1. Panels

The examination included a sum of 42 CLT boards with various lay-ups and geometrical measurements as showed in Table 1. The boards were provided by two makers (A and B) and because of very surprising methods for creation the boards displayed momentous contrasts in appearance and mechanical properties in spite of the fact that the crude material was in the two cases outwardly quality reviewed Norway Spruce (*Picea abies Karst*.).

Table 1. Geometrical properties of investigated CLT panels

Series	Length[1)] × Width (m)	Thickness (mm)	Lay-up (mm)	Number of panels
1	2.5 × 2.5	70	Product A and B: 10/50/10	9 of each product
			Product A and B: 25/20/25	3 of each product
2	2.5 × 2.5	110	Product A: 35/40/35	3
			Product B: 20/70/20	3
	4 × 2.5	80	Product A: 25/30/25	3
			Product B: 15/50/15	3
		110	Product B: 15/15/20/15/15	3
			Product A: 35/40/35	3

[1)] Direction parallel to the grain of the face layers

The face layers of item A (Fig. 1, left) have as per the assembling strategy to relate to quality class C24 (EN 338 [10]), while the internal layers can comprise of C20 lamellas. In an initial step of generation "glulam pillars" are created by gathering lamellas (sheets, if essential end-jointed) with a thickness of up to 70 mm. The "glulam" at that point is vertically cut into boards (the width of them being equivalent to the stature of the "glulam shafts") which arranged level savvy is utilized as face layers of the CLT boards. The littler sides of these boards are not reinforced.

The internal layers of the CLT boards comprise of single lamellas with a width of 100 – 150 mm which at their sidelong sides are not fortified. In the event that the thickness of the inward layers is ≥ 30 mm, grooves are cut into the internal layers keeping in mind the end goal to ensure an adequate quality of the bond line when preparing the board at low anxieties opposite with a vacuum press.

The dampness content (MC) of the layers is 12 – 14%. All bonds are made with a 1-part PUR cement. CLT item B (Fig. 1, right) is as per data by the maker produced using lamellas of at any rate quality class C24. In both face and internal layers the width of the lamellas is 25 mm. Before amassing the CLT, planking are delivered by side holding the single 25 mm lamellas. Ensuring that there is an adequate longwise cover of the single planking components, a few planking are reinforced glulam-like bringing about "Blockholz" which is then vertically cut into layers being the crude material for the CLT creation.

All bonds are made with a MUF compose cement and the MC of the lamellas and layers is 8%. Contrasted with item A, item B because of littler measured parts of the layers, lacking of notches and because of holding of the layers on all sides displays a higher level of homogenization. Before testing in the lab, the boards were put away in atmosphere 20°C/60% r h, which brought about a balance dampness substance of marginally beneath 12%. The r h was picked not quite the same as 65% with a specific end goal to keep item B from excessively solid changes in MC.

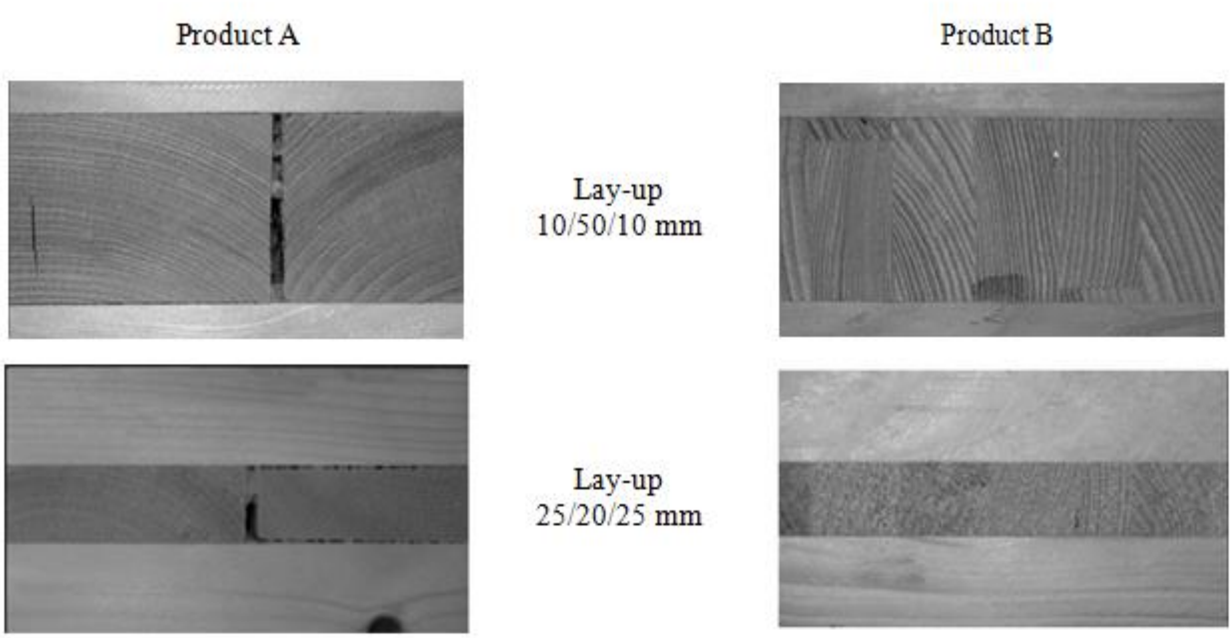


Fig. 1. CLT products A (left) and B (right). Thickness = 70 mm.

2. 2. Strip-shaped specimens

The plan of cutting the strip-formed examples parallel and opposite to the grain heading of the face layers from the arrangement 1 – CLT boards is appeared in Fig. 2 remaining. The boards were initially delivered fit as a fiddle and got quadratic in the wake of removing the strip-formed examples. The width of the 5 – 6 strips for every course was 100 mm. Throughout test arrangement 2 two 300 mm wide strips (one for each grain heading of the face layers) were removed each board as indicated by Fig. 2 right.

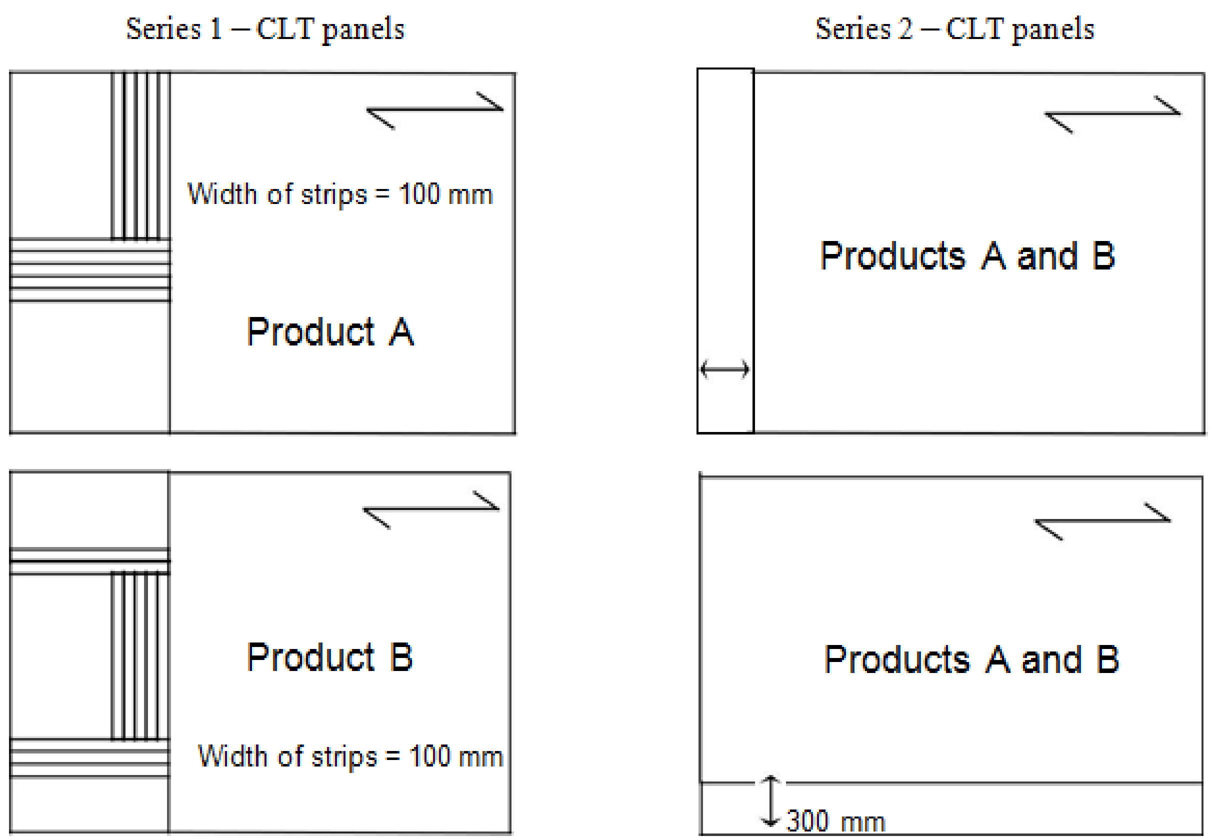


Fig. 2. Scheme of cutting strip-shaped specimens off CLT panels (series 1: left, series 2: right). The arrow sign indicates the grain direction of the face layers. The strip -shaped specimens as well were stored in climate 20°C / 60% r H in order to have the same MC as the CLT panels.

3. METHOD

3. 1. Evaluation of elastic properties of the CLT panels

To infer stiffness properties of entire CLT boards a strategy was connected which had as of late been examined and additionally created at the Swiss Federal Laboratories for Materials Testing and Research, Empa [11]. The strategy is non - dangerous and bases on test and hypothetical modular examination. It ended up being a productive and precise strategy to decide flexible stiffness components of board formed EWP [12-16]. The methodology depends on three noteworthy advances [17].

First, a trial modular investigation is performed on boards vertically suspended by thin lines: Resonance frequencies $f_{i,exp}$ and mode states of the boards are assessed. In a moment step, reverberation frequencies $f_{i,cal}$ and mode-states of the free vibrating, direct flexible board are depicted in a hypothetical model as elements of the versatile material properties utilizing Reddy's higher request plate hypothesis for the orthotropic case [18]. Since shear misshapenness assume a vital part in CLT, a model must be taken which can represent such distortions.

Finally, the reverse issue is fathomed by methodically altering the obscure stiffness properties until the hypothetically ascertained reverberation frequencies $f_{i,cal}$ coordinate the tentatively estimated ones $f_{i,exp}$. In this improvement procedure, the stiffness esteems are assessed at the same time utilizing a parametric model fitting calculation. In the initial couple of cycle steps the processed and estimated frequencies and mode shapes don't really harmonize, since the underlying estimations of the material parameters are just harsh appraisals. Coordinating of mode shapes in this way is required. This is finished by a system in light of MAC (Modal Assurance Criterion) values [19] which is a scalar measure of how much two mode shapes are indistinguishable (MAC = 1).

Over the span of applying and further building up the strategy at Empa, tests were first performed under lab conditions on one single plate comprising of 3 layers (10/50/10 mm) and having geometrical measurements of 1.0 m × 1.5 m × 0.07 m. By an exploratory confirmation with static bowing tests it was demonstrated that the strategy could effectively assess the important stiffness parameters of the CLT board [20]. This was a short time later indicated again for a sum of 42 CLT boards of various geometrical measurements and lay-ups (see Table 1) made by two unique makers [21]. In a last advance the appropriateness of the strategy under modern conditions (creation plant, CLT made for genuine items) was demonstrated and the technique was additionally enhanced (decrease of number of excitation focuses and plates bolstered via air course as opposed to suspending them from lines or link wires) [11].

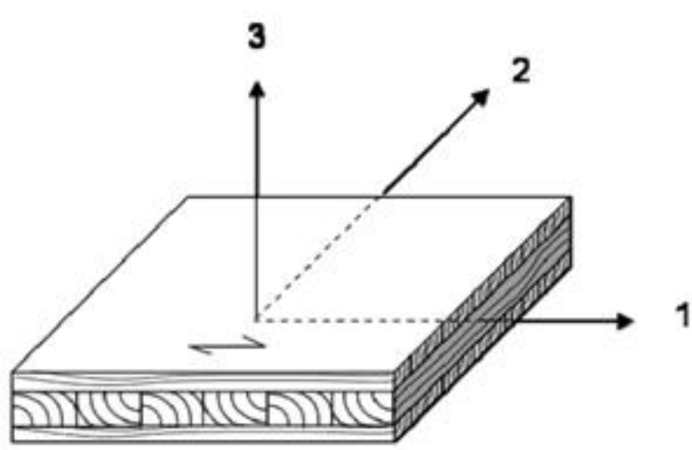


Fig. 3. Principal axis in CLT as used in this paper

The technique is equipped for inferring two in - plane flexible moduli (E_{11} , E_{22}) and the three shear moduli (G_{12}, G_{13}, G_{23}) of CLT boards with various geometrical measurements and lay-ups [21]. The bearings of the primary hub are appeared in Fig. 3. It is hard to appraise the shear modulus G_{23} (being a blend of moving shear modulus of the face layers and of shear modulus of the center layer) by modular investigation since this parameter does not take discernible impact on the mode shapes and reverberation frequencies. Bowing trial of strip-molded examples with variable traverse also are not equipped for inferring genuine G_{23} esteems since sections and layer sides not adhesively reinforced show distinctive stiffness while being situated at free traverse or close to the backings individually. The twisting tests however will let in any event affirm the right scope of the G_{23} esteems inferred by modular testing.

3. 2. Bending trial of strip-molded examples

3. 2. 1. Strips taken from arrangement 1 CLT boards to survey bowing quality and stiffness and in addition disappointment mode

4-direct bowing tests toward survey bowing quality and stiffness and sort of disappointment were completed with a traverse of 1100 mm and a separation between the stacking purposes of 300 mm (Fig. 4) [22]. Because of limitations by the accessible testing machine the width of the examples was just 100 mm (EN 789 would have required 300 mm!) and along these lines the traverse was decreased also (EN 789 would have required 2540 mm). The reference burdens to decide MOE were 10% and 40% of the expected disappointment stack and the disfigurements were estimated between the stacking focuses on the upper side of the examples (Fig. 4). Speed of the stacking head was balanced to such an extent that disappointment was come to following 300 120 seconds.

3. 2. 2. Strips taken from arrangement 2 CLT boards to evaluate twisting stiffness

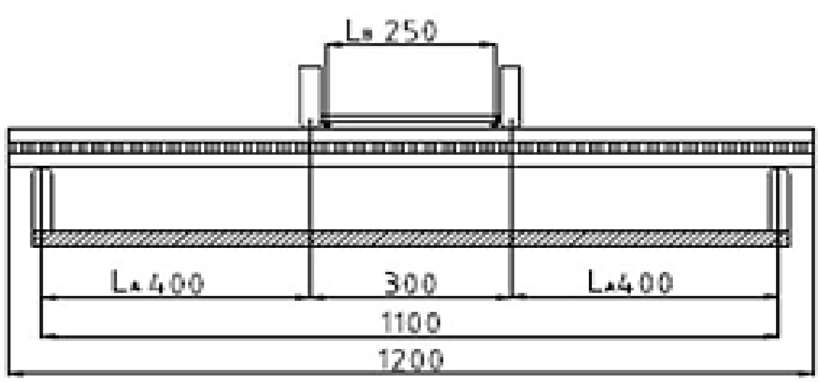


Fig. 4. 4-point bending tests on strip-shaped specimens cut off the series 1 CLT panels [22]

The MOE in twisting and the shear modulus were assessed by EN 408 [23] with the examples having measurements as asked by EN 789. The shear moduli G (underneath alluded to as G13 and G23) and the MOE Em (beneath alluded to as E11 and E22) were controlled by the variable traverse strategy from the evident MOE Em,app for each test piece [23]. The profundity (h) to traverse ( ) proportion was shifted between h/ = 0.0037 and 0.035. The disfigurements were estimated for 10% and 40% of the assumed disappointment stack and the speed of stacking was to such an extent that each test cycle kept going 1 minute, which is marginally over the test span asked by EN 408. The test course of action is appeared in Fig. 5. Strips with notches and cuts (which go for diminishing distorting because of evolving dampness) have been tried twice with changing introduction of strain and pressure side.

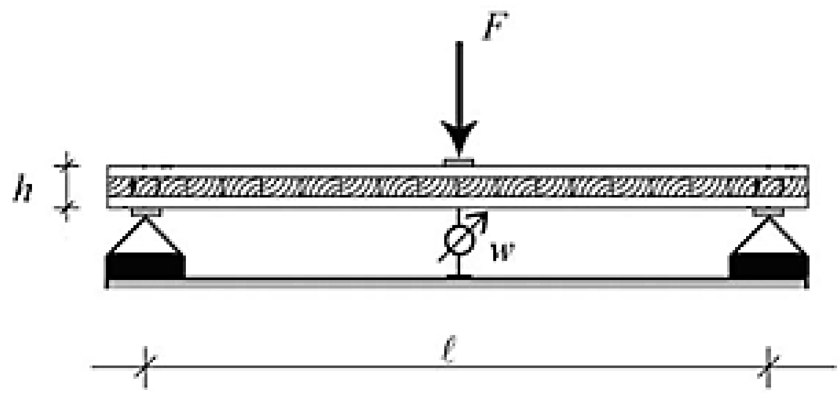


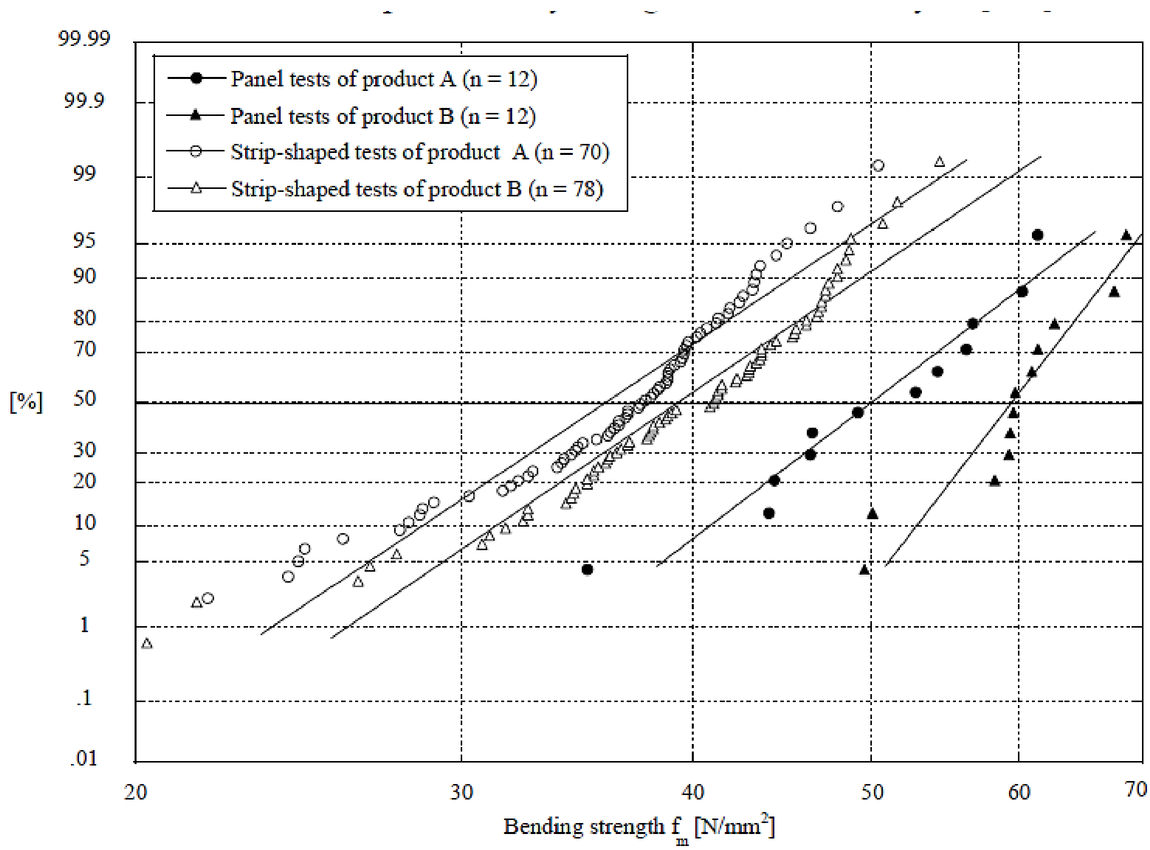
Fig. 5. 3-point bending tests with variable span on strip-shaped specimens cut off the series 2 CLT panels

4. RESULTS AND DISCUSSION

4. 1. Bending strength, MOE and failure modes of strips cut off the series 1 CLT panels

Fig. 6 demonstrates a correlation of twisting quality recorded along bowing trial of entire CLT boards (geometrical measurements: 2.50 × 2.50 × 0.07 m, lay-ups 10/50/10 mm and 25/20/25 mm) and of separate esteems got from strip-formed examples (1.20 × 0.10 × 0.07 m) remove the boards parallel to the grain course of the face layers (Fig. 2 (left)). The board tests comprised of 3 distinct kinds of stacking happening in down to earth circumstances: 4 single loads in the middle purpose of the boards' quadrants, b) 1 single load in the focal point of the board and c) 1 single load in the focal point of one quadrant [9]. The twisting quality was computed with the compound hypothesis considering all layers [5, 6].

For the two items bowing quality got from tests on strip-molded examples is extensively lower than when performing twisting tests on entire boards. Looking at the variety of results (spoke to by the incline of the straight relapse lines) it can be seen that testing of strip-formed examples with a width of 100 mm isn't skilled to accurately represent the higher level of homogenization of item B, though this distinction can unmistakably be seen when contrasting the test aftereffects of the entire CLT boards. Over the span of the strip tests in 4-point twisting shear disappointments happened oftentimes, while this was not the situation with the gross CLT boards. There, due to similarly bring down shear stresses, bowing disappointment on the pressure side was prevalent (Table 2).



	n	Minimum (N/mm^2)	Mean (N/mm^2)	Median (N/mm^2)	Maximum (N/mm^2)	Standard dev. (N/mm^2)	5th percentile (N/mm^2)	COV (%)
Tests on whole CLT panels 2.5 × 2.5 × 0.07 m with lay-ups 10/50/10 mm and 25/20/25 mm								
Product A	12	35.1	50.7	50	61.4	8.2	35.1	16.2
Product B	12	49.6	59.8	59.5	68.6	5.86	48	9.8
Tests on strip-shaped specimens 1.2 × 0.1 × 0.07 m								
Product A	70	18.7	36.5	37.6	50.4	6.18	25.5	16.9
Product B	78	20.3	39.9	41.1	54.4	6.71	28	16.8

Fig. 6. Comparison of bending strength derived from tests on whole 2.50 m x 2.50 m x 0.07 m CLT panels with lay-ups 10/50/10 mm and 25/20/25 mm [9] and on strip-shaped specimens (width = 100 mm) cut off these panels according to Fig. 2 (left).

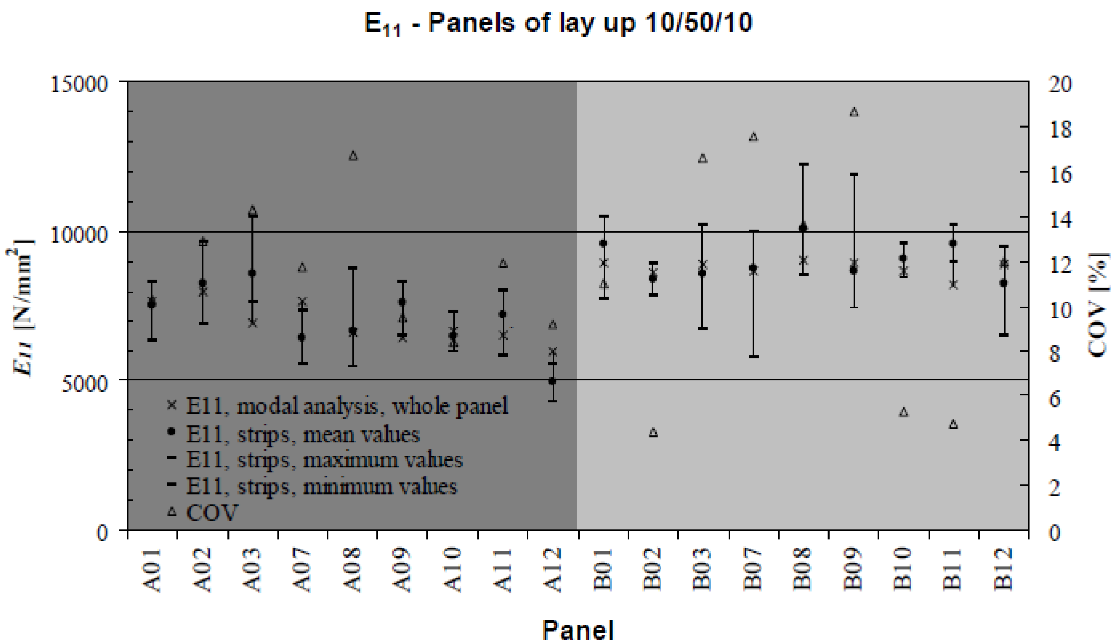
Table 2. Failure modes along the bending tests of strip-shaped specimens and gross CLT panels

Strip-shaped specimens (n_{tot} = 303)			**Gross CLT panels (n_{tot} = 24)**		
Type of failure	*Count*	*Percentage*	*Type of failure*	*Count*	*Percentage*
Bending failure	129	42.6%	Bending failure	22	91.6%
(Rolling) shear failure	97	32%	Shear failure	1	4.2%
Mixed mode	19	6.3%	Punching	1	4.2%
Local defects	58	19.1%			

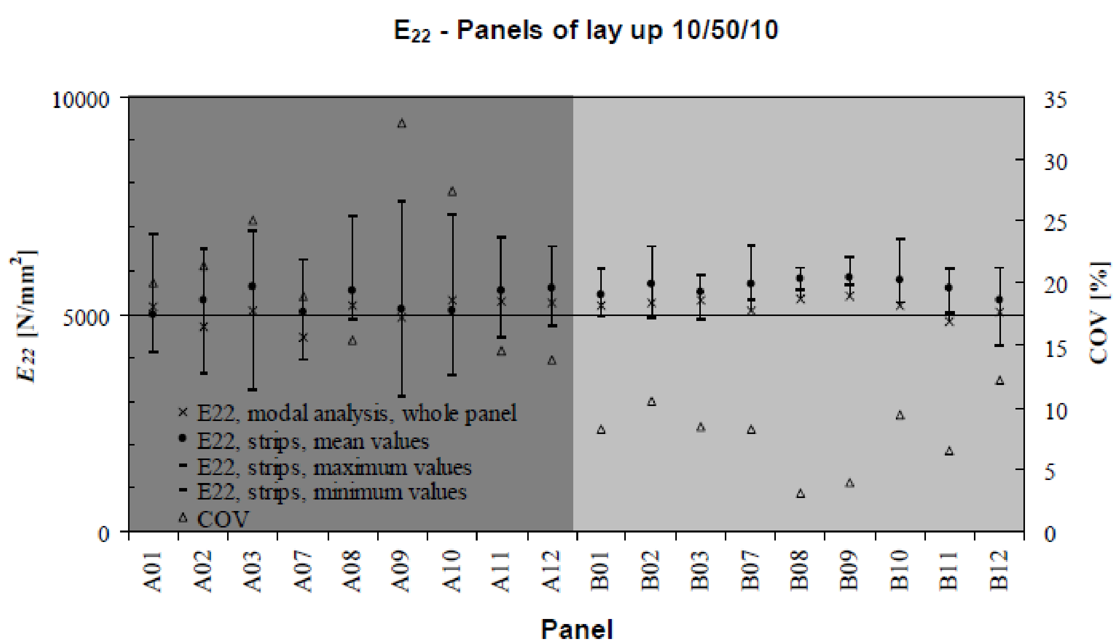
Fig. 7 shows mean, maximum and minimum values of the MOE *E11* and *E22* of 5 – 6 strips per panel and grain direction of the face layers. Left portions of the diagrams (with dark grey background) reflect test results of product A and right portions (light grey background) those of product B. For lay-up 10/50/10 mm the respective sample sizes were with product A: *nE11* = 57, *nE22* = 59 and with product B: *nE11* = 59, *nE22* = 57. The lay-up 25/20/25 mm sample sizes for product A amounted to: *nE11* = 18, *nE22* = 18 and for product B to: *nE11* = 17, *nE22* = 18.

The high COV obviously show an extensive variety of the stiffness properties inside a CLT board free of its lay-up. These enormous varieties result from the heterogeneity of the crude material. Greatest COV of E_{11} of strip test tests inside one CLT board was 16.7% for item An and 18.7% for item B. If there should arise an occurrence of E_{22} these qualities are 32.8% (item An) and 12.2% (item B). Particular mean estimations of COV were for E_{11} 11.6% (item An) and 12.8% (item B) and for E_{22} 14.8% (item A) and 9.6% (item B). The mean estimations of the strip test tests can be contrasted with the individual esteems determined by modular examination of the entire CLT board. The greatest distinction is 20.6% for strips tried parallel to the grain heading of the face layers (E_{11}) and 13.8% opposite to it (E_{22}). Along these lines no unmistakable pattern of over-or disparaging could be found. Consequently it isn't conceivable to determine redress stiffness properties of CLT boards by testing one or a couple of strip-formed examples. In normal (mean estimations of all strip-molded examples cut from a similar board) the distinctions are for E_{11} 10.2% (item A) and 6% (item B) and for E_{22} 6.9% (item A) and 7.8% (item B). This accuracy would be adequate for applications in structural building however happening contrasts up to 15 – 20% in particular cases all things considered feature the weaknesses of tests on strip-molded examples.

While plotting all arrangement of the CLT boards with lay-up 10/50/10 in ordinary likelihood plots (NPP) (Fig. 8) it can be seen that the mean estimations of the MOE of the strip tests are possibly higher than the ones inferred by modular examination of the entire board. The distinction in E_{11} is +1.5% for item A and +2.7% for item B. If there should be an occurrence of E_{22} the individual contrasts are +5.4% (item A) and +8.3% (item B). Looking at the inclines of the straight relapse lines in the NPP, significantly greater inconstancy of the strip test tests is self-evident. General varieties are higher in item A than in item B which can be clarified by an alternate level of homogenization because of the diverse methods for generation and the nature of the crude material (see 2.1). This wonder, be that as it may, is stamped more for MOE E_{11} and E_{22} of the entire board than for the strip test tests.



(a)



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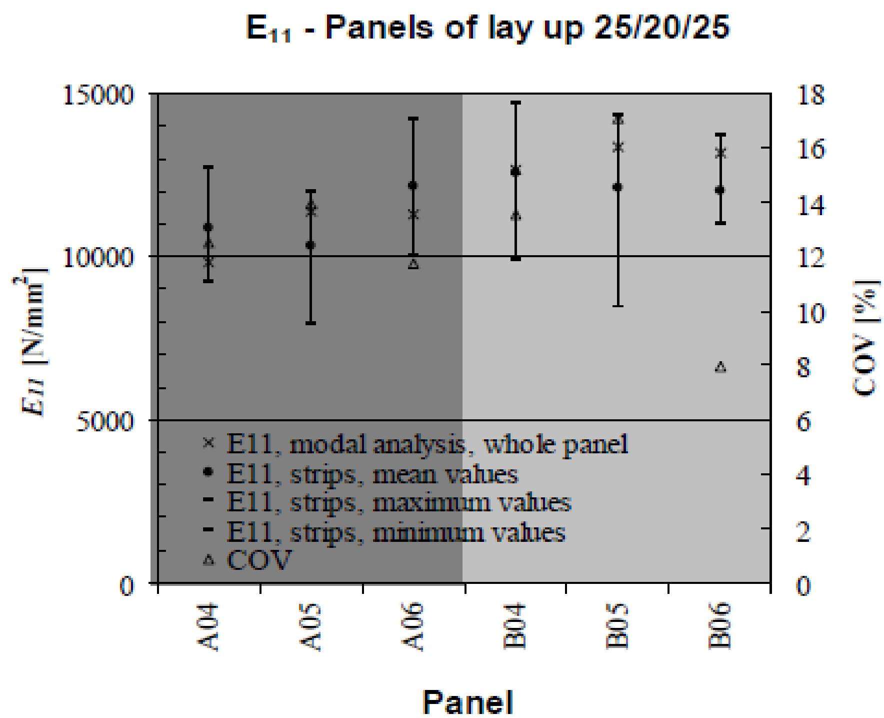

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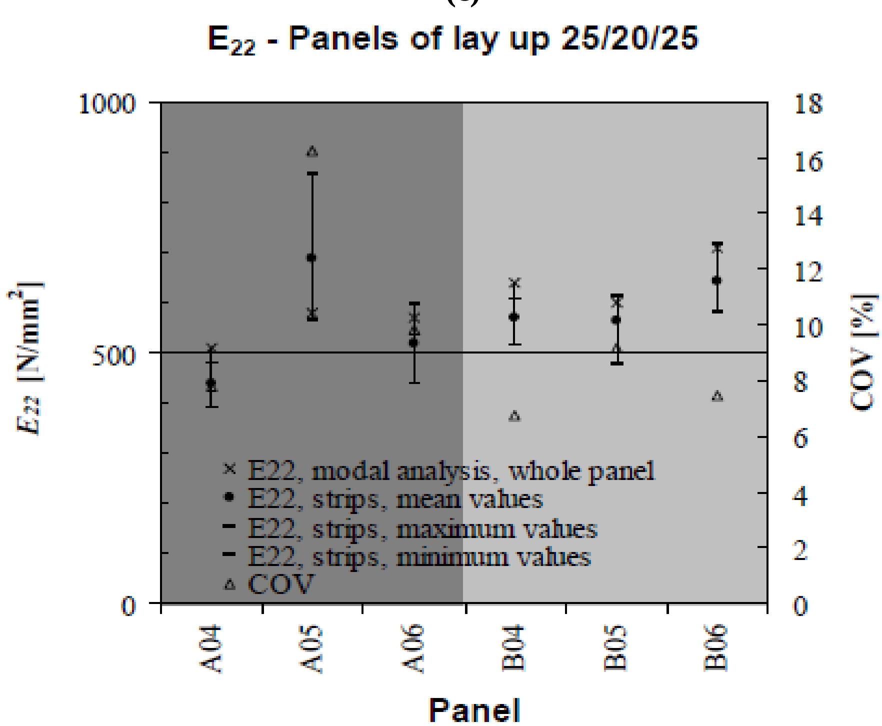
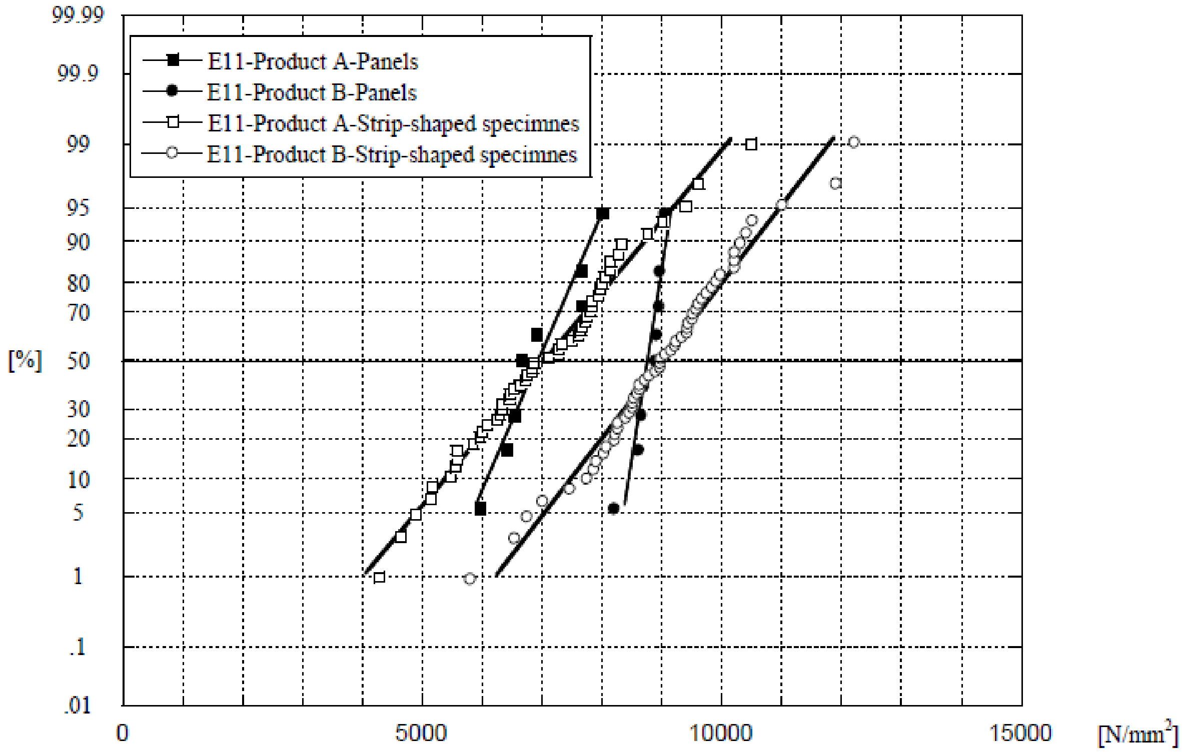


(d)

Fig. 7. MOE E11, E22 derived by 4-point bending tests of strip -shaped specimens (5 – 6 specimens per series 1 CLT panel) or by modal analysis together with respective coefficients of variation (COV) and by modal analysis derived MOE values (x-signs).



<table>
<tr><th rowspan="2">Parameter</th><th colspan="2">E₁₁ of product A</th><th colspan="2">E₁₁ of product B</th></tr>
<tr><th>Panels</th><th>Strip-shaped specimens</th><th>Panels</th><th>Strip-shaped specimens</th></tr>
<tr><td>Sample size</td><td>9</td><td>52</td><td>9</td><td>54</td></tr>
<tr><td>Mean value (N/mm²)</td><td>6936</td><td>7038</td><td>8759</td><td>8998</td></tr>
<tr><td>Standard deviation (N/mm²)</td><td>686</td><td>1304</td><td>260</td><td>1201</td></tr>
<tr><td>COV</td><td>9.9%</td><td>18.5%</td><td>3%</td><td>13.3%</td></tr>
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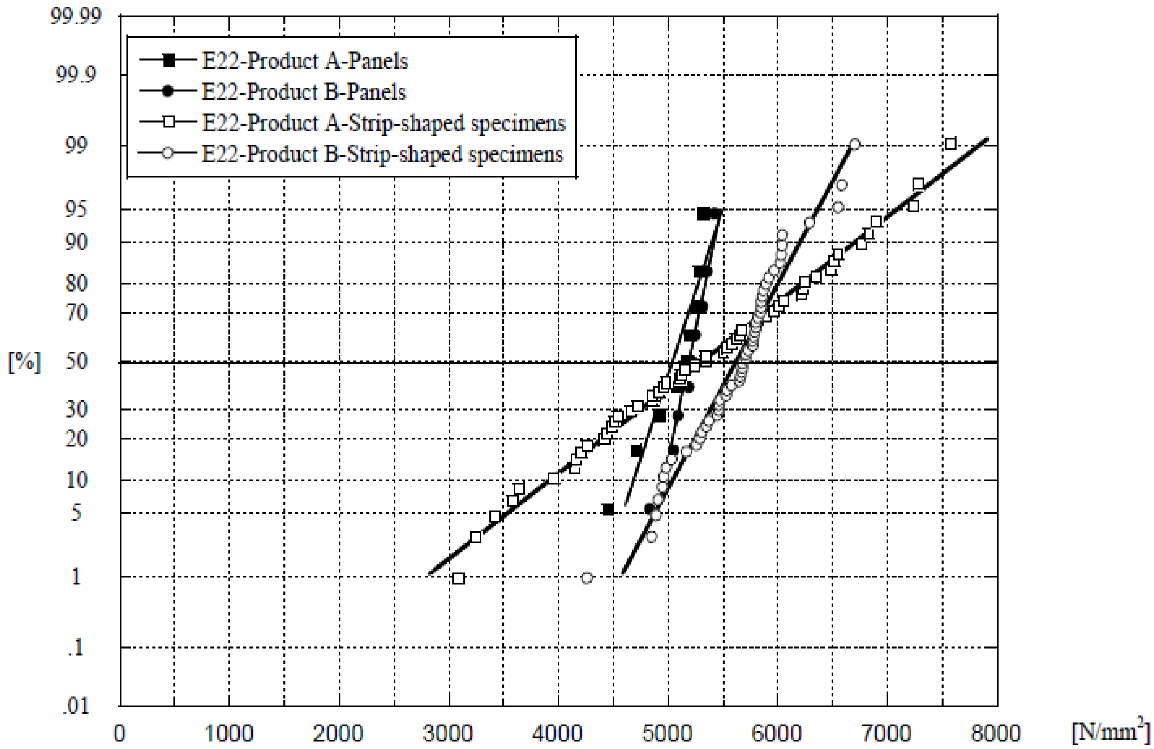
Fig. 8. Normal probability plot and statistical parameters of MOE E11 and E22 derived by 4-point bending tests of strip -shaped specimens (5 6 specimens per series 1 CLT panel) and by modal analysis. (Panels with lay-up 10/50/10 mm only)



Parameter	E_{22} of product A		E_{22} of product B	
	Panels	*Strip-shaped specimens*	*Panels*	*Strip-shaped specimens*
Sample size	9	53	9	52
Mean value (N/mm^2)	5043	5315	5190	5623
Standard deviation (N/mm^2)	295	1083	180	460
COV	5.8%	20.4%	3.5%	8.2%

Fig. 8(continue). Normal probability plot and statistical parameters of MOE E11 and E22 derived by 4-point bending tests of strip -shaped specimens (5 6 specimens per series 1 CLT panel) and by modal analysis. (Panels with lay-up 10/50/10 mm only)

4. 2. MOE and shear moduli of strips cut off the series 2 CLT panels

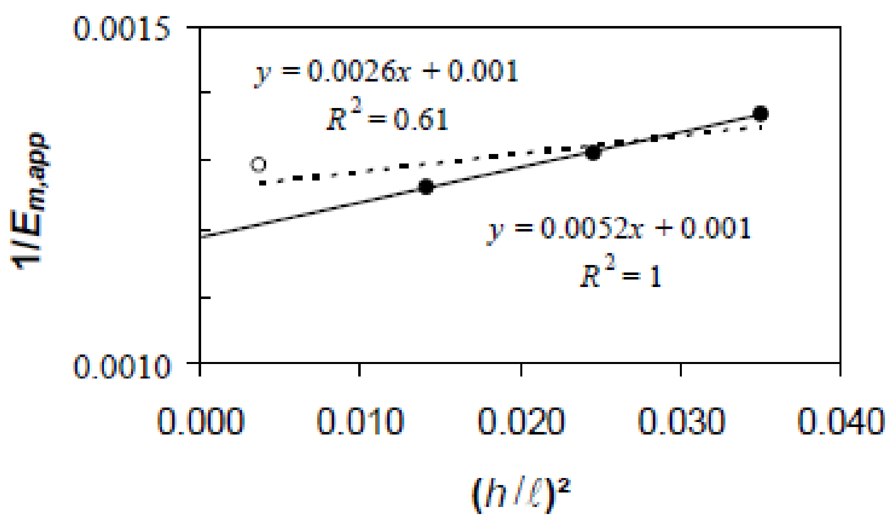


Fig. 9. Deriving of MOE and shear moduli in case of strips perpendicular to the face layers of the CLT panels concentrated only on test results (marked with) not being influenced by opening of gaps. Test results from strips with open gaps are marked with o.

By and large, straight relapse lines in plots of $1/E_{m,app}$ versus $(h/l)^2$ showed high coefficients of judgments which demonstrates that inferred MOE and shear moduli are of high exactness. Notwithstanding, some single esteems in the test arrangement with strips situated opposite to the grain heading of the face layers did not fit the pattern line well, this being because of opening of layers at lamella contacts which were not stuck together (Fig. 9).

At the point when such zones in examples tried everywhere traverse are set amidst the ranges, the openings take significantly more effect on the test comes about than while being put close to the backings in tests with limited abilities to focus. Subsequently particular test outcomes were prohibited from examination and the MOE were gotten from tests with 3 perspective proportions *h/l* just (Fig. 9, right). Another arrangement may have been to fill the scores with glue before testing.

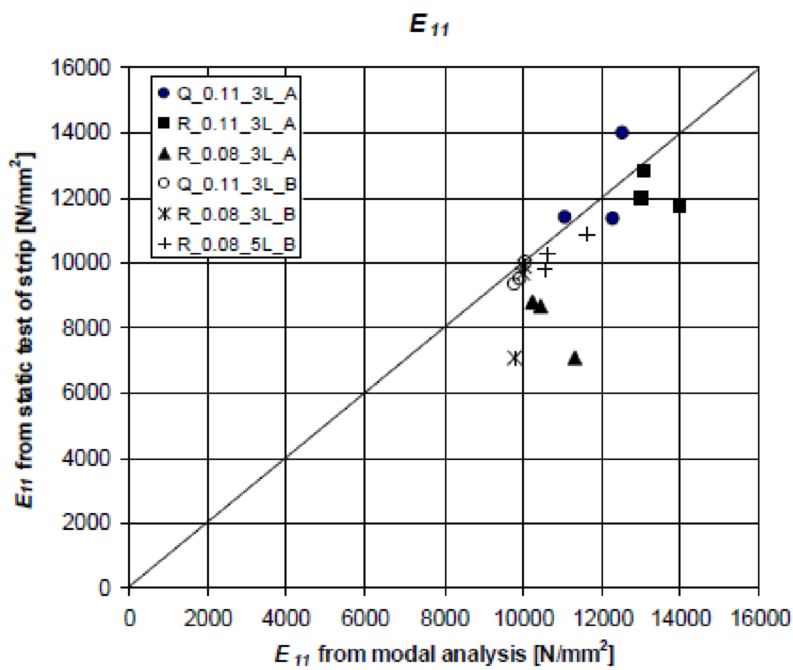
Fig. 10 demonstrates a correlation of MOE (E11, E22) and shear moduli (G13, G23) inferred by modular investigation of the entire CLT boards and by twisting trial of strip-molded examples remove the particular boards as indicated by Fig. 2, right. The corner to corner line in Fig. 10 demonstrates the perfect case, where parameters inferred by modular examination would be equivalent to those determined by static bowing trial of the strip - formed examples.

The outcomes are assembled by sort of item and geometrical parameters of the board as showed in Table 1 and in the subtitle of Fig. 10. In general the distinctions autonomous from kind of item are little to direct. Parameter E22 even demonstrates a decent assention. Some huge contrasts are unmistakable between values determined on net boards and on strip-molded examples individually particularly in regards to the MOE E11 and the shear moduli G13 and G23. A more critical look on the test information of examples displaying these enormous contrasts and on the examples themselves turned out, that huge contrasts fundamentally came about because of striking non-homogeneities in the utilized crude material.

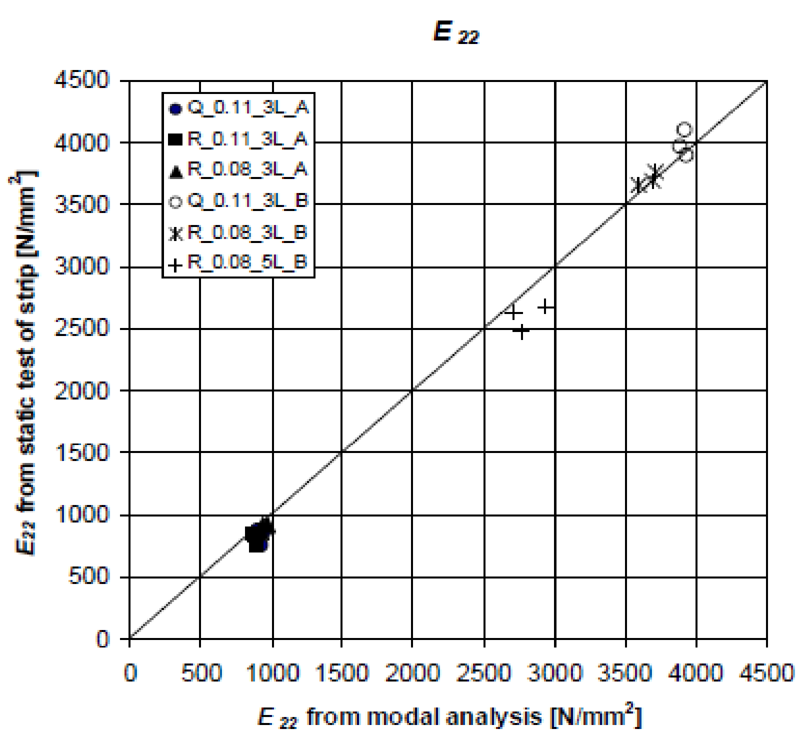
The greatest distinction in E11 (60%) happened with board R_0.08 _3L_A_P1. A nitty gritty examination of the explanations behind this huge contrast showed up deserts (ties pitch pockets and veered off grain) (Fig. 11) which halfway influenced entire layers bringing about a serious decrease of the stiffness of the face layers.

Keeping in mind the end goal to guarantee nature of information, examples with stamped cuts and furrows were tried twice with changing introduction of the pressure side in twisting. Table 3 demonstrates an examination of particular esteems. Generally speaking the distinctions are underneath 5% aside from shear modulus G13 of board R_0.08_5L_B_P3 (13.7%), wherefrom it can be presumed that the test methodology did not deliberately influence the information.

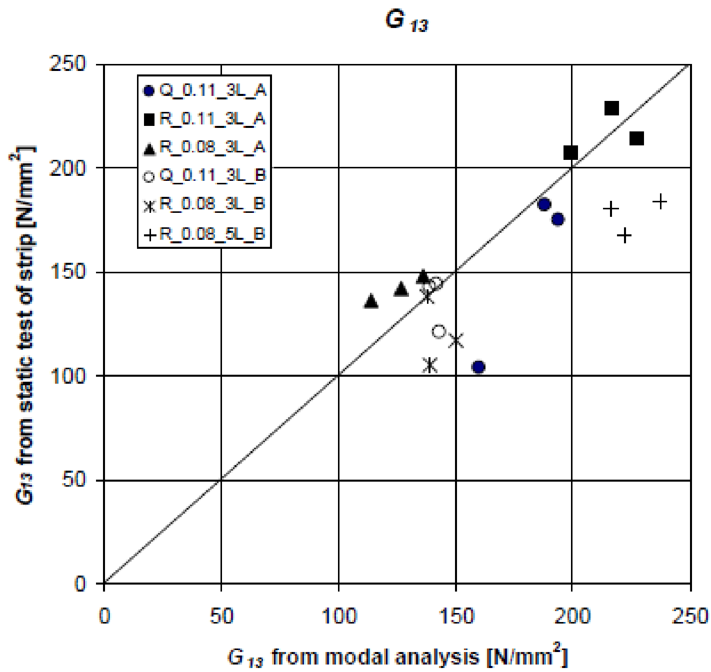
Contrasts between progressively (by modular investigation) inferred values and such determined by static testing, be that as it may, likewise result from the verifiable truth that stiffness parameters determined by methods for dynamic strategies because of the rapid of activity (motivation pound) are roughly 6% higher than those decided on base of static examinations at similarly bring down stacking rate [24, 25].


E 11
16000
14000
12000
10000
8000
6000
4000
2000
0
0
2000
4000
6000
8000
10000
12000
14000
16000
Q_0.11_3L_A
R_0.11_3L_A
R_0.08_3L_A
Q_0.11_3L_B
R_0.08_3L_B
R_0.08_5L_B
E11 from static test of strip [N/mm2]
E 11 from modal analysis [N/mm2]

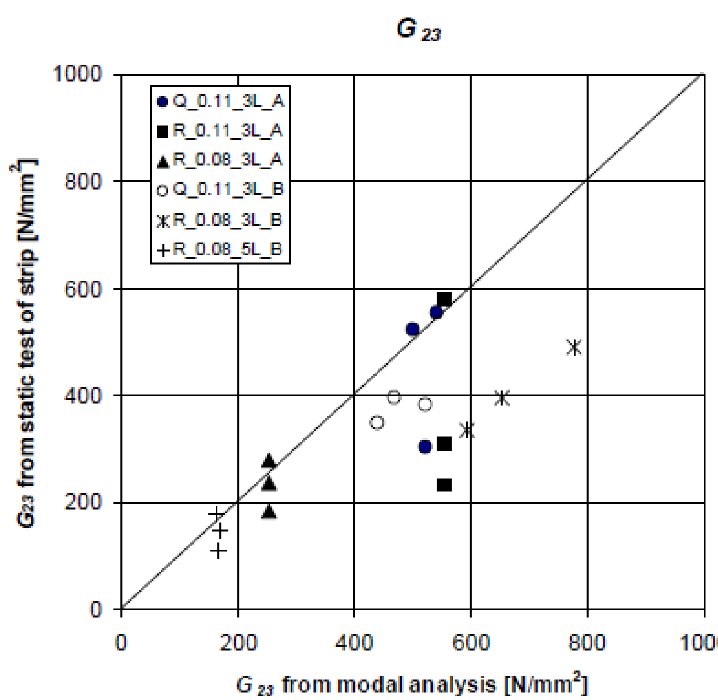
(a)


E 22
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Q_0.11_3L_A
R_0.11_3L_A
R_0.08_3L_A
Q_0.11_3L_B
R_0.08_3L_B
R_0.08_5L_B
E22 from static test of strip [N/mm2]
E 22 from modal analysis [N/mm2]

(b)



(c)



(d)

Fig. 10. Comparison of MOE and shear moduli derived by modal analysis of the whole CLT panels and by bending tests of single strip -shaped specimens cut off the respective panel according to Fig. 2, right. (Labels: Q/R = quadric/rectangular panel 2.50 × 2.50 m / 4.00 × 2.50 m, 0.11/0.08 = panel thickness [m], 3L/5L = 3/5 layers, A/B = Product)

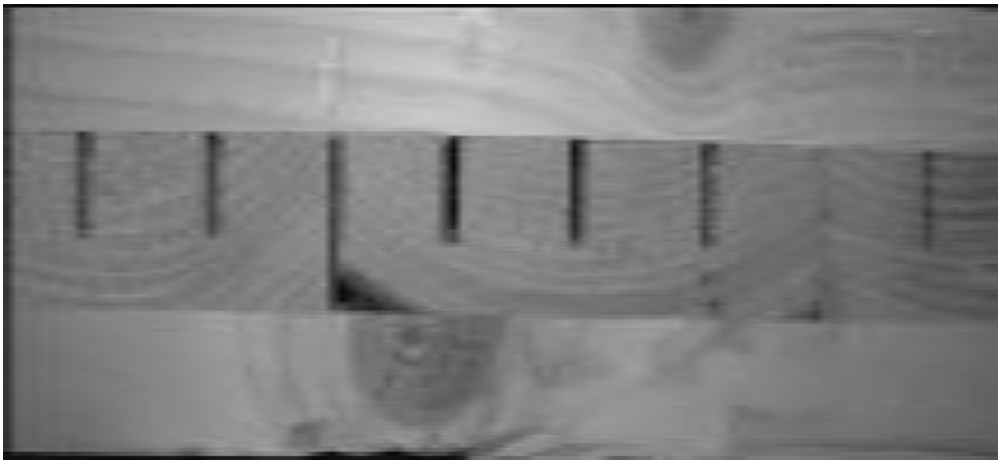


Fig. 11. Cross-section view of the strip taken from panel

Table 3. Comparison of MOE and shear moduli of strip-shaped specimens with cuts and grooves tested twice with changing orientation of the tension side

Panel	E_{11} (N/mm^2)	□E_{11}	G_{13} (N/mm^2)	□G_{13}
R_0.08_3L_A_P1a R_0.08_3L_A_P1b	7062 7082	0.3%	138 134	3.0%
R_0.08_3L_A_P2a R_0.08_3L_A_P2b	8681 8628	0.6%	149 145	2.8%
R_0.08_3L_A_P3a R_0.08_3L_A_P3b	8921 8688	2.7%	139 145	4.3%
R_0.08_5L_B_P1a R_0.08_5L_B_P1b	10858 10893	0.3%	170 166	2.4%
R_0.08_5L_B_P2a R_0.08_5L_B_P2b	10277 10277	0%	180 180	0%
R_0.08_5L_B_P3a R_0.08_5L_B_P3a	9579 10020	4.6%	195 172	13.4%

5. SUMMARY AND CONCLUSIONS

Quality properties can best be doled out to CLT by methods for the compound hypothesis. Be that as it may, the mechanical properties (quality and stiffness) of the layers must be known which implies that the crude material must be quality reviewed. Inferring stiffness properties of entire CLT boards with modular examination is a decent other option to assessing them on base of the mechanical properties of the separately layers by methods for the compound hypothesis. Particularly in situations where the crude material isn't quality evaluated or its mechanical properties are not known with adequate exactness, the modular examination can help in doling out right stiffness properties to CLT. In the wake of having demonstrated the rightness of the strategy by static verification stacking, the board properties were contrasted with bowing MOE and shear moduli got from tests on strip-formed examples remove the CLT boards. One a player in the tests also centered on bowing quality and disappointment modes.

Bending quality and stiffness of CLT boards can differ unequivocally inside one single board. For the two parameters contrasts between the quality and stiffness of strip-molded examples remove the boards of up to 100% have been found. Subsequently it isn't conceivable to determine quality and stiffness properties of CLT boards from twisting trial of few or single strip-molded examples. The precision of the test outcomes when performing bowing trial of strip-formed examples as indicated by EN 789 is expanded with expanding test measure. Mean estimations of no less than 5 – 6 examples better depict the genuine bowing stiffness of the boards. Normal contrasts at that point add up to 10% (E11) and 6% (E22) yet can in any case achieve 20%. As requested in EN 789, trademark estimations of quality and stiffness properties of CLT must be inferred on tests which satisfy the criteria of EN 14358. The variety of the stiffness properties relies upon the level of homogenization of the genuine CLT board item.

The littler the segments (lamellas) are and the less the variety in mechanical properties is (which can be come to by satisfactory quality reviewing of the crude material), the better it can be finished up from tests on strip-molded examples to the bowing quality and stiffness properties of the entire CLT board. Compared to net CLT boards, neighborhood non-homogeneities and issues (ties, pitch pockets, digressed grain, not adhesively reinforced contacts, cuts, grooves, and breaks) take more effect on the mechanical properties of the strip-formed examples. The littler the width of such examples is, the more their heap bearing conduct is influenced by nearby imperfections and non-homogeneities because of flaws in the crude material or because of method for delivering the boards.

The separations between center layer parts not adhesively reinforced at their sidelong sides and the quantity of cuts and scores, which are gone for decreasing the distortions of the CLT board if there should be an occurrence of evolving dampness, take a major impact on the shear moduli. When inferring individual esteems on base of testing strip-formed examples this conceivable variety must be considered by utilizing experimental connections. When testing strip-molded examples in 4-point bowing, (moving) shear disappointments happen every now and again, while such disappointment modes couldn't be watched when testing entire CLT boards to disappointment in stacking circumstances happening practically speaking.

There twisting disappointment was ruling. Punching, notwithstanding, ought to be respected, particularly with thin boards and items with sections and layers not adhesively reinforced at their parallel sides. Single tests on strip-molded examples may fill in as an instrument of creation control particularly with respect to the nature of holding. They should, however not be utilized to determine mechanical properties of CLT boards. In logical examinations testing of strip-molded shorts of CLT should just be completed on enormous examples. Geometrical measurements ought not to be taken littler than solicited by the guidelines and speculation from conclusions by and large isn't conceivable (e.g. sort of disappointment).

References

[1] EN, BS. "13986." Wood-based panels for use in construction—Characteristics, evaluation of conformity and marking,, European Norm (2004).

[2] Steiger, René, and Arne Gülzow. Validity of bending tests on strip-shaped specimens to derive bending strength and stiffness properties of cross-laminated solid timber (X-lam). The Future of quality control for wood and wood products (2010): 4-7.

[3] Steiger, René, Arne Gülzow, Christoph Czaderski, Martin T. Howald, and Peter Niemz. Comparison of bending stiffness of cross-laminated solid timber derived by modal analysis of full panels and by bending tests of strip-shaped specimens. *European Journal of Wood and Wood* Products 70, no. 1-3 (2012) 141-153.

[4] Jorissen, André, and Massimo Fragiacomo. General notes on ductility in timber structures. *Engineering structures* 33.11 (2011) 2987-2997.

[5] Gurau, Lidia, and Nadir Ayrilmis. "Effect of raw material composition of wood plastic composites on surface roughness parameters evaluated with a robust filtering method. *Journal of Thermoplastic Composite Materials* (2018) 0892705718759391.

[6] Blaß, H. J., and R. Görlacher. Bemessung im Holzbau: Brettsperrholz–Berechnungsgrundlagen. Holzbau-Kalender. Bruderverlag, Karlsruhe (2003) 580-598.

[7] Mallik, Avijit, Md Samdani Azad, Fazlur Rashid, and Md Emdadul Hoque. Dynamic Response Mechanics of 45 Degree Angled Layered Cross-Laminated Timber. *International Journal of Engineering Materials and Manufacture* 3, no. 1 (2018): 55-64. Doi: https://doi.org/10.26776/ijemm.03.01.2018.05

[8] Jöbstl, R. A., Moosbrugger, T., Bogensperger, T., & Schickhofer, G. (2006). A contribution to the design and system effect of cross laminated timber (CLT). International Council for Research and Innovation in Building and Construction, Working Commission W, 18.

[9] Czaderski, C., Steiger, R., Howald, M., Olia, S., Gülzow, A., & Niemz, P. (2007). Versuche und Berechnungen an allseitig gelagerten 3-schichtigen Brettsperrholzplatten. *Holz als Roh-und Werkstoff,* 65(5), 383-402.

[10] EN, BS. Structural timber. Strength classes. Assignment of visual grades and species. British Standards Institute, London (2004).

[11] Gülzow, Arne. Zerstörungsfreie Bestimmung der Biegesteifigkeiten von Brettsperrholzplatten. PhD diss., ETH Zurich, 2008.

[12] Bastos, Sergio Ferreira, Lavinia Borges, and Fernando A. Rochinha. Numerical and experimental approach for identifying elastic parameters in sandwich plates. *Shock and Vibration 9,* no. 4-5 (2002) 193-201.

[13] Frederiksen, Per S. Numerical studies for the identification of orthotropic elastic constants of thick plates. *European Journal of Mechanics A-Solids* 16 (1997): 117-140.

[14] Frederiksen, P. S. (1997). Application of an improved model for the identification of material parameters. *Mechanics Of Composite Materials And Structures An International Journal*, 4(4), 297-316.

[15] António, C. C., & Rasheed, S. (2018). A displacement field approach based on FEM-ANN and experiments for identification of elastic properties of composites. *The International Journal of Advanced Manufacturing Technology*, 1-13.

[16] Sumigawa, T., Fang, H., Sakurai, A., Wang, S., & Kitamura, T. (2018). Estimation of anisotropic properties of nano-structured arrays by modal vibration control at microscale. *Mechanics of Advanced Materials and Structures*, 25(5), 386-394.

[17] Viala, R., Placet, V., & Cogan, S. (2018). Identification of the anisotropic elastic and damping properties of complex shape composite parts using an inverse method based on finite element model updating and 3D velocity fields measurements (FEMU-3DVF): Application to bio-based composite violin soundboards.*Composites Part A: Applied Science and Manufacturing*, 106, 91-103.

[18] Tornabene, F., Fantuzzi, N., Bacciocchi, M., & Viola, E. (2018). Mechanical behavior of damaged laminated composites plates and shells: higher-order shear deformation theories. *Composite Structures,* 189, 304-329.

[19] Mbarek, A., Del Rincon, A. F., Hammami, A., Iglesias, M., Chaari, F., Viadero, F., & Haddar, M. (2018). Comparison of experimental and operational modal analysis on a back to back planetary gear. Mechanism and Machine Theory.

[20] Gsell, D., Feltrin, G., Schubert, S., Steiger, R., & Motavalli, M. (2007). Cross-laminated timber plates: Evaluation and verification of homogenized elastic properties. *Journal of structural engineering,* 133(1), 132-138.

[21] Gülzow, A., Gsell, D., & Steiger, R. (2008). Zerstörungsfreie Bestimmung elastischer Eigenschaften quadratischer 3-schichtiger Brettsperrholzplatten mit symmetrischem Aufbau. *Holz als Roh-und Werkstoff,* 66(1), 19-37.

[22] Zhou, Q. Y., Gong, M., Chui, Y. H., & Mohammad, M. (2014). Measurement of rolling shear modulus and strength of cross-laminated timber using bending and two-plate shear tests. *Wood and fiber science,* 46(2), 259-269.

[23] Moore, J., Achim, A., Lyon, A., Mochan, S., & Gardiner, B. (2009). Effects of early re-spacing on the physical and mechanical properties of Sitka spruce structural timber. *Forest Ecology and Management,* 258(7), 1174-1180.

[24] Görlacher, R. (1984). Ein neues Messverfahren zur Bestimmung des Elastizitätsmoduls von Holz. *Holz als Roh-und Werkstoff,* 42(6), 219-222.

[25] Machek, L., Militz, H., & Sierra-Alvarez, R. (2001). The use of an acoustic technique to assess wood decay in laboratory soil-bed tests. *Wood Science and Technology,* 34(6), 467-472.