Screw gluing Laminated Veneer Lumber (LVL) structures with polyurethane (PU)
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ABSTRACT
Gluing costs are generally rather high due to high pressures (0.6-1.5 MPa) and hydraulic pressing needed to press wood parts together to form thin and good quality glue line. In repairs nailing or screwing has been used to press wood members together. With mechanical fasteners a clearly lower and uneven compression (0.01-0.2 MPa) is achieved on glue line. The objective is to find out the applicability of low pressure and screw-pressing techniques and to determine factors affecting the strength and quality of glue line. The wooden material was LVL and the adhesive was one-component PU glue. In the german FMPA approval for PU glues, intended to use in structural purposes, glue line thickness is limited to 0.3 mm. Test made in laboratory and factory conditions showed that with low pressures, 0.03 MPa to 0.1 MPa, it is possible to accomplish a PU glue line in which thickness and shear strength is as good as those pressed at normal, 0.6-0.8 Mpa pressure. We have determined requirements for successful gluing such as adequate surface smoothness and right level of moisture content of LVL components, screw type, screw space, end distance, right amount of glue spread and glue line thickness.

INTRODUCTION
Glulam, finger jointed products and different types of I-beams are for example traditional and widely used glued structural building components. Uniform adhesion and adequate quality of glue line are often obtained by using high compression pressures (more than 0.6 MPa) during curing time. This means heavy and expensive hydraulic pressing devices in process. Pneumatic and vacuum techniques are cheaper, but lower pressures (0.05-0.4 MPa) can be obtained. Even lower and uneven compression (0.01-0.2 MPa) is achieved with mechanical fasteners.

Epoxy glue and nails have been used in constructions where it is not possible to obtain high compression pressure in uneven glue line. It is, however, reasonable to use a non-gap-filling glue like polyurethane adhesive in order to make as thin glue line as possible. By using screws with a higher compression pressure compared to nails and with an adequate surface smoothness and dimensionally stable material, like LVL, it is possible to produce economically larger structural wooden components. Figure 1 shows different types of continuous structural components manufactured by screw pressing technique.

Figure 1. Examples of screw gluing technique on A) T-beams, B) I-beams, C) thin flanged beams (stressed skin panel), D) flatwise glued double–beams and E) partially connected wood members. Kerto-Q is LVL with 20 % of the veneers crosswise, Kerto-S is standard LVL.

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The most important wood adhesives for load bearing structures are phenol-(PF), urea-(UF), melamine-urea- (MUF) and resorsinol-formaldehyde (RF) adhesives. Also casein glues belong to this group. These adhesives are well known for their suitability for wooden structures and are standardised in EN 301 (Viitaniemi et al. 1997). In addition, there are four types of adhesives that are considered as potential structural wood adhesives: epoxy adhesives, one- and two-component polyurethanes (PU) and emulsion polymer isocyanates (EPI). Within these four adhesive types there are brands for very different properties, but unfortunately no short-term approval test to identify the suitable brands (Raknes, E. 1995).

In this study PU adhesive was used in the joints of LVL-ribbed panels for many reasons. It does not need as high compression pressure as conventional structural wood adhesives, such as RF and MUF, and therefore pressing with mechanical fasteners is possible. PU adhesives are also not as brittle as the conventional structural wood adhesives, and by using them the local concentration of the stresses can be avoided. On the other hand the structural gluing with PU has not been studied extensively (Viitaniemi et al. 1997).

There are three main factors that affect the strength and quality of the bond line. First the pressure needed for gluing depends on the quality of the adhesive and the material to be glued. PU adhesives demand only about 0.01-0.1 MPa pressure for gluing (Housh, 1985) when PF adhesives demand about 1.4-2.0 MPa (Suomi–Lindberg, 1986). Too high pressure leads to a bad glue line because it presses so much glue out of the bond line (Hoyle 1989). It may also crush the wood cells on the surface and cause thin glue line and inadequate penetration into the wood cells (Kiviluoto & Muilu, 1988). A low pressure, on the other hand, causes a decrease in shear strength values. Too low pressure does not supply an adequate contact between the surfaces and the bond line may remain partly open (Suomi-Lindberg, 1986).

Second the moisture content of wood influences both bond formation and bond performance. The optimal moisture content of wood is 8-12 % with most adhesives (Kilpeläinen, 1989).

Third the ability of screws to compress the surfaces close enough to form a good glue line depends strongly on the straightness and smoothness of the wood surfaces. Due to low pressures obtained by screws, surface roughness and straightness are very important in order to make the conditions for the adhesion of the glue into the wooden surfaces good enough to get an adequately thin glue line. The surfaces must be sanded before gluing to correct dimensions by tolerance of ±0.5 mm, and cleaned from dust, oil and dirt. Continual quality control of dimensions is essential during the manufacturing.

Research problem
One-component polyurethane glue, Collano’s Purbond HB 110 has been accepted as structural adhesive by German authorities. They require that the glue line is kept under 0.3 mm thick, but no demands for the pressure is defined. The core problem of the study is thus the pressure and how the glue line is kept under 0.3 mm. The condition for the acceptable gluing is adequate shear strength and the thickness of the glue line.

The Sibelius hall in Lahti, Finland, is a pilot case were structural PU-gluing with screw-pressing technique is used in LVL balcony elements, see Figure 1 C.

Objectives of this study
The objective was to find out the applicability of screw-pressing technique in load bearing structures, and to determine the factors affecting the strength and quality of the glue line in screw-pressed elements. The production of these elements is based on one-component PU glue pressed with mechanical fasteners.

The aim was to clarify the effects of pressing conditions on the PU glue line quality, its thickness and strength. Based on this information, the critical conditions and proper manufacturing methods were determined to obtain satisfactory glue line.

The methods were based on literature review, theoretical analysis and several types of experiments. Requirements for successful gluing such as adequate surface smoothness of LVL components, right level of moisture content of LVL, screw type, screw space and end distance, and right amount of glue and glue line thickness were studied. Because proper standardised testing methods were not available for all studies, new testing methods were developped.

The experimental study consisted of two stages: the laboratory tests and the verification of the results in factory conditions.
METHODS AND EXPERIMENTAL STUDY

Modelling of glue line: strength and thickness of flue line in T-joints
In the first stage of the experimental study the effect of the uniform pressure on the thickness and strength of the PU glue line in T-joints was defined in laboratory conditions at the Laboratory of Wood Technology. The pressure was produced by using a hydraulic press or by weights. Figure 2 illustrates the T-joint.

The adhesive used in the T-joint was one-component PU glue, Collano’s Purbond HB 110. A reference group of five parallel samples was glued with resorcinol-phenol-formaldehyde glue, Neste Chemicals RF-30. With the reference group the shear strength of good quality glue line (wood failure) was determined.

The material to be glued was standard LVL that was conditioned at RH 65% for two weeks. At the LVL-factory, the edges of the all specimens were machined by portal-saw and the faces were sanded lightly.

The T-joints were made in two stages, pressures 0.2 MPa to 0.8 MPa were pressed in hydraulic press at VTT Building Technology. Low pressures, 0.01 MPa to 0.1 MPa were obtained by loading weights on the T-joints.

Shear strength was examined with Zwick material testing machine according to the standard ASTM D143. Figure 3 illustrates the block shear strength specimen. The results are presented in Figure 4.

![Figure 2. T-joint in the laboratory tests. Joint was pressed using hydraulic press or by using evenly distributed weights to obtain uniform pressure on glue line.](image1)

![Figure 3. Dimensions [mm] of shear strength specimen.](image2)

![Figure 4. Shear strength as a function of pressure, number of samples in brackets.](image3)

![Figure 5. Thickness of glue line as a function of pressure.](image4)
The thickness of the glue line was examined with Nikon light microscope attached to Leica image processing instrument. It was defined as the distance between the surfaces. The results are presented in Figure 5. Figure 6 shows a PU glue line pressed in laboratory conditions, and in Figure 7 there is a glue line pressed in factory conditions.

Figure 6. Example of a PU glue line pressed in laboratory conditions at 0.1 MPa; average glue line thickness was 0.01mm

Figure 7. Example of a glue line pressed in factory conditions, glue spread 250 g/m² and extreme screw space 300 mm. Average glue line thickness was 0.081 mm (see App. 1)

Among the results it is possible, with low pressures, 0.03 MPa to 0.1 MPa, to accomplish a glue line, which thickness is under 0.3 mm and which shear strength is as good as those pressed at normal pressures, 0.6 MPa to 0.8 MPa. Condition for successful gluing is that the glued surfaces are adequately smooth.

Experimental verification: effects of screw space, glue spread and moisture content
To find out the optimal combination of the glue spread, the screw space and the end distance, the effects of these three factors on the strength and thickness of PU glue line were examined in the third stage of the study. In addition, the extreme gluing conditions of the LVL-factory were tested. The tests were made for ribbed panels in factory conditions and the test arrangements were divided into two parts: the moisture content of glued material was approximately 9 % and 14 %. Three factors were examined: the spacing of the screws, the distance between the first screw and the end of the beam, and the amount of the glue spread. Total length of the ribbed panel was 2250 mm. Other dimensions were: the flanges 39 mm and the webs 45 mm. The dimensions of the ribbed panels and the locations of the block shear and microscopy test pieces of one specimen are shown in Appendix 1.

Pressing PU glue line with mechanical fasteners
In this stage we focused on ribbed panels produced in factory conditions. In screw-pressing the pressure distribution in the glue line is effected by the type, size and spacing of screws and the size and material properties of wood members. Four different screw types were tested to measure compressive screw force in the T-joint. The screw type Stadler IG 6x100 was found to be the most suitable for screw pressing and it was used in the glue joints of the test.

The results show that pressing the joints of the ribbed panel with Stadler IG d=6mm and l=100mm-type screws succeeds on condition that the glued surfaces are adequately smooth. The strength is adequate and thickness of a glue line is under the limit of 0.3 mm, when the glue spread is 250 g/m², screw space is less or equal to 400 mm and the end distance is 100 – 150 mm.

Full scale creep tests
In full scale creep test three two-webbed ribbed panels were glued at the LVL-factory. Two ribbed panels were glued with Collano’s Purbond HB110 and one reference specimen was glued using resorcinol-phenol-formaldehyde resin. The creep test was performed at VTT weather room in varying RH (40 – 90 %) lasting eight weeks as a whole. About 25 % of the ultimate load were applied to 1/3 points of the span. Test was started at 90 %, and after two weeks RH was changed to 40 % and kept two weeks constant. The cycle was repeated two times, and at the end of the test beams were conditioned to RH 65 % without load. The test set-up is presented in Figure 8. Deflection measurements during creep test are presented in Figure 9.
The instant deflection of the beams was about 20 mm, which corresponds to the theoretically calculated deflection. During the test, creep of the glue line was not observed.

**Figure 8. Test set-up of creep tests.**

![Test set-up of creep test, specimens PU1, PU2 and RF1](image)

**Figure 9. Mid span deflection of test pieces PU1, PU2 and RF1 (reference specimen) in creep test at varying humidity (40-90 % RH).**

![Graph showing mid span deflection](image)
Full scale short-term strength
After the creep tests two ribbed panel specimens were loaded to failure at the short-term tests at VTT. The ultimate load of RF-glued specimen was 50.9 kN and 65.9 kN was obtained for PU glued beam respectively (Figure 10). The shear stress in the glue line at the ultimate load was 2.1 MPa and 2.7 MPa for RF and PU glued beams respectively.

Figure 10. Load F (kN) as a function of mid span deflection (mm) in short-term bending test for RF and PU glued ribbed panels.

CONCLUSIONS

The purpose of this study was to find out the potential of manufacturing structural elements using screw gluing technique and PU glue. Furthermore, the aim was to define the limiting conditions where the gluing is still satisfactory in order to develop working and quality control instructions for industrial scale gluing. In this study, the main criteria for the acceptable gluing were adequate shear strength and the thickness of the glue line (<0.3 mm).

PU adhesives were used, because they do not need as high compression pressures as conventional structural wood adhesives, such as RF and MUF, and therefore pressing with mechanical fasteners is possible. With screw gluing the low and uneven gluing pressures can be obtained. Since PU glue has no gap-filling capabilities, extra cautions has to be focused on the gluing process and on the surface quality of wood surfaces to obtain thin and uniform glue line. Assembly gluing requires quality specifications and continual quality control of dimensions is essential during the manufacturing.

First in the experimental study the effects of pressing conditions on the thickness, strength and characteristics of the glue line were studied. The shear strength values of PU glued specimens were compared to the shear strength of RF-glued specimens and to the shear strength of LVL material. Then the optimal combination of the glue spread, the screw space and the end distance were examined.

The results of this study show that PU glue works at least as well as RF glue in Kerto-LVL ribbed panels. The shear strength values of PU glue corresponded to the strength value of uniformly pressed specimens. Thus, screw-gluing technique is applicable. Even with low pressures, 0.03 MPa to 0.1 MPa, it is possible to achieve a glue line thickness less than 0.3 mm, if glued surfaces are adequately smooth and straight.

There is relatively little experience of the performance of PU glue joints over longer time periods. The results of this research concerning the long-term creep properties of PU adhesive were promising.
REFERENCES

Collano Purbond HB 110. Application Laboratory Collano Adhesives for Wood Constructions/12-97.


Specimen 10 and 11, L = 2250 mm

Materials:
Flanges 2x Kerto-St = 39 mm
Webs 3x Kerto-St = 45 mm

Bock shear specimens:
from webs 1 is 2 top and bottom glue lines
the number 40 / specimen
Web 3 is sawn apart but not cut to smaller specimens
Microscopy samples:
from web 1 upper glueline and web 2 lower glueline
6 / specimen

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1 = block shear test piece
2 = microscopy sample