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Schraubenverleimungen erlauben neue Möglichkeiten im Ingenieurholzbau

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Screw gluing gives new possibilities for wood engineering

Introduction

Glulam, finger-jointed products and different types of I-beams are traditional and widely used glued structural building components. In glued joints and screw glued wooden structures it is important to achieve sufficiently thin glue lines. Uniform adhesion and good quality of glue lines are often obtained by using high compression pressures (more than 0.6 MPa) during curing time. This means that heavy and expensive hydraulic pressing devices are needed in process. In contrast, pneumatic and vacuum techniques are cheaper, but lower pressures (0.05 - 0.4 MPa) can be obtained. Mechanical fasteners achieve the lowest and more uneven compression (0.01 – 0.2 MPa)

Applications of screw gluing technique

Epoxy glue with nails has been used in constructions where it is not possible to obtain high compression pressure in uneven glue lines. However, it is reasonable to use non-gap-filling glue in order to make glue lines as thin as possible. By using screws with a higher compression pressure compared to nails and with an adequate surface smoothness and dimensionally stable material, like Laminated Veneer Lumber (LVL), it is possible to produce economically larger structural wooden components (Figure 1).

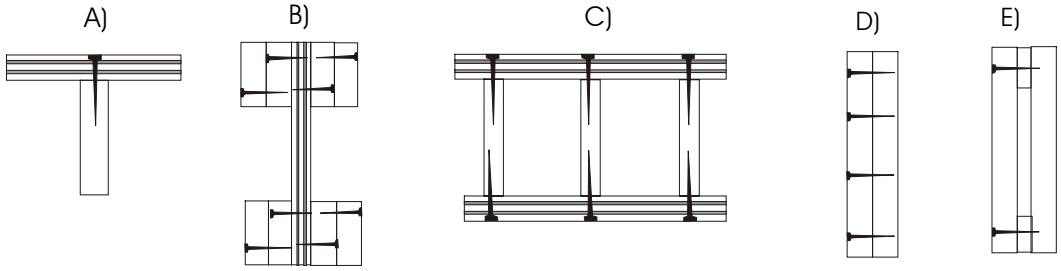

Figure 1. Examples of screw gluing technique on A) T-beam, B) I-beam, C) ribbed panel (stressed skin panel), D) side by side glued double–beam and E) box-beam. The wood materials showed are LVL (Other structural composite timber can also be used).

Structural wood adhesives

The most important wood adhesives for load bearing structures are phenol- (PF), urea- (UF), melamine-urea- (MUF) and resorcinol-formaldehyde (RF). Also casein glues belong to this family. These adhesives 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 types there are brands for very different properties, but there is no short-term approval test to identify the suitable brands (Raknes, 1995).

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One-component polyurethane glue, Collano's Purbond HB 110, has got approval as structural adhesive first by the German and this year also by the Scandinavian authorities. The glue line is required to be kept under 0.3 mm thick, but no demands for the pressure are defined. The core problem is the pressure, how the PU glue line is kept under 0.3 mm thick. The conditions for the acceptable gluing are adequate shear strength and the thickness of glue line.

The study results (Kairi et al., 1999) have indicated that PU adhesives are not as brittle as the conventional structural wood adhesives, and by using them the local concentration of the stresses can be avoided. For example, the ductility of glueline and the handling stability of ribbed elements are improved with the PU gluing. PU glue works at least as well as RF glue in Kerto-LVL ribbed panels. The shear strength values of PU glue coincide with to the strength values of uniformly pressed specimens. Thus, screw-gluing technique is applicable. Even with low pressures, 0.03 - 0.1 MPa, it is possible to achieve a glue line thickness less than 0.3 mm, so long as glued surfaces are adequately smooth and straight.

In practice, it has been recommended that the glue lines of RF glues should be under 0.5 mm thick. During the manufacture of Expo-Roof 2000 it was studied how it is possible to produce demanding wooden structures with structural screw gluing instead of nail gluing.

Factors affecting strength and quality of bond line

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 adhesive and the material to be glued. PU adhesives demand only about 0.01-0.1 MPa pressure (Housh, 1985) whereas PF and MUF adhesives demand about 1.4-2.0 MPa and RF adhesives about 0.6-0.8 MPa (Suomi–Lindberg, 1986). Too high pressure leads to a non-reliable glue line because it presses so much glue out of the bond line (Hoyle&Woeste, 1989). It may also crush the wood cells on the surfaces 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. Too low pressure does not provide close contact between the surfaces and the bond line may remain partly poor (Suomi-Lindberg, 1986).

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

Thirdly, 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 ensure the conditions for the good adhesion of the glue on the wooden surfaces. Therefore, the surfaces must be sanded before gluing to correct dimensions by tolerance of $\pm$0.5 mm for RF, and cleaned from dust, oil and dirt.

The gluing tolerances of PU glues are more restrict regarding too thick glue line than the tolerances of RF glue.

Pressing the glue line with mechanical fasteners

PU adhesives do not need as high compression pressure as conventional structural wood adhesives, such as PF and MUF. Therefore, pressing by mechanical fasteners is possible. However, with screw gluing the low and uneven gluing pressures are obtained.

In screw pressing the pressure distribution in the glue line is affected by the type, size and spacing of screws and the size and material properties of wood members. The screw type Stadler IG 6x100 mm was found to be the most suitable for screw pressing in the tests for Sibelius Hall, in Lahti, Finland (Kairi et al., 1999). Pressing of the joints succeeds, when 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/m^2, screw spacing is less than or equal to 400 mm and the end distance is 100 – 150 mm.

In Expo-Roof 2000, the assembly gluing was carried out as screw gluing following instruction of the nail gluing method according to DIN 1052. In fact, in the revision of DIN 1052, it will be proposed that the nail gluing method is changed to screw gluing method. There is one screw for every 150 cm^2 area according to the standard. In this project more screws were used. The screw type used was certificated SPAX®-S screw. The gluing of wooden components was carried out with the gap-filling type glue Dynosol S 204. The glue spread was distinctly over 500 g per m^2 to include extra spread.

The screws can be driven with electric drill to achieve the right compression pressure. Usually, the adequate pressure is achieved when the screw head penetrates just into the wood surface. The screw gluing technique is more stationary than nail gluing because the compression pressure is produced like hydraulic pressure without any impact. In gluing it is important that the glue lines stay undisturbed during manufacture and curing.

The screw gluing technique is ideal for gluing at construction site because the screws can be driven out if necessary.

Test methods

The effect of the uniform pressure on the thickness and strength of the PU glue line can be tested for example with T-joints in laboratory conditions (Figure 1A). Also, shear strength tests and creep tests can be done to test the joints (ASTM D143).

According to the test results (Kairi et al., 1999), it is possible, with low pressures (0.03 - 0.1 MPa), to achieve a PU glue line, which thickness is under 0.3 mm and shear strength is as good as those pressed at normal pressures (0.6 - 0.8 MPa). The important requirement for successful gluing is the adequately smooth surfaces.

In the case of Expo-Roof 2000, the delamination tests were carried out with the test specimens made according to DIN 1052.

Quality control

The main objective of the quality control is to ensure continuous traceability from the beginning of manufacture to the complete glued component and to installed element. The traceability is essential in the case of possible failure or confusion situation. Each manufactured or assembly glued component and structural part has to have a mark that details the manufacturer and manufacturing time.

The working and quality control instructions for industrial scale gluing are needed. The satisfactory result of gluing must be checked with quality control. Quality control record for each working phase can be designed according to the instructions of DIN 1052 Bescheinigung C. For example, the main parameters for acceptable gluing can be adequate shear strength and the thickness of the glue line (for PU glues < 0.3 mm and for RF glues <0.5 mm).

Since PU glue has no gap-filling capacity, extra cautions have to be paid on the gluing process and on the surface quality of wood surfaces to obtain thin and uniform glue lines. Assembly gluing requires quality specifications and continuous quality control of dimensions is essential during the manufacturing.

Research needed

The factors affecting the strength and quality of the glue line in screw-pressed elements need to be further studied. The applicability of screw pressing technique and the performance of PU joints over longer time period in load bearing structures need to be investigated with long-term tests.

In order to obtain satisfactory glue lines, the critical conditions and proper manufacturing methods affecting the PU glue line quality, thickness and strength should be figured out. The development of measuring methods for roughness and quality of wooden surfaces to be glued is a challenging task for further research.

In screw gluing, the design principle for the spacing of screws taking into account member sizes, orientations, thickness and surface quality has to be developed. For quality control and inspections reliable destructive and non-destructive test methods have to be standardised.

To ensure the manufacture of good quality screw glued wooden structures, the development and formation of training and registration system of qualified professional producers (glue joiners) of screw glued structures and components have to be established.

Reference projects

Ylöjärvi multistorey houses in Finland

The first three modern wooden multistorey houses in Finland has been built in Ylöjärvi 1995. The floor elements are screw glued ribbed panels, figures 1A and 2-5. The glue was Dynosol S 204 and the screws Stadler IG 6x100 mm with spacing of 200 mm.

Figure 2. Assembling of the 39 mm thick Kerto-LVL skin panel with cross veneers on the 51x360 mm Kerto-LVL beams with glue spread on the edges.

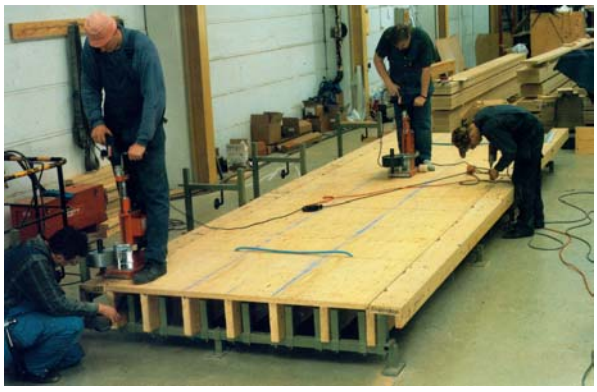

Figure 3. Screwing of the Stadler IG 6x100 mm with the spacing of 200 mm.

Figure 4. Stress skin elements were erected rapidly on the building site

Figure 5. One of the tree ready made multistorey houses

Waldau Stadium

Not far away from well-known TV tower in Stuttgart is located Waldau Stadium. By renovation the football stadium got on the opposite side of the main stand a new 1,800 m^2 large shelter made with slender wooden elements. The design is like a 17 m wide and 104 m long wing of an aeroplane.

In factory 3,39 m wide and full 17 m long elements were screw glued and transported to the building site. Two elements were screw glued together 6.78 m wide components on the site and lifted on the steel columns, figure 7. The elements are box construction, figure 1C, with gluelam I-beam webs and Kerto-LVL panels flanges with cross veneers. The gluing was made with Dynosol S 204 and ABC Spax® screws.

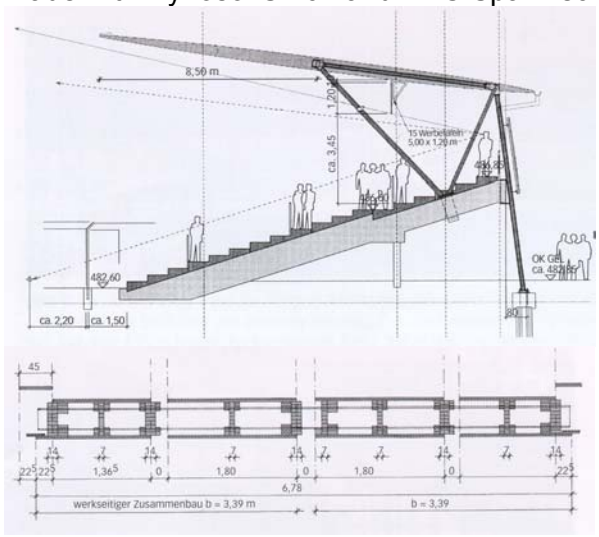

Figure 6. The cross sections of the shelter and roof elements

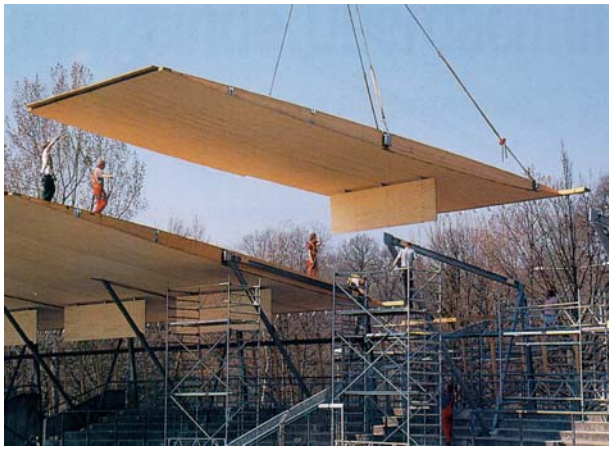

Figure 7. Elements are 6.78 m wide and 17 m long box constructions

Figure 8. Light and airy roof construction gives wide view over the playing field. The roof consist of 15 elements 6.78 m wide and two 1.15 m wide elements in the both ends. The length is 104 m and area of 1,800 m^2.

Sibelius Hall

New wooden Sibelius Concert and Congress Hall in Lahti, Finland, is a pilot project in which structural PU gluing with screw pressing technique is used in LVL balcony elements (Figures 1 C, 9 and 10), ceiling elements and wall structures. The balconies have span length of 8.1 m. Those elements utilise the full composite action of the ribs and skin panels. Thus, ribs provide shear resistance and skin panels provide moment resistance.

The top and bottom panels of the balcony element are made of optical sanded 49.0 mm thick Kerto-LVL panels. When using LVL as a panel, 20 % of the veneers are crosswise glued like in the plywood, whereas Kerto-LVL as a beam is a standard LVL with all the veneers glued parallel longitudinally. All wooden parts were sawn to desired sizes, optical sanded and the grooves were milled in the machining line of the fabricating hall.

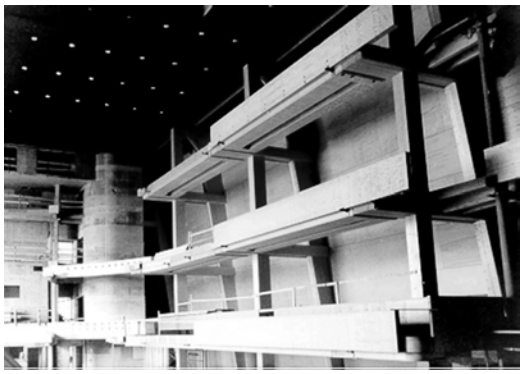

Figure 9. Sibelius Hall, in Lahti, Finland, used PU gluing with screw pressing technique in balcony elements, wall structures and ceiling elements.

Figure 10. LVL stressed skin panels as balcony elements stored in the construction site.

Expo-Roof

Resorcinol-formaldehyde (RF) glue has been used in Expo-Roof 2000 in Hanover, Germany (Figures 11-14). Expo-Roof 2000 is comprising 10 umbrella-like canopies. Each of the canopies covers an area 40x40 m^2, and contains three parts; tower, girder and network; that were manufactured using structural assembly gluing.

The height of tower is 18 m. Four wooden columns in each tower (leg) were braced with triangulated box-beams made of glulam flanges and Kerto-LVL panel webs. Thickness of Kerto-LVL panels is 33 mm (Figure 1E). The components were connected with steel plates and dowels.

Four cantilever girders made of box-beams (Figure 1E) situate at the top of tower. Each girder consists of two box-beams, which are connected and braced with screw gluing to each other with Kerto-LVL panel webs.

The network structure of the roof was manufactured with assembly gluing in the construction site. The network structure was made of sawn timber and Kerto-LVL lamellas that were glued together (Figure 1D). The Kerto-LVL lamellas were settled to the most demanding parts of the roof structure, where the tension and compression loads are the most critical. The lamellas are full-length lamellas without finger joints.

Figure 11. The assembly of the box-beams of girder. The flanges are made of glulam and two Kerto-LVL panels thickness of 33 mm are screw glued both sides of flanges. The upper flange is straight and the lower one is curved

Figure 12. One cantilevered truss consists of two box beams, which are braced against lateral deformation. The weight of one element is 35 tons.

Figure 13. Double-curved lattice shells has been screw glued close the site in one of the exhibition halls Hanover.

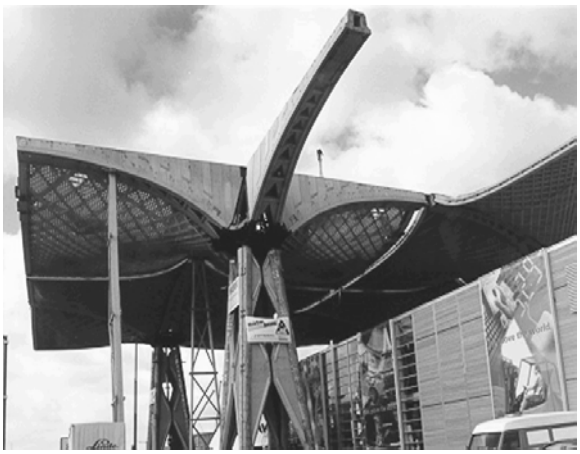

Figure 14. The leg and large girders are assembled from two box-beams. The lenght of the girder is 18.6 m.

Silva Stadium

The concept of Silva is developed based on Waldau Stadium, figure 8. The construction consists of box-beams, –columns and ribbed panels.

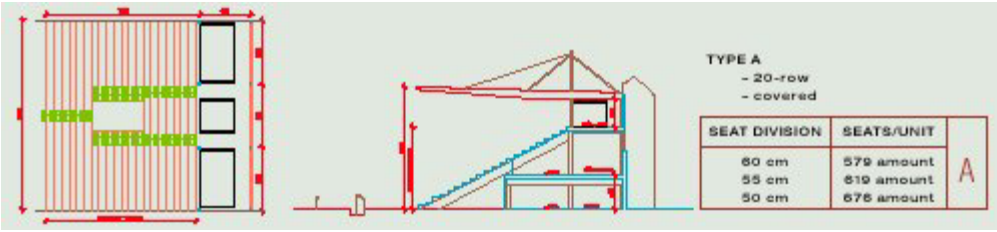

Figure 15. The cross sections of the Silva Stadium type A.

Figure 16. The wooden frame of Silva Stadium in Vantaa, Finland.

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