# Glulam Posts with Thermally Modified Spruce for Outdoor Applications

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## ABSTRACT

Glulam posts with themally modified wood have been prepared by two different methods, thermal modification of glulam posts and gluing of thermally modified boards. Four different kinds of commercial adhesives has been used, emulsion polymer isocyanate, melamine urea formaldehyde, melamine formaldehyde, and phenol resorcinol formaldehyde. The structure of the adhesive joints was evaluated in a scanning electron microsocope while the mechanical performance was evaluated by shear strength and delamination tests. The thermal modification of glulam posts was successful since interior cracking was avoided even though the posts were of 90 mm thickness. The emulsion polymer isocyanate adhesive did not withstand the high temperatures during thermally modification process but the other systems performed well. The adhesive bonds in the posts glued with thermally modified boards showed somewhat lower shear strength but high wood failure percentage.

## INTRODUCTION

Glulam posts and other type of engineered wood products from thermally modified wood is a research field of increased activity. The posts evaluated in this study are intended to be used in outdoor applications such as carports, for example. They are expected to have improved properties compared with posts of untreated wood. Thermally modified wood show different properties than ordinary dried wood. In addition to increased durability and color changes, one important property is the decreased hygroscopicity, which decreases the wood-vapor interaction. This reduces the equilibrium moisture content (MC) and moisture induced swelling and shrinkage of the wood. The environmental impact of thermally modified wood is lower compared with impregnated wood.

In this work, different ways of producing laminated Thermo-D (www.thermowood.fi) thermally modified spruce wood posts with the final cross sections of about 100x100 $mm^2$ have been investigated. This was done by thermally modifying glulam posts and by gluing already thermally modified boards. One advantage with thermally modified glulam posts is that the gluing is carried out on unmodified wood with the advantage of using already existing gluing techniques and adhesives. The drawback is that the adhesive needs to sustain the high temperature (212 °C) during the thermal modification process as well as the large shrinkage occurring in the individual boards that may cause stresses and interior cracks when the wood material is subjected to the thermal modification process. In the present work two moisture content levels of unmodified spruce boards were used in order to study the effect of moisture content on possible formation of cracks.

For the posts prepared by gluing thermally modified wood the problem with large dimension changes is avoided. The challenge is the changed surface properties of the modified wood, which decreases the wettability of spruce (Hakkou *et al*. 2005).

## EXPERIMENTAL

### *Materials*

Norway spruce center boards with the dimensions 22x125 $mm^2$ were dried at a sawmill to approximately 18% MC and then they were dried in a small pilot drying kiln in two batches to 12% and 5% MC at maximum 75 °C dry temperature using circulating air. The boards were cut to 630 mm in such a way that pith and knots in the lamellas were omitted to the greatest extent possible. The boards were delivered by Norrskog Wood Products AB.

Thermally modified Norway spruce center boards with the dimensions 38x150 $mm^2$ were delivered by HeatWood AB. The boards were modified with the Thermo-D process with a heat treatment plateau of 212 °C during three hours. The moisture content of the boards was 6%. The boards were cut to 630 mm by omitting pith and knots in the lamellas to the greatest extent possible.

Four different cold setting, two component adhesives from Dynea AS were used; emulsion polymer isocyanate (EPI), melamine urea formaldehyde (MUF), melamine formaldehyde (MF), and phenol resorcinol formaldehyde (PRF). For details see Table 1.

***Table 1: Name and mixing ratio for the adhesives and hardeners used in this study.***

| | Adhesive/hardener | Ratio adhesive:hardener |
|---|---|---|
| EPI | Prefere 6151/6651 | 100:15 |
| MUF | Prefere 4535/5046 | 100:30 |
| MF | Prefere 4720/5020 | 100:20 |
| PRF | Prefere 4040/5839 | 100:20 |

### *Preparation of thermally modified posts*

The untreated spruce boards were planed to 18x125x630 $mm^3$ and five boards per post were glued in a laboratory press using 0.8 MPa pressure and pressing times according to recommendations of the adhesive manufacturer. The boards with 12% moisture content were glued with EPI, MF and PRF adhesives, while the boards with 5% moisture content were glued with MF and PRF. The adhesives were single sided manually applied with a glue spread of 200 $g/m^2$ (EPI) and 350 $g/m^2$ (MF and PRF). Three posts were prepared with each adhesive. One post glued with EPI was used without further treatment as a untreated reference post (Ref-EPI).

The thermal modification process was carried out in a pilot-scale kiln, manufactured by Valutec, according to the Thermo-D strategy with steam as a "shielding gas" and a maximum plateau temperature of 212 °C for three hours. The thermally modified posts are termed 12-EPI, 12-MF, 12-PRF, 5-MF, and 5-PRF where the number refers to the original moisture content of the board.

***Preparation of posts glued with thermally modified boards***

Five boards of thermally modified spruce planed to 21x150x630 $mm^3$ were glued together in a laboratory press using 0.8 MPa pressure. Four different adhesives, EPI, MUF, MF and PRF, were double sided manually applied with a total glue spread of 200 $g/m^2$ for EPI and 400 $g/m^2$ for MUF, MF, and PRF. The recommended pressing time was doubled as an attempt to increase the quality of the adhesive bond (Ormstad 2007). Three posts were prepared with each adhesive. The final posts are termed TM-EPI, TM-MUF, TM-MF and TM-PRF, respectively, where TM stands for thermally modified.

***Structure characterization***

The adhesive bonds were studied with scanning electron microscopy, SEM, (Hitatchi Tabletop Microscope TM-1000). The samples were cut using a pulsing UV excimer laser with a wavelength of 284 nm. The irradiation energy was 333 mJ and the frequency was 3 Hz.

The thermally modified posts were scanned for interior characterisation using a Siemens Somatom Emotion X-ray Computed Tomography (CT) scanner. Scans were taken before and after the thermal modification process. The spatial resolution was approximately 1 mm.

***Mechanical testing***

Shear strength and wood failure percentage were tested according to European standard EN 392. Delamination was tested according to European standard EN 391 with the modification that the samples were subjected to only one cycle. For both tests, two specimens were cut from each individual glulam post which results in a total of 6 specimens for each system, except for the 12-EPI posts where a total of 4 specimens were prepared. For Ref-EPI four specimens were cut from the single post prepared. Prior to testing, at least 1 cm was trimmed of the edges of each post and the specimens were cut at least 50 mm from the ends of the posts in order to avoid edge effects. Care was also taken to avoid knots and other defects in the test specimens.

## RESULTS AND DISCUSSION

The untreated spruce boards were glued according to recommendations from the adhesive manufacturer. For the thermally modified boards the adhesive was applied double sided and the pressing time recommended for untreated wood was doubled (Ormstad 2007). Initially there were problems with crack formation in the boards during planing and pressing. This was avoided by more cautious handling and planing and by lowering the pressure during pressing of the posts.

The method for thermally modifying posts needed more caution in order to limit the degree of interior cracking. Johansson (2006) has shown that spruce with 50 mm of thickness is susceptible for interior cracking when being thermally modified according to the Thermo-D process. In this study the thickness was 90 mm for the posts, consisting of five lamellas each. The reduction of moisture during the modification process induces shrinkage and the thick dimension gives moisture gradients within the wood during drying. In turn, the moisture gradients give strain variations and stresses in the material. Also, the thermal degradation of the spruce wood in the thermal modification process reduces mass and strength in the wood both at micro- and macro level. Hence, the interior crack formation is a complex behavior which is not fully understood today.

In the present work the thermal modification process were tested on four posts in two pre-tests, with one PRF- and one MF-post in each pre-test trial. The first was a faster schedule, 60 h duration, which gave a lot of interior cracking. It has been reported that interior cracks can be avoided to some extent by slower increase to heat treatment plateau (Johansson 2006) due to this the second was prolonged to 94 h with decreased rate of drying, heating and cooling of the wood. Also this second trial gave interior cracking. Anyway, the 49 h process was chosen for the treatment of the posts for which the glue line properties were evaluated. However, these did not show at all that high frequency of interior cracking as the pre-test posts after thermal modification. The interior cracks found in CT-images were in the vicinity of knot whorls. Since the process was similar to the second pre-test trial the main reason of cracking is likely to be due to the material structure, whereof the pre-test material included pith in the lamellas. The position of the pith is known to cause interior cracks (Johansson 2006) and it indicates how important it is to carefully choose the raw material for this type of products.

In the evaluation of the CT-images for interior cracking, it seemed like starting with 5 or 12% initial MC in the beginning of the thermal modification process did not make a difference for PRF and MF glued posts. This is interesting, since Johansson (2006) shows that when starting with low moisture content in a solid wood spruce board of 50 mm thickness, the number of interior cracks decrease. However, in this study, it is still possible that the 5% initial MC has given lower stresses in the material during the process.

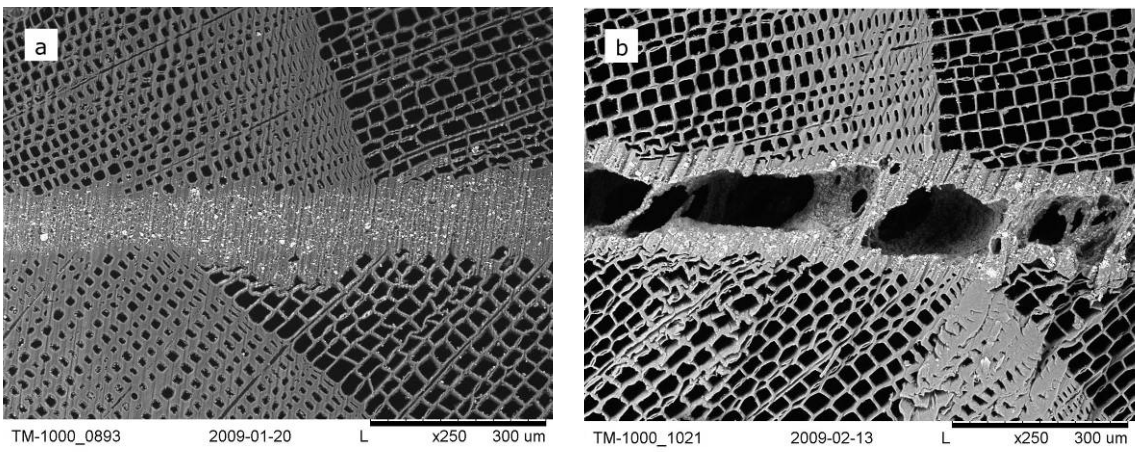


***Figure 1: SEM image of adhesive bonds in a) untreated post glued with EPI (Ref-EPI) and b) thermally modified post glued with EPI (12-EPI). The scale bar is 300 µm.***

The appearance of the adhesive bonds for all different glulam post systems were studied in SEM. In general good penetration is shown for all tested adhesives into both untreated and thermally modified wood (Figure 1-3). The parallel lines apparent in the SEM images are artifacts due to the laser cutting used during sample preparation.

In Figure 1 SEM images of the adhesives bonds for untreated wood glued with EPI adhesive are shown for the untreated reference post (Ref-EPI) and for posts after thermally modification (12-EPI). After thermally modification the EPI adhesive bond show large fraction of cracks due to degradation during the thermal modification. The adhesive also showed changes in color after being subjected to the high temperature during the modification process. Compared with the Ref-EPI, the 12-EPI system also showed inferior results in the shear tests and delamination tests (Table 2). The Ref-EPI fulfilled the requirements according to EN 386 since this adhesive is approved for gluing of untreated wood. MF and PRF seems to have withstood the high temperature treatment much better than EPI (Figure 2). This can also be seen in the test results in Table 2.

There is no obvious difference in the appearance of the bonds in the posts, glued with either MF or PRF, for boards with 5% MC compared with 12% MC (Figure 2). A few thin cohesive cracks that run parallel with the glue line are observed for the posts glued with boards with 5% MC (5-MF and 5-PRF). An example is illustrated in Figure 2d. These cracks were not observed in any of the other studied systems. This is somewhat contradicting since it was expected that the adhesive bonds for the posts glued with 12% MC would have been objected to larger strains. Only a total of 2 cm of adhesive bonds were observed for each system (two adhesive bonds of approximately 1 cm each) due to limitations with the SEM technique (sample preparation, observation time). Therefore, it is not possible to make any conclusions without collecting more information from these samples. It should also be mentioned that 12-MF and 5-MF also contained a few larger cracks perpendicular to the glue line.

***Table 2: Results from shear and delamination tests. Values in parentheses are standard deviation.***

| Method | Specimen | Average shear strength [MPa][a] | Wood failure percentage [%] | Delamination [%] |
|---|---|---|---|---|
| Non treated reference | Ref-EPI | 10.0 (1.6) | 88 (20) | 0 (0) |
| Thermally modified posts | 12-EPI | 1.8 (1.6) | 3 (6) | 77.6 (7.2) |
| | 12-MF | 7.5 (1.3) | 74 (20) | 1.5 (2.3) |
| | 12-PRF | 7.8 (1.3) | 83 (15) | 3.1 (4.1) |
| | 5-MF | 7.2 (1.3) | 90 (10) | 1.2 (2.4) |
| | 5-PRF | 7.1 (2.0) | 86 (16) | 3.2 (5.2) |
| Posts glued with thermally modified boards | TM-EPI | 6.3 (2.0) | 95 (9) | 1.0 (1.3) |
| | TM-MUF | 6.6 (1.5) | 94 (12) | 5.3 (4.5) |
| | TM-MF | 6.1 (1.6) | 96 (4) | 0.9 (0.9) |
| | TM-PRF | 6.9 (1.7) | 97 (5) | 0 (0) |

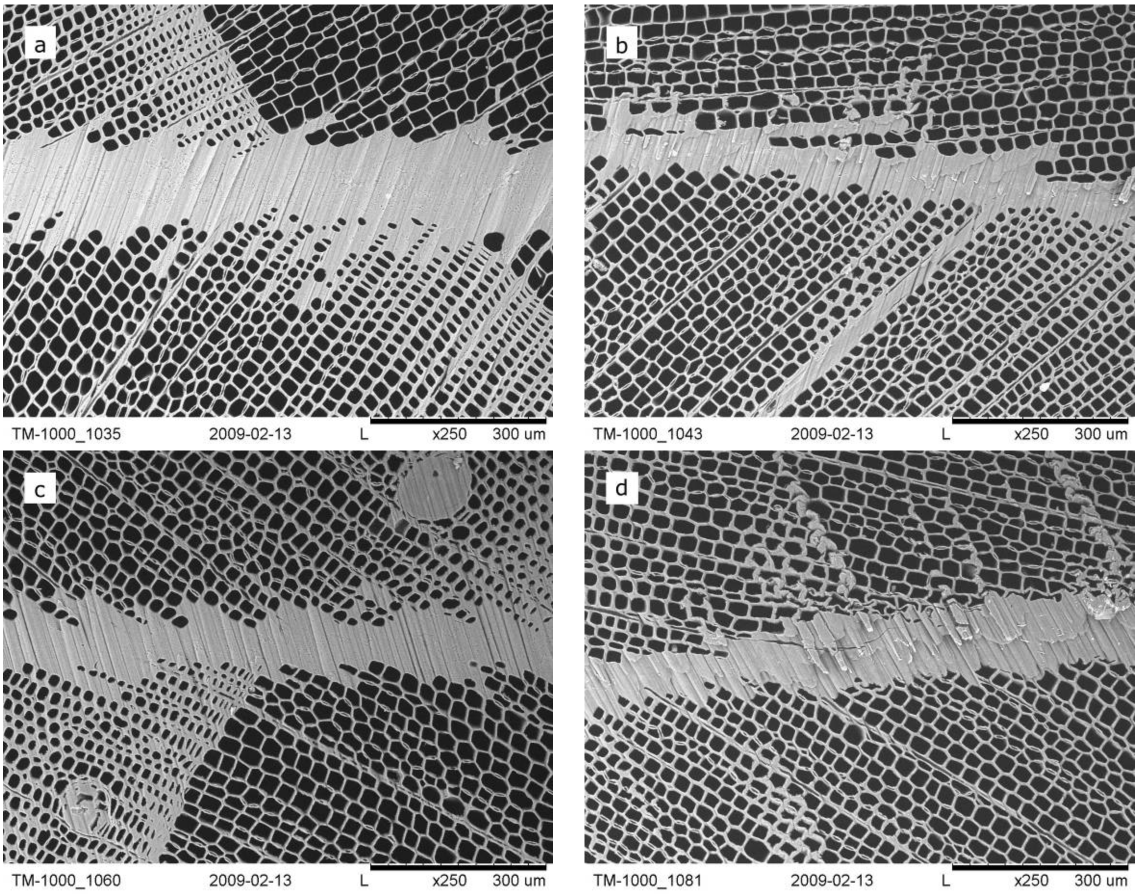


***Figure 2: SEM image of adhesive bonds in thermally modified post glued with a) 12-MF, b) 12-PRF, c) 5-MF, d) 5-PRF. The scale bar is 300 µm.***

As shown in Table 2 the shear strength of bonds both in modified posts and in posts glued with modified wood show lower shear strength than the bonds in the untreated reference post (Ref-EPI). For the posts made with thermally modified boards the wood failure percentage (WFP), which is close to 100%, indicates that the low shear strength is primary due to the lower shear strength of thermally modified wood. In the case for posts subjected to thermal modification the WFP is somewhat lower, indicating a combination of decreased adhesive properties due to the high temperature treatment in addition to the expected decrease in wood shear strength. All samples, except for the thermally modified post with EPI adhesive bond, show no or little delamination.

In a previous study by Sernek *et al*. (2008), PRF was found to perform poorly with thermally modified wood (2.18 MPa shear strength, and 54.7% delamination). The WFP was low, 33%, indicating a weak adhesive bond. In the present study no such behavior was observed. The present PRF adhesive performed well when used for gluing thermally modified boards.

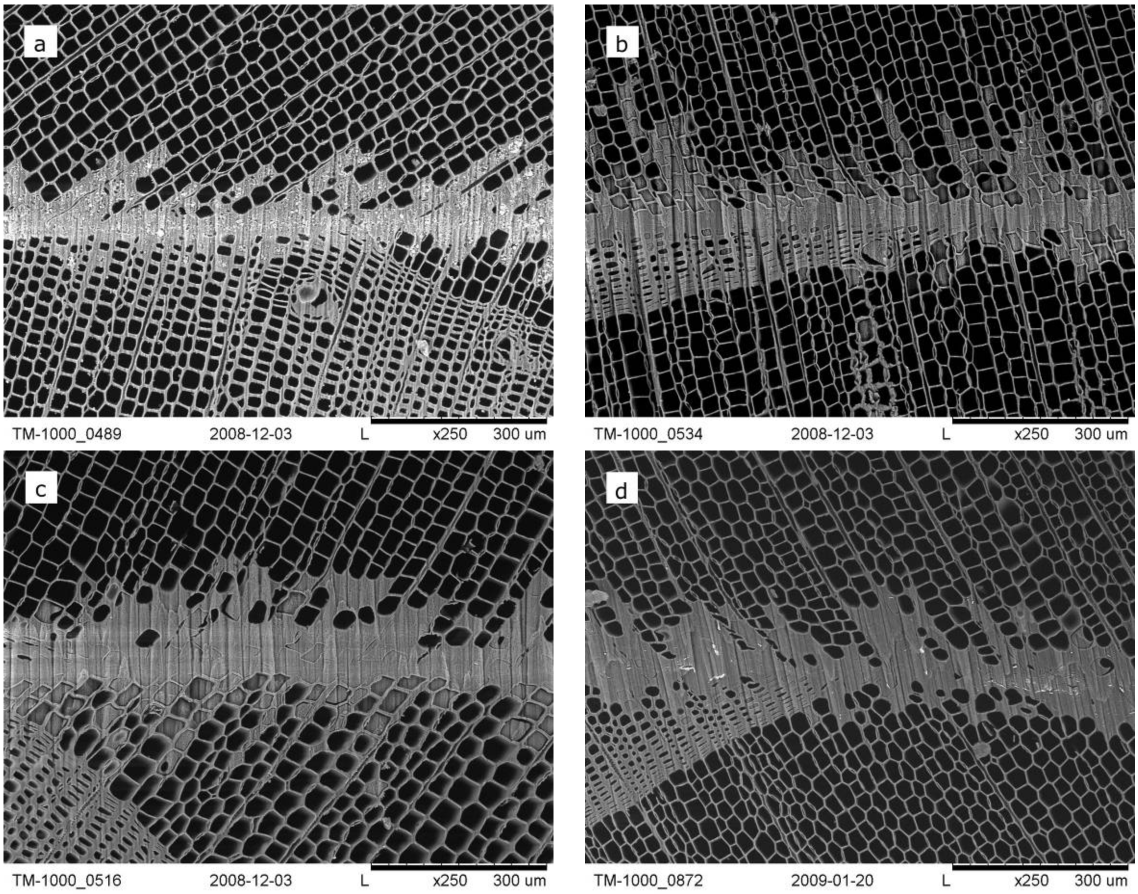


***Figure 3: SEM images of adhesive bonds in posts glued with thermally modified wood. a) TM-EPI, b) TM-MUF, c) TM-MF, d) TM-PRF. The scale bar is 300 µm.***

## CONCLUSIONS

Glulam posts with thermally modified wood can be prepared either by thermally modify glulam posts or by gluing posts with thermally modified boards. In the present study there was no large difference between these two methods for the adhesives used. The major difference was that during shear test the adhesive bonds in the thermally treated posts seemed to fail cohesively to a larger extent than adhesive bonds in posts glued with thermally modified boards. This indicates that the adhesive has been affected by the high temperature during the high temperature treatment. The EPI adhesive did not withstand the thermal modification and is not suitable to use in thermally modified posts.

This study showed that it is possible to avoid internal cracking of thermally modified posts with thickness and width of 90 mm. It is important to choose boards in order to avoid pith and large knots. However, it would be desirable to be able to process any kind of materials, but then the process duration and possible the choice of process would be affected.

It is known that thermally modified wood get a large reduction in strength, but the stiffness does not experience that much decrease (Bengtsson et al. 2002). Often in construction, the strength and not the stiffness is the dimensioning property for a glulam beam. Therefore it is generally not recommended that thermally modified wood is used for load bearing constructions. However, the authors encourage to question this statement in cases when stiffness, and not strength, is of high importance, as for the case with posts loaded in longitudinal compression.

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