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Insights into stability of glued joints between thermally modified timber: adaptation of an artificial weathering test

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ABSTRACT

Thermal modification leads to enhanced dimensional stability among other property changes. There is interest in using mild thermal modifications to add value to joinery products. A mild-modification system for Welsh timber has been developed to improve dimensional stability and working properties of fast grown softwoods such as larch (*Larix kaempferi*) and Western hemlock (*Tsuga heterophylla*). There is potential to combine this with lamination to achieve large section pieces suitable for joinery applications. This paper reports a set of tests developed to investigate the strain within glued joints in modified wood under combined wetting, UV and humidity cycling regimes.

The developed method was based on EN 927-6, which is a QUV artificial weathering test typically used to evaluate the performance of coatings on wood. By omitting a mask, and allowing UV exposure over the total surface, the glued joints within the samples were exposed to rapid drying during the UV phases of the cycle and wetting during spray cycles. This places significant strain on any paint films or glue joints, providing a challenging test method, enabling comparison of film performance and bonding. After six days cycling between spray and UV the samples were removed and placed above a water bath to provide elevated humidity on the underside (uncoated face). This had the effect of permitting asymmetric swelling through the thickness of the sample. Samples were removed from the QUV chamber between each one week cycle, to gather data relating to moisture content, degree of splitting, checking or delamination.

The samples were prepared from modified Japanese larch. Pieces were planed and laminated with four lamellae using a polyurethane adhesive. In the final piece the lamellae were aligned radially, tangentially or half-radially or half-tangentially, laid up to minimise and to maximise strain at the glue-line by deliberately favouring matching (e.g. radial to radial) or poor (e.g. tangential to radial) combinations. In addition, combinations of mild and moderate thermal modification were placed in adjacent glue-lines. Samples were tested uncoated, or with clear varnish coating on only the upper face.

Swelling in tangential dimensions of the segments was greater than in the radial dimensions, resulting in visible difference of thickness where radial-tangential bonds had been created. However bonding remained good through the 12 week period. The performance of a high gloss varnish was also monitored, and only minor defects observed in the majority of segments. The observed dimensional changes, moisture uptake and development of splits and checks within the wood will be discussed to illustrate stress development within the laminated samples. The results clearly highlight the potential of this test method as a severe combination of cyclic conditions, with potential for evaluating adhesive performance under asymmetric conditions.

INTRODUCTION

Thermal modification is a well-established form of wood modification, leading to enhanced dimensional stability among other property changes. It may be used to add value to readily available timbers, not only due to greater suitability for joinery products resulting from reduced moisture movement but also aesthetic benefits. Development of a mild-modification system for Welsh timber was motivated by a desire to improve dimensional stability and working properties of fast grown softwoods such as larch (*Larix kaempferi*) and Western hemlock (*Tsuga heterophylla*) (Spear *et al.* 2016). Lamination of these thermally modified timbers was proposed as a method to achieve large section pieces suitable for joinery applications such as window components. As a result a set of tests was developed to investigate the strain within glued joints in modified wood under combined wetting, UV and humidity cycling.

A test method was developed and trialled, based on EN 927-6, which is a QUV artificial weathering test typically used to evaluate the performance of coatings on wood. By omitting a mask, and allowing UV exposure over the total surface, the glued joints within the samples were exposed to rapid drying during the UV phases of the cycle (90 mins), and wetting during spray cycles (30 mins). This places significant strain on the glue joints, and any paint films or covering. The aim was to find a challenging test method for rapid evaluation and comparison of glueline and film performance. After the six days UV and water spray cycle, the samples were moved and placed above a water bath to provide elevated humidity on the underside (uncoated, or unexposed face) for one day. This had the effect of permitting asymmetric swelling through the thickness of the sample. Samples were observed between each one week cycle, to gather data relating to moisture content, degree of splitting, checking or delamination.

EXPERIMENTAL

Sample material and preparation

Samples of modified Japanese larch were generated by a mild and a moderate treatment intensity thermal modification process as described in Spear et al. (2015). Pieces were planed and laminated into workpieces with four lamellae using a polyurethane adhesive. Once cured the work pieces were rip sawn perpendicular to the glued joint to provide samples containing 4 segments and three glued joints (Figure 1a,b). The samples were then re-planed to give a smooth finish prior to varnish coating. The dimensions of the samples for the weathering test were 150x74x18 mm

The samples were prepared with the lamellae aligned radially, tangentially or half-radially or half-tangentially, so that the growth rings within segments were aligned parallel, perpendicular or at an intermediate angle to the plane of the test sample. The lamination of the pieces was designed to minimise and to maximise strain at the glue-line by deliberately favouring matching (*e.g.* radial to radial) or poor (e.g. tangential to radial) combinations of growth ring alignment. In addition, combinations of mild and moderate thermal modification were placed in adjacent glue-lines (Figure 1b).

Figure 1a: Laminated samples after cutting and planing to the required thickness. Small matching samples for moisture uptake study were cut from the ends of the longer weathering samples. 1b: End grain of a selection of moisture content samples, showing matched and non-matched grain orientation within the laminate

Much is known about the ideal lay-up for laminating wood for joinery applications, for example selecting the location of the pith within adjacent pieces, and orientation of growth rings; however within a high throughput environment this process may be time consuming, or not possible for long lengths of timber. The test deliberately generated poorly matched samples to maximise likelihood of defects.

Moisture content

From each laminate two matched moisture samples were cut. These were conditioned at 20°C and 65% r.h. for one week until stable. Pieces were matched, allowing maximum moisture uptake to be observed on soaking without oven drying (leaching would alter an oven drying value after soaking), and determination of an oven dry value for never soaked material. Weight and dimensions in the conditioned state was recorded for all samples.

To determine the maximum moisture content, one set of the conditioned samples were placed in a beaker under ballast and a vacuum applied (20 min.), then soaked, by introducing deionised water while the samples were still on the vacuum. The weight and dimensions were recorded when fully soaked.

The other set of moisture content samples were oven dried, and weight and dimensions recorded. The determined value for conditioned moisture content was used in calculating estimated oven dry weights for the matching sample material.

Weathering test to observe laminate performance

Weathering exposure samples were tested either uncoated or coated. The coating was a transparent marine varnish (International Paints), applied as two coats on only one face. The coated face was the face exposed to the UV and the simulated rainfall. The weathering test was based on EN 927-6, but omitted a mask, allowing UV light to access the entire upper face of the sample. Samples were removed, measured and observed at each one week cycle to determine dimensional change and development of any defects. Three cycles were performed and evaluated here.

RESULTS AND DISCUSSION

Moisture content test observations

The moisture soaking test revealed the maximum dimensional change likely within the samples (Figure 2). Distortion resulted from differences in swelling between laminae, and diamonding of laminae where grain orientation favoured this, e.g. in the ½ radial or ½ tangential or intermediate (45°) pieces.

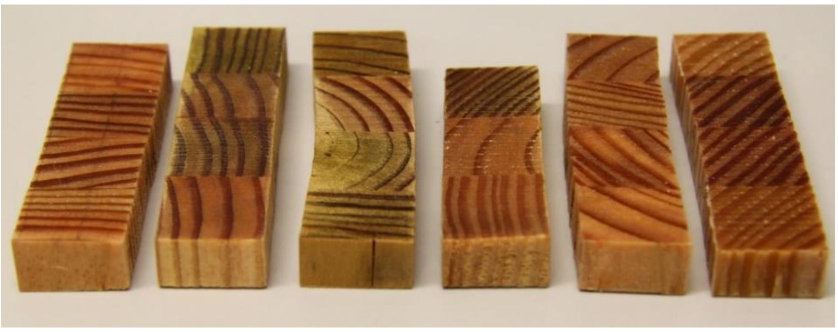

Figure 2: Moisture content samples reveal maximum deformation of the sample due to dimensional change

Table 1: Moisture content test

Sample	Weight after soaking	Estimated weight in dry state	Total weight uptake	% moisture content	Conditioned weight	Conditioned moisture content
A1b	14.36	7.80	6.56	84.10	8.62	10.51
B1b	15.41	8.31	7.10	85.44	8.96	7.82
C1b	14.87	6.93	7.94	117.98	7.44	7.36
D1b	12.19	6.36	5.83	91.67	6.85	7.70
E1b	15.27	7.39	7.88	106.63	8.11	9.74
F1b	17.32	8.19	9.13	111.48	8.94	9.16

Table 2: Dimensional change (%) on complete wetting

Sample	Average segment 1	Average segment 2	Average segment 3	Average segment 4	Largest difference	Measurement pair and notes	
A1b	8.34 T	7.59 T	7.74 ½T	7.57 T	0.71	9-10	1/2Tan to Tan
B1b	3.80 R	3.78 R	3.54 ½R	8.15 R	4.39	9-10	Moderate to Mild
C1b	6.38 T	2.71 1/2R	3.95 ½R	5.50 ½T	2.16	3-4	1/2Tan to 1/2Rad
D1b	5.12 R	2.16 R	4.92 ½R		2.46	3-4	Mature to Juvenile
E1b	4.35 int	8.22 ½R	6.67 int	6.43 int	2.75	3-4	Juvenile to mature
F1b	7.49 int	3.39 int	3.74 int	6.98 int	2.25	9-10	Mature to juvenile

Note: T = tangential, R = radial, ½T = half tangential, ½R = half radial, int = intermediate or 45° growth ring alignment. These are recorded for the measurement direction, i.e. the thickness of the laminate.

The moisture content of the pieces was relatively consistent on conditioning (7.3 to 10.5%, Table 1), with the variability likely reflecting differences in numbers of mild and moderate treated pieces within the laminated sample, and their density (*e.g.* relating to juvenile wood).

The change in thickness was measured at twelve locations on each sample, i.e. three locations per strip within the laminate – at the edge middle and edge. Average percent change in thickness within a single strip is presented in Table 2, and reveals a larger change for samples in the tangential than the radial orientation, as expected. It is this difference which was harnessed in the weathering test, to induce stress in the glued joints. The greatest difference between pairs of measurements at a joint were also noted in Table 2. Examination of the soaked samples revealed that large differences in the observed swelling related to combinations of grain angle, combinations of the mild and moderate treatment intensity, and combinations of juvenile wood with more mature wood.

Weathering test to observe laminate performance

In the weathering test, the growth ring orientation, intensity of treatment and presence of juvenile wood again influenced the swelling seen between strips with in the laminates. However bonding remained good through the full test period (Figure 3).

BEFORE	AFTER

Figure 3: Photographs of samples A1b, B1b, C1b and F1b before and after QUV weathering exposure

Samples were examined after each week long conditioning cycle, and any splits, checks or delaminations were marked. Development of splits relating to knots was the most common fault. Checking in the end grain was observed in many pieces, but was minor, as would be seen in exposed end grain of joinery. One sample developed a radial split which led to a defect within the weathered face. After the second cycle, no new faults were seen on the third cycle.

The performance of a high gloss varnish was also monitored in a separate set of samples (not shown), and only minor defects in the varnish coating were observed in the majority of segments.

CONCLUSIONS

The presented results demonstrate that the mild and moderate thermal treatment in larch was successful in lamination trials. The differential swelling and shrinkage at glue joints did not lead to failures during the test period. The test deliberately generated poorly matched laminae within the samples to maximise likelihood of defects occurring during the test. Therefore the low incidence of defect formation despite high differences in swelling (up to 4.39%) between adjacent laminae was satisfactory, indicating the suitability of mild thermally modified larch for further development.

The results also clearly highlight the potential of this test method to provide a severe combination of cyclic conditions, with potential for evaluating adhesive performance under asymmetric conditions. The humidity differential generated by the conditioning stage of the cycle led to cupping in all samples at the end of the week, demonstrating the moisture gradient across the samples.

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