Short report of the research project

Shrinkage behaviour of reinforced glulam members

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The responsibility for the content of the report lies with the authors.

1 Background

A direct reaction of wood with respect to changes of the wood moisture content is the process of swelling or shrinkage. The increase in load-carrying capacity by reinforcing elements in wooden members is in conflict with the effect of restraining the free shrinkage of wood with respect to changes in wood moisture content. The extent to which cracks are induced as a result of this restraining effect and the resulting consequences to load-carrying capacity are still unclear.

2 Objective

The main objective of the research project was to investigate the shrinkage behaviour of reinforced glulam members. The types of reinforcement used were drilled-in, internal as well as glued on, external reinforcing elements. To clarify the above-mentioned question the restraining effect of typical applications of reinforcing elements was quantified for three groups of glulam members (homogeneous arrangements over a section of the beam, local arrangements at notches and holes) in the form of experimental and numerical investigations.

Within the experimental investigations, the reinforced test specimens first were exposed to a slow drying process over a period of 410 days to mirror the climatic conditions in insulated, heated buildings. The glulam specimens from two manufacturers featured different initial wood moisture contents (manufacturer A: u_0 = 10.2% - 11.5%, manufacturer B: u_0 = 13.2% - 13.6%). During the drying period the distribution of wood moisture in the test specimens was determined over the cross-sectional width as well as in fiber direction in the vicinity of end grain surfaces over time by resistance measurements and kiln-drying (see Figure 1).

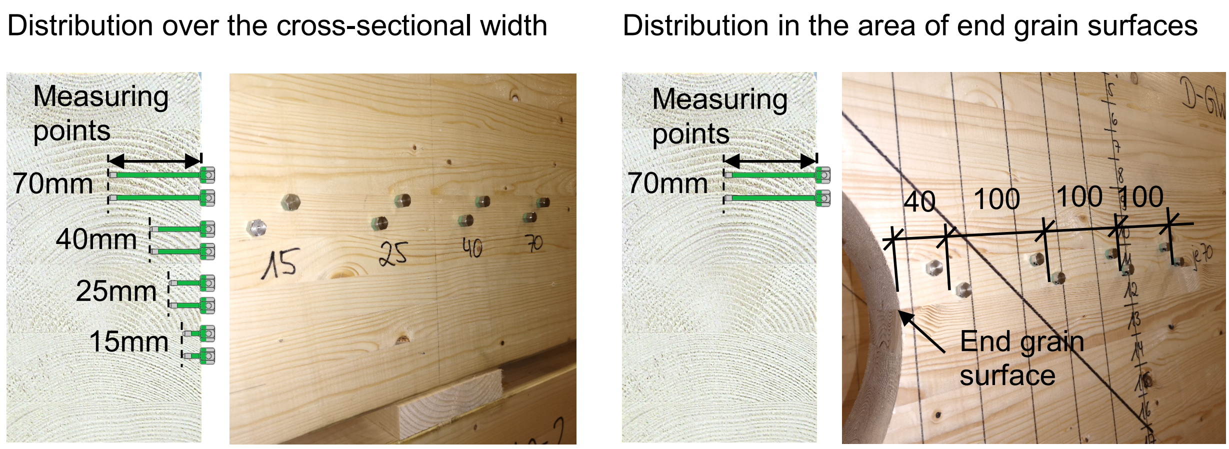


Figure 1: Situations of measuring the distribution of wood moisture by resistance measurements

In order to quantify the restraining effect, the formation of cracks on all specimens was recorded in terms of time, number, position and extent over time (see Figure 2). While only very few cracks were detected on test specimens from the manufacturer with lower initial wood moisture content (differential wood moisture $\Delta u < 3\%$ at the end of the drying period), cracks were found on the specimens from the other manufacturer in the range of a differential wood moisture $\Delta u \approx 3\%$ -

5.5% in most configurations. Inclined arrangement of the reinforcing elements proved to be consistently more favorable with regard to the restraining effect than comparable arrangements perpendicular (i.e. 90°) to the grain.

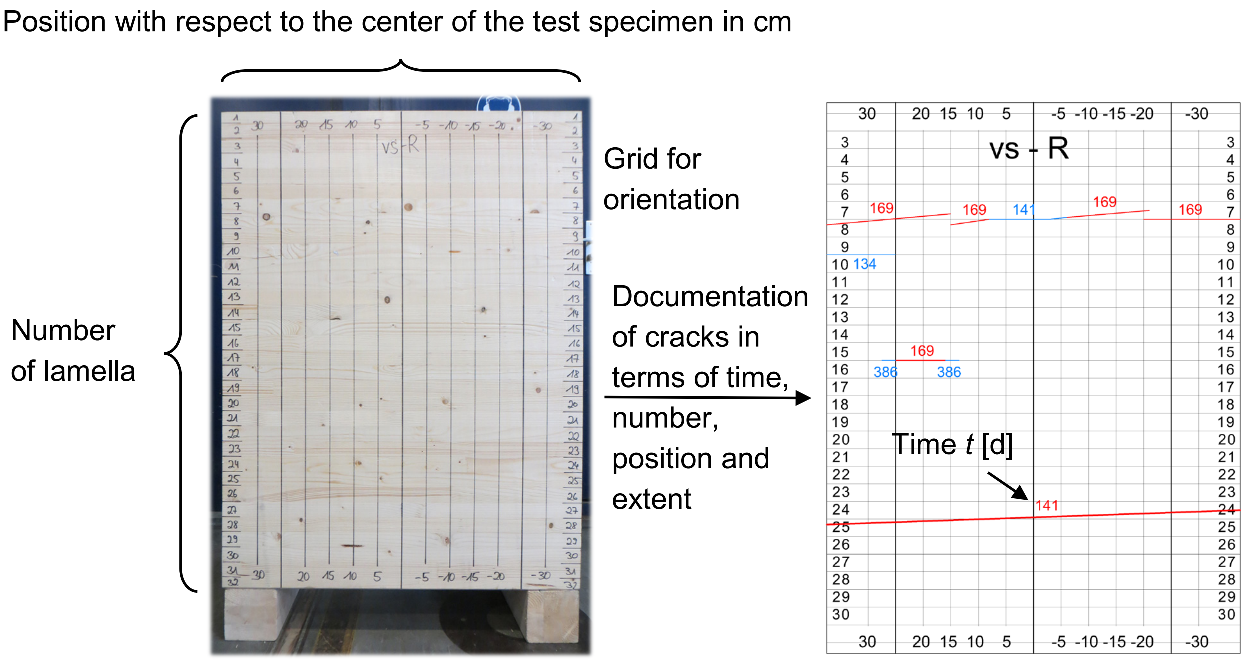


Figure 2: Exemplary documentation of crack occurrence on the rear side of a specimen

To further quantify the restraining effect, shrinkage deformations over time were recorded in form of changes in height between upper and lower edges of the test specimens in the member group "Homogeneous Arrangements" (see Figure 3). As a result of the different initial wood moisture contents, the shrinkage behaviour on the test specimens of the two manufacturers differed significantly. The determined shrinkage deformations confirm the different degrees of restraining effect of the reinforcement depending on the geometry of arrangement.

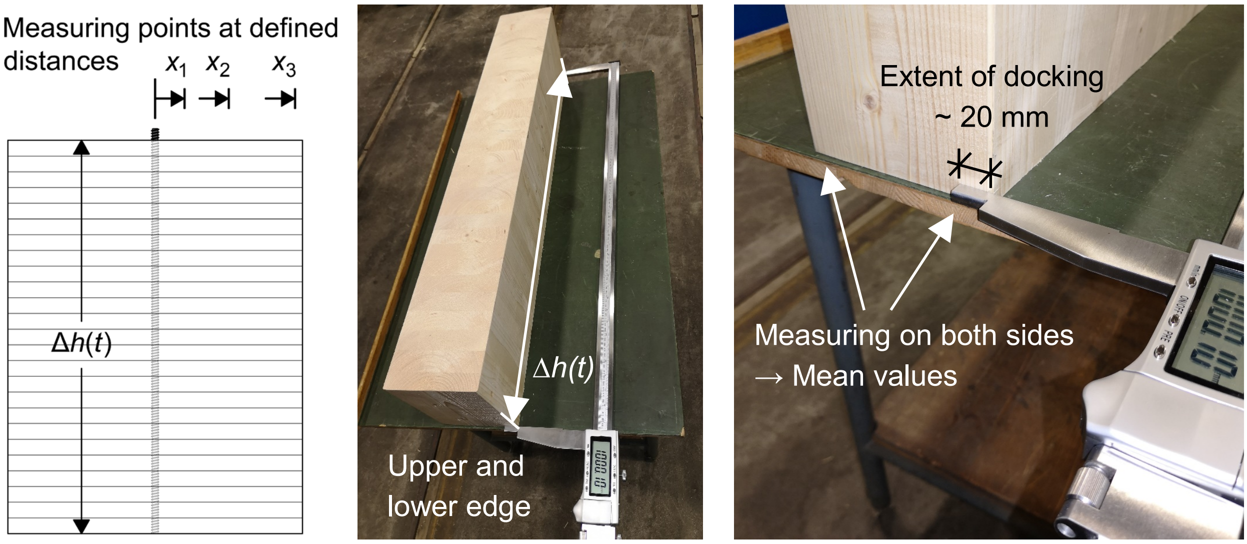


Figure 3: Measuring shrinkage deformations between upper and lower edge of the test specimen

After climate storage destructive tests were realized on members with holes and notches. During climate storage, one side of the otherwise symmetrically manufactured beams with holes and notches remained unreinforced. After climate storage, the unreinforced sides were reinforced in the same way to the opposite side and the load-carrying capacities of both sides were determined (with/without restraining effect of reinforcement due to shrinkage) in a two-stage test procedure (see Figure 4).

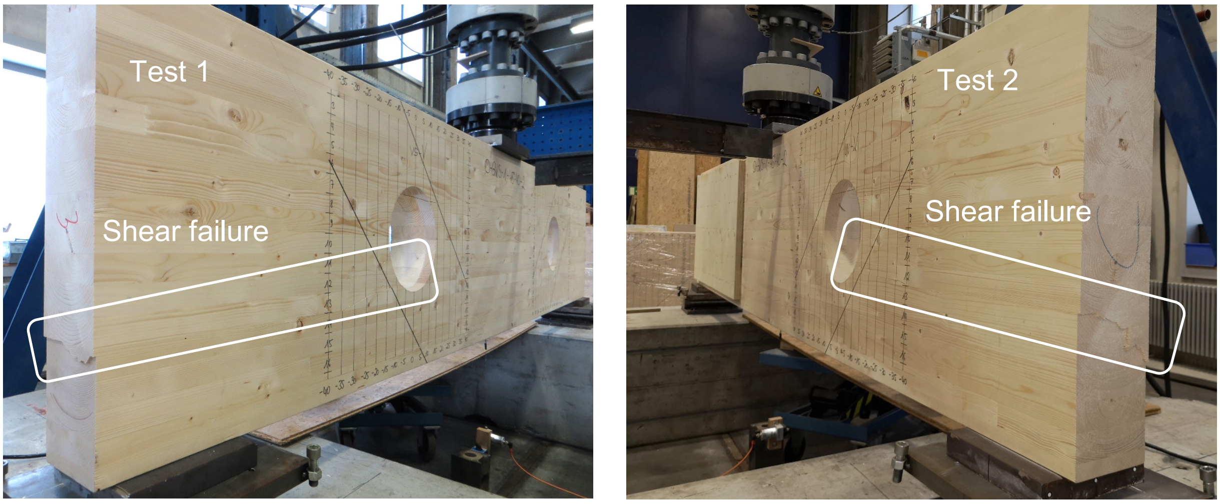


Figure 4: Exemplary shear failure of a beam with holes

In case of the beams with reinforced holes, the load-carrying capacity decreased to around 65% - 79% due to the restraining effect (see Figure 5) and to around 69% - 83% in the case of beams with notches, depending on the type and arrangement of the reinforcement. In both member groups, inclined, internal arrangements resulted in the least reduction of load-carrying capacities.

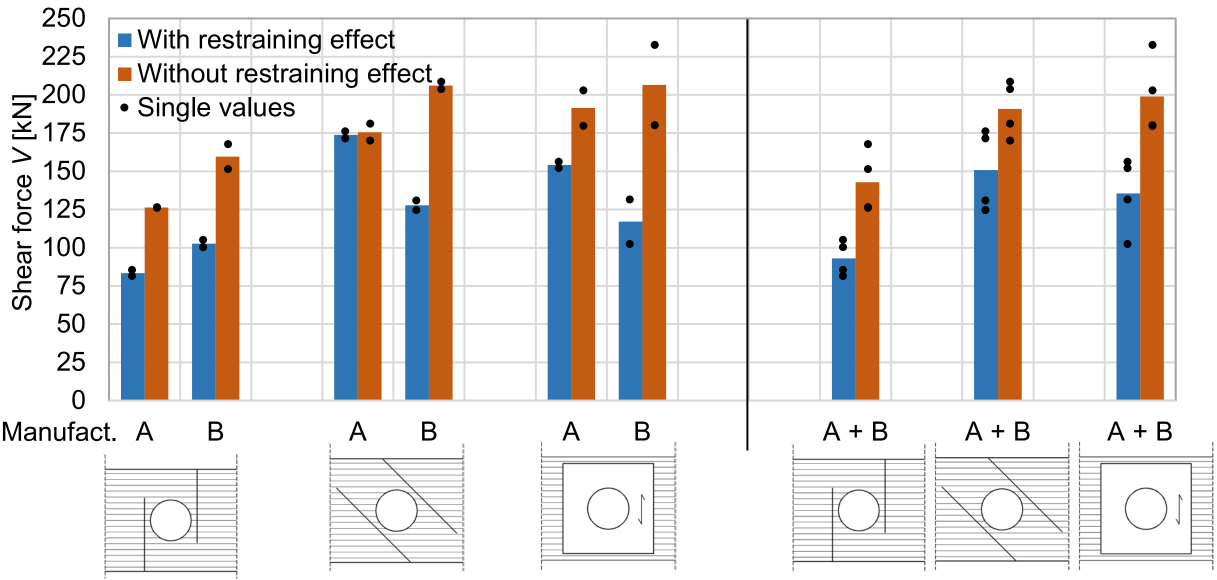


Figure 5: Failure loads of member group “Holes“ (bxh = 140x700mm, h_d/h = 0.4)

In numerical investigations, three-dimensional simulation models, considering the lamella structure of glulam as well as the cylindrical orthotropy of the wood structure were created (see Figure 6). Parameter studies on the three member groups showed that the onset of cracking is influenced in particular by the degree of reinforcement, the inclination to grain direction and the member height. All three influencing factors have a negative effect on the formation of cracks with increasing magnitude. In addition, the axial withdrawal stiffness between reinforcing element and wood also is an important factor, demonstrated in a comparison of fully-threaded screw – threaded rod or screwed-in threaded rod – glued-in threaded rod.

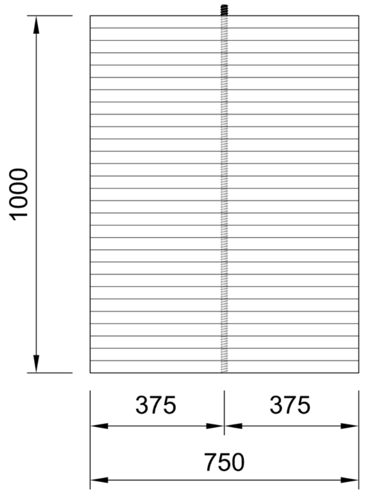
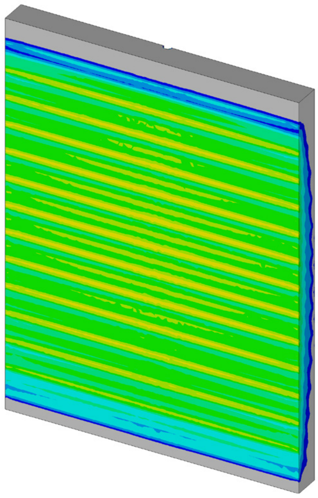
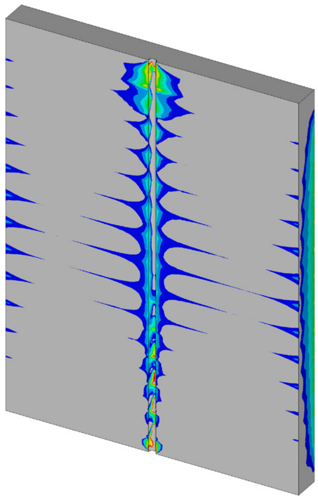
Test specimen	Isometric view side surface	Isometric view symmetry plane
		

Figure 6: Stressed volume in tension perpendicular to the grain of an exemplary test specimen

3 Conclusion

The objective of the research project was to clarify whether and to what extent reinforcing elements have a negative impact on the structural behaviour of glulam members due to their potential of restraining the free shrinkage behaviour of wood and hence the inherent risk to induce cracks. This objective has been reached by determining critical differential moisture contents with respect to the start of cracking for typical applications of reinforcements in glulam members by means of long-term climate storage. By destructive tests after climate storage, the restraining effect of the reinforcement was quantified in form of reduced residual load-carrying capacities of the dried and partially cracked specimens.

4 Key figures

Short title:	Shrinkage of reinforced glulam members
Project realisation:	Martin Danzer, M.Sc.
Principal investigator:	Dr.-Ing. Philipp Dietsch
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Project duration:	22 months