LOAD DIRECTION DEPENDENCY OF THE EMBEDMENT BEHAVIOUR OF DOWEL-TYPE FASTENERS IN LAMINATED VENEER LUMBER

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1. INTRODUCTION

In modern timber structures, dowel-type fasteners are widely used. The simple production process for wood and easy assembling of this type of connection allows a flexible design of joints in timber structures. As a consequence of this flexibility, in general, single dowels are loaded in arbitrary directions with respect to the grain direction of wood, denoted as the force-to-grain angle, which depends on the specific combination of internal forces acting on a joint, i.e. on a group of dowels. In order to predict realistic load-deformation characteristics of a dowel group, and consequently realistic force distributions within a timber structure, an accurate knowledge of the embedment behaviour of a single dowel is essential. Since the wood itself exhibits an anisotropic behaviour, the embedment behaviour strongly depends on the loading direction. Therefore, the embedment strength is nonlinear with respect to the loading direction. Several studies on the load direction dependency of the embedment behaviour of wood have been conducted previously [1,2,3]. However, these studies were restricted to selected force-to-grain angles or limited to small deformations. The aim of the investigations presented herein is to give new insights into the direction dependent behaviour of wood for the entire range of force-to-grain angles from 0° up to 90°, for elastic deformations, as well as for plastic deformations up to a total deformation larger than twice the dowel diameter.

2. MATERIALS AND METHODS

2.1. Samples

In this study, the embedment behaviour of laminated veneer lumber (LVL) of spruce with strands orientated only in longitudinal direction has been studied. Tests were performed on two different dowel diameters and two different LVL thicknesses. Boards with a thickness of 45 mm were used in combination with a dowel diameter of 12 mm, and 51 mm boards for a dowel diameter of 16 mm, respectively. For the 12 mm dowel, a steel-blank, hardened steel dowel was chosen, in order to avoid dowel bending, while for the 16 mm dowel tests an electric galvanized dowel with a standard steel quality (S235) has been used. The embedment tests were conducted as full-hole tests according to EN 383 [4]. Related to this standard, a sample size of 200 x 200 mm² has been used. Samples for tests under a force-to-grain angle of 90° had a size of 400 x 200 mm². The position of the borehole itself, was located in the centre of the sample. In order to prevent splitting along the grain (due to forces perpendicular to grain), samples (200 x 200 mm²) were reinforced by two screws. In total, 75 samples have been tested, half of them with a dowel diameter of 12 mm and half of them with 16 mm dowels (see Table 1). The investigated force-to-grain angles are given in Table 1 as well.

Several samples were tested under standard climatic conditions. Additionally, the moisture dependent embedment behaviour was investigated on additional samples for force-to-grain angles of 0° and 90°.

2.2. Test procedure

In order to allow the direction dependent embedment behaviour of wood to be studied on the same sample geometry, a loading unit that allows changing the base angle of the sample was constructed. It allows to fix the sample orientation in steps of 5° with respect to the force-to-grain angle. The loading by means of a compression force, was always applied in vertical direction. For this purpose, a displacement-driven Walter & Bai LFM 150 uniaxial electro-mechanic universal testing machine was used. Since the displacement direction is different from the loading direction in anisotropic materials (with the exception of loads in and perpendicular to grain direction), the dowel itself was loaded via pendular steel plates, in order to allow free movement of the dowel in lateral direction (see Figure 1). Samples were loaded with displacements up to two times of the dowel diameter (Ø 16) and 2.5 times of the dowel diameter (Ø 12), respectively. Samples loaded under 90° with respect to the grain direction were tested till much higher deformations. Additionally to the initial loading sequence, an unloading and reloading cycle approximately at half of the elastic limit was performed.

The displacements of the loading device and the steel dowel, as well as the surface deformations of the wood sample were recorded by a digital image correlation (DIC) system. In total, four cameras (two on each side of the test setup)
were used. The DIC measurement system enabled recording the exact position of the dowel as well as the current deformation state of the LVL sample at each load step.

3. RESULTS AND DISCUSSION

The homogeneous layout of LVL as compared to structural timber results in small variations in the test results. Therefore, the small number of replicates as given in Table 1 was adequate to accurately characterize the embedment behaviour of LVL. In general, the trends observed on 12 mm dowels and discussed in the following were also similar for 16 mm dowels.

The diagram in Figure 2 illustrates the observed load-deformation behaviour for selected force-to-grain angles. The loading is expressed by the fictitious embedment stress, which can be calculated as the load divided by the embedment length times the dowel diameter. In general, an increase of the force-to-grain angle leads to a decrease of the elastic limit, as well as increase of the compliance in the elastic stage. The embedment behaviour itself changes significantly in the plastic region. For force-to-grain angles between 0° and 60°, the load-deformation behaviour can be approximated as linear elastic – ideal plastic, with decreasing elastic limit for increased force-to-grain angles. For force-to-grain angles of 60° and higher, the elastic limit further decreases, and the elastic compliance increases, while the plastic compliance decreases. For force-to-grain angles larger than 60° the embedment stress even exceeds significant the level of the embedment stress for loading in grain direction.

Besides the significant change of the embedment behaviour for changing force-to-grain angles, also the displacement direction of the dowel changes with the amount of the dowel displacement, as well as with the applied force-to-grain angle. As mentioned before, the displacement direction stays nearly constant with the initial loading direction for loading under 0° and 90°. Particularly for force-to-grain angles up to 60° the dowel deformation leans strongly into grain direction, which means for deformations at the plastic stage the deformation direction ends up to be almost parallel to the grain direction. For larger force-to-grain angles this effect is not that dominant anymore.

Figure 1. Loading situation.  
Figure 2. Embedment behaviour of LVL for different force-to-grain angles.

4. CONCLUSIONS

A significant change of the embedment behaviour for different force-to-grain angles was observed. In general, increasing the force-to-grain angle causes a decrease of the elastic limit and an increase of the compliance in the elastic stage. However, for force-to-grain angles of 60° and larger pronounced hardening effects are revealed. In these cases, the embedment stress was found to even exceed the embedment stress parallel to the grain at large deformations.

References