Tensile Proof Loading to assure Quality of Finger-Jointed Structural Timber

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ABSTRACT

The paper describes how a quality assuring measure can be applied for finger jointed structural timber by integrating a tensile proof loading device in the production process. Thereby every produced beam is clamped on both ends with profiled steel plates and subjected to a defined tensile loading in terms of duration and stress level. With this method, depending on the set proof level, greatly strength reducing timber features such as the global and local grain deviation, faulty finger joints, compression failures or reaction-wood are recognized by failure and can be rejected. With the currently common grading processes such defects are only ascertainable with difficulty and often not economically.

This paper shows the possibility to improve the safety factor of timber within the scope of design purposes by using this proof loading procedure depending on the proof level and the coefficient of variation of the tested material.

The results of experimental research work on a high number of specimens (series A: 4,886 #, series B: 565 #) show clearly, that there is no appreciable damage to surviving timber due to tensile proof loading at low load levels. Within a double and a triple proof loading procedure about 99.96 % of all specimens could sustain higher stresses than at the first time, indicating not being damaged.

The advantage of the developed procedure is that all specimens are loaded in tension which is rather more sensitive in respect of failure recognition than bending, because the whole cross section and the whole length is stressed uniformly. Overall, the assessed tensile proof loading procedure enhances confidence in the wood as a building material. A timber product with more reliable minimum strength can be made available to the construction industry.)

INTRODUCTION / PROBLEM / MOTIVATION

Timber as a natural growing raw material displays large variations in its mechanical characteristics like strength and stiffness in comparison to other materials such as e.g. steel. These variations can be considerable precise with the beam-shaped product structural timber, characterized by lack of homogenisation over the cross-section through gluing of individual components. A statistical ‘system effect’ which can be considered for glulam or bi- or trilam is not present for single sections. Although grading criterions are defined in DIN 4074-1 with the currently common grading processes strength reducing defects such as the global and local grain deviation, compression failures, reaction wood, pre-broken timber or damage of tree-top are only with difficulty and often not economically ascertainable. Rogues in the lowest quantile area of strength cannot be excluded for sure. The grading process within the production of structural timber is therefore still a challenge.

Even so, performance and minimum production requirements for finger joints of structural timber are regulated in EN 385, a similar difficulty comes up with the joining. This is because for internal and external quality control only the bending strength and mode of failure of few randomly taken finger joint samples are determined in destructive tests. This also results in the fact that structural timber with features responsible for poor finger joint strength can reach the customers.

STATE OF THE ART

Grading of Structural Timber

In the German speaking area the most common grading method for structural timber is done by visual inspection according to DIN 4074. The structural timber is mostly graded to class S10 which is assigned strength grade C24 pursuant to EN 338. The grading criterions most commonly used are knottiness, cracks, deformations, annual ring width, wane and discolorations. For the product KVH® (Konstruktionsvollholz) additional stricter requirements like the moisture content (um = 15 ± 3%), sawing pattern (pith separated), the dimensional stability (± 1 mm for cross-sections ≤ 100 mm, ± 1.5 mm for cross-sections > 100 mm) and visual appearance (seasoning cracks, knottiness, discolorations,
warping, surface quality, wane) are to be obtained. The requirements for KVH® differentiate between applications in visible and non-visible areas.

Stress grading of structural timber by means of bending machines, which determine average Modulus of Elasticity (MOE) over short lengths, is because of the limited operating range restricted to the grading of glulam laminations and scaffold boards with a maximum thickness of 75 mm. By use of X-ray radiation and vibration measurements (eigenfrequency) joists and beams up to 100 mm can be graded [4]. The preferred cross sections (width up to 140 mm, thickness up to 240 mm) used for KVH® production go beyond the capabilities of approved grading machines.

Proof Loading

Commonly spoken, ‘proof loading’ as a testing method is defined by specimens which are subjected to a defined and generally brief mechanical loading. All samples not reaching a set proof level due to premature material failure can be separated from those with greater strength. Proof loading is a recognized quality control technique to improve the characteristics of the lower tail of strength distribution. Numerous scientific research works on the topic and especially in respect of possibly damaging the material have been published since the late sixties of the last century. Proof of any possible damage is generally considered to be very difficult to impossible. Strickler et al. (1969) for example investigated in [7] proof loaded finger joints and concluded that a bending proof load up to 90 % of the expected ultimate strength did not significantly reduce the strength and by comparison, a tensile proof load was considered feasible, without qualification.

Woeste et al. (1987) conducted in [8] experiments on 1,200 pieces of lumber with single and reverse bending loads and detected no damage due to proof loading. Heatwole et al. (1991) stated the following in their literary research on damage [9]: ‘Based on published research it is valid to assume there is no appreciable damage to surviving lumber due to proof loading in tension or bending at these low load levels’. Lam et al. (2003) pointed out in [10] that one of the difficulties is the need of rather large sample sizes for an experimental-based study to develop statistical solutions to quantify the effectiveness on the use of proof loading in relation to the proof level, the potential damage on the members and the improvement of performance in the context of reliability based design methods.

Proof loading is therefore not a new development in the timber construction sector; it is rather already familiar for many years, primarily from North America and Australia and also embedded in manuals [5] and standards [6]. Whereas in Europe apart from those stress grading machines mentioned in 2.1, which in principal do a proof loading of the material in bending, the authors know of no approved industrial proof loading application for structural timber. Test methods working with tensile loads are still uncommon obviously due to the difficulties of applying the loads.

TENSILE PROOF LOADING / FUNCTION OF THE TESTING DEVICE

The target definition of the research project ‘qm_online’ was the development of a quality control method to assure high product performance of finger jointed structural timber especially in respect to strength characteristics. In particular the following aspects should be fulfilled:

- Every produced piece and therefore the whole volume of the material should be tested.
- No dents should remain on the surface and damage is allowed.
- Testing has to be integrated in production and must not reduce production output.
- Information valuable for design purposes - like strength and stiffness - should be available.

The approach to comply with all defined aspects was tensile proof loading at a high production level. Because loading in bending is difficult to achieve with cross sections typical for structural timber and has disadvantages when stress reducing failures have to be detected in the compression zone, loading in tension was selected. Further this implies, in contrast to bending, a constant stress distribution over the entire timber volume within the free test length.

For development of an appropriate device for industrial applications research was carried out in respect of determination of the most significant mechanical parameters of the testing device (maximum tensile
force, clamping plate geometry and surface structure, capacity of the machine and measuring technique) and to determine the time dependant strength of the adhesive used for the finger joints [11]. The 8 to 18 m long rods are individually loaded into the transverse conveyor of the proof loading device at least two hours after the finger jointing process. A curing time of 120 minutes for the PU adhesive Purbond® HB 530 is considered as sufficient for the application of a proof level up to 10 N/mm² without damage of the finger joint. Tensile tests on not fully cured finger joints were worked out to for confirmation. The PU adhesive Purbond® HB 530 showed that already after 90 minutes a strength level is achieved which is within the scattering of the end strength determined on fully cured joints.

Figure 1. System sketch of the tensile proof loading device for industrial application

Within the proof loading process a centering device puts each beam into a defined test position. As shown in figure 1 the beam ends are then clamped with profiled steel plates over a length of 400 mm and the corresponding section width. In this way the structural timber is subjected to a defined stress in terms of duration and load factor. During the stress test the proof load and associated deformations are continuously recorded, whereby the mean MOE over the full length up to 18 m can be determined. Rejection parameters of the control program can be sudden drops of the tensile force, too great deflections or when the set proof level is not reached in a certain time or held constant over the defined period. Only those rods running through the test without fraction or error in the control program are fed to the following profiling process. Adjustment to the length of the structural timbers to be tested is provided by the lengthways continuously movable clamping unit.

CYCLING TENSILE PROOF LOADING / EXPERIENCE

Especially to clarify the risk of eventually damaging the material within a tensile proof loading process a cyclic stressing of finger jointed structural timber was analyzed with a high number of specimens. Therefore, within special observation periods timber with various cross sections and lengths were produced. All rods were mechanically tested (proof loaded) using the device as described in figure 1 in industrial environment. In principle two different series (A and B) were investigated in respect of type of loading. Within series A the specimens were tensile stressed to approximately 7 N/mm² and after a short release to a level of approximately 8 N/mm². In contrast the specimens of series B were stressed three times to 12.8 N/mm² but had the same level of release as in series A. Within all cycles the time of effectively loading the material at constant stress was in the range of 1.3 to 2.0 seconds. The speed of loading was, depending on the actual cross section, in the range of 20 to 30 kN/s. Within the total time of loading data (time, tensile force, and extension of end grain) was recorded automatically at a rate of 4 Hz. In table 1 the proof loading programmes are illustrated exemplarily.
Table 1. Test series to clarify risk of damage when tensile proof loading

<table>
<thead>
<tr>
<th>Double stress test (Series A)</th>
<th>Triple stress test (Series B)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>proof level_1 = 7 N/mm², level_2 = 8 N/mm²</strong></td>
<td><strong>proof level_1 = level_2 = level_3 = 12.8 N/mm²</strong></td>
</tr>
<tr>
<td>Various cross sections:</td>
<td>Cross section:</td>
</tr>
<tr>
<td>65 mm &lt; width &lt; 125 mm,</td>
<td>63 x 145 mm²</td>
</tr>
<tr>
<td>105 mm &lt; height &lt; 285 mm</td>
<td></td>
</tr>
<tr>
<td><strong>Tested volume: ~ 1.100 m³</strong></td>
<td><strong>Tested volume: 63 m³</strong></td>
</tr>
<tr>
<td>number of tested rods: 4,886 # (39,000#)</td>
<td>number of tested rods: 575 # (5,480#)</td>
</tr>
<tr>
<td>number of tested finger joints: ~ 30,000 #</td>
<td>number of tested finger joints: ~ 3,000 #</td>
</tr>
</tbody>
</table>

The tested volume equals approximately one thousand one hundred (!) cubic meters and 63 m³ of structural timber in series A and series B, respectively. The mean free testing length for both series was approximately 12.0 m. Transposed onto the referred test piece length, acc. to EN 408 of nine times the larger cross-sectional dimension, this would roughly equal 39,000 (!) and 5,480 (!) tests with a free span of approximately 1.6 m und 1.3 m for series A and series B, respectively.

The timber (spruce and pine) for both series was graded acc. DIN 4074 to class S10 by means of visual inspection and an X-ray scanner. There was no separation of higher class material. The finger joints, fulfilling the requirements acc. to EN 385, were characterized by a finger length of 20 mm and a distance between fingers of 5 mm.

The dominant cause of failure within the lower tail of strength distribution was, as shown in table 2, failure of the wood at 70.9 % and 88.9 % for A and B, respectively. The failure analysis further shows that the local grain deviation often associated with the surrounding area of knots, knot clusters or a broken tree-top is thereby the main cause of failure of this material. It has to be noted that many of the failure causing features could only be detectable with difficulty and apparently not with the applied grading procedure. This was confirmed by close examination of the broken pieces in respect to the grading criterions. Hence the associated grading represents the limiting factor for structural timber from this production.

The following figures show some typical examples of severe timber defects which could be detected by means of tensile proof loading. Figure 2 shows an extreme local grain deviation caused by a broken tree top responsible for low tensile strength. It was also observed that not only one defect causes the failure, rather as illustrated in figure 3, it is a combination - often with reaction wood.
Table 2. Results of cyclic stress tests of finger jointed structural timber

<table>
<thead>
<tr>
<th></th>
<th>Double stress test (Series A)</th>
<th>Triple stress test (Series B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of fractures:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>within 1st loading:</td>
<td>37 #</td>
<td>79 #</td>
</tr>
<tr>
<td>within 2nd loading:</td>
<td>28 #</td>
<td>3 #</td>
</tr>
<tr>
<td>within 2nd loading and</td>
<td>2 #</td>
<td>1 #</td>
</tr>
<tr>
<td>below level_1:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnitude of damage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>expressed as loss of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>strength = 9 % resp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 %</td>
<td></td>
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![Graph A](image1.png)

![Graph B](image2.png)

![Graph C](image3.png)

![Graph D](image4.png)

Figure 2. Low tensile strength due to local grain deviation caused by a broken tree-top
Compression damages are due to deformations of the wood fibres resulting from excessive compression shakes (impacts) along the grain. They may develop in standing trees due to high loads from storm or snow. They also may result from stresses imposed by lumbering or inadequate handling. As shown in figure 4 (left) they are very difficult to detect on planed surfaces. Because the distorted fibres lead to brittle fracture in processed timber already at relatively low stresses, compression damages can be detected with a tensile proof loading procedure.

**REDUCTION OF THE PARTIAL-SAFETY-COEFFICIENT**

Generally, a timber product with a more reliable minimum strength should be made available to the construction industry by the presented tensile proof loading method as every piece in the lower area of the strength distribution is rejected. The increased reliability for proof loaded finger jointed structural timber could also be reflected in a more favorable partial-safety-coefficient. The corresponding quantification in dependency of the proof level and coefficient of variation of the base material was part of an investigation in cooperation with G.I. Schüeller (Institute of Engineering Mechanics, Leopold-Franzens University, Innsbruck, Austria).
DISCUSSION AND CONCLUSION

The completed cyclic stress tests, as described in this paper, confirm that a low tensile stress not leading to failure, only minimally affects the strength of structural timber. The evidence that the material is not significantly damaged is herewith clearly adduced. The number of tested specimens (4,886 #) or rather 39,000 # with the referred test length of 1.6 m of series A in relation to the number of faults with slightly reduced strength characteristics (2 #) after the first stressing seems to be sufficient to confirm that statement. The triple stress test of series B confirm further, that a tensile load that could be sustained once (not leading to failure) can be sustained in 99.47 % of the cases again and in 99.29 % of the cases a third time, indicating not being damaged. The results of experimental research work as presented on that high number of specimens show clearly that there is NO appreciable damage to surviving timber due to tensile proof loading at low load levels. Or in other words: The timber is not significantly damaged within tensile proof loading as described in this paper.

The conclusion therefore clearly is that it is better to have tensile proof loaded timber in structural applications than the risk of ‘rogues’ with poor strength characteristics. Further there should not be any doubt of stressing timber up to the level of design strength which is specified for grade C24 with $f_{t,0,d} = f_{t,0,k} / \gamma_m$ * $k_{mod}$ = 14 / 1.3 * 1.1 = 11.8 N/mm², assuming an instantaneous load duration.

A further area of application of the test method presented here and implanted on an industrial level exists for other sawn timber products in the branch. Glulam production is particularly considered here. It is conceivable to also implement the presented proof loading method in an adapted form for the online quality assurance of finger jointed single lamellas. Furthermore application of the method for testing finger jointed flange sections of I-profiles and nail plate binders is considered sound.

REFERENCES

COST E 53 Conference - Quality Control for Wood and Wood Products


