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11TH HARDWOOD CONFERENCE PROCEEDINGS

Róbert Németh, Christian Hansmann, Holger Militz, Miklós Bak, Mátyás Báder

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Editors: Róbert Németh, Christian Hansmann, Holger Militz,
Miklós Bak, Mátyás Báder

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Dynamic fatigue tests of hardwoods

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ABSTRACT

Static testing of the parameters of wood as a structural material has been practised for at least 100 years. In the meantime, investigating repeated dynamic impacts and loads required significant improvements in measurement techniques. These cyclic fatigue tests became widespread for assessing metals, rubber and plastics, rather than wood.

This study aims to examine the dynamic strength characteristics of wood as an elastic material. This will provide data for designing wooden structures exposed to dynamic loads, like wooden bridges, lookout towers and possibly innovative machine parts. Based on the available literature, this appears to be an extensive, little researched topic of investigation.

The goals of the research is to create Wöhler curves for hardwoods, which shows the fatigue limits of wood as a function of the applied stresses. This involves performing cyclic tensile tests with maximum loading levels of 60, 70, 80 and 90 % of the static tensile strength. At least three specimens are tested at each load level for calculating the average fatigue limit.

Tests are currently underway. Completed tests yielded a fatigue curve for oak. Results show that oak material resists fatigue testing well, even at high stress levels. It can withstand hundreds of thousands of cycles at stress levels as high as 80 % of the static tensile strength.

INTRODUCTION

Wood is one of the most ubiquitous construction materials due to its specific strength, rigidity, and easy workability. Wooden bridges need to withstand dynamic loads from vehicular traffic, and wooden lookout towers and other wooden structures are exposed to wind loads. The fatigue characteristics of wood at different levels of loads are important when designing structures in earthquake-prone areas. Despite all of these areas of application, information and examination of wood under special circumstances like fatigue is not common. The most important reason for this is that classic dynamic fatigue tests are especially time-consuming.

Karr et al. (2022) examined birch wood using a newly developed ultrasonic resonance test at a frequency of 20 kHz, up to 109 cycles. They compared the results to those of servo-hydraulic testing at 50 Hz and 5×10^6 cycles. The number of cycles as a function of stress amplitudes measured at both frequencies show similar slopes and deviations up to failure in the system of overlapping life spans.

Myslicki et al. (2016) created a new measurement technique whereby the amplitude was increased by 2.5 MPa after each 10,000 cycle. Measurements were validated against constant amplitude measurement results. Furthermore, they compared beech samples with various grain orientations. At identical loading levels, the more the specimens deviated from 0° grain angle, the lower number of cycles were necessary to induce failure.

Bao et al. (1996) tested various composite materials like chipboard, MDF, OSB and plywood. Based on their results, each material exceeded 1 million cycles of fatigue life span at stress levels corresponding to 30% of the MOR.

Gašparík and Gaff (2015b) examined the effect of cyclic stresses on the deflection damping rates of beech solid wood and laminated wood. Solid wood results showed that the thicker the material, the higher the attenuation. The effect of cycle number on the damping ratio is negligible. They found similar trends for laminated wood too. There was no significant difference between the behaviour of solid and laminated specimens.

Bonfield and Ansell (1991) investigated the fatigue characteristics of wood laminates in tension, compression and shear. Fatigue life spans were significantly lower in compression than in tension. They determined the existence of an inflection point in the constant life span lines at the transition of all compression and partial tensile fatigue loads.

Tsai and Ansell (1990) provided an overview of the literature on wood fatigue and emphasized the necessity of experiments performed with load control at various moisture contents. They tested two laminated harwoods Khaya ivorensis and beech, and a softwood Sitka spruce under load control, using four-point loading. They established that increasing moisture contents decreased the static strength and fatigue life span.

Watanabe et al. (2014) examined the fatigue behaviour of Japanese cedar and Selangan batu. They used irreversible triangular wave forms of 0.5 and 5 Hz in frequency for loading. The applied load level was 110-70 % of the static strength. The fatigue life of Japanese cedar was longer at 5 Hz, especially at lower stress levels. In case of Selangan batu, loading frequency did not influence the fatigue life span.

Yildirim et al. (2015) investigated the static strength and fatigue of Scots pine and oriental beech wood. Fatigue and static strength were measured using three-point bending. Specimen preparation and fatigue/static bending tests followed the protocol of ISO 3129 (1975) and ISO 3133 (1975) respectively. Fatigue tests were performed at stresses corresponding to 80, 70, 60, 50 and 40 % of the MOR. Allowable design stresses are based on a certain percentage the furniture design MOR. In this regard, beech and Scots pine allowable design stresses can be determined at 50 and 40 %, respectively.

One lesser-known aspect of modified wood is dynamic strength, and the effect of modification thereupon. Pečnik et al (2020) applied low molecular weight phenol-formaldehyd (PF) resin onto Scots pine and European beech wood. They evaluated the effect of such modification using cyclic three-point bending tests. Compared to the control sample, modified wood resulted in higher strength, but the cyclic fatigue strength decreased (by 9 % and 14 % for pine and beech, respectively. The cyclic fatigue strength of the control sample was 67 % of the static MOR for both species. The fatigue strength of PF resin-modified pine and beech decreased to 58 % and 54 % of the original, respectively.

Based on the available literature, research into the dynamic strength of wood is still ongoing. Measurement methods are diverse, because there is no standard for fatigue testing of wood.

MATERIALS AND METHODS

Dynamic strength investigation involved English oak (Quercus robur) material. For tensile tests parallel with the grain, the cross section of the 20 x 50 x 300 mm specimens was reduced in both directions over an 18 cm long section, according to DIN EN ISO 527-2:2012 (Figure 1)

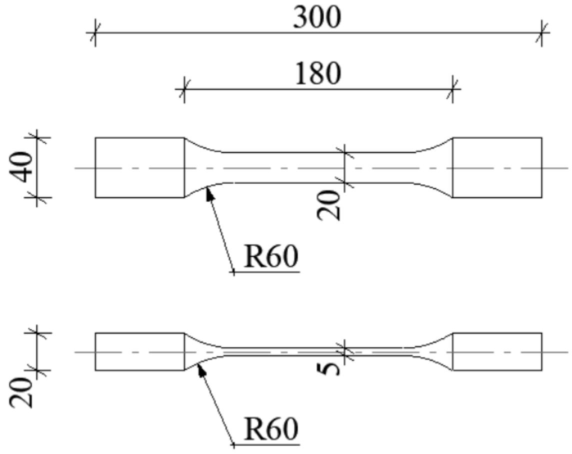

Figure 1: Dumbbell shaped specimens according to DIN EN ISO 527-2:2012 (dimensional unit in mm)

Weakening the cross section on both sides ensures that the compound stresses arising at the clamp are distributed over a larger cross section. This ensures that failure occurs in the section of the specimen subjected to pure tension.

The raw material of the specimens came from logs grown in various sites. Samples were stored in a normal climate according to ISO 554:1976 (at a temperature of 20±2 °C and Relative Humidity of 65±5 %), until reaching an equilibrium moisture content of 8 to 13 %. Dynamic loading was performed at 7 different load levels, at 60 to 90 % of the static tensile strength, with 5 % increments, and an amplitude of ±1 kN.

The amplitude of ±1 kN resulted from preliminary experimentation. This meant that frequencies higher than 20 Hz were not possible to apply, because it would have prevented regular sine waves to be induced. This lead to significantly increased measurement times.

3 specimens were tested at each load level, for a total of 21 specimens. Static tensile strength was determined from another 3 specimens, tested using linearly increasing loading. Average results at f_{mean}=95,95 Mpa (Table 1) were very close to literature data $f_{t,0,k}$=89,9 MPa (**Németh et al. 2015**). Cyclic testing occurred at a frequency of 20 Hz, using sine wave loading. Testing duration was 2 million cycles or failure, using an INSTRON 8802 servo hydraulic fatigue testing machine (Figure 2).

Figure 2: Fatigue Testing Set Up In Instron 8802

RESULTS AND DISCUSSION

Collected results yielded two Woehler curves (Figures 3 and 4).

Table 1: Results of the test (loads of 80 to 90% of static strength)

Stress level [%]		static testing	90%	85%	80%
σ [Mpa]		95,9	86,4	81,6	76,8
F [N]		12081	10873	10269	9665
Number of cycles	Mean value		4219	9292	16159
	Min.		1129	4072	4373
	Max.		9978	16469	25961
	Std. Deviation		4991	6426	10929

Table 2: Results of the test (loads of 60 to 75% of static strength)

Stress level [%]		75%	70%	65%	60%
σ [Mpa]		72	67,2	62,4	57,6
F[N]		9061	8457	7853	7249
Number of cycles	Mean value	34436	363121	1445966	2000000
	Min.	11619	142475	766978	2000000
	Max.	73249	662589	1831884	2000000
	Std. Deviation	33785	268866	589850	0

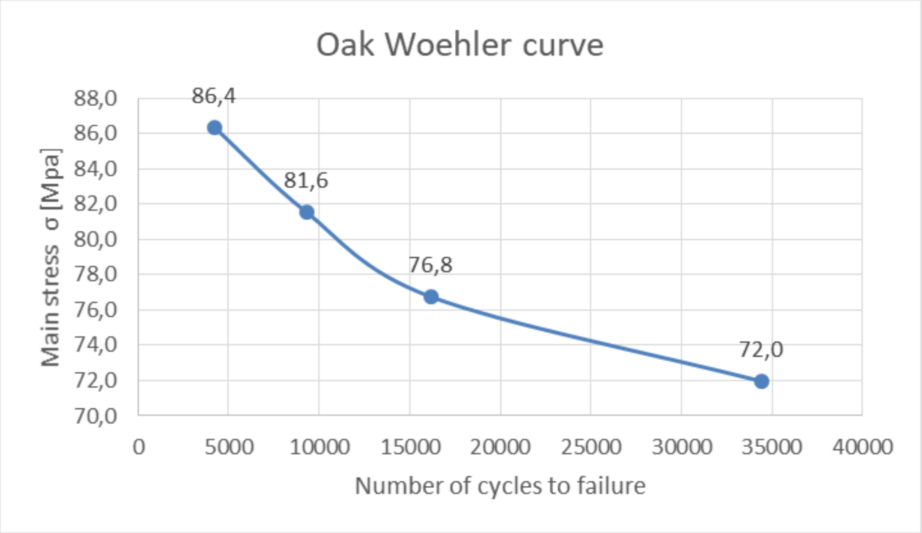

Figure 3: Woehler curve (90-75%) based on the results of the test

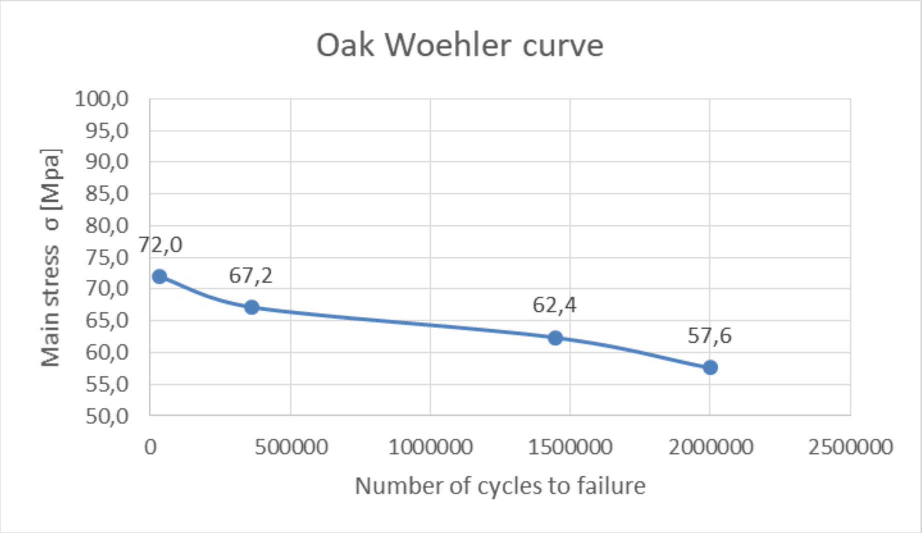

Figure 4: Woehler curve (75-60%) based on the results of the test

The current stage of our research may be regarded as a preliminary testing. We determined the order of magnitude of points of the fatigue curve based on a relatively small sample. Results show that, when loading was close to static strength (80 to 90%), failure occurred after a few thousands to 16,000 cycles (see Table 1 and Figure 3). At load levels of 70 to 75 %, failure happened at nearly identical cycle numbers, at 35,000 cycles (Table 2, Figure 4). Significant change occurred at a stress level of 65%, where approximately 1.5 million cycles were needed to reach failure, while specimens did not fail until up to 2 million cycles at a 60 % stress level. This indicates the fatigue limit of the oak material tested. This means that the wood is not expected to fail in tension at a stress level of 60 % or lower at a frequency of 20 Hz. During its service life wood is exposed to cyclic wind loading. According to our tests, wood will not fail if stresses do not exceed 60 % of the static tensile strength in the tension zone during wind-induced cyclical bending. Cyclical bending tests, coming up next in our research agenda, may be able to confirm or disprove this statement.

CONCLUSIONS

The examination of fatigue limits of wood is an important area of research in the dynamic assessment and design process of wooden bridges and lookout towers. The presented research aims to provide a basis of investigating such characteristics. Our study established that the fatigue limit corresponds to approx. 60 % of the tensile strength, since at this load level the examined material withstood more then 2 million cycles at a frequency of 20 Hz. Further examinations are required that include compression and bending as well as the dynamic investigation of other species in addition to oak tensile tests.

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