Detection of fungal damage of wood in early stages using drilling cores and drilling resistance compared to non-destructive testing methods

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In the structural inspection of load-bearing timber structures, the condition of each individual wooden component is determined considering its influence on the entire structure. For this purpose, it is important to find defects, damages and material heterogeneities in the interior of wooden construction components. Undetected, interior damages (especially interior rot, but knots, cracks and delamination in glued components as well) can result in a sudden failure of the construction.

Assessing the structural safety of timber structures usually starts with estimating damages and their extent by visual inspection and tapping with a hammer on the surface. Among the minor-destructive testing techniques, extraction of drilling cores, the drilling resistance, electrical moisture measurements and endoscopy are the most common approaches. Test loading is rarely done as well as – mostly in the context of research projects – radiographic inspections, usually with X-ray. The only possibility of non-destructive, large-scale, laminar measurements of all statically relevant areas is the ultrasonic echo technique, which is currently not always used for inspections of timber structures.

Fungal growth can be detected in the wood by the **drilling resistance method**. But it is usually not possible to assess the precise extend of the destruction, especially for early stages of infestation. Strength characteristics of the component cannot be concluded, under certain conditions the density can be estimated. The drilling resistance method is minor-destructive, the 3 mm drilling needle leaves barely visible holes.

In the usual structural safety analysis of timber structures, the extend of decay is estimated by visual inspection of **drilling cores** and the remaining cross-section of the timber beam is calculated. With the visual inspection of the drilling cores without further inspection devices decay can only be detected in the advanced stage. Incipient fungal attack, which already has a significant influence on the elasto-mechanical properties, cannot be detected.
In a research project the problem of the low reliability of assessing the drilling cores only by visual inspection, especially for incipient fungal infection, is optimized by non- and minor-destructive testing

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of the drilling cores by X-ray radiation, neutron radiation and staining as well as destructive testing of the moisture content, density, stiffness and strength. It is examined, whether a low reduction of the density of the drilling cores show incipient loss of strength. Incipient decay is conjunct with a reduction of density and an increase of moisture content (both resulting in a decrease of the strength), which cannot be detected visually and which is difficult to detect with the known imaging techniques (especially X-ray).

The information from the drilling resistance method and the drilling cores is restricted to the pertaining measurement points. It requires of a lot of experience to conclude on the status of the whole subject. Often numerous measurement points are necessary, which still may remain insufficient for larger buildings. The destruction especially from drilling cores (up to 30 mm diameter) must be considered which may not be tolerable for statically highly stressed parts (which should all be covered). In heritage-protected buildings, drilling resistance measurements and drilling cores are understandably limited.
However, the drilling resistance method and drilling cores are mostly used in suspected areas to exclude a putative fungal damage and to calculate the remaining cross section. But there are – especially for hardwoods – other important strength influencing grading characteristics like knots and fiber deviation, which cannot be detected with these techniques.

With the laminar **ultrasonic echo method**, these (macroscopic) characteristics of wood affecting the strength and stiffness (e. g. knots, cracks, fungal decay) can be detected. Undamaged areas can be defined very quick, the extension of damaged areas can be localized for the minimum required restoration.
The ultrasonic echo technique needs only access to one side. It is based on the reflection of the acoustic waves on heterogeneities in the material, such as the rear surface of the specimen or at any other interface. So it is possible to get indirect information from the received signals about the condition of the construction element or on internal damage. The measured time of the echo signal can be converted to spatial lengths by referring to the known dimensions of the construction. The low density of wood ($\rho_{wood} << \rho_{concrete} << \rho_{steel}$) is caused by a high porosity, which requires probes with high intensity and low-frequency (50-200 kHz). A low frequency results in a small attenuation of the signal; however, the pertaining large wavelength limits size of the detectable defect accordingly.
Because of the radial/tangential anisotropy on longitudinal waves, transverse wave transducers are used, which do not require a coupling agent since they are coupling by point contact, making the handling less complicated. The centre frequency ranges from 40 kHz up to 60 kHz. The ultrasonic echo technique is currently not always used for inspections of timber structures, because many of the parameters influencing the results are currently known only partially. This requires a lot of experience with the ultrasonic echo technique and the method can therefore be used seriously only by specialists.
There is only little experience in the detection of fungal decay by ultrasonic echo with transverse waves (Hasenstab 2005; Baron 2009). Near-surface damages in the area of impulse initiation show very strong damping effect. In addition to this a large number of cracks lead to additional shadowing and scattering effects. The detection of fungal decay is currently indirectly obtained by the absence of the signal.

In the paper the inspection procedure for the wooden roof structure St. Cornelius Church in Tönisvorst / Germany is shown. The whole wooden structure of the roof was examined visually, tapped with a hammer, selected areas were examined using ultrasonic echo. In suspected areas the wooden construction was selectively examined with drilling resistance technique and core samples were taken to estimate the remaining cross-sections of selected nodes.

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