



Review

A review on the mechanical properties of aged wood and salvaged timber

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HIGHLIGHTS

- Effect of aging on the mechanical properties of wood and timber.
- Aging is a complex phenomenon including load history and chemical composition change.
- Contrasting results reported due to the difficulty to test old wood/timber.
- Majority of works agree on the fact that MOR and MOE are slightly affected by aging.
- Needs to standardize tests on old wood/timber to allow a reliable comparison process.

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ABSTRACT

The effect of time on the mechanical properties of wood is of interest for structural engineers, wood technologists and conservators; for the old timber structure assessment, for the potential reuse of salvaged timbers and poles and for the conservation of wooden artefacts as well. The topic was investigated since the 50's, but the results reported in literature are not always concordant. This is a consequence of the fact that this kind of research works are quite difficult, as a consequence of the material characteristics itself: mechanical properties variability, low availability of material, uncertainty about the “history” of the tested material, unknown original mechanical properties. Another source of uncertainty between the research works is a consequence of the different research approaches: some have investigated only the effect of the time passing (therefore, aging), others consider the aging effect together with other effects, like the state of conservation and the duration of load. The main interest of the researchers was in the bending properties variation, while for other mechanical properties less information is available. In this paper, the results of several research works are presented and analysed regarding the differences in the mechanical properties for elements with different age levels. Moreover, recommendations for future research are included attending to the conclusions drawn from the analysed literature.

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Contents

1. Introduction	682
2. Mechanical properties variation	683
2.1. Bending stiffness (MOE)	683
2.2. Bending strength (MOR)	684
2.3. Compressive strength	684
2.4. Tensile strength	685
2.5. Tensile and compressive MOE	685
2.6. Shear strength	685
2.7. Impact bending strength	685

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3. Salvaged timber	685
4. Strength reduction causes	686
5. Testing recommendations	686
6. Conclusions	686
References	686

1. Introduction

A very common question on wood is if its mechanical properties are affected by time. This question is of interest for both timber structures conservation and assessment, as well as in wooden artefact conservation field. Many factors affect the structural health of timber and the mechanical properties of wood, as instance: the presence and extension of biological attacks (insects degradation or decay), the material quality, the history and duration of load acting on the structure (is it the original one or has it changed during time?). However the problem must be distinguished: mechanical properties of wood affected by decay decrease strongly, but decay is a consequence of the state of conservation, not a consequence of the wood age itself. Similarly, the effect of the load history is related to the age of wood, but it is not a consequence of the wood's age [1]. The first systematic research works on aged wood mechanical properties were carried out in Japan during the 50's [2–9]. The aim of these works was to investigate only the effect of time passing on the mechanical properties of wood.

Later, many research works were published also in Europe, especially in Germany [10–15]. Since the 90's large testing campaigns were carried out, mainly in the United States of America, although with slightly different aims: not only the effect of the aging was investigated [16], but also the effect of the load history on the timber mechanical properties [17] and the potential reuse of reclaimed timber [18–23] or poles [24,25] were studied.

In recent years, Japanese researchers demonstrated an increased interest in this field [26–36].

Nevertheless, the published results raise several questions because testing aged wood or timber is influenced by different factors, such as:

1. initial properties (past) of the tested material are unknown, so it is difficult to compare them to the actual properties (present).
2. the inherent natural wood variability may cover the influence of aging and preclude any definitive conclusions. For instance, for small and clear specimens of the same species, modulus of rupture (MOR) and modulus of elasticity (MOE) can vary in the range of approximately 7–20% [37].
3. it is difficult to test large quantities of old material, as it is not easily available, especially structural timber.
4. no single standardized procedure has been adopted for testing, so it may be difficult to find basis of comparison between different works.
5. aging has a different effect on different species. For example, when testing small and clear specimens of keyaki (*Zelkova serrata*, Makino) and hinoky (*Chamaecyparis obtusa*, Siebold & Zucc), Kohara [8] obtained a MOE reduction of about 30% for the first species, and a MOE increase for the second species during the first 300 years.
6. if the tested materials were exposed to particular environmental conditions allowing decay, their mechanical properties can be affected even at an early stage [38]. However, early stage decay can only be detected at microscopy level.
7. for structural timber damage resulting from the mounting/dismantling operations may affect the original mechanical properties of timber [18,20,22,29,31,39].

8. the effect of the load history (duration of load) is well known for structural timber that remain in service for long periods of time [40–42]. This effect must be taken into account when testing material that has been in service, but it is erroneous to consider it as an aging effect [1].

Another important aspect concerning old timber structures is the possibility to assess the residual mechanical properties of timber by means of visual inspection and non-destructive/semi-destructive techniques. For example, the work of Sandoz and Vanackere [43] considers the use of non-destructive measurements of moisture content and density in order to estimate the residual strength of wood poles, whereas in Ross and Pellerin [44] a review is provided for non-destructive assessment methods for testing wood members in structures, and in Baraneedaran et al. [45] a review of methods including drilling, sounding, modal testing and stress wave propagation technique are discussed for the assessment of in-service timber poles. More recent works have provided guidelines and general information on both the prediction of the mechanical properties of wood by use of semi-destructive methods [46] and also about the in situ assessment of historic timber structures [47]. The application of these methods to in situ assessment and some of its limitations are further discussed in [48] and in [49]. Globally it is accepted that the results obtained through these methods have large variability, therefore they must be combined together as to decrease its subjectivity for both an initial survey, as well as in more detailed surveys [50]. Moreover, the combination of methods should consider the mechanical property that is being assessed, as well as the size scale of the analysis [51]. Nevertheless, it is common to use non-destructive methods to assess the residual cross-section and also durability related issues (e.g. level of biological attack) [52,53], therefore its present conditions, rather than to assess the effect of the aging phenomena which must also consider the wood structure and its chemistry [54].

The goal of this paper is to discuss the relevant primary research literature, and summarize the current understanding of the problem, as well as to provide recommendations for future research on this topic. Literature investigating the mechanical properties affected by aging effects is summarized in Table 1.

It can be perceived that different researchers understand the effect of aging in very different perspective by simply reading the titles of the referenced works. The terms old wood/old timber, historical timber, aging of wood, effect of time, are used in research works carried out with the same aim: to compare the mechanical properties of wood of different ages. However, there are differences between these concepts that should be considered. What can be considered as old wood (or old timbers)? When a timber element should be considered historical or remain simply old?. Some have investigated the aging phenomena, including the effect of the load history and in-service condition on the mechanical properties of timber [36,55,56]; while others have investigated aging of wood, considering only the effect of the “age” on the mechanical properties of wood [1,30,57]. In literature two main approaches were found: i) consideration of small clear specimens, and ii) consideration of structural size elements with intended use of reutilization. The research works using small and clear specimens were carried out aiming at the analysis of the aging effect on the wood

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