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

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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.

Keywords: old timber; old wood; aging effect; salvaged timber.

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, bending strength (MOR) and bending stiffness (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 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 mechanical properties for different grain directions. The advantages using such specimens are related to their lower variability and wider availability comparing to larger size elements including natural defects. Moreover, small test samples allow for easier, cheaper and more standardized test setups. Anyway, when small specimens are extracted from timber elements that had been in service, the duration of load effect must be taken into account, as well as the position of the specimens inside the original element.

On the other hand, research works were carried out on structural size elements in order to investigate the perspective to reuse them (for instance for salvaged poles or timbers), including not only the analysis of the mechanical properties, but also aiming at the development of applicable visual strength grading rules. In this case, the mechanical properties of the element are not only affected by the natural aging phenomena, , but also by other factors like the duration of load (DOL), the state of conservation and the presence of damages.

2. Mechanical properties variation

2.1 Bending stiffness (MOE)

A large number of authors agree on the fact that the MOE remains unchanged, or that it is not significantly affected, over time. In the analysed literature, 20 research works reported that MOE increased or remained unchanged over time, while only 5 reported a MOE decrease. The average MOE variation between old and new wood/timber is summarized in Fig. 1.

The highest MOE increase, of about 11% and 27%, is reported in [27] where the authors compared new and 270/290 years old small specimen of akamatsu (*Pinus densiflora*, Siebold & Zucc). Contrary results are reported in [4] where Kohara reported a MOE decrease of about 25% for keyaki. Later, Kohara [8] found that the MOE increased during the first 300 years testing hinoki small specimens.

The highest MOE decrease was found in [58] where Cai et al. compared the edgewise and flatwise bending MOE of 9 old Loblolly pine (*Pinus taeda* L.) joists 90 years old, to new timber of southern pine. The new and old joists were tested in similar conditions of density and moisture content (MC).

The old joists' MOE was of approximately 15 and 42% lower for the flatwise and edgewise MOE, respectively.

Smith [23] tested 200 structural joists and small specimens (species not identified) from 40 to 160 years old, for the calculation of bending MOE and MOR. A comparison between old wood and new wood was made to infer about the mechanical properties variation. In that work, new wood was selected on the basis of similarity to the density range of the salvaged timber, without considering the species itself, so it is not possible to prove that the salvaged timber and new timber were from the same species (nor that the salvaged species were the same species or not). Moreover, the density of the new timber was between 433 and 490 kg/m^3 while the salvaged joist density varied in the range of 400-750 kg/m^3. Additionally, the MOE was calculated incrementing the load from 1000 to 10000 N (1000 N for each increment), waiting 30 seconds from one step to the following. The final load-displacement graph used for the MOE calculation is biased from the viscoelastic deformation of wood under load, and the MOE is not calculated on the base of a pure elastic deformation.

It is interesting to note that, among the carried out research works on old structural timber, no one recorded a higher MOE compared to new timber, confirming the in-service influence on the mechanical properties.

MOE decrease was also observed by several authors testing small and clear specimens: -15% [27]; -25% [4]; -12% [25].

2.2 Bending strength (MOR)

Larger part of literature reported no MOR decrease. The other ones reported a MOR decrease between 7 to 60% (Fig. 2). A clear trend cannot be found for small specimens nor for structural timber.

Chini et al. [21] tested 32 structural members of southern pine with around 85 years in 3 point bending tests. The timber elements were obtained from different buildings. The average allowable MOR for salvaged timber was around 15% higher than new wood, showing a very high variability in function of the timber construction origin (from 67-117% of the new timber MOR). For this research, the great difference in density, between old timber and new timber (new wood density was more than 50% lower), does not allow to make any consistent conclusion about the results. Similarly Falk et al [19] tested 100 old joists with 90 years (53 were of Douglas-fir and 25 of Hem-fir) for the MOE and MOR calculation. The elements have been dismantled from military buildings. The calculated data were compared to the characteristics value for the in-grade study, assigned to the tested material according to the applied grading rule. According to that comparison, the authors concluded that strength parameters were lower than expected.

Falk [18] performed bending tests in 90 timber beams with 55 years old, where 30 of them presented heart checks and 60 did not. It was found that the bending strength of checked beams was 15% lower than the beams without checks.

Nakajima [31] tested 633 lumbers salvaged from two different deconstructed buildings. All the lumbers were visually graded and the bending strength calculated in 4 point bending tests. The mechanical properties were compared to the ones reported for new solid timber by Japanese grading rules resulting in a 13% lower bending strength for salvaged timber. Moreover, a relation between lower bending strength and nail holes was found.

Rammer [20] tested 69 Douglas fir lumbers salvaged from a dismantled military building. 40 pieces were tested in 5 point bending test as to calculate the shear strength, whereas 29 pieces were tested in four point bending tests as to calculate the bending strength. The research was carried out to investigate the effect of split and checks on both the shear and bending strength. The author observed that the bending strength decreased significantly. and that shear strength was negatively affected by the presence of split and checks.

In the case of Schultz et al [59], no difference was found for MOR between new and 300 years old Norway spruce (*Picea abies*, Karst.) structural timber. Whereas, Hirashima et al [27] observed a MOR increase for 270 and 290 years old akamatsu specimens (17 and 42%, respectively), when testing small size specimens.

Crews and Mackenzie [22] investigated the possibilities to reuse salvaged timber testing 90 specimens extracted from structural timber considering the extraction of specimens from different cross section locations (from the compressed face, from the tensioned face and from the lateral faces). The timber elements came from different structures that had been subjected to different load levels. The specimens were graded and tested in bending with results evidencing a lower MOR (35-50%) compared to new timber, also attending to different load magnitudes. Similarly, Smith [23] reported that MOR decreased about 20% as a consequence of the load history effect for both structural timber and small specimens.

Except for [20,22,31], that reported only MOR reduction but no MOE reduction, in the other cases MOE and MOR evidenced the same behaviour: i) no variation was found in [1,17,24,26,27,36,60]; ii) minor variation was found in [30,34]; iii) decrease for both MOR and MOE was found in [4,27,55]. Since the MOE and MOR are related, this seems to suggest that the differences between old and new wood are much more related to the original quality of the tested material, rather than to the effect of aging itself. The research works in which MOR reduction is observed and MOE remains unchanged [20,31] were carried out on structural timber, confirming that load history has a more significant influence on MOR rather than on MOE.

2.3 Compressive strength

Kohara [4] reported a compressive strength reduction of about 15% testing small and clear specimens. Also, Yorur et al. [56] reported a compressive strength reduction up to 27%, testing small specimens of *Pinus sylvestris*, L., but in this case the results are compromised by different densities ranges between the old and new wood specimens (new wood was 18% denser).

The comparison between new and old wood is quite difficult because compressive strength is largely affected by density. The already mentioned work by Kohara [4] reports a compressive strength reduction, obtained comparing new and aged specimens with a different mean density of about 12% on the new wood side, probably explaining a large part of the reported strength difference.

The other analyzed researches reported no compressive strength variation [12–15,36],a slight increase [11,55,61] or a significant compressive strength increase [62,63].

On the structural size, Falk [18] selected around 60 timber columns, with and without checks, and tested them in compression. On that study, all columns were found to have higher strength than expected by the specific grading rule [64]. A schematic representation of the compressive strength variation is showed in Fig. 3.

2.4 Tensile strength

Since the tensile strength of wood in longitudinal direction is very high compared to the other directions, only occasionally it is a limiting design factor, and thus few research works were made regarding the age effect on this property. Only Attar-Hassan [55] reports a clear tensile strength reduction of about 29%, observed while testing small clear specimens. However, other works present significant different outcomes on their results. In [11] a lower tensile strength, comparing old wood to new wood, was reported for Norway spruce with density up to 520 kg/m^3, whereas higher tensile strength for density above 520 kg/m^3 was found. Hirashima [57] did not found a clear relation between age and tensile strength on akamatsu specimens, as no variation was found for 115 years old specimens comparing to new wood, while 29% reduction for 270 years old specimens and 18% reduction for 290 years old specimens was found.

The low number of research works and the discordant results do not allow to draw a clear conclusion about the aging phenomena effect on tensile strength.

2.5 Tensile and compressive MOE

Ooka et al [36] tested small specimens of keyaki, hinoki and akamatsu in compression perpendicular to the grain, aiming at calculating the MOE. The specimens were taken from timber members rescued from Japanese traditional buildings, with 90 to 365 years old. In this case, the calculated MOE was found to be similar to the one of new wood.

Froidevaux et al [65] tested 200-500 years old Norway spruce small and clear radial specimens in tensile test, in order to verify the elastic, creep, relaxation and rupture behaviour under controlled temperature and relative humidity. Authors reported that it was not possible to observe a clear aging effect. Moreover, a significant higher MOE was obtained for the specimens from wood coming from a parquet floor, compared to wood coming from structural timber, suggesting a combined effect of age, load history and defect presence also on tensile properties.

2.6 Shear strength

Also in the case of shear strength the results are not concordant between different researches. In [12,28] no shear strength variation was reported comparing new and old specimens of respectively 120 and 270 years, while Attar-Hassan [55] reported a shear strength increase of about 17%. Only Chini et al [21] and Kohara [4] agreed, reporting a shear strength reduction of about 25%. However, the causes of this reduction were attributed to more reasons rather than solely to aging. As instance, the first author obtained its results by testing 32 small specimens extracted from 4 different old beams, ascribing the reduction in shear strength, mainly, to the presence of bolt and nails hole.

Rammer [20] records that shear strength is negatively affected by the presence of split and checks on salvaged Douglas fir lumbers.

2.7 Impact bending strength

Impact bending strength calculated on small specimens is affected by density and MC, but the effect of the testing methods is much more important than the mentioned factors [66]. Although it is quite difficult to compare the different research works, due to the different materials and methodologies (meaning different MC, density and test methods), the analyzed literature evidences that impact bending strength is largely affected by aging, as only Krànitz [1] reported no significant variation for aged specimens impact bending strength. All the other authors reported a significant reduction [4,50,57] with values up to 70% [9] obtained while testing small and clear specimens of hinoki and keyaki aged up to 1300 and 650 years respectively. Also, Kollmann and Schmidt [10] observed an impact bending strength reduction when testing small specimens of pitch pine, extracted from 30 years old damaged wooden pillars.

3. Salvaged timber

A significant number of the research works investigated the performance of salvaged materials comparing their properties to new timber, testing structural members. In this case the effect of age is not always an important parameter as mentioned by [29,31,68] when testing material up to 20 years old.

In the work of [69], the main goal was to assess the potential reuse of rescued timber or poles, according to their positive environmental effect and economical, direct and indirect, benefits. In this case the mechanical properties variation is influenced by different factors, such as the duration of load, aging, in-service conditions and the state of conservation. All the researchers tested the bending mechanical properties of the rescued materials founding that the bending strength decreases. This is probably a consequence of the DOL effect, and of the damages due to mounting and dismantling operations. Only Cai et al [58] observed a MOE reduction testing salvaged joists, the other researchers found no MOE variation.

Anyway, the research works outlined that many of the dismantled timber members can be reused, according to the residual mechanical properties and effective cross-section.

4. Strength reduction causes

Kohara and Okamoto [9] speculated that the mechanical properties variation of wood due to aging, is a consequence of the change in the microstructure of wood. They reported a decrease in the amount of “cellulosic materials”, attributing the enhanced stiffness of aged wood to the cellulose crystallinity, observing an increment in the crystallinity for the first 100 years, followed by a progressive decrease.

This hypothesis was not confirmed by other studies, as instance Noguchi et al [35] reported that the Kohara’s hypothesis does not sufficiently explain the aging process, because the viscoelastic properties of amorphous matrix substances in the wood cell wall also play an important role on variation of the mechanical properties. Additionally, other authors report no significant variation in crystallinity between aged and new wood of hinoki [70] or for other wood species [28,32,71].

Krànitz [1], analysing the relevant literature, reports that many authors confirm the general increase of cellulose crystallinity over the long term.

The other principal source of strength reduction is related to the load history effect and confirmed by the studies carried out on structural material [17,40,42].

5. Testing recommendations

The various ways in which the tests were carried out, and the lack of information about the specimens, makes it difficult to compare the results of different research works. Therefore, it will be useful, for further works, to follow a common approach that may be based on the following recommendations:

a. The tested species should be reported as well as the dimensions of the specimens. The size of the specimens affects the prediction of the mechanical properties and should, therefore, be considered in the grading protocol [72].
b. Since different research works use the term “old” in different way, also the age of the material used for testing should be reported.
c. Origin of the elements should be reported with respect to the provenience of the wood and the location of the structure where they were used.
d. When new and old wood is compared, they should be as similar as possible for basic characteristics, like density, moisture content and overall quality; otherwise it could be difficult to ascribe any difference, in the mechanical properties, to other factors.
e. For small specimens it is useful to know from which kind of material they were extracted from, and its location on the original element, to take into account the potential DOL effect.
f. Since early stage decay has a significant effect on some mechanical properties, it should be assessed carefully.
g. For long-term experimental campaigns, a sample of elements should be used for determination of a reference property using non-destructive testing (e.g. determination of bending MOE in elastic field) as to allow for a basis of comparison and correlation between tests made at different ages.

h. Methods of survey may limit the quality of the assessment of the mechanical properties, therefore the same procedure and methods must be considered to assess old and new wood, as to obtain a reliable basis for comparison.
i. A combination of different measuring methods is recommendable in order to decrease the variability of the analysis.

6. Conclusions

Many research works investigated the mechanical properties variation of wood over time, on different scales (small specimens and structural timber), and the possibilities to reuse salvaged timber. The results are not always in agreement, as a consequence of the complexity to compare the mechanical properties of old and new wood/timber due to the high variability on the mechanical properties, the uncertainty about the original mechanical properties of old wood and timber, and the effect of different factors, like the duration of load and the state of conservation. Additionally, in many cases, the lack of information and the use of non-standardized tests makes it difficult to make solid comparisons.

The mechanical properties in bending were largely investigated and the majority of research works agreed on the fact that the bending strength and bending stiffness remain unchanged over the time, or decrease in a not significant way. Highest bending MOE and MOR reductions are reported for structural timber, which is affected by the in-service condition, such as duration of load, state of conservation and dismantling damages, that are not a direct consequence of aging.

Besides bending MOE and MOR, only a reduced number of research works investigated other mechanical properties variation, so it is not possible to draw definite conclusions. The compressive strength seems to remain unchanged, although the published results are, sometimes, influenced by an important density difference between the compared new and old specimens. Few researchers investigated the tensile strength obtaining completely different results. Nevertheless, tensile and compressive MOE seem to remain unchanged over time. Also for shear strength it was not possible to reach a definite conclusion due to the limited number of research works. The published research works seem to agree on the fact that the impact bending strength is largely affected by aging.

The effect of time on the mechanical properties of salvaged timber and poles is quite complex, because the mechanical properties of timber that remained in service for many years, are a consequence of several interacting factors, namely the state of conservation, the load history, the original quality of the material and the damages occurred during the service life or the mounting/dismantling operations. However, this material can still be reused in structures, according to the residual mechanical properties and effective cross-section.

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Table 1 – Summary of the literature investigating the aging effect on the mechanical properties of wood and timber.

reference	**species**	**approximate age**	**mechanical properties***	**specimens dimensions (wxhxL - cm^3)****
Ando et al. (2006)	*Pinus densiflora*, Sieb. et Zucc.	270	f_v	3x3x3
Attar-Hassan G (1976)	*Pinus strobus*, L.	142	E_f, f_c, f_m, f_v, f_t	12x15x230 (A)
Cai et al. (2000)	*Pinus taeda*, L.	90	E_f	5x3x90 (A)
Chini et al. (2001)	Southern pine	85	E_f, f_m, f_v	4.8x9.7x60 (A)
Crews et al. (2008)	hardwood	?	E_f, f_m	5x5x300-5x19x300
Deppe et al. (1993)	*Pinus sylvestris*, L.	600	f_c	-
Ehlbeck et al. (1990)	softwood	?	f_c	-
Erhardt et al. (1996)	*Pinus sylvestris*, L.	300-400	E_f	S
Falk (1999)	*Pseudotsuga menziesii*, (Mirb.) Franco	55	f_c, f_m	14x19x330 19x19x320
Falk et al. (1999)	*Pseudotsuga menziesii*, (Mirb.) Franco; *Tsuga heterophylla* (Raf.) Sarg.	90	E_f, f_m	5x25x490
Feio et al. (2007)	*Castanea sativa*, Mill.	?	f_c	5x5x10
Fridley et al. (1996)	?	85	E_f, f_m	S
Froidevaux et al. (2010)	*Picea abies*, Karst.	100-700	E_t,E_c	0.3x0.3x5
Hirashima et al. (1955)	*Zelkova serrata*, Makino; *Pinus densiflora*, Siebold & Zucc	115-290	f_t	S
Hirashima et al. (2005)	*Zelkova serrata*, Makino; *Pinus densiflora*, Siebold & Zucc	115-290	E_f, f_m, w	S
Horie (2002)	*Picea jezoensis*, (Siebold & Zucc.) Carr.; *Abies sachalinensis*, F.Schmidt	27 a 83	E_f, f_m	S
Kawai et al. (2008)	*Chamaecyparis obtusa*, (Siebold & Zucc.) Endl.	up to 1600	E_f, f_m, w	S
Kohara (1953-1955)	*Zelkova serrata*, Makino; *Chamaecyparis obtusa*, Siebold & Zucc	310-530	E_f, f_c, h, f_m, f_v, w	S
Kollmann et al. (1962)	pitch pines	30	E_f, w	L
Kranitz (2014)	*Picea abies*, Karst.*;* *Abies alba*, Mill.; oak	90-250	E_f, f_m, w	2x2x30
Kuipers (1986)	?	100-120	f_c, f_v	L
Leichti et al. (2005)	*Pseudotsuga menziesii*, (Mirb.) Franco	20-90	E_f, f_m	5x5x30
Lin et al. (2007)	*Cyclobalanopsis longinux*, (Hayata) Schottky; *Schima superba*, Gardner & Champ; *Castanopsis carlesii*,Hayata; *Litsea acuminata* (Teschner) Kosterm; *Cyclobalanopsis gilva* (Blume) Oerst.; *Pasania harlandii*, Hance	20	E_f, f_m	2x2x32

Nakajima (2008)	?	≈ 20	E_f, f_m	3.8x8.9x236
Narayanamurti et al. (1958)	*Tectona grandis*, L.f.	1800	f_c	S
Ooka et al. (2012)	*Zelkova serrata*, Makino; *Cryptomeria japonica* (L.f.) D.Don, *Chamaecyparis obtusa*, (Siebold & Zucc.) Endl.; *Pinus densiflora*, Siebold & Zucc	90-375	E_f, f_m, f_c, E_t,E_c	3x3x60
Piao et al. (2009)	southern pines	8 a 17	E_f, f_m	2x2x41
Rammer (1999)	*Pseudotsuga menziesii*, (Mirb.) Franco	?	E_f, f_m	15x35x540 25x46x530
Rug et al. (1991)	pine, oak, *Picea abies*, Karst.; *Fagus sylvatica*, L.	60-140	f_c	1.5 (diameter) x4 2x2x3
Schultz et al. (1979)	*Picea abies*, Karst.	>300	f_c, f_m, f_t	16x16x230

* E_f = bending MOE; f_m = bending strength; f_c = compressive strength; h = hardness parallel to the grain; f_v = shear strength; f_t = tensile strength; w = impact bending strength; E_t/E_c = tensile or compressive MOE; ? = unknown data. **A = average dimensions; S= small and clear specimens (unknown dimensions); L= structural timber (unknown dimensions).

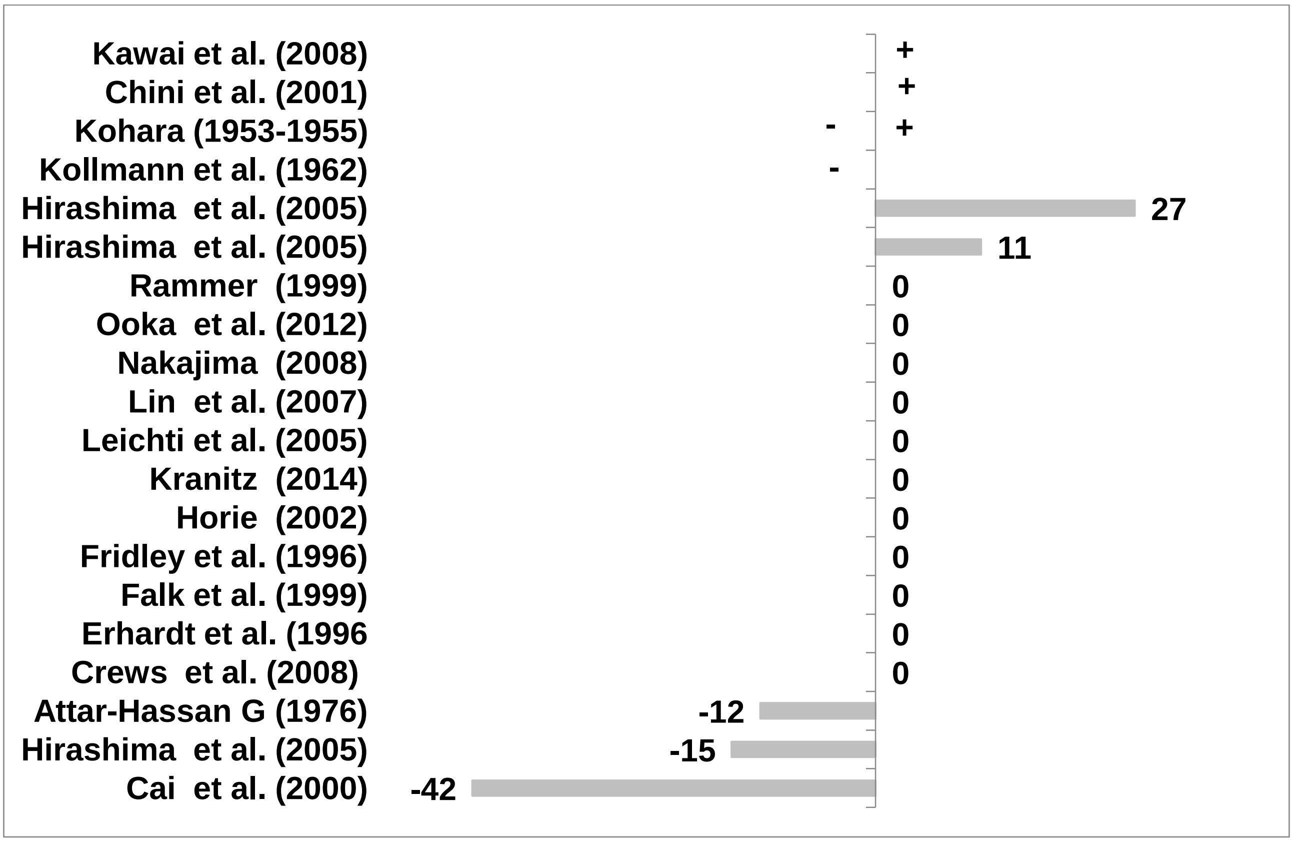

Fig. 1 – percentage difference between old and new wood/timber bending MOE. Positive values indicate higher MOE for old timber. When a specific value is not indicated in the research work, the trend is indicated as increment (+) or decrement (-).

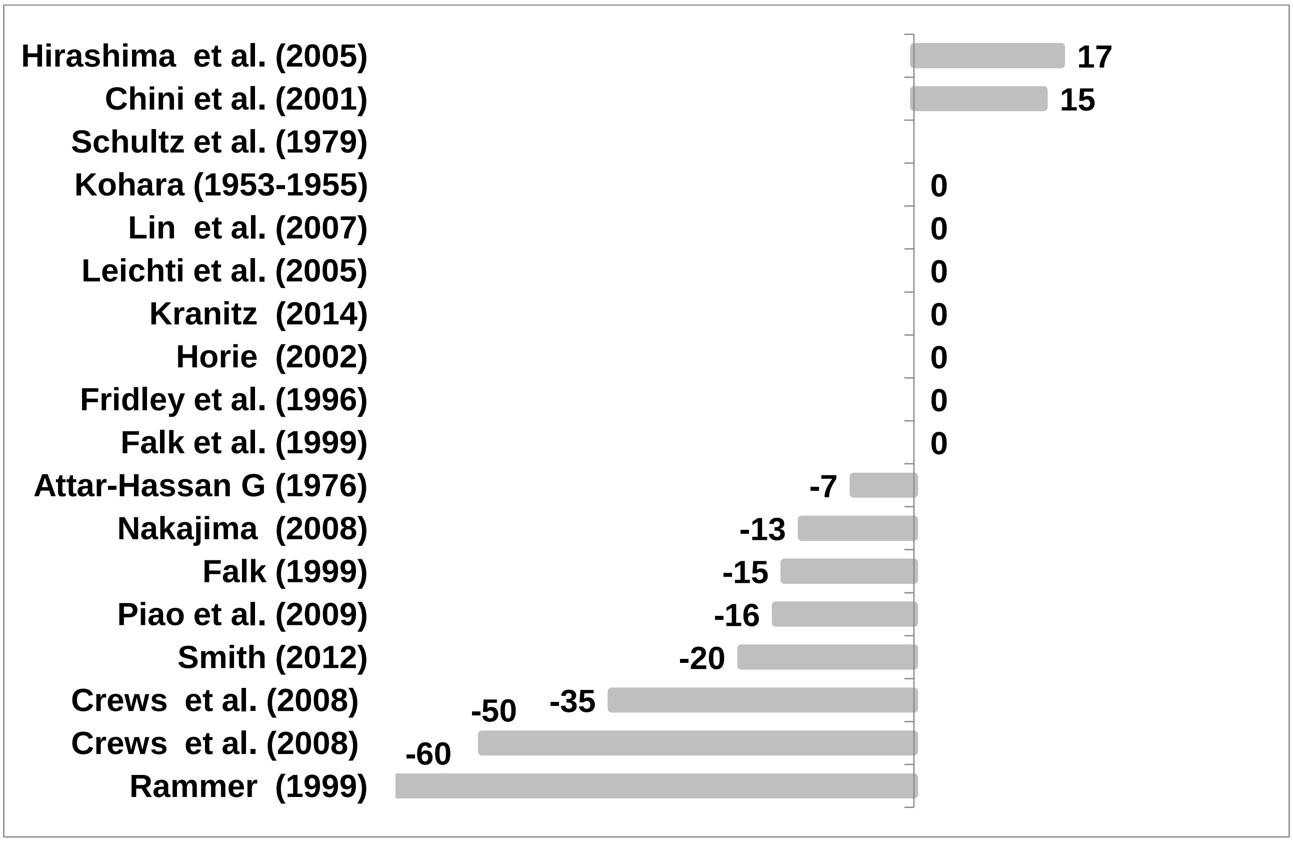

Fig 2 – percentage difference between old and new wood/timber bending strength (MOR). Positive values indicates higher MOR for old timber.

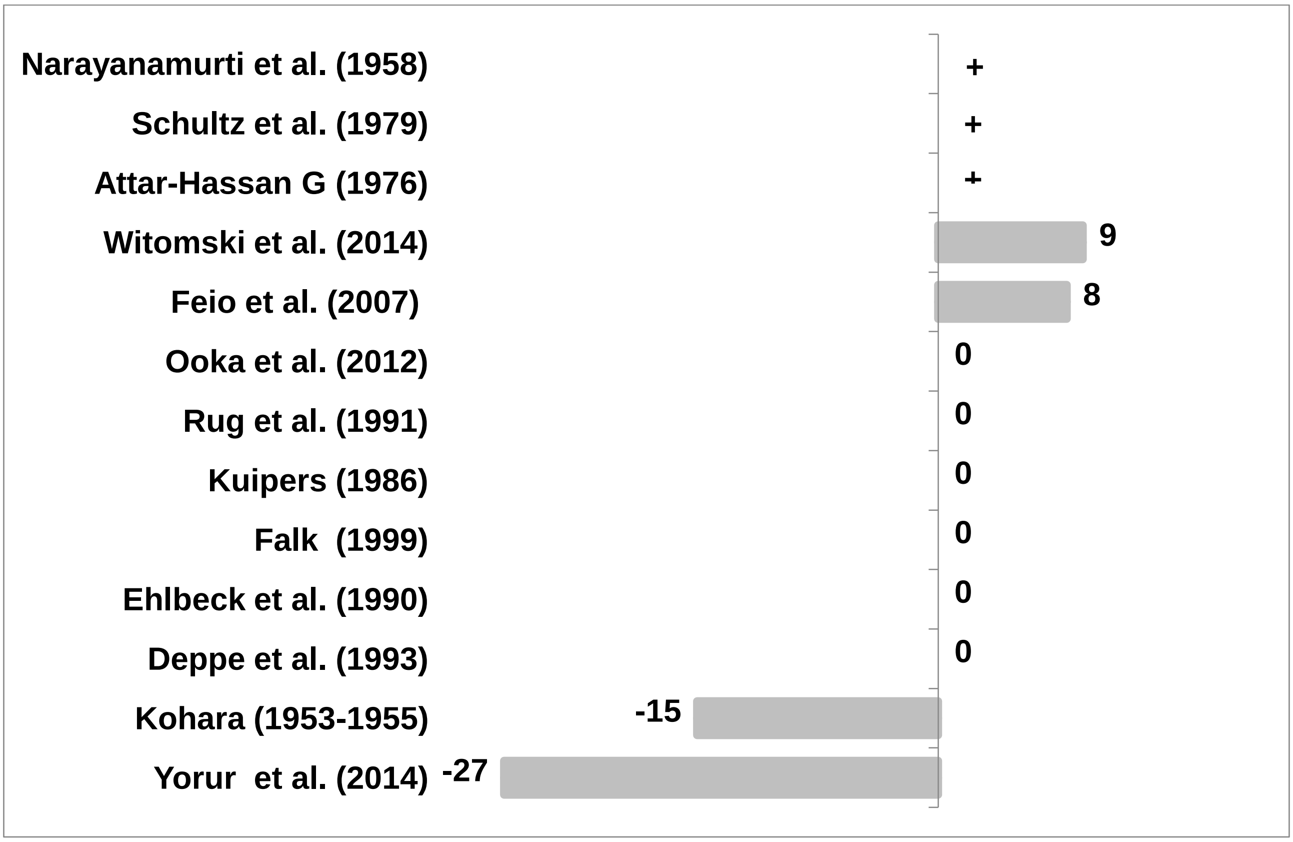

Fig 3 – percentage difference between old and new wood/timber compressive strength. Positive values indicates higher compressive strength for old timber. When a specific value is not indicated in the research work, the trend is indicated as increment (+) or decrement (-).