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BRIEF ORIGINAL

Selected mechanical properties of Scots pine wood from antique churches of Central Poland

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Abstract Scots pine (*Pinus sylvestris* L.) wood is the most frequently used building material in old churches of Central Poland. In the article, the density and compressive strength of Scots pine heartwood samples taken from old churches from the sixteenth, seventeenth, and eighteenth century were examined. The properties of the old wood were compared with contemporary wood of similar density. The results showed better quality of the ancient wood as compared to modern wood.

1 Introduction

Scots pine heartwood is the most frequently used building material of large constructional elements in antique churches of Central Poland. These churches are the oldest preserved wooden buildings in this area. In the preserved sacral buildings from the past centuries, building timber with little or no sapwood was used. The remaining sapwood had usually been destroyed by xylophagous insects. Unfortunately, the quality of the original old wood is usually mistakenly estimated as poor in preservation works, based on ravages appearing mostly in the outer areas of constructional elements (where sapwood dominates). Does this mean, however, that the entire constructional element, consisting mostly of heartwood, is in poor condition?

An attempt to answer this question has been made owing to the possibility to obtain an appropriate quantity of Scots pine heartwood from four antique churches from sixteenth to eighteenth century between 1994 and 1999. As a result, a relatively big number of samples were tested regarding compressive strength. The present article contains the results of this examination.

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2 Methods

Chocks of large constructional elements were taken from four churches: in Boguszyce (1,550–1,553, 16 samples from 2 elements), Długa Kościelna (before 1630, 15 samples from 1 element), Łaszew Rządowy (1,531, 13 samples from 1 element), and Puszcza Mariańska (1,755, 114 samples from 7 elements).

Prior to the examinations, the ancient chocks were seasoned in a laboratory for 11–18 years to achieve moisture content of 8–10 %. In total, 158 standard samples ($20 \times 20 \times 30$ mm^3) were extracted (according to ISO 3129:1975).

Contemporary wood was taken from constructional elements and seasoned for 4 years. More than 142 standard samples ($20 \times 20 \times 30$ mm^3) were taken from them and compressive strength parallel to grain was examined in the same way. In this case, moisture content of 8–10 % was also achieved.

The examination of the compressive strength parallel to grain was executed both for the ancient and the modern constructional wood according to procedures in DIN 52185:1976. The modulus of elasticity was determined during a compression test with an LVDT displacement sensor (recording of the displacements of the compressed samples with growing load). The moisture content of the wood was 9 % (in accordance with ISO 3130:1975 and ISO 3131:1975). The obtained data were verified statistically using student's *t* test with 95 % confidence level.

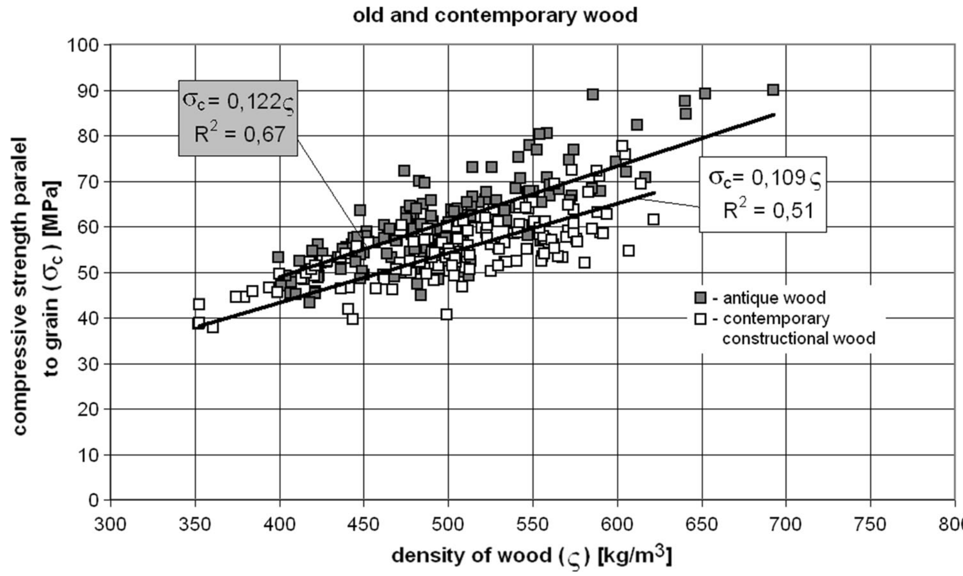

Fig. 1 Relationship between the density of ancient constructional wood from sixteenth–eighteenth century and contemporary constructional wood (*Pinus sylvestris* L.) and their compressive strengths parallel to grain

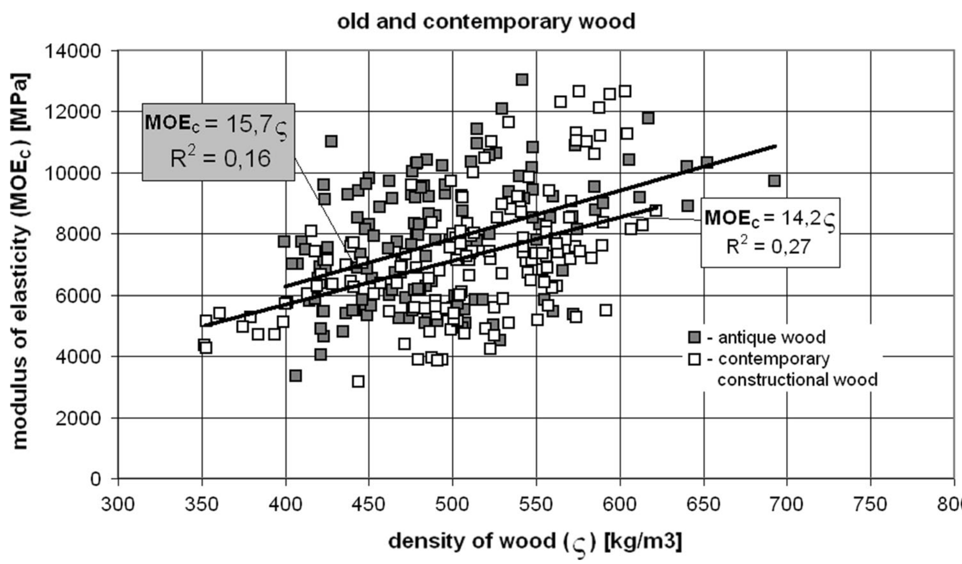

Fig. 2 Relationship between density and modulus of elasticity of antique and contemporary constructional Scots pine wood (*Pinus sylvestris* L.)

3 Results

The relation between wood density and compressive strength, resulting from the examination, is shown in Fig. 1. The relationship between wood density and modulus of elasticity from compression test parallel to grain of ancient and modern constructional wood is shown in Fig. 2.

4 Discussion

The antique wood had a slightly smaller density (494 kg/m^3) than modern wood (509 kg/m^3). If the compressive strength parallel to grain is taken as a criterion for evaluating the quality of constructional wood, the results of the examination point explicitly to a better quality of antique wood, which was characterised by a significantly higher value of compressive strength (60.2 MPa) compared to modern wood (55.3 MPa). The trend line of the relationship between compressive strength and density of ancient wood, determined by the results, lies clearly above the line for the modern wood (Fig. 1). The relationships are characterised by big correlation values ($r = 0.82$ for ancient wood and $r = 0.72$ for modern wood). The linear equation describing the relationship between the compressive strength parallel to grain and the density of heartwood extracted from six modern constructional elements $\sigma_c = 0.109\varsigma$ is practically consistent with the analogical equation given by Kollmann and Côté (1984) for wood with moisture content of 10 %, $\sigma_c = 0.105\varsigma$.

It should be emphasised that the wood from antique churches was generally taken from older trees than the modern constructional wood. Because some growth rings had been hewn to obtain rectangular cross-section of the beam, it was only possible to determine the approximate age of the trees. In the case of ancient churches, the trees were cut at the age of 100–120 years (Puszcza Mariańska) or even 120–130 years (Długa Kościelna). Only the growth rings of one chock from the church in Boguszyce indicated that the tree might have been cut at the age of 90 years. As for the tested modern constructional wood, it seems that it was made from trees cut at the age of about 60–70 years or at most 100 years.

The technical value of constructional material grows with its compressive strength and its modulus of elasticity from compression test parallel to grain. The results of the latter property of the wood also points to the benefits of Scots pine heartwood taken from the ancient buildings. The modulus of elasticity of the antique wood ranged from 6,680 to 9,120 MPa, with an average value of 7,740 MPa, and was significantly higher than the modulus of elasticity of the modern wood, which ranged from 5,140 to 8,360 with an average of 7,220 MPa. In spite of the difference described above, this property was characterised by high volatility (visible dispersion of points in Fig. 2 and relatively small coefficients of determination for the correlation lines). Despite that, in all analysed relationships between the features of both the ancient and the modern wood, the correlation coefficients (r) exceeded their critical values resulting from the number of tests and fixed statistical significance $\alpha = 0.05$. Thus, the relationships need to be taken as significant.

Similar results for Scots pine were obtained by Deppe and Rühl (1993), who tested the wood of a beam made from a tree cut in 1355 and remaining part of a roof construction of St Nicholas Church in Spandau (nowadays Berlin-Spandau). It turned out that as a result of 600 years natural aging the dispersion of mechanical features of the wood grew, but at the same time the average compressive strength of the ancient wood was close to, or the same as, the compressive strength of new wood. Earlier, Burmester (1967) examined Scots pine wood which had been used as a window frame and as an element of roof construction in a shed. He also noticed a higher compressive strength of the old wood as compared to the modern wood. He attributed the higher endurance of old material to hardening of resin. Currently it should be explained by the increase in cellulose crystallinity, which results in strengthening of cell walls of structural elements of old wood. According to Kohara and Okamoto (1955), who tested the wood from Japanese temples, the half-life or the depolymerisation time of cellulose at 19 °C is 1,500 years for softwood and 420 years for hardwood. They believed that with the age of wood reaching up to 300 years, due to crystallinity growth, both brittleness and compressive strength slightly increase and both hygroscopy and contractility decrease.

Schulz et al. (1984) also obtained better results for Norway spruce (*Picea abies* L. Karst) wood taken from rafter framing of Seefeld castle, which had growth rings from 1,656 to 1,678. However, in this case also, because of the number of growth rings, it can be assumed that the old pine wood was made from trees in or after rotation age.

Similar conclusions were drawn by Fukada (1957), who tested cypress wood from the oldest existing wooden buildings in the world, e.g., the Hōryūji built late in the sixth century. Consequently, the wood has well-developed heartwood. Modern wood used in this experiment was, at most, reaching the rotation age and thus had less heartwood. The increase in technical qualities of antique wood is also confirmed by the results of the examination of over 1,000-year-old hinoki (*Chamaecyparis obtusa Endl.*) softwood taken from Japanese temples (Yokoyama et al. 2009).

Almost identical direct proportionality between the modulus of elasticity and the compressive strength parallel to grain, designated for both the antique and the modern wood, described by the equation $MOE_c = 130\sigma_c$, shows that both those features of the antique wood are strengthened approximately in the same degree. To determine the technical value of antique wood it is only necessary to test one of those features. Due to its strong correlation with density and its low variability, compressive strength parallel to grain seems the best indicator of technical value of antique wood as compared to modern wood.

5 Conclusion

The examinations proved that the values of compressive strength parallel to grain are bigger for the wood from antique buildings from sixteenth to eighteenth century than for modern construction wood. The results obtained for this feature, as well as for modulus of elasticity, clearly point to the better technical value of Scots pine heartwood taken from antique churches in Central Poland as compared to modern constructional wood.

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