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SHORT NOTE

SHEAR STRENGTH OF SCOTS PINE (*PINUS SYLVESTRIS* L.) FROM THE HISTORICAL BUILDINGS

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ABSTRACT

Comparative research was conducted on shear strength parallel to grain of heartwood of Scots pine (*Pinus sylvestris* L.) from the 16-18th century from Central Poland and of modern wood. Tests were performed on 150 samples of aged wood from 13 construction elements of 4 historic buildings and on 100 samples from 10 modern constructional elements. Aged wood revealed a better technical quality. The difference of average shear strength parallel to grain values equaled 0.09 MPa and the translation of correlation line was about 0.35 MPa in favour of aged wood.

KEYWORDS: Shear strength, aged wood, Scots pine, carpentry joints, wooden churches.

INTRODUCTION

Mechanical qualities of aged wood have been a subject of research for many years. A great contribution was made by Kohara, who in 1950-1955 examined *Chamaecyparis obtusa* Endl. and *Zelkowa serrata* Thunb. (Obataya 2007). The wood of *Ch. obtusa* in some Japanese temples is even 1300 years old and that is why it has attracted curiosity of scientists. In the research of Yokoyma et al. (2009) 3-point bending tests were performed in longitudinal and radial directions on small clear wood specimens of *Ch. obtusa* cut from 8 historical samples and one modern reference considered of high quality by craftsmen.

Old softwood from Europe, including pine wood (Kránitz et al. 2010) and spruce wood (Schulz et al. 1984, Kránitz et al. 2010, Thaler et Miha 2013) are less commonly subject to examination of mechanical qualities and the wood is usually much younger than *Ch. obtusa*

(Obataya 2007, Yokoyma et al. 2009). Especially Scots pine wood (*Pinus sylvestris* L.) used in such experiments is usually not older than approximately 100 years (Kràniz et al. 2010).

Among laboratory tests of mechanical qualities of wood from historical constructions, determining compressive strength along the grain is by far the most frequent subject (Deppe and Ruhl 1993, Obataya 2007, Witomski et al. 2014). The reason for this is probably the fact that samples for such tests have simple shapes and require a relatively small amount of original wood from the construction. Thus, it is relatively easy to obtain a significant number of normative samples for the tests.

However, this kind of experiments does not cover the whole spectrum of scientific issues. Shear strength, a physical quantity which characterizes transverse cohesion, is particularly important for carpentery joints of wooden constructions. It is often crucial for the durability of the whole construction. However, typical samples required for normative tests of shear strength parallel to grain are relatively big, so it is much more difficult to obtain an appropriate amount of wood from old constructions for such experiments.

Heartwood of Scots pine has been the most popular material for large constructional elements of historic churches in central Poland. Shear strengths along the grain of wood are present in roof trusses (Fig. 1) and in carpentry connectors of beams in log constructions of walls of historical buildings. They can be particularly significant in the case of peg loosening in constructions with short pieces of wood along the grain, cut with grooves for other constructional elements (Fig. 2).

Fig. 1: Typical roof construction of a 16-18th century church in Central Poland (arrow – shear strength; here: The church in Cegłów, 16th century.

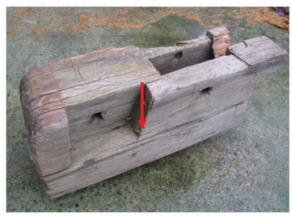

Fig. 2: The ending of roof construction element with short pieces of wood along the grain cut with grooves for other constructional elements (church in Boguszyce).

The present examination is intended to compare shear strength parallel to grain of aged heartwood of Scots pine (aged around 250-400 years) and modern wood of the same species. The problem has a significant practical value for evaluating the condition of building statics of architectural monuments.

MATERIAL AND METHODS

150 samples of aged heartwood Scots pine (*Pinus sylvestris* L.) were obtained from 13 construction elements of four historic buildings:

1) the church in Długa Kościelna, built certainly before 1630 (probably in the 16th century) – 5 samples from 1 element;
2) roof construction of the church in Cegłów (Fig. 1), built before 1629 (probably in the 16th century) – 61 samples from 3 elements;

3) the church in Łaszew, built in 16th century – 3 samples from 1 element;
4) the church in Puszcza Mariańska, built in 1755 – 81 samples from 8 elements.

A total number of 100 samples of modern Scots pine building heartwood were also obtained. Contemporary wood was taken from 10 constructional elements and seasoned for 6 years. Before the experiment, the age of both old and new elements was estimated based on growth rings. The moisture content of the wood was 8 – 10 % (in accordance with ISO 3130:1975 and ISO 3131:1975).

The aged wood was obtained from trees about 100-150 years old. The average density (ς) of the aged heartwood, estimated stereometrically, was 505 kg.m^{-3}, with standard deviation of 38 kg.m^{-3} and coefficient of variation of approximately 8 %. The new building wood was cut at the age of 80-100 years. The average density of to modern heartwood, estimated stereometrically, was 531 kg.m^{-3} with standard deviation of 79 kg.m^{-3} and coefficient of variation of approximately 15 %.

The examination of shear strength parallel to grain (τ) was executed both for the aged and the modern constructional wood according to procedures in (DIN-52187:1979), and using samples produced accordingly to Polish norm (PN-D-04105:1979). The shape and sizes of the samples are given in Fig. 3.

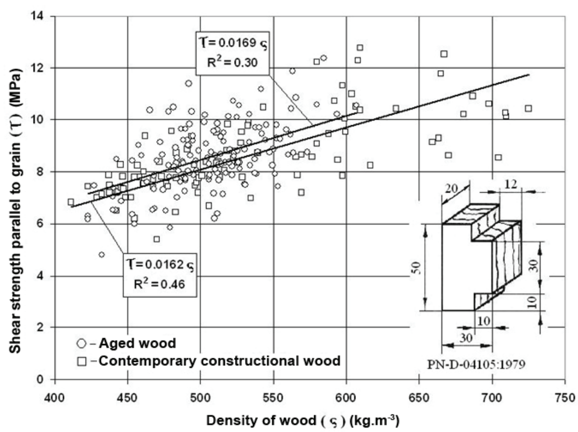

Fig. 3: The relationship between wood density and shear strength parallel to grain.

A five-ton INSTRON testing machine was used in the examination, controlled by a computer program. The obtained data were verified statistically using Student's t-test with 95 % confidence level.

RESULTS

The relationship between wood density and its shear strength, detected in the experiment, is presented in Fig. 3 (separately for aged and modern wood). The average shear strength in radial plane of the aged wood was 8.55 MPa with standard deviation of 1.29 MPa and coefficient of variation of 17 %. The average shear strength in radial plane of the modern wood was 8.64 MPa with standard deviation of 1.47 MPa, which is a result of a bigger density of the wood. The coefficient of variation was also approximately 17 %.

DISCUSSION

The experiments on the wood of *Ch. obtusa* and the wood of *Z. serrata* in Japan in 1950-1955 revealed that the value of compressive strength parallel to grain increased about 50 % in the first 300 years, and after that time it remained approximately at the same level. Thus, the value of compressive strength of the oldest *Ch. obtusa* wood samples (aged around 1300 years) as calculated by J. Kohara, remains bigger than compressive strength of modern wood (Obataya 2007). Unfortunately, in the case of East European wood species, such old and biologically undegraded material for experiments is not available, unlike in Japan or Egypt, respectively, where ancient buildings still exist, as Horyu-ji temple, built in 607, or the funeral boat of pharaoh Khufu, made of *Cedrus libani* A. Rich wood around 4600 years ago. However, also in the case of Scots pine aged heartwood, samples aged 250-400 years (Witomski et al. 2014) and over 600 years (Deppe and Ruhl 1993) revealed a bigger value of compressive strength than modern wood samples, which is undoubtedly a result of a higher crystallinity level of cellulose (Obataya 2007).

On the other hand, aging process is not always beneficial for all the features of wood. The growing crystallinity of unstructured cellulose results in a higher stiffness of wood when cohesion of fiber matrix is weakened. Natural aged wood becomes brittle. It is believed that some qualities of old wood, e.g. shear strength, static bending strength and splitting strength are degrading in the aging process (Obataya 2007). Brittleness of old wood may be attributed to chemical degradation of amorphous matrix substances, i.e. hemicelullose and lignin. The speed of the process varies for different wood species. For example, chemical degradation of *Z. serrata* wood is faster than chemical degradation of *Ch. obtusa* wood (Obataya 2007). However, the results obtained in the present experiment point to a good shear strength parallel to grain of aged heartwood of Scots pine of the same density as modern wood material. Although the difference between average values of shear strength parallel to grain of aged wood and modern wood was 0.09 MPa, the translation of correlation line was about 0.35 MPa. At the same time, aged heartwood of Scots pine reveals a smaller statistical dispersion of shear strength than modern wood. Of course, it must be noted that Scots pine wood tested in the experiment was not as old as the wood of *Ch. obtusa* (Obataya 2007, Yokoyma et al. 2009) or the wood of *Z. serrata* (Obataya 2007). However, constructions including big share of biologically undegraded aged heartwood of Scots pine preserve their high mechanical value, which has a big significance to building statics of architectural monuments. It can be also noted that the density of many samples of modern constructional wood is higher as compared to samples of wood from historical construction used in the research. It results from the necessity of using available aged wood which has not been biologically degraded. The available aged wood is often limited to internal parts of heartwood, which is basically juvenile wood. This issue is particularly significant if bigger samples are required, as it is in the case of samples used in examination of shear strength parallel to grain.

CONCLUSIONS

The experiments showed that aged heartwood of Scots pine aged around 250-400 years has a high shear strength parallel to grain, slightly bigger than modern construction wood. The results obtained for this feature of wood point to a very good technical value of Scots pine heartwood obtained from old churches in Central Poland.

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