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COMPARISON OF OUTDOOR AND ARTIFICIAL WEATHERING USING COMPRESSIVE PROPERTIES

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ABSTRACT

The purpose of study was to comparison of outdoor and artificial weathering of wood using compressive strength along fibers. The study involved tropical wood species from South America: garapa (*Apuleia leiocarpa* (Vog.) Macbride.) and angelim pedra (*Hymenolobium* sp.) available commercial in Europe and Scots pine (*Pinus sylvestris* L.) and European oak (*Quercus* sp.). The specimens were exposed to outdoor weathering and an artificial weathering consisting of alternating soaking wood in water, drying at 70°C and UV radiation exposure. Three-step aging cycle was repeated 56 times. In general, the process of artificial weathering caused a decrease in strength of all tested wood species. A significant relation between artificial weathering (carried out in laboratory) and weathering performed in the external environment in temperate climates was found.

KEYWORDS: Tropical wood, artificial weathering, natural weathering, *Apuleia leiocarpa*, *Hymenolobium*.

INTRODUCTION

The decisive element for use of different wood species in the harsh outside environment is its durability. Variability of weather conditions and prolonged exposure to them cause the process called wood weathering. Some knowledge of these processes is needed in prediction life time of products, important from technological and economical point of view and selection of proper materials depending on future conditions of use (Williams 1999, Kilic and Niemz 2012).

The natural weathering of wood is described as a process of irreversible changes in the appearance and properties of a material being effect of a long-term impact of the weather: solar radiation, air and oxygen contained in it, changes in temperature and humidity, assuming no direct influence of biotic factors (Holz 1981; Feist 1983, 1988, 1990; Feist and Hon 1984, Hon et al. 1986, Colom et al. 2003, Williams 1999, 2005). Wood weathering is a complex phenomenon (multifactorial) caused by solar radiation and by hydrolysis and leaching out of wood components. Cyclical changes in humidity, swelling and shrinkage have a significant influence on changes in wood properties during the weathering process. Because of slowness of the process, examination of wood weathering and its consequences is difficult. Noticeable changes often appear in real terms after many years of using wood. Therefore, various methods of artificial weathering were developed in laboratories to simulate natural influence of weather conditions and to determine changes occurring in wood in short time. These methods differ from themselves in order and intensity of effects of individual factors (eg. Temiz et al. 2007, Evans et al. 2008, Follrich et al. 2011). It should be taken into account the fact that the samples size used to determine the mechanical properties of wood artificially weathered is unrestricted, one published study - right for the type of test samples and artificial weathering - cannot be directly related to the results obtained in other trials. Moreover, the results of outdoor weathering are current only for a given climate. Some trials of natural weathering are reported in literature, e.g. Evans et al. (1996) studied loss of mass and chemical changes taking place in wood *Pinus radiata* D. Don. during weathering. Evans et al. (2008), Bhat et al. (2010) tested wood and modified wood materials during weathering including its mechanical properties.

In this study, comparison influence of natural and artificial weathering on compressive properties of wood (assuming the absence of biotic interactions) were undertaken. The study includes species of wood from foreign forests (heartwood), commercially available in Europe: garapa (*Apuleia leiocarpa* (Vog.) Macbride.) and angelim pedra (*Hymenolobium* sp.). Parallel studies were performed on European wood species: Scots pine *Pinus sylvestris* L. (individual sapwood and heartwood) and European oak *Quercus* sp. (heartwood). As the processs of weatehring progressed, compression strength along fibers were determined. The scope of the study includes the analysis of the relation between artificial weathering and weathering taking place in natural conditions. The determination of ergosterol in wood were also tested.

MATERIAL AND METHODS

Preparation of test specimens

Selected for the research wood species represents different types of structures (coniferous – Scots pine, deciduous ring-pours – European oak and diffuse-pours – garapa and angelim) and differs in details of the anatomy and density (Tabs. 1, 2). Samples of each type of wood were collected from one board to obtain "identical sample". Thanks to that a density moved close and a structure were kept for so that appearing changes in the weathering process are a main factor deciding on the examined properties. From each species of wood were obtained 21 groups of 6 samples. Each group was intended for the study of different stages of weathering conducted in natural environment and in laboratory. Prior to the determination of properties, each group was conditioned in air at a temperature close to 20°C and relative humidity around 65 %.

Tab. 1: The research material.

Latin name	Trade name and name according to EN 13556 (2003)
Apuleia leiocarpa (Vog.) Macbride	garapa*
Hymenolobium sp.	angelim pedra
Pinus sylvestris L.	Scots pine
Quercus petraea sp.	European oak

* Apuleia leiocarpa (Vog.) Macbride are not included in EN 13556 (2003)

Tab. 2: The comparison of average wood density of the tested species (for the whole batch of samples).

Wood name	Density at moisture content 12 %	Standard deviation
	kg.m^{-3}	
Sapwood of Scots pine	590	20
Heartwood of Scots pine	598	35
European oak	626	25
garapa	727	22
angelim pedra	759	34

Wood weathering methods

The design of the artificial weathering cycle was roughly based on literature (Matejak et al. 1983, Follrich 2010). One artificial weathering cycle took 30 hours and was separated into three steps (Fig. 1). The first step was soaking speciemens in water at 20°C (16 h). The conditions of second step (8 h) were 70°C and 5-10 % rH and the third step was performed at 30°C and 20-25 rH (6 h) with irradiation with UV rays. Four fluorescent lamps 100R's Lightech of 100 W each, and the spectrum 300 - 400 nm (90 % of the radiation spectrum is a wavelength of 340-360 nm) were used for irradiating. 56 cycles of artificial weathering were conducted.

To find the relation between the weathering of wood in a temperate climate typical for the area of Central European lowlands (Poland) and the artificial weathering - effects of weathering conducted in the laboratory and in natural outdoor conditions were compared. The natural weathering was based on exhibiting wooden samples in outdoor in a 3 class of use (according to the EN 335-1 (2006) - wood or wood based product is not under a roof and is not in contact with the ground, or is constantly exposed to atmospheric conditions, or is protected from the weather, but subjected to frequent wetting). Wood weathering was conducted since 20 January 2009 to 21 January 2011 and took place in the experimental field the Warsaw area (Poland, geographical coordinates: 51°34'35''N, 21°33'26''E). The effects were compared on the basis of the determination of compressive strength along fibers.

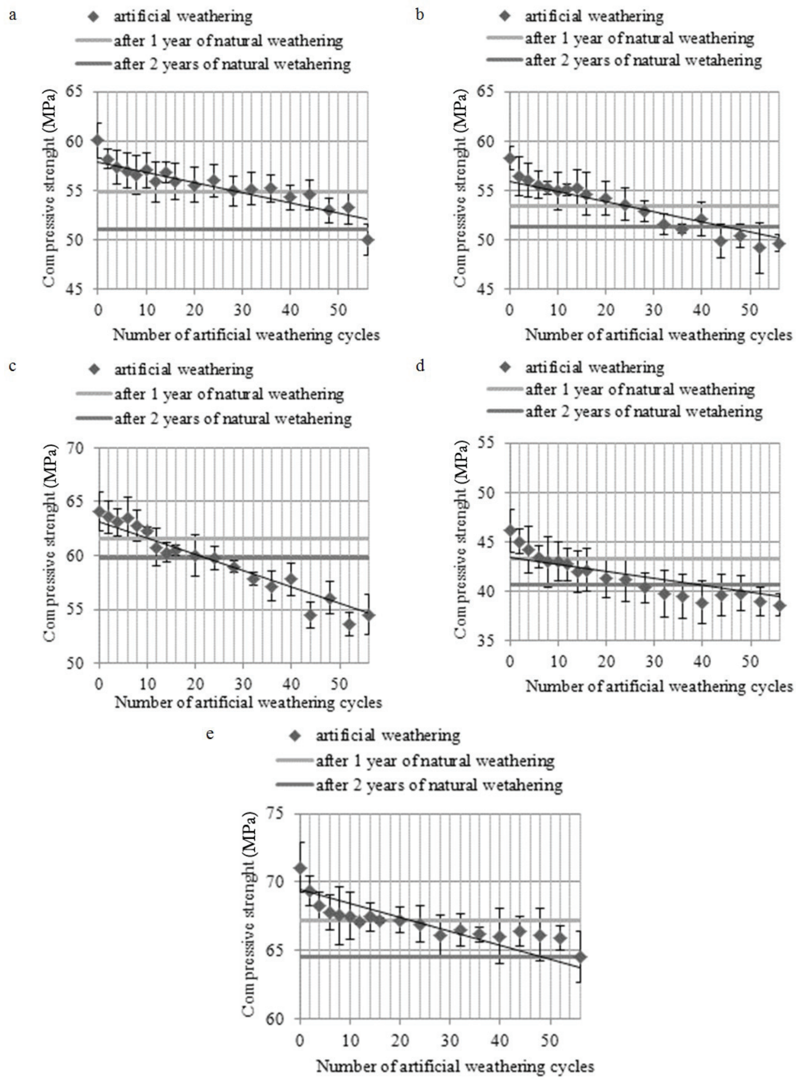

Fig. 1: Statement of results testing mechanical properties of wood during artificial and natural weathering: a) – heartwood of Scots pine, b) – sapwood of Scots pine, c) – garapa, d) - European oak, e) – angelim pedra.

Mechanical testing

Examination of compressive strength of wood along fibers was performed before weathering, during artificial weathering and during natural weathering with yearly intervals. The study was conducted according to PN-D 04102 (1979). Dimensions of samples were: 15.0 x 15.0 x 22.5 mm (last dimension along fibres). The use of slightly smaller dimensions of samples was a departure from the mentioned norm. The deviation concerning the sample size occurred in view of the fact that no relation exists between the compressive strength along fibers and the size of samples when they are geometrically similar and when section of the samples contained at least a couple of annual increments (Matejak et al. 1983). The aim of this action was to cause great changes in wood during the weathering process. Examination of compressive strength of wood along fibers was carried out on the 10-ton universal testing machine INSTRON 3382. Constant speed of loading samples of 2 $mm.min^{-1}$ was used during the compression tests. For the individual groups of samples average values as well as standard deviation were calculated.

Determination of content of ergosterol

In order to confirm that the course of weathering changes in wood properties did not affect the action of fungi (according to the provisions contained in the standard EN 335-1 (2007), in the 3 class of use an activity of wood decaying fungi is possible), ergosterol content determination was made in control wood samples and wood subjected to natural weathering. Ergosterol is a lipid which builds the fungal cell wall (Hass et al. 2004). The increased content of ergosterol refers to the development of these organisms in wood. Determination was performed according to Seitz et al. (1979) modified at the Institute of Fermentation Technology and Microbiology, PL (Gutarowska and Żakowska 2002). The principle of the method consists in determining the amount of ergosterol extracted from all of sterols by spectrophotometry at a wavelength in which ergosterol gives the distinguishing characteristic of the spectrum (λ =282.6 nm).

RESULTS AND DISCUSSION

The study shows that due to the artificial weathering process the compressive strength of wood along fibers was reduced. The same direction of changes was observed for every tested wood species. The statement of results of testing compresive strenght of wood during weathering is given in Fig. 2.

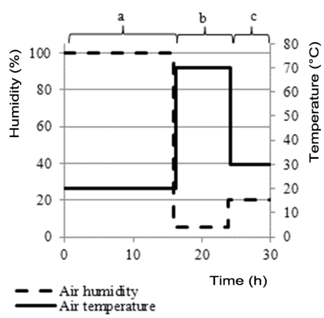

Fig. 2: Changes in humidity and temperature during full one cycle of weathering: a) soaking in water for 16 hours, b) drying at 70° C for 8 h, c) UV irradiation for 6 hours.

It can be assumed that due to weathering the decrease of compressive strength of wood along fibers is mainly caused by changes in wood structure. Matejak et al. (1983), Feist (1993) and Williams (2005) the main cause of deterioration of mechanical properties consider cyclical changes in moisture conditions causing destruction of wood tissue (wood cracks). It is hard to indicate one particular factor which affects the extent of decrease of compressive strength along fibers of tested wood species. This is interaction of many factors with many interactions between them - submicroscopic construction of wood (cell walls), microscopic (size, layout and contribution of individual structural elements - rays, parenchyma, fibers, vessels), macroscopic (width and layout annual growth, the share of earlywood and latewood) and its chemical composition (types of extractives substances-resins, tannins, oils, minerals and other).

The aim of the field test was to find the relation between the artificial weathering carried out in laboratory and the natural weathering taking place in the external environment (determining how many cycles of artificial weathering corresponds to an annual weathering in outdoor conditions). The number of cycles corresponding to annual weathering of wood in outdoor conditions was obtained at the intersection of two sets of data - the results of testing the strength of wood aged artificially and strength of wood aged under natural conditions (mean values obtained from two-year follow up, compression strength along fibers was examined at yearly intervals). Number of artificial weathering cycles is different for each of wood species. The statistical analysis confirmed that in case of sapwood of Scots pine this number ranges from 10 to 28; in case of heartwood of Scots pine – from 4 to 42, in case of garapa from 8 to 24, in case of European oak from 2 to 26 and in case of angelim pedra number of artificial weathering cycles corresponding to yearly weathering ranges from 6 to 32 (t-test was used to determination differences signification). The wide range shows that despite of examination many wood species of different density and anatomical structure, evaluation of the relation between artificial and natural weathering is difficult. Mean value of number of artificial weathering cycles corresponding to yearly exposition wood in 3 class of use (according to EN 335-1 (2006)) is 18.

Presence of fungal infection during outdoor exposure was also examined. Wood samples exposed to outdoor conditions did not show macroscopic signs of fungal infection (no evidence of blue stainor change color indicating a biological degradation, lack of fruiting bodies). Additionally changes at chemical structure level were tested - the content of ergosterol were determined and compared in control samples and subjected to natural aging. The results of UNICA Spectrophotometer UV/Vis did not indicate any increase in ergosterol content in wood subjected to weathering in any tested group (compared volumes the absorbance of methanolic solution of alcohol from the extraction of aged wood and not aged wood). If the absorbance of the alcoholic solution obtained by extraction of weathering-treated wood was less than the absorbance of the alcoholic solution obtained from the extraction of control wood, it was considered no difference – aim of tests was to verify that due to weathering of wood does not exhibit an increased content of ergosterol (Tab. 3).

Tab. 3: Statement of absorbance alcoholic solutions of wood before and after weathering.

Wood name	**The absorbance of methanol (the average of three trials, standard deviation is given in parenthesis)**		t_{emp}	**Significance of the difference***
	Control samples of wood	**Samples of wood after natural weathering**		
angelim pedra	0.513 (0.001)	0.626 (0.010)	-2.712	-
European oak	0.332 (0.014)	0.300 (0.001)	7.341	+
garapa	0.502 (0.036)	0.307 (0.001)	5.401	+
Sapwood of Scots pine	0.498 (0.031)	0.509 (0.006)	-0.602	-
Heartwood of Scots pine	2.570 (0.108)	2.045 (0.005)	8.784	+

* T-test was used to determine significance of differences (the resulting t value wass compared to the tabular t value at the 95 % probability level; $t_{0,05}$ = 2.776).

CONLUSIONS

Application of artificial weathering of wood simulates actual conditions and allows to determine changes in properties of wood in a short time and thus predicts its behavior. Determination of ergosterol confirmed the lack of biological corrosion during weathering. The artificial weathering program used to illustrate the natural weathering of wood in outdoor conditions in a temperate climates (typical of the Polish territory) - approximately 18 cycles of artificial weathering - corresponds to the annual wood work in the external environment, but each wood species shows clear differences.

These findings provide a helpful basis for further investigation of service life of wood during weathering.

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