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ACOUSTIC ACTIVITY OF WOOD DURING ACROSS TO-THE-GRAIN BENDING *

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Acoustic emission (*AE*) was investigated during 3-point perpendicular to-the-grain bending test. Experiments were carried out with green and air-dry beech wood. While air-dry wood tested it was revealed that *AE* signals appeared at stress level equal to proportional limit. *AE* signals number is growing asymptotic when non-linear segment of deflection-load curve is increasing. During green wood bending *AE* appears practically in the moment of rapid (catastrophic) material failure. The results of experiments suggest that there a defined threshold of elastic energy exists. When that energy value is reached the process of wood failure starts.

INTRODUCTION

An acoustic emission (*AE*) method provides a lot of important information connected to development and process of failure phenomena in various materials [5]. An information received from measurement of *AE* generated in material being under loading, is valuable because of coming from the very source where *AE* is being induced. The basic reason of *AE* generation in material being deformed is stress waves formation resulting from releasing of elastic energy formerly accumulated in deformed the material. Various structural defects created then, are the sources energy releasing.

Previous investigation on *AE* generated by mechanical stresses of wood revealed that *AE* impulses are possible to register at very low deformation level [1, 2, 25]. That is the result of stress field of highly complex structure which exists there as a reason of wood structure unhomogenity. The increase of wood moisture content results in significant decrease of *AE* activity [2, 4, 12, 23]. *AE* in wet wood is not registered before stress value closed to the breaking stress.

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An important effect of loading method on *AE* course was exhibited as well. It is common opinion that the *AE* of the highest intensity is generated during along to-the-grain tensile test. Some less acoustic activity is observed in bending and compression tests [12, 14, 24]. From Ansell [2] paper it emerges that wood acoustic activity depends on failure pattern as well. While wood failure runs with shearing domination, *AE* activity is lower than in fibres tearing process. An analogy between wood creep and wood acoustic activity curves [10, 11] points to the *AE* method as an usefull tool for monitoring of structural defects accumulation in wood being under a load. The linear relationship between load value at the first *AE* impulse and ultimate load value [16, 20] enables a prediction o failure process basing on so called threshold of *AE*.

In spite of great number of papers published on *AE* generated in wood under mechanical loading there still is lack of quantitative relationship between *AE* parameters and wood mechanical properties. Taking under consideration the fact that mechanical destruction process of a material is the result of formerly accumulated elastic energy lost [6] there was undertaken the attempt to refer the *AE* basic parameter i.e. *AE* counts number related to elastic energy losses in wood expressed as the linearity deflection parameter in load-deformation graph in three-point bending accros to-the-grain test.

MATERIAL AND METHODS

An attempt to show the relationship between *AE* and mechanical loading was carried out on beech-wood (*Fagus silvatica* L.) in across to-the-grain bending test with specimens of dimensions: 20(L) × 20(R) × 150(T) mm. A load was realized at bending test-machine type BPG-50 (former GRD made) in three-point load system, with bearing distance 120 mm, bending force acting in radial direction. Regarding the fact that the *AE* and mechanical properties of wood could be different depending on creacking path direction (bark-side or pith-side directions) [24] in this experiment bending force was acting into bark-side direction each time. Bending force value, with measuring accuracy 1 N and deflection value, accuracy 0.1 mm were recorded from digital indicator of testing machine. Loading speed was 0.5 mm per minute.

The *AE* signals were recorded with EA-3 analyzer (Techpan, Warszawa made) with measuring track total amplification of 80 dB. Basing on introductory experiments the noise discrimination threshold was set at 0.25 V value to eliminate the electrical interferences produced by testing machine. For *AE* signals receiving the piezoelectric transducer of resonance frequency 200 kHz was used. The transducer was fastened to load applying bar with a clamp. The *AE* signals as a cumulative count were registered with $X-Y$ pen-recorder TZ-4100 type (Tesla, Brno made). A diagram showing the method of specimens loading and *AE* signals recording track is presented at Fig. 1.

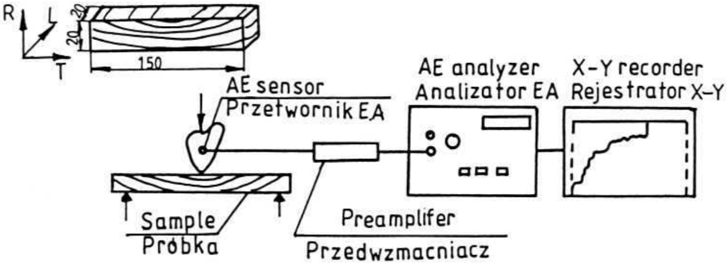

Fig. 1. Diagram of sampels shape and dimensions, load applying system and *AE* signal recording method

Ryc. 1. Kształt i wymiary próbek oraz schemat wywierania obciążenia i sposobu rejestracji sygnałów *EA*

The above experiment was conducted in room temperature with specimens taken from the same zone of a plank. The wood moisture content was 8 per cent-dry wood, and *MC* close to fibre saturation point (FSP) for wet wood. The specimens group of FSP moisture content had never before been dried to any lower moisture level. For each moisture groups the experiment was carried out with 10 specimens.

RESULTS AND DISCUSSION

Some characteristics which are typical for wood bent across to-the-grain are presented at Fig. 2a. At this Figure the curve of *AE* cumulative counts and the increase in deviation from Hooke'an behaviour in "load-deflection" graphs (Fig. 2b) are presented there. A measure deviation from linear behaviour of the curve ($F(d)$) is, according to O'Halloran [15] between force attributed to linear relation (F_H) due to the Hooke's law, and a real force (F) measured at the given deformation value (Fig. 3). Some selected mechanical properties of tested wood, determined in base of above mentioned graphs, are presented in Table 1. Even a rough analyze of curves shown at Fig. 2 reveals that *AE* impulses appear in dried wood, practically at the moment when non-linear behaviour in bendend wood starts. The wet wood emitted the *AE* signals only very close to ultimate load. Nevertheless the values of deformation work defined from the *AE* initial moment for both of moisture contents in wood, are close to each other (Tab. 1). This seems to suggest, that cumulation of elastic energy of constant value in some areas of wood structure is a necessary condition for cracking process initiation. Some differences in *AE* observed for dried wood and for wet wood loading is probably the result of various stress field distribution for those two kinds of examined samples.

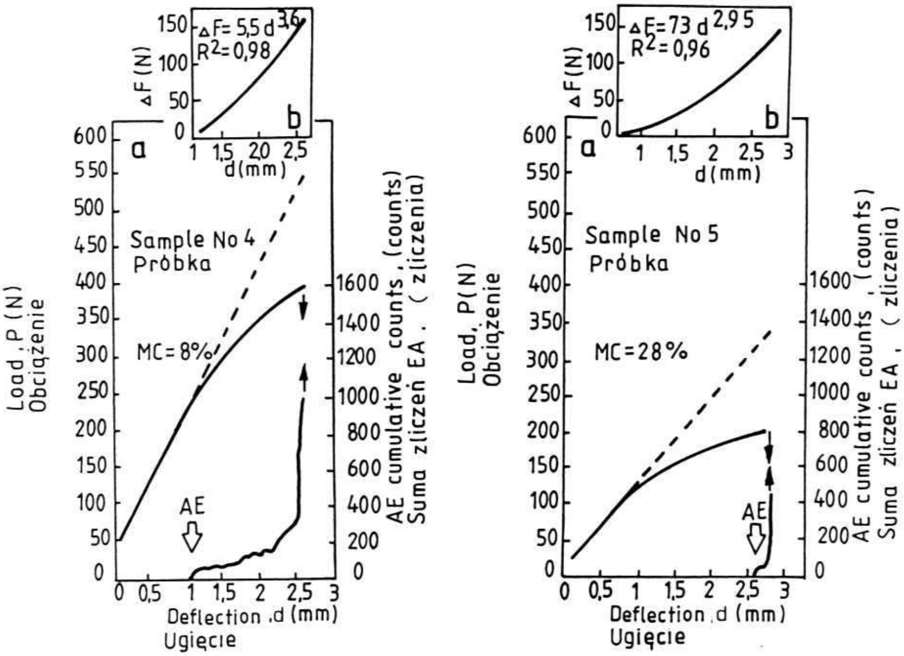

Fig. 2. Examples of load-deflection curves of beech wood in across to-the-grain bending test and typical graphs of *AE* cumulative count (a) and nonlinearity parameter increasing (b)

Ryc. 2. Przykładowe krzywe obciążenie-ugięcie drewna buka zginanego w poprzek włókien i typowe przebiegi sumy zliczeń *AE* (a) oraz narastanie parametru nieliniowości (b)

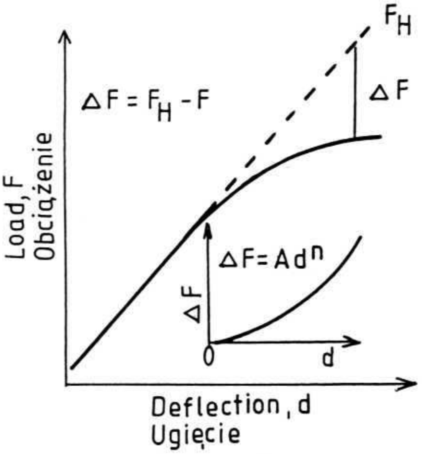

Fig. 3. Method of nonlinearity estimation for load-deflection curve according to O'Halloran [15]

Ryc. 3. Sposób oceny nieliniowości krzywych obciążenie-ugięcie według O'Hallorana [15]

Table 1

Selected mechanical properties of beech wood used for across to-the-grain bending test

Niektóre parametry mechaniczne drewna buka zginanego w poprzek włókien

Property Określana właściwość	Statistic value Wielkości statystyczne				
	X_{min}	$\bar{X}$	X_{max}	$\pm S$	V [%]
Bending strength, Rg [MPa]	8.2	9.3	10.8	0.86	9.2
Wytrzymałość	4.0	4.4	4.8	0.25	5.8
Proportional limit stress σ_H, [MPa]	3.8	5.5	6.9	0.88	16.2
Naprężenie na gr. prop.	1.6	2.1	2.7	0.31	18.1
Threshold stress, σ_{EA} [MPa]	4.7	5.8	7.4	1.02	17.6
Naprężenie progowe	3.2	4.2	4.8	0.45	10.9
Ultimate deformation in tensile zone, ε_{max} [%]	1.9	2.3	3.1	0.35	15.5
Odkształcenie niszczące w strefie rozciąganej	2.4	2.9	3.4	0.30	10.9
Proportional limit deform. in tension zone, ε_H [%]	0.58	0.91	1.17	0.15	16.6
Odkształcenie na gr. prop. w strefie rozciąganej	0.45	0.61	0.84	0.13	19.7
Work of bending forces up to the threshold stress, L_{AE} [J]	0.121	0.210	0.330	0.07	35.3
Praca zginania do naprężenia progowego	0.122	0.259	0.340	0.07	26.2

* Value above for $MC=8\%$, value below for $MC=28\%$

For dried wood ($MC=8\%$), the high rigidity of anatomical elements being the result of low moisture content, causes an extremelly non-homogeneous internal stresses distribution. Therefore, in this state of stresses even very low external stress can develop the stresses of values higher than wood local strength in the weakest areas of wood structure. This process is observed as *AE* of a discrete nature. The local destruction in wood structure is able to result in equalizing of internal stress [19] or stress concentration in remote areas of wood structure. In dependece on those two possible results it can induced there the *AE* slow or *AE* rapid signals with different intervals of silence registered in a diagram. It is necessary to mention here, that in spite of very slow, and natural process of tested wood drying the defects structure could be created there, within the wood structure. The defects being created during wood drying process are additional areas of stress concentration [9]. Those can be revealed already in very early stages loading, especially in tension stress area [16].

For wet wood ($MC=28\%$) loading because of its high deformability internal stress distribution is more homogeneous. In this state, microfibrils in cellular walls are maximal relaxed. The lack of *AE* signals from wood being under loading until specimen breaking, points for lack of brittle fracture process in wood tissue for this range of loads. High inelastic deformations are mostly observed – as it seems – as a result of high deformation in bent beam compressive zone. Since the previous investigations [8] have shown that compression stresses induced during totaly restrained across to-the-grain wood swelling have not generated *AE* phenomenon.

Cellulose frame in lignine matrix displacement during inelastic deformations of wood, induce probably *AE* of continuous nature. Amplitudes of that kind of signals, similarly to movement of lattice defects in metals [22] are approximately 100 times lower than *AE* signals amplitudes characteristic for micro- and macrocrack creation and development processes. A fairly high noise discrimination threshold and increased damping coefficient caused that *AE* impulses were not registered.

The consideration presented above seems to show for differences in mechanism of nonlinearity formation in load-deformation curves for dry and for wet wood. In case of dry wood the fundamental reason of the nonlinearity appearance are the processes of destruction (cracking) in wood structure. While for wet wood, inelastic deformations are the result of non-destructive modification of wood structure and its matching to a new loading condition [7].

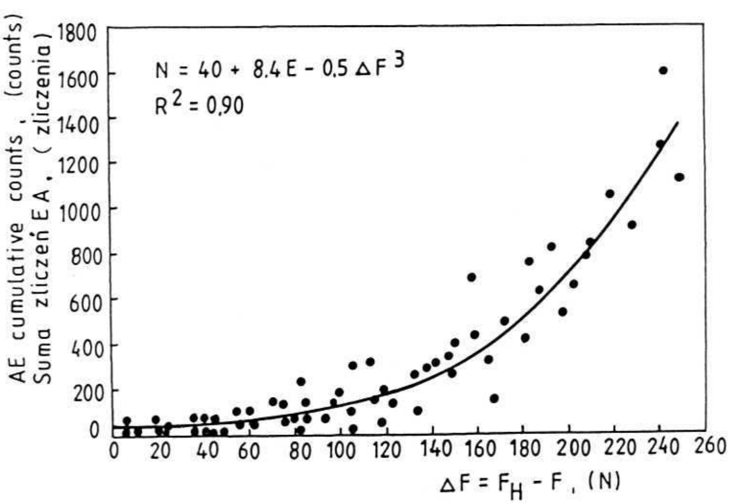

Fig. 4. Relationship between *AE* cumulative count generated during beech wood across to-the-grain bending test (dry wood) [N] and nonlinearity parameter [*ΔF*]

Ryc. 4. Zależność sumy zliczeń [N] sygnałów *EA* generowanych podczas zginania drewna buka (drewno suche) w poprzek włókien od parametru nieliniowości [*ΔF*]

A process of discrete *AE*, generated from dry wood being under loading was analized as a function of load deviation from Hooke'an behaviour of wood ($\Delta F = F_H - F$). The function defined as given above, describes the nonlinear behaviour of wood being under bending load acting across to-the-grain, as presented at Fig. 4. A dependence shown at Fig. 4 reveals very close relation between nonlinearity parameter (ΔF) of wood being bent across to-the-grain and *AE* cumulative count. In other words, the described relationship which characterizes corelation between nonlinearity parameter (ΔF) thus between mechanical destruction of wood structure and acoustic activity of wood. The higher is that numerical value of the parameter and consequently the destruction of wood structure, the higher is acoustic activity of wood being under across to-the-grain bending load. The empirical relatioship shown above is very similar to nonlinearity function in dry wood creep process when bending load is applied in a discrete manner [17]. Relation between *AE* parameters and previously determined the linear dependence between length and surfaces of developing cracks [13, 18, 21] prove, that *AE* method can be useful tool for monitoring of defects accumulation in wood being in various state of stress.

CONCLUSIONS

1. Mechanism of nonlinearity creation in load-deformation curves for wood depends on wood moisture content. For dry wood, destruction (cracking) processes in wood structure are the basic source of nonlinearity. In wet wood nonlinearity is meanly a result of nondestructive modification of wood internal structure.

2. In case of dry wood there a close relation between nonlinearity parameter for wood across to-the-grain bending test and *AE* exists. That enables to use the *AE* method for monitoring of destruction processes in wood being under external, mechanical loading.

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AKTYWNOŚĆ AKUSTYCZNA DREWNA ZGINANEGO W POPRZEK WŁÓKIEN

Streszczenie

Badano emisję akustyczną (*EA*) podczas trójpunktowego zginania drewna w poprzek włókien. Badania przeprowadzono na drewnie buka w stanie suchym i mokrym.

Podczas zginania drewna suchego stwierdzono, że sygnały *AE* pojawiają się przy naprężeniu na granicy proporcjonalności, a liczba zliczeń sygnałów rośnie asymptotycznie w miarę narastania nieliniowości w zależności ugięcie-siła. W przypadku drewna mokrego *AE* praktycznie ujawnia się w momencie nagłego (katastroficznego) zniszczenia. Przeprowadzone badania sugerują istnienie określonego progu energii sprężystej, po którego osiągnięciu następuje inicjacja procesu zniszczenia drewna.

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