IDENTIFICATION OF WOOD DESTRUCTION DURING DRYING*

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ABSTRACT

The subject of this paper concerns destruction of timber during drying. The main goal is to propose a method of avoiding destruction through a suitable programming of drying processes, controlled with the help of the acoustic emission (AE) method. Three different programs of convective drying of pinewood (Pinus sp.) samples are presented. The high and slow rate drying programs were applied to show an evident dependence between the intensity of AE signals (their number and energy) and the degree of destruction of pinewood during drying. The third drying program was controlled, i.e. the drying was accelerated, when the acoustic emission was low, or slowed down, when the acoustic emission started to grow rapidly. In this way , the drying process was optimized for the purpose of shortening of the drying time and avoiding a destruction of the material.

Keywords: destruction, pinewood, controlled process, acoustic emission.

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INTRODUCTION

Drying of timber is the one of fundamental technological processes in wood industry. A proper realization of this process is necessary to obtain a good quality product. The high costs of drying involves to look for optimized processes with respect to drying time and energy consumption and, in particular, for processes not causing destruction of timber during drying. A very helpful in this afford seems to be the acoustic emission (AE) method that enable monitoring *on line* the material destruction, and thus, give a basis to drying control.

The studies on AE in drying of wood were already carried by some authors, e.g. Cunderlik et al. (1996), Kagawa et al. (1980), Kitayama et al. (1985), Noguchi et al. (1980), Skaar et al. (1980), Kowalski et al. (2004). These authors noticed that an increase of drying rate involves an instantaneous increase of AE signals originated from created defects in wood and the drying induced stresses. Therefore, one came to the idea to use the AE for monitoring the process and control followed by change in drying parameters. This is just the main goal of the present studies.

Monitoring a drying process by making use of the AE method one can observe the mechanical behavior of the material (in our case pinewood samples) during drying and thus to draw some conclusion from these observations for the purpose of construction of optimized processes. To this aim a number of tests in different drying conditions were carried out, starting from the high drying rates, at which an intensive cracking of wood structure was observed, up to the very slow drying rates, at which no any crack occurred. Based on the conclusions drawn from those studies, an optimized process was programmed with controlled temperature of the drying medium. The rate of drying in that process was changed periodically, i.e. it was increased at that moment, when the intensity of AE was low, and decreased, when the number of AE signals and, in particular, their energy started to increase rapidly. In such a way the time of drying was shortened by no cracks on the dried samples occured.

EXPERIMENTAL PROGRAM

The experimental equipment applied in our studies enables direct measurement of drying parameters (temperature and humidity of the drying medium), loss of sample weight, and in particular the AE signals, among others such descriptors as: the number of AE signals, the energy of AE signals, the total number of AE signals, the total amount of AE energy emitted. Figure 1 presents the drying set-up, with the measuring set for AE.

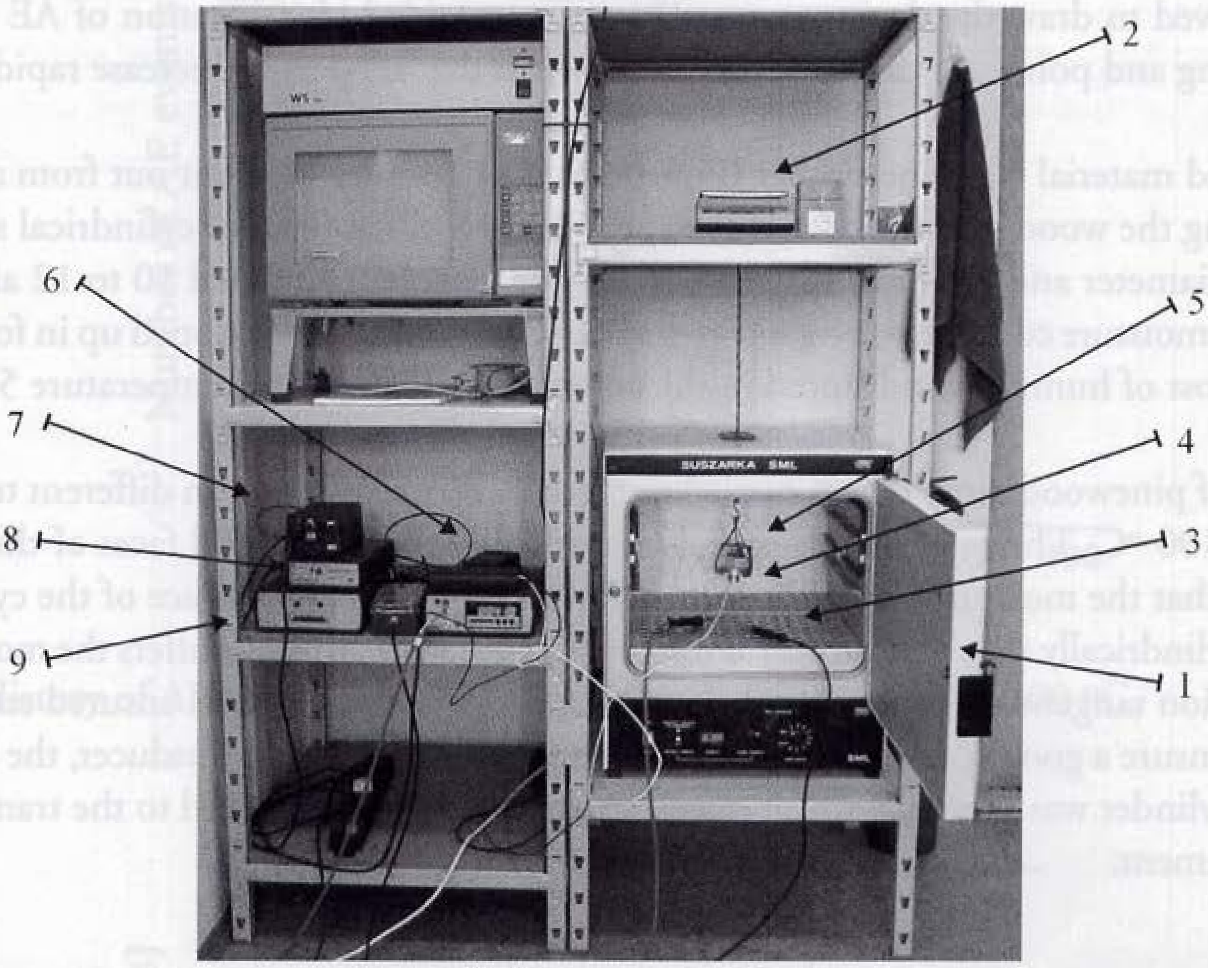

Figure 1: Measuring set for AE: : 1 - chamber drier; 2-balance;3-temperature and humidity sensors; 4-piezoelectric transducer;5-wood sample; 6-detector AE; 7-amplifier; 8-conversion of AE signals; 9-GPID card.

The acoustic emission (AE) method enables registration of sonic signals generated by fracture and microcracking of the structure in stressed materials. It provides unique advantages of early detection of crack growth and recognizing when the crack occurred. The piezoelectric transducer 4 can detect and a very sensitive receiver 6 can register, the acoustic signals transported by elastic waves released due to destruction of the material. The pine-wood sample 5, placed in the laboratory dryer 1 constituted the generator of acoustic signals during drying. The transducer transforms the acoustic signals into electric impulses. These impulses arrive to the preamplifier 7 that has the following function: pre-amplifying the impulses and filter them with respect to frequency ranges (linear band, lower and upper band), and finally convert the voltage impulses into the current ones. The next element is the logarithmic converter 8 integrated with the pre-amplifier, which converts the current impulses of the transmission line into the variable voltage proportionally to the magnitude of a impulse, and next detects and enhances unipolar output signals. It is the peak detection of the envelope type from the absolute value of both the signal amplified logarithmically and that of the impulse type from maximal amplitude and the length corresponding to the time of signal duration. Both signals, the envelope (logarithmic) type and the impulse type, can be observed during the process on the oscilloscope HP 54603B.

All incoming data were possible to analyze on-line and store in the computer memory. The computer by way of a software compatible with the canvassing card GPIB 9 registered the acoustic signals and the remaining data, as the laboratory balance 2, temperature and humidity sensors 3 were also connected to the computer via GPIB card.

The pinewood sample 5 and the piezoelectric transducer 4 were suspended to the balance and weighted in prescribed time periods with accuracy up to 0.01 g. The loss of sample weight registered in time allowed to draw the drying curve. This curve enabled identification of AE intensity in time of drying and point out those moments, at which the AE start to increase rapidly.

The tested material was pine timber (Pinus sp.). The samples were cut out from a cylindrical timber having the wood core in the middle, and prepared in the form of cylindrical samples of 5 to 6 cm in diameter and of 1.5 to 2.5 cm height. The samples contained 10 to 12 annual rings. Their initial moisture content was c.a. 60%. Before drying they were wrapped up in foil to protect against the lost of humidity and stored in the laboratory cooler in the temperature 5 ºC.

Drying of pinewood samples was carried out in the laboratory dryer in different temperatures from 80 to 100 ºC. The metal plates of the sample grip covered the end faces of the cylindrical samples, so that the moisture removal proceeded through the lateral surface of the cylinder only. Choose of cylindrically shaped samples followed from the fact that wood suffers the most shrinkage in the direction tangential to the annual rings, what by covered end faces ensured enhanced AE. In order to ensure a good contact of the sample with the piezoelectric transducer, the bottom end face of the cylinder was greased with silica gel, and the sample was pressed to the transducer with an elastic element.

EXPERIMENTAL STUDIES AND RESULTS

High drying rate tests

The first series of drying tests were carried out in convective laboratory chamber at temperature of 100 ºC and 4% humidity of the drying medium. Figure 2 presents the typical history of the drying medium temperature during these processes.

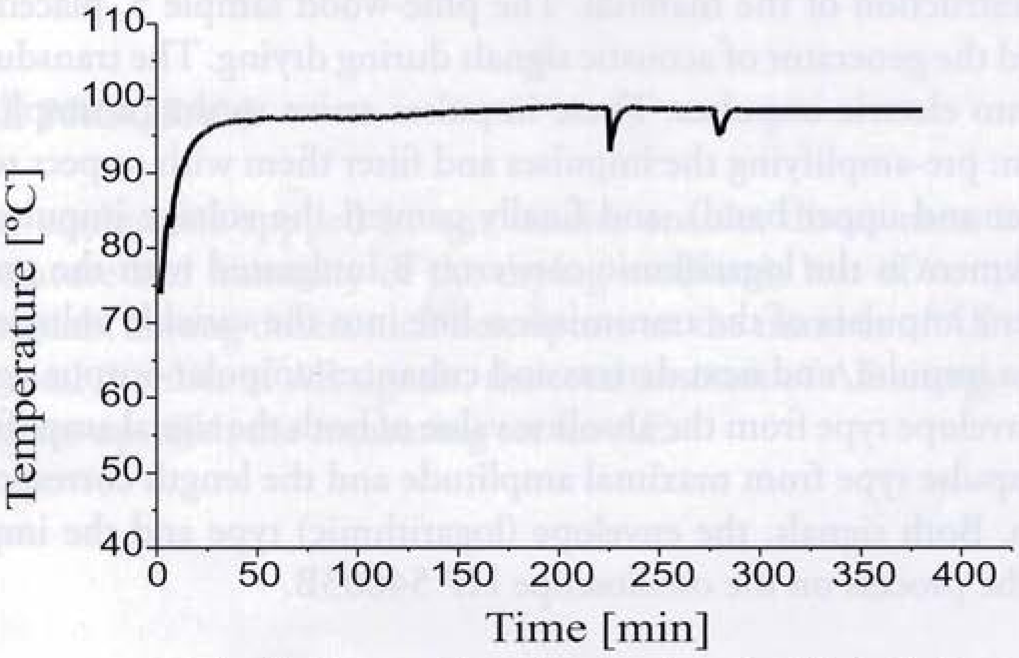

Figure 2: The temperature of the drying medium in the dryer by high drying rate.

The small drops of the temperature visible in the c.a. 230 and 270 minutes drying process are caused by open dryer door for short time. Figure 3 presents the history of AE events intensity, i.e. the number of acoustic signals per 30 s time intervals. Figure 4 presents the total energy emitted by the pinewood sample dried at 100 ºC.

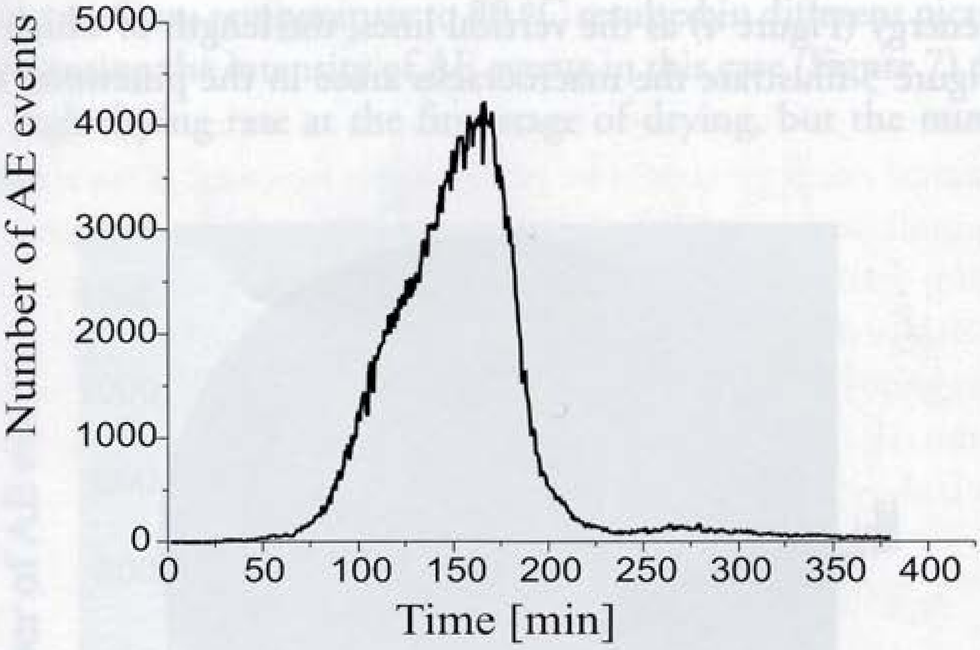

Figure 3: History of AE events intensity in pinewood samples dried at 100 °C.

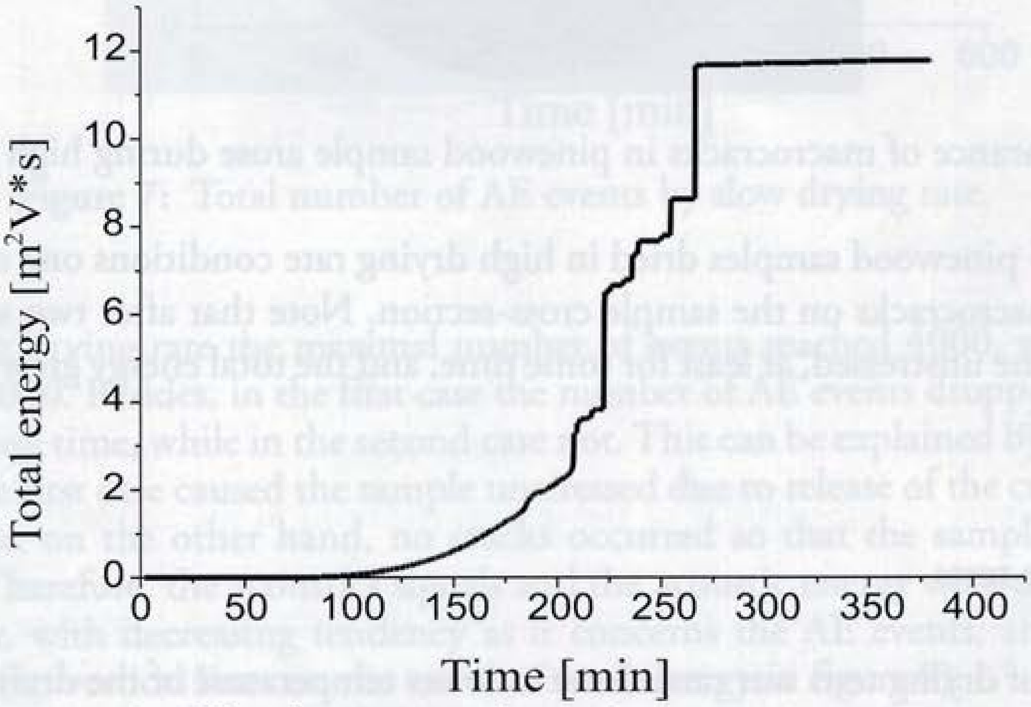

Figure 4: Total energy emitted by the pinewood sample during drying at 100 °C .

Analyzing the obtained results of AE on tested samples one can differentiate three stages, during which the picture of recorded acoustic emission changed in time, and thus also the mechanical state of the samples. At the initial stage of drying, i.e. when the free water evaporates from the wet surface, the number of AE events is small, even less visible in the figure 3 up to 50 min drying time. Next, as the drying proceeds further, the acoustic activity starts grow intensively, and after 2.5 hour of drying time the number of AE events reach maximal value. The reason for the constantly increasing number of AE events in this stage is the shrinkage of external surfaces of the samples. When wood dries, the drier surface attempts to shrink but is restrained by the wet core. The surface is stressed in tension and the core in compression. The non-uniform shrinkage of wood tissue generates the stresses that cause microcracks at the surface, which number grow more and more if drying advances, (see Kowalski, 2003). The energy of the first AE signals is insignificant up to 100 min drying time. Since that time the energy start to grow rapidly.

The tensional stresses in the external layer of the cylindrical samples, when they reach critical values (yield stress), create macrocracks that are visible even with a naked eye. The creation of macrocracks is accompanied by the release of big energy. The portions of this energy are visible on the curve of total energy (Figure 4) as the vertical lines, the length of which depends just on the energy released. Figure 5 illustrate the macrocracks arose in the pinewood samples during high drying rate.

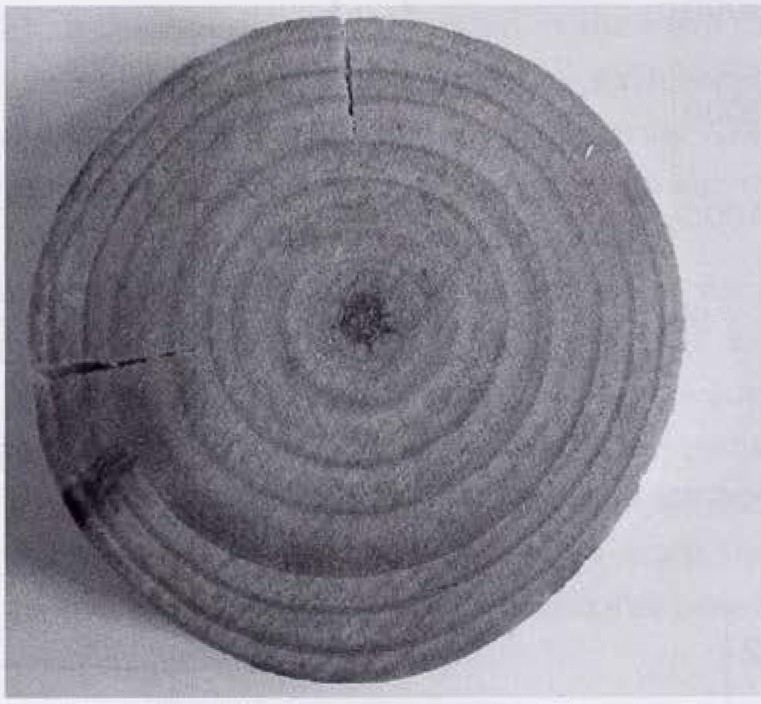

Figure 5: Appearance of macrocracks in pinewood sample arose during high drying rate.

In the series of 5 pinewood samples dried in high drying rate conditions one could observe from one to several macrocracks on the sample cross-section. Note that after two strong macrocracks the sample became unstressed, at least for some time, and the total energy grew no more since 290 min drying time.

Slow drying rate tests

The next series of drying tests was carried out at lower temperature of the drying medium, that is, at the temperature by which no any crack occurred in the dried sample. In our case it was c.a. 80 ºC, (Figure 6).

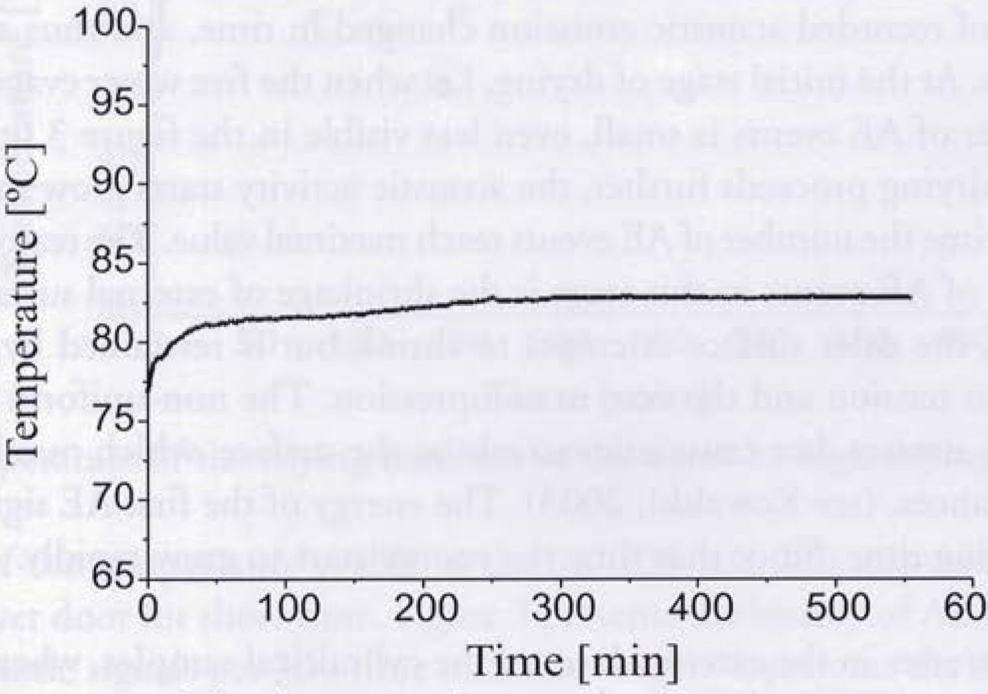

Figure 6: The temperature of the drying medium in the dryer by slow drying rate.

Lowering of the drying medium temperature to 80 °C resulted in different picture of the AE. The shape of the curve presenting the intensity of AE events in this case (Figure 7) differentiate not so much from that by high drying rate at the first stage of drying, but the number of AE events decreased significantly.

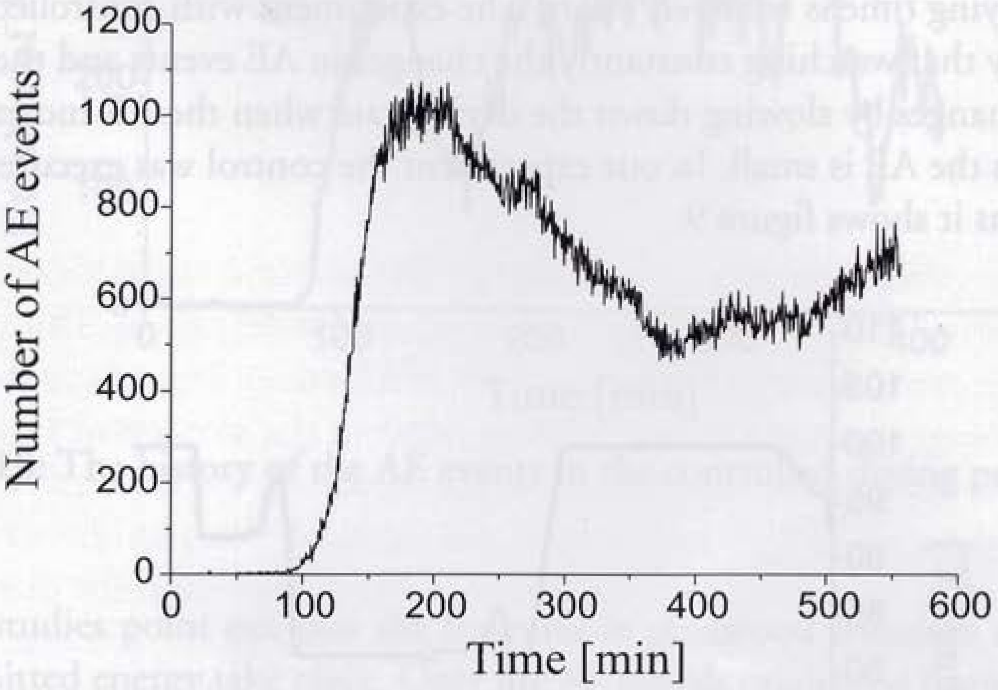

Figure 7: Total number of AE events by slow drying rate.

In the case of high drying rate the maximal number of events reached 4000, while by the slow drying rate only 1000. Besides, in the first case the number of AE events dropped almost to zero after 200 min drying time, while in the second case not. This can be explained by the fact that the macrocracks in the first case caused the sample unstressed due to release of the cumulated energy. In the second case, on the other hand, no cracks occurred so that the sample was constantly slightly stressed. Therefore, the acoustics signals and the acoustic energy were emitted further in this case, however, with decreasing tendency as it concerns the AE events, and without rapid growth in energy (no vertical lines on the curve of total energy in figure 8).

Cracking in material structure, when they occur, manifest themselves on the total energy curves through the rapid increase of this energy.

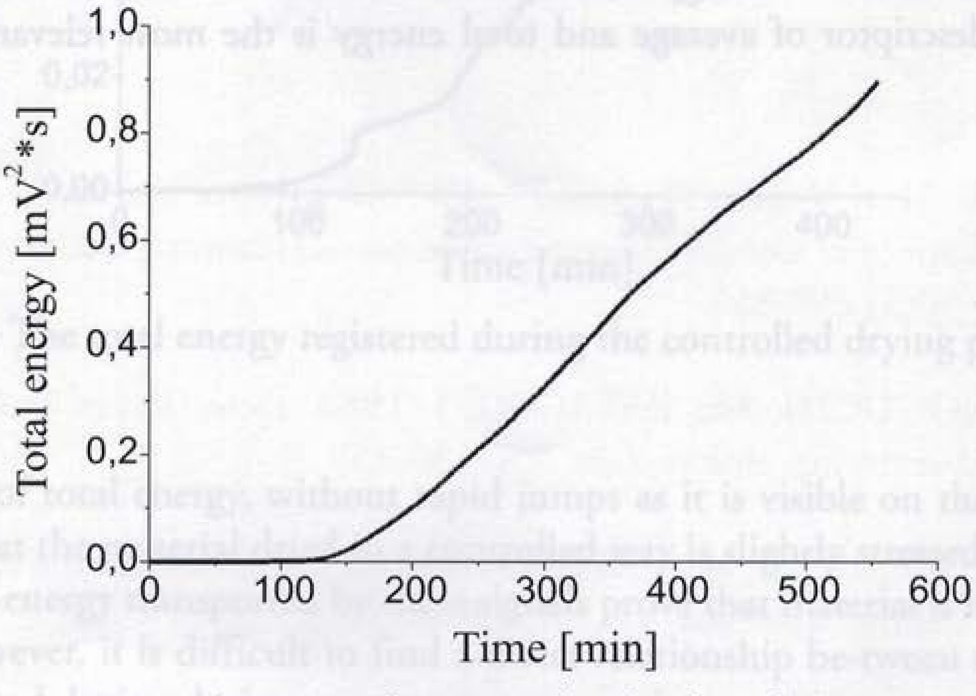

Figure 8: Total energy of AE impulses by slow drying rate.

Controlled drying process

The characteristic feature of the acoustic emission method is that it provides a possibility of early detection of subcritical crack growth. The conclusions followed from the tests described above supply arguments to draw a controlled drying process, by which no cracks in the dried material occur and the drying time is relatively short. The experiment with controlled process was carried out in such a way that watching constantly the changes in AE events and the emitted energy one reacts on their changes by slowing down the drying rate when the AE increases or accelerate the drying rate when the AE is small. In our experiment the control was executed through alteration of temperature, as it shows figure 9.

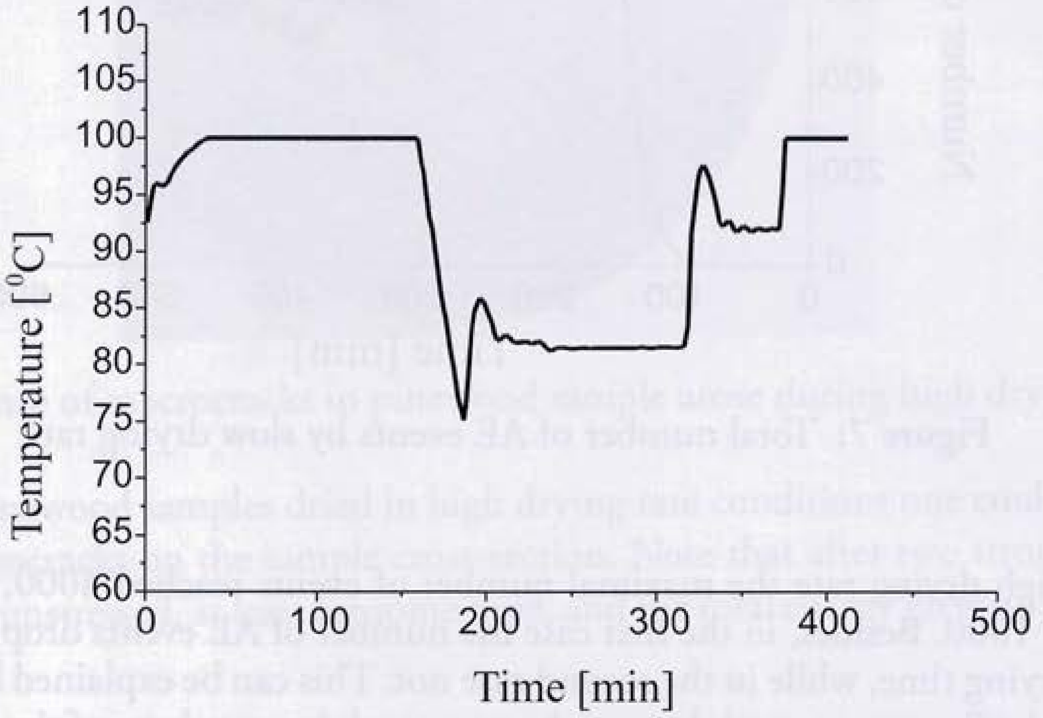

Figure 9: The history of temperature of the drying medium in the controlled drying process.

Recalling the former experiments carried out in high drying rates, i.e. in the temperatures of 100 ºC, one can state that the risk of cracking is not great at the initial period of drying. Based on this statement, the controlled process was begun at temperature of 100 ºC. The development of AE was observed constantly and at the moment when the energy of the acoustic signals began to increase, c.a. at 150 min drying time, the temperature of the drying medium was decreased. It is worth to noise that when the energy started to increase the number of AE events slowed down. It means that the descriptor of average and total energy is the most relevant for drying process control.

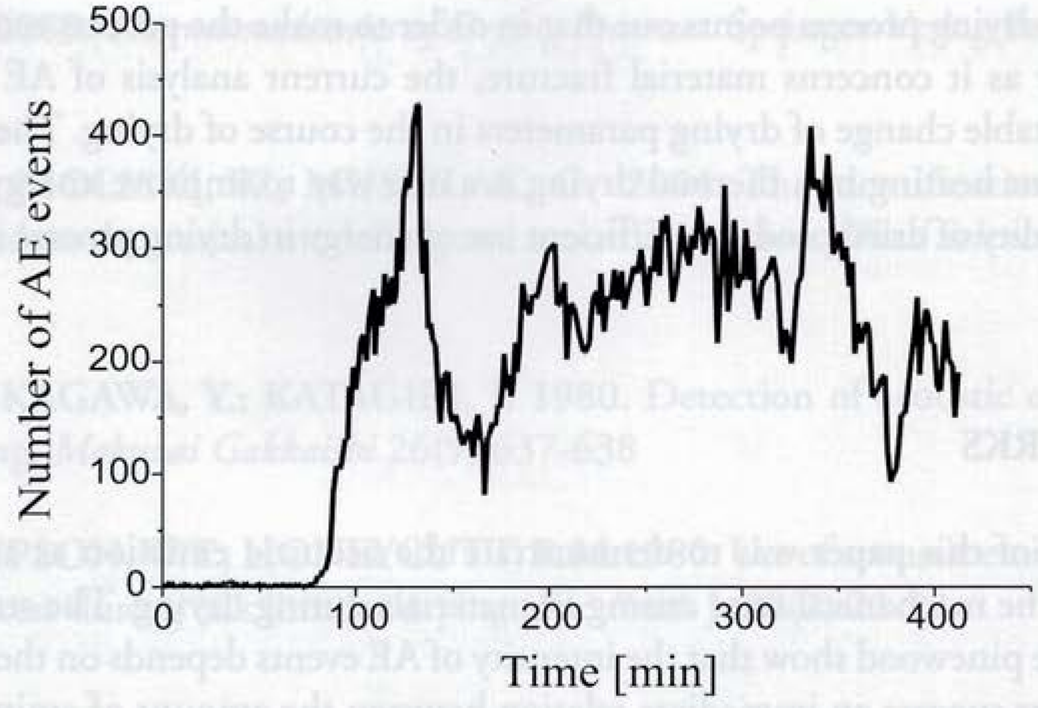

Figure 10: The history of the AE events in the controlled drying process

The results of our studies point out that the fractures in pinewood structure may arise when a rapid increase of emitted energy take place. Only the AE signals originated from crack growth are recognized as being high energetic. The current control of the emitted AE signals, and in particular of the average and total energy emitted during drying, suggested the suitable changes in drying medium temperature in order to assure a reasonable dynamics of drying in order to avoid fractures of the material. The gentle increase of total energy by controlled drying process, as it is seen in figure 11, gives evidence that during this process no any cracks occurred.

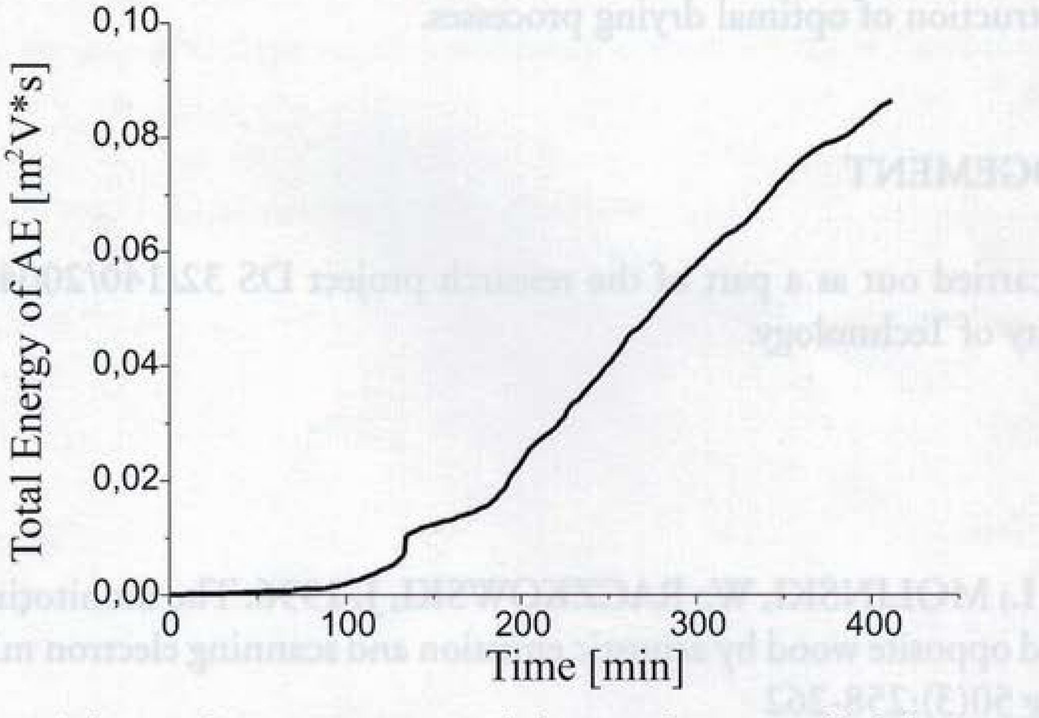

Figure 11: The total energy registered during the controlled drying process.

The gentle increase of total energy, without rapid jumps as it is visible on the energy curve in figure 4, bespeaks that the material dried in a controlled way is slightly stressed. The AE signals, and in particular the energy transported by these signals prove that material is longer time under a state of stress. However, it is difficult to find a direct relationship be-tween the magnitude of stresses and the emitted during drying energy.

The controlled drying process points out that in order to make the process economically efficient and save, as far as it concerns material fracture, the current analysis of AE signals have to be followed by suitable change of drying parameters in the course of drying. The controlled process with intermittent heating in a thermal drying is a one way to improve energy utilization and to enhance the quality of dried products. Efficient use of energy in drying process is of great economic benefit.

FINAL REMARKS

The main goal of this paper was to demonstrate the acoustic emission as a method useful for monitoring of the mechanical state arising in materials during drying. The studies carried out in this work on the pinewood show that the intensity of AE events depends on the drying conditions. The experiments suggest an immediate relation between the amount of emitted energy (less the number of AE events) and the destruction of the material. By convective drying, particularly when the drying proceeds in high temperature and small relative humidity of the drying medium, the thermodiffusional flux of moisture blockades the outflow of moisture due to diffusion, mainly at the boundary, and this causes strongly non-uniform distribution of the moisture content, what results in generation of stresses. The stresses are responsible for fracture of the dried material. In order to foreseen the fracture one ought to observe the number of AE events and, in particular, the amount of emitted energy. Making use of the AE method, we can control drying process and choose the drying conditions in such a way in order the drying induced stresses were possible small. In this paper the control was realized through changes in temperature program. When the weaker stresses are generated during drying a better quality dry product from the mechanical standpoint is obtained. Thus, the acoustic emission method may be proposed as a very useful method by construction of optimal drying processes.

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