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ACOUSTIC EMISSION IN WOOD UNDER DRYING

Stefan Jan Kowalski, Anna Smoczkiewicz

Institute of Technology and Chemical Engineering,
Poznań University of Technology

SYNOPSIS. The analysis of sensitiveness to cracking of various sorts of wood by drying is the subject of this paper. The development of micro- and macrocracks in oak, pine, and birch samples generated due to shrinkage and the drying induced stresses is analyzed with the help of acoustic emission (AE). The plots of the AE signals and the AE energy recorded *on line* during drying from these sorts of wood indicate a differentiated tendency of them to shrinking and cracking. The results of this analysis may help the researchers and engineers dealing with wood to more profound understanding of the phenomenon of wood behavior by drying.

KEY WORDS: drying, oak, pine, birch, acoustic emission, development of cracks

INTRODUCTION

Drying of wood is one of the fundamental technological processes in wood industry. A proper realization of this process is necessary to obtain a good quality product (Glijer et al. 1984). Because of high costs of drying the technologists are forced to look for new methods of drying or for improving the old ones in order to minimize the drying time and the energy consumption, and, in particular, to project processes not causing destruction of timber during its drying.

The main goal of this paper is to present the results of the studies concerning wood destruction during drying, where the acoustic emission (AE) method was used for detection of this phenomenon. Particular effort is devoted to proper interpretation of the characteristic groups of the AE events that may occur in various sorts of wood. We want to present the acoustic emission (AE) as the method that could be useful in projection of save drying processes. Namely, it enables identification of material destruction *on line* and thus gives a basis to controll drying process in order to avoid destruction of timber under drying (Kowalski et al. 2004, Moliński et al. 1994, Moliński 1998).

In our studies, a great number of AE signals was recorded during the first period of drying, however, these signals were of low energy and therefore they were insignificant from the destruction point of view. These signals originated from such effects as thermal deformations, friction between fibers, or movement of moisture, and not from wood structure cracking.

The second group of AE signals appeared at the moment when the moisture content neared and passed below the fiber saturation point (FSP). From that moment wood started to shrink, first at the surface layer and next the shrinkage zone displaced inwards. The drier surface attempted to shrink but was restrained by the wet core, so the surface was stressed in tension and the core in compression. The emitted in this period AE signals were less numerous but of high energy. In some cases, large inelastic strains occurred at the surface layer causing a reduction of the surface shrinkage.

In the case of a surface with reduced shrinkage, it can happen that when the wet core start to dry and the shrinkage is restrained by the former deformed surface, the stress state becomes reversed, that is, the surface becomes stressed in compression and the core in tension. In such circumstances, the third group of AE events appears in the AE diagrams, which is supposedly generated by the tensional stresses in the core.

Three sorts of wood were tested in our studies: oak, pine and birch. The wood cylindrical samples of different diameter were cut out from a green timber. The choice of the cylindrically shaped samples followed from the fact that wood suffers the most shrinkage in the tangential direction to the annual rings, and this ensured enhanced acoustic emission in our studies, particularly, when the end-faces of the cylindrical sample were protected against moisture removal.

THE ACOUSTIC EMISSION GENERATED DURING DRYING OF VARIOUS SORTS OF WOOD

The drying tests were carried out on the laboratory chamber dryer provided with the measuring set for acoustic emission, as it is presented in Figure 1. The experimental equipment used in our studies enables direct and continuous measurement of drying parameters as the temperature and the humidity of drying air. The wood samples were dried convectively in the temperature of 100°C and 4 percent humidity of the drying medium.

The continuous measurement of sample weight during drying allowed plotting the curve of drying illustrating the kinetic of drying. The piezoelectric transducer that recorded the AE signals and transformed them into electric impulses was fastened directly to the metal plate (acoustic wave-guide) on which the dried sample was supported. In order to ensure the proper contact of the sample with the wave-guide, and thus also with the transducer, the sample planes were smoothened with the abrasive paper and covered with the silica grease. The AE signals transformed into the electric impulses were suitably processed. The processing required several electronic components like transducer, filters, amplifiers, cables and the counting

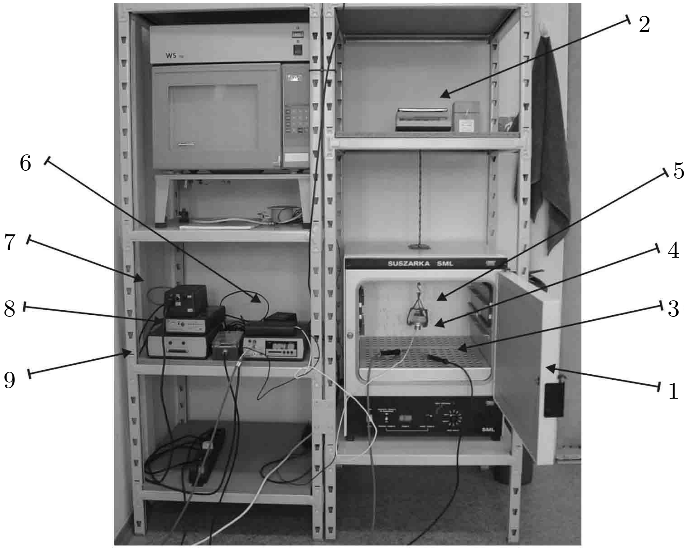

Fig. 1. Measuring set up for acoustic emission (AE): 1 – chamber drier, 2 – balance, 3 – temperature and humidity sensors, 4 – piezoelectric transducer, 5 – wood sample, 6 – AE detector, 7 – amplifier, 8 – conversion of AE signals, 9 – GPID card
Rys. 1. Stanowisko badawcze emisji akustycznej: 1 – komora suszarnicza, 2 – waga, 3 – czujniki temperatury i wilgotności względnej, 4 – przetwornik piezoelektryczny, 5 – próbka drewna, 6 – detektor emisji akustycznej, 7 – wzmacniacz, 8 – konwersja sygnałów emisji akustycznej, 9 – karta GPID

instrumentation, computer and suitable software. The AE equipment enabled not only the record of the AE signals, but also the analysis of the signal shape, the distribution of signals, and their characteristics.

Figure 2 presents the special grip with an elastic element assuring a suitable pressing of the sample to the metal plate. One end face of the cylindrical sample was supported on the metal plate that played the role of wave-guide, and the other was covered with another metal plate that protected the sample against the moisture removal through that end faces. Thus, the moisture removal proceeded through the lateral surface of the cylinder only.

To prove whether the measuring set records unnecessary noise coming from

Fig. 2. Wood sample in the grip with the pressing elastic element
Rys. 2. Próbka drewna w zacisku z elastycznym elementem dociskowym

the surroundings, some additional tests were curried out to measure eventual intensity of this noise. Fortunately, these additional tests confirmed that not extra noise and no unnecessary signals came from the surroundings or the measurement equipment alone.

The destruction by drying of three kinds of wood was studied, namely: oak, pine and birch. The wood samples were cut out from the green and cylindrically shaped timber. In order to protect them against the loss of humidity in the time between the cutting out and their drying, they were wrapped up in foil and stored in a laboratory cooler at the temperature of 5°C. Directly before drying the samples were weighed. Each drying test was carried out in the temperature of 100°C. The end of each drying test was decided when the mass of the wood sample did not change any more. After drying the samples were weighed again for the purpose of estimation of the initial moisture content. The moisture content is defined here as the ratio total moisture loss to the weight of dry sample, i.e. the difference between the weights of the sample before and after drying related to the weight of dry sample.

The removal of "free water" did not cause any change of sample dimensions (no shrinkage occured). It is known that shrinkage begins when the moisture content in wood reaches the fiber saturation point (FSP). The majority of destruction of wood, confirmed in our tests by the high energetic AE signals, started at that time when the surface started to shrink intensively while the moisture content in the core was still above the FSP. Our test confirmed the well-known items that the unitary shrinkage is the highest in tangential direction and the smallest along fibers. The scale of shrinkage is different for early and late wood. Therefore, the way of cuting out of samples from a trunk has an essential influence on the course of drying. Structural defects and knots that usually exist in wood make difficulties to carry out measurements on the so-called twin samples.

RESULTS AND DISCUSSION

Oak: The cylindrical samples of 4.5 cm in diameter and 1.5 cm in height were cut out from the middle part of green timber. Their geometrical form was excellent at once so they did not need any extra corrections. The bottom end face of each sample was covered with silica grease and weighed. Such a prepared sample was put into the laboratory drier being formerly heated up to the temperature of 100°C. The initial moisture content of oak samples was ca. 50%. Due to the relatively low initial moisture content in oak samples the duration of the drying tests took a comparatively short time.

Acoustic emission was recorded continuously from the beginning of drying. The obtained AE diagrams, Figures 1-3, characterize the behaviour of the oak wood under drying.

At the beginning of drying process the oak sample had the greatest acoustic activity as it is presented in Figure 3, however, the recorded during the first 50 min AE signals were low energetic (see Fig. 4 and 5). Else later, when the moisture

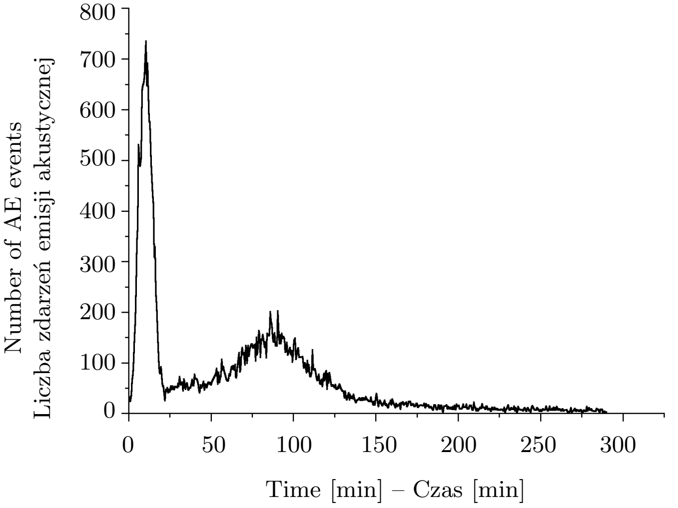

Fig. 3. Exemplary plot of AE signals emitted during drying of oak samples
Rys. 3. Przykładowy wykres sygnałów emisji akustycznej wyemitowanych przez próbki drewna dębowego w czasie suszenia

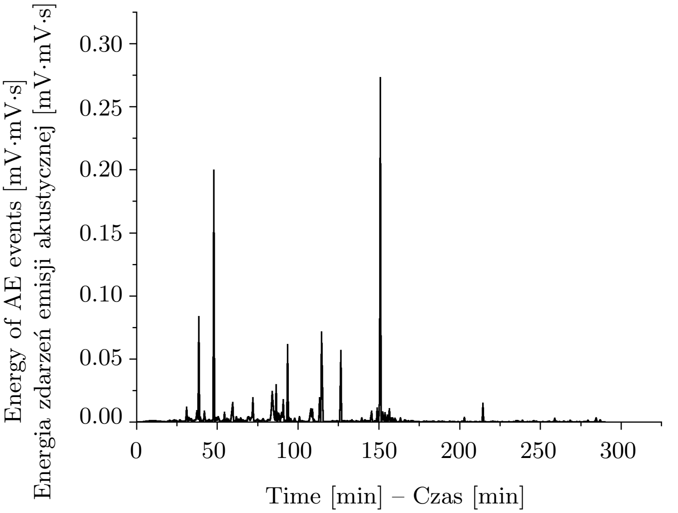

Fig. 4. Energy of AE signals generated in oak sample during drying
Rys. 4. Energia sygnałów emisji akustycznej powstających w próbce drewna dębowego w czasie suszenia

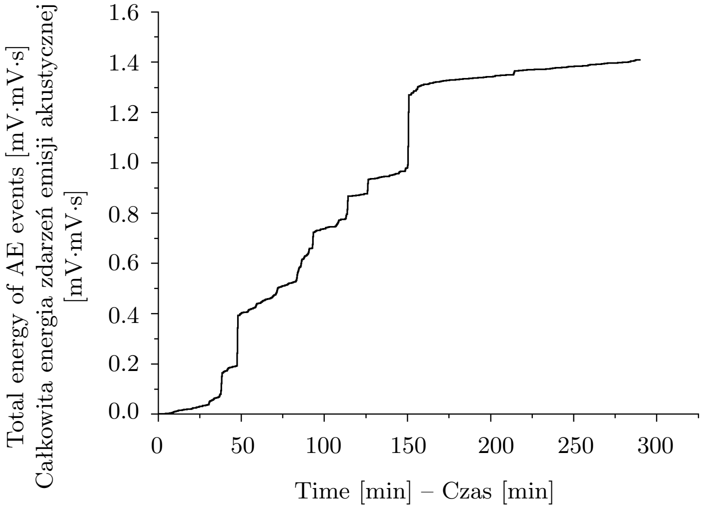

Fig. 5. Total energy of AE signals emitted by oak wood sample during drying
Rys. 5. Całkowita energia sygnałów emisji akustycznej wyemitowanych przez próbkę drewna dębowego w czasie suszenia

content at the sample surface falls below the FSP, the surface starts to shrink and the highly energetic AE signals are recorded. The wet core of the sample being still moistened above FSP restrains the free shrinkage of the surface layer. The surface is stressed in tension and the core in compression.

Fig. 6. Appearance of macrocracks in oak sample arisen after the stress reverse
Rys. 6. Pojawienie się makropęknięć w próbce drewna dębowego po zmianie znaku naprężeń

During further drying, the core dries and starts to shrink but its shrinkage is also restrained but this time by the previously permanently deformed surface. This causes the stress state to reverse, that is, the previously tensional stresses at the surface and compressional in the core change their sign after stress reverse.

The tensional stresses in the core after the stress reverse are responsible for the large cracks formation in the core of the sample. This effect is visible in Figure 6 presenting the picture of the sample cross section at the final stage of drying.

Pine: The samples of pinewood, similarly as those of oak, were cut out from green wood having the wood core in the middle. The samples had cylindrical form of 5 to 6 cm in diameter and 2.5 cm in height. To assure a good contact of the sample with wave-guide and the piezoelectric transducer the bottom end face of the cylindrical sample was smoothened with the abrasive paper and covered with the silica grease. The woody bark was removed from the lateral surface of the cylinder to make easier the drying process. The sample was pressed to the wave-guide plate with the elastic element. The initial moisture content of the sample was ca. 120%, that is far above FSP. The pinewood sample was dried at the temperature of 100°C for 7 hours.

Analyzing the obtained plot of AE signals for pinewood one can differentiate three periods of AE signal variation. At the beginning of drying, when the free water evaporates from the wet surfaces, the number of AE signals is very small. Next, as the drying proceeds further, the acoustic activity starts to grow, Figure 7. The reason for such a considerable increase of AE signals in that period of drying is the intensive shrinkage of sample surfaces. The external surface of the sample, and in particular decorticated one, dries very quick while the wet core not. The very high drying rate causes a great number of small microcracks, the maximum of which takes place ca. in the third hour of drying (see Fig. 7). Both the first and the second group of AE signals is of small energy, as it is seen in Figure 8.

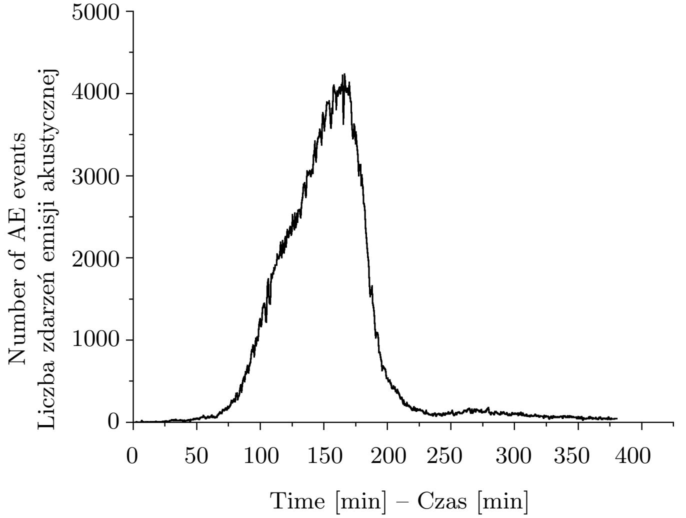

Fig. 7. Exemplary plot of AE signals emitted during drying of the pinewood samples
Rys. 7. Przykładowy wykres sygnałów emisji akustycznej wyemitowanych przez próbki drewna sosnowego w czasie suszenia

After nearly 3 hours of drying, the number of AE signals decreases significantly, but the signals emitted after this period are of high energy. In this period, the highly non-uniform distribution of the moisture takes place and this is the reason for generation of shrinkage stresses, which causes cracks of wood tissue at the surfaces. Each crack releases the elastic energy stored in the material, therefore the number of signals decreases. The signals appear seldom but are highly energetic, which is illustrated in Figures 8 and 9.

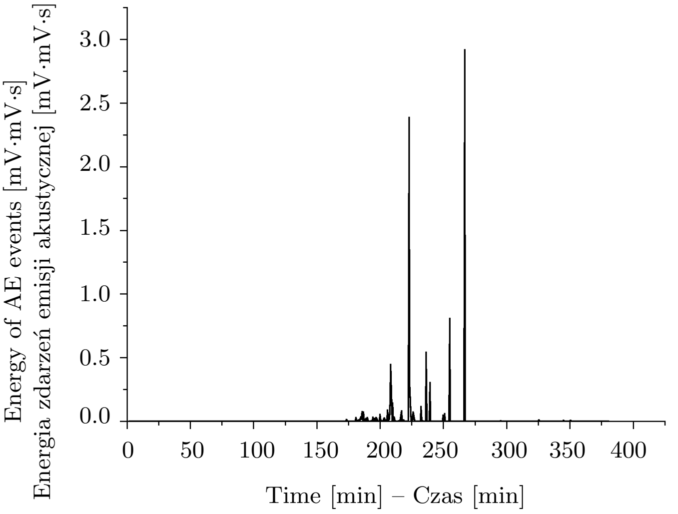

Fig. 8. Energy of AE events generated by pine during drying
Rys. 8. Energia zdarzeń emisji akustycznej powstającej w drewnie sosnowym w czasie suszenia

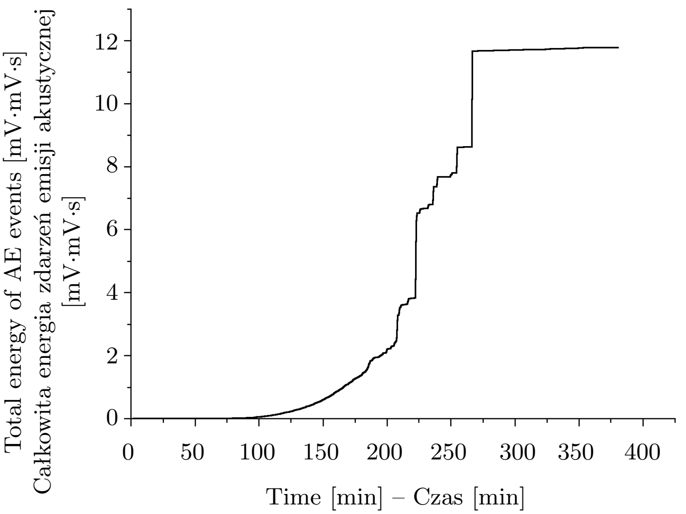

Fig. 9. Total energy emitted by pinewood sample during drying process
Rys. 9. Całkowita energia wyemitowana przez próbkę drewna sosnowego w czasie procesu suszenia

The rapid increase of total energy presented in Figure 9 (the vertical line) denotes macrocracks, usually visible with a necked eye. The sudden growth of total energy seen in Figure 9 is a result of arising of two large macrocracks perpendicular to the annual rings as it illustrates Figure 10.

Fig. 10. Appearance of macrocracks in pinewood sample arisen during drying

Rys. 10. Pojawienie się makropęknięć w próbce drewna sosnowego powstających w czasie suszenia

It is important to underline that the pine samples were chosen and prepared fairly well to avoid all existing defects in timber structure. In reality the pine timber contains a number of knots and local deformations in fiber structure, which violates the homogeneity of the wood structure. The knots shrink faster than the surrounding wood because the shrinkage is greater in tangential direction of the knots rings than along wood fibers. Therefore, they may fall out during industrial drying of pine timber. Interdependence between defects in wood structure and activity of AE must be handled as a distinct problem and will not be considered in the present discussion.

Birch: The samples of birch wood have the same diameter and height like presented earlier samples of pinewood. Also the way of sample preparation was very similar. But in the case of birch, the shape of samples was slightly irregular because the wood core was shifted a little with respect to the center of cylinder. The moisture content of the samples before drying was between 60 and 90 percent. After removal of woody bark the sample was smoothened with the abrasive paper.

The plots obtained from the drying tests of birch samples present a different quality behaviour of birch than those of oak and pinewood (see Fig. 11). The difference can be explained by the fact that birch is more elastic than oak or even pinewood. It is visible from this plot that birch emitted AE signal during the whole process of drying. Contrary to the pinewood, the birch sample generates a great number of signals during the first period of drying. These signals are of low energy, similarly as it was in the case of oak and pinewood.

The first maximum of AE signals that is visible in Figure 11 comes as usual from the thermal expansion, displacements in birch structure, migration of moisture, etc. The second group of signals appears when the moisture content falls below FSP. At that time the external layer begins to shrink and the tensile stresses are developed. AE signals of the second group are less numerous but higher energetically. However, the total energy (see Fig. 12) increases relatively smoothly. There are no such rapid jumps of total energy as it was shown in the plot for pinewood.

The cracks observed in the sample cross section (see Fig. 13) were rather small, perpendicular to the annual rings, and situated not on the external surface of the sample but nearer the core of birch. The internal cracks can be explained by the effect of stress reverse, similarly to the sample of oak. However, in the case of birch this effect is much smaller because birch is more elastic than oak.

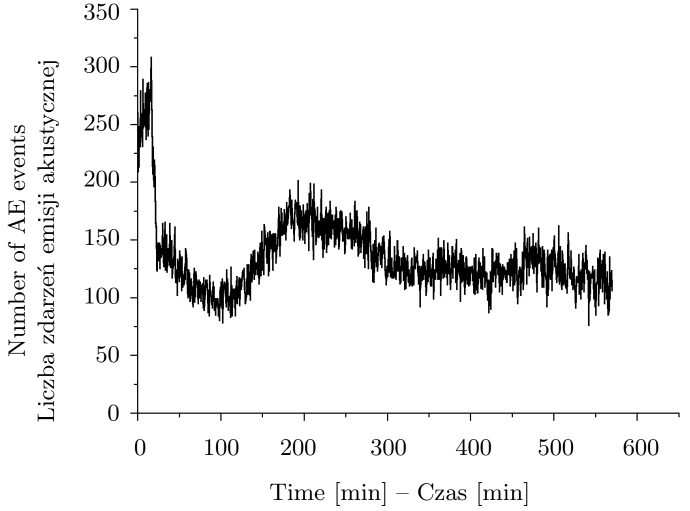

Fig. 11. Exemplary plot of AE signals emitted during drying of the birch samples
Rys. 11. Przykładowy wykres sygnałów emisji akustycznej wyemitowanych w czasie suszenia próbek brzozowych

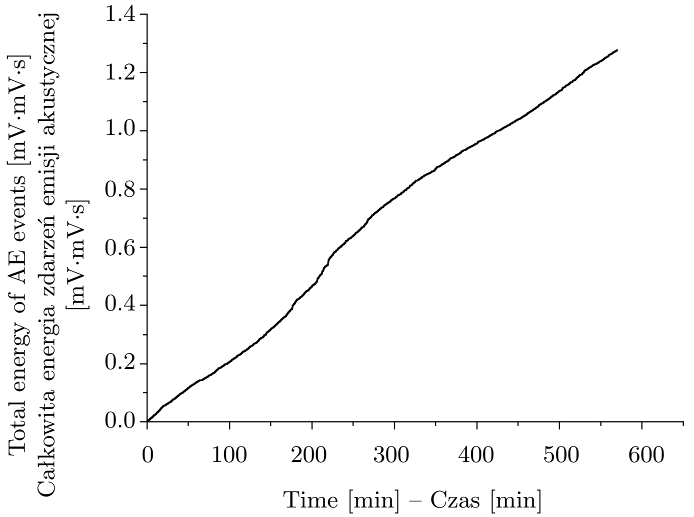

Fig. 12. Total energy emitted by birch sample during drying process
Rys. 12. Całkowita energia wyemitowana przez próbkę drewna brzozowego w czasie suszenia

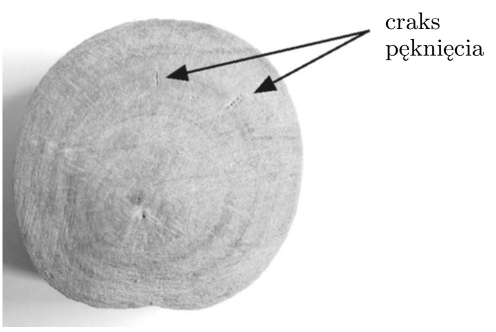

Fig. 13. Appearance of macrocracks in birch sample arising during drying
Rys. 13. Pojawienie się makropęknięć w próbce drewna brzozowego powstających w czasie suszenia

The existence of great number of AE signals in the later stage of drying can be explained also by the stress reverse effect. The energy of these signals is evidently greater than the energy of the signals evidenced at the beginning of drying but smaller than energy of the signals emitted in between.

CONCLUSIONS

The results of the experimental investigation show that each sorts of wood manifest different preservation to drying, which is evidenced due to the acoustic emission analysis. The wood of oak and birch emitted the greatest number of AE signals at the beginning of drying, later the number of signals fell down reaching twice much lower level for longer time, and finally dropped to zero. In the case of pinewood, on the other hand, the acoustic activity gradually grew reaching maximum at the time when the moisture content reached FSP, and next began to fall down.

Each sort of wood has a different history of AE events. Particularly, the number and the energy of AE signals differentiate significantly for the studied sorts of wood. However, a comparison of the AE results for the three different sorts of wood that were analyzed in this paper and drawing some general conclusions from these studies that could be pertinent for all sorts of wood is a very difficult task. For example, the differences between the young and older layers of annual rings and defects of wood structure involve different stress intensities. These factors are particularly important for pinewood that characterizes with many and clearly visible annual rings. Therefore the pine samples had the biggest AE activity and the greatest total energy jumps during drying. Conversely, the samples of birch, which is characterized by rather uniform structure, manifested relatively low AE activity. We can state, however, a good repeatability of results obtained with the help of AE method within the same kind of wood.

The effect of shrinkage depends at most on the wood tissue. Quite small differences in shrinking of neighbouring layers of wood (e.g. young and older layers of annual rings) may generate great stresses that can reach critical values in some places. In such circumstances the crack formation may develop, particularly in those regions, where the maximal tensional stresses occur. The size and kind of cracks depends on the sort of wood, dimension, and place, from which the sample was gained.

Finally, one can state that the acoustic emission method can be applied successfully for monitoring and controlling of the development of wood destruction during drying. The record of total number of AE events and their energy aids the control of drying by changing drying parameters in order to avoid destruction of the material (see e.g. Honeycult et al. 1985, Kitayama et al. 1985). In order to establish the influence on AE of such factors as the kind and age of wood, presence of natural structural defects, also the shape and dimension of dried sample, additional studies ought to be carried out.

Acknowledgement

This work was carried out as a part of research project DS 32/112/2003 sponsored by the Poznań University of Technology.

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EMISJA AKUSTYCZNA W SUSZONYM DREWNIE

Streszczenie

Celem pracy jest ocena wrażliwości na pękanie różnych rodzajów drewna w procesie suszenia. Analizowany jest rozwój mikro i makropęknięć drewna dębu, sosny i brzozy spowodowany nadmiernym skurczem suszarniczym – za pomocą metody emisji akustycznej (EA). Przedstawione wykresy ilości sygnałów EA i wyemitowanej w trakcie suszenia energii EA wyraźnie wskazują na zróżnicowaną tendencję skurczową i destrukcyjną różnych rodzajów drewna przy ich suszeniu. Przedstawione w pracy wyniki badań pozwalają lepiej poznać problem destrukcji materiałów suszonych i metodę emisji akustycznej, która analizę tego zjawiska umożliwia.

Received in October 2003

Authors' address:
Prof. dr hab. inż. Stefan Jan Kowalski
Mgr inż. Anna Smoczkiewicz
Poznań University of Technology
Institute of Technology and Chemical Engineering
Pl. M. Skłodowskiej-Curie 2
60-965 Poznań
Poland
tel. (061) 6653698