Acoustic emission generated from wood-polypropylene composites

CEZARY GOZDECKI, ARNOLD WILCZYŃSKI

Institute of Technology, Kazimierz Wielki University in Bydgoszcz

Abstract: Acoustic emission generated from wood-polypropylene composites. The objective of the study was to assess the effect of wood particle size on the characteristic of acoustic emission generated from wood-polypropylene composites and on their tensile strength. The maximum event count, total event count, percentage of maximum force at the time of acoustic emission initiation and tensile strength were determined. It was found out that the filling of polypropylene with larger wood particles significantly increases the maximum event count, total event count and tensile strength, and decreases the percentage of maximum force.

Keywords: wood-plastic composite (WPC), wood flour, wood particles, acoustic emission (AE), tensile strength

INTRODUCTION

The wood-plastic composites (WPCs) have recently been increasingly applied in those cases in which so far solid wood has been used. Strong interest in WPCs causes that newer and newer the methods of research into them are being sought. One of the most interesting methods of assessing changes occurring in materials due to their loading is a method of acoustic emission (AE). These changes can occur both in wood and in the polymer matrix of WPCs. Studies on the analysis of AE generated from wood during its cracking were conducted by Moliński (1998). He showed that the local destruction of wood in places of stress concentrations causes the increased activity of AE. However, whether such a local failure will result in the destruction of the entire constructional node or only in the relaxation of internal stresses depends on the mechanical properties of the material as well as the value of the load. Reiterer et al. (2000) showed that the process of AE propagation is affected by wood density, and that AE signals are more generated from softwood than hardwood.

An important application of AE is to control some of the manufacturing processes of wood products such as a mechanical sorting of timber (Dzbeński 1984, Knuffel 1988, Sato et al. 1990), wood drying (Kitayama et al. 1985, Honeycutt et al. 1985, Noguchi et al. 1987), and detection of defects brought about by the increased generation of AE caused by stress concentrations in the places of discontinuity in the laminated wood materials such as plywood and LVL (Yoshimura et al. 1987, Ishibashi et al. 1990, Ritschel et al. 2013, 2014).

This method has also been proved to be useful in monitoring and controlling the parameters of woodworking (Sadanari 1991; Cyra 1997) and evaluation of the effort of adhesive joints (Gozdecki and Smardzewski 2005, Ni and Pizzo 2012). It is also possible to use AE to study particleboard. Niemz and Hansel (1988) found out that the wood particle geometry, particleboard density and resin content affected the activity of AE. Niemz et al. (2009) showed that it is possible to predict the cracks of OSB, MDF and plywood by using AE signals.

AE was also used in the studies of composites. Haselbach and Lauke (2003) studied the AE during the separation of glass fiber from the polymer matrix. They observed that AE signals can be generated from the breaking of fibres and cracks in the matrix and the interfacial debonding. Dányádi et al. (2007) used AE in the study of WPC properties. Tensile properties were determined and micromechanical deformation processes were traced by AE as...
well as volume strain was measured. Renne et al. (2009) studied the deformation and destruction processes of WPC containing PP and small wood particles. They noticed that the performance of AE signals depends among others on the degree of filling, the filler particle size and arrangement of the particles.

Although it was established (Gozdecki et al. 2011, Gozdecki et al. 2012) that the coarse wood particles used in producing a core layer of particleboard can be employed for filling a polypropylene matrix, and that WPCs with coarse wood particles show good mechanical properties, so far there is no studies on the characteristics of AE generated from WPC with coarse industrial wood particles.

To assess the suitability of products of WPC for specific applications it is very important to understand the processes occurring during the destruction of loaded composites. Because the AE method allows to record and analyze these processes, it was decided to conduct studies to assess the effect of wood particle size on the characteristic of AE generated from wood-polypropylene composites. Additionally, the study was also aimed at evaluating the effect of wood particle size on the tensile strength of composites.

MATERIALS AND METHODS

Investigations were carried out into the composites made of polypropylene (PP) homopolymer Moplen HP 648T obtained from Basell Orlen Poliolefin (density 900 kg/m³) and three types of wood particles (WPs): (1) wood flour (WF) C120 (mesh 170-100), produced by J. Rettenmaier & Söhne GmbH+Co (Germany), (2) fine industrial soft WPs (mesh 35-18) used for manufacturing the face layer of three-layer particleboards, marked as F1 and (3) coarse industrial soft WPs (mesh18-10) used for manufacturing the core layer of three-layer particleboards, marked as F2. The industrial WPs were supplied by Kronospan Szczecinek (Poland). Both WF and WPs are presented in Fig. 1.

The industrial WPs were screened by an analytical sieve shaker LAB-11-200/UP using the calibrated sieves of 10, 18 and 35 mesh. After screening the WPs as well as WF were dried in a laboratory oven at 105°C for 24 h to achieve a moisture content of less than 3%. Next PP and wood component were mixed in a ratio of 60/40%. Test specimens were made by injection moulding using a screw injection moulding machine Wh-80 Ap, employing the standard temperature program for WPC. The specimens had a shape according to EN ISO 527 but their cross-section (6×15 mm²) and length (230 mm) were larger. After processing, specimens were stored under controlled conditions (50% relative humidity and 20°C) for 2 weeks prior to testing. In this way tree kinds of WPC were obtained: PP with WF (PP/WF), PP with WPs F1 (PP/F1), and PP with WPs F2 (PP/F2). Ten specimens were produced for each kind of WPC.

In order to determine acoustic signals from the WPCs an AE analyzer EA SYSTEM (sampled at a frequency of 44.1 kHz), an analog-digital card Adlink 9112, and a 200 kHz
piezoelectric-type contact transducer were used. In term loads (tensile test) were applied using the Instron 5966 testing machine and registered using a computer program. The traveling of the movable cross-bar was 0.5 mm/min. The load was applied until the specimen was damaged, while the force and AE registration continued for the entire duration of the experiment. The following parameters were determined: event count of AE, maximum generated AE impulse, the percentage of force during AE initiation, the percentage of force during specimen destruction, and tensile strength. The obtained data were statistically analyzed using the Statistica version 10.

RESULTS

The representative charts of the AE event count in time function for the PP/WF, PP/F1 and PP/F2 composites are shown in Fig. 2a, 2b and 2c, respectively.

In the process of WPC loading, three developmental phases of its destruction can be observed (Fig. 2). They can be traced on the basis of courses of acoustic signals and values of forces as follows: AE initiation, next increasing AE intensity if a further increase of forces can be halted at this stage, development of further defects is also arrested, and next sudden defect propagation and, consequently, material destruction confirmed by a rapid increase in AE signals. These characteristics can be observed during the load of all three tested types of WPC, but they occur with different intensity. When comparing the characteristics of the AE event count in time function (Fig. 2) one can see that with increasing WP size, the angle of inclination of \( f(e) \) decreases. The relative decrease of this angle, compared with the PP/WF composite, is 12% for the PP/F1 and 16% for the PP/F2 composites.

Table 1 presents the results of the one-way ANOVA test on the effect of filler type on AE descriptors generated from WPCs and tensile strength of WPCs. They show that analyzed AE descriptors generated by WPCs and tensile strength of these composites vary significantly depending on the type of WPs.
Table 1. The effect of filler type on AE descriptors generated from WPC samples and tensile strength of WPC.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Max event count</th>
<th>Total event count</th>
<th>Percent of max force at the time of AE initiation</th>
<th>Tensile strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of WPs</td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
<td>0.0110**</td>
<td>0.0320**</td>
</tr>
</tbody>
</table>

*Denotes significance at 0.01; **denotes significance at 0.05.

The mean values of the AE descriptors generated from WPCs and tensile strength of the tested WPCs are given in Fig. 3. Tukey’s test was used to evaluate statistical significance (at $\alpha = 0.05$) between mean values of AE descriptors and tensile strength of WPCs containing different WP types. The values marked with different letters for a given property are significantly different at the 5% significance level.

![Fig. 3. Effect of WP type on the AE generated from WPCs and tensile strength of the tested WPCs: a) maximum event count, b) total event count, c) percent of maximum force at the time of AE initiation, and d) tensile strength](image)

Having analyzed the results of investigations (Fig. 2 and 3) it should be noted that with increasing the size of WPs used as a filler of PP the count of AE signals generated from loaded WPC increases. We can see that the PP/F2 during destruction time generates a AE signal on average by 16% greater than that by the WPC containing WPs F1 and by 49% greater than that by the PP/WF. The total event count recorded during loading the PP/F2 is greater on average by 19% than that by the WPC containing WPs F1 and on average by 65% than that by the PP/WF. A very important point on the chart of the AE event count in time function is the initiation of AE. It should be noted that the initiation of AE during the loading of the WPC containing WF occurs after exceeding 78% of maximum force causing the destruction of this composite. The initiation of AE for the PP/F1 occurs after exceeding 86% of maximum force and after exceeding 94% of maximum force for the PP/F2.
The results of the effect of WP type on the tensile strength of the examined composites are presented in Table 1 and Fig. 3. It should be noted that that filling WPC with WPs F2 increases its tensile strength on average by 19% in comparison to the WPC containing PP and WF. There is no statistically significant difference between the average values for tensile strength of PP/WF and PP/F1.

CONCLUSIONS

The AE generated from wood-PP composites and the tensile strength of these WPCs substantially depend on the size of WPs. Using larger WPs increases significantly the maximum event count, total event count, tensile strength and decreases the percentage of maximum force at the time of AE initiation.

REFERENCES

1) CYRA G., 1997: Acoustic emission monitoring of the wood machining process. The United Graduate School of Agric. Univ. Tottori Ann Arbor.
Streszczenie: Emisja akustyczna generowana z kompozytów drewno-polipropylen. Celem badania było określenie wpływu wielkości cząstek drzewnych na charakterystykę emisji akustycznej generowanej z kompozytów drewno-polipropylen oraz na ich wytrzymałość na rozciąganie. Wyznaczano maksymalną liczbę zdarzeń, całkowitą liczbę zdarzeń, procent siły maksymalnej, przy której zachodzi inicjowanie sygnału akustycznego oraz wytrzymałość na rozciąganie. Stwierdzono, że napelnienie polipropylenu większymi cząstkami istotnie zwiększa maksymalną liczbę zdarzeń, całkowitą liczbę zdarzeń i wytrzymałość na rozciąganie oraz obniża procent siły maksymalnej.

Corresponding author:

Cezary Gozdecki
Institute of Technology,
Kazimierz Wielki University
Chodkiewicza 30 str.
85-064 Bydgoszcz, Poland
e-mail: gozdecki@ukw.edu.pl