Fracture behaviour of natural fibre reinforced composites

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Abstract

This paper deals with the microfracture behaviour of natural fibre reinforced composite materials. The acoustic emission (AE) method was applied to detect various micro-scale energy release phenomena during tensile deformation not only of Manila hemp fibre, but also of three kinds of composites with three different fibre orientation angles, namely 0° , 45° and 90° . In the case of Manila hemp fibre testing, low amplitude AE events (40–60 dB) were measured at an intermediate strain range and high amplitude events were also measured at a final fracture stage. In the case of 0° composite, AE signals having a wide range of amplitude distribution were measured from the beginning of deformation and the AE activity was found to become significant with further tensile deformation. On the other hand, a few AE data with low amplitude were measured in 45° and 90° composites. In conclusion, low and high amplitude AE events observed during tensile deformation of natural fibre composites originated from fibre splitting and fibre fracture, respectively.

Keywords: microfracture, acoustic emission, starch based resin, hemp fibre, fibre fracture, debonding.

1 Introduction

Recently, much of the research on natural fibre composites, carried out in Europe, North America and Asia, has focused on the enhancement of their mechanical properties [1–13]. Natural fibre composites are materials that usually consist of a biodegradable resin matrix mainly derived from natural resources and natural plant fibres as reinforcement. Therefore, they are derived from yearly renewable resources and, at the same time, their disposal after usage becomes relatively easy. A natural fibre composite material has been recognized as an

environment-friendly material that can be a substitute to conventional glass fibre reinforced plastics (GFRP). As various functions of natural fibre composites to be further investigated, the following are mentioned: strength characteristics, damping characteristics and sound-absorbing characteristics, which thereby allow their expanded application into various products.

However, information on the microscopic fracture behaviour of natural fibre composites is still lacking, because of the many complicated factors affecting their fracture behaviour [14]. Three types of hemp fibre reinforced composite specimens (0° , 45° and 90° composites), as well as plain resin specimens, were fabricated in this study. Their microscopic fracture behaviour was investigated using an acoustic emission (AE) method.

2 Experimental methods

2.1 Materials

A starch-based biodegradable resin (CP-300, Miyoshi Oil and Fat Co. Ltd., Japan) was used as a matrix resin [8–10]. This biodegradable resin is not pellet-type, but dispersion-type. Fine starch-based biodegradable resin particles, approximately $6\text{ }\mu\text{m}$ in diameter, are well dispersed in a water-based solution of pH 5.0.

Manila hemp fibre was chosen as the reinforcing fibre due to its high performance with respect to physical properties and availability [8, 10]. The diameter of the Manila hemp fibre is approximately $200\text{ }\mu\text{m}$. It should be noted that this macroscopically single Manila hemp fibre consists of hundreds of unidirectional single fibres.

2.2 Fabrication method

To start with, preliminary unidirectional composite sheets of approximately $100\times 100\text{ mm}^2$ were prepared by putting the dispersion-type, biodegradable resin on the surface of unidirectionally aligned Manila hemp fibre sheets. These preliminary composite sheets were dried at 105°C for 2 hours in an oven. Then, these dried preliminary composite sheets were cut into three types of strips of 10 mm width having different fibre orientations at 0° , 45° and 90° . The obtained strips were stacked in a metallic mould and finally hot-pressed at 10 MPa and 140°C for 10 min. The final specimen size was $10.0\times 100.0\times 1.5\text{ mm}^3$. The fibre content of all specimens was fixed to be 50 wt.%. Macroscopic views of the three types of specimens are shown in fig. 1.

2.3 Tensile tests with AE measurement

Quasi-static static tensile tests were carried out in order to evaluate the mechanical properties and microfracture behaviour of the hemp fibre reinforced composites. The tensile tests were conducted using a universal testing machine

(5567, Instron Co., U.S.A) at room temperature. The cross-head speed and gauge length were 1.0 mm/min and 40.0 mm, respectively.

Two-channel AE measurement was simultaneously performed to evaluate the micro-scale damaging processes of natural fibre reinforced composites during tensile tests. Two AE sensors (F217M, Showa Electric Laboratory Co. Ltd.,

Figure 1: Macroscopic view of Manila hemp fibre reinforced composites: (a) 0° composite, (b) 45° composite, and (c) 90° composite.

Figure 2: Two-channel AE signal measurement system.

Japan) were attached on the specimen as shown in fig. 2. The distance between AE sensors was 30 mm. The AE signals passed through a pre-amplifier (1220A, Physical Acoustics Co., U.S.A) with a gain of 40 dB and were recorded in an AE analyzing system (MISTRAS 2001, Physical Acoustics Co., U.S.A). At the same time, tensile force information from the specimen was also recorded in the same AE analyzing system. The threshold value used in the AE measurement was set to be 40 dB.

2.4 Surface characterization

The fracture morphology of the three kinds of hemp fibre composites and Manila hemp fibre was examined by optical microscope (SZH-10, Olympus Co., Japan) and field emission-type scanning electron microscope (SEM: S-4700, Hitachi Ltd., Japan). All samples were sputter-coated with gold using a sputter coater (E-1010, Hitachi Ltd., Japan) prior to SEM observation.

3 Experimental results and discussion

3.1 Deformation and fracture behaviour of Manila hemp fibre

The AE event diagram for Manila hemp fibre is shown in fig. 3. The stress–strain curve of Manila hemp fibre is also demonstrated in the same graph. The tensile strength of Manila hemp fibre reaches a value higher than 800 MPa,

Figure 3: Stress–strain diagram of Manila hemp fibre with AE activities.

Figure 4: Fracture behaviour of Manila hemp fibre.

showing excellent mechanical properties. It can be seen that relatively low amplitude AE events (40–60 dB) are measured at an intermediate strain range ($\varepsilon = 0.02$) and that high-amplitude AE events are also measured just before final fibre fracture. Furthermore, the Manila hemp fibre is split into many single fibres as shown in fig. 4. From these results, it is found that high-amplitude AE events are derived from the fracture of a single fibre, and that low amplitude AE events might be derived from fibre splitting among the single fibres. Similar fracture behaviour of natural fibre has been reported in flax fibre reinforced composites [15].

3.2 Tensile properties of Manila hemp fibre-reinforced composites

3.2.1 0° composite

The stress–strain curve with AE activities of the 0° composite is presented in fig. 5. Many AE events having a wide amplitude distribution, i.e. from low amplitude to high amplitude, are measured from the early stage of tensile deformation to the final composite fracture [16]. It should be noted that relatively high amplitude AE events are frequently observed even at the beginning of the deformation process. This strain range is much smaller than the fracture strain of Manila hemp fibres themselves as shown in fig. 3. It is therefore suggested that this AE event is derived from the microfracture of pre-damaged Manila hemp fibres. Some damage might be introduced into Manila hemp fibre during its extraction process or composites' fabrication process. Low amplitude AE events less than 60 dB are also often found in the middle of deformation process. These low AE events seem to be derived from matrix deformation and fracture or fibre-matrix debonding [17]. However, no AE event was detected during tensile deformation of plain resin. Hence the low AE events are presumably derived from fibre-matrix debonding.

Figure 5: Stress-strain diagram of 0° composite with AE activities.

Figure 6: Fracture surface of 0° composite, showing many pull-out fibres.

Fig. 6 depicts the fracture surface of 0° composite. It can be seen that there are many pull-out fibres on the fracture surface and that the interfacial fracture also occurs extensively.

3.2.2 45° composite

The stress-strain curve with AE activities of the 45° composite is shown in fig. 7. It can be seen from this figure that many low amplitude AE events are observed during deformation and that the deformation stress of 45° composite is

Figure 7: Stress–strain diagram of 45° composite with AE activities.

Figure 8: Fracture surface of 45° composite, showing a shear fracture mode.

only 12 MPa, which is almost equivalent to that of plain resin. In addition, these composites exhibit ductile behaviour with high fracture strain. Figs 8 and 9 demonstrate the fracture behaviour of this composite. It can be seen that the

composite is fractured in a shear mode and that the fracture is governed by interfacial debonding.

Figure 9: Fracture surface of 45° composite, showing interfacial fracture between resin and fibre.

Figure 10: Stress–strain diagram of 90° composite with AE activities.

3.2.3 90° composite

The stress–strain curve with AE activities of the 90° composite is shown in fig. 10. On the contrary, there is only one AE event with very low amplitude at around the final fracture. A microscopic view of the fracture surface of the 90°

composite is shown in fig. 11. In this case, an interfacial fracture between matrix resin and reinforcing fibre governed the final fracture. Therefore, it is demonstrated that the AE event generated from interfacial fracture has relatively low amplitude and that a few AE events occur during the entire deformation.

Figure 11: Fracture surface of 90° composites, showing interfacial fracture between resin and fibre.

4 Conclusions

In summary, in the case of 0° composite, AE events having a wide range of amplitude distribution are measured from the beginning of deformation, and AE activities become pronounced with further deformation. On the other hand, a few AE events with low amplitude are measured in 45° and 90° composites. These results suggest that low amplitude and high amplitude AE events are derived from fibre splitting and fibre fracture, respectively.

References

- [1] Wollerdorfer, M. & Bader, H., Influence of natural fibres on the mechanical properties of biodegradable polymers. *Industrial Crops and Products*, **8(2)**, pp. 105–112, 1998.
- [2] Luo, S. & Netravali, A.N., Interfacial and mechanical properties of environment-friendly “green” composites made from pineapple fibers and poly(hydroxybutyrate-co-valerate) resin. *Journal of Materials Science*, **34(15)**, pp. 3709–3719, 1999.
- [3] Luo, S. & Netravali, A.N., Mechanical and thermal properties of environment-friendly green composites made from pineapple leaf fibers and poly(hydroxybutyrate-co-valerate) resin. *Polymer Composites*, **20(3)**, pp. 367–378, 1999.

- [4] Lodha, P. & Netravali, A.N., Characterization of interfacial and mechanical properties of “green” composites with soy protein isolate and ramie fiber. *Journal of Materials Science*, **37(17)**, pp. 3657–3665, 2002.
- [5] Netravali, A.N. & Chabba, S., Composites get greener. *Materials today*, **6(4)**, pp. 22–29, 2003.
- [6] Mohanty, A.K., Misra, M. & Hinrichsen, G., Biofibres, biodegradable polymers and biocomposites: An overview. *Macromolecular Materials and Engineering*, **276/277(1)**, pp. 1–24, 2000.
- [7] Mueller, D.H. & Krobjilowski, A., New discovery in the properties of composites reinforced with natural fibers. *Journal of Industrial Textiles*, **33(2)**, pp. 111–130, 2003.
- [8] Takagi, H. & Ochi, S., Characterization of high-strength “green” composites using Manila hemp fibers and starch-based resin. *Proceedings of the Third Japan-Canada Joint Conference on New Applications of Advanced Composites (JCJC-III)*, pp. 19–27, 2003.
- [9] Takagi, H. & Ichihara, Y., Effect of fiber length on mechanical properties of “green” composites using a starch-based resin and short bamboo fibers. *JSME International Journal, Series A*, **47(4)**, pp. 551–555, 2004.
- [10] Takagi, H., Biodegradation behavior of starch-based “green” composites reinforced by Manila hemp fiber. *Proceedings of Third International Conference on Eco-Composites*, pp. 14-1–14-6, 2005.
- [11] Takagi, H. Kako, S. Kusano, K. & Ousaka, A., Thermal conductivity of PLA-bamboo fiber composites. *Advanced Composite Materials*, **16(4)**, pp. 377–384, 2007.
- [12] Takagi, H. & Asano, A., Effects of processing conditions on flexural properties of cellulose nanofiber reinforced “green” composites. *Composites Part A*, **38(4)**, pp. 685–689, 2008.
- [13] Tokoro, R., Vu, D.M., Okubo, K., Tanaka, T., Fujii, T. & Fujiura, T., How to improve mechanical properties of poly lactic acid with bamboo fibers. *Journal of Materials Science*, **43(2)**, pp. 775–787, 2008.
- [14] De Rosa, I.M., Santulli, C. & Sarasini, F., Acoustic emission for monitoring the mechanical behaviour of natural fibre composites: A literature review. *Composites Part A*, **40(9)**, pp. 1456–1469, 2009.
- [15] Romhany, G., Karger-Kocsis, J. & Czigany, T., Tensile fracture and failure behavior of thermoplastic starch with unidirectional and cross-ply flax fiber reinforcements. *Macromolecular Materials and Engineering*, **288(9)**, pp. 699–707, 2003.
- [16] Shin, F.G. Xian, X.J., Zheng, W.G. & Yipp, M.W., Analysis of the mechanical properties and microstructure of bamboo–epoxy composites. *Journal of Materials Science*, **24(10)**, pp. 3483–3490, 1989.
- [17] Park, J-M., Kim, P-G., Jang, J-H., Wang, Z., Hwang, B-S. & DeVries, K.L., Interfacial evaluation and durability of modified Jute fibers/polypropylene (PP) composites using micromechanical test and acoustic emission. *Composites Part B*, **39(6)**, pp. 1042–1061, 2008.