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 degree. In the case of Manila hemp fibre testing, low amplitude AE events (40–60 dB) are measured at an intermediate strain range, and high amplitude events are also measured at a final fracture stage. In the case of 0 degree composite, AE signals having a wide range of amplitude distribution are measured from the beginning of deformation, and the AE activity becomes significant with further tensile deformation. On the other hand, a few AE data with low amplitude are measured in 45 and 90 degree composites. In conclusion, low and high amplitude AE events observed during tensile deformation of natural fibre composites are derived 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 has been carried out in Europe, North America, and Asia and focused on the enhancement of their mechanical properties [1–13]. The natural fibre composites are the composite material that usually consists of biodegradable resin matrix mainly derived from natural resources and natural plant fibre as reinforcement. Therefore, they are derived from yearly renewable resources, and at the same time their disposal

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after usage becomes relatively easy. The natural fibre composite materials have been recognized as an environment-friendly material that can be substituted for conventional glass fibre reinforced plastics (GFRP). As various functions of natural fibre composites to be further noticed, the following are mentioned: strength characteristics, damping characteristics and sound-absorbing characteristics, which thereby allow the expanded application to various products.

However, the 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 degree composites), as well as neat 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 μm in diameter are well dispersed in a water-based solution of pH 5.0.

Manila hemp fibre was chosen as a reinforcing fibre due to its high performance in physical properties and availability [8, 10]. The fibre diameter of the Manila hemp fibre is approximately 200 μm. It should be noted that this macroscopically single Manila hemp fibre consists of the hundreds of unidirectional single fibres.

2.2 Fabrication method of three types of natural fibre reinforced composites with different fibre angles

First of all, preliminary unidirectional composite sheets of approximately 100 x 100 mm 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 having different fibre angles of 0, 45, and 90 degrees, and of 10 mm width. These stripes obtained were stacked in a metallic mould and finally hot-pressed at 10 MPa and 140°C for 10 min. The final specimen size is 10.0 x 100.0 x 1.5 mm. 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

We carried out quasi-static static tensile tests 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 degree composite, (b) 45 degree composite, and (c) 90 degree composite.

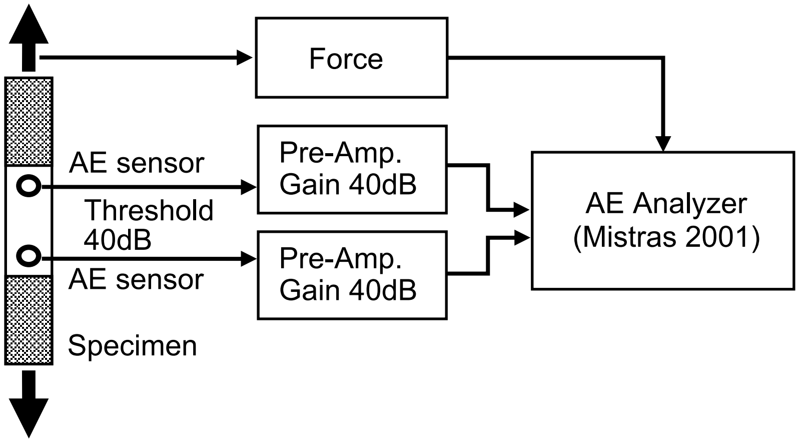

Figure 2: Two-channel AE signal measurement system.

Japan) were attached on the specimen as shown in fig. 2. The distance between AE sensors was 30mm. The AE signals passed through a pre-amplifier (1220A, Physical Acoustics Co., U.S.A) with a gain of 40 dB were recorded in an AE analyzing system (MISTRAS 2001, Physical Acoustics Co., U.S.A). At the same time, tensile force information of 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. Tensile strength of Manila hemp fibre reaches a value higher than 800 MPa,

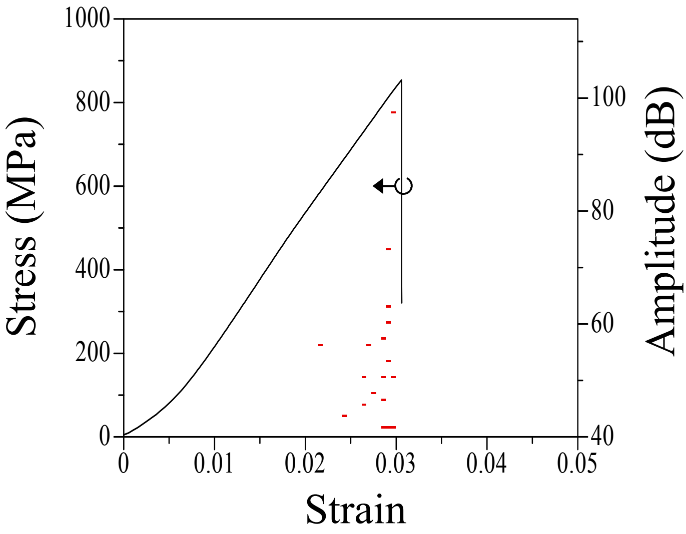

Figure 3: Stress–strain diagram of Manila hemp fibre with AE activities.

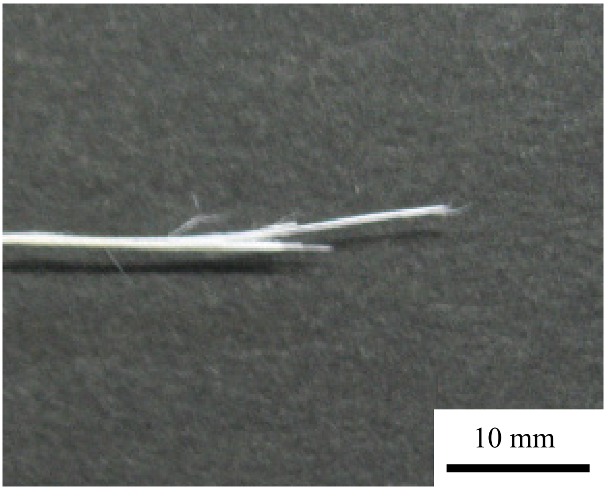

Figure 4: Fracture behaviour of Manila hemp fibre.

showing excellent mechanical properties. It can be seen that relatively low amplitude AE events (40–60 dB) are measured at an intermediate strain range (ε=0.02) and that high-amplitude AE events are also measured just before final fibre fracture. Furthermore, Manila hemp fibre is split into many single fibres as shown in fig. 4. From these results, we found that high-amplitude AE events are derived from the fracture of 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 degree composite

Stress–strain curve with AE activities of the 0 degree composite is represented 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 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 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 damages 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 neat resin. Hence the low AE events are presumably derived from fibre-matrix debonding.

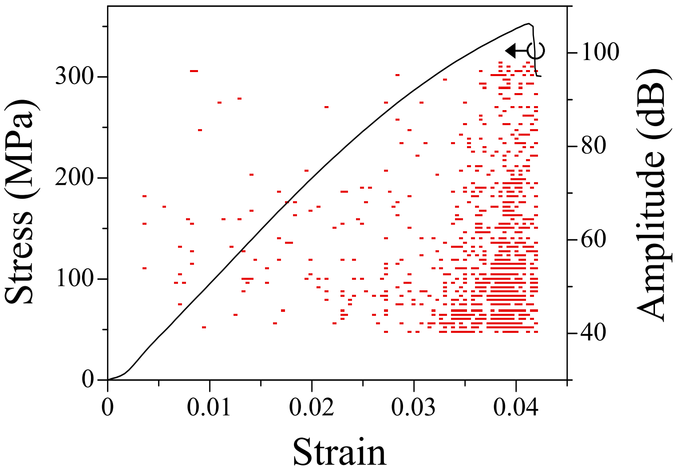

Figure 5: Stress–strain diagram of 0 degree composite with AE activities.

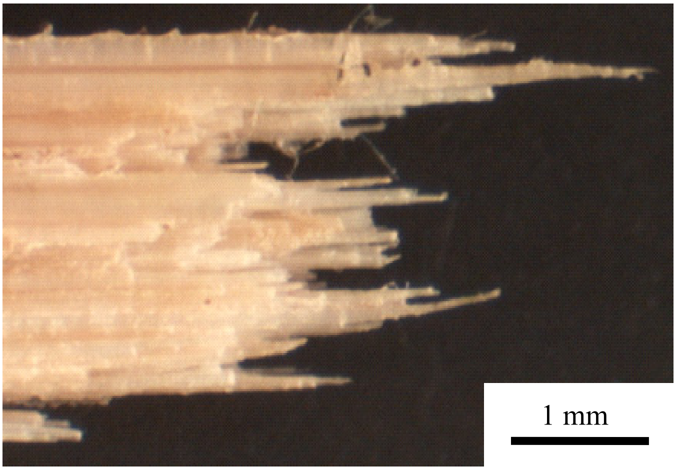

Figure 6: Fracture surface of 0 degree composite, showing many pull-out fibres.

Figure 6 depicts the fracture surface of 0 degree 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 degree composite

Stress–strain curve with AE activities of the 45 degree 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 degree composite is only 12 MPa, which is almost equivalent to that of neat resin. In addition, these composites exhibit ductile behaviours with high fracture strain. Figures 8 and 9 represent the fracture behaviour of this composite. It can be seen that the composites is fractured in a shear mode and that the fracture is governed by interfacial debonding.

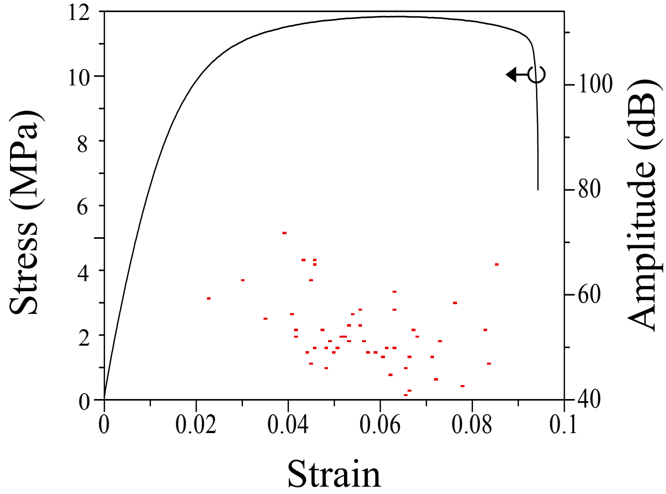

Figure 7: Stress–strain diagram of 45 degree composite with AE activities.

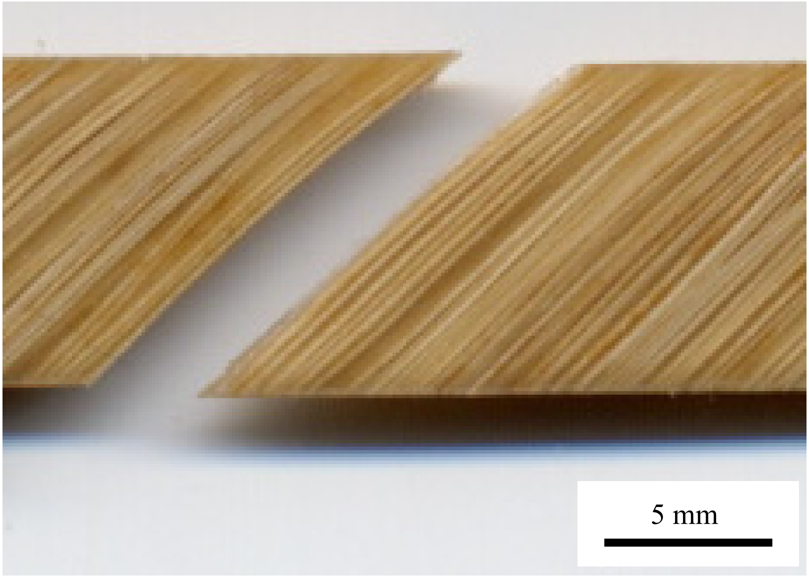

Figure 8: Fracture surface of 45 degree composite, showing a shear fracture mode.

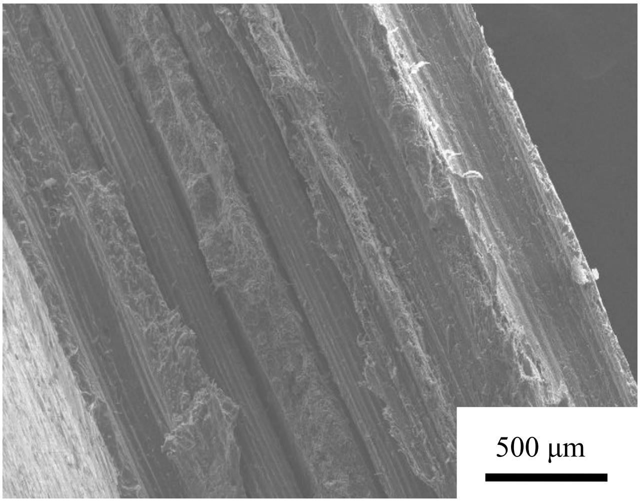

Figure 9: Fracture surface of 45 degree composites, showing interfacial fracture between resin and fibre.

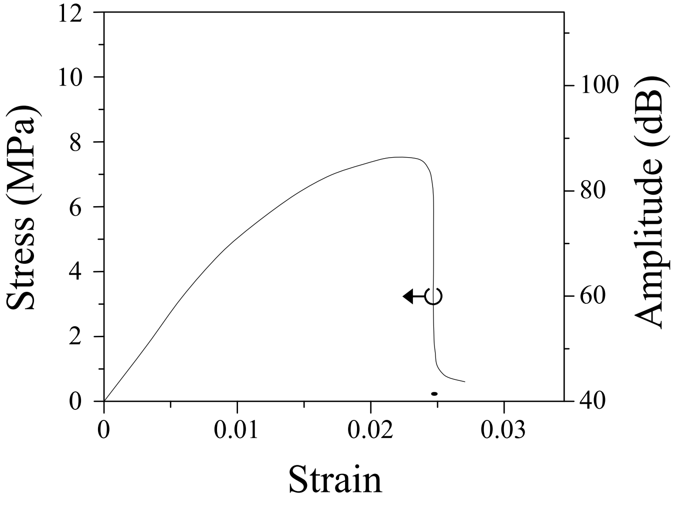

Figure 10: Stress–strain diagram of 90 degree composite with AE activities.

3.2.3 90 degree composite

Stress–strain curve with AE activities of the 90 degree composite is shown in fig. 10. On the contrary, there is only one AE event with very low amplitude at around the final fracture. Microscopic view of fracture surface of 90 degree 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 AE event generated from interfacial fracture has relatively low amplitude and that a few AE events occur during the entire deformation.

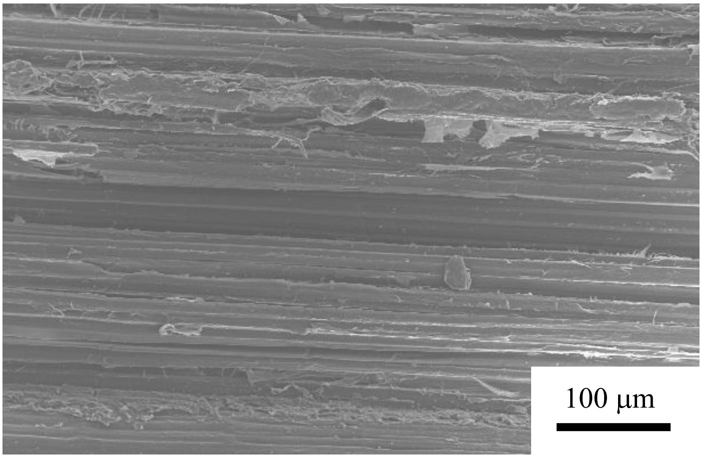

Figure 11: Fracture surface of 90 degree composites, showing interfacial fracture between resin and fibre.

4 Conclusions

In summary, in the case of 0 degree 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 degree composites. These results suggest that low amplitude events and high amplitude AE events are derived from fibre splitting and fibre fracture, respectively.

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