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Study on damage and fracture characteristics of wood based on acoustic emission b-value and seismic magnitude difference entropy

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Abstract

To assess the damage and fracture behavior of wood under load, a wood damage assessment method was proposed based on acoustic emission (AE) b-values and seismic magnitude difference entropy. First, AE signals from *Pinus sylvestris* var. mongolica (softwood) and *Zelkova schneideriana* (hardwood) specimens were collected separately at a sampling frequency of 500 kHz in a three-point bending test. Then, 52 dB was taken as the threshold of the AE event, and the b-value and seismic magnitude difference entropy were calculated at 4-s intervals. Finally, by comparing with the load–time curve, the b-value and seismic magnitude difference entropy were used to evaluate the damage fracture degree. The results showed that an increase in the b-value indicates the accumulation of strain energy, and vice versa, corresponding to the concentrated release of strain energy. At the same time, the test process can be divided into three stages—elastic, elastic–plastic and plastic—based on the level of the seismic magnitude difference entropy.

Keywords Wood, Damage and fracture, Acoustic emission, b-value, Seismic magnitude difference entropy

Introduction

Wood is a natural composite material with a high strength-to-weight ratio and environmental protection and is widely used in construction. Due to the characteristics of wood and the external environment, a wooden structure will inevitably be damaged in the process of use, resulting in a decline in its mechanical properties. Therefore, the nondestructive testing (NDT) of wood plays an important role in the use and maintenance of wood structures. AE technology, an NDT method, is a method for real-time dynamic inspection of wood structures without damaging the object under inspection or the material's serviceability. It allows researchers to determine the damage status without regular visual inspection.

When a material is deformed and fractured by an external force or internal force, strain energy is released in the form of a transient elastic wave [1]. The state of releasing strain energy is called the AE phenomenon. Typical AE parameters that can be obtained from the AE signal include amplitude, energy, and duration, which can reflect the state of unreachable places [2–6]. In addition, AE technology, as an NDT testing method, has been widely used in metal [7–10] and composite materials [11–19]. Lamy et al. [20] studied the failure process of *Pseudotsuga menziesii* (Mirbel) Franco under monotonic

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loading and compared the force–displacement curve, AE signal and damage image. Friedrich et al. [21] discussed several indices calculated from experimental records of AE signals and their efficiency in describing the structural failure process and compared their sensitivity with other classic parameters commonly used in AE analysis. By analyzing the number of AE events and AE amplitude, Zhang et al. [22] found that the results had a strong correlation with the actual crack state, indicating that AE characteristics can effectively reflect the damage state of materials. Guo et al. [23] analyzed the relationship between cumulative AE events and time–load curves and determined the critical failure load of wood; the damage of wood can be divided into three stages: elastic deformation, crack generation and propagation, and fracture. At present, AE events in AE signals are regarded as deterministic events, but the generation process of AE signals is often random. Therefore, to clearly reflect the damage and fracture process of materials, this paper analyzed and identified the damage characteristics of materials through the entropy and b-value of seismic waves.

The b-value is a basic concept originating from seismology. As early as 1941, the b-value was first applied in the empirical equation for the interconversion between earthquake magnitude and earthquake number proposed by B. Gutenberg and C. F. Richter. In fact, seismic waves are vibrations that propagate from the source to the surroundings, which means that elastic waves radiate from the source to the surroundings. This is similar to the elastic wave produced in the process of material failure. Therefore, the b-value is widely used to evaluate the damage characteristics of rock, concrete and composite materials. Colombo et al. [24] analyzed the b-value of the measured data of concrete beams, and their results showed that the change in the b-value was in good agreement with the crack propagation of concrete beams. Sagar et al. [25] studied the AE characteristics of ordinary concrete and cement mortar. Their results showed that the b-value analysis of AE can be used as a tool to identify the damage of concrete structural members. Liu et al. [26] explored the characteristics of b-values of rock fracture AE and the factors affecting the calculation of b-values under the two loading methods by performing Brazilian cracking and uniaxial compression tests on tuffs. It can be seen from the above research results that the b-value of AE plays a vital role in predicting material damage.

Information entropy, as a method of describing the nature of information and its quantitative measure, can describe the uncertainty of a system, and the smaller the entropy value is, the less uncertain information exists in the system [27]. Zhang et al. [22] and Karimian et al. [28] applied information entropy to study composite materials and metal materials. Their results showed that information entropy can well reflect the chaotic degree of the signal and clearly characterize the initial stage and time of material damage. According to relevant research [29–31], the AE signal generated in the process of wood fracture under force has the characteristics of uncertainty, complexity, nonstationarity and nonlinearity. Therefore, the combined application of the b-value and entropy value can effectively identify the damage and fracture process of wood, especially the release process of the stress level and strain energy.

The existing research shows that the b-value can reflect the changes in microcrack scale in a material, and the entropy value reflects the concentrated release time of strain energy. Therefore, in this paper, the combined method of b-value and seismic magnitude difference entropy was adopted to study the damage and fracture behavior of wood under load. First, the magnitude of the AE signal of wood was defined according to the seismological method. To correspond with the actual stress–time curve, the magnitude of the wood AE signal was counted at 4-s time intervals, and then the seismic magnitude difference entropy and b-value were calculated. By analyzing the b-value and seismic magnitude difference entropy, the release state of strain energy and damage characteristics during wood damage fracture can be effectively identified.

Materials and methods

Experimental materials

In this study, *Zelkova schneideriana* (hardwood) and *Pinus sylvestris* var. mongolica (softwood) with straight texture were selected as the experimental materials; four groups of specimens were selected for testing, including 2 groups of *Zelkova schneideriana* and 2 groups of *Pinus sylvestris* var. mongolica. The results of the same specimens were consistent, so this article shows a set of data. The densities of the selected *Zelkova schneideriana* and *Pinus sylvestris* var. mongolica were 0.709 g/cm^3 and 0.373 g/cm^3, the moisture contents (MC) were 11.4% and 10.8%, respectively, and the specimen sizes were 300×20×20 mm (L×W×H). The three-point bending test parameters were set according to ASTM-D198-21a, and a UTM5105 electronic universal mechanical testing machine was used to load each specimen at a speed of 2 mm/min until the specimen was fractured. The test was based on a NI USB-6366 high-speed acquisition card and LabVIEW software to build a 2-channel AE signal acquisition system (NI USB 6366, American national instrument company) using an RS-2A single-ended resonant AE sensor (RS-2A single-ended resonant, Beijing Soft Island Times Technology Co., Ltd.) with a resonant frequency of 150 kHz. To realize the long-distance transmission of the AE signal, a PAI

front-end amplifier with a gain of 40 dB was adopted. During the test, the sampling frequency of the system was set to 500 kHz, and the output range of the output voltage was set to (−5 V, 5 V).

Experimental method

As shown in Fig. 1, the wood specimen was placed on support points A and B, and the distance between the two points was set to 200 mm. Sensors S1 and S2 were placed on the side of the specimen. The distance between the midpoint P and the left end was 150 mm. The three-point bending test at room temperature was carried out on the midpoint P by using a universal mechanical testing machine. The test was carried out at room temperature, the temperature was 25 degrees and the relative humidity was 37%. To ensure full contact between the sensor and the wood during the experiment and to isolate the influence of the air medium on the AE signal, high-temperature insulating silicone resin was used to ensure full coupling, and a rubber band was used to fix the sensor on the side of the specimen to provide constant pressure to ensure the accuracy of signal acquisition.

b-value calculation

In 1941, Gutenberg and Richter proposed the famous G–R relationship between earthquake magnitude and frequency in the study of world seismic activity [32]:

$$\lg N = a - bM, \tag{1}$$

where M is the magnitude, N is the number of earthquakes of the corresponding magnitude, and a and b are constants.

In earthquakes, the maximum likelihood estimation method is typically used to calculate the b-value [33], and the calculation equation of the b-value is:

$$b = \frac{\lg e}{\overline{M} - M_{\min}}, \tag{2}$$

where $\overline{M}$ is the average magnitude and $M_{\min}$ is the minimum magnitude.

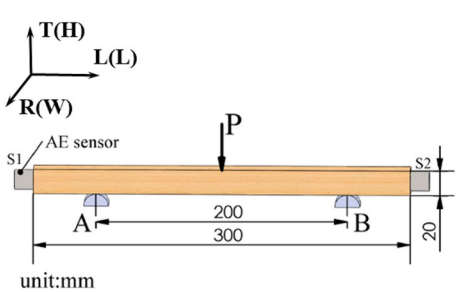

Fig. 1 Sensor placement

When calculating the b-value of the material damage AE, the AE amplitude is generally used to reflect the size of AE events [34]. Similarly, the magnitude was defined according to the amplitude of the wood AE signal. First, according to Eq. (4), the AE event amplitude u was transformed into the decibel value D, and then the decibel value A_{dB} corresponding to the maximum AE signal amplitude generated in the test process was defined as magnitude 10, and the decibel value D_1 corresponding to the threshold was defined as magnitude 1. Thus, the calculation formula (3) of the magnitude is obtained. The y in Eq. (3) represents the magnitude. This magnitude is transformed from the amplitude of the acoustic emission event, and the magnitude of the magnitude represents the amplitude of the acoustic emission event. The specific calculation equation is:

$$y = \frac{9}{A_{\mathrm{dB}} - D_1} x + 1 - \frac{9 * D_1}{A_{\mathrm{dB}} - D_1}, \tag{3}$$

$$D = 20 * \log(u) + 80, \tag{4}$$

where D_1 is the threshold, which was set to 52 dB in this paper according to the maximum decibel value of the collected noise signal, and u is the actual voltage value amplified by 40 dB.

During the damage fracture of the wood, within a fixed time interval, the maximum magnitude difference of the AE signal objectively reflects the strain energy release strength of the specimen to a certain extent. Therefore, $M_{\max}$ is used to replace $\overline{M}$. According to Eq. (2), and the equation can be revised as follows:

$$b = \frac{a - \lg N}{M_{\max} - M_{\min}}, \tag{5}$$

where N is the number of AE events in the period under consideration; $M_{\max}$-$M_{\min}$ is the magnitude difference in statistical time; a is a constant, and the b-value needs to be limited to a range greater than zero by setting the value of a, which is set to 5 in this paper; and b is the b-value of AE. The b-value is not only a statistically analytical parameter, but also has a direct physical meaning. The change trend of the b-value can effectively indicate the degree of material damage during cyclic loading [34].

Calculation method of the seismic magnitude difference entropy

Entropy is an important concept in information theory. Entropy can simplify complex information through quantitative representation and measure the certainty of information in a certain state [35]. To determine the AE threshold, before the three-point bending test, a section of blank noise signal was initially collected, and the

maximum decibel value of the collected noise signal was taken as the AE threshold. Those less than this threshold were considered to be noise signals. The amplitude of the AE signal greater than the threshold was transformed into the magnitude, and the magnitude difference was counted in *t*. Then, the seismic magnitude difference entropy was calculated by the time interval *T*.

The seismic magnitude difference entropy reflects the change rate of the AE event amplitude, which can be seen from the overall change rate of a system. Because the AE source produced during the fracture of wood is discrete, a one-dimensional random variable X can be used to describe the output of the source, that is, the seismic magnitude difference of the AE event. The mathematical model of the source is unified and abstracted as

$$\begin{bmatrix} x \\ p(x) \end{bmatrix} = \begin{bmatrix} a_1 & a_2 & a_3 & \dots & a_n \\ p(a_1) & p(a_2) & p(a_3) & \dots & p(a_n) \end{bmatrix}, n = \left\lfloor \frac{T}{t} \right\rfloor . \tag{6}$$

In Eq. (6), $p(a_i)$ ($i=1, 2, 3\ldots, n$) is the ratio of the seismic magnitude difference (a_i) corresponding to the AE event amplitude output by the AE source in unit t time to the seismic magnitude difference of the whole interval, namely, the occurrence probability. Then, there are

$$\sum p(a_i) = 1, i = 1, 2, \ldots, n . \tag{7}$$

When the AE source is given, the corresponding probability space is determined, which can characterize the statistical properties of the discrete source. At this point, the seismic magnitude difference (a_i) corresponding to the amplitude of the AE event output by the AE source in unit t time has been determined; then, the self-information of the specimen is

$$I(a_i) = \ln \frac{1}{p(a_i)} . \tag{8}$$

I(a_i) is the amount of information provided by the seismic magnitude difference (a_i). Different specimens contain different amounts of information, so the self-information I(a_i) is a random variable and cannot be used as the information measurement of the entire information source. Therefore, the mathematical expectation of self-information is used as the average information of the source, that is, the seismic magnitude difference entropy.

$$H(x) = E\left[\ln \frac{1}{p(a_i)}\right] = -\sum p(a_i) \ln p(a_i) . \tag{9}$$

In this paper, the amplitude of statistical AE events was transformed into seismic magnitude, and the seismic magnitude difference entropy was calculated by using the seismic magnitude difference. The seismic magnitude difference entropy H (x) represents the average information provided by the seismic magnitude difference of each interval after the AE source produces the AE signal and reflects its randomness. Information entropy and magnitude difference entropy can reflect the change process of the degree of disorder of the system, and a decrease in entropy indicates a decrease in the degree of disorder of the system and the strong certainty of AE events. Information entropy can indicate the local release of strain energy, and seismic magnitude difference entropy can holistically express the release of strain energy. The seismic magnitude difference represents the change in the amplitude of AE events. Magnitude difference entropy reflects the change rate of the amplitude of AE events. The larger the magnitude difference entropy H (x) is, the smaller the change in magnitude difference is. The distribution of AE events is uniform, which means that the randomness is large and the degree of chaos is higher.

Results and analysis

Analysis of the seismic magnitude difference entropy

The amplitude of the AE event was transformed into the magnitude of the earthquake, and then the seismic magnitude difference was generated by the maximum amplitude and the minimum amplitude within $t=50$ ms. According to $n=T/t$, it can be concluded that n is 80. The seismic magnitude difference entropy was further calculated by using 80 seismic magnitude differences. The compression processes of *Pinus sylvestris* var. mongolica and *Zelkova schneideriana* experienced 244 s and 246 s, respectively, and the intervals were divided by $T=4$ s to obtain 60 and 61 subintervals, respectively. The seismic magnitude difference entropy statistics of *Pinus sylvestris* var. mongolica and *Zelkova schneideriana* are shown in Figs. 2b and 3b, respectively.

Figure 2b shows the variation in the entropy value of *Pinus sylvestris* var. mongolica, with the continuous increase in loading time, the entropy value increased step by step, viewing the wood damage fracture process as a nonlinear system, and the increase in entropy value indicates that this system gradually increased the degree of chaos with increasing time. According to the entropy change trend, the entropy map of *Pinus sylvestris* var. mongolica can be divided into three stages: [0,32 s], (32 s, 132 s], and (132 s, 244 s]. Before the loading time was 32 s, the entropy values were all at a low value, indicating that the system had the lowest degree of chaos and high degree of order at this stage. According to Fig. 2a, there was no obvious AE signal during this period, indicating that the wood damage was relatively small at the early stage of loading and indicating that there was not much wood strain energy release during this period. With the continuous increase in load, the entropy value within (32 s, 132 s) was higher than that before 32 s, indicating that the degree of system chaos in this stage was

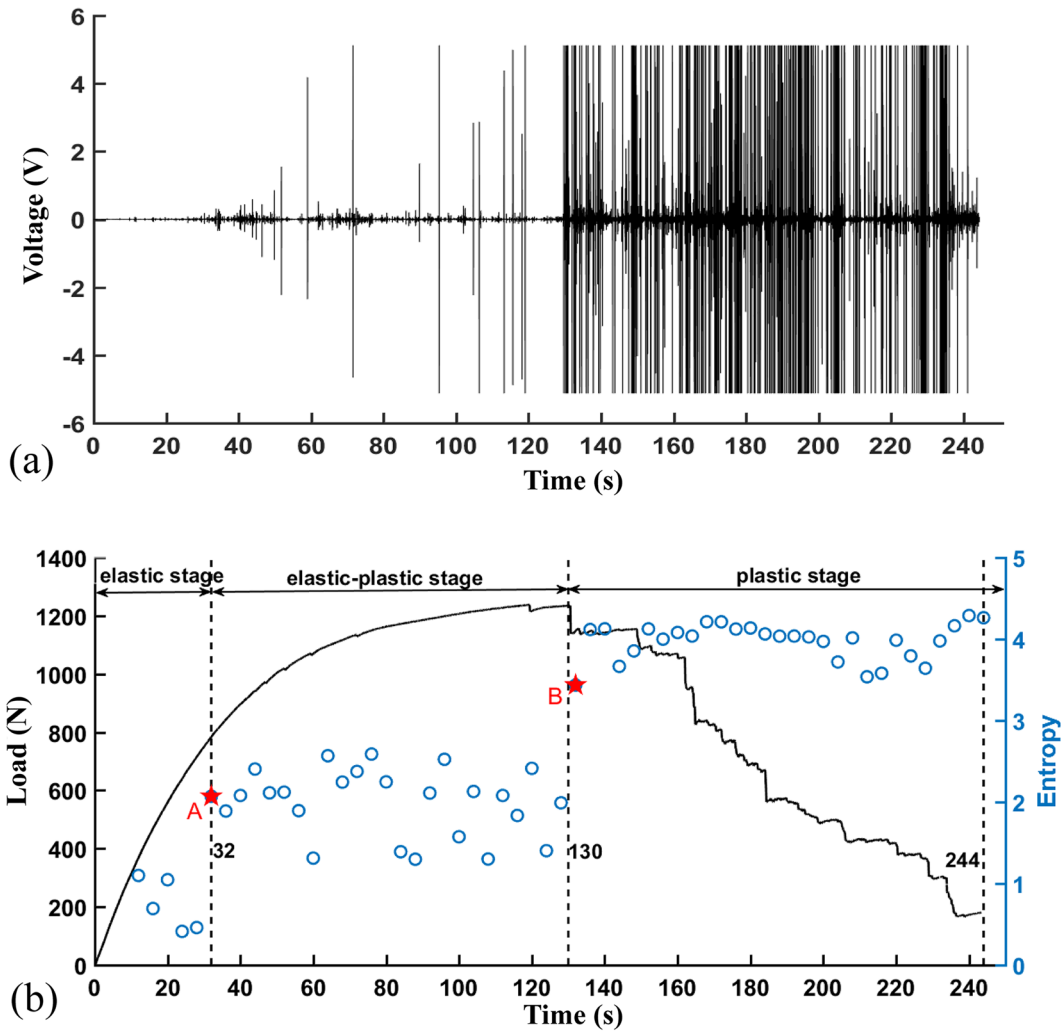

Fig. 2 AE waveform, load–time curve and seismic magnitude difference entropy map of *Pinus sylvestris* var. mongolica. **a** AE waveform, **b** load–time curve and seismic magnitude difference entropy

improved, that is, the degree of disorder generated by the AE signal was increasing. Combined with Fig. 2a, it can be seen that there were high-amplitude AE events in this stage, and low amplitude AE events were more intensive than in the first stage, indicating that damage to the wood occurred. However, there was no obvious macroscopic cracking on the outside of the wood during this stage, indicating that the damage at this time occurred inside the wood, along the expansion of the original crack and new cracks occurred inside the wood, and the concentrated release times of strain energy increased and the strain energy accumulated during this period. In (132 s, 244 s], the entropy value was the largest in the three stages, indicating that the degree of chaos in this system reached the maximum and the degree of the order was the lowest. This is because at this stage, macroscopic fracture occurs in *Pinus sylvestris* var. mongolica, and cracks were randomly generated. With the formation and expansion of new cracks, the concentrated release of strain energy made the AE source produce intensive AE signals.

According to relevant research, the damage process of wood can be divided into three stages: elastic deformation, elastic–plastic deformation and plastic deformation [36]. In the elastic stage, the damage degree of wood is smaller; when the added load is removed, the wood will return to the original state. With the continuous increase in the load, the damage to the wood gradually intensifies, which makes the wood unable to restore its original state, and this stage is defined as the elastic–plastic stage. Finally, it exceeds the bearing limit of wood, resulting in macroscopic fracture of wood and loss of its original mechanical properties, and this stage is called the plastic deformation stage. The load–time curve in Fig. 2b

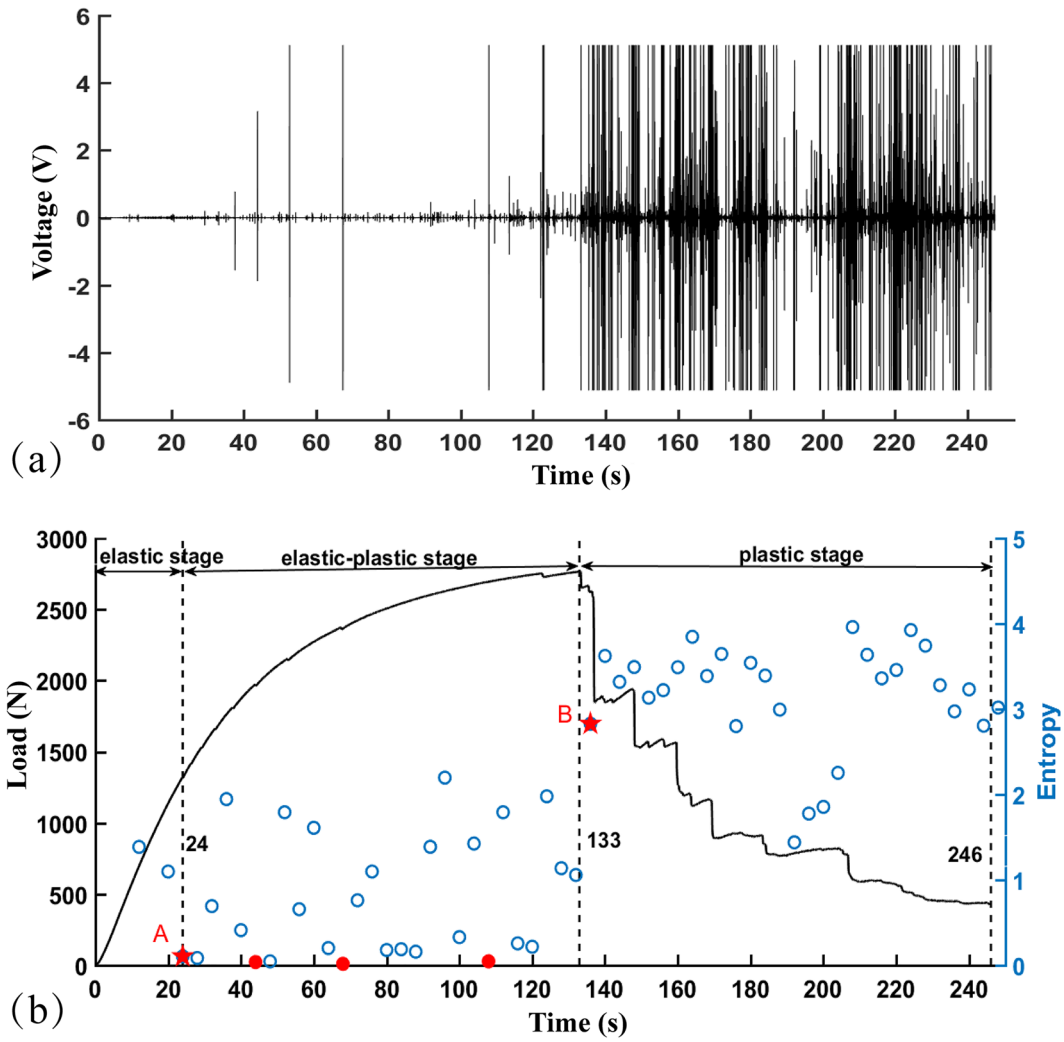

Fig. 3 AE waveform, load–time curve and seismic magnitude difference entropy map of *Zelkova schneideriana*. **a** AE waveform, **b** load–time curve and seismic magnitude difference entropy

clearly shows that the load of *Pinus sylvestris* var. mongolica abruptly changed at 130 s, and at the same time, it corresponded to the change in entropy value in this stage. This shows that at this time, the wood had produced obvious macroscopic cracks, and the concentrated release of strain energy had occurred. Corresponding to the AE waveform, a large number of intensive AE signals can be seen, and significant macroscopic fracture of the wood results in loss of original mechanical properties. At some time in 0–50 s, the load curve of *Pinus sylvestris* var. mongolica began to change from a linear relationship to a nonlinear relationship, that is, from the elastic stage to the elastic–plastic stage, it cannot be distinguished between the elastic stage and the elastic–plastic stage through the load–time curve in Fig. 2b. Combined with the distribution of entropy in Fig. 2b, it can be seen that the seismic magnitude difference entropy increased at point A, indicating that the degree of chaos increases in this interval, generating multiple high-amplitude AE events. Wood damage no longer disappears with the disappearance of external force; therefore, *Pinus sylvestris* var. mongolica changed from the elastic stage to the elastic–plastic stage at point A. At point B, the magnitude difference entropy increased again compared with the previous stage. Combined with Fig. 2a, it can be seen that after 130 s, an intensive AE event was generated, the accumulated strain energy was released centrally, and the specimen was macroscopically fractured; after point B, it entered the plastic stage. Therefore, according to the change in entropy value, the damage and fracture process of *Pinus sylvestris* var. mongolica can be clearly divided, and the damage state in each stage can be characterized.

Figure 3 shows the AE waveform, load–time curve and entropy change map of *Zelkova schneideriana* during

loading. According to the change in entropy value in Fig. 3b, the damage stage can be clearly divided into two intervals: [0, 136 s] and (136 s, 246 s]. In [0,136 s], the seismic magnitude difference entropy of *Zelkova schneideriana* was the smallest in some intervals, such as the points marked in red in Fig. 3b, which shows that the AE source generated AE signals in this interval with high certainty and that the order degree increases. Combined with Fig. 3a, it can be seen that the point with the smallest entropy value had obvious high-amplitude AE events, and the strain energy was released. At (136 s, 246 s], the seismic magnitude difference entropy increased compared with the entropy value of the previous period, indicating that the degree of chaos in this stage increased and intensive AE events occurred. However, in (190 s, 204 s], the entropy value decreased compared with the third stage, indicating that the degree of chaos in this period was reduced. Combined with Fig. 3a, AE events were reduced. It can be seen from the load–time curve in Fig. 3b that the load changed suddenly at 133 s, indicating that the macroscopic fracture of *Zelkova schneideriana* began at this moment. From 0–50 s, the load–time curve changed from a linear relationship to a nonlinear relationship. According to wood theory, when the external force exceeds the proportional limit, the deformation does not disappear with the elimination of external force, and the wood transitions from the elastic stage to the plastic stage. Combined with Fig. 3b, it can be seen that the entropy value of *Zelkova schneideriana* decreased for the first time at point A, and the strain energy was released, indicating that obvious AE events occurred at point A, and cracks were generated inside the wood. Therefore, *Zelkova schneideriana* at point A transitioned from the elastic deformation stage to the elastic–plastic stage. At point B, the entropy value increased, and the wood underwent macroscopic fracture and entered the plastic deformation stage. According to the above analysis, the damage process of *Zelkova schneideriana* under bending load can be divided into three stages: elastic deformation, elastic–plastic deformation and plastic deformation, as shown in Fig. 3b.

By comparing the entropy change diagrams of *Pinus sylvestris* var. mongolica and *Zelkova schneideriana*, as shown in Figs. 2b and 3b, it is found that there is a great difference in the damage and fracture process between them. The elastic and elastic–plastic stages of *Pinus sylvestris* var. mongolica are better distinguished than *Zelkova schneideriana*., and after the macroscopic crack, the entropy increases obviously. This is because of the difference between the two materials. *Pinus sylvestris* var. mongolica belongs to the layer-by-layer fracture, which is closer to the ductile fracture. Each stage corresponds to the fracture of different layers, so the entropy value can better identify these two stages. While *Zelkova schneideriana* is close to brittle fracture, there is always fiber fracture in *Zelkova schneideriana*, which makes elastic and elastic–plastic stages difficult to identify. The overall entropy value of *Pinus sylvestris* var. mongolica is larger than that of *Zelkova schneideriana*, which further proves that the layer-by-layer fracture of *Pinus sylvestris* var. mongolica continues to have obvious fractures, and *Zelkova schneideriana* expands along the main crack after the main crack occurs. The entropy value can effectively identify the fracture mode of the two materials and distinguish the damage stage to judge the damage degree of wood.

b-value analysis

The original amplitude and the number of AE events were processed using MATLAB software, and the b-values were analyzed. The compression process of *Zelkova schneideriana* and *Pinus sylvestris* var. mongolica were 246 s and 244 s, respectively. To clearly characterize the energy release process in the damage process of the two materials, the b-value was calculated at 4-s intervals, and the variation curve of the b-value is shown in Figs. 4 and 5.

Figure 4 shows the curve of the b-value during the damage and fracture process of *Zelkova schneideriana*. According to the change in the b-value, the damage and fracture process of *Zelkova schneideriana* can be divided into four damage stages. The first stage is 0–12 s; this stage belongs to the initial stage of loading, and the wood was in the complete elastic stage. In this stage, the wood mainly accumulated strain energy, and there was no AE event, resulting in the AE event number N of the statistical Eq. (2) being 0, and the b-value cannot be calculated at this time. With continuous loading, at 12–36 s, AE events with small amplitudes appeared in the waveform from the time domain diagram, and at this time, the b-value was the largest in the four stages and fluctuated significantly. This is because N is small during this stage and the seismic magnitude difference ΔM is also small, resulting in a large b-value and obvious change. It can be shown that during this stage, less release of the strain energy accumulated in the wood, and damage to the wood occurred, mainly extending along the original cracks inside the wood.

As the load continued to increase, the wood entered the elastic–plastic stage [36]. At 36 -132 s, the b-value at this time fluctuated continuously because the magnitude difference ΔM changed greatly in this stage, while the change in N was not obvious. According to the corresponding AE waveform, the high-amplitude events gradually increased in this stage. However, there was no macroscopic crack outside the wood at this

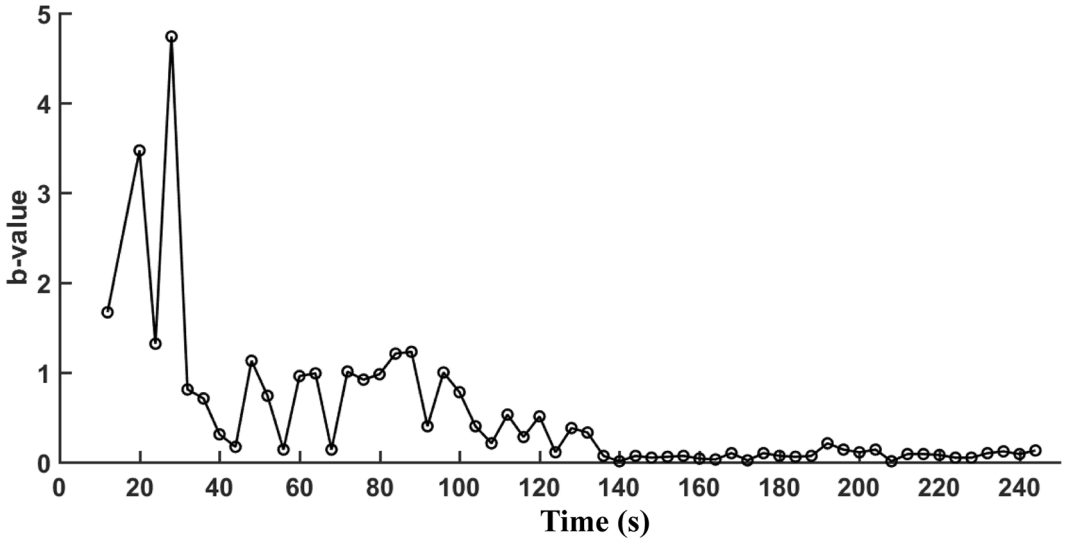

Fig. 4 b-value of *Zelkova schneideriana*

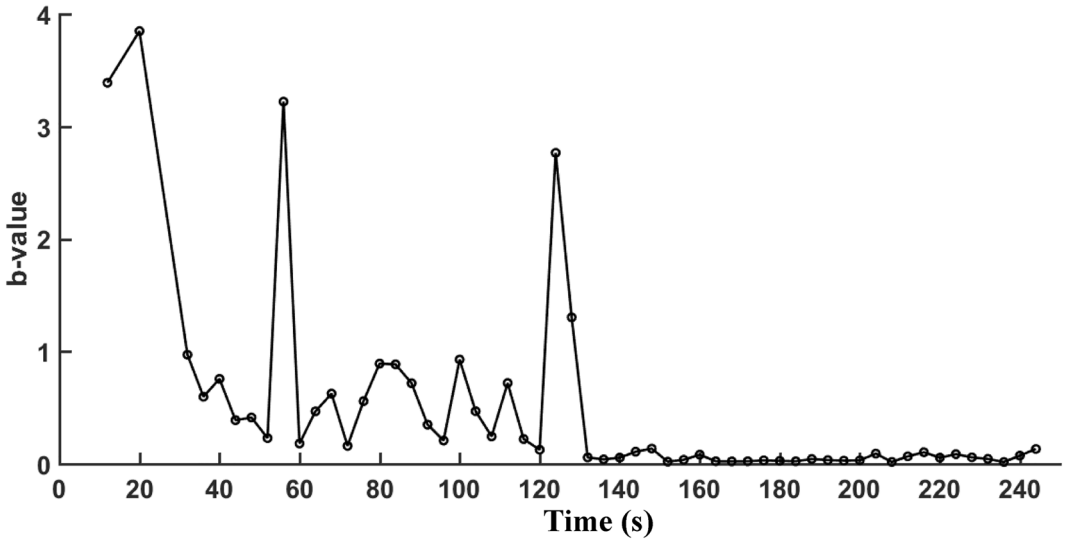

Fig. 5 b-value of *Pinus sylvestris* var. Mongolica

stage, indicating that the damage at this time was still dominated by internal damage. However, new cracks would appear inside the wood at this stage, indicating that the number of concentrated releases of strain energy was relatively large. At 72 -92 s, it was in the middle stage of loading, and the b-value changed little. This is because the magnitude difference ΔM was small, and the change in N was not obvious. According to the corresponding AE waveform, there was no AE event with a large amplitude in this stage, but the AE event with a small amplitude was relatively intensive, indicating that the wood continuously accumulated energy in this period. At 36–132 s, the lowest point of the b-value can correspond to the high-amplitude event of the AE original signal one by one, indicating that the b-value can describe the concentrated release of strain energy from a more subtle perspective, thus reflecting the microscopic fracture inside the material. After the loading time exceeded 132 s, the frequency of AE events increased significantly, and the amplitude was large. The b-value at this stage remained at a low value without obvious fluctuation. Combined with Fig. 3b, it can be seen that the load

suddenly decreased at 133 s, which indicated that the macroscopic fracture of *Zelkova schneideriana* occurred and the wood lost its original mechanical properties, indicating that there was a concentrated release of strain energy in the wood at this time.

Figure 5 shows the b-value variation curve during the fracture process of *Pinus sylvestris* var. mongolica. The b-value variation curve of *Pinus sylvestris* var. mongolica is very different from that of *Zelkova schneideriana*, which is caused by the difference between the two materials. According to the b-value variation curve of *Pinus sylvestris* var. mongolica, it can be roughly divided into four stages, which are similar to *Zelkova schneideriana*. The first stage is 0–12 s, and the wood is in the fully elastic stage. Combined with Fig. 2a, it can be seen that there was no obvious AE event in this period, and the wood did not release strain energy. In the second stage from 12 to 32 s, the b-value is larger because the magnitude difference ΔM and N is small; at this time, the wood is in the range of the elastic stage, the deformation is small, and the strain energy release is low. With continuous loading, at 32–132 s, the b-value first decreased and then fluctuated continuously. The decrease in the b-value is due to the gradual increase in the magnitude difference ΔM and N. Combined with Fig. 2a, it can be seen that before 52 s, intensive low amplitude AE events began to appear, indicating that the strain energy was gradually released and irreversible damage occurred to the wood. In the interval [52,56] and [120,124], the b-value is larger, which is due to the smaller magnitude difference ΔM and N, resulting in a larger b-value. Combined with the AE waveform diagram, there was no obvious AE event, indicating that the strain energy gradually accumulated at this time. With continuous loading, when the time exceeded 132 s, *Pinus sylvestris* var. mongolica obviously fractured, the b-value remained at a low value, and the strain energy was released intensively. From the research results on the damage and fracture of *Pinus sylvestris* var. mongolica and *Zelkova schneideriana*, the dynamic change in the b-value can represent the accumulation and release process of strain energy. The increase in the b-value indicates the gradual accumulation of strain energy, and the decrease in the b-value indicates the concentrated release of strain energy.

Conclusions

In this paper, three-point bending tests were conducted on *Pinus sylvestris* var. mongolica and *Zelkova schneideriana,* respectively, and the AE signals collected were analyzed by using the change law of the b-value and seismic magnitude difference entropy, and the following conclusions were drawn:

1. In this paper, the increase in the b-value indicates the gradual accumulation of strain energy, and the decrease in the b-value indicates the concentrated release of strain energy. The constant b-value indicates that the distribution of AE events is constant and the strain energy state is relatively stable. The change law of the b-value can effectively reflect the damage process and the release state of the strain energy of wood under cyclic loading.
2. The seismic magnitude difference entropy can accurately reflect the randomness and chaos of the signal and provide an objective basis for the level evaluation of wood damage and fracture. Based on the analysis of the seismic magnitude difference entropy, the damage process of wood can be divided into the elastic stage, elastic–plastic stage and plastic stage. In the elastic stage, the chaos degree of the AE signal is the lowest, and in the plastic stage, the macroscopic fracture of wood occurs, and the chaos degree reaches the highest value.
3. Through the analysis of seismic magnitude difference entropy, it can be seen that *Zelkova schneideriana* and *Pinus sylvestri*s var. mongolica show some differences in the process of damage and fracture: because *Zelkova schneideriana* is more brittle than *Pinus sylvestris* var. mongolica, as seen from the seismic magnitude difference entropy, the elastic–plastic stage of *Pinus sylvestris* var. mongolica is more obvious than that of *Zelkova schneideriana*; the overall entropy value of *Pinus sylvestris* var. mongolica is larger than that of *Zelkova schneideriana*.

The b-value and seismic magnitude difference entropy of AE can identify the damage of wood. However, the critical value of the b-value of AE and the differential entropy of the seismic level at the time of wood fracture are still difficult to solve. Evaluating the damage and fracture process of wood is always a research direction in the future; therefore, this issue needs to be further explored in future studies.

Abbreviations

AE Acoustic emission
NDT The nondestructive testing
MC Moisture content

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Not applicable.

Author contributions

YZ conceived the study and designed the methodology; NX, FM and GQ conducted the lab work; YZ collected the data, conducted the statistical analysis and led the writing of the manuscript; ML, SF, and DZ devised conceptual ideas and provided project support and added substantial edits to the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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Availability of data and materials
The experimental data used in this study are available on request from the corresponding author.

Declarations

Competing interests
Conflicts of interest the author declares that he has no conflict of interest.

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