Scholars Journal of Engineering and Technology
Abbreviated Key Title: Sch J Eng Tech
ISSN 2347-9523 (Print) | ISSN 2321-435X (Online)
Journal homepage: https://saspublishers.com

OPEN ACCESS

Experimental Study on the Crack Evolution Pattern of Pine Wood with Different Moisture Content

Jiaming He[1], Yanhua She[1*], Meng Li[1], Gaojie Cai[1], Bin Hu[1]

[1]School of Urban Construction, Yangtze University, Jingzhou, Hubei, China

DOI: 10.36347/sjet.2022.v10i06.002 | **Received:** 13.05.2022 | **Accepted:** 25.06.2022 | **Published:** 29.06.2022

***Corresponding author:** Yanhua She
School of Urban Construction, Yangtze University, Jingzhou, Hubei, China

Abstract **Original Research Article**

To investigate the crack development of wood specimens under different water content working conditions, and to explore the effect of water content on the mechanical properties of wood and the crack evolution law, pine wood specimens with 0%, 10%, 20%, 30%, 40% and 50% moisture content is used for this study. The mechanical testing machine and acoustic emission equipment is used to collect the energy signals emitted from the wood under load, and the AE signals (ringing counts, energy) is obtained using acoustic emission (AE) technique, and the acoustic AE signals is profiled using parametric analysis. The crack evolution pattern of the cracked wood specimens with different moisture content is consistent with the results obtained from the acoustic emission test, and the ringing count and energy can accurately reflect the damage of the wood, while the higher the moisture content, the flatter the crack development and the lower the bearing capacity of the specimens. The crack evolution of cracked wood specimens with different moisture content can be accurately predicted by acoustic emission ring counts and energy, and the degree of crack evolution of wood is inversely proportional to the moisture content. The test results provide a reference for further research on the relationship between moisture content and wood effects.

Keywords: Pine wood; moisture; acoustic emission; crack evolution.

1. INTRODUCTION

As an environmentally friendly, convenient and renewable natural resource, wood has been a hot spot for application and research since ancient times. Pinewood has a straight main pole, a tall body, and is hardy and drought-resistant, making it a world-renowned tree species. Pine wood has a solid texture and dense grain, and is an important material for furniture, construction, bridges, and ships. Pine wood and its products under normal conditions contain some moisture, and this moisture can have a significant effect on the physical properties of the wood, so it is necessary to study the law of moisture content on the evolution of cracks. Acoustic emission (AE) technology, as a dynamic non-destructive testing technique, collects transient elastic waves within the wood, which are processed by sensors into electrical signals, and these signals contain information about the state within the material [1-4], while moisture content affects the speed of wave propagation within the wood, which is inversely proportional to each other within a certain moisture content range [5-8]. Sun *et al.*, [9] then used the acoustic emission technique for dynamic load detection of wood using sorrel as test wood and predicted wood damage fracture using acoustic emission parameter analysis. Shao *et al.*, [10] showed that during damage destruction of wood under compression, different energy is released at each damage stage of the specimen, generating acoustic emission signals. Zhang *et al.*, [11] showed the quantitative relationship between the acoustic emission signal and the damage suffered by the specimen by modeling the wood damage evolution under different loading conditions. By creating artificial surface cracks in wood, Wang *et al.*, [12] investigated that the AE signal of wood received the effect of surface cracks. For glued wood, Li *et al.*, [13] combined with AET method, the study proved that the gluing layer affects the AE signal propagation, and the finger-joined gluing layer has more significant effect on the signal propagation rate than the glued gluing layer. Ju *et al.*, [14] used a transient frequency-based method to study and summarize the characteristic pattern of AE signals during wood damage. Li *et al.*, [15] used four moisture content Yunnan pine wood specimens as the basis of their study to explore the effects of wood with different moisture content on acoustic emission signals and characteristics. Tu *et al.*, [16] prepared wood containing cross-grain cracks and used a combination of AE and DIC to monitor the crack evolution pattern of the specimens. The use of acoustic emission technology for wood inspection is relatively mature, but most experimental studies only focus on a single moisture content of wood, while moisture content has an important impact on all properties of wood, especially its mechanical properties, the mechanical properties of wood at different moisture content vary greatly, and the analysis of the effect of moisture content on the crack evolution of wood specimens is still lacking.

Based on the above research results, this experiment takes prefabricated 0%, 10%, 20%, 30%, 40% and 50% moisture content pine wood as the research object, and analyzes and studies the acoustic emission dynamic evolution characteristics of pine wood cracks from the acoustic emission signal parameters of the material under different moisture content conditions to find the crack evolution law of pine wood under different moisture content.

2. MATERIALS AND METHODS

2.1 Test material

The specimen is North African cedar wood with a radius of 30 mm, a height of 200 mm, a density of 0.56 g/cm^3, and a pine wood age of 15 years. Before the test started, three groups of specimens is labeled as TP-1, TP-2, TP-3, the number of each group was 6, the specimens is dehydrated with a dryer (105±5℃), and then one specimen in each group was completely wrapped with cling film and marked as WC0 (the number indicates the specimen's Water content), and then the other test pieces is taken out and put into water to fully soak, and after their water content reached 10%, 20%, 30%, 40%, 50% respectively, they is taken out and wiped with filter paper to remove the excess water on the surface and set aside, and finally wrapped with cling film and marked as WC-10, WC-20, WC-30, WC-40, WC-50 respectively. Since the data collected in this test are large and the damage process pattern of each group of specimens is similar, the test data of TP-2 group is taken as an example, and Table 1 is the mass change during the preparation of each moisture content specimen in this group.

Table 1: Specimen preparation

Test piece	Dewatering quality /g	Soaking quality /g	Error
WC-0	202.109	202.109	0%
WC-10	196.522	216.435	0.1%
WC-20	200.826	241.289	0.1%
WC-30	181.723	236.645	0.2%
WC-40	212.895	298.411	0.2%
WC-50	178.523	267.918	0.1%

2.2 Test method

The equipment used for the test is shown in Fig 1 and Fig 2. The set of equipment consists of loading system and acoustic emission system. The loading rate was 0.2mm/s; Using DS5 acoustic emission detection system as an acoustic emission detection instrument system (the arrangement of six sensors, sensor location from the bottom of 40mm, 100mm, 140mm, respectively), the channel threshold value is set to 25mV, amplifier gain of 40dB, sensor frequency range of 50 ~ 400kHz, sampling frequency of 2.5MHz/s, and Vaseline was selected as the coupling agent to reduce noise. The acoustic emission system is triggered at the same time when the tester is started, and the acoustic emission signal data of the damage process of the specimen is collected simultaneously.

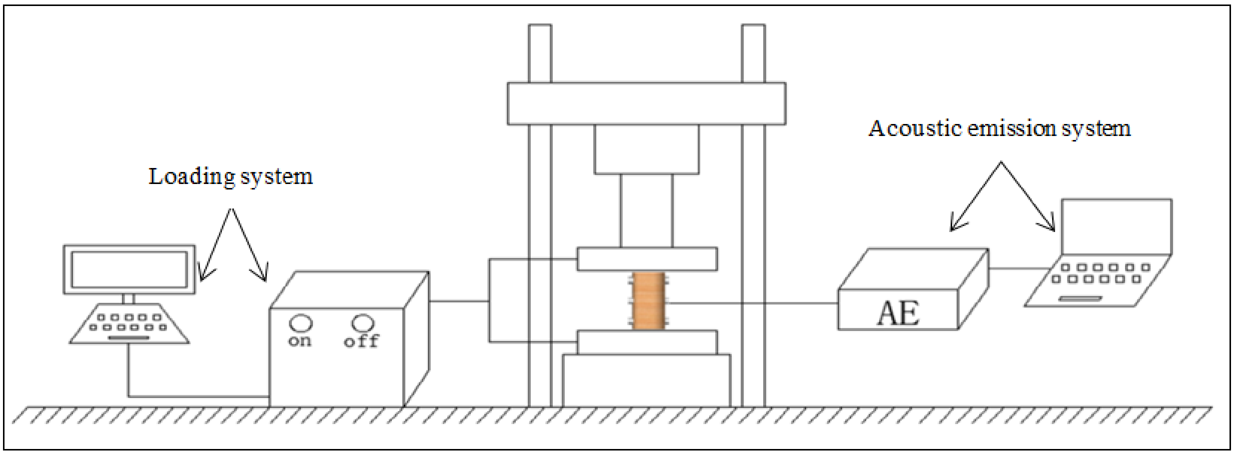
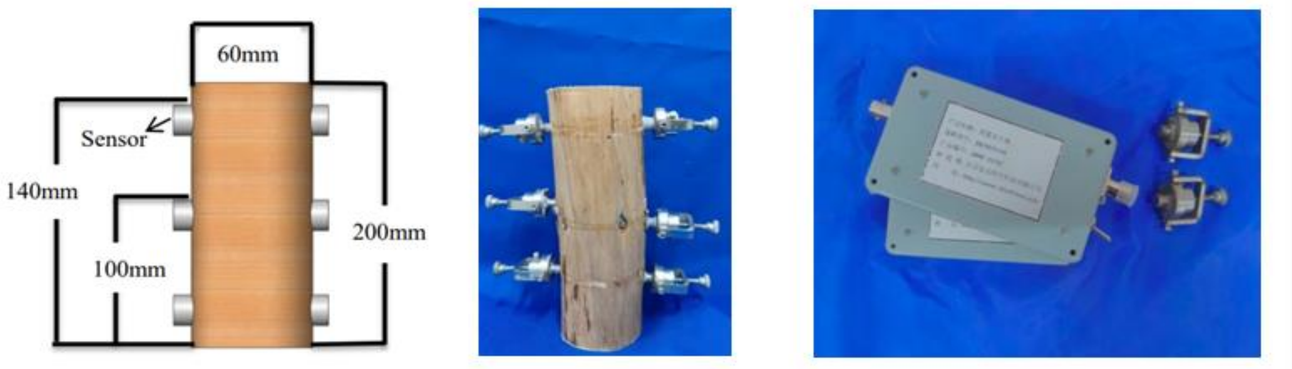


Fig 1: Loading schematic



(a) Sensor position pattern diagram (b) Object (c) Acoustic emission amplifiers and sensors

Fig 2: Testing equipment

3. RESULTS AND ANALYSIS

Under the same test conditions, pine specimens with different moisture content is loaded and the acoustic emission signal data of the specimens is collected to investigate the crack evolution pattern of pine wood specimens with different moisture content. Based on the acoustic emission parameter analysis method, the data of loading time, load, loading point displacement, ringing count and energy parameters is selected to characterize the acoustic emission signals collected during the loading of pine specimens with 0%, 10%, 20%, 30%, 40% and 50% moisture content, and to obtain the acoustic emission signal history diagram, acoustic emission cumulative ringing count and cumulative energy diagram, acoustic emission signal data tab and acoustic emission source schematic diagram. The whole experiment can be divided into five evolutionary stages according to the process of each parameter over time: initial pressurization stage, elastic deformation stage, crack initiation stage, crack spreading stage and compression failure stage.

3.1 Analysis of Evolution Stage

1. The acoustic emission signal of pine wood with 0% moisture content is shown in Fig 3.

Initial pressurization stage: In the range of about 0 to 20s, the load curve is approximately straight. At this stage, the test machine indenter contact with the top of the specimen, the contact position buckling reaction, the specimen internal vertical stress, while the acoustic emission signal is small, the specimen did not occur damage;

Elastic deformation stage: In the range of about 20 to 35s, the elastic deformation of the material grows with the increasing load, and the specimen may produce a small amount of microscopic deformation damage, but the crack is not found, and the ringing count and energy increase accordingly, but the acoustic emission signal is still small;

Crack initiation stage: In the range of about 35 to 42 s, the load value reaches 85.47 kN at the P 0% point and the displacement of the specimen at the loading point $\delta = 2.23$ mm. A large number of cracks appear on the specimen, and the number of cracks is increasing, the sound of crack expansion is emitted inside the specimen, and the acoustic emission ringing count and energy signal increase sharply. From the point P 0%, the slope of the load curve changes gradually, the load value decreases continuously, while the damage of the specimen increases further;

Crack spreading stage: In the time period of about 42-70s, a large number of visible cracks appear in the specimen, and the width of the cracks is increasing, the damage of the specimen is further deepened, at this time the bearing capacity has significantly declined, the acoustic emission signal is reduced, there is a larger rupture sound in the process of pressure, when loading to Q 0% point, the slope of the slope of the load curve has changed, and most of the specimen has been destroyed;

Compression failure stage: The acoustic emission signal is more intensive after about 70s, and the specimen is basically destroyed by 300s, and the damage integrity of the specimen is very low at this moisture content.

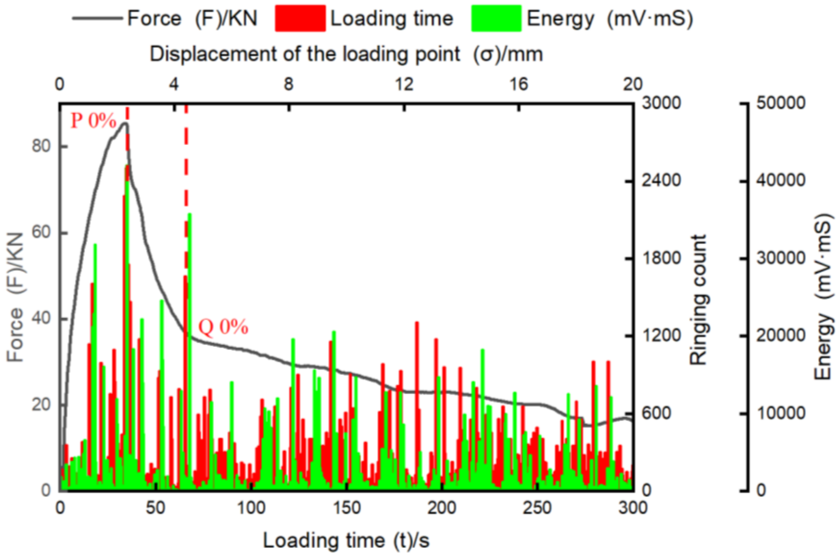


Fig 3: WC-0 acoustic emission signal history

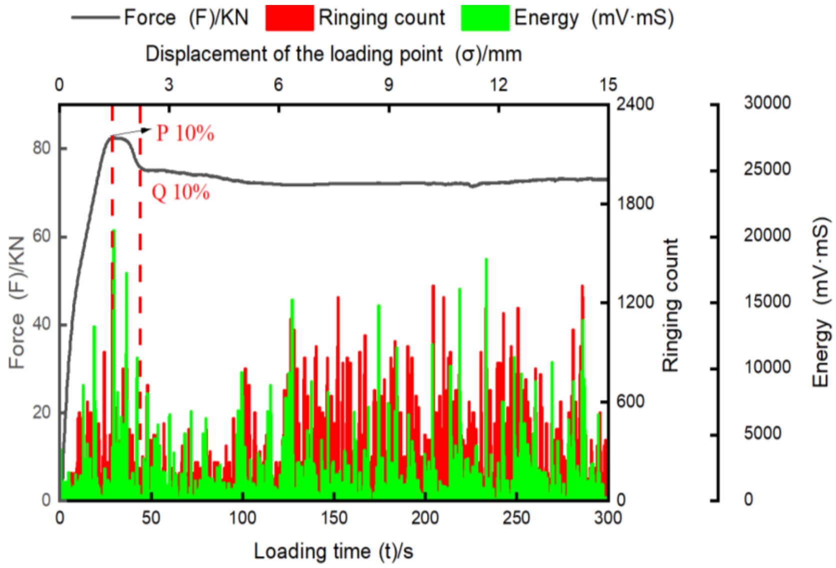


Fig 4: WC-10 acoustic emission signal history

2. The acoustic emission signal of pine wood with 10% moisture content is shown in Fig 4.

Initial pressurization stage: In the range of about 0 to 15 s, when the tester was loaded on the 10% moisture content pine specimen, the tester indenter was in contact with the top of the specimen and the acoustic emission signal was generated simultaneously. Compared with the 0% moisture content pine specimen, the flexural response of the 10% moisture content pine specimen was stronger and the top deformation of the specimen was more obvious, but the brittle damage was not as severe as that of the 0% moisture content specimen due to the effect of moisture;

Elastic deformation stage: In the range of about 15 to 27s, the ringing count, energy and amplitude signal of the specimen are increasing, the damage degree of the specimen is increasing, and the elastic deformation also occurs, and the acoustic emission signal is still small;

Crack initiation stage: In the range of 27 to 40s, cracks is generated on the specimen, but the sound of crack propagation was small, and the specimen had visible bending. At the same time, the acoustic emission signal gradually increased, reaching a new peak at P10%, and the load value reached 82.49 KN. The displacement of the loading point of the specimen was δ = 1.61 mm. The specimen bends more after the P 10% point and the crack expands rapidly;

Crack spreading stage: In the range of about 40 to 45s, the specimen becomes compressed, and when loaded to Q 10% point, the specimen has cracks all over, and the crack development is also accompanied by cracking sound, but compared with the 0% moisture content pine specimen, the 10% moisture content pine specimen cracking sound is smaller, and the damage form is relatively good, in this time period, the acoustic emission signal appears more intensive peak;

Compression failure stage: In the range of about 45 to 300s, the pine specimens with 10% moisture content is cracked, but their compressive capacity and stability is significantly better than those under 0% moisture content working condition.

3. The acoustic emission signal of pine wood with 20 % moisture content is shown in Fig 5.

Initial pressurization stage: Approximately in the range of 0 to 8s, 20% moisture content of pine specimens under pressure to produce acoustic emission signal, the moisture content of pine wood to produce acoustic emission signal is smaller, the wood within the cells absorb more water;

Elastic deformation stage: In the range of about 8 to 13s, the acoustic emission signal of the specimen gradually increases, moisture appears on the specimen but not much, and the energy release is less;

Crack initiation stage: In the range of about 13～20s, the specimen was pressed to be extruded moisture and appeared obvious bending, the acoustic emission signal reached a new peak at P 20% point, the maximum load value was 51.83kN, the specimen loading point displacement δ=2.38mm. With the increase of pressure of the testing machine, the specimen continuously emerged moisture, the specimen surface appeared visible cracks, but the cracking sound of the specimen was small;

Crack spreading stage: In the range of about 20 to 245s, cracks develop rapidly on the specimen, but compared with the 0% and 10% cases, the crack expansion is not too drastic at this moisture content, and the specimen undergoes slow lateral deflection, and after reaching the Q 20% point, the specimen already has visible cracks;

Compression failure stage: After 245s, the specimen was gradually squeezed, after which secondary cracking and complete destabilization occurred.

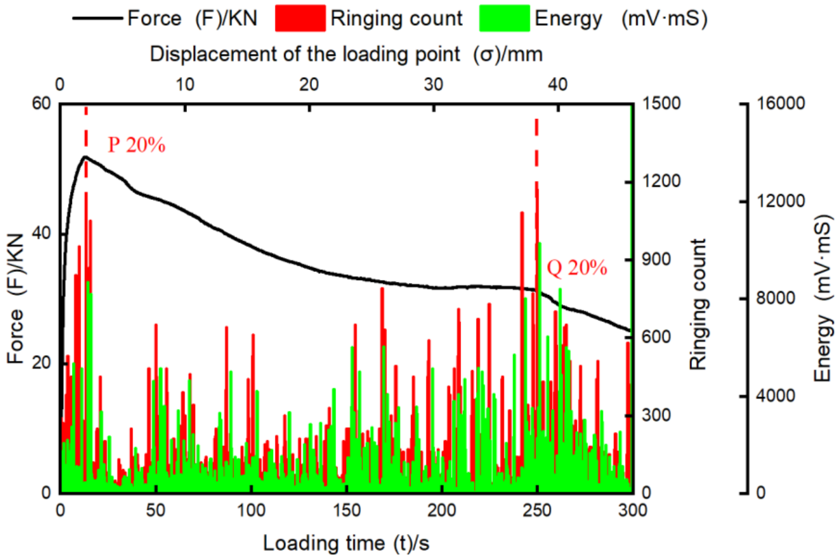


Fig 5: WC-20 acoustic emission signal history

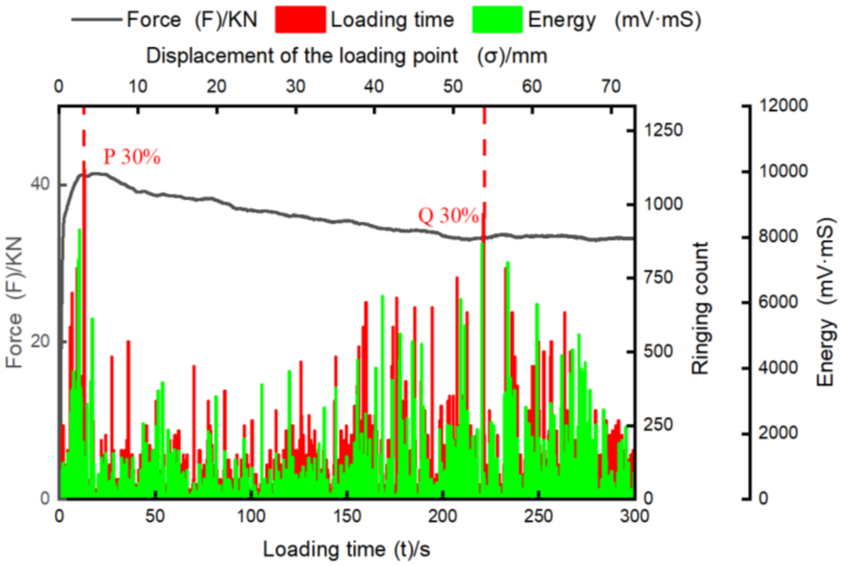


Fig 6: WC-30 acoustic emission signal history

4. The acoustic emission signal of pine wood with 30% moisture content is shown in Fig 6.

Initial pressurization stage: Approximately in the range of 0 to 7s, 30% moisture content of pine specimens acoustic emission signal is weaker year-on-year, the load curve is approximately straight line, and climbs faster, the surface of the specimen with the pressure and moisture;

Elastic deformation stage: In the range of 7 to 11s, a small amount of water appears on the surface of the specimen, the bending of the specimen is obvious, and the energy release increases gradually;

Crack initiation stage: In the range of 11 to 21s, the specimen buckled under compression, and the surface of the specimen was extruded with small water droplets. The specimen cracked, but there was almost no cracking sound. The acoustic emission signal reached a new peak at p 30%, and the load reached 41.45 kN. The displacement of the loading point of the specimen was δ = 3.17 mm;

Crack spreading stage: In the range of about 21 to 227s, the specimen is deformed by pressure, and although no cracking sound can be heard at the Q 30% point, the surface of the specimen is already covered with cracks, while the specimen does not have a relatively violent reaction;

Compression failure stage: In the range of 227 to 300s, the specimen is compressed, and the crack is gradually widened and deepened until the specimen is damaged.

5. The acoustic emission signals of pine with 40 % moisture content are shown in Fig 7.

Initial pressurization stage: In the range of 0 to 5s, the acoustic emission signals of pine wood specimens with 40% moisture content are similar to those of pine wood specimens with 30% moisture content, but they are relatively weak, and the surface of the specimen rapidly appears moisture;

Elastic deformation stage: In the range of about 5 to 13s, moisture appears on the surface of the specimen, and the bending of the specimen is more obvious;

Crack initiation stage: In the range of 13 ~ 19s, the lateral displacement of the specimen occurs under compression, but there is no cracking sound. The acoustic emission signal reaches the peak at P 40%, and the maximum bearing capacity reaches 40.66 kN. The displacement of the loading point of the specimen is 2.79 mm;

Crack spreading stage: In the range of 22 to 220s, the deformation of the specimen is serious, and a large number of water droplets appear on the surface of the specimen. There is a small piece of water in the test bench, and the specimen deforms greatly when it reaches Q 40%;

Compression failure stage: In the range of about 220 to 300s, the specimen is squeezed out of moisture and then squeezed to destruction.

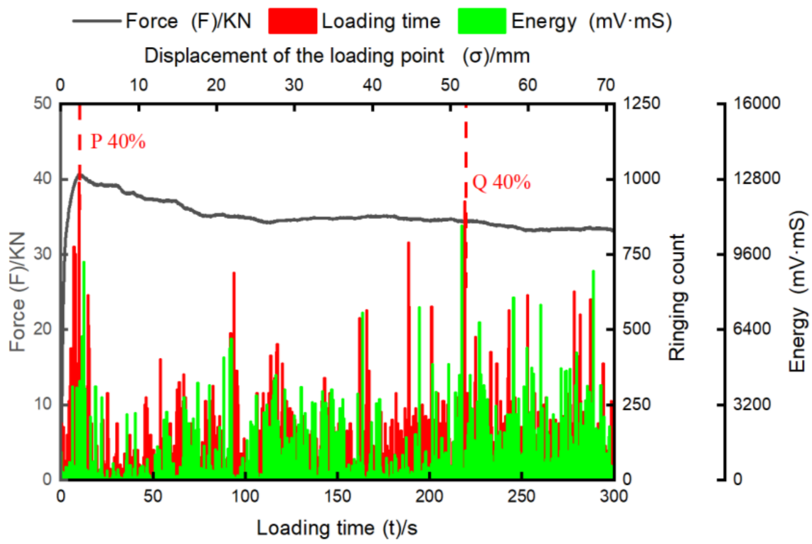


Fig 7: WC-40 acoustic emission signal history

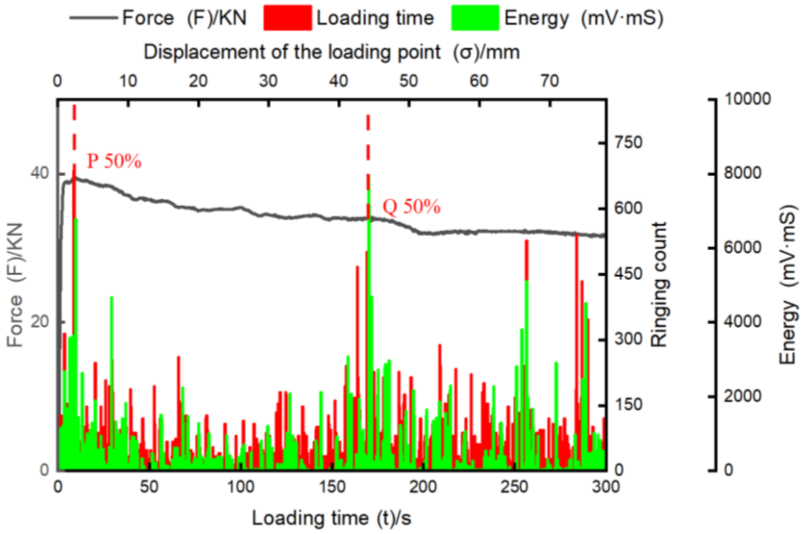


Fig 8: WC-50 acoustic emission signal history

6. The acoustic emission signals of pine with 50 % moisture content are shown in Fig 8.

Initial pressurization stage: In the range of 0 to 5s, the peak time of acoustic emission signal of pine specimen with 50 % moisture content is shortened, and the specimen has visible bending deformation;

Elastic deformation stage: In the range of about 5 to 10s, visible water droplets on the surface of the specimen occur obvious deformation;

Crack initiation stage: In the range of 10 to 17s, the specimen was subjected to lateral displacement failure under compression, and the contact area between the specimen and the pressure head was subjected to compression failure. The acoustic emission signal reached the peak at P 50%, and the maximum load was 39.50 kN. The displacement of the loading point of the specimen was δ = 2.13 mm. At this time, there was a lot of water on the testing machine;

Crack spreading stage: In the range of 17 to 170s, the specimen moves laterally and is extruded with more water. Although the specimen cracks, the number and depth of cracks are less than those of other moisture content specimens;

Compression failure stage: In the range of about 170 to 300s, the specimen occurred serious deformation, with the operation of the press, the greater the degree of deformation until failure.

3.2 Acoustic emission signal data analysis

Table 2 shows the acoustic emission signal (ringing count, energy) data of specimens with different moisture content at various stages, with the increase of moisture content of the specimens, the acoustic emission signal continuously decreases, and the two are inversely proportional. Under the same water content condition, the acoustic emission signal is the strongest in the crack growth stage, the acoustic emission signal in the initial pressurization stage and the elastic deformation stage before this stage is increasing with loading, and the acoustic emission signal in the crack expansion stage and the damage stage under pressure after this stage is decreasing with loading.

Table 2: Acoustic emission signal data

Stage / AE / Specimen	Initial pressurization stage	Elastic deformation stage	Crack initiation stage	Crack spreading stage	Compression failure stage
	Ringing Energy count /mV·mS	Ringing Energy count /mV·mS	Ringing Energy count /mV·mS	Ringing Energy count /mV·mS	Ringing Energy count /mV·mS
WC-0	<300 <5000	<1700 <34000	<2300 <42000	<1700 <35000	<1400 <20000
WC-10	<200 <2000	<1000 <15000	<1500 <22000	<1000 <20000	<1400 <18000
WC-20	<500 <5500	<600 <6000	<1100 <10000	<900 <8000	<1100 <12000
WC-30	<350 <3000	<750 <6000	<1200 <8000	<800 <7500	<1000 <8200
WC-40	<300 <2000	<850 <5000	<950 <10000	<600 <7400	<1000 <12000
WC-50	<400 <3500	<400 <4000	<700 <7500	<00 <7500	<550 <6000

Fig 9 shows the variation of cumulative ringing count and cumulative energy with time for specimens with different moisture content. The graph reflects that the cumulative acoustic emission ringing count and cumulative energy decrease as the water content of the specimens increases. Taking one of the a plots as an example, the slope of the cumulative ringing count and cumulative energy curve change before and after the P 0% point and the Q 0% point, but the change in the cumulative ringing count and cumulative energy curve before and after the P 0% point is greater than that of the Q 0% point.

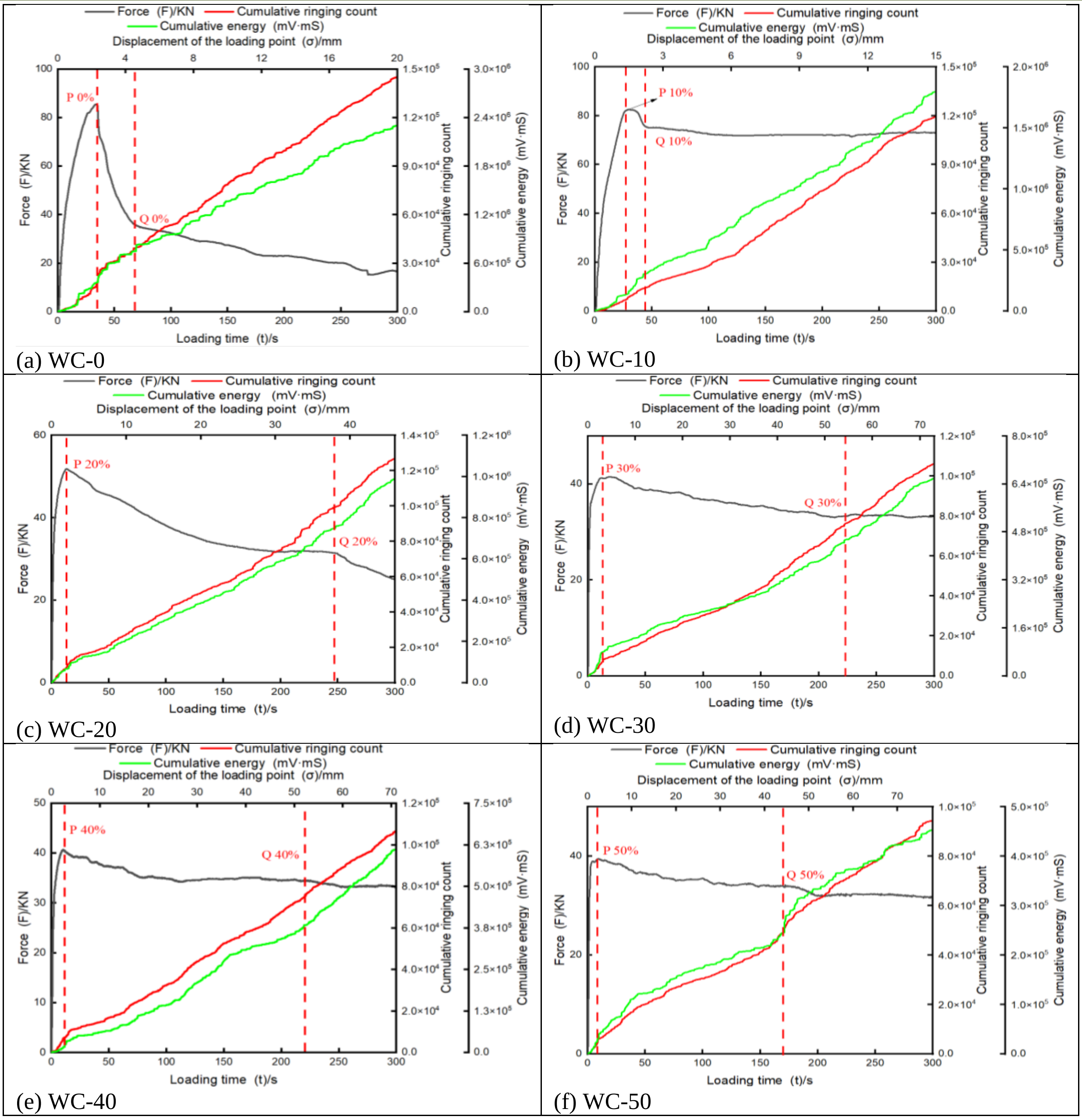


Fig 9: Acoustic emission cumulative ringing count and cumulative energy

4. CONCLUSION

The experimental study of monitoring the crack evolution law of pine specimens at different moisture content using acoustic emission (AE) technique and related test instruments, analyzing the acoustic emission signals (ringing counts, energy) by collecting specimens for loading, analyzing and summarizing the test results, led to the following conclusions:

1. Using the acoustic emission technique, the crack evolution and damage degree of pine specimens with different moisture content can be monitored, which can reflect the development and expansion of cracks inside the specimen.
2. The maximum load-bearing capacity of pine specimens with 0% moisture content is higher compared with that under 10% moisture content, but the crack development is more violent. The damage is greater and the damage pattern is poor, while the crack development of pine specimens with 10% moisture content is smoother, and the secondary damage will occur after the water is squeezed out of the pine specimens with 20% moisture content. Although the crack development of pine specimens with 30% moisture content is gentle, but the wood absorbs water causing load-bearing capacity decreased, this situation is more obvious in 40% moisture content of pine specimens, more prominent in the case of 50% moisture content, and high moisture content will also cause changes in the form of damage. The top and low end of the specimen

is extruded offset phenomenon. The tests show that moisture has a significant effect on the development of cracks in the pine specimens.

3. Acoustic emission technology in the monitoring process is easy to operate, applicable to a wide range, high accuracy, acoustic emission signal reflects the characteristics of the parameters and the damage of the test piece, can be in the actual project with this paper as a reference.

REFERENCE

1. Zhang, J. H., Dai, Y., & Li, J. Q. (2020). A review of the nondestructive testing of wood based on acoustics. *Science & Technology Review*, 38(22), 95-103.
2. Wang, F. H., Zhu, X. D., & Yang, L. Q. (2006). Acoustic emission testing technology and its application prospect in nondestructive testing of wood materials. *World Forestry Research*, (2), 55-60.
3. Strojecki, M., Lukomski, M., & Colla, C. (2012). Acougstic emission as a non-destructive method for tracting damage:from laboratory testing to monitoring histric strucyures. *RILEM Bookseries*, 6, 1131-1136.
4. Ando, K., Hirashima, Y., & Suginara, M. (2006). Microscopic processes of shearing fracture of old wood examined using the acoustic emission technique. *Journal of Wood Science*, 52(60), 483-489.
5. Liu, H., & Gao, J. M. (2014). Effect of moisture content and density on the stress wave velocity in wood. *Journal of Beijing Forestry University*, 36(6), 154-158.
6. Si, H., & Lu Z. Y. (2007). Impact of growth characteristics of larchwood on velocity propagating of the stress wave. *Wood Processing Machinery*, (5), 14-17.
7. Montero, M. J., Jimenez, J., De. La. M., & Eateban, M. (2015). Intiuence of motsture content on the wavevelocly to eaimate the mechanlcal properies of large cross-section pleces for stuctural use of scots pine from Spaln. *Maderas Ciencia Y Tecnologia*, 17(2), 407-420.
8. Peng, H., Jiang, J. L., & Zhan, T. Y. (2016). Influence of density and moisture content on ultrasound velocities along the longitudinal direction in wood. *Forestry Science & Technology*, 52(10), 117-124.
9. Sun, J. P., Wang, F. H., & Zhu, X. D. (2006). Testing damage process of david poplar under the dynamic loads based on acoustic emission technique. *Forestry Science & Technology*, 42(9), 89-92.
10. Shao, Z. P., Chen, P., & Zha, C. S. (2009). Acoustic emission characteristics of damage and fracture process of wood and Felicity effect. *Forestry Science & Technology*, 45(2), 86-91.
11. Zhang, Z. Y., & Zhao, D. (2009). Study on the acoustic emission model of wood damage. *Mechanics in Engineering*, 31(2), 74-77.
12. Wang, M. H., Deng, T. T., & Ju, S. (2020). Effect of wood surface crack on acoustic emission signal propagation characteristics. *Journal of Northeast Forestry University*, 48(10), 82-88.
13. Li, X. C., Ju, S., & Luo, T. F. (2019). Influence of adhesive layer at masson pine glulam on acoustic emission signal propagation characteristics. *Journal of Northwest Forestry University*, 34(3), 185-190.
14. Ju, S., Li, M., & Luo, T. F. (2020). Acoustic emission signal identification of wood damage process with instantaneous frequency. *Journal of Northeast Forestry University*, 48(02), 87-92.
15. Li, Y., & Xu, F. Y. (2019). Acoustic emission signal characteristics of pinus yunnanensis with different moisture content. *Forestry Science & Technology*, 55(6), 96-102.
16. Tu, J. C., Zhao, D., & Zhao, J. (2020). Experimental study on in situ monitoring of the evolution law of cracks in wood components with trasverse cracks based on acoustic emission and image correlation. *Journal of Beijing Forestry University*, 42(1), 142-148.