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Effect of Wetting Agent on Acoustic Emission of Wood[*1]

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濕潤劑 濃度에 따른 木材의 音響放射[*1]

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要 約

제지공장에서 사용하는 습윤제는 물의 표면장력을 낮춤으로써 목재섬유가 물을 빨리 흡수하여 팽윤하도록 도와준다. 목재섬유가 물을 흡수하여 팽윤하는 과정을 밝히기 위한 연구가 많이 진행되어 왔지만 목재섬유와 물의 상호작용을 상세히 연속적으로 측정할 방법이 전에는 별로 없었다. 목재섬유가 팽윤할 때 발생하는 팽윤압력은 음향방사를 동반하기 때문에 이를 측정하여 팽윤과정을 알아내는 기술이 개발되었다. 본 연구에서는 이 방법을 이용하여 목재를 여러 농도의 습윤제에 담갔을 때 발생하는 음향방사와 중량증가를 측정하여 이 두 변량의 상관을 조사하고 이 방법이 목재의 습윤과정연구에 유용하게 사용될 수 있는지를 조사하였다. 아까시나무와 라디에타 파인의 두 수종을 사용하였는데 두 수종의 흡수 형태는 매우 달랐다. 5분 동안 용액에 침지하였을 때 후자가 전자보다 10배 정도 더 많이 중량증가하였으며, 발생한 음향방사도 후자가 전자보다 훨씬 많았다. 아까시나무의 중량증가와 음향방사는 습윤제 농도에 거의 무관하였으나 라디에타 파인의 음향방사는 습윤제 농도의 증가에 따라 증가하였으며 라디에타 파인의 중량증가는 습윤제의 표면장력 변화와 일치하였다. 수종별 중량증가와 음향방사의 관계는 아까시나무가 음의 상관을 나타냈으나 라디에타 파인은 양의 상관을 나타내었다. 자비처리 시편은 무처리 시편보다 음향방사가 적었다.

Keywords : Wetting agent, acoustic emission, AE Hit, AE Count, ***Robinia pseudoacacia, Pinus radiata***

1. INTRPDUCTION

Wettability of wood is one of the important factors influencing the bonding properties of wood. A good correlation between the gluability and the wettability in water of five lauan species was reported by Bodig(1962). To determine the wettability of wood the contact angle method has generally been used (Hodgson *et al.*, 1988; Liptakova, 1994). However measuring the contact angle of a droplet on the wood surface is very difficult. To overcome this problem Casilla *et al.*(1981) have developed a simpler method by modifying the Wilhelmy slide technique(Young, 1976) and claimed that their method doesn't measure only the wettability of

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wood surface, but also absorption into wood.

To investigate the wetting process of wood when immersed in a liquid, its weight or swelling volume must be continuously measured with time, which is difficult and subject to error. Fortunately the acoustic emission(AE) technique can be usefully adopted to this application. When wood absorbs a polar liquid swelling pressures develop within the cell walls and between regions with different swelling coefficients as wood and liquid interact(Rice & Kabir, 1992). This wood and liquid interaction might lead to dislocation within the cell walls and to the generation of acoustic emissions from the wood during swelling.

Rice and Kabir(1992) reported that acoustic emissions and wood swelling are highly correlated and that both species and solution effects evidently exist when acoustic emissions are measured while wood is being immersed in a solution. The species effect results from the density, structure and extractives. The solution effects result from the polarity and size of the molecules and from the surface tension of a solution.

Molinski *et al.* (1991a) correlated acoustic emissions with the values of swelling pressure and verified their hypothesis that during the soaking of dry wood in water internal defects can be activated, most probably microchecks which show a tendency to increase in size at even low tensile stresses.

Molinski *et al.*(1991b) showed a decreasing trend in AE generation with an increase in the initial moisture content in the wood. They also concluded that the tensile stresses accompanying the soaking process produce acoustic phenomena, but that in contrast the compressive stresses do not produce acoustic emissions. This was confirmed by the lack of acoustic emissions during wood swelling under biaxial restraint.

Wetting agents, which can lower the surface tension of water, have been used to increase the drying rates of some species(Chen & Simpson, 1994), and to improve the preservative treatability of wood (Kumar & Morrell, 1992). A highly significant linear correlation between wettability and liquid surface tension was found for species with low and medium wettability, while that with high wettability showed no correlation(Casilla *et al.*, 1984). They also found that the type of wetting agent affected wettability, with the cation type yielding the greatest wettability followed by anionic and nonionic types.

The major objective of this study was to investigate the effect of wetting agent concentration on the acoustic emission of wood immersed in a solution and the possibility of the use of acoustic emission technology for the research on absorption phenomena of wood by correlating the number of acoustic emissions and the weights of absorbed liquid. The effect of boiling wood on acoustic emission was also examined.

2. MATERIALS & METHODS

Seventy matched samples of 2×2×2cm cube were cut from air-dried black locust (***Robinia pseudoacacia*** L.) heartwood and radiata pine (***Pinus radiata***) sapwood boards. Approximately two third of the samples of each species were boiled in water for one hour and the rest remained as controls. Prior to oven-drying the boiled samples were air-dried at room temperature for 3 days to avoid drying defects. During oven-drying the oven temperature increased gradually from room temperature to 103℃. The oven-dried samples were cooled and stored in a desiccator until the start of testing.

The wetting agent used for this study was anioic Aerosol E-DO #113, whose main constituent was sodium dialkyl sulfosuccinate, obtained from a local paper mill. According to its manufacturers its surface tensions at 0.001 and 1.0% concentration are 0.0640 and 0.0269N/m, respectively.

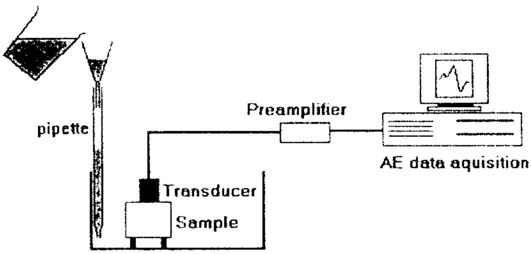

Fig. 1. A schematic diagram of the experimental set-up. A pipette was used to avoid AE noise during solution pouring.

The AE monitoring apparatus used for this research consisted of one 150kHz piezoelectric transducer, a 40/60dB dual preamplifier and a 2-channel analysis system manufactured by the Physical Acoustics Corp. (LOCAN 320). A high vacuum grease was used as a coupling agent. AE signals in wood were pre- and main-amplified by 40dB and 50dB respectively, and were filtered to eliminate frequencies above 200kHz. A threshold of 25dB was applied.

A schematic diagram of the experimental set-up is shown in Fig. 1. A transducer was coupled to the cross section of a sample. A long pipette was used so that pouring solution into the container would not cause AE noise. Pouring of the solution stopped when half of the sample thickness was immersed, which took no longer than a few seconds. Simultaneously AE signal aquisition started. The samples were deliberately half immersed to create shrinkage differentials so that a lot of AEs would be generated. Each AE measurement lasted for 5 minutes. Each sample was weighed before and after the experiment to calculate the weight of absorbed liquid. The experiment was repeated with seventy samples.

The calculation of weight percentage gain (WPG) of each sample is :

$$WPG(\%) = \left(\frac{W_{wood} - W_{od}}{W_{od}}\right) \times 100\ \% \quad \cdots\cdots [1]$$

where, W_{wood} : the weight of a sample after immersion(g),
W_{od} : the oven-dry weight of a sample(g).

3. RESULTS & DISCUSSION

3.1 WPGs

In terms of WPG the radiata pine samples absorbed 10 times more liquid than the black locust samples during the first 5 minutes immersion(Fig. 2). Statistical analyses of the WPG data, using a factorial design method, revealed that significant differences existed between the two species and between the solution concentrations(Table 1). But within a species significant differences didn' t exist between the boiled and control samples.

Regardless of this statistical result, Fig. 2 shows that for black locust the WPGs of the boiled samples are always higher than those of the controls while radiata pine does not follow the same tendency. This fact implies that the boiling effect on WPG varies from a species to another. Since boiling wood removes water soluble extractives from its cell walls and creates sorption sites, a species of high extractive content is more influenced by boiling than that of low extractive content(Chafe, 1993). It is no doubt that black locust heartwood is a species of high extractive content and radiata pine sapwood is a species of low extractive content.

The WPGs of the radiata pine sapwood increased with increased wetting agent concentrations, but those of the black locust didn' t (Fig. 2). This confirms that species and solution effects evidently exist for wood being immersed in a solution(Rice & Kabir, 1992).

However the WPGs of the radiata pine do not always increase linearly with the increase of solution concentrations. As shown in Fig. 3, they increase steeply at low concentrations and level off at around 0.3%. Thus it can be concluded that the absorption property of wood can

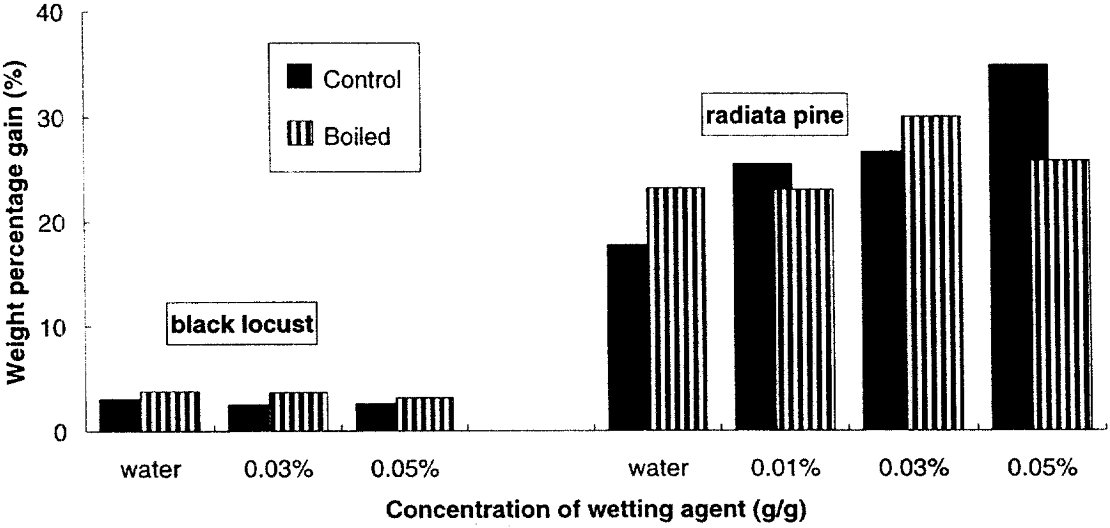

Fig. 2. The WPGs of the black locust and radiata pine samples when immersed in wetting agent solutions of various concentrations. The WPGs of radiata pine increase with the increase of wetting agent concentrations, while those of black locust don' t.

Table 1. Completely Randomized Factorial ANOVA for three factors of species, pretreatment and solution concentration. The last two factors are Split Plots on the first.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
Total	46	7460.6			
Species (A)	1	6479.8	6479.8	4712.8	0.0000
Error	6	8.3	1.4		
Pretreatment (B)	1	1.4	1.4	0.1	
AB	1	3.4	3.4	0.3	
Concentration (C)	2	192.2	96.1	9.7	0.0006
AC	2	241.9	121.0	12.2	0.0001
BC	2	125.6	62.8	6.3	0.0053
ABC	2	119.5	59.8	6.0	0.0066
Error	29	288.6	10.0		

be improved to a limited extent by reducing the surface tension of liquid, which decreases as the concentration of wetting agent increases.

3.2 AE signals

AE signals were monitored in terms of hit, count, amplitude, average frequency and duration. Cumulative AE hits showed a good linear relationship with cumulative AE counts for both species (Fig. 4), so the former were analysed hereafter.

In general the boiled samples emitted fewer acoustic emissions than the controls (Fig. 5). For black locust the boiled samples absorbed even more liquid than the controls (Fig. 2), but the former emitted fewer than the latter. This fact could be explained in a couple of ways. As described before, boiling wood removes water soluble extractives from its cell walls and creates sorption sites. These new sorption sites are

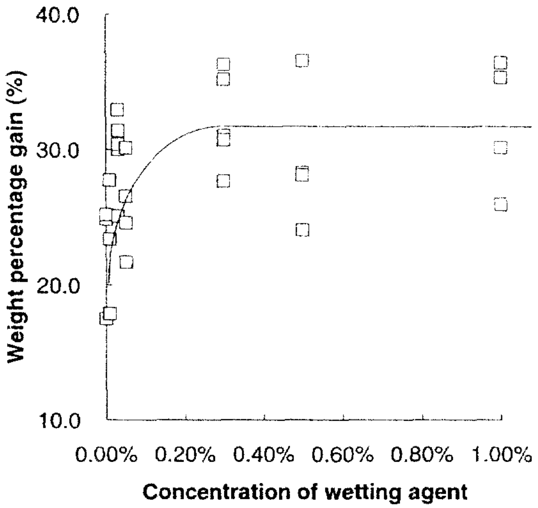

Fig. 3. Plot of WPGs at various wetting agent concentrations for radiata pine. They increase steeply at low concentrations and level off at around 0.3%.

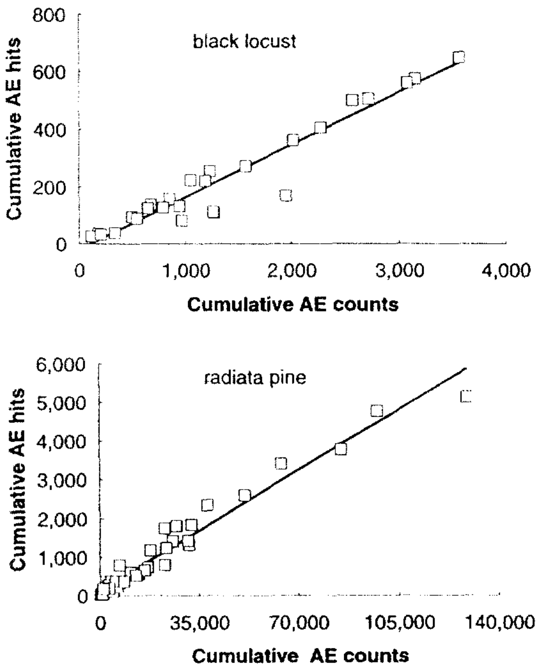

Fig. 4. Good linear correlations between cumulative AE hits and cumulative AE counts for the black locust(top) and the radiata pine(bottom) samples.

not so tightly closed that the absorbed water molecules can freely access to them without swelling the cell walls of wood. So the boiled samples absorbed more liquid, but emitted fewer acoustics.

However since the samples of radiata pine sapwood have little extractives and their boiled samples did not absorb more liquid than the controls(Fig. 2), their result can not be explained by the same way. It has been known that the strength of wood decreases by boiling (Kang, 1995). The swelling stress caused by water molecules absorbed in boiled wood also decreases, so resulting in fewer acoustic emissions.

The cumulative AE hits of radiata pine increased with the wetting agent concentrations (Fig. 5), while those of black locust didn' t, as did the WPG plots in Fig. 2. It is very interesting to notice that the number of cumulative AE hits of radiata pine at 0 and 0.01% are as low as those of black locust, but those at 0.03 and 0.05% increase sharply. Comparing with the WPG plot in Fig. 2, it could be concluded that some water molecules absorbed by the radiata pine samples at low concentrations remain in the cell lumens and don't contribute to emit acoustics because of their high surface tensions.

The WPGs and cumulative AE hits of the black locust and radiata pine controls are plotted in Figs. 6 and 7, while those of the boiled samples are not plotted because of their poor correlations. It was expected that the cumulative AE hits were positively correlated to WPGs. But the two species showed different correlations from each other: a negative for black locust and a positive for radiata pine.

This negative correlation of black locust implies that the samples absorbing more liquid emits fewer acoustics, which is very hard to explain. This may due to the complexity of the anatomical structures of black locust. For example, a sample with vessels filled with tyloses absorbs less liquid, but emits more acoustics if most liquid penetrates into the cell walls. On the contrary a sample with vessels free from

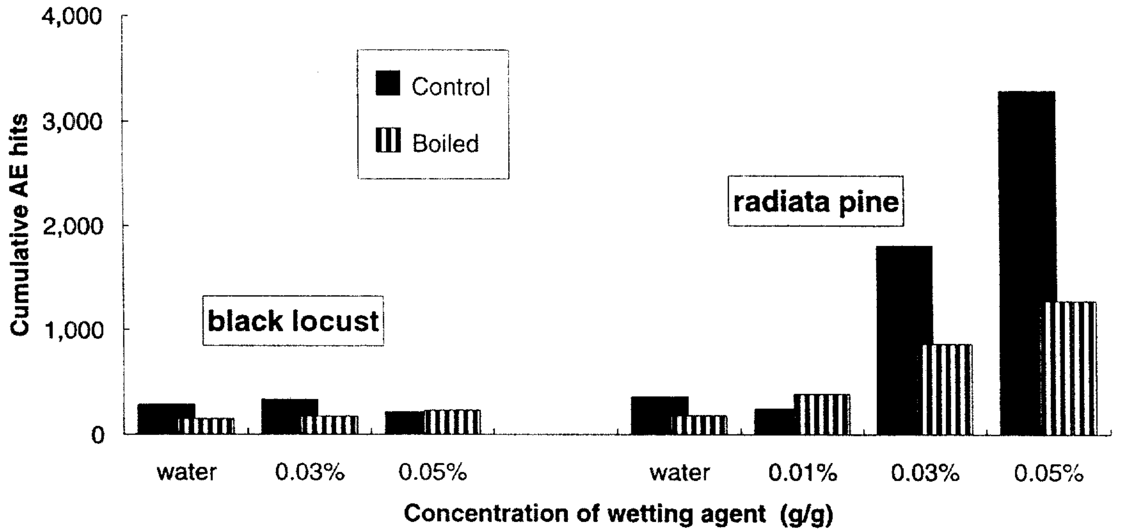

Fig. 5. The cumulative AE hits of the black locust and radiata pine samples when immersed in wetting agent solutions of various concentrations. The samples of radiata pine at 0.03 and 0.05% generated much more AE hits than others.

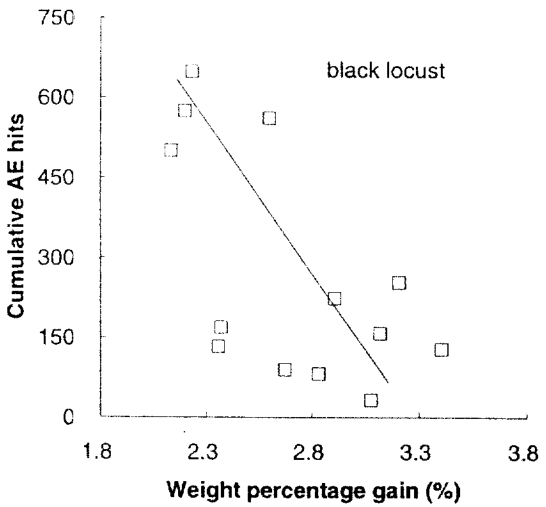

Fig. 6. A negative correlation between the cumulative AE hits and WPGs of the black locust samples.

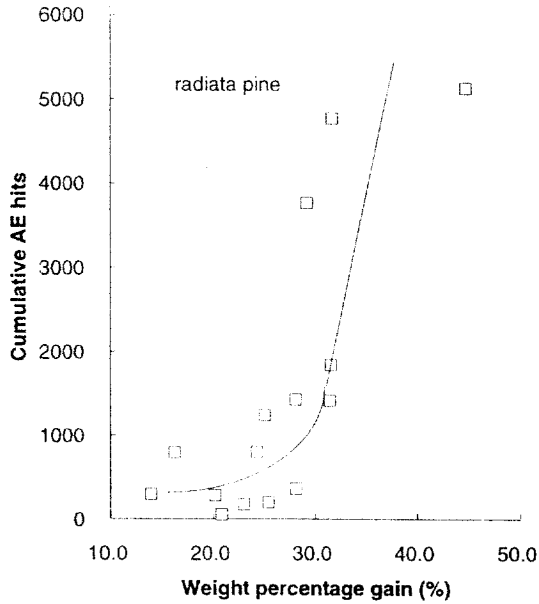

Fig. 7. A positive correlation between the cumulative AE hits and WPGs of the radiata pine samples. Above 25% of WPG, the cumulative AE hits increase enormously.

tyloses absorbed more liquid, but emits fewer acoustics if most liquid remains in vessels.

The cumulative AE hits of the radiata pine increase with WPG (Fig. 7). Especially, above 25% of WPG, the cumulative AE hits increase enormously.

The two species used in this study differ as much in water absorption properties as they differ in anatomical structures. Fig. 8 shows how

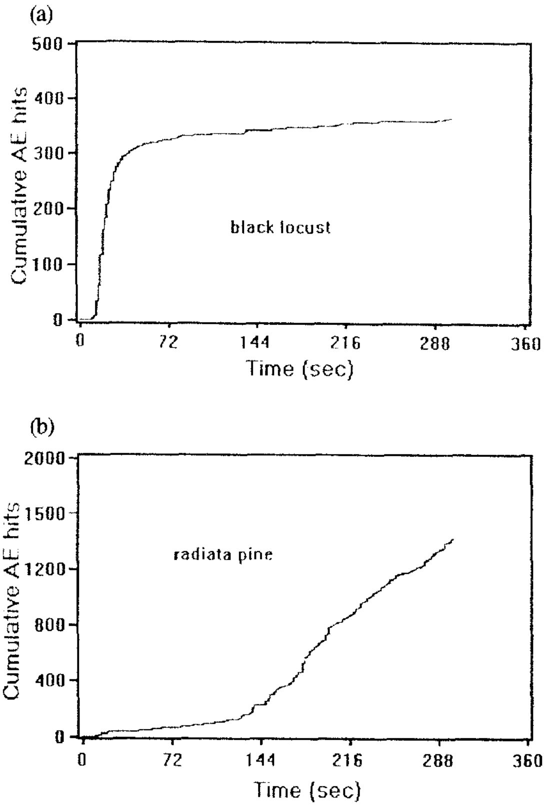

Fig. 8. Typical cumulative AE hit curves for the black locust(a) and radiata pine(b) samples. The two species show quite different patterns from each other.

the cumulative AE hits change with time for the two species. The cumulative AE hits of the radiata pine steadily increase after a delay of about 144 seconds, while those of the black locust steeply increase soon after immersing and level off at 36 seconds. According to Molinski *et al.* (1991) this fact implies that microcracks preexisted in the black locust samples. They found that microcracks causes the AE signals to appear faster, beginning practically at the moment the soaking starts and that the character of the distribution of the AE signals can be a quantitative index of the history of wood.

The AE amplitudes and durations of the radiata pine samples were much larger than for the black locust. The maximum amplitude and duration of the former were 80dB and 1,000μs, respectively, while those of the latter were 45 dB and 240μs, respectively.

As a conclusion, the acoustic emission technology is a useful tool to monitor the absorption behaviour of wood when immersed in liquid regardless that the cumulative AE hits do not directly correlate with the weight of absorbed liquid. To develop this technology the effects of species and solution should be assessed.

4. CONCLUSION

Acoustic emission phenomena of boiled and control wood samples immersed in wetting agent solutions of various concentrations were examined and the following conclusions were derived:

1. In terms of WPG the radiata pine samples absorbed solutions 10 times more than the black locust samples during a 5 minute immersion.
2. In general the boiled samples emitted fewer acoustics than the controls, even though the former absorbed more liquid than the latter.
3. Water absorption behaviour of the two species were quite different from each other. The WPGs and cumulative AE hits of radiata pine increased with the wetting agent concentrations, but those of the black locust didn' t.
4. The correlation between the WPGs and cumulative AE hits were negative for black locust and positive for radiata pine.

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