

ACOUSTIC AND OPTICAL MEASUREMENTS DURING THE STRAINING OF PAPER

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ABSTRACT

Acoustic emission(AE) and optical measurements were simultaneously applied to investigate the deforming process of paper materials. Samples used here were the handsheets from bleached softwood kraft pulp with variety of beating degree. The increase in the optical reflectance under tensile elongation could be caused by the separation of the optical contact of fibers, not depending on the bond breakage. Most plausible deforming process is described.

KEYWORDS: Acoustic measurement, Failure, Fiber bonding, Handsheets, Light scattering, Plastic deformation, Tensile tests.

INTRODUCTION

The work described in the earlier papers^{1,2,3)}, has enabled us to discuss in more detail the breakage of fiber-fiber bonds and the deforming process of paper by using acoustic emission (AE) method. The authors have been able to show that AE is a sound emission caused by microfailure and implies the fiber-fiber bond breakage and/or fiber failure under tensile elongation.

The plastic deformation in the load-elongation relationship has been described in two different processes⁴⁾. One is based on the progressive breakage of fiber-fiber bonds, and the other is based on the irreversible deformation occurring in the fiber wall. The former description was deduced experimentally from optical data^{5,6)}, that is, an increase in scattering coefficient during straining of paper. The latter was from thermal behavior⁷⁾ and also from AE behavior^{1,3)}. Numerous authors have discussed the tensile properties of paper in terms of one of these two explanations. Consequently, simultaneous AE and optical measurements during straining of paper is expected to give a new insight into the controversial discussion.

In this work, a series of handsheets from kraft pulp beaten to various degrees was prepared for the investigation. Optical reflectance, AE event count and tensile load were simultaneously measured during straining of the handsheets. The scat-

tering coefficient of the sheets was also determined before and after straining to failure. The results obtained were used to examine the cause of the increase in optical reflectance and further to describe the deforming process of paper materials.

EXPERIMENTAL

Materials

A commercially available bleached softwood kraft pulp was beaten to various degrees with a PFI mill under standard conditions. Handsheets were made from the pulp, according to TAPPI standard procedure.

Instrumentation

Tensile testing: A paper specimen, cut to 15 mm in width by 120 mm in length, was strained in tensile mode using an Instron type machine (Shimadzu Autograph AGS-100) with a span of 100 mm and at a crosshead speed of 2mm/min.

AE measurement:The AE signal from the transducer, which was attached to the clamp of the Autograph, was amplified by 40 dB and filtered through a high-pass filter with a low-frequency cutoff of 50KHz to eliminate low frequency noise, using a preamplifier. The signal was further amplified with a logarithmic amplifier in an AE data processor.

Optical measurement: A photovolt type reflectometer with FMY/C filter was used. The aperture of the reflectometer was placed perpendicular to the surface of the sheet and was also adjusted to the center of the sheet. The diameter of the circular aperture was 10 mm, and accordingly the area for measurement represented about 5% of the strained area of the sheet. Reflectance, R_0 , was measured

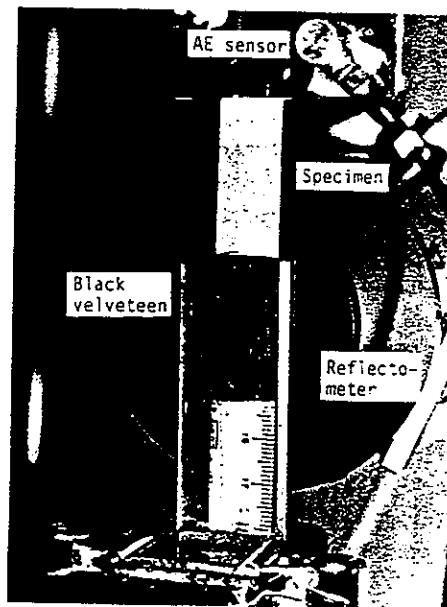


Fig.1 Experimental arrangement for simultaneous mechanical, optical and AE measurements.

with a black velvet backing during the straining, as shown in Fig. 1. This value gives a sufficiently accurate estimate of the change in the scattering coefficient of the paper sheets⁵.

The instrumental arrangement for simultaneous mechanical, AE and optical measurements is shown in Fig. 2. The tensile load, reflectance (R_0) and AE were processed in the AE data processor and then were recorded with a multi-pen recorder.

The usual R_0 and R_∞ measurements before straining and after straining to failure were made separately at several points through the specimen, taking into account the variation in the reflectance⁵. The scattering coefficient was calculated from the values of the measured R_0 , R_∞ and basis weight using the Kubelka-Munk theory.

All measurements were made under standard conditions, 20°C and 65%RH.

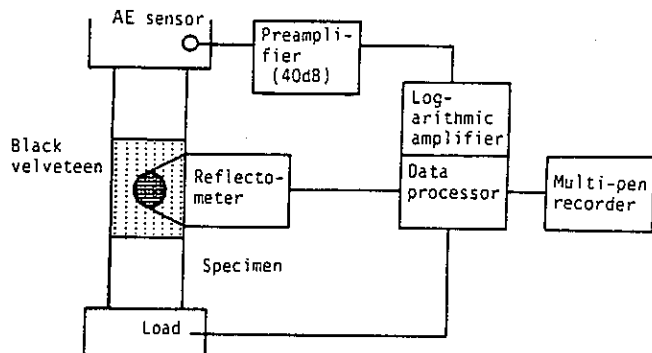


Fig. 2 Block diagram of load, reflectance and AE measuring system.

RESULTS AND DISCUSSION

AE and optical behavior of handsheets during the straining

According to the study by Nordman, the increment of the reflectance was varied throughout the specimen and the failure zone showed a pronounced increase in the reflectance⁶.

In the preliminary study, the specimen in which the center was narrowed to 15mm wide by semicircular cuts, was used to ensure that the zone of failure coincided with the aperture of the reflectometer. Although there was slight difference in the increment of the reflectance between the usual rectangular specimen and the center narrowed specimen, mechanical and AE behavior of the center narrowed specimen considerably differed from those of usual specimen. For the sake of referring to the previous studies^{1, 2, 3}, the specimen with usual geometry was employed in this study here after.

Figure 3 shows the simultaneous mechanical, optical and AE responses of the handsheet from moderately beaten pulp during straining to failure.

Corresponding results for the handsheets from unbeaten and lightly beaten pulp are shown in Figs. 4 and 5, respectively. The AE results were almost the same as those in the previous report¹. That is, AE began to occur immediately after the elastic deformation for the unbeaten pulp, but not until half way through the plastic deformation in the load/elongation relationship for the beaten pulp. The elongation at which AE began to occur increased with the degree of beating. AE occurred most frequently at or after maximum loading, namely at the moment of fracturing.

On the other hand, the optical reflectance of the handsheet from moderately beaten pulp started to increase at elongation of about 1%, which was before the beginning of AE event occurrence and continued to increase linearly to failure. The results for the handsheet from lightly beaten pulp are similar to those for the handsheet from moderately beaten pulp. In contrast, the reflectance of the handsheet from unbeaten pulp little increased with the elongation.

The proportional increase in optical reflectance with the elongation after beginning of the increase is in agreement with the result obtained by Nordman⁶, and is also similar to the increase in scattering coefficient after straining at different elongation levels^{4, 8}.

The scattering coefficient of the sheet before straining and after straining to failure is shown in Table 1 along with freeness, sheet density, tensile index and per cent elongation at failure. The increment in scattering coefficient is comparable to that reported previously^{4, 8}. There seems to be a linear relationship between the increase in scattering coefficient and the per cent elongation at failure. This is a matter that needs further study.

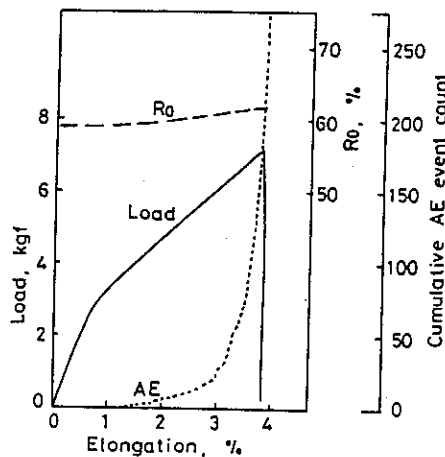


Fig. 3 Load, reflectance and AE event count vs. elongation curves for the handsheet from moderately beaten pulp.

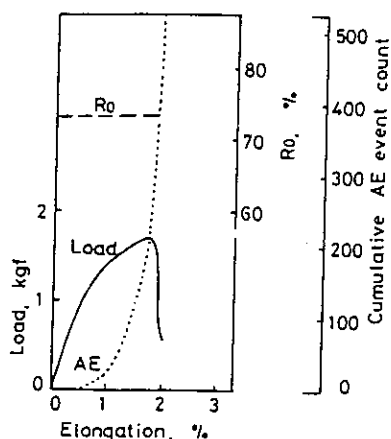


Fig. 4 Load, reflectance and AE event count vs. elongation curves for the handsheet from unbeaten pulp.

Origin of optical phenomena during tensile straining

The increase in the reflectance has been interpreted as a result of bond breakage under tensile elongation⁵⁾. Van den Akker and Anderson, however, pointed out two other possible explanations¹⁾. First, some of the change in reflectance could be caused by the separation of fibers that were not originally mechanically bound, i.e. in optical contact. Second, the change in reflectance could be caused in part by increased light scattering power within the fibers. With the latter explanation, the experimental results finally showed that there was little effect on the amount of light scattered by a fiber when it was strained²⁾.

There are significant differences in the phenomena during straining between AE and optical reflectance as follows. First, the reflectance proportionally increased to the elongation, con-

Table 1, Properties of handsheets

PFI mill rev.,		0	2000	5000	10000
CSF,	ml	690	665	465	265
Sheet density*,	kg/m ²	520	650	795	810
Tensile index,	Nm/g	16	60	71	90
Increase in scattering coefficient,	cm ² /g	4	34	34	46
Elongation at failure, %		1.9	3.4	3.8	4.1

*The density was determined by using thickness value measured by the rubber platen method^{9,10)}.

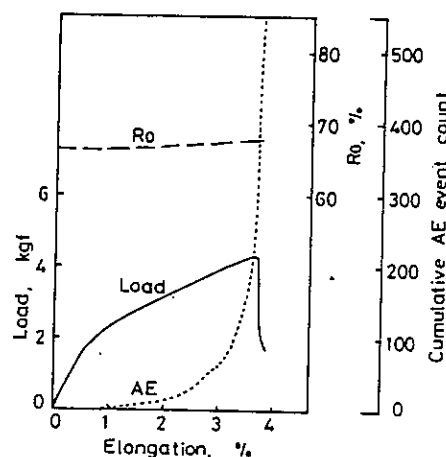


Fig. 5 Load, reflectance and AE event count vs. elongation curves for the handsheet from lightly beaten pulp.

trasting to the exponential increase in AE event. Second, the sheet from unbeaten pulp gave a large AE event count at failure but small increase in reflectance, compared to those of the sheet from beaten pulp. Third, the per cent elongation at which AE began to occur increased from about 0.5% to about 1.5% with an increase in the beating degree, on the other hand, the elongation at which the reflectance began to increase was nearly constant at about 1%, irrespective of beating degree.

Considering that AE is mainly caused by the bond breakage³⁾, the above mentioned experimental results could suggest that the separation of fibers in optical contact caused the increase in the reflectance. The fiber separation caused by straining, of course, accompanies with the bond breakage.

Stress relaxation

Straining and destaining cyclical test or stress relaxation test could give more information on optical and AE behavior during deformation. In the preliminary cyclical testing, it was found that when destaining, in other words, when the sheet somewhat contracted, there was little or no detectable change in the reflectance and a little increase in AE event count. The subsequent straining beyond the maximum load of the previous cycle caused a further increase in the reflectance and AE event count.

The mechanical, optical and AE behavior during straining and the following relaxation periods is shown in Fig. 6 for the sheet from moderately beaten pulp as a function of time. There was no detectable change in the reflectance during the relaxation period, and the subsequent straining beyond the previous maximum load gave a faint increase in the reflectance. On the other hand, AE

event count still increased in the beginning of the relaxation period and then it gradually levelled off. The subsequent straining beyond the previous maximum load gave a rapid rise in the AE event count curve. As the load came close to the breaking load, however, AE event count continued to occur at a slower rate despite the relaxation period. These appear to indicate that the structural change concerning the mechanical response continues to occur during the relaxation, but the structural change concerning the optical response does not occur during the relaxation. The former is, of course, obviously smaller in size than the later.

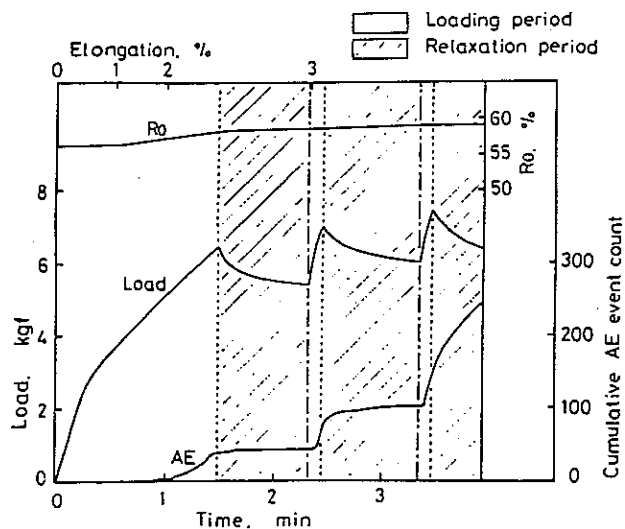


Fig.6 Effect of repeated loading and relaxation on load, reflectance and AE event count curves for the handsheet from moderately beaten pulp.

Deforming process of paper

Extensive study using various methods are needed to examine precisely the deforming process. The experimental results now incorporates with the previous work^{1,2,3)} and thus, could describe a reliable deforming process of paper as follows. Except for the paper from unbeaten pulp, the plastic deformation arises largely from the irreversible deformation within fibers, and it accompanies with the gradual separation of fiber contacts. The latter leads the increase in scattering coefficient of paper. Concurrently fiber-fiber bonds with low bonding energy begins to fail at half way through the plastic deformation and additionally breakage of fiber-fiber bonds with high bonding energy and further failure of fiber follows. The number of the bond breakage exponentially increases to failure of paper.

ACKNOWLEDGEMENT

The authors wish to thank Prof. Noguchi for allowing us to use the AE measuring system.

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