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Analysis of Acoustic Emission on White-Coated Paperboard During a Wedge Cutting Process

Yasushi Fukuzawa and Shigeru Nagasawa

Department of Mechanical Engineering, Nagaoka University of Technology, Nagaoka, Japan

1. Introduction

In our social life, paperboard and its finished products have been become widespread as any recycled materials. The structure of paperboard is composed of multiple plies (normally, lamination structure of 3~8 layers) with the hydrogen-bonded natural fibers which have the vertically beaten shape. The material property of paperboard has an anisotropic characteristic and may be understood as orthotropic-nonlinear elasticity^[1].

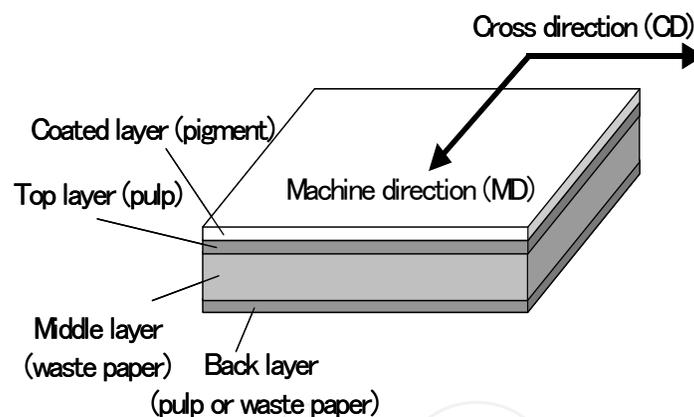


Fig. 1. Paperboard structure.

A typical structure of white-coated paperboard is illustrated in **Fig.1**. A clay pigment layer is coated on the front surface to improve the printing quality. The top layer and back layer tend to be relatively stronger and white, compared with the middle layer. The bonding strength of a ply interface is usually a little weaker than the yielding stress of considered plies.

Die-cutting machine (such as a flat-bed type) consists of a die board, in which the cutting rules and creasing rules are embedded, and a face plate (called as the counter face plate). The flat-bed cutting machine (called as the platen) is widely used in the packaging and printing industry, for processing paperboards, labels, laminated resin sheets, ductile metal film and so on. As other machine types, there are several rotary die cutters and combination (cylinder) type of a half-rotary die with a flat-bed in the packaging industry.

In this book, a simple crank cutting machine as the flat-bed type was considered for the authors' experimental analysis. Fig. 2 shows a schematic of experimental apparatus, which was designed and developed as a small size machine for the purpose of continuous cutting test [2]. A reciprocal motion is used for indentation of a center-bevelled blade (symmetric wedge) into and cutting off the paperboard. The cutting blade is fixed on the upper holder and reciprocally moves with a certain speed. The cutting force is measured by using four load cells mounted underneath the lower base table. Fig. 3 illustrates a quarter-stroke motion of a cutting blade of the crank machine. At the bottom-dead position, the blade tip is slightly crushed. In this situation, the unevenness of the blade height causes an eccentric tip crushing and it is needed to detect such state of pressure unbalance using a non-destructive inspection method. In this case, the blade is moved in the upward/downward direction resulting from the rotation of the crank mechanism, which has a speed N_C rpm and the length of an eccentric arm $e=25\text{mm}$. The blade tip continues to penetrate the paperboard until it reaches the bottom-dead point (BDP) (Fig. 3 (b,c)) where the paperboard is separated before returning to the position of Fig. 3(d).

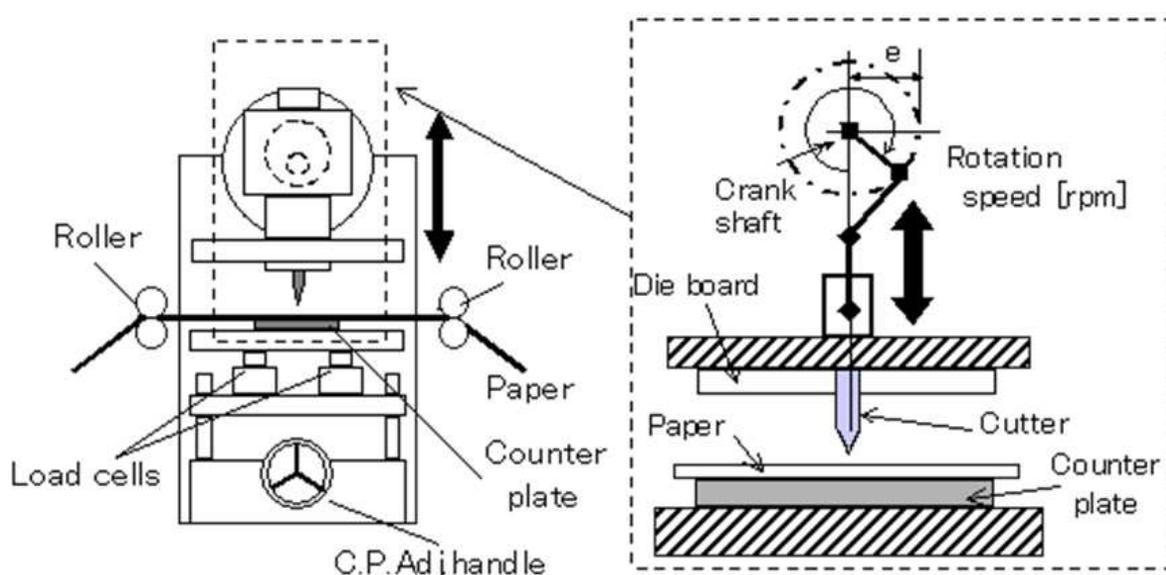


Fig. 2. Schematic outline of die cutting system for paperboard.

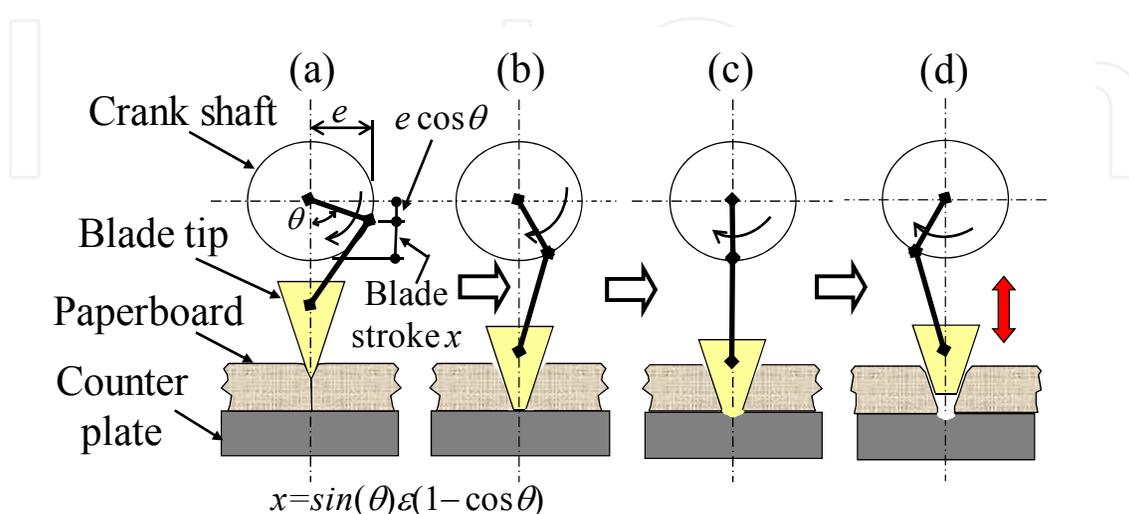


Fig. 3. Mechanic of paperboard cutting on the crank motion.

The crushing of blade tip occurs at the BDP during paperboard separation and this is the position where the severe crushing and eccentric cutting pressure of blade tip are reduced using an expert's adjustment technique (shimming by one's hand working).

From aspects of energy-saving and optimal quality on the material processing, the non-destructive diagnosis with the ageing of cutting tools and the mechanical condition of specified paperboard is important for corresponded companies and our social life.

2. Measurement methods and its object

In the die cutting process of paperboards that used for packaging containers, the following items are important for quality control: (1) adjustment of cutter clearance, shimming of die board; (2) restriction of occurrence of dust chips or string-like chips; (3) prediction of dynamic cutting state with respect to the ageing of cutting tools. In many converting plants of packaging containers, these assignments are empirically solved and maintained by operators' senses. Often it depends on the variation of audible sound from the cutting machine. For increasing productivity and reducing operator's task, any kind of automatic technique for detecting cutting condition is required.

In the author's research, several diagnoses of a tool condition have been investigated. The ageing of a cutting edge nose was acoustically estimated by measuring sound wave during the process of paperboard cutting [3]. In this chapter, a correlation between the blade tip thickness and a solid interior elastic wave that occurs in the cutting tools (the blade and the counter face plate), or the rigid body vibration that occurs in the perimeter where the blade edge collides, is explained by using Acoustic Emission (AE) method.

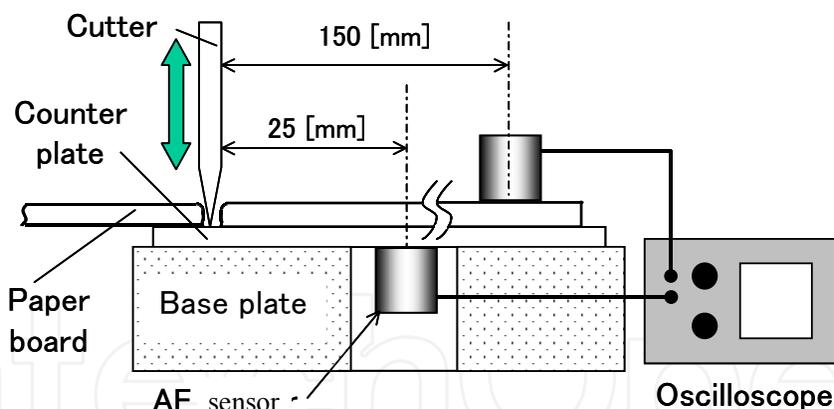


Fig. 4. Detection system of AE signals on the die cutting

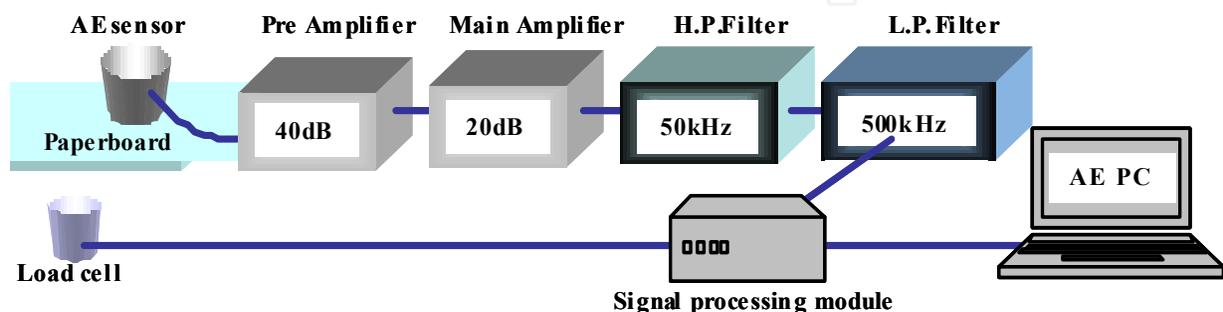


Fig. 5. Measurement and analysis system using AE sensor and load cell

The AE signal was detected at the backside of counter face plate as shown in **Fig. 4**. AE signals measured by an AE transducer were processed as displayed in **Fig. 5**. The amplitude of AE signals were used here. The AE transducers [4] that were a resonant type of 220 kHz (effective frequency range: 1-5 MHz, being products of Physical Acoustics Corporation), were set behind of counter face plate (distance from the cutting edge end, $L_a=25$ mm) and on the paperboard (distance from the cutting edge end, $L_a'=150$ mm). The provided voltage signals were recorded as the function parameter of AE. The waveforms of AE signals were detected in a digital oscilloscope and analyzed by using a computer with FFT software.

In order to describe the correlation between the cutting process of paperboard and generation of AE signals, the developed small size die cutting machine shown in **Fig. 2** was used for this experiment [2]. The following experimental parameters are examined.

1. Material structure of paperboard: the cutting direction (angle) $\phi = 90^\circ$ (across to MD), 45° and 0° (parallel to MD) to Machine Direction (MD) of paperboard, the thickness direction concerning the coated layer.
2. Machining speed: the rotation speed N_C rpm for the crank arm length of $e=25$ mm. The rotation speed was chosen as 5, 10, 20, 30 and 40 rpm for the cutting test.
3. Shape and width of blade tip: a single-straight wedge cutter, the tip thickness t_C μm of which has the apex angle of α .

The specification of paperboard, that of cutting blade, and that of counter face plate were chosen as follows, owing to their popularities:

- Paperboard: White-coated board, of which the nominal basis weight was $\rho = 350$ g/m², the thickness was $t = 0.44$ mm, the width of web sheet was 100 mm, and the in-plane tensile strength in MD (the machine direction) was $\sigma_B = 33$ MPa (the breaking nominal strain of 1.85%, at Room env.: 42%RH, 279K). All the specimens were reserved and the cutting test was carried out at Room env.: the humidity 63%RH, the temperature 303K¹.
- Blade: Thomson's knife (JIS-G3311, SK5) of $\alpha=42^\circ$, the hardness of tip/core were 680/465 VHN, the initial (virgin) tip thickness of 5 μm was modified as two kinds of blunt wedges. One is a naturally crushed tip of $t_C = 18$ μm , which was dynamically ($N_C=80$ rpm) subjected to 100 times of the maximum line force of $f = 27.5$ kN/m². Another is artificially made as a trapezoidal shape of $t_C=19\mu\text{m}$ using emery papers. **Fig.6** illustrates two kinds of tip profile. The length of blade was 80 mm, the thickness of core body was 0.71 mm³
- Counter face plate: Hardened stainless steel plate (JIS-G4304/5, SUS630) of 1.5mm thickness, which was a rectangular form of 180mm length and 140 mm width. Its surface hardness was 510 VHN.

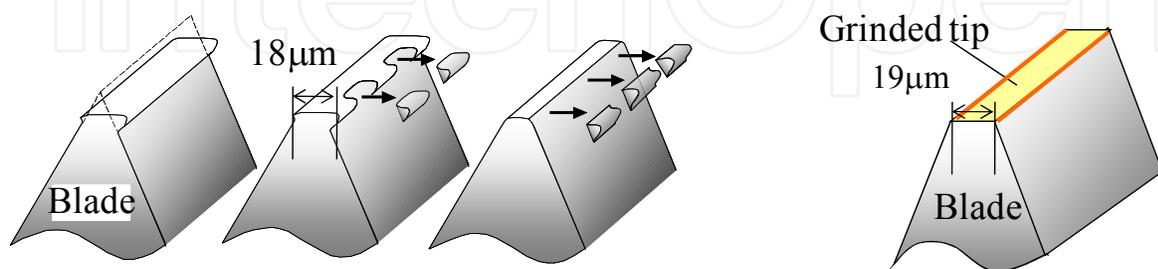
¹ Hopefully, all of reservation of specimens and cutting tests should be considered at the standard room environment, 50%RH, 296K.

² After 100 times of punching onto the paperboard, the burrs of crushed tip tend to be sufficiently removed. Namely, round-edge ends are expected to be formed on the crushed tip without any burrs. See the reference [2].

³ There are several standard knives well known in the world, the tip angle of which is symmetrically $\alpha = 30, 42, 53,$ and 60° . The 42° knives are well used for separation of coated paperboard in Japan. There are the woven-tip type, the side wedge (asymmetric wedge) and the two-line wedge cutter and so on for various purposes.

The cutting test was carried out across to the MD (machine direction) with the direction angle $\phi=0, 45, 90^\circ$. The cutting-line force f kN/m and the amplitude of AE signal a mV were measured with respect to the elapsed time t_{ep} .

When the effect of blade tip shape (naturally crushed, artificially mended) was compared with respect to the cutting load response, the cutting direction was only chosen as $\phi=0^\circ$ for $N_C=5, 10, 20$ rpm⁴. 10 pieces of specimens were prepared and inspected for each cutting condition. The contact condition between the blade tip and the counter face plate was considered as non-lubricant.



(a) Variance of edge end by continuous cutting (b) Edge end of mended blade

Fig. 6. Preparation of crushed blade tip

Regarding the transient response of cutting force and the AE signal in the cutting duration, the naturally crushed blade was used with the cutting attitude of $\phi=0^\circ$ when the rotation speed was chosen as $N_C = 5, 10, 20, 30, 40$ rpm.

3. Outline of cutting characteristics and measurement principle

Before describing the correlation between the AE signal and the cutting line force when the cutting speed is varied for the two kinds of blade tip profile, the relationship between the cutting line force and the modified blade tip thickness should be explained. In a case of the cutting direction $\phi=90^\circ$, the basis weight $\rho=350$ g/m², the thickness $t=0.44$ mm and the rotation speed $N_C=5$ rpm, the authors investigated the cutting line force response^{[5][6]}. The relationship between the cutting line force f and the normalized tip stroke x/t of crankshaft was shown in Fig.7.

The origin of the tip stroke x is here defined as $x=0$ with reference to the bottom dead point (BDP) of the crankshaft. When the blade is in the rising process, the sign of x is defined as positive: $x>0$, while the blade is in the descent process, the sign of x is defined as negative: $x<0$. If the blade tip is fairly crushed, the cutting line force response $f-x/t$ has usually two-peaked points f_{c1}, f_{c2} during the cutting process.

For such the experimental relationship between the blade tip profile and the cutting load, there is a technical report written by Grebe and Hofer^[7]. The authors have also studied about the effects of blade tip thickness on the cutting line force. The authors prepared artificially a trapezoidal bevel blade, of which the normalized tip thickness was t_c/t , by

⁴ Due to a mass effect of lower base table, the dynamic high-speed resonance of implemented load cells was restricted. Therefore, the response of load cells should be mainly discussed before the second peaked line force.

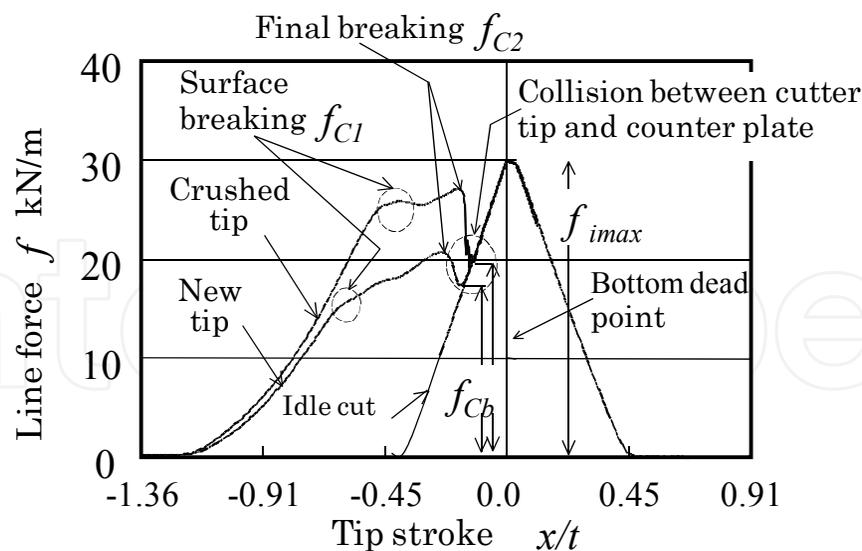


Fig. 7. Relationship between cutting line force and tip stroke ($\phi=90^\circ$, $N_C=5$ rpm)

grinding a new cutting blade. By using the trapezoidal bevel blades, many useful results were obtained [5]. From that work, it is found that trapezoidal bevel blade shows a similar cutting load response to the naturally wrecked blade tip by continuous cutting [6]. When the trapezoidal bevel blade was used for cutting the white-coated paperboard, the relationship between f_{C2} kN/m and t_C/t was approximated with Eq. (1).

The coefficients $k_{f_{C2w}}$ and f_{C20w} were decided from the cutting experiment. For an example, when the trapezoidal bevel blades of $\alpha=42^\circ$, $t_C=10\sim55\mu\text{m}$ were used for cutting the white-coated paperboard of $t=0.44$ mm ($\rho=350$ g/m²), under $N_C=5$ rpm and $\phi=90^\circ$, the coefficients were obtained as $k_{f_{C2w}}=129$ kN/m, $f_{C20w}=19$ kN/m.

$$f_{C2} = k_{f_{C2w}} (t_C/t) + f_{C20w} \quad (1)$$

Generally, these coefficients appear to be varied with the following conditions: (a) the friction coefficients between blade and paperboard, and/or that of counter face plate and paperboard; (b) the brand and the moisture (water) content of paperboard (mechanical properties); (c) the room humidity and the room temperature; (d) the cutting speed; (e) the shape of blade tip and its surface roughness.

Especially, as the room environment of (c) changes all the friction coefficients and the material properties of paperboard, a person who wants to estimate Eq. (1), must pay attention to maintain the room humidity and temperature for a long duration. Therefore, it is necessary to investigate and decide these coefficients in specified working environment.

At the local maximum (peaked) point f_{C2} in Fig. 6, the necking burst⁵ of wedged zone occurs at the lower layers of paperboard, and the cutting line force suddenly decreases. Complete separation of paperboard occurs at the line force f_{Cb} when the blade tip contacts with the

⁵ Strictly speaking, since the paperboard is not any continuum body, but a laminated composite material with paper fibers, the necking is generally invisible. However, as a certain kind of slide and pull-out deformation exists among the laminated fibers, we can understand it as an equivalent necking burst.

surface of the counter face plate. Since the blade is driven by the crank shaft, the blade tip moves to a rising process after reaching the BDP line force f_{imax} . Variance of crushed tip thickness t_c fundamentally depends on the magnitude of f_{imax} , while the cutting resistances f_{c1} and f_{c2} depend on t_c . So far, we should understand that f_{imax} indirectly affects the variance of f_{c1} and f_{c2} .

When the cutting line force of the paperboard passes through the peaked point f_{c2} , the blade tip collides on the surface of counter face plate. At this time, the cutting load drop expressed by Eq.(2) occurs in a short time.

$$\Delta f = f_{c2} - f_{cb} \tag{2}$$

Over here, the dynamic energy, scattered by collision, is equal to the discharged elastic energy expressed by Eq.(3) [8].

$$\Delta E = (f_{c2}^2 - f_{cb}^2) / (2k) \tag{3}$$

The stiffness coefficient k is defined as the gradient df/dx of the line force f by the tip stroke x , when the blade tip is elastically pressed against the surface of counter face plate.

Mechanical vibration occurs in the counter face plate by this blade collision, and hence it can be detected by AE transducer. Putting A to the maximum amplitude of detected signal wave, since the square of the A corresponds to the dynamic energy of vibration, the A is related to $\Delta E^{0.5}$ that is a function of the magnitude of f_{c2} . According to the author's experimental results [9][10], the relation of f_{c2} and A and the relation of t_c and A can be expressed as follows:

$$A/A_o = C_w (t_c/t) \tag{4}$$

$$f_{c2} = k_{fc2A} (A/A_o) + f_{c20A} \tag{5}$$

The coefficients C_w , k_{fc2A} and f_{c20A} are experimentally decided for the specified measuring condition. For an example, when several trapezoidal bevel blades of $\alpha=42^\circ$, $t_c = 10\sim 55 \mu\text{m}$ were used to wedge the white-coated paperboard, mentioned above, the experimental coefficients were $k_{fc2A} = 45.8 \text{ kN/m}$, $f_{c20A} = 21 \text{ kN/m}$ and $C_w = 2.3$. Over here, the rotation speed was $N_C = 5 \text{rpm}$ while the blade attitude was $\phi = 90^\circ$. A_o is a voltage base signal, derived from a standard evaluation method for AE: "When a protruded pencil lead, of diameter 5mm and length 3mm, is pressed on a target, the generated wave is assumed to have a standard signal strength."

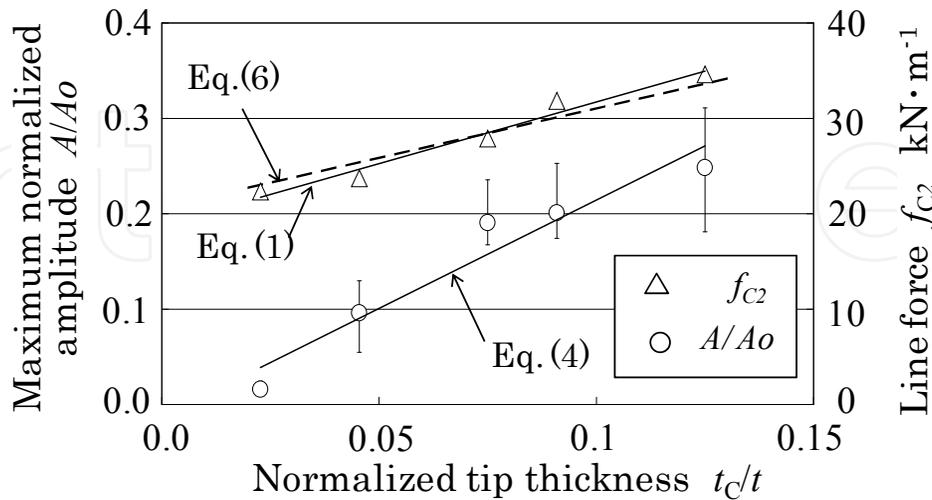
In the experiment [9][10], a specified pencil lead was pressed on the counter face plate, instead of collision of the cutting blade. When the pencil lead broke, we evaluated the maximum value A from the voltage signal measured at the specified AE transducer.

Substituting A/A_o of Eq. (4) to Eq.(5), A/A_o can be erased. The relationship between f_{c2} and t_c/t is derived from this elimination, as shown in the Eq. (6):

$$f_{c2} = k_{fc2A} C_w (t_c/t) + f_{c20A} \tag{6}$$

Fig.8 shows the approximation of Eqs (1), (4), (6) and the experimental results. The Eqs (1) and (6) are matched overall. You can see how much is the expected accuracy of f_{c2} and t_c/t

from this figure. At least, by using a straight blade of length 80mm under a low speed cutting condition ($N_c=5$ rpm), it is possible to estimate the tip thickness t_c/t from the AE signal A/A_o in a fairly good accuracy.



($\rho=350$ g/m², $\phi=90^\circ$, $N_c=5$ rpm)

Fig. 8. Relationship among AE amplitude, breaking line force and tip thickness

Although we used AE transducer as the sensor device in this experiment, since the piezo-electric element principally detects mechanical vibration, various sensors based on the piezo-electric element can be apply to measure such the solid wave. At least, if AE transducer is successfully applied to the die cutting machine, the contact time of the blade tip with the paperboard and also the contact time of the blade tip with the counter plate can be detected.

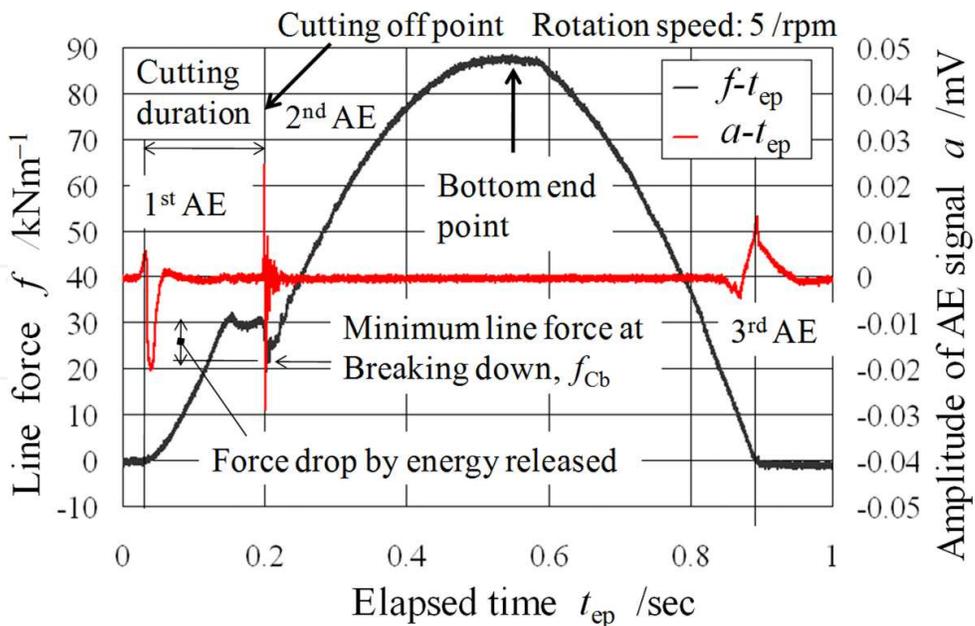


Fig. 9. Cutting line force and AE wave signal with elapsed time

At the setting place of Fig.4, the following AE signals were observed. Typical AE signals detected and its corresponded cutting line force f are shown in Fig. 9. In this case, AE signals

could be detected at three positions: (1) **1st AE**, the first contact of blade tip on the surface of paperboard stacked on the counter face plate; (2) **2nd AE**, the cutting off point which is coincident to the second peaked load; (3) **3rd AE**, the final detached of blade tip from the counter face plate.

The second AE signal (2) which was detected near the cutting off point, which was caused by the collision between the cutting edge tip and the counter face plate.

Using the three positions (1),(2) and (3), the contact time of blade tip can be estimated [9]. From this detection of contact time of blade tip, the ageing of blade tip height or the time variance of contact with the blade and the counter face plate can be estimated. In other words, AE transducer can be used to diagnose the time variance of the detected signal against the angular position of the crankshaft of the pressing device.

As shown in Fig.8, the tip thickness t_c of crushed blade can be detected by the magnitude of the AE signal, and also the height change of the blade can be detected by observing the time difference of the generated signal. If these two matters are analyzed in the same time, then a highly reliable diagnose of cutting state is possible.

4. Results and discussions

4.1 Sheared profile and 2nd AE signal

Fig.10 shows the normalized amplitude of 2nd AE signal A/A_0 with the cutting speed $N_C=5,10$ and 20 rpm for two cases of blade tip shape. Here, the cutting attitude was chosen as $\phi=0^\circ$. According to the dynamic load response during cutting process [8], the ratio of dynamic amplitude by static one is theoretically estimated as 1.41. The 2nd AE amplitude at 20 rpm appeared to almost reach such the dynamic state, compared with that at 5 rpm.

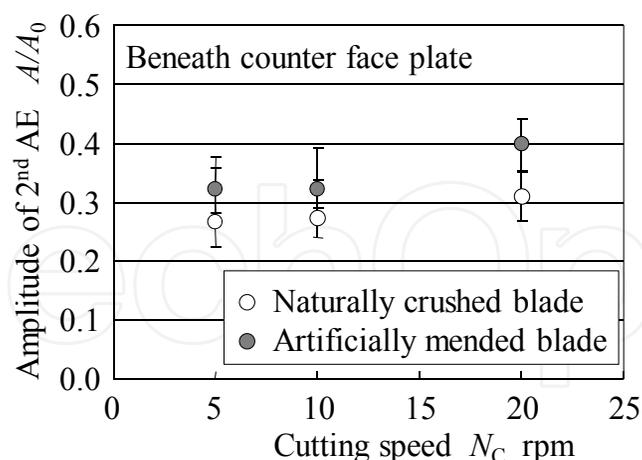


Fig. 10. Amplitude of 2nd AE signals

Fig.11 shows the wear height of upper layer with respect to the cutting speed. **Fig.12** shows representative photographs of sheared section of paperboard, in case of $N_C=5$ rpm, $\phi=0^\circ$. The wear height h_W was measured from CCD microscope photographs. Although there are many unknown phenomena concerning the dynamic high-speed cutting, the sheared profile of paperboard appears to be varied with rotation speed, depending on the blade tip shape.

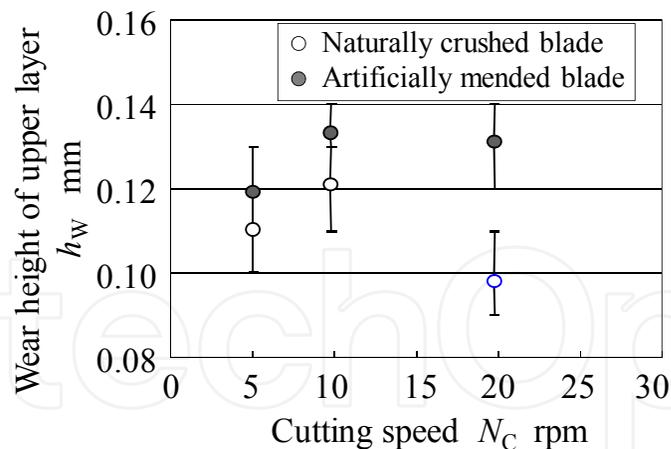


Fig. 11. Wear height of upper layer

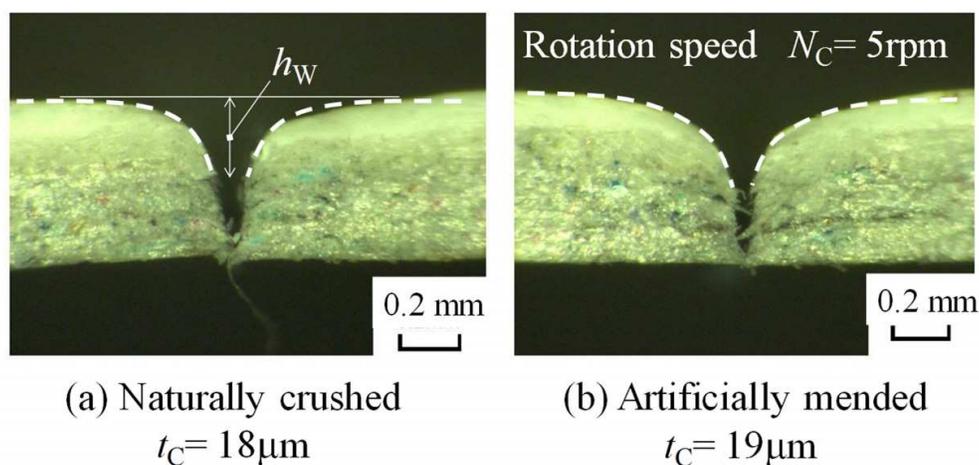


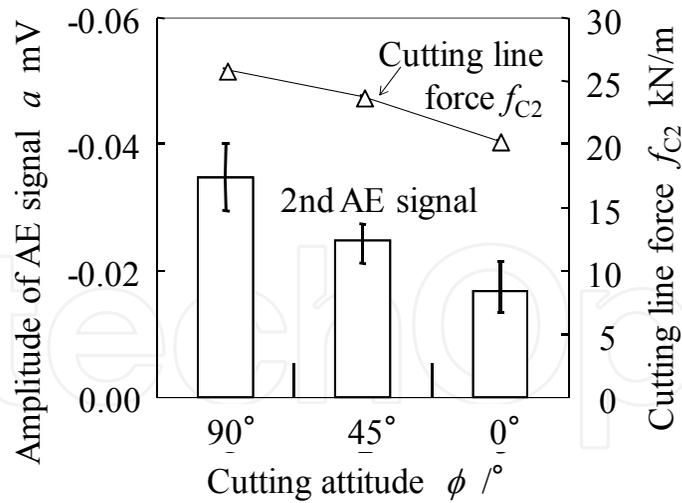
Fig. 12. Side views of sheared section of paperboard ($\phi=0^\circ$ by CCD microscope)

4.2 Estimation of cutting attitude from 2nd AE signal

From Eqs (1),(5), there is a linear relationship between the amplitude of 2nd AE signal and the peaked cutting line force f_{C2} . Hence, the variance of f_{C2} with ϕ corresponds to that of A/A_0 (or a mV) with ϕ . Fig. 13 shows the amplitude of second AE signal and the peaked line force f_{C2} in terms of the cutting attitude angle $\phi=0, 45$ and 90° . The ratio of 2nd AE signal with $\phi=90^\circ$ by $\phi=0^\circ$ was about 2.0, while that of line force f_{C2} with $\phi=90^\circ$ by $\phi=0^\circ$ was 1.25. The last value of 1.25 was known from the authors' report [11]. When we consider Eq.(5) with the cutting attitude ϕ , we need to calibrate the coefficients k_{fC2A}, f_{C20A} with ϕ . They are not usually constant with ϕ .

4.3 Spectrum distribution at 2nd AE signal

According to the authors' investigation [12], the crank type, small cutting test machine has several natural frequencies. The upper-half die cutter device has the natural peak points near 0.6, 0.9, 2, and 5 kHz, while the lower-half die cutter device has that near 0.4, 0.8 kHz. When the blade collides to the face plate, some natural peak points are observed near 0.2, 0.5 and 1.3 kHz. Fig.14 shows the linear spectrum distribution of 2nd AE signal using the naturally crushed blade ($t_C=18\mu\text{m}$), while Fig.15 shows that using the artificially mended trapezoidal blade ($t_C=19\mu\text{m}$).



($N_C=5$ rpm in case of naturally crushed blade)

Fig. 13. Dependency of cutting line force and 2nd AE on cutting attitude

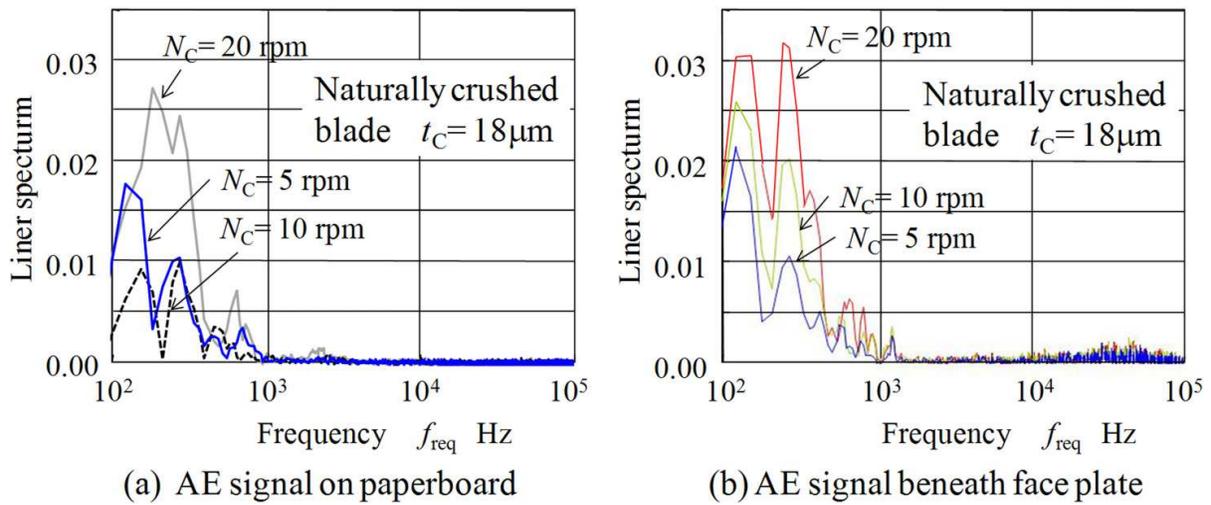


Fig. 14. Linear spectrum of 2nd AE signal (naturally crushed blade)

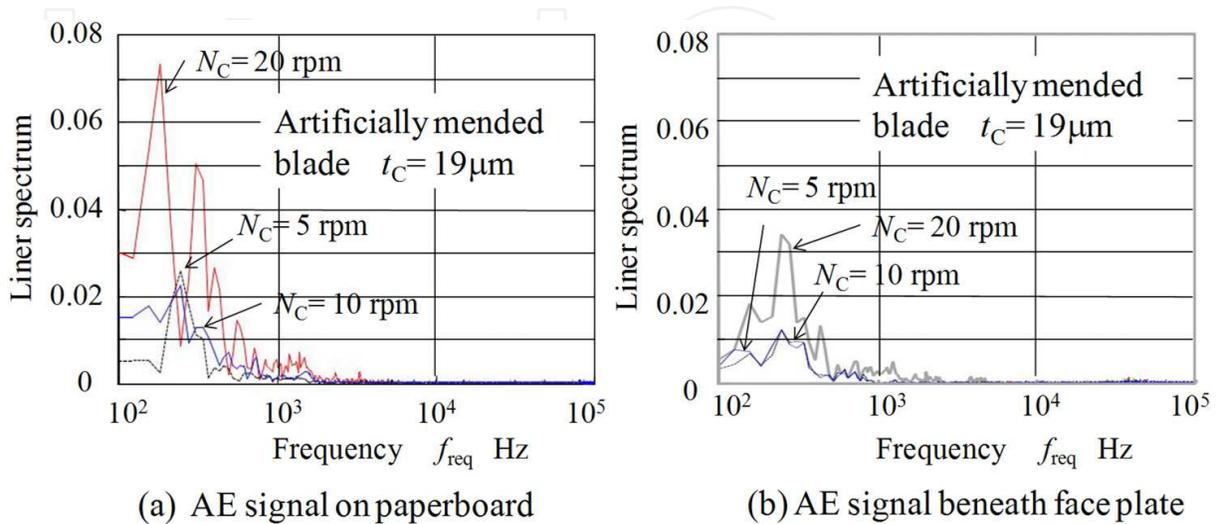


Fig. 15. Linear spectrum of 2nd AE signal (artificially mended blade)

It was confirmed that there were the natural peak points of 0.2, 0.5 and 0.8 kHz, which were independent to the rotation speed, in those figures 14, 15. In general, when the rotation speed is increased, the linear spectrum of natural peak points with the 2nd AE signal also tends to be increased due to increasing of the motion energy of the blade crank system [8].

Using the artificially mended blade of $19\mu\text{m}$ tip thickness in case of $N_C=20$ rpm, the spectrum peak points of 0.2, 0.5 kHz were relatively large compared with other cases. This appears to be caused by the increasing of line force f_{C2} . From those results, it is appeared that a smart round-edge shape of blade tip is preferable for performing to restrict the wear height h_W , to reduce the second-peaked cutting line force f_{C2} .

4.4 Transient response of cutting force and AE signal for cutting process

The second AE signal, which corresponded to the second peaked line force f_{C2} , was discussed with respect to the rotation speed N_C in the sections 4.1, 4.3. The transient response of cutting line force was analyzed by the authors when the rotation speed was

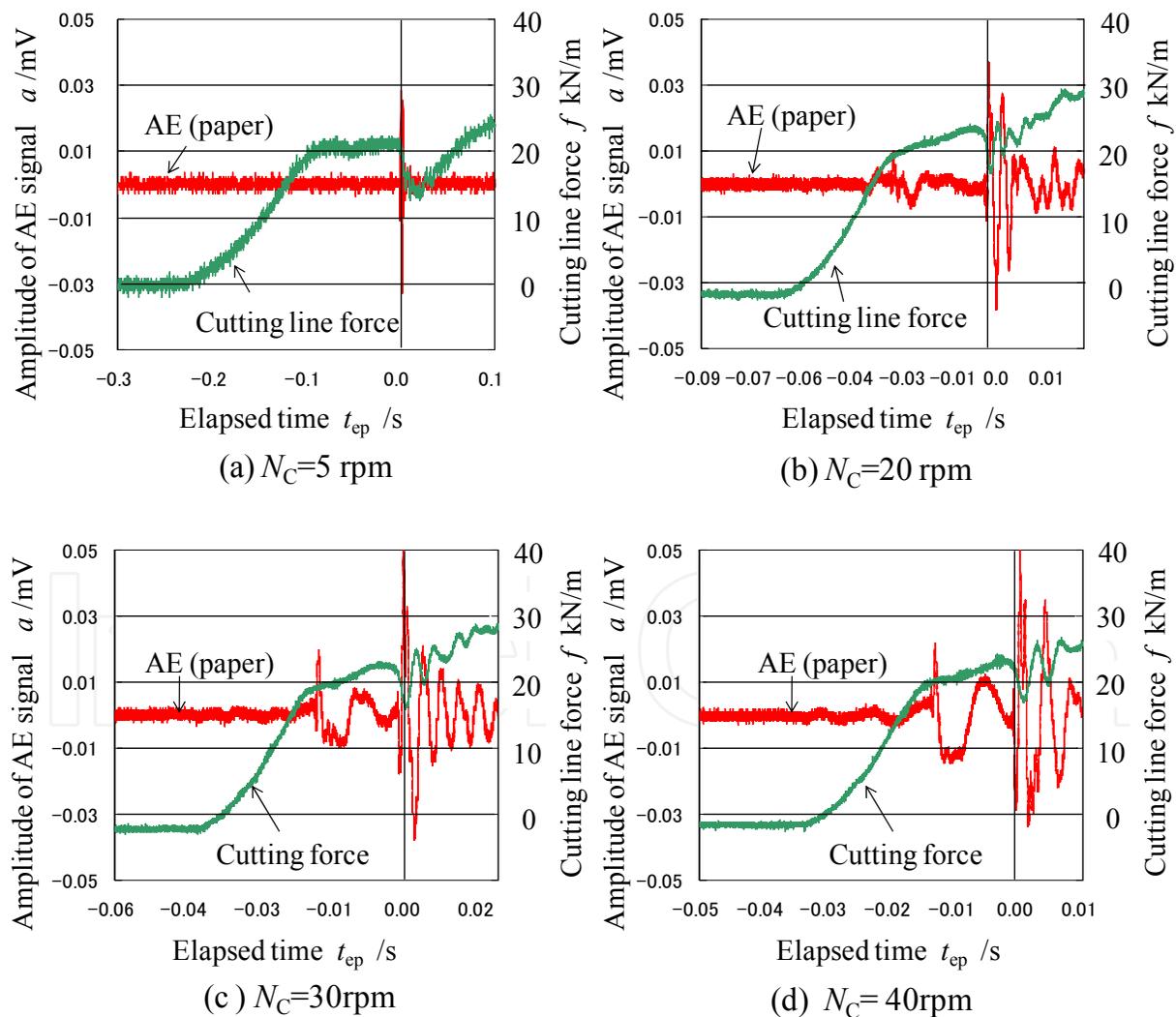


Fig. 16. Transient response of cutting force and AE signal measured on paperboard ($\phi=0^\circ$, by naturally crushed blade)

varied from 5 rpm up to 80 rpm⁶ [8]. However, the dynamic state of AE signal is not discussed for the cutting duration.

In this section, the cutting line force f kN/m and the amplitude of AE signals a mV, which were measured on the paperboard and beneath the counter face plate, were investigated for the elapsed time t_{ep} . Here, the rotation speed of the crank shaft N_C was varied from 5 rpm up to 40 rpm.

Fig.16 shows the cutting line force f kN/m, which was measured by the load cells with the naturally crushed blade, and the AE signal measured on the paperboard with respect to the elapsed time t_{ep} . Here, the rotation speed N_C was setup to (a) 5rpm, (b) 20rpm, (c) 30rpm and (d) 40rpm, while the cutting attitude was chosen as $\phi=0^\circ$. Similarly, **Fig.17** shows the same cutting line force f kN/m and the AE signal measured beneath the counter face plate⁷. From those figures, we can detect several features:

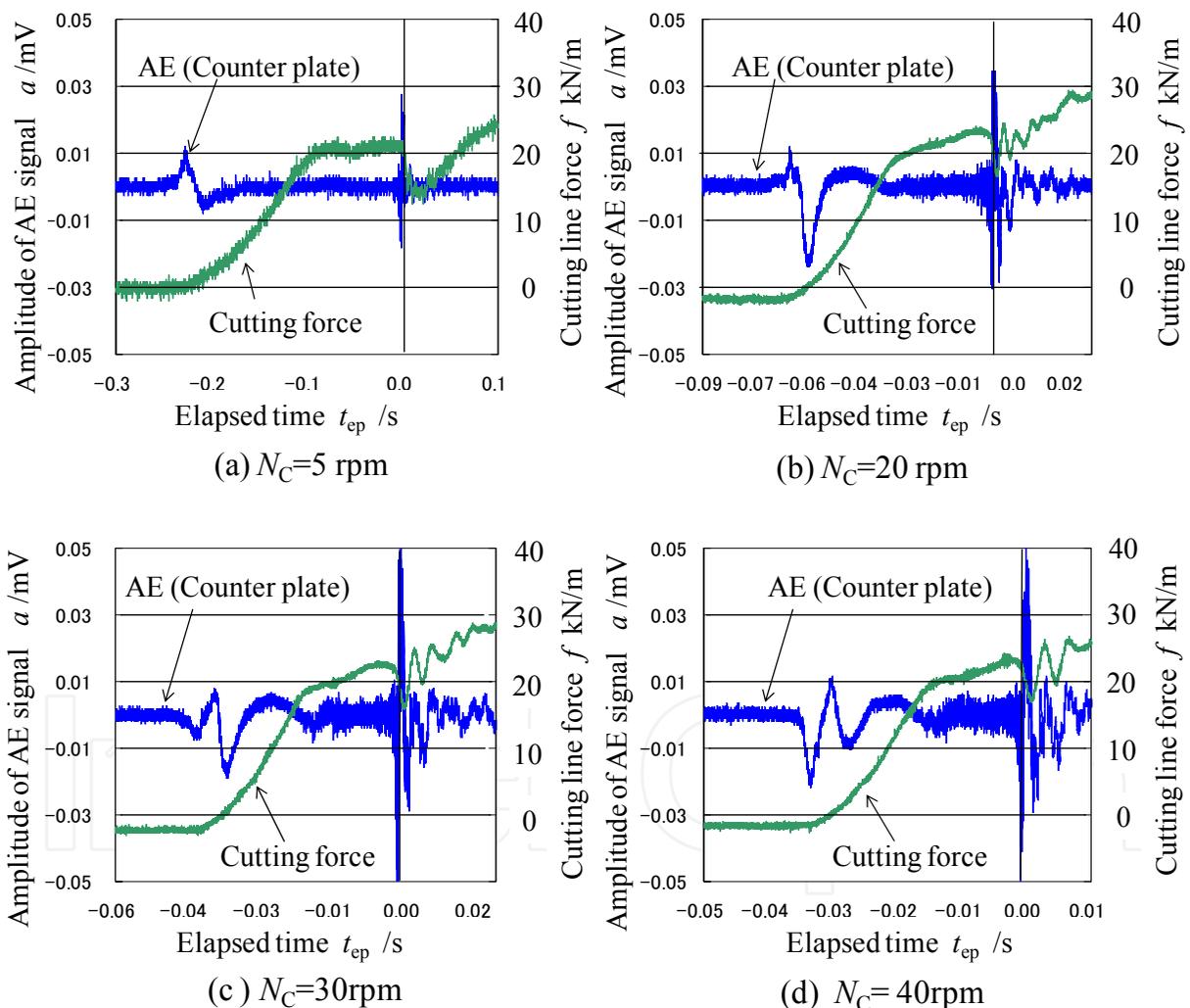


Fig. 17. Transient response of cutting force and AE signal measured beneath face plate ($\phi=0^\circ$, by naturally crushed blade)

⁶ The dynamic line force was measured by using the strain-gauge method in the past work [8], due to mass effect of lower base table. The strain-gauge was mounted on the blade.

⁷ The AE signals on paperboard and beneath face plate were measured by two sensors at the same time.

1. Comparing $N_C=20$ rpm with $N_C=5$ rpm, the AE signal on the paperboard varied (been a little increased and dropped down in a short time) at the first peak point of cutting force f_{C1} . This transient variation was observed for $N_C \geq 20$ rpm. From the physical aspects of sheared process, this transient variation seems to correspond to *the surface breaking of the upper layer* (coated layer).
2. When $N_C \geq 30$ rpm, the AE signal on the paperboard was increased in the middle time zone between the timing of f_{C1} and that of f_{C2} , and the AE signal was remarkably decreased at the position of f_{C2} . This seems to mean that *the lower layer* of the paperboard reached a *half-breaking state*.
3. Observing the AE signal beneath the counter face plate, the first AE signal (waveform) which occurs at the initial contact of the blade with the paperboard, varies with the rotation speed. It consists of a positive overshoot and a negative overshoot, and/or several overshoots. This seems to correspond that the face plate is vibrated (bounded) in the vertical direction (out-of-plane) via the compressed paperboard.
4. Observing the AE signal beneath the counter face plate, the stationary level of AE signal (at the early stage before the first AE signal position) is relatively small, while the level of AE signal for the cutting duration (from the position of f_{C1} by that of f_{C2}) is fairly large. This variation seems to be caused by a high-compressive wedging process and a sliding/machining state derived from the wedge friction.

5. Summary

Referring the effect of the blade tip shape on the load response of the paperboard cutting, the principle of identification of the blade tip thickness was surveyed by using the solid acoustics emitted, and the application technique of AE was reviewed in order to diagnose the cutting state. The summary of this work is as follows:

- Measuring the load response of paperboard cutting and the mechanical vibration, caused by collision of the blade tip, the blade tip thickness t_C can be estimated.
- The contact time when the blade tip contacts with the work sheet and the separated time when the blade tip separates from the counter plate can be detected by signal response of AE transducer. By using these timing data, it is possible to diagnose the ageing of the blade tip height and the position adjustment of the die board in the flat bed machine.
- The principle of diagnosing the ageing of irregularity of a cutter height on the flat bed machine was described.

After describing those reviews for the principle of diagnosis, several new problems were discussed for the speed effect of paperboard cutting and the transient response of AE signals measured on the paperboard and/or beneath the counter face plate.

In case of low speed condition: $N_C \leq 20$ rpm, the followings are revealed.

- Magnitude of the second AE signal, which is related to the potential drop from the second-peak line force f_{C2} to the break-down line force f_{Cb} , increases with respect to the rotation speed N_C .
- The wear height of upper layer h_W is sensitively varied with the blade tip shape when N_C is increased. A smart round-edge blade is preferable for reducing the cutting line force f_{C2} and the wear height h_W .

In case of $40 \geq N_C \geq 30$ rpm, the following points are confirmed.

- The first-peak position of f_{C1} and the just-before state (middle zone, cutting duration) with the second-peak position of f_{C2} are detected from the AE signal measured on the paperboard.
- The stationary level of AE signal, measured beneath the face plate, is useful for detecting the cutting duration from the position of f_{C1} to that of f_{C2} .

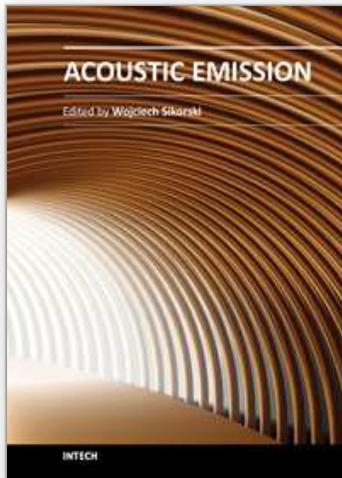
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Acoustic emission (AE) is one of the most important non-destructive testing (NDT) methods for materials, constructions and machines. Acoustic emission is defined as the transient elastic energy that is spontaneously released when materials undergo deformation, fracture, or both. This interdisciplinary book consists of 17 chapters, which widely discuss the most important applications of AE method as machinery and civil structures condition assessment, fatigue and fracture materials research, detection of material defects and deformations, diagnostics of cutting tools and machine cutting process, monitoring of stress and ageing in materials, research, chemical reactions and phase transitions research, and earthquake prediction.

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University Campus STeP Ri
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51000 Rijeka, Croatia
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InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

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