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Acoustic Emission and Cutting Resistance in Cutting of Solid Wood, MDF and Particleboard

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In this study, to obtain basic knowledge on AE characteristics in the cutting process of wood and wood–based materials, the acoustic emission and cutting resistance in the cutting of solid wood, MDF and particleboard were examined.

The following main results were obtained :

(1) In the cutting of solid wood, with increasing slope angle of grain the R_H showed an increasing tendency and the R_V had a negative value with slight increase. The AE signals showed a rapid increase at slope angle range of 30 to 60 degree and then decreased or kept constant. It was found that the AE generation was closely linked to state of chip formation, compared with cutting resistances.

(2) In the cutting of MDF, with increasing slope angle from pressing face of board the R_H showed an increasing tendency and the R_V had a negative value with slight increase. The AE signals also showed a rapid increase at slope angle range of 30 to 60 degree and then almost kept constant. It was found that the AE generation in cutting was closely linked to slope and orientation of fiber. Comparing with edge cutting, it was suggested that the values of cutting resistances and AEs in the cutting of only surface layer of MDF became more higher.

(3) In the cutting of PB, the resistances showed irregular variations with time and AE was generated continuously. With increasing resin content of made board the R_H showed an increasing tendency and the AE signals also increased. It was found that the AE generation in cutting of PB was complicatedly linked to cutting of particle and presence of adhesive.

INTRODUCTION

Acoustic emissions (AEs) refers to the elastic stress waves generated by the sudden release of energy in deforming or fracturing materials. Therefore, wood machining processes such as cutting and sanding all generate acoustic emission. The acoustic emissions generated in the wood machining process hold promise as a means to monitor tool wear, chip formation, surface roughness, and so on (Lemaster *et al.*, 1982; Denaud *et al.*, 2004).

In the previous studies, authors examined the AE characteristics in the veneer peeling process (Murase *et al.*, 2004, 2005). The following results were obtained in the veneer peeling with a roller bar: (1) The AE level caused by compression of the roller bar was low, while that caused by cutting with the veneer knife was remarkably high. (2) Large–amplitude AE and the depth of the lathe check decreased as the compression and restraint increase in the roller bar settings. On the other hand, the following results were obtained in the veneer peeling with a nose bar: (1) The AE level caused by compression or friction of the nose bar was low, while that caused by cutting with the veneer knife was remarkably high. (2) Under variable nose bar openings, veneer thickness and specimen temperature, AE generation was closely linked to the occurrence of lathe check. It was found from these results that the AE technique is promising for the monitoring of veneer quality in the peeling process.

Furthermore, authors examined the effects of cutting and clearance angles on acoustic emission and cutting resistance in 90–0 cutting, 0–90 cutting and medium density fiberboard (MDF) cutting (Murase *et al.*, 2007). The following results were obtained : (1) With increasing cutting angle, horizontal cutting resistance increase. On the other hand, The AE level increases and reaches a maximum at cutting angle of 40 or 50 degree, and then decreases. It is suggested that the variation of AE level is linked intimately to the process of chip formation. (2) With decreasing clearance angle, horizontal cutting resistance does not change very much and the AE level decreases. However, at clearance angle of 0 degree, horizontal cutting resistance increases remarkably and the AE level decrease continuously. It is suggested that the AE level caused by friction between clearance face of knife and workpiece is low.

In this study, to obtain basic knowledge on AE characteristics in the cutting process of wood and wood–based materials, the acoustic emission and cutting resistance in the cutting of solid wood (spruce), MDF and particleboard (PB) were examined.

MATERIALS AND METHODS

Experimental apparatus

The experimental apparatus shown in Figure 1 was used in this study. In this apparatus, the wood specimen

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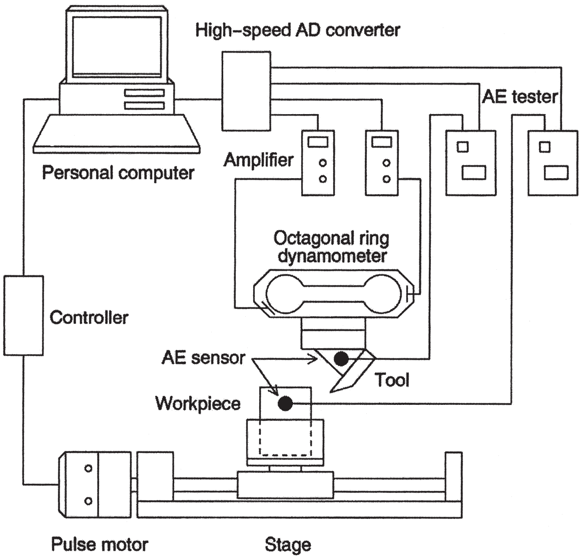

Fig. 1. Schematic diagram of the experimental apparatus.

was set on the stage driven by a pulse motor controlled with personal computer (PC). The cutting tool was mounted on a dynamometer. Cutting was carried out by moving a wood specimen forward to the cutting tool.

Two AE transducers (150 kHz resonant frequency) were used : one was mounted on the side face of the tool holder with a thermoplastic adhesive while the other was mounted on the side face of the workpiece with a rubber band, using silicon grease as the couplant between workpiece and AE transducer. In the experiment, the latter transducer was kept at a constant distance (10 mm) from the cutting line.

In measurement of AEs and cutting resistances during cutting , the output signals of the AE transducers or dynamometer were each amplified and then input simultaneously to a PC with a high speed A/D converter. For AEs, after the output signals were amplified by 50 dB and then 100 kHz high–pass filtered, the average signals by half–wave rectification were input to the PC.

Experimental conditions

Cutting conditions are shown in Table 1. The tool was composed of high speed steel (SKH51). The cutting angle was constant 40 degree at clearance angle of 10 degree and the cutting speed was 0.5 mm/sec. The dimension of a workpiece was 30 mm (length)×10 mm (width)×50 mm (height). The depth of cut was varied at 0.1 mm and 0.3 mm.

The detail of spruce specimen are shown in Table 2. The specimens used were the average moisture content

Table 1. Cutting conditions

Cutting tool	High–speed steel (SKH51)
Cutting speed (mm/sec)	0.5
Depth of cut (mm)	0.1, 0.3
Cutting angle (deg.)	40
Clearance angle (deg.)	10
Work dimension (mm)	30×10×50

Table 2. Details of Spruce specimen

Specific gravity	0.47
Moisture content (%)	13.8
Slope angle (deg.)	0, 15, 30, 45, 60, 75, 90

Table 3. Details of MDF specimen

Specific gravity	0.62
Moisture content (%)	9.4
Slope angle (deg.)	0, 15, 30, 45, 60, 75, 90

Table 4. Manufacturing conditions of particleboard

Board size (mm)	365×255×10
Particle size (mesh)	under 24
Average moisture content of particles (%)	6.3
Traget board density (g/cm^3)	0.7
Adhesive	Meramin–urea formaldehyde resin
Resin content (%)	6, 8, 10, 12, 14
Pressing temperature (°C)	160
Pressing time (min)	8
Thickness of distance bar (mm)	10

Table 5. Details of particleboard specimen

Resin content (%)	6, 8, 10, 12, 14
Specific gravity	0.66, 0.70, 0.69, 0.70, 0.71
Moisture content (%)	9.0, 9.2, 8.8, 8.3, 9.2

of 13.8%, average specific gravity of 0.47. The LT face (30 mm×10 mm) of specimen was cut parallel to the grain. In experiments, the slope angle of grain was varied at 0, 15, 30, 45, 60, 75 and 90 degrees.

The detail of MDF specimen are shown in Table 3. The MDF specimens used were the average moisture content of 9.4%, average specific gravity of 0.62. The MDF specimens were cut from the block that 6 plies of a commercial MDF board (thickness: 9 mm) were laminated using the adhesive of vinyl acetate resin. For cutting from the block, the cutting angles to the pressing face were varied at 0, 15, 30, 45, 60, 75 and 90 degrees. In the cutting of 0 degree, the center layer of MDF board was cut parallel to the pressing face.

The manufacturing conditions of particleboard and the detail of PB specimen are shown in Table 4 and 5. The particles under screen of 24 mesh are prepared as a raw materials and a single layer PB are made with varied resin contents of 6, 8, 10, 12, 14% using melamine–urea formaldehyde adhesive. The moisture content and specific gravity of PB specimen tested are shown in Table 5 and the edge face was cut for PB specimen. In addition, MOE and MOR of PB were obtained.

RESULTS AND DISCUSSION

Cutting of solid wood

The typical variations of the resistances (R_H ; horizonta, R_V ; vertical) acting on the tool and the AE signals at tool side (upper in each figure) and at workpiece side (lower in each figure) during cutting (from start to finish of cutting) of spruce wood are shown in Figure 2 and 3. In the figure 2, the upper (a) is 0 degree of slope angle, the middle (b) is 15 degree and the lower (c) is 30 degree. In the figure 3, the upper (a) is 45 degree of slope angle, the middle (b) is 60 degree and the lower (c) is 90 degree. Also, the resistance (R_V) acting on a tool was represented as positive (+) when a tool was pushed up from the specimen.

For cutting of 0 degree of slope angle, the resistances showed large periodic variation with time. This occurrence of periodic variation was thought to be caused by chip formation of split type. Also, it was found that a large–amplitude AE was generated immediately after the peak in a periodic variation of resistance. For cuttings of 15 and 30 degree of slope angle, as the pitch in the split type chip become more shorter the resistances showed small but high frequency periodic variation with time, compared with 0 degree cutting. On the other hand, a remarkably large–amplitude AE generation was clearly observed.

For cutting of 45, 60 and 90 degree of slope angle, as the shear type chip were formed continuously the resistances showed relatively large value although a periodic

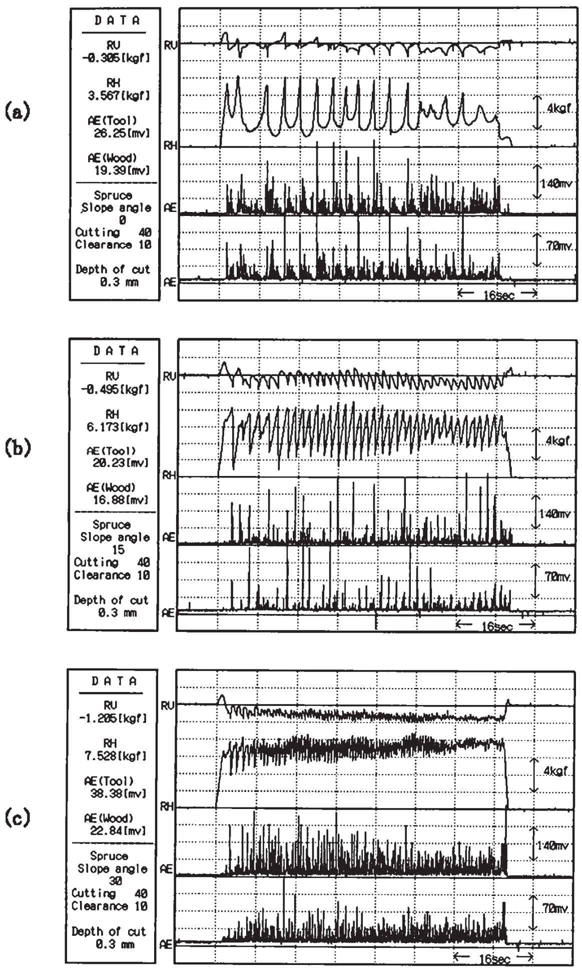

Fig. 2. Variations of cutting resistances and AEs during cutting of spruce wood (cutting angle 40 °, clearance angle 10 °, depth of cut 0.3 mm).
Notes : (a) Slope angle of grain : 0 °, (b) 15 °, (c) 30 °

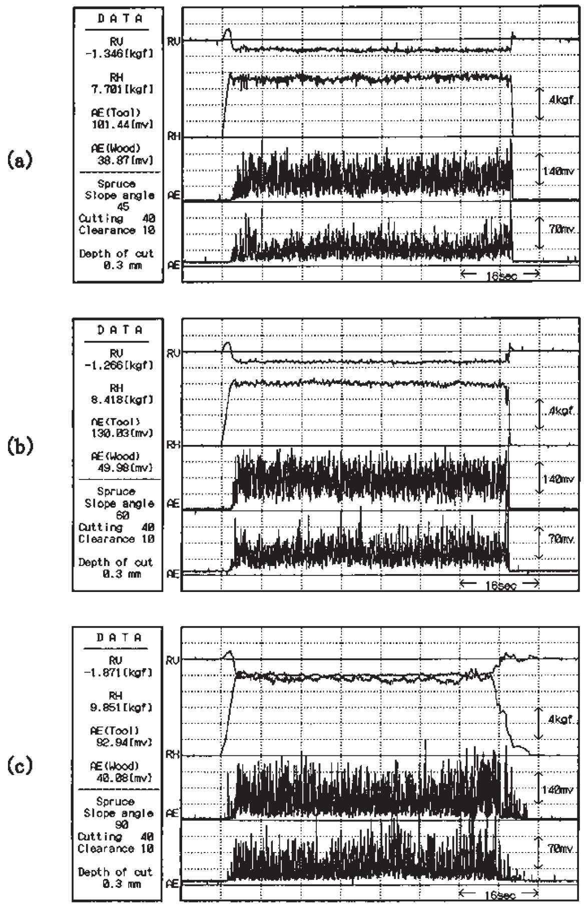

Fig. 3. Variations of cutting resistances and AEs during cutting of spruce wood (cutting angle 40 °, clearance angle 10 °, depth of cut 0.3 mm).
Notes : (a) Slope angle of grain : 45 °, (b) 60 °, (c) 90 °

variation was not clearly observed. On the other hand, a remarkably large–amplitude AE generation was observed continuously.

Relationships among cutting resistances (R_H, R_V), AEs, chip length and slope angle of grain in the cutting of spruce wood at depth of cut of 0.1 mm and 0.3 mm are shown in Figure 4. Here, the measuring values are all the average values and AE values are the AE signals measured at tool side. With increasing slope angle of grain the R_H showed an increasing tendency to 90–90 cutting of 90 degree and the R_V had a negative value with slight increase. The AE signals at tool side showed a rapid increase at slope angle range of 30 to 60 degree and then decreased or kept constant. On the other hand, by the variation of chip formation mechanism the chip length changed at slope angle range of 30 to 60 degree. From the above results, It was found that in solid wood cutting the AE generation was closely linked to state of chip formation, compared with cutting resistances.

Cutting of MDF

The typical variations of the resistances (R_H, R_V) acting on the tool and the AE signals at tool side (upper in each figure) and at workpiece side (lower in each figure) during cutting of MDF are shown in Figure 5 and 6. In

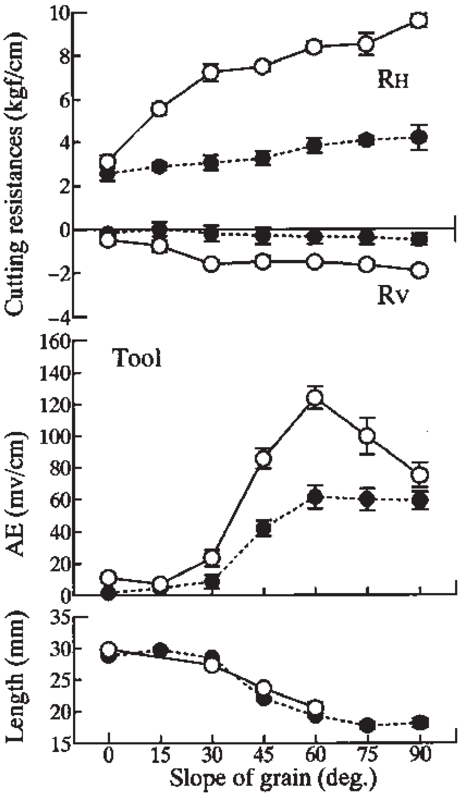

Fig. 4. Relationships among cutting resistances (R_H, R_V), AEs, chip length and slope angle of grain in the cutting of spruce wood (cutting angle 40 °, clearance angle 10 °).
Legend : ● : depth of cut 0.1 mm, ○ : depth of cut 0.3 mm
Note : R_H : Horizontal component of cutting resistance, R_V : Vertical component of cutting resistance

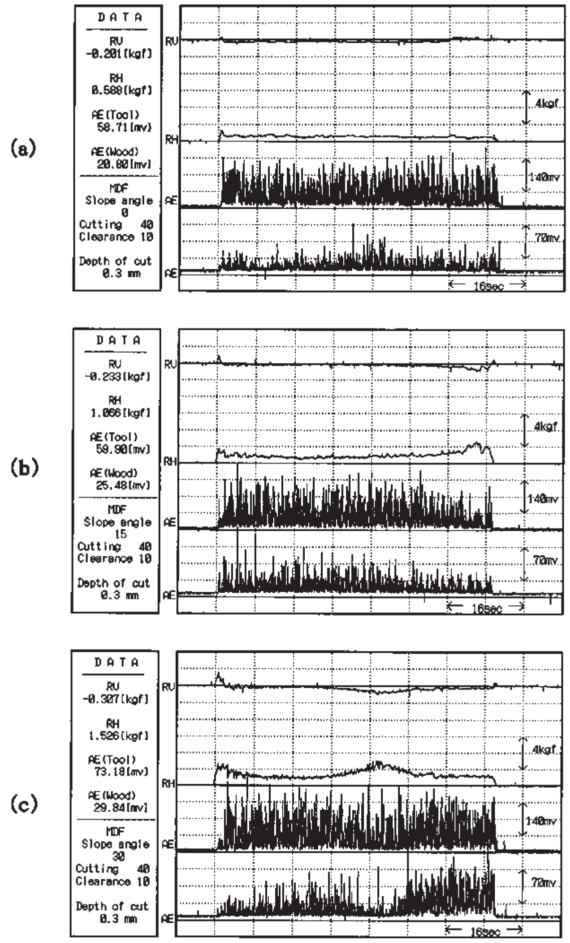

Fig. 5. Variations of cutting resistances and AEs during cutting of MDF (cutting angle 40 °, clearance angle 10 °, depth of cut 0.3 mm).
Notes : (a) Slope angle from pressing face of board : 0 °, (b) 15 °, (c) 30 °

the figure 5, the upper (a) is 0 degree of slope angle from pressing face of board, the middle (b) is 15 degree and the lower (c) is 30 degree. Also, in the figure 6, the upper (a) is 45 degree of slope angle from pressing face of board, the middle (b) is 60 degree and the lower (c) is 90 degree.

For cutting of 0 degree of slope angle that the center layer of MDF board was cut parallel to the pressing face, the resistances showed small value and little periodic variation with time, compared with solid wood cutting of 0 degree. On the other hand, it was observed that a relatively large–amplitude AE was generated continuously.

For cutting of 45, 60 and 90 degree of slope angle, It was clearly observed that the resistances showed a wave–like variation in the cutting process (from start to finish of cutting). This occurrence of wave–like variation was thought to be caused by the lamination of a commercial MDF board (thickness: 9 mm). That is to say, by density distribution (high at surface layer and low at core layer of a board) of MDF the resistances showed a high value in the cutting of high density layer near the adhesion phase. On the other hand, It was found that a large–amplitude AE generation was observed in the cutting of low density layer (core layer of a board).

Relationships among cutting resistances (R_H, R_V), AEs and slope angle from pressing face of board in the cutting of MDF at depth of cut of 0.1 mm and 0.3 mm are shown in Figure 7. Here, the measuring values are all the average values in the cutting of low density layer (core layer of a board). With increasing slope angle from pressing face of board the R_H showed an increasing tendency to 90 degree and the R_V had a negative value with slight increase. The AE signals at tool side also showed a rapid increase at slope angle range of 30 to 60 degree and then almost kept constant. These variation tendencies of cutting resistances and AEs are similar to the variations of resistances and AEs with slope angle of grain in the cutting of solid wood. From the above results, It was found that the AE generation in cutting was closely linked to slope and orientation of fiber. Comparing with edge cutting of MDF that the high density layer at surface and the low density layer at core of a board were cut simultaneously, even for cutting of 90 degree of slope angle the values of cutting resistances and AEs are low. It was suggested that the values of cutting resistances and AEs in the cutting of only surface layer of MDF became more higher.

Cutting of particleboard

The typical variations of the resistances (R_H, R_V) acting on the tool and the AE signals at tool side (upper in

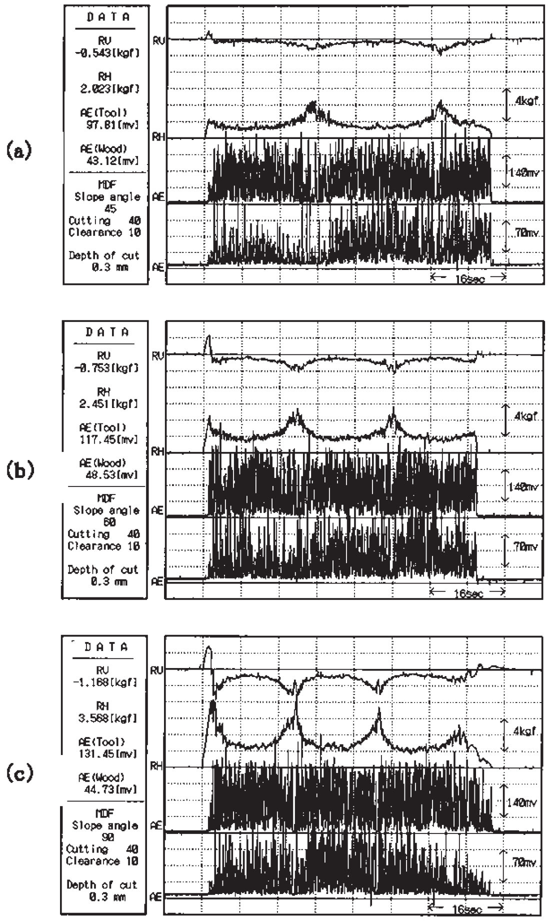

Fig. 6. Variations of cutting resistances and AEs during cutting of MDF (cutting angle 40 °, clearance angle 10 °, depth of cut 0.3 mm).
Notes : (a) Slope angle from pressing face of board : 45 °, (b) 60 °, (c) 90 °

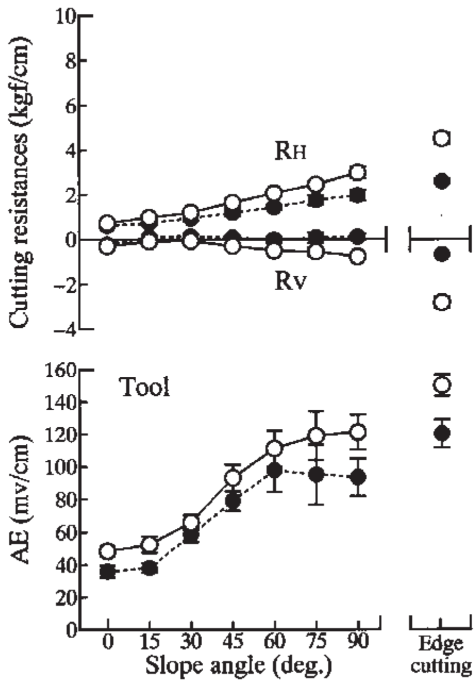

Fig. 7. Relationships among cutting resistances (R_H, R_V), AEs and slope angle from pressing face of board in the cutting of MDF (cutting angle 40 °, clearance angle 10 °).
Legend and Note : Same as Figure 4.

each figure) and at workpiece side (lower in each figure) during cutting of particleboard are shown in Figure 8. In the figure, the upper (a) is 6% of resin content of made board, the middle (b) is 10% and the lower (c) is 14%.

By the observation of cutting surface of PB, It was suggested that the draw–out or drop–out of particle occured besides cutting of a particle and the draw–out or drop–out of particle decreased with increasing resin content. Therefore, for cutting of PB, the resistances showed irregular variations with time. On the other hand, AE was generated continuously.

Relationships among cutting resistances (R_H, R_V), AEs at tool side and workpiece side, MOE and MOR and resin content of made board in the cutting of PB at depth of cut of 0.1 mm and 0.3 mm are shown in Figure 9. With increasing resin content of made board the R_H showed an increasing tendency and the AE signals at tool and workpiece sides also increased. On the other hand, MOE and MOR showed increase tendency at resin content range of 6 to 10% and then almost kept constant. From the above results, It was found that the AE generation in cutting of PB was complicatedly linked to cutting of particle and presence of adhesive.

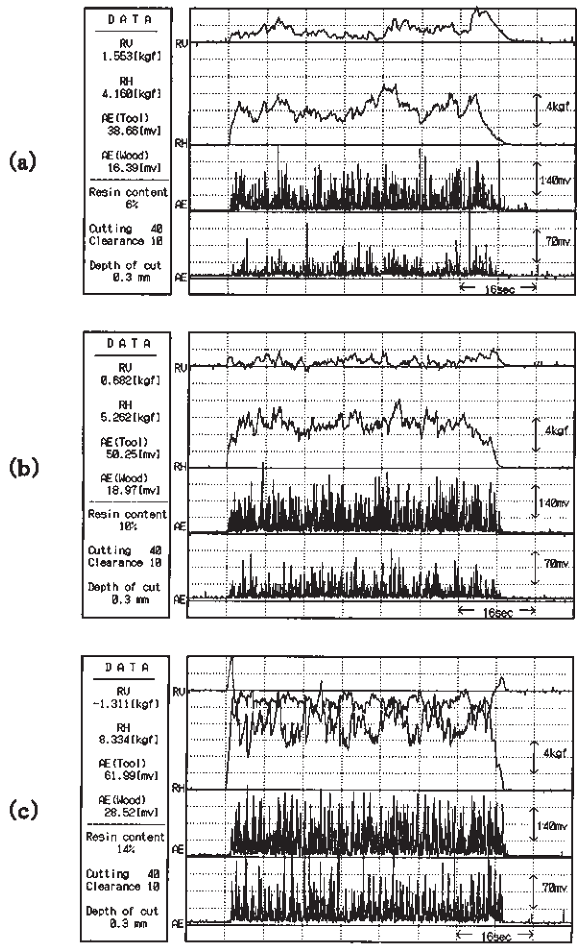

Fig. 8. Variations of cutting resistances and AEs during cutting of particleboard (cutting angle 40 °, clearance angle 10 °, depth of cut 0.3 mm).
Notes : (a) Resin content : 6%, (b) 10% , (c) 14%

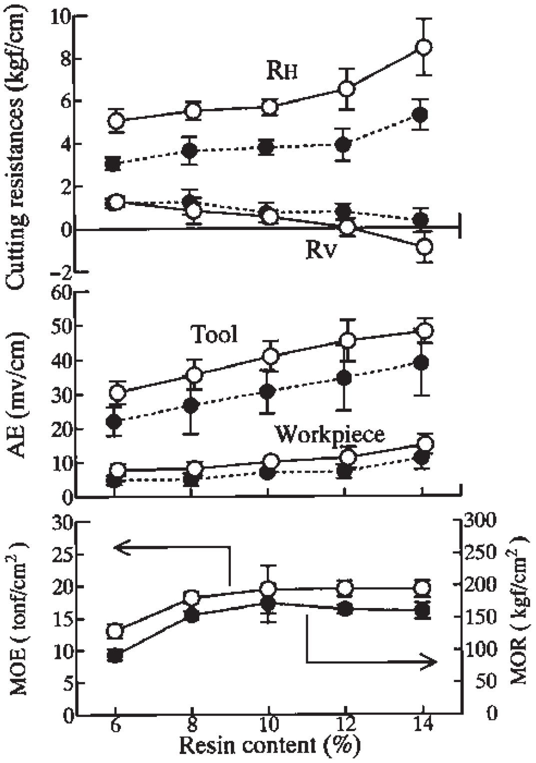

Fig. 9. Relationships among cutting resistances (R_H, R_V), AEs, MOE , MOR and resin content in the cutting of particleboard (cutting angle 40 °, clearance angle 10 °).
Legend and Note : Same as Figure 4.

CONCLUSIONS

In this study, to obtain basic knowledge on AE characteristics in the cutting process of wood and wood–based materials, the acoustic emission and cutting resistance in the cutting of solid wood, MDF and PB were examined.

The following main results were obtained :

(1) For 0, 15 and 30 degree of slope angle of solid wood cutting, the resistances showed clear periodic variation with time. This occurrence of periodic variation was thought to be caused by chip formation of split type. It was found that a large–amplitude AE was generated immediately after the peak in a periodic variation of resistance.

(2) For cutting of 45, 60 and 90 degree of slope angle, as the shear type chip were formed continuously the resistances showed relatively large value although a periodic variation was not clearly observed. A remarkably large–amplitude AE generation was observed continuously.

(3) With increasing slope angle of grain the R_H showed an increasing tendency and the R_V had a negative value with slight increase. The AE signals at tool side showed a rapid increase at slope angle range of 30 to 60 degree and then decreased or kept constant. It was found that in solid wood cutting the AE generation was closely linked to state of chip formation, compared with cutting resistances.

(4) For 0, 15 and 30 degree of slope angle from pressing face in MDF cutting, the resistances showed small value and little periodic variation with time. It was observed that a relatively large–amplitude AE was generated continuously.

(5) For cutting of 45, 60 and 90 degree of slope angle, It was clearly observed that the resistances showed a wave–like variation in the cutting process. By density distribution of MDF the resistances showed a high value in the cutting of high density layer near the adhesion phase. It was found that a large–amplitude AE generation was observed in the cutting of low density layer .

(6) With increasing slope angle from pressing face of board the R_H showed an increasing tendency and the R_V had a negative value with slight increase. The AE signals at tool side also showed a rapid increase at slope angle range of 30 to 60 degree and then almost kept constant. It was found that the AE generation in cutting was closely linked to slope and orientation of fiber. Comparing with edge cutting of MDF, It was suggested that the values of cutting resistances and AEs in the cutting of only surface layer of MDF became more higher.

(7) It was suggested that in the cutting of PB the draw–out or drop–out of particle occured besides cutting of a particle and the draw–out or drop–out of particle decreased with increasing resin content. For cutting of PB, the resistances showed irregular variations with time and AE was generated continuously.

With increasing resin content of made board the R_H showed an increasing tendency and the AE signals at tool and workpiece sides also increased. It was found that the AE generation in cutting of PB was complicatedly linked to cutting of particle and presence of adhesive.

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