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Study on the Power Consumption Characteristics of Korean Domestic Species in Peripheral Milling with Image Analysis Technique*1

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ABSTRACT

Peripheral milling is one of the most important wood machining processes in wood industry. Power consumption characteristics of twelve Korean domestic species in peripheral milling were investigated in this study. Image analysis technique was applied to extract proper data from the power consumption profiles. Average power consumption increased as cutting depth increased and specific cutting power decreased as cutting depth increased. However, no significant relationship could be found between density and power consumption and between cutting depth and surface roughness.

Keywords : wood machining, peripheral milling, power consumption, specific cutting power, image analysis, surface roughness

1. INTRODUCTION

Peripheral milling is one of the most important wood machining processes in wood industry. Peripheral milling conditions affect the power consumptions and quality of cut surfaces greatly influences following processes, such as painting and adhesion. Therefore, optimization of the peripheral milling process is essential to save energy and costs and even to guarantee the quality of final products.

Davis and Nelson (1954) measured power consumed in operating a molder during machining of wood samples. Factors affecting power for planing of hardwoods were analyzed by Stewart (1974). Medic and Fajdiga (1996) investigated the effects of inclined cutterheads on specific cutting forces, which were measured by special torque-measurement probe incorporated in the driving shaft. Riegel (1997) described the state of technology concerning the machining effects and introduced the possible measuring methods for wood machining process. Recently, Japan Wood Society (2001) has published the experimental manual for measuring power consumption in wood machining process.

Naderi and Hernandez (1999) investigated the effects of planing on physical and mechanical properties of sugar maple wood. They suggested the fixed-knife pressure-bar method to obtain

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Table 1. Species, moisture contents and densities of specimens

	Species	MC (%)	Density* (kg/m^3)
Softwood	*Abies holophylla* MAX	10.75	420
	Larix leptolepis	12.90	630
	Pinus densiflora SIEB. et Zucc	10.91	430
	Pinus koraiensis SIEB. et Zucc	11.49	390
Hardwood	*Acer mono* MAX	11.72	660
	Betula schmidtti REGEL	11.90	910
	Fraxinus mandshurica RUPR	11.75	750
	Maackia amurensis RUPR. et MAX	12.75	570
	Meliosma myrianta SIEB. et Zucc	14.48	680
	Prunus sargentii REHDER	9.23	420
	Robinia pseudo-acacia LINN	11.04	740
	Ulmus. davidiana var. japonica NAKAI	12.73	630

(* based on oven-dry weight and oven-dry volume)

less affected properties.

In this study power consumption characteristics in peripheral milling process were investigated for some Korean domestic species with image analysis technique to recommend more efficient wood machining process for wood industry.

2. MATERIALS and METHODS

2.1. Materials and Equipments

Experiments were carried out with four domestic softwood species and eight domestic hardwood species. Each specimen was flat-sawn and air-dried to about 12% moisture content and cut to 430 mm-long, 90 mm-wide, and 20 mm-thick. The scientific name, number of specimen pieces, and density of each species were shown in Table 1. Densities (based on oven-dry weight and oven dry volume) were measured by water-displacement method. Four specimens were prepared for each species.

Tests were made with automatic planer (DELTA Model 22-560 ; 2Hp). Number of rotations per minute of cutterhead was 8000 rpm. Cutterhead has 2 knives with cutting angle of 40^o. Diameter of cutterhead was 51 mm. Specimen was fed automati cally into the planer and feed speed was set at 8 m/min. Cutting depths of 1 mm, 2 mm, and 3 mm were applied to investigate the effects of cutting depth on the power consumption.

Power consumptions were monitored by power analyzer (GLA electronica-6500) which was connected power source. Electrical power should be supplied to planer only through the power analyzer. Therefore, it was possible to analyze the power consumption changes during peripheral milling. All the data was input to the personal computer which was connected with power analyzer through RS-232 communication.

2.2. Image Analysis for Calibration

There are two rollers which feed automatically and fix the specimen during peripheral milling. If the length of specimen is too short in comparison with the distance between two rollers, it becomes impossible to feed specimen into the planer. Therefore, each specimen should be long enough to guarantee the stable machining process. However, Korean domestic species have lots of defects on the surfaces such as knots which would give false data. It was difficult to

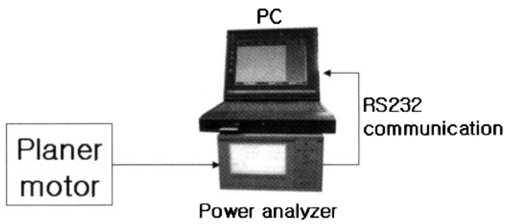

Fig. 1. Diagram of measuring set-up.

prepare the clear specimens with enough length. Thus the specimens cut from some species had defects inevitably on the surface.

Image analysis techniques were applied to calibrate the data from the specimens with defects. PC camera (manufactured by Mira Co., Ltd.) with resolution of 1.3 Mega pixels was used to capture the images of specimen cut-surfaces. Software was developed to analyze the captured images and locate the coordinates of defects exactly. Gray levels of all the pixels in images were measured and the images were converted into the binary images according to the threshold values for each image. Several threshold values were selected through the analysis of histogram and the optimal threshold value was determined by comparing the original image with binary images which were obtained with selected threshold values for each specimen. The coordinates of defects were located easily through leveling process. Fig. 2. shows the binary surface images of *Pinus densiflora Sieb.* et *Zucc.*

All the data at the location of defects were eliminated. Since the specimen was not pressed simultaneously by two rollers during the initial entering and final exiting period, somewhat lower power consumption would be obtained. Therefore, the data obtained during the entering and exiting period were also eliminated.

2.3. Measurement of Surface Roughness and Specific Cutting Power

Noncontactive type laser displacement sensor (resolution 10 μm, range of measurement ±10

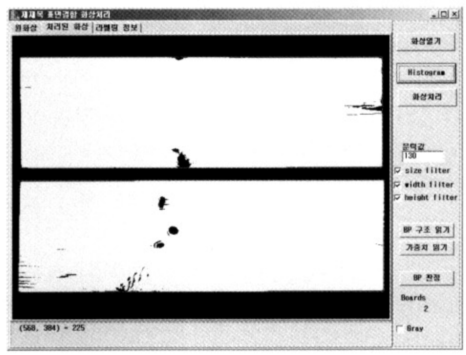

Fig. 2. Binary surface images of specimens of *Pinus densiflora* Sieb. et Zucc.

mm) was used to measure the surface roughness of each planed specimen for evaluation of the surface quality. Laser displacement sensor was fixed and the conveyor moved the specimen under the sensor at constant speed of 10 m/min.

Root mean square (rms) method as follow equation (1) was applied to the obtained data to evaluate the quality of planed surface.

$$Rrms = \sqrt{\frac{1}{L}\int_0^L f^2(x)\,dx} \qquad (1)$$

where $Rrms$: roughness root mean square
L : length of the profile (mm)
$f(x)$: profile height at the co-ordinate x

Specific cutting power means net cutting power consumed in removing unit volume of wood material. Specific cutting power is defined as follow equation.

$$E_S = \frac{E_N}{V_R} \qquad (2)$$

where E_S : specific cutting power (W/cm^3)
E_N : net cutting power (W)
V_R : volume of wood material removed by cutting (cm^3)
(= specimen length × specimen width × cutting depth)

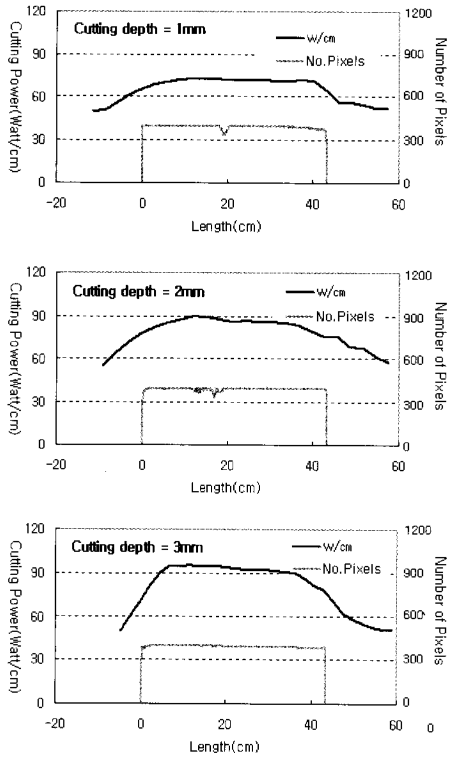

Fig. 3. Cutting power consumption and number of pixels which represent clear wood on the line perpendicular to longitudinal direction (*Pinus densiflora* SIEB. et Zucc).

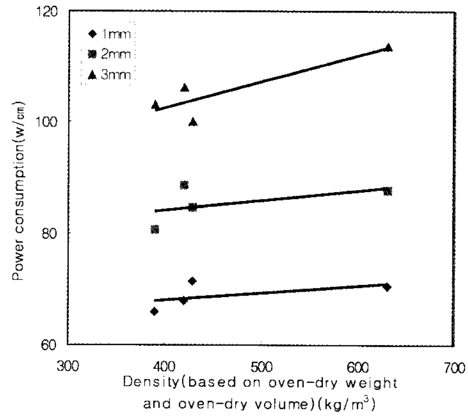

Fig. 4. Effect of wood basic density on power consumption in peripheral milling of softwood species.

3. RESULTS and DISCUSSION

3.1. Effect of Cutting Depths and Basic Densities on Power Consumption

Fig. 3. shows the profiles of power consumed during peripheral milling of *Pinus densiflora* with cutting depth of 1, 2, and 3 mm, respectively. Power consumption was increased gradually in the initial stage when the specimen was entering the planer. Then relatively same level of power consumption was maintained during main process. When the specimen was exiting the planer power consumption was decreased gradually. Therefore, the data obtained during the entering and exiting period were eliminated to extract the proper data for the investigation of power consumption characteristics.

The profiles of numbers of pixels of binary images were presented also in each graph. Binary image is composed of only black (0) and white (1). Black co-ordinates mean that co-ordinates are part of defects such as knots. The data obtained at these black co-ordinates were also eliminated. The power consumption was expressed as power consumption per unit cutting width (Watt/cm).

This calibration process was applied to all the species selected for this study. Fig. 4 and 5 shows the effect of cutting depth and basic density on average power consumption for softwood and hardwood species, respectively. Larger cutting depth resulted in higher average power consumption. Average power per unit width of about 70, 85, and 110 Watt/cm was consumed in peripheral milling of softwood species with cutting depth of 1, 2, and 3 mm, respectively. For hardwood species about 100, 115, and 150 Watt/cm with 1, 2, and 3 mm, respectively. Since the average basic density of hardwood species was higher than those of softwood species, more power seemed to be consumed in peripheral milling of hardwood than of softwood

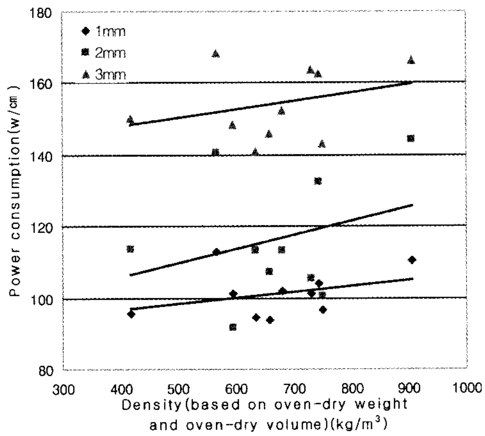

Fig. 5. Effect of wood basic density on power consumption in peripheral milling of hardwood species.

species. Higher basic density also induced higher average power consumption. However, since there were so many factors that could not be represented only by basic density, the relationships between basic density and average power consumption were not significant.

3.2. Surface Roughness and Specific Cutting Power

Fig. 6 and 7 shows the surface roughnesses of softwood and hardwood species, respectively, after planing process. There was no significant relationship between cutting depth and surface roughness. In view of the great variations in anatomical and physical properties between species, it is not surprising that some species would not follow a simple relationship based on basic density. Generally, planed surface quality depends on anatomical characteristics of wood, especially on the character istics of main tissues exposed on surface. As follow equation Koch (1964) proposed, the maximum height of chip mark is a function of feed per knife, radius of cutting circle, number of knives and rotation of cutterhead per minute. This equation does not

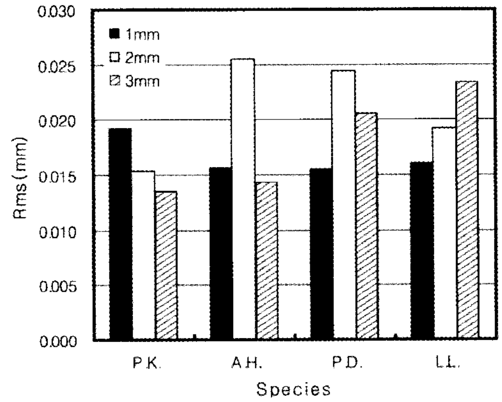

Fig. 6. Effect of cutting depth on surface roughness of softwood (P.K.: *Pinus koraiensis*, A. H.: *Abies holophylla*, P.D.: *Pinus densiflora*, L.L.: *Larix leptolepis*).

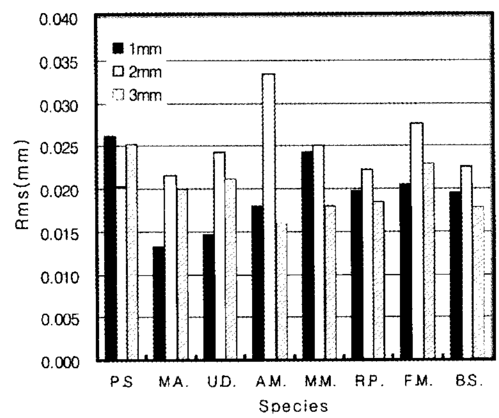

Fig. 7. Effect of cutting depth on surface roughness of hardwood (P.S.: *Prunus sargentii*, M.A.: *Maackia amurensis*, D.: *Ulmus davidiana var. japonica*, A.M.: *Acer mono*, M.M.: *Meliosma myrianta*, R.P.: *Robinia pseudo-acacia*, F.M.: *Fraxinus mandshurica*, B.S.: *Betula schnidtti*)

include cutting depth as a factor which can affect surface quality.

$$h_{\max} = \frac{F_t^2}{8\left(\frac{R}{2.54} + \frac{F_t T}{\pi}\right)} \tag{3}$$

$$F_t = \frac{31683F}{Tn} \tag{4}$$

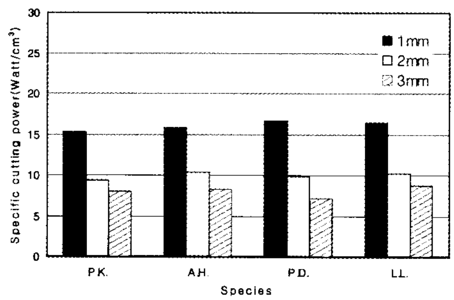

Fig. 8. Specific cutting energies for softwood species by cutting depth (Legends same as Fig. 6)

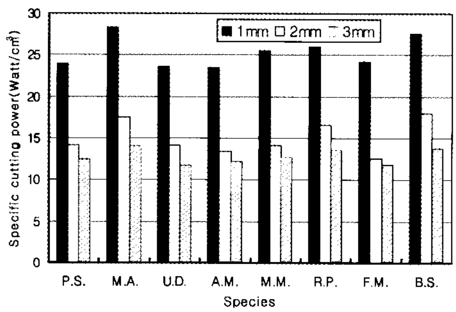

Fig. 9. Specific cutting energies for hardwood species by cutting depth (Legends same as Fig. 7)

where h_{max} : maximum height of chip mark in peripheral milling (cm)

F_t : feed per knife (cm)

R : radius of cutting circle (cm)

T : number of knives

F : feed speed (cm/minute)

n : rotation of cutterhead per minute (rpm)

Specific cutting energy was calculated by three different cutting depths for each species and the results were shown in Fig. 8 and 9 for softwood and hardwood species, respectively. Specific cutting power decreased as cutting depth increased. Average specific cutting power was 16.03, 9.93, and 8.05 Watt/cm^3 at cutting depth of 1, 2, and 3 mm, respectively, for softwood species and 25.32, 15.09, and 12.81 Watt/cm^3 for hardwood species. Specific cutting power at cutting depth of 1mm was much higher than at cutting depth of 2 and 3 mm.

Since there was no significant difference in surface roughness between different cutting depths, it is recommended that cutting depth should be as large as possible to save energy and processing time when the cutting depth is smaller than 3 mm.

4. CONCLUSIONS

Power consumption characteristics of twelve Korean domestic species in peripheral milling were investigated with image analysis technique. Average power consumption increased as cutting depth increased. However, significant relationships between basic density and average power consumption could not be found. There was no significant difference in surface roughness between different cutting depths. Specific cutting power increased as cutting depth decreased. Therefore it is recommended that cutting depth should be as large as possible to save energy and processing time when the cutting depth is small than 3 mm.

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