Incision Effect in Ultrasonic Vibratory Cutting of Wood*

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木材の超音波振動切削における切込促進効果

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要　　旨

切削中，切込量が直線的に増加する二次元勾配切削を用いて，木材の超音波振動切削における切込促進効果（工具が被削材に切込み易くなる効果）を検討し，次の結論を得た。

振動切削においては切込促進効果が存在する。この効果は振幅 a，切削速度 V_0，被削材の傾斜角 θ（切削方向と被削材原表面のなす角）によって影響される（振動数 f は17.6kHz で一定）。一般に切込促進効果は振幅の増大とともに良くなり，高切削速度，小傾斜角において顕著である (Fig. 3)。また切込促進効果と切削速度比 $\alpha_v(=V_0/2\pi af)$ の間には一次的な関係は存在せず，α_v のある変化域で切込効果が最良になる (Fig. 4)。

切込促進効果は切削面の性状においても現われる。振動切削における切込みは円滑で，切削面の粗さは相当減少し，また木口切削における繊維方向の割れも顕著に減少する (Fig. 5, 7)。

本実験においては加工精度向上効果が認められた。この効果は切削速度よりもむしろ振幅によって大きく左右される (Fig. 8)。

1. Introduction

In vibratory cutting of wood, generally the quality of machined surface is much improved as exemplified by the decrease in the roughness of surface finish,[1)2)] the decrease of wood split at right angles to the machined surface and parallel to the grain,[3)4)5)] etc. This improvement seems to be due to the combined effect of intermittent and infinitesimal cutting,[6)] decrease of the coefficient of friction,[7)] etc., i. e., incision effect (promotion effect of the penetration of cutting edge into wood). Furthermore, it seems that this effect has a great influence on machining accuracy.

Though the incision effect is one of the important effects of vibratory cutting, there are scarcely any concrete studies concerning this effect. Hence, using an inclined cutting as a suitable cutting method for the direct observation of incision effect, the one in ultrasonic vibratory cutting of wood was examined.

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2. Experimental

2. 1. Experimental set-up and conditions

Fig. 1 shows the experimental set-up schematically. A nickel magnetostrictive transducer was vibrated by a generator, and the vibration was propagated to a tool via a concentrator. The tool-transducer assembly was mounted on the carriage of a metal-working lathe having an automatic feeding device. On the other hand, a work material was mounted on an inclination plate so that its original work surface might incline by a given angle θ toward the cutting direction (see Fig. 2). The inclination device was fixed on the bed of the lathe via a pedestal having a gage for the selection of the desired depth of cut.

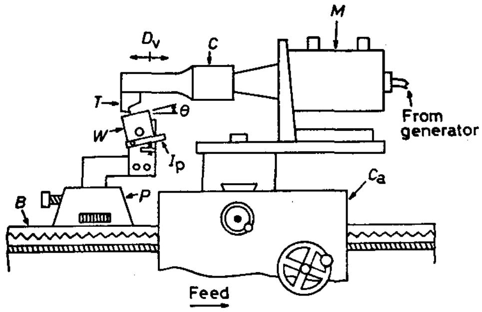

Fig. 1. Schematic diagram of experimental set-up. M, nickel magnetostrictive transducer; C, concentrator; T, tool; W, work material; I_p, inclination plate; P, pedestal; C_a, carriage of lathe; B, bed of lathe; θ, inclination angle; D_v, direction of vibration.

A reading microscope (×25 magnification), furthermore, was mounted on the carriage of the lathe, was focussed on the cutting edge from a side of the tool and was fed at the same speed with the tool. Hereby, cutting process could be continuously observed through the reading microscope.

The work material used was BUNA (*Fagus crenata* Blume) with specific gravity in air dry of 0. 61 and moisture content of 9% or the same wood saturated with water. Using a tool (SK4) with a rake angle of 30°, a clearance angle of 5° and a sharpness radius of the cutting edge of ca. 15μm, mainly orthogonal cutting parallel to the grain with cutting edge perpendicular to the grain (90°−0° cutting)[3] was carried out under a constant frequency of 17. 6kHz, amplitudes of 0～15μm, cutting speeds of 0. 23～4. 60mm/s and a width of cut of 4mm. The direction of vibration was always parallel to the cutting direction. Since the original work surface to be cut stood in need of flatness, the one for 90°−0° cutting was finished using the ultrasonic vibratory cutting (amplitude 10μm) and for other cuttings using a miter saw.

2. 2. Determination of incision effect

In the present inclined cutting, cutting process in the region of infinitesimal cutting, i. e., tool-work material contact, subsequent rubbing between tool and original work surface, initial stage of chip formation and gradual increase of the depth of cut, can be minutely observed. Taking advantage of this cutting process, incision effect in the ultrasonic vibratory cutting of wood is determined as follows.

Cutting process in the inclined cutting is schematically shown in Fig. 2. Original work surface inclines by a given angle θ toward the cutting direction (ideal cutting plane).

Cutting edge is set so as not to contact with the original work surface and is fed at a constant speed V_o (cutting speed). After a little while, the cutting edge comes into contact with the original work surface at point C and advances to point C_f rubbing the original work surface. At C_f the cutting edge penetrates into work material, i. e., at this point the chip moves up the rake face. These points are discerned using the reading microscope. The travel length of cutting edge L (designated contact length) between C and C_f can be obtained from the measurement of contact duration time. Incision effect can be assessed using L_u/L_o (designated contact length ratio). Where, L_u is the contact length in the vibratory cutting and L_o that in the conventional cutting (cutting without vibration).

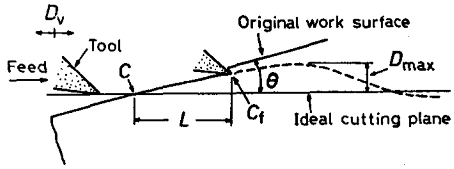

Fig. 2. Schematic diagram of cutting process in inclined cutting. θ, inclination angle; D_v, direction of vibration; C, initial point of tool-work material contact; C_f, initial point of chip formation; L, contact length; D_{max}, maximum deviation between ideal cutting plane and machined surface.

Passing through the initial point of chip formation C_f, the cutting edge moves forward creating such a machined surface as the dotted line. As the depth of cut increases up to a some value, the cutting edge fully penetrates into work material. Consequently, there is a difference between the machined surface and the ideal cutting plane. In order to discuss machining accuracy, the maximum deviation between them D_{max} is measured using the reading microscope.

3. Results and discussion

3. 1. Incision effect

Fig. 3 shows the dependency of contact length ratio L_u/L_o on amplitude. L_u/L_o in the conventional cutting is equal to 1. In the vibratory cutting, incision effect was recognized under every set of conditions, i. e., $L_u/L_o<1$. And this effect became greater with increasing amplitude with exception of several measured values. In 90°−0° cutting, the incision effect at a cutting speed of 0.69mm/s (curves 3 and 6) was greater than that at 0.23mm/s (curves 1 and 5). Furthermore, when cutting speed was constant, the incision effect at an inclination angle of 0.7° was greater than that at 1.9°. This indicates that the incision effect is conspicuous at a smaller grain angularity relative to the tool path.

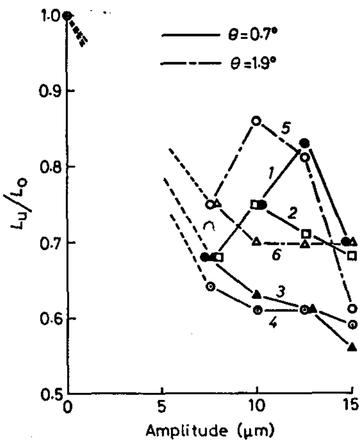

Fig. 3. Relation between contact length ratio L_u/L_o and amplitude. *1* and *2* (V_o=0.23mm/s, 90°—0° cutting); *5* (V_o=0.69mm/s, 0°—90° cutting); *3* and *6* (V_o=0.69mm/s, 90°—0° cutting); *4* (V_o=0.69mm/s, 90°—0° cutting, saturated wood).

Cutting direction affected the incision effect. At a cutting speed of 0.69mm/s the incision effect in 90°−0° cutting (curve 3) was greater than that

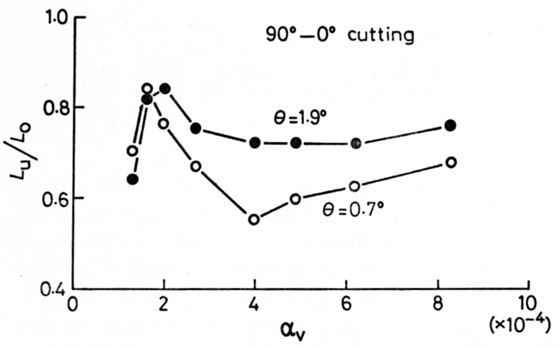

Fig. 4. Relation between contact length ratio L_u/L_o and cutting speed ratio α_v.

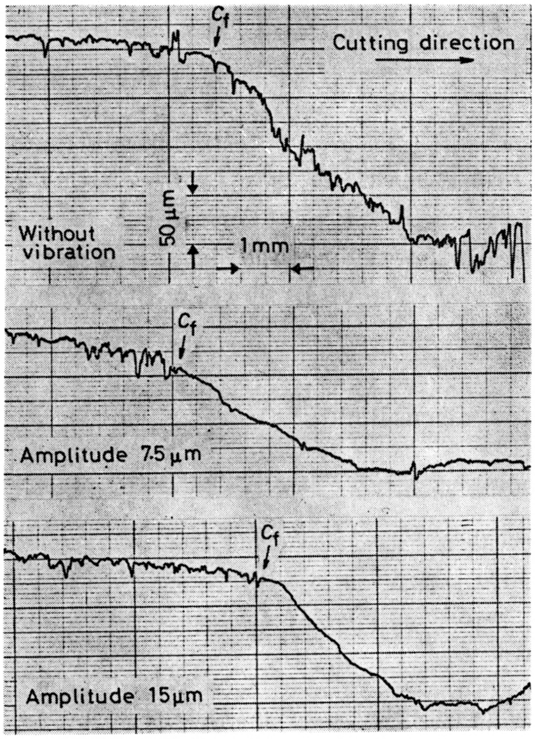

Fig. 5. Profiles of machined surface in inclined cutting. θ=1.9°, V_o=0.69mm/s, 90°—0° cutting.

in 0°—90° cutting (curve 2).

There was no marked difference between air dry wood (curve 3) and saturated wood with water (curve 4).

Fig. 4 shows the relation between contact length ratio L_u/L_o and cutting speed ratio α_v. α_v is defined as $V_o/2\times\pi af$. V_o, a and f are, respectively, cutting speed, amplitude and frequency. As previously noted, the incision effect was conspicuous at a smaller inclination angle of 0.7°. L_u/L_o was a non-linear function of α_v. This relation indicates that the most marked incision effect can be obtained at a certain variable range of α_v. For more detailed discussion, however, experiments covering more wide ranges of α_v must be carried out.

Fig. 5 shows the profiles of machined surface in 90°—0° cutting. In the conventional cutting the cutting edge abruptly penetrated into wood at C_f, and the depth of cut and the roughness of machined surface greatly increased. In the vibratory cutting, however, especially at an amplitude of 7.5μm the penetration of cutting edge into wood went on smoothly, and the roughness of machined surface decreased considerably.

Figs. 6 and 7 show the machined surfaces in 90°—90° cutting. Three different figures in Fig. 6 or 7 have been arranged so that these positions in the horizontal direction may coincide with one another. In the conventional cutting (Fig. 6), the cutting edge contacted with wood at C and abruptly penetrated into at C_f. The roughness of machined surface and the wood split parallel to the grain increased with increasing depth of cut. These were also clearly recognized from the profile of machined surface. In the vibratory cutting (Fig. 7), however, the cutting edge smoothly penetrated into wood, and the wood split parallel to the grain was much reduced. The roughness of machined surface increased with increasing depth of cut, but the cutting action went on favourably without abrupt penetration of cutting edge into wood.

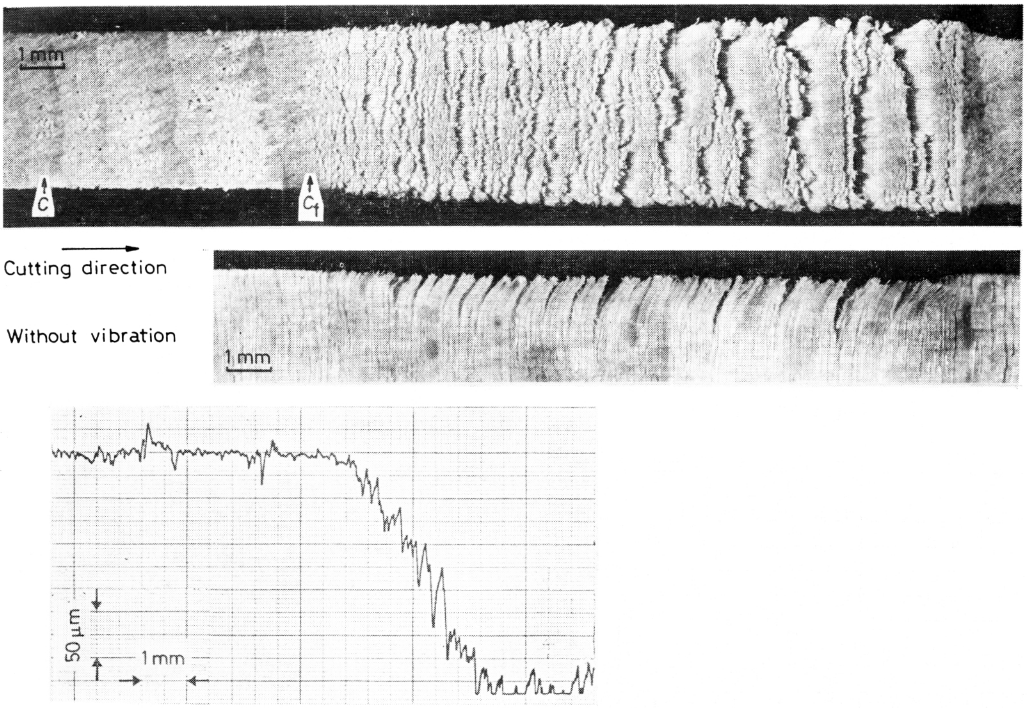

Fig. 6. Machined surface in inclined cutting. θ=0.7°, V_o=0.69mm/s, 90°—90° cutting.

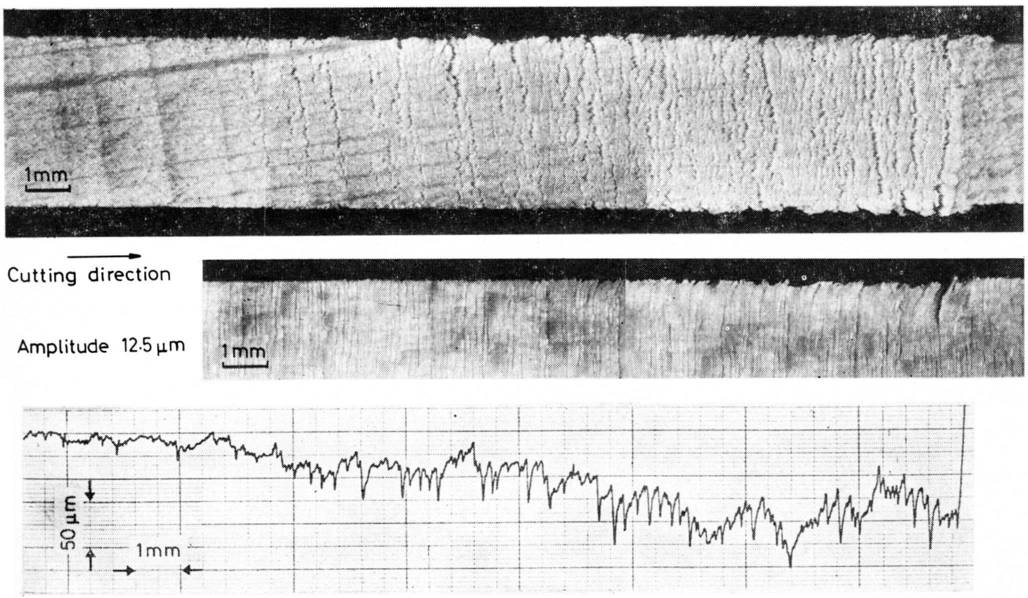

Fig. 7. Machined surface in inclined cutting. θ=0.7°, V_o=0.69mm/s, 90° —90° cutting.

3. 2. Effect to elevate machining accuracy

As previously noted, in the present inclined cutting there is a difference between the machined surface and the ideal cutting plane (Fig. 2). The maximum deviation between them D_{max} is shown in Fig. 8 as a function of cutting speed ratio α_v. The measured values plotted could be divided into three groups by cutting speed. Comparing D_{max} in the vibratory cutting with that in the conventional one by cutting speed, in general the former was smaller than the latter. This indicates that the vibratory cutting has an effect to elevate the machining accuracy. Based on the definition of α_v, under a constant cutting speed the greater the amplitude becomes, the smaller α_v becomes. Hence, it can be recognized from Fig. 8 that D_{max} generally decreases with increasing amplitude under all the cutting speeds used. On the other hand, the distribution range of measured values in the direction of the ordinate is not greatly affected by cutting speed. These indicate that the maximum deviation D_{max} is affected by vibration amplitude rather than by cutting speed. That is, the machining accuracy is greatly affected by amplitude under the variable range of α_v used in the present study.

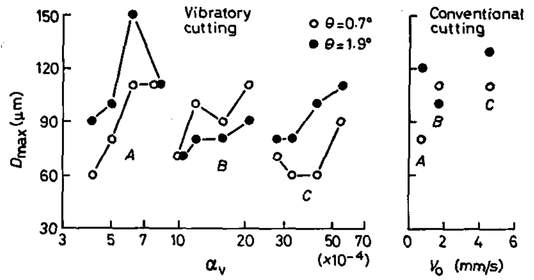

Fig. 8. Relation between maximum deviation D_{max} and cutting speed ratio α_v in 90°—0° cutting. A, V_0=0.69mm/s; B, V_0=1.72mm/s; C, V_0=4.60mm/s.

References

1) Kato, K., Tsuzuki, K. and Asano, I.; Studies on Vibration Cutting of Wood. I, Mokuzai Gakkaishi, **17** (2), 57—65 (1971)
2) Fujiwara, K., Noguchi, M. and Sugihara, H.; Ultrasonic turning wood, Effects of ultrasonic vibration on roughness of machined surfaces, Mokuzai Kogyo, **29** (2), 61—65 (1974)
3) McKenzie, W. M.; Fundamental Analysis of the Wood-Cutting Process, Univ. of Michigan, Ann Arbor, Mich., (1961)
4) St. Laurent, A.; Effect of Induced Lateral Vibration of a Saw Tooth on the Cutting of Wood, Forest Products Journal, **15** (3), 113—116 (1965)
5) Hamamoto, K. and Mori, M.; Fundamental Studies on Low Frequency Cutting of Wood. I, Mechanics of Vibratory Cutting Parallel to Feeding Direction, Mokuzai Gakkaishi, **17** (4), 137—146 (1971)
6) Fujiwara, K.; Fundamental Analysis of the Ultrasonic Turning Process of Wood, Doctoral thesis, Kyoto Univ., (1976)
7) Pohlman, R. and Lehfeldt, E.; Influence of Ultrasonic Vibration on Metalic Friction, Ultrasonics, **Oct.**, 178—185 (1966)

Résumé

Using an inclined cutting in which original work surface inclines by a given angle toward the cutting direction and the depth of cut increases linearly during cutting, incision effect (i. e., promotion effect of the penetration of cutting edge into work material) in

ultrasonic vibratory cutting of wood was examined.

The application of ultrasonic vibration to cutting edge resulted in the appearance of incision effect under every set of conditions. This effect was affected by vibration amplitude, cutting speed and inclination angle between original work surface and the cutting direction. In general, the incision effect increased with increasing amplitude and was conspicuous at a higher cutting speed and a lower inclination angle (Fig. 3). Furthermore, there was a non-linear relation between the incision effect and cutting speed ratio α_v (Fig. 4). This relation indicates that the most beneficial incision effect can be obtained under a certain limited range of α_v.

The incision effect resulted in the improvement of the quality of machined surface; the penetration of cutting edge into wood went on smoothly, and the roughness of machined surface decreased considerably (Figs. 5 and 7). Furthermore, the wood split at right angles to the machined surface and parallel to the grain was much reduced (Fig. 7).

On the other hand, in the present study an effect to elevate the machining accuracy was recognized (Fig. 8). This effect was greatly affected by vibration amplitude rather than by cutting speed.