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SOME CONSIDERATIONS ON FLOW OF CUTTING FLUID BETWEEN TOOL AND CHIP

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Abstract

Considerations were made on the flow of cutting fluid between tool rake and chip on the basis of orthogonal cutting experiments. The main experiments are as follows:

(1) Variation of friction was measured when the cutting fluid was smeared instantaneously on the rake face through a small hole drilled on the workpiece side parallel to the cutting edge.

(2) Conventional wet cuttings were made at various cutting speeds and widths of cut, and coefficient of friction was measured.

It is ascertained that the cutting fluid flows into tool-chip contact region from the side of chip, and the lubricated area is restricted to the area near the side of the chip.

Introduction

The most important actions of cutting fluids during machining are considered to be lubrication in the tool-chip contact region and heat transfer from the source.

Various explanations or hypotheses have been advanced as to the method of entry and lubricating behavior of cutting fluids, but the inconsistency among these explanations makes it still unclear as to where the fluid actually enters and how much it lubricates in the tool-chip contact region.

W. E. Lauterbach et al. [1] concluded from the cutting test at very low speed that the fluid enters the tool-chip contact region from tool relief (from C in Fig. 1).

N. Shinozaki et al. [2] observed the machined surfaces when oils are supplied from rake, relief and side surface, and concluded that the fluid entered the contact region from relief.

H. Takeyama et al. [3] observed the rake face by means of a movie camera when leads were cut with glass tool, and concluded that the fluid enters the tool-chip interface almost parallel with the cutting edge from both sides of free boundary of the chip on the rake face (from B in Fig. 1).

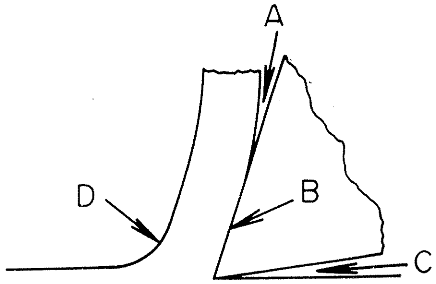

Fig. 1. Direction of cutting fluid entry.

Entry into the contact region from rake against the chip flow (from A in Fig. 1) may be possible, and P. L. Barlow [4] reported some effect of fluid existing on back surface of the chip (D in Fig. 1).

The aim of the present investigation is to elucidate from where the fluids enter the tool chip contact region and where the region is lubricated under a set of practical cutting conditions.

Experimental Methods

The cutting tests were made on a hydraulically driven planer of 150 mm stroke. The cutting tool used was of high speed steel ground by diamond wheel, with a rake angle of 20 degree and a relief angle of 7 degree.

The work materials were rolled copper plates of 99.9 % purity. The plate was clamped by the vise on the table and the side surface was cut in the rolled direction under orthogonal conditions.

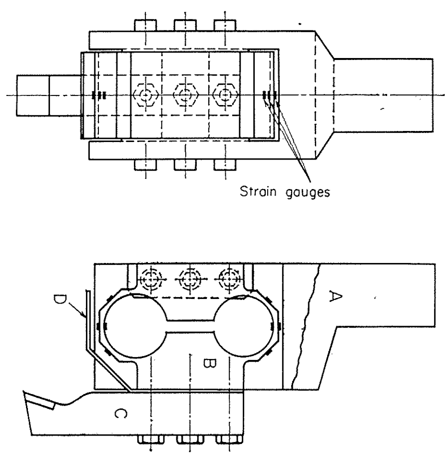

Fig. 2. Tool and dynamometer.

The cutting force dynamometer (B) consisted of half-rings at the end of two rigid plates and resistance strain gauges suitably located on the rings, as shown in Fig. 2. The whole instrument was cut out of a solid piece of steel. The principles of design for this type of dynamometer can be found in the reference [5]. Tool (C) was attached to the dynamometer which was bolted to the tool holder (A). The strain gauges are protected by the cover (D). The result of the calibration of the gauge strain of this dynamometer due to horizontal and vertical load shows that the accuracy is ±5 %. With this apparatus, two components of cutting force were measured.

The cutting fluids used in the tests and its viscosities are listed in Table 1.

In the present study, three experimental techniques were used.

Cutting fluids	Viscosities 20°C cst
Rape seed oil	84
Machine oil	140
Spindle oil	19
Cutting oil No 1-2	93

Table 1. Cutting fluids and its viscosities.

Experimental Processes and Results

Experiment I

The first experiment was rather preliminary test to examine the Rehbinder effect on the rake face friction.

After a drop of fluid was applied over an area of length 1 on cutting surface, the fluid existing on the surface was wiped by a cloth. Then, the surface are contaminated with the fluid over the area of length 1. During the cutting, the two component of the cutting force were measured.

Fig. 3 shows an example of the records of two components of the cutting force. The area of length 1 in the figure is contaminated with the fluid and the other is clean. Coefficient of frictions calculated from the cutting forces on the contaminated and the clean areas of surface were compared in Fig. 4. The differences of

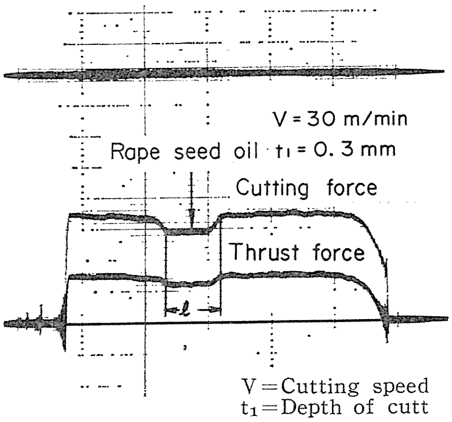

Fig. 3. An example of records of two components of cutting force.

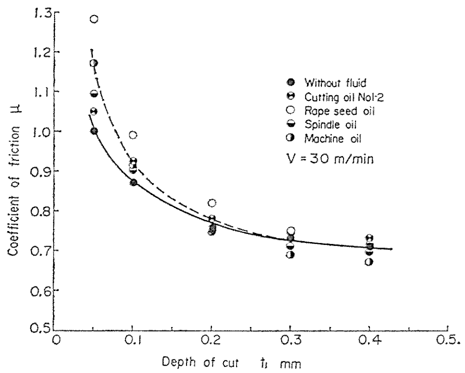

Fig. 4. Comparison of coefficients of frictions in cutting contaminated and clean surfaces.

the coefficients of frictions between the two areas are scarcely recognized except in the case of small depth of cut, though the cutting forces were decreased noticeably on the contaminated area by the Rehbinder effect of fluid on deformation of workpiece.

On the other hand, the coefficient of friction was measured under the conventional wet cutting in which the surface was sufficiently flooded with fluid. The results of measurments are shown in Fig. 5. The coefficients of frictions in the cutting flooded with fluids are, of course, considerably lower than in the dry cutting. The difference between the coefficients of frictions in Fig. 4 and Fig. 5 can be attributed to the lubricative action of the fluid in the tool-chip contact region.

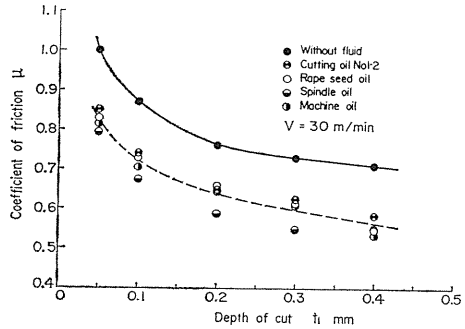

Fig. 5. Comparison of coefficients of frictions on cutting flooded and dry surfaces.

Experiment II

Prior to cutting tests, a small hole was drilled on the plate surface parallel to the cutting edge and filled with cutting fluid. After the plate was clamped on the table of the planer, cutting was done just as the tool edge penetrated the hole as shown in Fig. 6. As the cutting fluid will be smeared on the rake face when the tool edge penetrates through the hole filled with fluid, the property of the friction just after the hole passes through the rake face, will correspond to that of the lubricated sliding friction. In this experiment, variations of two components of cutting force were measured during these cutting processes. The diameter of the hole in this process is 0.5 mm. The center of the hole is located at the point 0.5 mm under the cutting surface and the depth of cut t_1 is 0.4 mm. Cutting speed of 30 m/min was adopted.

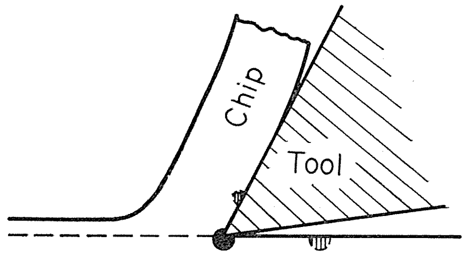

Fig. 6. Side view of cutting workiece having a hole.

An example of the recorded charts of two components of cutting force is shown in Fig. 7. Fig. 7 (a) shows the transition of the cutting force without fluid in the

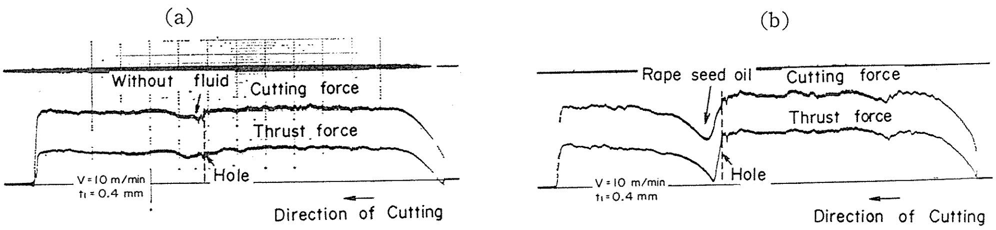

Fig. 7. Recorded charts in cutting workpieces having a hole with or without fluid.

hole and Fig. 7 (b) with rape seed oil. With fluid, the cutting force decrease abruptly when the tool penetrates the hole, and increases gradually with the advance of the cutting to become a steady cutting force.

Transitions of the coefficient of frictions calculated from the cutting forces were shown in Fig. 8. It shows that, immediately after the tool edge penetrates the hole with fluid, the coefficient of friction take a minimum value of 0.35-0.45. Thereafter, the coefficient of friction increases gradually to the initial steady value with the distance x from the point where it took a minimum value. These properties of the coefficient of friction depend on the lubricating action of the fluid

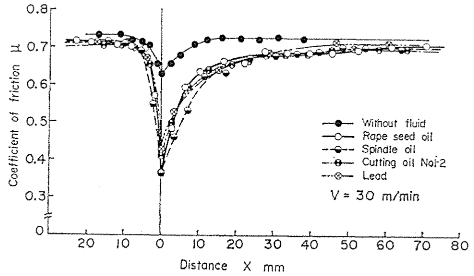

Fig. 8. Transitions of coefficients of frictions when tool penetrates hole with various fluid.

smeared on the rake face when the hole passed through the rake face. The lubricant will soon be exhausted with the chip flow, and the transition properties of the coefficient of friction will therefore depend on the wear properties of the lubricant in the contact region.

The result in the case of the hole filled with lead instead of fluid is shown in the same figure. This represents the behavior of the lead particle in cutting of the leaded material. The figure shows that both lead and fluids act as a good lubricant.

It is noticeable that, even without fluid, the variation in the coefficient of friction observed. This is probably caused by the variation of the chip deformation caused by the hole, or the lubricating action of air in the hole. In any case, the ratio of coefficient of friction with fluid μ to that without fluid μ_0, μ/μ_0, at each point are worth examining. Fig. 9 shows the variation in μ/μ_0. The three horizontal lines in the figure show the ratios of the coefficients of frictions which

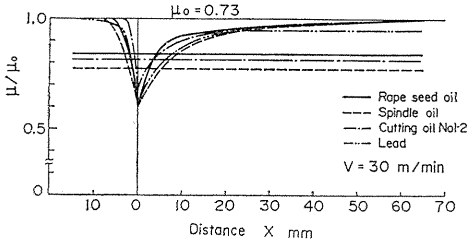

Fig. 9. Ratio of coefficient of friction with and without fluid.

were obtained from the conventional wet cutting.

The minimum value of the coefficient of friction in cutting the workpiece with hole filled with fluid is lower than that in conventional wet cutting. This fact suggests that the rake face is lubricated considerably with the fluid in hole when the hole passes through the rake face, but on the other hand, it was not lubricated so much with the fluid in conventional wet cutting. Roughly speaking, only half an area of the rake face may be lubricated in conventional wet cutting in this case, if we determine the lubricated area from the comparison with the coefficients of frictions in two cases. Of course, the lubricated area is varied by the cutting speed, width of cut, kinds of fluids and so on. As to the type of fluid, spindle oil is most effective in this case, though the ability of boundary lubrication of mineral oil is said to be low in comparison with that of vegetable oil.

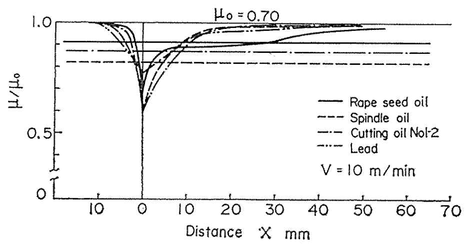

Fig. 10. Ratio of coefficient of friction with and without fluid.

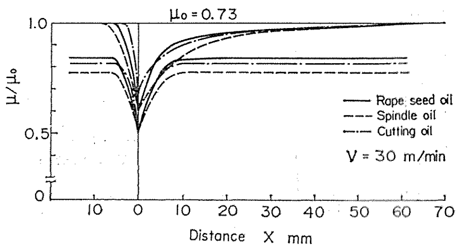

Fig. 11. Variation in coefficient of friction in cutting when hole is filled with fluid and a large quantity of fluid is simultaneously supplied from outside.

Fig. 10. shows the results of the experiment at a cutting speed of 10 m/min. The variation properties in the coefficient of friction are like those in Fig. 9.

Fig. 11. shows the variation in coefficient of friction of the cutting when the hole was filled with fluid and a large quantity of fluid was simultaneously supplied around the tool-chip contact region from the outside. Just after the tool penetrates the hole, the lubricating effect of the fluid smeared from the hole are superimposed on the effect of the fluid supplied from the outside. This fact shows that only the restricted area on the rake face is lubricated with the fluid supplied from the outside.

Experiment III

This experiment is merely a conventional cutting test under various cutting speeds and widths of cut. Cutting speed v and width of cut b were varied from 6 to 50 m/min and from 1 to 6.0 mm respectively. Depth of cut is 0.1 mm in this case.

The results of the conventional cutting tests are shown in Fig. 12. It is clear that the coefficients of frictions vary in terms of cutting speed and width of cut. The greater the cutting speed and cutting width, the higher the coefficient of friction. These properties can be explained by taking into consideration the direction of flow of the fluid into tool-chip contact region. If the fluid enters the tool-chip contact region from the relief or against the chip flow from the position where the chip leaves the tool rake face, the coefficient of friction does not depend on the width of cut. If the fluid enters from both sides of the tool-chip contact region, the region lubricated with fluid is shown in Fig. 13. Supposing that the speed of

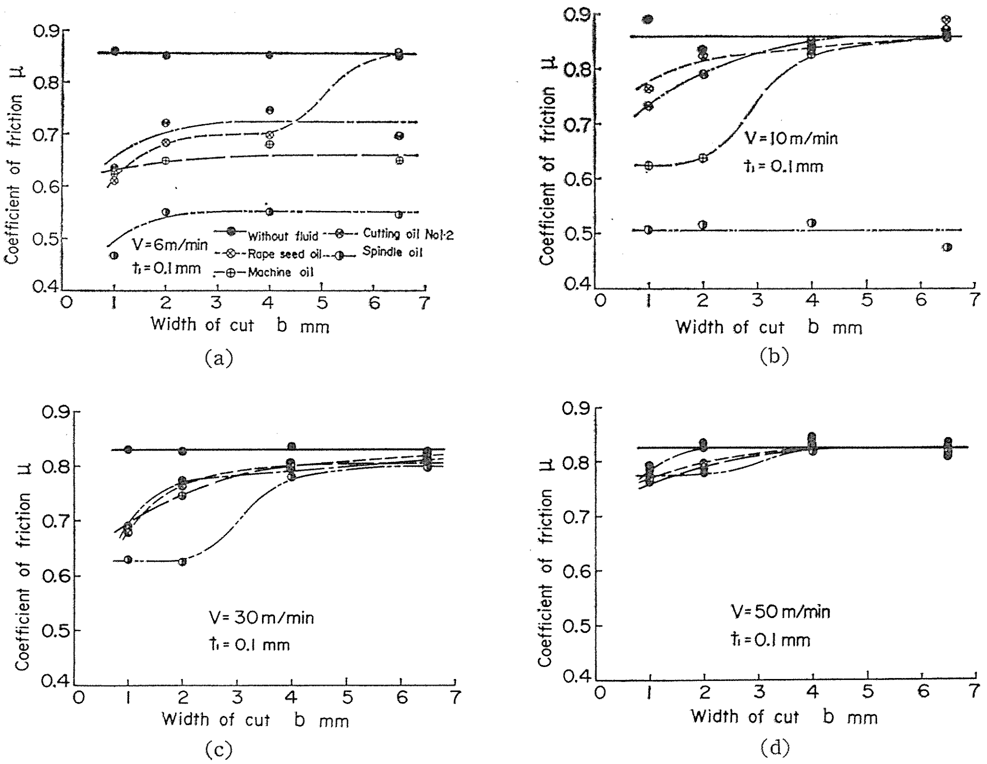

Fig. 12. Effect of cutting speed and width of cut on coefficient of friction.

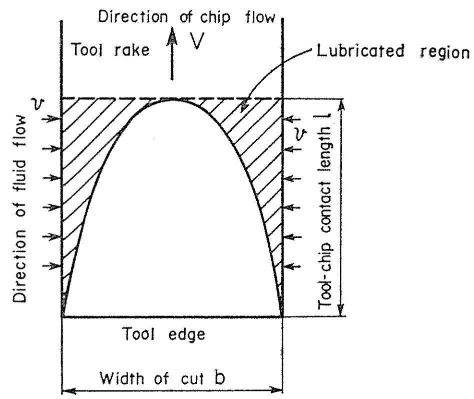

Fig. 13. Schematic view of the lubricated region.

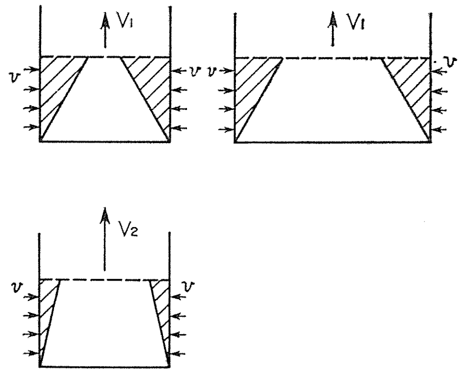

Fig. 14. Schematic view of contact region, assuming a constant speed of entry all over contact region.

entry of fluid v were a constant along the flow line all over the tool-chp contact region, the lubricated region could be shown as in Fig. 14. It is recognized from this figure that the increase in both cutting speed and width of cut give rise to decrease in the percentage of the lubricated area in relation to the entire contact area. Assuming that the fluid enters the tool-chip contact region from both sides of the chip, the cutting speed and the width of cut have a similar effect on the mean coefficient of friction of the tool-chip contact region. This fact coincides with the experimental results shown in Fig. 12.

Therefore, it is concluded that the fluid in practical cutting enters the tool-chip contact region from side of chip.

Conclusion

The simple experiments in practical cutting conditions were undertaken to inquire into the flow of the fluid in the tool-chip contact region. The results are as follows:

The cutting fluid enters the tool-chip contact region from both sides of the chip, and the region lubricated with fluid is restricted to the area near both sides of the contact region.

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