Fundamental Research of the Superfinish

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Summary

On the various work materials, the most suitable condition of cutting motion in the superfinish, and the relation of the abrasive stone pressure and cutting direction angle to the characteristics of superfinished surface have been investigated. As to the speed of cutting, it was found that the higher the speed, the better the efficiency provided the speed is kept within the range in which harmful vibrations of superfinishing machine bed is not produced, and as to the cutting direction angle, 40°~60° to be most efficient. In addition, the characteristics of superfinishing process may be classified into "cutting", "semi-cutting" and "mirror-finishing" according to the values of stone pressure and cutting direction angle, and the most efficient cutting condition has been found on the boundary line of "cutting" and "semi-cutting".

1. Introduction

The superfinishing process was first developed in the United States in 1934 and it has ever since become an important precision machining process throgh many researches conducted in various countries.

In this paper, the relation between the working conditions of superfinish and the cutting performance has been investigated and the cutting mechanism of superfinish has been clarified.

2. Experimental equipment, Work materials and Abrasive stone

Experimental equipment: An assembly drawing of the superfinishing attachment mounted on a lathe which has been used in this experiment is shown in Fig. 1. This superfinishing attachment is designed so as to take various values of stone oscillating frequency and oscillation amplitude.

Using a variable speed AC motor, the frequency of oscillation is allowed to the automatically varied in the range of 0 to 4000 complete cycles per minute, and the amplitude of oscilation a can be changed in the range of 0 to 10 mm by adjusting

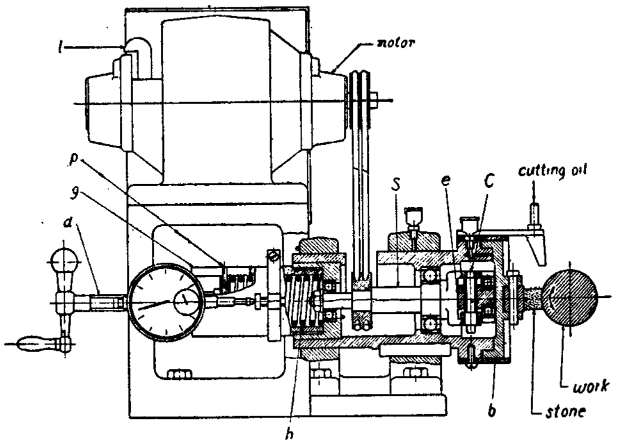

Fig. 1

relative position between s and e with the eccentric mechanism. The stone pressure which is indicated by the position of pointer p can be defined by the helical spring h and the spring force can be varied by manipulating the handle d. Wear of stone can be measured by the aid of dial gage attached to the frame of the equipment.

Work materials: For the test materials, various kinds of steel and iron shown in Table 1 are used and the characteristics of cutting and the influence of motional condition which are affected by the quality of material are studied.

Table 1. Fundamental Research of the Superfinish.

Material	Brinell Hardness	Chemical Composition					
		C	Si	Mn	P	S	Cr
Cr Steel (quenched)	418	0.94	—	—	—	—	1.61
Cr Steel	188						
Mild Steel	163	0.43	0.44	0.95	—	—	—
Cast Steel	257	0.75	0.62	0.76	0.02	0.015	—
Cast Iron	241	2.83	2.30	0.82	0.11	0.108	—

Abrasive stone: Abrasive stones used in this experiment process the following designation:

Size : $15\times20\times60$ mm, abrasive grain: Aluminum oxide, grit: 600 mesh, bond: vitrified, grade: Rockwell H hardness 60.

3. Experimental results and their discussions on the cutting motion of superfinishing

As the factors which influence the efficiency of finishing and the quality of finished surface, we can point out materials of work, abrasive stone, work speed, amplitude and friquency of oscillation, stone pressure and cutting fluid. However, considering the fact that the special feature of superfinishing process is the multidirectional cutting, it is clear that the motional conditions have the greatest influence of all. Therefore, the motional conditions giving the best efficiency of stock removal was mainly investigated in this experiment.

3. 1. Determination of motional conditions: Generally the cutting motion in the superfinish is determined by the rotation of work N, frequency f, amplitude a and feed of stone. But we consider that the cutting motion should be determined by the maximum cutting speed V or mean cutting speed $\bar{v}$, maximum cutting direction angle θ (which means the angle between the moving direction of abrasive grain of the work surface and the rotating direction of work at the middle of oscillition amplitude) and amplitude a. The values of $V, \bar{v}, \theta$ and a are calculated from the given values of N and f by the following equations: (See Fig. 2)

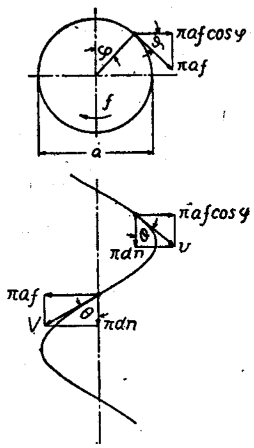

Fig. 2

cutting speed: $$v = \pi\left\{(DN)^2 + (af\cos\varphi)^2\right\}^{\frac{1}{2}}$$

cutting direction angle: $$\theta = \tan^{-1}\left(\frac{af}{DN}\cos\varphi\right)$$

max. cutting speed: $$V = \pi\left\{(DN)^2 + (af)^2\right\}^{\frac{1}{2}}$$

max. cutting direction angle: $$\theta = \tan^{-1}\left(\frac{af}{DN}\right)$$

mean cutting speed: $$\bar{v} = \frac{2}{\pi}V\int_0^{\frac{\pi}{2}}(1-\sin^2\theta\cdot\sin^2\varphi)^{\frac{1}{2}}\,d\varphi$$

where D is the diameter of work.

3. 2. Cutting speed: Fig. 3 and Fig. 4 are examples of the results finished with the various cutting speeds under the constant cutting direction angle $\theta = 50°$. They show the variation of roughness of surface H_{max} (the distance from peak to valley measured on the profilograph of the finished surface), stone wear S and stock removal W with the various cutting speeds. Fig. 3 shows the experimental results obtained under a constant time of working

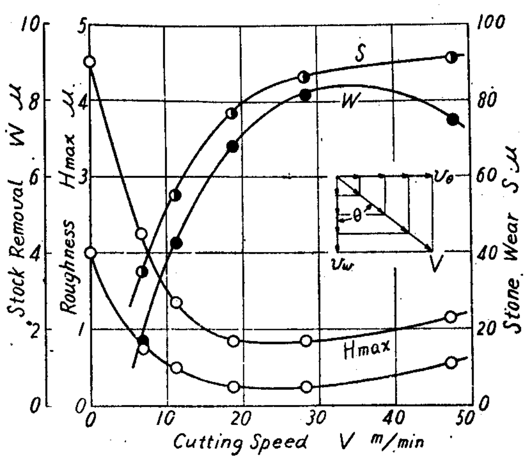

Fig. 3

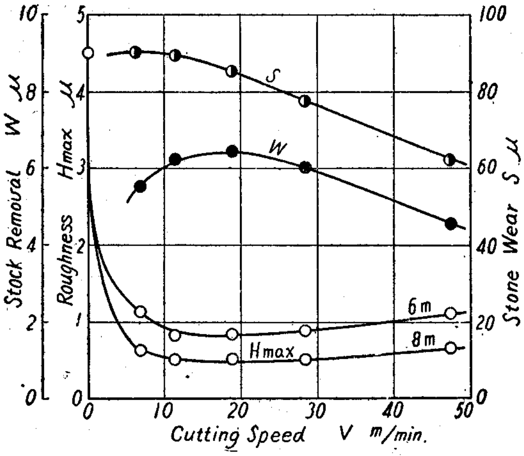

Fig. 4

and Fig. 4, under a constant distance of working.

From the roughness of surface H_{max} curve shown in Fig. 3, we find that the greater the cutting speed, the better the smoothness until the cutting speed reaches 40 m/mn; however, in Fig. 4, the roughness of surface H_{max} shows little or no change with the cutting speeds. The curve of stone wear S, in Fig. 3, increases linearly up to a cutting speed of about 20 m/mn, at which point the tendency to increase diminishes, but, in Fig. 4, it decreases linearly. In both cases, the curve of stock removal W shows the maximum value within the range of cutting speed applied in this experiment.

To summarize, although the cutting efficiency increases with the increase of cutting speed, we find that the mechanism of superfinishing does not change in accordance with the variation of cutting speed. Accordingly, the best cutting efficiency is obtained as the cutting speed is increased within the range in which harmful vibration of superfinishing machine bed is not produced.

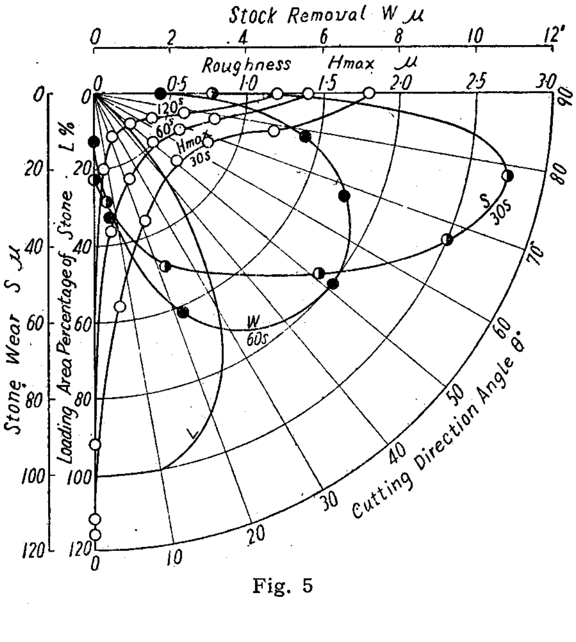

Fig. 5

3.3. Cutting direction angle: As an example of the results of the finishing with the various cutting direction angle under the constant cutting speed $V=25$ m/mn, Fig. 5 shows, by the polor-coordinate, the relation of the cutting direction angle to the roughness of surface H_{max}, stone wear S, stock remaval W and loading area percentage of stone L.

The roughness of finished surface H_{max} and the stock removal W respectively show the minimum and maximum values at the cutting direction angle of 40°~50°. As the cutting direction angle becomes larger, the stone wear S increases rapidly until $\theta = 80°$, and decreases abruptly beyond this angle. The loading area on the contact surface of stone extends to all part at $\theta = 0°$ and becomes smaller as the cutting direction angle increases.

Considering from the four kinds variations of H_{max}, S, W and L, mentioned above, it is clear that the grains on the contact surface undergoes the change from falling-off, cleavage and loading as the cutting direction angle becomes smaller. The grains fall off when the cutting direction angle is large and the loading extends over all parts of cutting surface of stane when the cutting direction angle is small.

These phenomena are explained as follow: that, due to the broadening of angle in which the cutting direction changes the falling-off of grains is accelerated owing to the increment of possibility for the cutting force to act in the wearable direction of each grain, because the greater is the cutting direction angle, the wider is the range of angle in which the direction of cutting force changes.

Consequently, we have come to know that the cutting direction angle is the fundamental factor which produces differance in the superfinishing mechanism. In this expriment, the best cutting efficiency is found in the cutting direction angle of 40°~50° in which the grains on the acting surface of stone cleave.

3.4. Oscillation of stone: When the value of cutting speed V and cutting direction angle θ are given as above, the most suitable velocity of stone can be determined and, consequently, the product of amplitude and frequency af is given; however, each value of a and f is not determined. Fig. 6 is an example of experimental results obtained with the various amplitude under the constant value of af. As it is shown in the figure, the variation of amplitude has no influence on the roughness of finished surface. Both the stone wear S and stock removal W increase as the amplitude decreases, in other words, as the frequency

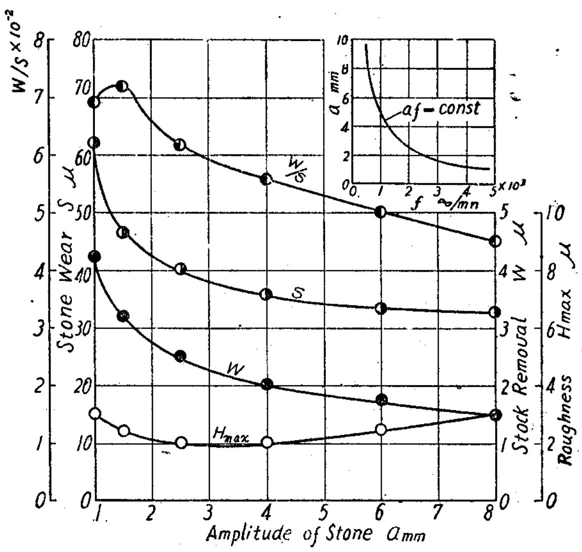

Fig. 6

increases. The cutting ratio, defined as the ratio of stock removal W to stone wear S, shows the maximum value in the amplitude of $1\sim2$ mm.

From these facts, it has become clear that it is more efficient to take the small amplitude and the large frequency.

The above description refers to the case in which mild steel is used as a test material, however, the similar results are obtained for other materials as shown in Table 1.

4. The mechanism of superfinishing

Generally, there are two types of superfinishing: one of them is that the cutting operation is recognized at first and the surface, gradually becoming smooth, finally turns into mirror-finished surface; and the other is that the cutting operation steadily continues. Of all the working conditions of the superfinishing work, these differences depend mainly on the cutting direction angle and the stone pressure.

4. 1. Classification of the characteristics of Superfinish:

Depending upon the conditions of contact surface of work and stone after the ordinary process is completed, the characteristics of superfinish are classified into "cutting", "semi-cutting" and "mirror-finishing".

"Cutting" ○: The surface of work has numberless cutting streaks and no luster, and the contact surface of stone has no loading.

"Semi-cutting" ◐: The surface of work has thin cutting streaks all over and shows a little luster, and the contact surface of stone has a little loading.

"Mirror-finishing" ●: The surface of work has no cutting streaks and gives luster, and the contact surface of stone is loaded all over.

4. 2. Critical phenomenon: Fig. 7 shows the characteristics of superfinish when the cutting direction angle and the stone pressure are varied. The characteristics of superfinish is divided into three ranges of I, II and III by the curves of (1) and (2). The curves (1) and (2) are the critical

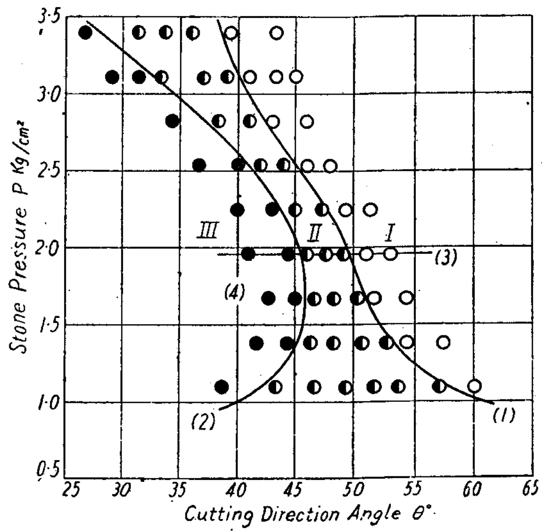

Fig. 7

curves of cutting and mirror-finishing respectively. The width of range II becomes minimum in the vicinity of the stone pressure of 2.0 kg/cm². At the stone pressure below 1.0 kg/cm², neither "cutting" nor "mirror-finishing" are hardly recognizable.

Although it is conceivable that the states of the critical curves will change depending upon the kind of stones, but these curves are serviceable in selecting stones and determining working conditions when the stone is given.

4. 3. Relation between the quality of work material and the critical phenomenon: The critical curves obtained for every work material in Table 1 are shown in Fig. 8 in which the curves denoted by the dotted lines, ○ and ●, are the critical curves of "cutting" and "mirror-finishing" respectively. As seen in Fig. 8, the positions of the critical curves differ depending on the kinds of work materials even with the same stone. The position of the critical curves move toward the greater cutting direction angle as the hardness of materials increases.

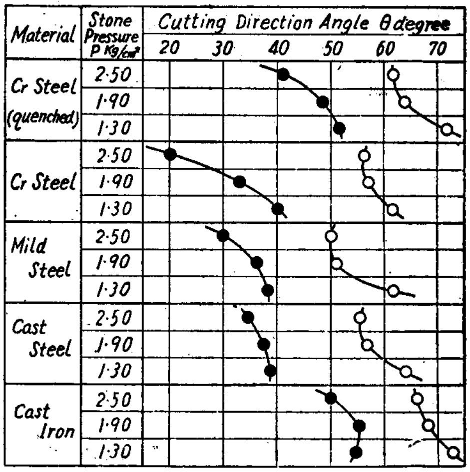

Fig. 8

4. 4. Relation between the mechanism of superfinishing and the critical phenomenon: In order to investigate the relation between the stone wear and the critical phenomenon, the stone wear of the superfinish along the straight lines of (3) and (4) in Fig. 7 has been measured and they are shown in Fig. 9 (a) and (b). The variation of stone wear has exactly the same tendency regarding the cutting direction angle

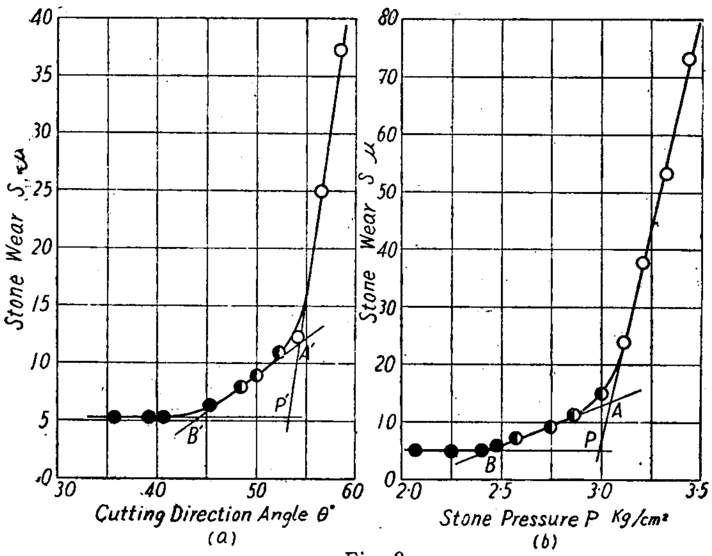

Fig. 9

and also the stone pressure; that is, the stone wear has small constant value in the range of "mirror-finishing", and it begins to increase in the range of "semi-cutting". In the range of "cutting", the stone wear increases rapidly. This curve is replaceable by three approximate lines and it is conceivable that these two points of intersection, A and B, show respectively the critical points of "cutting" and "mirror-finishing".

At the same time, the grains and chips contained in the cutting fluids in this experiment has been observed. As the results of this observation, the following facts are found. In the range of "cutting", the sizes of grains are distributed in 0.01 mm ~0.02 mm which are the similar to these before bonding stone. In the range of "semi-cutting", the sizes of grains are smaller and their maximum size near the critical curve of "mirror-finishing" is about 0.003 mm. Further, in the range of "mirror-finishing", the grains and chips can hardly be observed in the fluid.

Therefore, it is well to consider that the critical curve of "cutting" shows the limits of falling-off and cleavage, and the critical curve of "mirror-finishing" shows the limits of cleavage and loading.

Moreover, the relations among the critical curve, the stone wear and the stock removal investigated on the materials of work in Table 1 are as shown in Fig. 10.

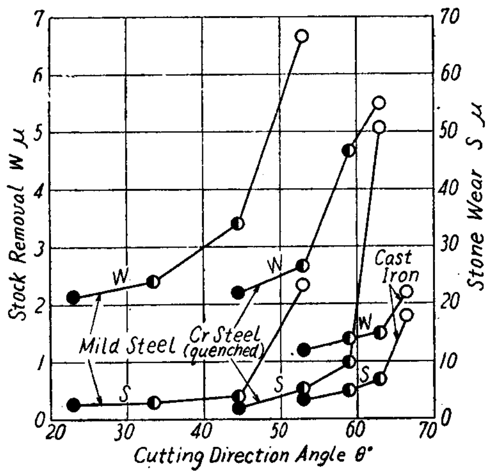

Fig. 10

The curves of stone wear and the stock removal show the similar tendencies with the variation of cutting direction angle, however, the rate of increase of the stock removal is smaller than that of the stone wear. Accordingly, the best working conditions in the superfinish is found on the critical curve of "cutting" on which the grains show a great deal of cleavage.

From the above consideration, it is made clear that these two critical curves show quite precisely the mechanism of superfinishing and the most efficient conditions in the superfinish. With reference to this problem, the idea of the critical abrasive pressure has been suggested by Dr. T. ASAEDA, Tokyo Institute of Technology. The pressure pointed out by him is the pressure of P in Fig. 9.

5. Conclusions

The above study leads into the following conclusions:

(1) The best cutting efficiency, on consideration of speed, is found at the higher cutting speed within the range in which the harmful vibration of superfihishing machine bed is not caused and, on consideration of cutting direction angle, it is found in the cutting direction angle of $40°\sim50°$ in which the grains on the acting surface of stone cleave.

(2) It is benificial to take comparatively small amplitude and large frequency when the values of cutting speed and cutting direction angle are selected.

(3) The characteristics of superfinishing procedure can be classified into "cutting", "semi-cutting" and "mirror-finishing" according to the values of stone pressure and cutting direction angle.

(4) In the characteristics of superfinishing procedure, there are two curves dividing into the three ranges, one of them is called the critical curve of "cutting" and the other is called the critical curve of "mirror-finishing".

(5) The critical curves of "cutting" and "mirror-finishing" are considered to show the limit of falling-off and cleavage and the limit of cleavage and loading respectively.

(6) The position of critical curves differ depending on the kind of materials even in case of the same stone, and it moves toward the greater cutting direction angle as the hardness of materials of work increases.

(7) The best cutting conditions in the superfinish is found on the critical curve of "cutting".