Surface Roughness and Work Hardening in Hot Machining

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(Received June 30, 1978)

Abstract

In this report, surface roughness, tool wear and work hardening when carbon steel, 18–8 stainless steel and 13 Cr stainless steel were cut with ceramic tool under Local Electric Resistance Heating are shown. The results of these experiments are as follows:

Case of carbon steel.

(1) Until cutting speed exceeds the speed of 160 m/min, we can expect to have surface roughness of better quality under or by this hot machining method than under or by conventional machining.

(2) At a higher cutting speed than 220 m/min, surface roughness obtained remains the same whether electric current is used or not.

(3) When the depth of cut is large, better surface roughness can be obtained by increasing cutting speed.

(4) The most hardened layer generated by repeating contact stress exists in about 0.2 mm below the contact surface.

Case of 18–8 stainless steel and 13 Cr stainless steel.

(1) A better surface roughness is expected of both of work materials when this method is used.

(2) When this method is used, cratering for 18–8 stainless steel decreases. But for 13 Cr stainless steel, cratering little decreases.

(3) When machining both of work materials with ceramic tool, cutting speed must be kept at a higher point than 100 m/min.

1. Introduction

In the wake of rapid developments in the hot machining in recent years, the electric resistance heating, among other methods, has been proven to be very useful for improving the machinability not only in lathing[1)], but in drilling[2)], milling[3)], as well.

On the other hand, the cutting speed has been brought to increasingly higher levels as a result of the development of ceramic tools which excel in heat resistance in concert with developments in machine tools, and some experiments have been run at such a high speed as 2,000 m/min[4),5)]. However, studies on the use of ceramic tool in the hot machining are rare[6),7)]. Moreover, in usual studies, the hot machining is performed mostly in speed ranges below 100～150 m/min.

In the present study, hot machining of S45C carbon steel, 13Cr steel and 18–8 stainless steel was conducted by use of a ceramic tool under local electric resistance heating[8)], and mainly, the surface roughness and work hardening were examined for.

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The ideal machined surface roughness may be determined by the cutting edge configuration and feed, but generally, it is altered by (1) the built up edge and welded matters on the cutting edge, (2) vibration of the tool-work system, or by (3) the change in the cutting edge configuration due to tool wear. For this reason, in this report, the surface roughness as well as the tool wear and welding are discussed in reviewing the characteristics of the ceramic tool in the hot machining.

2. Experimental apparatus, Tool and Works

The machine tool used was Mitsubishi high speed lathe (type HL300–G), and for the heating of works, the local electric heating was applied. The apparatus is schematically shown in Fig. 1. The tool employed was a ceramic tool (mechanical clamp type), which had the configuration as shown in Fig. 2. It was ground with a diamond wheel on tool grinder, and the ground tool was observed at a magnification of 50 by the aid of a projector to ensure uniform configuration. Work materials are S45C carbon steel, 13Cr stainless steel and 18–8 stainless steel. Their compositions were as shown in Table 1. These works had a configuration of 34 mm OD and 300 mm length and roughness of 9–11 μm.

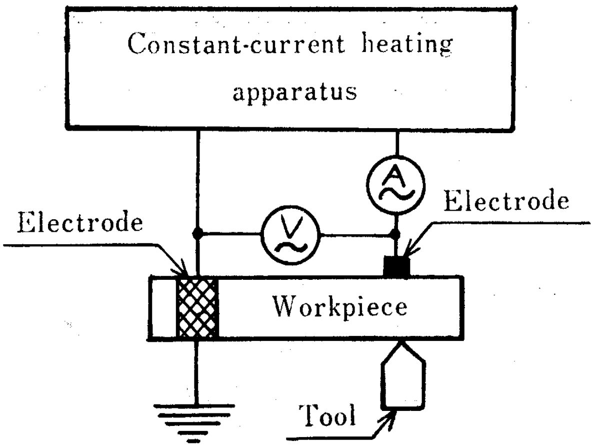


Fig. 1 Local electric resistance heating apparatus.

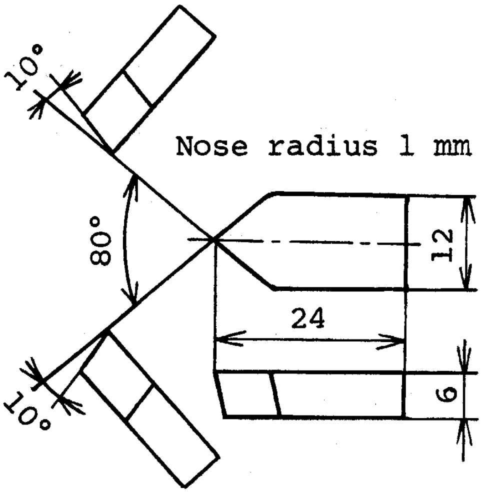


Fig. 2 Shape of tip.

The configuration of the works on which the work hardening was examined was 30 mm OD, 16 mm ID and 8 mm width. Before the works were subjected to the machining, they were held at 850°C for 2 hours, and thereafter, were cooled in the furnace.

3. Testing Method

For S45C, the machining condition was chosen as follows: depth of cut, 0.2$\sim$1.0 mm; feed, 0.03$\sim$0.09 mm/rev; cutting speed, 110$\sim$220 m/min; and electric current, 0$\sim$450 amp.

Table 1. Chemical composition of workpieces.

	C	Si	Mn	P	S	Ni	Cr
Carbon steel S45C	0.44	0.37	0.61	0.019	0.011	—	—
13 Cr stainless steel	0.12	0.54	0.62	0.032	0.020	0.60	13.50
18–8 stainless steel	0.13	0.61	1.22	0.030	0.016	8.80	18.70

Then, for 13Cr steel and 18–8 stainless steel, the machining condition chosen was: depth of cut, 0.5 mm; feed, 0.06 mm/rev.; cutting length, 110 mm; cutting speed, 25～385 m/min; and electric current, 0～450 amp.

For the combinations of the conditions above mentioned, first, straight turning of cylindrical works was performed to make examinations for the machined surface and tool wear. With regard to the machined surface, the surface roughness was measured on Kosaka surface tester (type SD5). The tools were photographed at a magnification of 20. Their crater wears were measured on the surface tester after they were subjected to an acid treatment.

In order to determine the rolling fatigue time strength, one of the mechanical properties which depend on the machining condition, the Nishihara's metal wear tester was used under the state of being lubricated at a rotational frequency of 800 rpm., 9% relative sliding speed and 1.26 m/sec frictional speed, with the oil supply made by a pump circulating system. The lubrication was made by feeding light oil at the normal temperature from above the upper test piece.

Furthermore, after being hot-machined and after completion of the rolling fatigue test, the test piece was cut through at a right angle to its axis, to be examined for its work-hardened state by measuring the hardness using a micro-hardness tester.

The work used in this fatigue test was S45C. The tool was of a cemented carbide, and had a configuration of 12.7 mm square, 4.8 mm thickness and 0.8 mm R.

4. Experimental Results and Discussion

4.1 *Surface roughness of S45C*

4.1.1 *Visual observation by naked eyes*

The surface of the work, even when subjected to the conventional machining, as observed by naked eyes, is lustrous, and shows a desirable roughness, because the cutting speed is higher than 100 m/min.

When the conventional electrical resistance heating (by alternate current) is applied, in which the tool is used as the medium for the transmission of the heating energy, a stripe pattern appears on the machined surface. In this experiment, this stripe pattern could not be observed at all. The reason is believed to be because, according to the present method, a local heating surface is located just before the machining position, whereas in the conventional electrical resistance heating, the tool tip serves as the medium for passing the current during the machining.

4.1.2 *Judgment by use of surface roughness tester*

Fig. 3 shows roughness curves obtained when the feed is altered, at vertical and horizontal magnifications of 2,000 × 50.

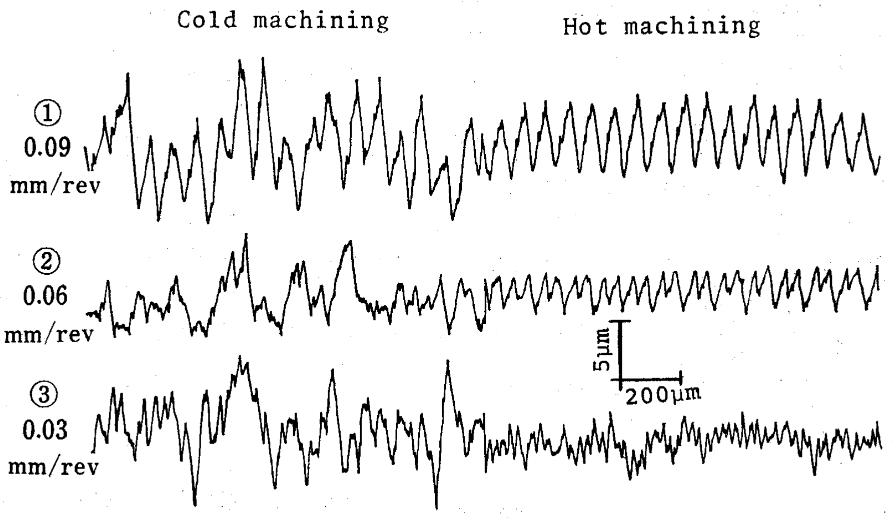
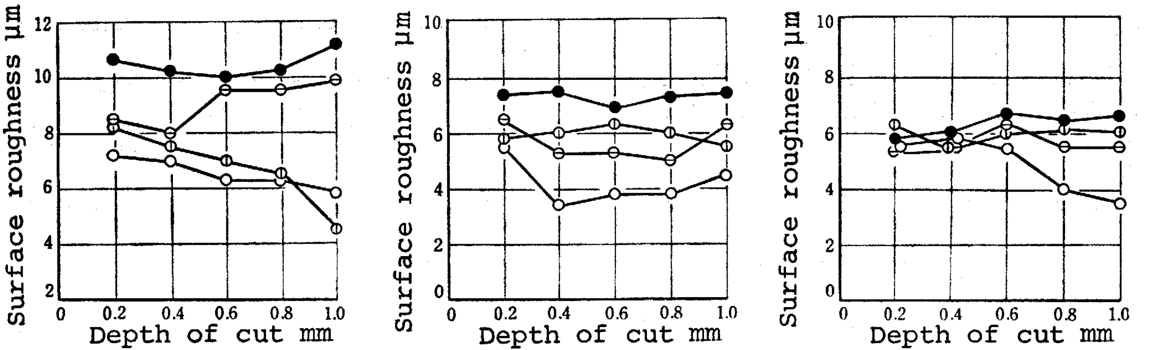


Fig. 3 Profile of machined surface.
Depth of cut : 0.8 mm
Cutting speed : 110 m/min
Heating current : 420 A

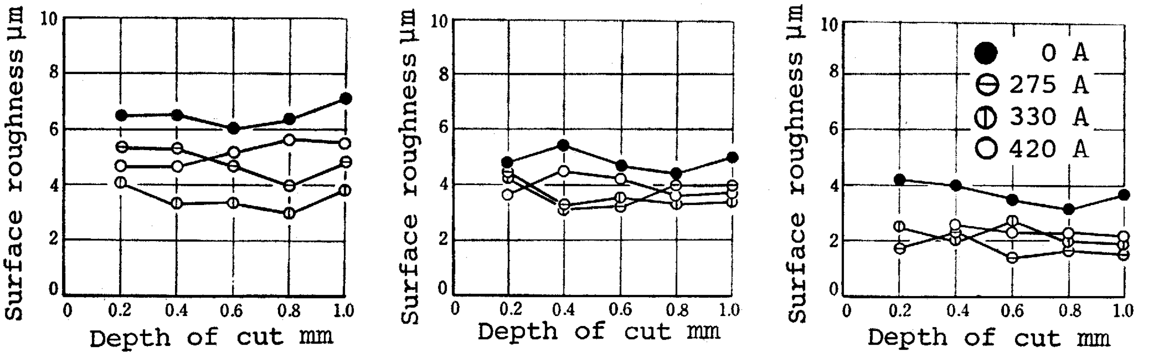
As is seen in Fig. 3, the hot machining produces highly improved surface roughness, as compared with the conventional machining. Then, the surface roughness is related to depth of cut, feed, cutting speed and current in Fig. 4. For the cutting speed of 110 m/min, an improvement of about 3 μm in the surface roughness is achieved by the hot machining, as compared with the conventional machining, when the feed is 0.09 mm/rev. When the feed is 0.03 mm/rev., the difference between the surface roughnesses obtained by these two methods is small, and when it is 0.06 mm/rev., the best surface roughness is attained with the current at 420 amp.

For the cutting speed of 160 m/min, when the feed is 0.03 mm/rev., the surface roughness of the work after being subjected to the hot machining is around 2 μm, and when it is 0.06 mm/rev., no large difference from (b) is recognized, when compared at 420 amp.

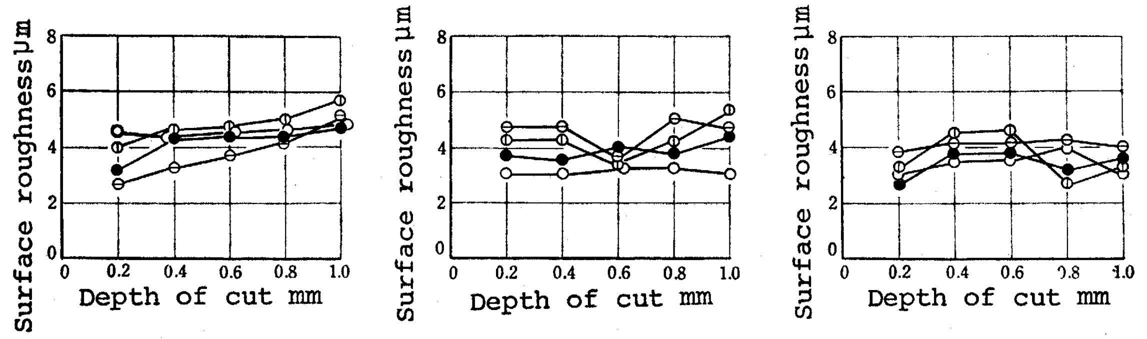
Then, when it is 0.09 mm/rev., some improvement is noted, as compared with (a). For the cutting speed of 220 m/min, the surface roughness is improved as a whole, but similar surfaces are obtained either by the conventional or by the hot machining. (a), (d) and (g) show the tendency of the surface roughness getting markedly improved with increasing cutting speed, when the feed is 0.09 mm/rev. Generally speaking, in the hot machining, as in the conventional machining, the smaller the feed and the faster the cutting speed, the better surface roughness results.



(a) 110m/min,0.09mm/rev (b) 110m/min,0.06mm/rev (c) 110m/min,0.03mm/rev



(d) 160m/min,0.09mm/rev (e) 160m/min,0.06mm/rev (f) 160m/min,0.03mm/rev



(g) 220m/min,0.09mm/rev (h) 220m/min,0.06mm/rev (i) 220m/min,0.03mm/rev

Fig. 4 Relationship between depth of cut, feed, cutting speed and surface roughness.

4.2 *Surface roughness of* 18–8 *stainless steel and* 13*Cr steel*

The relationship between the cutting speed and the surface roughness is shown in Figs. 5 and 6. In the case of 18–8 stainless steel, both the hot and the conventional macining are influenced by the cutting speed, producing very rough surface at cutting speeds below 100 m/min, but smooth surface of around 2 μm roughness above 100 m/min, and with good stability. Moreover, the surface roughness is improved by the local electric resistance heating, and this improvement further gains by the increase of current.

13Cr steel is also subject to the influence of the cutting speed, but not so much as 18–8 stainless steel. The heating effect does barely manifest itself in low speed range, but is notable above 100 m/min cutting speed, and the comparison between Fig. 5 and Fig. 6 shows that at low speeds, 13Cr steel, but at high speeds, 18–8 stainless steel,

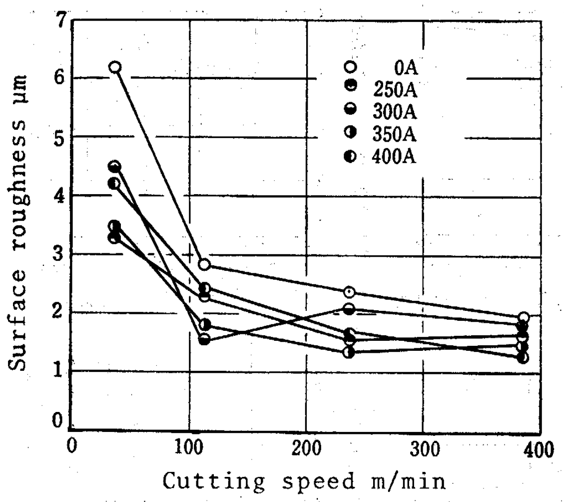


Fig. 5 Relationship between cutting speed and surface roughness.

Workpiece : 18–8 stainless steel
Depth of cut : 0.5 mm
Feed : 0.06 mm/rev

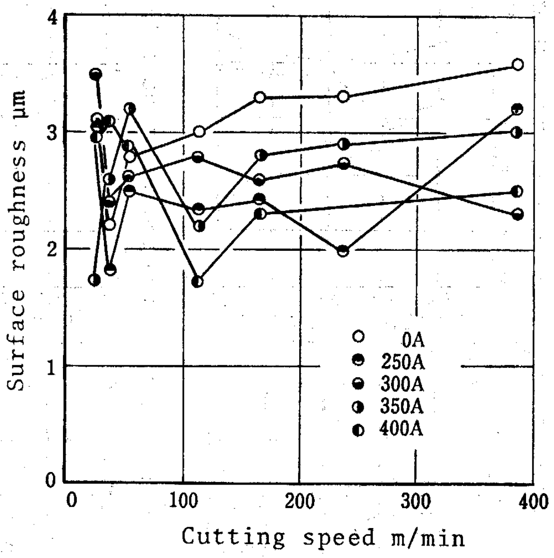


Fig. 6 Relationship between cutting speed and surface roughness.

Workpiece : 13 Cr stainless steel
Depth of cut : 0.5 mm
Feed : 0.06 mm/rev

give better surface roughnesses.

4.3 *Welding and wear of cutting tool*

The welding and wear of the tool that occur after it is used for machining 18–8 stainless steel and 13Cr steel are described hereunder:

4.3.1 *Photo-micrographic study*

A photograph of the tool after being used for the machining (18–8 stainless steel, a cutting length of 195 m) is shown in Fig. 7. (That for 13Cr steel is omitted.)

While it is not at all recognizable both in 18–8 stainless steel and 13Cr steel at such a high cutting speed as 385 m/min, the welding (mainly the rake face) is notable below 100 m/min, whether the machining is done in hot or conventional way.

At an identical cutting speed, with the increase in the heating current, the welding diminishes. It is to be noted that the welding of 18–8 stainless steel is slight, as compared with that of 13Cr steel, consistent with their characteristics in terms of surface roughness above described.

With both of these works, the flank wear is uniform, showing almost no change at high speeds above 100 m/min, but slightly increases below 100 m/min.

The boundary wear is small in high speed range, but increases in low speed range. Comparing the results obtained with these two works, no major difference is apparent in high speed range, but it is more pronounced with 18–8 stainless steel especially at a low speed of 36 m/min.

4.3.2 *Crater wear*

In taking the measurement of the crater wear of the tool, it was necessary to re-

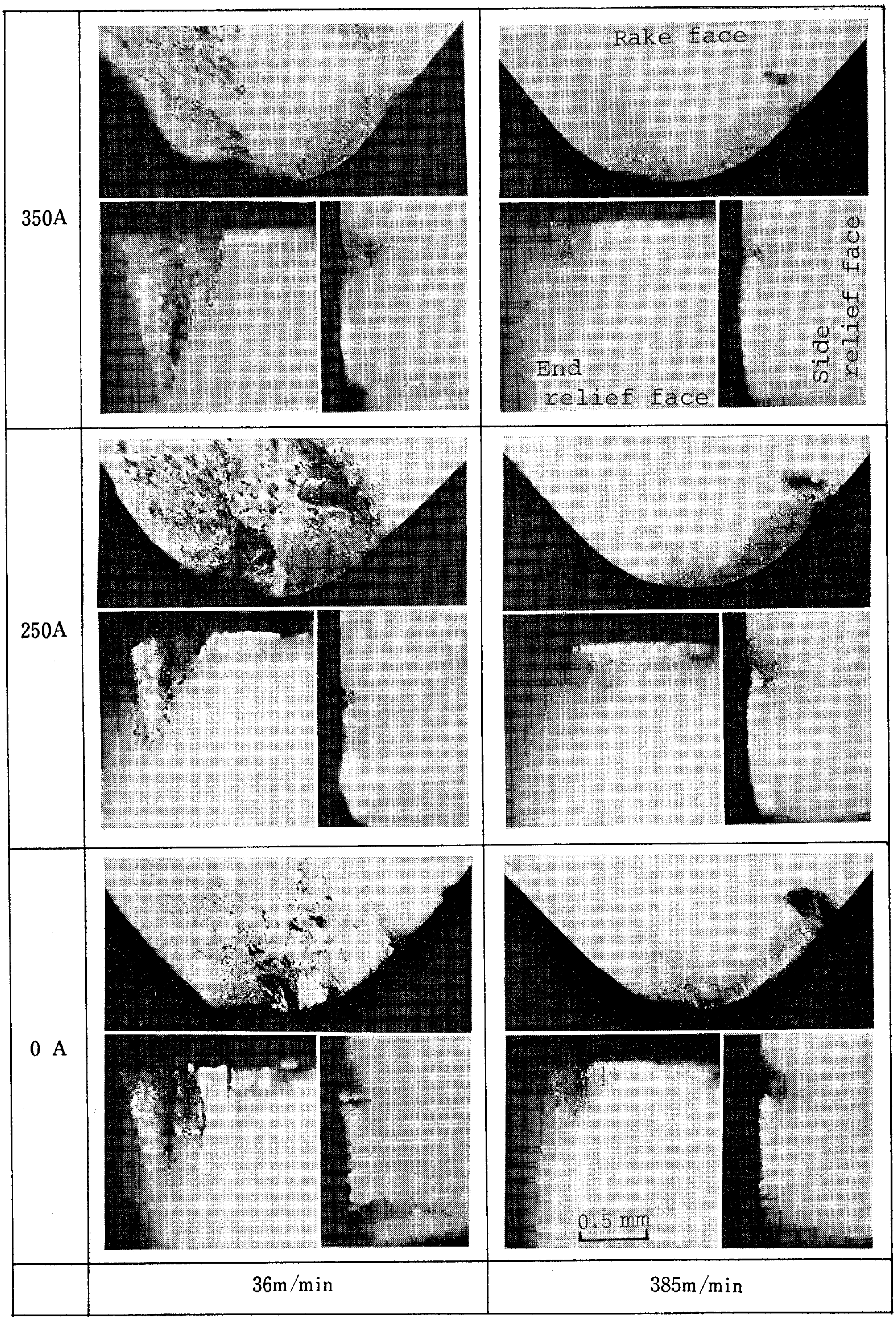


Fig. 7 Photographs of tool.

Workpiece: 18–8 stainless steel Depth of cut: 0.5 mm Feed: 0.06 mm/rev Cutting length: 195 m move the deposits on the rake face, and for this purpose, the tool was subjected to an acid treatment with HCl. The rake face after being subjected to the acid treatment was measured for crater wear, using a surface tester. The results are shown in Figs. 8 and 9.

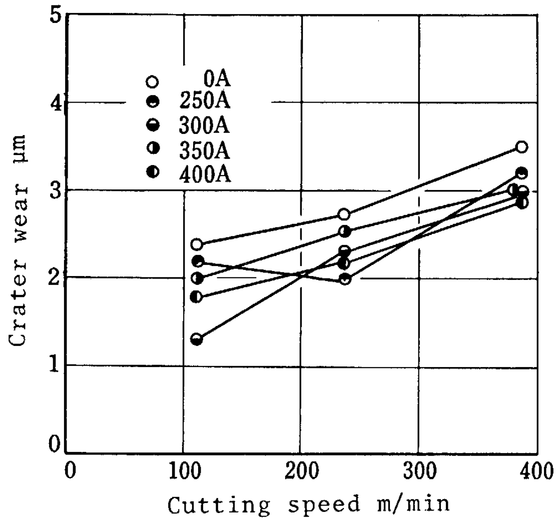


Fig. 8 Relationship between cutting speed and crater wear.

Workpiece : 18–8 stainless steel
Depth of cut : 0.5 mm
Feed : 0.06 mm/rev
Cutting length: 195 m

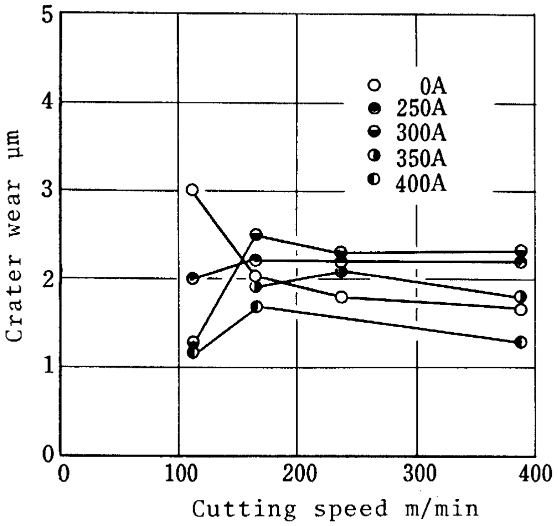


Fig. 9 Relationship between cutting speed and crater wear.

Workpiece : 13 Cr stainless steel
Depth of cut : 0.5 mm
Feed : 0.06 mm/rev
Cutting length: 195 m

The crater wear in the case of hot machining 18–8 stainless steel tends to grow with increasing cutting speed. It is slightly smaller than in the case of conventional machining. Almost no changes occur in high speed range with 13Cr steel. As for the heating effect, it was small, and was only recognizable particularly at cutting speeds around 100 m/min, and it gave minimum values in all speed ranges with the heating current at 400 amp.

Comparing Fig. 8 and Fig. 9, the former shows relatively high stability, while the latter displays greater variation. Where the tool wear is concerned, 13Cr steel is slightly favorable than 18–8 stainless steel.

5. Work Hardening

When the conventional machining and the hot machining were performed, growing formation of work hardened layer with increasing heating current was observed near the machining surface. This hardening went to the depth of about 0.15 mm from the surface. Fig. 10 illustrates the change in the hardness of the substrate under the contact surface, as the contact stress is varied. Thus, it is indicated that the larger the contact stress, the more is the hardness increased, and the deeper the depth at which

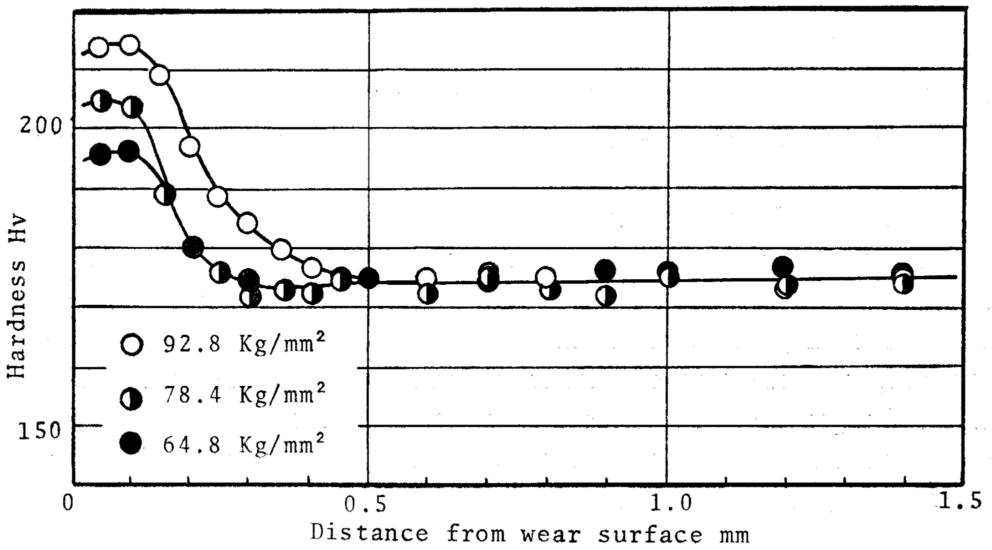


Fig. 10 Vickers hardness distribution below a contact surface.

Cutting speed : 110 m/min
Depth of cut : 0.4 mm
Feed : 0.045 mm/rev
Heating current: 350 A

the maximum hardness is registered tends to be, these positions ranging 0.10∼0.20 mm below the contact surface. Now, the difference between the maximum hardness of the substrate of each test piece attained and the hardness of the substrate before the test is defined as hardness increment ΔHv. The relationship between the contact stress and this ΔHv is shown in Fig. 11.

Allowing for some dispersion, the experimental values show that ΔHv increases as the contact stress rises.

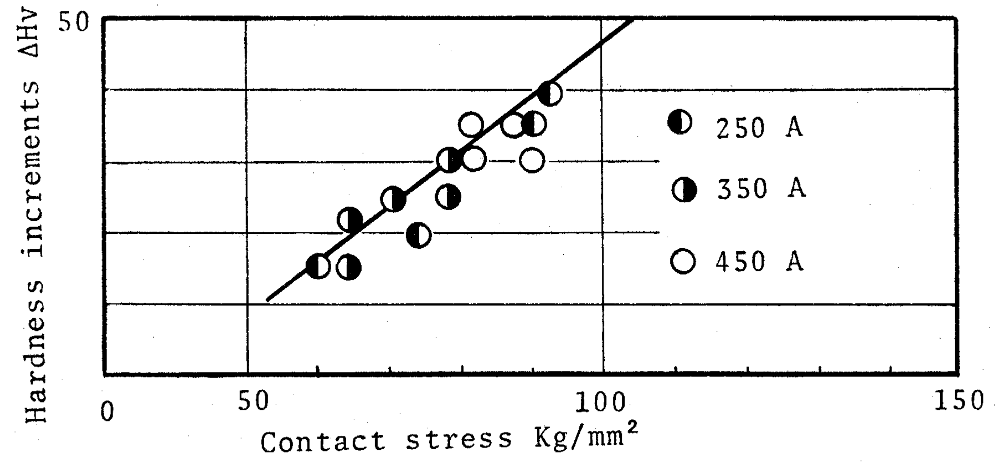


Fig. 11 Effect of contact stress on hardness increments of workpieces.

6. Conclusions

Following conclusions have been derived from the results described in the foregoing:

In the case of S45C carbon steel:

(1) At cutting speeds up to 160 m/min, the hot machining always produces better surface of the machined work than the conventional machining.

(2) At a cutting speed of 220 m/min, the surface roughnesses obtained by the hot machining and the conventional machining are about the same, and show no appreciable changes even when other conditions are altered.

(3) When the depth of cut is made relatively large, the higher the cutting speed, the more improved is the surface roughness.

(4) The effect of the depth of cut is small.

(5) The best result was obtained at a cutting speed of 160 m/min and a feed of 0.03 mm/rev., among other varied conditions.

(6) The larger maximum value of the increase in hardness due to repetitive applications of contact stress is obtained, the greater the contact stress applied, and it occurs at a position 0.10 ∼ 0.20 mm below the contact surface.

Then, in the case of 18–8 stainless steel and 13Cr steel:

(1) As applied to both materials, this hot machining effects a slight improvement in the surface roughness.

(2) The hot machining causes a slightly less tool wear than the conventional machining with 18–8 stainless steel, but they show almost no difference with 13Cr steel.

(3) In performing the machining of 18–8 stainless steel and 13Cr steel by use of the ceramic tool, the cutting speed should be maintained above 100 m/min.

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