Effect of Plasma Nitriding on Cutting Performance of Stainless Steel Cutlery

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Abstract

The demand for more durable edge shape has increased for higher cutting performance of cutlery, such as razor blades. In a plasma nitriding, high ion density can be obtained efficiently by installing a hollow cathode, and the samples can be cleaned, etched, heated and nitrided effectively. In this study, the durability and cutting performance of stainless steel razor blade treated by the plasma nitriding were investigated in order to evaluate the applicability of plasma nitriding into the surface treatment of razor blades. The experimental results made it clear that the durability of blade was improved by the plasma nitriding, and that the cutting performance was kept in the case of low process temperature.

1 Introduction

In high precision machining technology for cutlery such as razor blades, durability of sharp edge is strongly needed. For improving the durability of cutlery, sputter deposition and plasma nitriding are expected. In the sputter deposition, hard films like DLC can be deposited on the cutting edge, which leads to long durability. However, a thick deposition layer is necessary for high durability, which causes larger radius of the cutting edge and deterioration of cutting performance. On the other hand, a plasma nitriding is an effective surface treatment for stainless steels because an oxide contamination film on the surface can be removed by the plasma etching effect during the treatment [1], [2]. K. G. Marche et al. succeeded in increasing the hardness of razor blade edge by plasma nitriding. [3] However, the cutting performances have not been made clear sufficiently, and the process needs to be improved because of its low process efficiency due to long process time and high treating temperature. Then in this study, the cutting performance of the stainless steel cutting edge treated with the plasma nitriding is experimentally evaluated.

2 Plasma Nitriding Apparatus

Figure 1 shows a schematic illustration of plasma nitriding apparatus. The apparatus consists of a vacuum chamber, a vacuum pump and a hollow cathode. In the vacuum chamber, the workpiece is set on a stage connected to a bias power supply. A tungsten filament and an introduction port for nitrogen gas are installed in the hollow cathode, and high density plasma is generated here. Then, by applying a pulsed bias voltage to the workpiece, the nitrogen ions are guided to the workpiece and collide with the surface. Moreover, the workpiece is heated up and the nitrogen ion diffuses into the workpiece surface. The surface temperature during the process is monitored with an infrared thermometer. The process temperature is controlled to the setting one by changing the ion collision speed to the workpiece surface with adjusting of the bias voltage applied to the workpiece. In this study, the change of edge shapes, cutting performance and durability of the cutlery were evaluated with varying process temperature in the plasma nitriding. Hardened stainless steel of GIN-5 (Hitachi Metals) equivalent to SUS420J2 in JIS specifications was used as a workpiece.

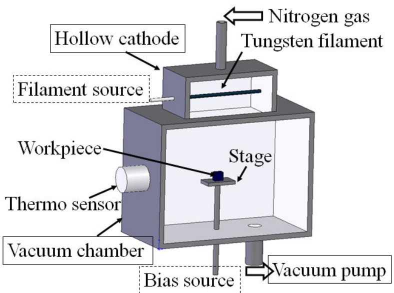

Figure 1: Plasma nitriding apparatus

Table 1: Process conditions

Process temperature T (K)	513 - 603
Process time t (min)	120
Bias voltage V (V)	400 - 600
Filament current I (A)	120
Pressure P (Pa)	2.0

3 Results and Discussion

3.1 Evaluation of durability performance

In this section, the durability of the blades treated by the plasma nitriding was evaluated. In the durability test, the blade edge was worn by cutting a felt repeatedly with the cutting edge. The width of felt is 8mm and the thickness is 8mm. The cutting edge of blade after every 10 cuttings was observed by SEM, and the edge radius was measured by an image analysis software. In general, the wear of cutting edge and the radius increase with an increase of cutting stress to the edge. In other words, little change in the radius of cutting edge means high wear resistance. Figure 2 shows the SEM images of the nitrided and unprocessed blade edge in the cutting test. As shown in the figure, the radius of the unprocessed edge becomes larger with cutting number. On the other hand, the nitrided edge surface is a little rough but the radius doesn't change so much with cuttings, compared to the unprocessed one. Figure 3 shows the variations of cutting edge radius with the number of cutting. It is confirmed that the edge radius of unprocessed sample is larger than that of nitrided one, and increases with the cutting number. In the case of nitrided blade, the edge radius becomes smaller as the process temperature increases.

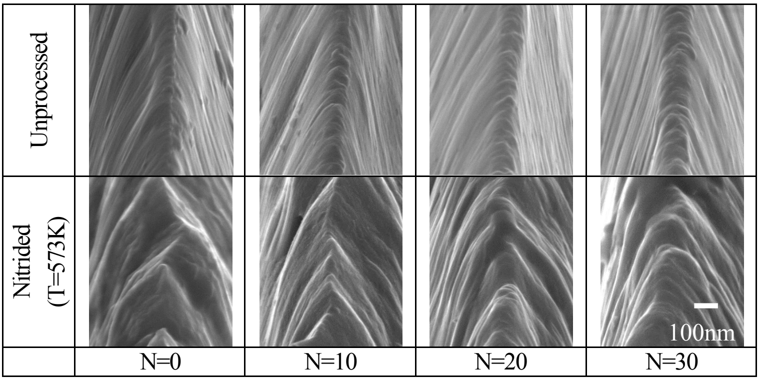

Figure 2: Change in blade edge shape with cutting number

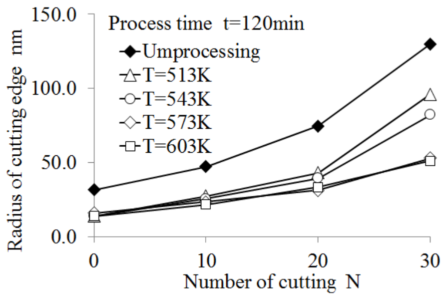

Figure 3: Variations of cutting edge radius with cutting number

3.2 Deformation of edge shape

The blade edges with varying nitriding condition were observed by SEM, and the edge shapes were measured by using an image analysis software. Figure 4 shows

SEM images of the blade edge with several nitriding process temperatures. It is confirmed that the blade edge was etched by the etching effect of plasma nitriding. In addition, as the process temperature increases, the edge shape is deformed gradually. This is because the surface is activated with the increase in the blade temperature, and the etching rate increases by the collision of the ion. Under any process conditions, the edge angle seems to become obtuse as the processing progresses. Then, in order to evaluate quantitatively the change in blade shape by nitriding, the blade edge shapes were measured. Figure 5 shows the measurement results the thickness of the edge. With the increase of process temperature, the thickness of blade at the top edge increases. From the result, it is obvious that the blade edge is etched under higher process temperature, and the edge angle becomes obtuse due to the increase of blade thickness.

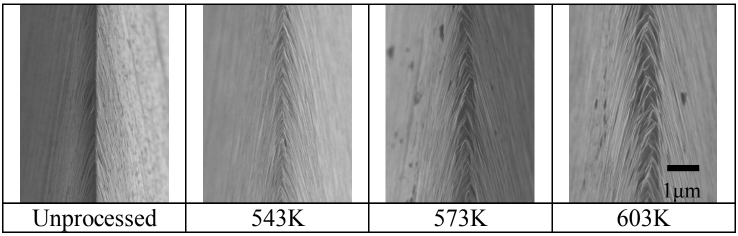

Figure 4: SEM images of blade edge under various process temperatures

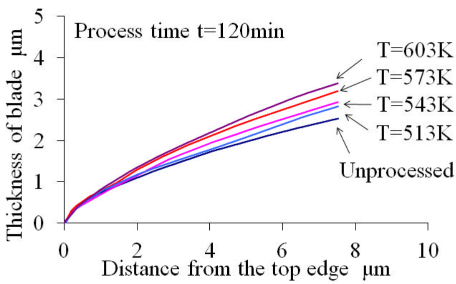

Figure 5: Variations of edge shape with process temperature

3.3 Evaluation of cutting performance

Finally, the influence of edge shape change by nitriding on the cutting performance was evaluated. Figure 6 shows a schematic illustration for measuring the cutting force. The device is consisted of electric cylinder, load cell and amplifier. A nylon string of 0.1mm in diameter is set on the table driven by the electric cylinder, and the cutting force is measured by moving the cylinder with a constant feed of

0.025mm/sec. When the nylon string is cut with the blade, the maximum cutting load was measured. Figure 7 shows the cutting test result with several nitriding temperatures. As shown in the figure, the cutting force slightly increases, and then the cutting performance decreases with the increase of process temperature. The edge angle became obtuse with the increase in the process temperature, which causes the increase of cutting force. However, the cutting force does not change so much in the case of 543K, although the edge shape was deformed. In this case, the low cutting force is corresponding to the small radius of cutting edge generated by nitriding as mentioned before.

4 Conclusions

Main conclusions obtained in this study as follows;

(1) The wear resistance and the durability of blade tip can be improved by the plasma nitriding with relatively low temperature proposed in this study.

(2) Increasing process temperature of plasma nitriding causes the durability to increase, but it leads to deterioration in the shape accuracy of the edge.

(3) It is confirmed by the cutting force test that the cutting performance does not change at all when the process temperatures are 513K and 543K.

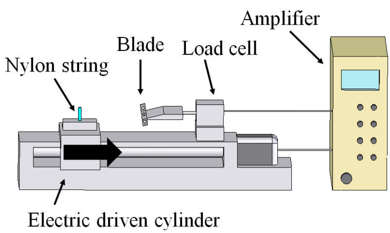

Figure 6: Schematic illustration of cutting test

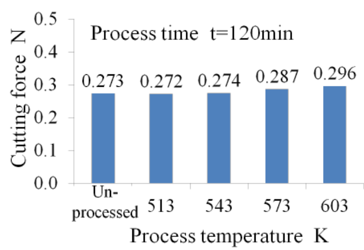

Figure 7: Relation between cutting force and process temperature

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