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Microstructure Changes of Machined Surfaces on Austenitic 304 Stainless Steel

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***Abstract*—**This paper presents a experiment to estimate the influences of cutting conditions in microstructure changes of machining austenitic 304 stainless steel, especially for wear insert. The wear insert were prefabricated with a width of 0.5 mm. And the forces, temperature distribution, RS, and microstructure changes were measured by force dynamometer, infrared thermal camera, X-ray diffraction, XRD, SEM, respectively. The results told that the different combinations of machining condition have a significant influence on machined surface microstructure changes. In addition to that, the ANOVA and AOM were used to tell the different influences of cutting speed, feed rate, and wear insert.

***Keywords*—**Microstructure Changes, Wear width, Stainless steel

I. INTRODUCTION

THE austenitic 304 stainless steel is hard machined material, because of its high strain, high strain hardening, and low heat conductivity. When stainless steel is used in a product, the microstructure changes of the machined surfaces generated significantly influence the product performance [1, 2].

Many investigators have studied the effects of machining conditions on microstructure changes in 304 stainless steel. Ezugwu and Olajire evaluated the machining performance of stainless steel in different machining conditions [3]. In their work, they concluded that the microstructural alterations of the machined surfaces were predominantly plastic deformation of grain boundaries in addition to untempered and overtemperated matensites. Kurniawan et al also researched the influences of cutting parameters and wiper tool on machined surfaces microstructure changes [4]. And, they found that the combination of low cutting speed and feed rate resulted in preferable surface integrity, minor microstructure alteration, and compressive residual stress. However, as investigated by these researchers, the relationship between the machining parameters and microstructure changes is unclear. Chien and Chou used the ANN theory to predict the machinability of 304 stainless steel [5]. And, they trained the ANN model with experimental data and proposed an optimized approach to obtain optimal cutting conditions for desired surface roughness, cutting force and tool life, that maximizes material removal rate (MRR). In addition to that, Dabade et al used ANONA to research the influences of machining parameters in surface finish and integrity, and they found that the feed rate was the most significant factor influencing the magnitude of cutting force, the wiper insert obviously reduced the feed marks, pits and cracks [6].

Unfortunately, very few researchers have studied the effect of wear width. The main obstacles to the development of experimental researches for wear influence are to measure the temperature distribution, forces, and wear width. Therefore, considered all above facts, the present study intends to study the influence of wear on microstructure changes in machining austenitic 304 stainless steel. In this work, a new experiment is presented to estimate the influences of wear on machined surfaces. And, the forces, temperature distribution, and microstructure changes are measured, then the influence of wear on surface are talked.

II. EXPERIMENTAL DETAILS

A. Design of experiment

The cutting tool with prefabricated wear width of 0.5 mm is shown in Fig.1, the tool radius is 0.4mm, and the rake angle is 3 °. The experimental measurement of machining temperature distribution is shown in Fig.2. To study the cutting area temperature distribution along the tool flank wear width, the camera was placed sufficiently close to the cutting zone, at a distance of 40 mm. And, to protect the camera lens, two chips of silicon with a thickness of 0.5 mm each were placed in front of the camera, while other areas were protected using IR-proof Plexiglass. The camera was placed on the small pallet of a lathe, which continuously moved with the cutting tool. The length of the feed was limited to 10 mm to minimize the variability of the new cutting tools and prevent the introduction new tool wear. A new cutting tool was used for each experimental parameter.

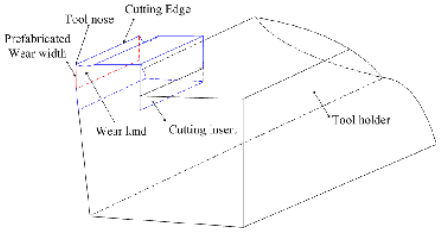

Fig. 1 Cutting tool system with prefabricated wear width

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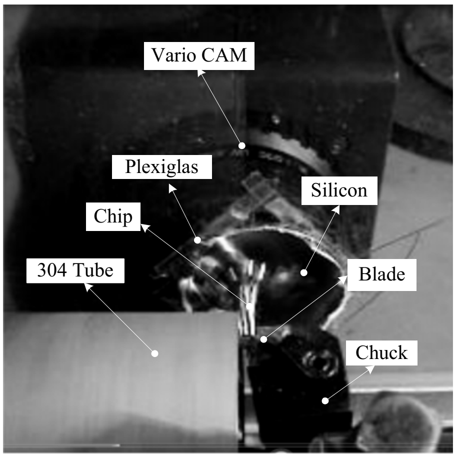


Fig. 2 Designed experiment to measure machining temperature

B. Experimental setup

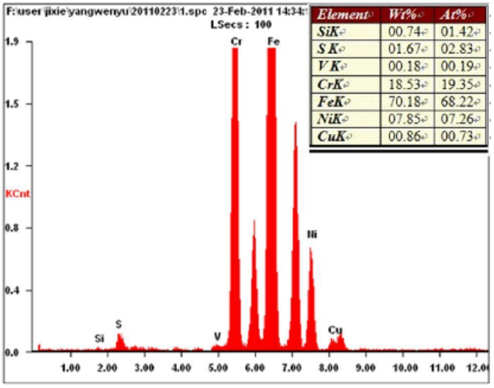
In this experiment, a Kistler cutting force dynamometer 9257, a three-component tool-holding dynamometer with a minimum resolution of 2 N, was used to measure the forces. And, temperatures were measured by a VarioCAM IR thermal imager, which is a modern thermo-graphic system used to obtain precise, quick and non-contact measurements of the surface temperatures of objects. Its compact, robust design and durability make it especially suitable for industrial applications, even under unfavorable external conditions. The infrared thermal-imaging camera has a 640×480- or 384×228-pixel array, a target image temperature range between -40°C and 1200°C, and a minimum resolvable temperature difference of approximately 0.2°C. And, the experiment design matrix is shown in Tab1. After turning, the residual stresses was measured by Proto MG2000 X-ray, the surface microstructure changes were measured by scanning electron microscope (Quanta 200), the transformations of machined surfaces were measured by XRD (X' Pert PRO).

TABLE I
THE L4 EXPERIMENT DESIGN MATRIX

Condition No.	Wiper width(mm)	Cutting speed(m/min)	Feed rate(mm/rev)
1	0	100	0.11
2	0	175	0.2
3	0.5	100	0.2
4	0.5	175	0.11

C. Workpiece material

In the cutting experiments, 304 stainless steel tubes with the same external diameter of 150×48×3.5 mm were used. The reason why 304 stainless steel was chosen is due to its wide application in the production of critical structural components in chemical industries and nuclear power stations and their provision of a unique combination of strong mechanical properties and corrosion resistance. However, it is often regarded as a difficult-to-machine material because of its high sensitivity to strain and stress rates and severe work hardening. Moreover, its low thermal conductivity leads to heat concentration in the cutting zone, resulting in high localized temperatures; the chemical composition of the stainless steel is shown in Fig. 3.



Element	Wt%	At%
SiK	00.74	01.42
S K	01.67	02.83
V K	00.18	00.19
CrK	18.53	19.35
FeK	70.18	68.22
NiK	07.85	07.26
CuK	00.86	00.73

Fig. 3 The composition of austenitic 304 stainless steel

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

A. Experimental measurements of temperature, forces and RS

The image of temperature distribution along wear width was shown in Fig. 4. From the figure, we can see that the contact width of the tool-workpiece interface is the same as that of the tool wear width, and the temperature in this region is obviously higher than in other regions along the workpiece surface, since the process-generated heat along the tool flank wear width has no time to diffuse. The location of the maximum temperature in workpiece along tool-workpiece interface is at the end area of the wear width because the amount of heat generated along the wear width is greater than the heat diffused, which agrees with the results of Huang and Liang[7].

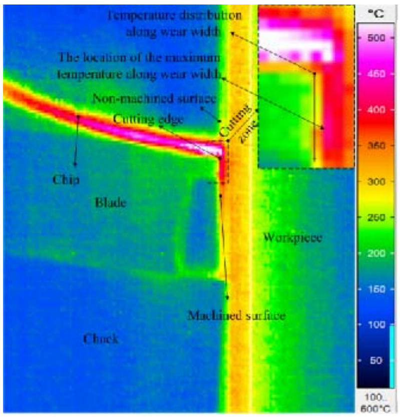


Fig. 4 Temperature measurement along wear width

The variations in the absolute magnitude of forces during machining are shown in Figs.5. It is observed that the magnitude of force in cutting direction is always higher than that in other directions. Residual stress pattern induced by machining is critical for component life and corrosion resistance. The residual stress is significantly influenced by feed rate, cutting speed, and tool geometry. In these experiments, residual stress measurements were carried out using Proto MG2000 X-ray diffraction technique. In the experiments, the tube was Mn_K-Alpha, and the test head was with 2mm diameter. Every measurement was taken at four different points on the same surface, and the measured values were shown in Tab.2.

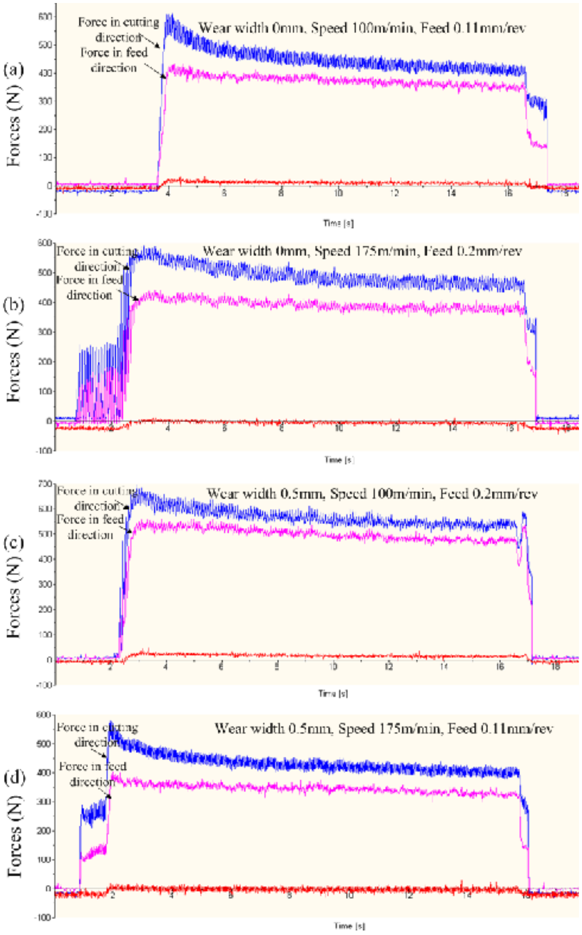


Fig.5. Absolute magnitude of force components during machining

TABLE II
RESIDUAL STRESS COMPONENTS FROM MEASUREMENTS

Condition No.	RS in feed direction (MPa)	RS in cutting direction (MPa)	RS in radial direction (MPa)
1	-145±35	150±15	-10±25
2	-45±15	475±30	-35±15
3	-175±20	165±35	55±20
4	-105±25	655±15	-15±25

B. Statistical analysis of factors influencing temperature, forces and RS

The statistical analysis involving ANOVA and AOM was used to research the factor influences. The ANOVA for temperature, forces and RS is shown in Tab 3. And, the AOM plots of temperature are shown in Fig.6. They told that cutting speed is the most significant influencing the magnitude of temperature, and with the increasing of wear, feed rate and cutting speed, the temperature increases, which are same as that talked by Grzesik [8]. The forces of AOM plots are shown in Fig.7. The thing must be pointed out that the forces in radial direction were ignored because of zero values. From the Fig and Tab.3, we can know that the most significant influencing the magnitude of forces is feed rate. And, an interesting thing can be seen that with the increasing of cutting speed, the forces are reduced. These trends could be due to larger cutting speed could cause larger heat generation in the cutting zone leading to increased thermal softening. The AOM plots of residual stresses are shown in Fig.8. It is observed from the Fig that residual stresses are tensile for the machined workpiece surface, which agrees with the earlier results by Jang et al in machining stainless steel because of its harden machining [9]. Further, the tensile stresses are reduced by wear, the reason is related to the increased of tool-workpiece contact area.

TABLE III
ANONA (P VALUES) FOR CUTTING 304 STAINLESS STEEL

Cutting condition	Cutting force	Feed force	Cutting temperature	RS in feed	RS in cutting	RS in radial
Wear width	0.185	0.124	0.023	0.025	0.387	0.291
Feed rate	0.003	0.007	0.318	0.191	0.271	0.012
Cutting speed	0.031	0.062	0.009	0.008	0.513	0.154

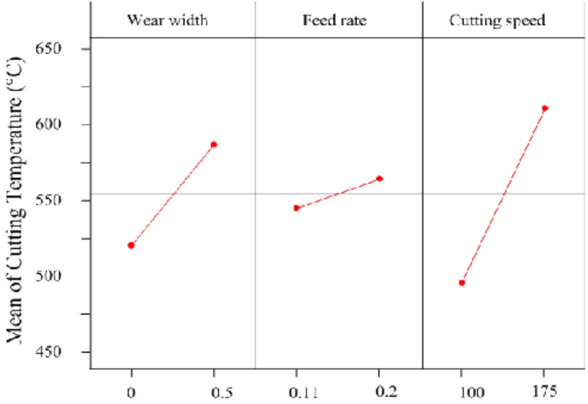


Fig. 6 Main effect plots for temperature

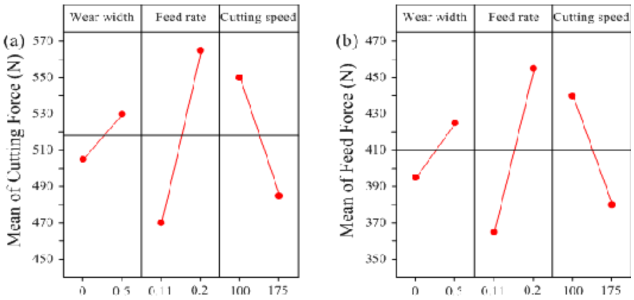


Fig.7 Main effect plots for force components (a) cutting forces (b) feed forces

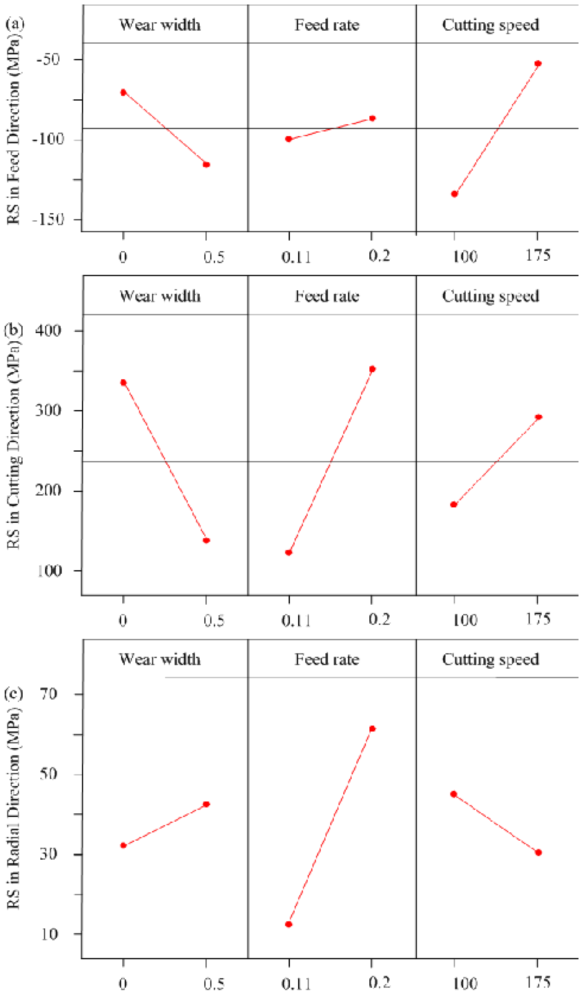
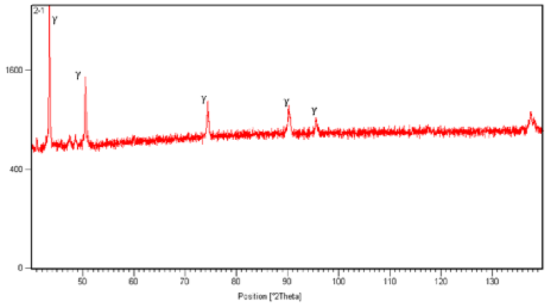


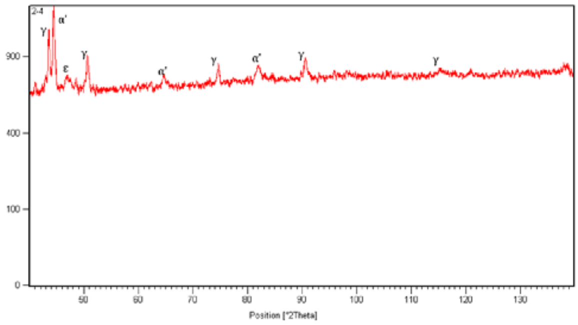
Fig. 8 Main effect plots for RS (a) RS in feed direction (b) RS in cutting direction (c) RS in radial direction

C.Analysis of surface transformation

XRD measurements were made on un-machined and machined workpiece surfaces, respectively. The measured results are shown in Fig.9. The transformations of machined surfaces are obviously captured, and γ and α represent the austenite and martensite phases, respectively. The figure shows that the austenite near the machined surface transformed to martensite. This result was also found by Ghosh [2].



(a)



(b)

Fig.9 XRD images of the un-machined and machined surfaces, (a) un-machined surface, (b) machined surface.

D.Analysis of microstructure changes

The machined surfaces were observed by scanning electron microscope (SEM), and the SEM photographs were shown in Figs. 10 (a-d). It is well known that the microstructure changes are caused by thermal, mechanical, and chemical energy. From the figure, it is obviously seen that the wear cutting is more effective in reducing the number of microscopic pitting, cracks, and feed marks than no wear insert. Moreover, the machined surfaces of wear insert are much cleaner than wearless inserts are used. The machined surface generated using wear inserts show fine fragments of reinforcement particles adhered on them. Thus, it can tell that the wear is relatively successful in improving the quality of machined surface. However, one should note that wear insert may cause deeper work hardening.

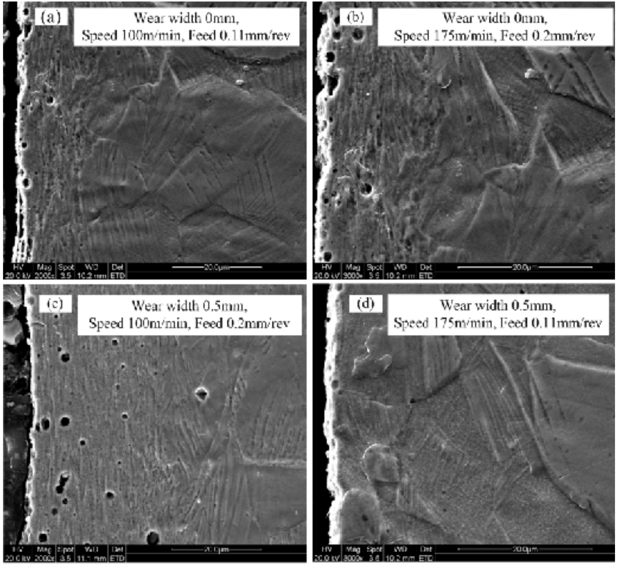


Fig. 10 SEM images of the machined surface and subsurface

IV. CONCLUSIONS

The experiments were conducted to determine microstructure changes of different machining conditions of austenitic 304 stainless steel, and the following conclusions were thus made:

1) The statistical analysis of the temperature indicates that cutting speed is the most significant factor influencing

magnitude of them. The location of the maximum temperature in workpiece along tool-workpiece interface is at the end area of the wear width because the amount of heat generated along the wear width is greater than the heat diffused.

2) The statistical analysis of the forces indicates that feed rate is the most significant factor influencing magnitude of them. Also, with a wear insert tool the forces are also improved, and this trend could be due to the increased of friction between wear and workpiece contact. And, the magnitudes of these forces components tell that the mechanical influence of friction is greater than thermal softening of stainless steel material.
3) The state of residual stresses changes from tensile to compressive with wear insert at the combination of low feed rate and cutting speed.
4) Lastly, the wear cutting is significantly effective in reducing the number of microscopic pitting, cracks, and feed marks than no wear insert. Moreover, the machined surfaces of wear insert are much cleaner than non-wear inserts are used. Thus, it can tell that the wear is relatively successful in improving the quality of machined surface.

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