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Experimental Study of Machining Residual Stresses in Plasma Assisted Turning Process

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ABSTRACT

The possibility of workpiece deformation after or during machining due to residual stresses is of crucial importance in precise components. These stresses are induced mainly due to the plastic deformation or heat generation during metal cutting process. Therefore, the magnitude of machining residual stresses are affected by mechanical and thermal stresses. Mechanical stresses depend on the cutting forces and thermal stresses originate from the magnitude of heat generation during cutting action. Therefore, it is expected that machining processes with lower cutting forces and cutting temperatures, will induce lower machining residual stresses as well. Plasma assisted machining is a process which uses a heat source to increase workpiece local temperature and thereby decrease the strength of material which is to be removed; therefore lower values of cutting forces, temperatures and residual stresses are expected. In this research work, the effects of undeformed chip temperature, cutting speed and feed have been investigated on the machining induced residual stresses in plasma-assisted orthogonal turning of AISI 4140. According to the achieved results, undeformed chip temperature is the most effective parameter on machining residual stresses and by increasing this parameter from 75 to 220˚C, machining induced surface residual stresses became more compressive averagely by 85.30%.

KEYWORDS

Residual stress; Heat Assisted Machining; Plasma; Cutting Forces; X-ray Diffraction.

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1. Introduction

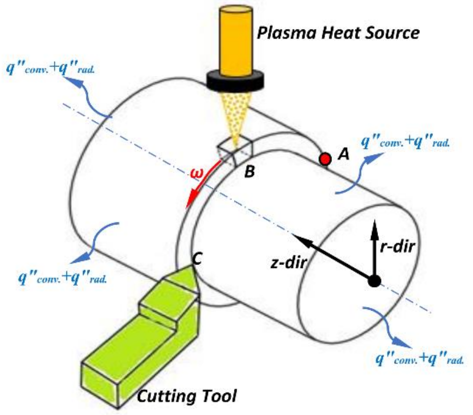
Heat assisted machining is a process which uses a heat source, Fig. 1(a), to increase workpiece local temperature and thereby decrease the strength of material which is to be removed; therefore lower values of cutting forces and cutting temperatures are expected [1-3]; Farahnakian et al. studied plasma-assisted machining of hardened steel 4140. They found that if the heat source is controlled so that the undeformed chip temperature could vary between 150 and 390˚C, the main component of cutting force will be reduced by 27% (relative to traditional machining) [2]. On the other hand, cutting forces and cutting temperature are the main causes of machining residual stresses; therefore, it is expected that applying concentrated local heat source will also lead to lower level of machining induced residual stresses. For instance, Balba et al. studied residual stress in Inconel 18 alloy by developing a SPH model. They showed that in contrary to traditional machining which produce tensile residual stress on the workpiece surface, laser-assisted machining, in the selected range of machining parameters, will result in compressive residual stresses [3]. However, these authors did not present any experimental data to verify their claim and did not address the effect of heat source parameters or undeformed chip temperature on the type and magnitude of machining residual stresses. Therefore, in this research work, the effect of undeformed chip temperature, cutting speed and feed has been investigated on machining induced surface residual stresses in plasma-assisted turning of AISI 4140.

2. Methodology

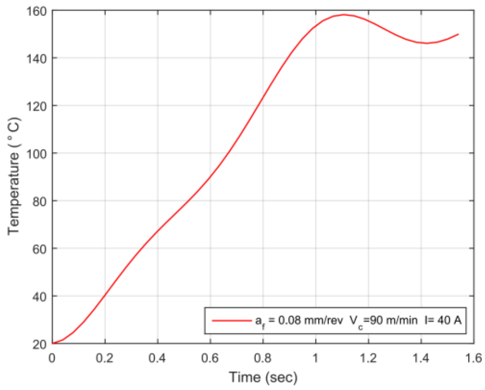
2.1. Plasma Assisted Machining

The plasma assisted machining process is schematically shown in Fig. 1(a). Consider an element of workpiece located on the outer surface of the workpiece at position A. This element comes close to the heat source due to workpiece rotation and its temperature rises rapidly, Fig. 1(b). When this element reaches the location of the heat source (Point B), it will achieve its maximum temperature. By moving away from the heat source, the temperature of the element begins to decrease due to heat transfer to the surrounding environment (mainly due to thermal conduction and convection). Finally, the element is exposed to the cutting tool at Point C. The temperature of element at this point is a good approximation of undeformed chip temperature (i.e. T_{uch}).

Controlling T_{uch} is one of the most important challenges in heat-assisted machining process; if this temperature is below a certain limit, the material flow stress will not change significantly, therefore, reduction in cutting forces can't be expected. On the other hand, if the temperature exceeds the temperature of the re-crystallization, the unwanted changes in the microstructure of the machined workpiece will be inevitable. Therefore, in order to achieve the required levels of T_{uch}, it is necessary to determine the temperature distribution of the workpiece so that the plasma source current can be adjusted according to the required T_{uch}. To achieve this goal, a mathematical model was developed to predict the effect of feed, cutting speed and electrical current density on the value of undeformed chip temperature.



(a)



(b)

Fig. 1. Modeling of undeformed chip temperature in heat assisted turning [1] (a) heat transfer problem boundary condition, (b) undeformed chip temperature variations and (c) effect of feed, cutting speed and electrical current intensity on undeformed chip temperature.

2.2 Experimental Setup

In this research, tests were done by universal machine (TN50BR). Plasma-assisted machining equipment included an inverter and a plasma torch from Saba electric Company. The model of the applied generator was CUT 121 which supplied electric current in the range of 20-120 A and in voltage of 70 V. The machining setup is shown in Fig. 2.

2.3. Design of experiments (DOE)

In this study, to conduct the experiments and investigate the effect of machining parameters (including cutting speed and feed) and undeformed chip temperature on machining induced residual stresses, full factorial method was implemented. Finally, 24 experiments were defined. Parameters and their levels are presented in Table 1.

Table 4. Variables and their levels.

Parameter	Level			
	1	2	3	4
Cutting Speed (m/min)	60	90	120	-
Feed (mm/rev)	0.08	0.14	-	-
Undeformed Chip Temperature (˚C)	20	75	150	200

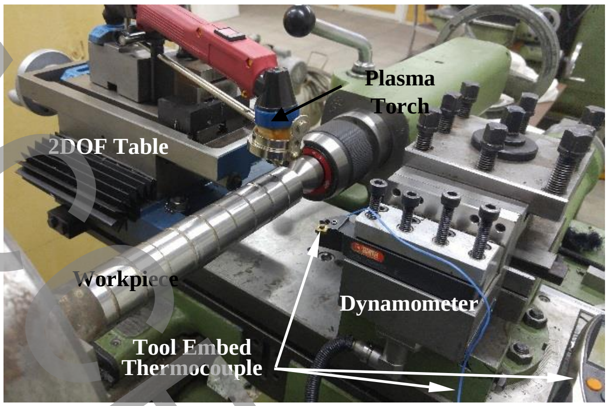


Fig. 2. Experimental setup of plasma assisted machining.

3. Results and discussion

The results of surface residual stresses measurement in plasma-assisted turning show that by increasing T_{uch}, machining induced residual stress reduces and becomes more compressive, Fig. 3(a). Reduction of material flow stress due to increased temperature caused by plasma source is the key point regarding the ability of the laser-assisted process to make machining induced residual stresses more compressive. In present study, increasing T_{uch} form 75 to 220˚C resulted in 85.3% increase in compressive residual stress due to lower flow stress.

In constant value of T_{uch}, increasing cutting speed resulted in more tensile residual stresses mainly due to higher heat generation, Fig. 3(a); for example it is observed that at T_{uch}=75˚C, increasing cutting speed from 60 to 120 m/min made machining induced residual stresses more tensile by about 50.00%.

Increasing feed will make machining induced residual stresses more tensile in both traditional and plasma-assisted machining, Fig. 3(b); increasing feed will increase the undeformed chip cross section and thereby cutting forces. Therefore, the amount of heat generation in cutting regions will increase. Generating more heat during cutting action will lead to an increase in tensile stresses and reduces the compressive residual stresses; for example increasing feed from 0.08 to 0.14 mm/rev made machining induced residual stresses more tensile; this increase in tensile stresses is about 38.9% in traditional cutting while this increase was about 28.34% in case of plasma-assisted machining.

As mentioned above, increasing cutting speed and feed will make machining induced residual stresses more tensile but plasma assisted machining, attenuates this phenomena; for example in Fig. 3(b), it is observed that at T_{uch}=75˚C, increasing feed from 0.08 to 0.14 mm/rev made machining induced residual stresses more tensile by about 40.00%; but at T_{uch}=150˚C and 220˚C, the same increase in feed will respectively make machining induced residual stresses more tensile by about 25 and 20%.

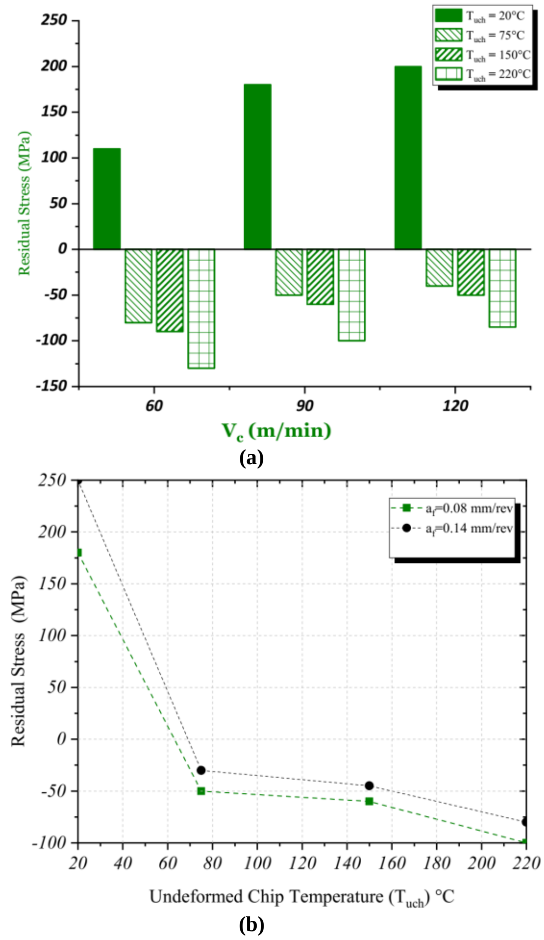


Fig. 3. The effect of cutting parameters and undeformed chip temperature on residual stress (a) af= 0.08 mm/rev, (b) Vc=90 m/min.

4. Conclusion

According to the achieved results, in plasma assisted turning of AISI 4140, in the selected range of machining parameters, by increasing undeformed chip temperature from 75 to 220˚C, machining induced surface residual stresses became more compressive averagely by 85.30%

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