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Full Length Article

Effect of nose radius on forces, and process parameters in hot machining of Inconel 718 using finite element analysis

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ABSTRACT

In the present work, the variation of nose radius on forces, cutting temperature, stress, has been studied using finite element modeling in hot turning operation of Inconel 718. Three values of nose radius were taken (0.4, 0.8 and 1.2 mm). Cutting force, thrust force, stress, and cutting temperature have been predicted using commercial DEFORM™ software at different cutting tool nose radius in both room and heated conditions. With the increase of tool nose radius in both room and elevated machining conditions the cutting force and thrust force increased. The cutting temperature, chip thickness and chip tool contact length also have been studied. In order to validate the numerical results an experimental analysis has been performed and good agreement between them has been observed

1. Introduction

Machining of hard materials like Nickel, Titanium and copper base alloys are the now great used in the aerospace sector, marine sector, biomedical equipment, and much more sector due to excellent properties like high indentation hardness, high abrasiveness, etc.[1]. But the removal of these materials in metal cutting operation creates a great challenge to industries due rapid tool wear. Although there are many techniques are available for machining hard materials like non-conventional machining process, hard turning, grinding etc., but there is some advantage and disadvantage of the process shown in Fig. 1. Hot machining is a method which overcomes the following above process without compromise the quality and cost. Machining of hard material using hot machining carried out by different researchers using the different heating method. Each heating methods have some disadvantage and disadvantage shown in Table 1[2]. Heating the material using different method was studied by a different researcher, Induction method [3–5], plasma heating [6–10], flame heating [11–14] etc. From the literature review, it was found that the heating of material influences the machinability.

The surface integrity, cutting forces, and the tool faces temperature affected by cutting geometry of the tool. Tool live, surface integrity is mostly influenced by the tool nose geometry was investigated by different researchers. Woon et al. [15] used finite element simulation to study the effect of nose radius on chip formation, shear stress distribution, hydrostatic stress distribution and effective rake angle in micromachining of AISI 4340 steel. They had taken four value of cutting tool nose radius (0, 1, 5, and 8). The ratio of uncut thickness and nose radius affect the chip formation process [15,16] Arif et al. [17] analyzed the change of tool nose radius on MRR(material removal rate), subsurface damage, and specific cutting energy. They found that the increase of undeformed chip thickness and Thrust changes MRR in milling. The mechanism of tool wear in thermally enhanced machining was studied by Bermingham et al. [18]. They used furnace heating method for heat the Ti-6Al-4V work material and taken 30 °C, 150 °C, 250 °C and 350 °C as material removal temperature. At 350 heating temperature cutting force decreased, but tool wear increased. For validate to this result, a finite element simulation has been carried out by Xi et al. [19] using ABAQUS software.

Yang et al. studied the cutting temperature generation in micro end milling process of Al2024-T6 with WC micro cutter using finite element method [20]. Saedon et al. studied the finite element analysis of micro machining and macro machining, the effect of nose radius on chip thickness on machining [21]. Liu et al. analyzed ductile cutting of silicon wafers using different cutting noses. It was found that the critical value of uncut chip thickness changes with the cutting noses and linear relationship between the uncut chip thickness and cutting noses [22].

A numerical modeling was reported by Wu et al. in micro turning machining operation using different nose radius. The cutting

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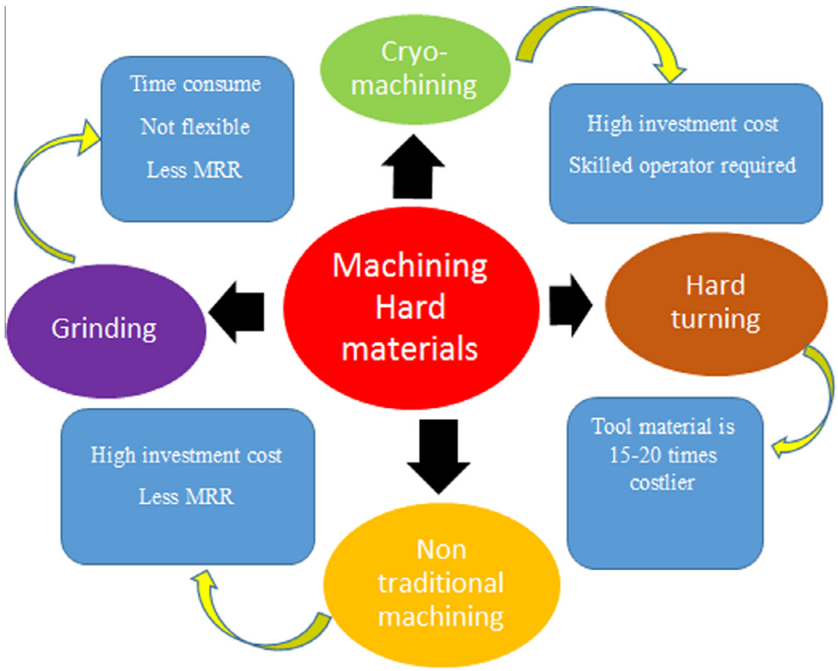

Fig. 1. Different machining process used for machining hard materials.

Table 1
Heat source/Heating Method Used.

Heat source	Advantage	Disadvantage
Laser	Local heat concentration Delicate shape machining	High investment cost Not able to all materials
Induction coil	Easy to use Heat can be imposed through	Low penetration of heat Tool mobility is not possible
Gas flame	Simple design	Low on penetration of heat Titanium alloy reacts with the tool material
Plasma	Local heat concentration	Cannot control accurately
Electricity	Simple equipment Low cost investment	Cannot control accurately

force and specific cutting force were greatly affected by the grain size. It was found that higher cutting force and specific cutting energy obtained on the smaller variation of grain size [22]. The wear of cutting tool and how it is affected by cutting tool nose radius was studied by Rech et al. using PM-HSS milling inserts. Numerical modeling also carried out to validate the experimental results. The formation chip in metal cutting operation with curvilinear nose tools and its mechanism was analyzed by Karpat and Ozel [23]. Chamfered nose along with different nose designs was taken for machining AISI 4340 steel using PCBN tools. They found that mechanics of machining was immensely affected by the size of cutting nose. The residual stresses were also reported by many researchers using different nose radius value [24–27].

But a little work was found Preparation of nose radius in the hot machining process. Among all heating method gas flame heating is simple and cheap compared to another heating process, so the present work is based on the effect of nose radius on hot machining using FE analysis. The aim of the study is to analyze the preparation of noses on temperature distribution on the tool and process variables. Investigations of the preparation of noses with different machining conditions were carried out in both conventional and hot turning operation. Analyze the effects of the process variables like temperature distribution of tool, stress, strain using finite element simulation.

2. Experimental work

All tests were performed on a center Lathe for both room temperature and preheating machining conditions. The workpiece Inconel 718 (Diameter 50 mm and 300 mm length) in the form of round bar and hardness of 43 HRC as received from the supplier. Tables 2 and 3 shows the workpiece material composition and Thermomechanical properties of Inconel 718. It is found in the literature review that the shear strength of Inconel start decreases when the heating temperature around 600 °C [28]. So in this study, the 600 °C temperature has been taken for simulation and experimental study. The experimental and schematic diagram for hot machining is illustrated in Fig. 2.

The temperature of workpiece surface was measured with the help of thermocouple (K-type) range of (200–1200 °C). The flow

Table 2
Chemical composition of Inconel 718[29].

Ni	Fe	Cr	Cb	Mo	Ti	Al	C	S
53.46	18.31	18.29	4.97	3.01	1.02	0.52	0.015	0.0004

Table 3
Thermo-mechanical properties of Inconel 718 and WC[30].

Properties	Inconel 718	WC
Density (kg/m^3)	8080 (kg/m^3)	15,000
Thermal conductivity (W/m/°C)	10.5 (W/m/°K)	46
Specific heat (J/kg/)	515 (J/kg°K)	203
Melting Temperature (°C)	1336	2870
Thermal Expansion (mm.mm$^{-1°}$/C)	13	4.7×10^{-6}

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