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Enhancement of Machinability of Inconel 718 in End Milling through Online Induction Heating of Workpiece

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Abstract. This paper presents the outcome of a study on heat assisted end milling of Inconel 718 using inducting heating technique conducted to enhance the machinability of the material. The heating temperature maintained below the phase transformation temperature was aimed at softening the top removable material layers. The experimental results of both conventional and heat assisted machining were compared. The machinability of Inconel 718 under these conditions was evaluated in terms of tool life, tool wear morphology and chatter. The advantages of Induction heating is demonstrated by an longer tool life and lower chatter. The study showed that preheated machining facilitates up to 80% increase of tool life over conventional machining conducted using TiAlN coated carbide inserts.

Introduction

Inconel 718 has excellent creep–rupture strength, high fatigue endurance limit up to 700 °C [1,2] which make it suitable for wide application in gas turbines, rocket engines, spacecraft structural components, nuclear reactors, and many other applications. However, the very metallurgical and mechanical characteristics that give nickel alloys the highly valued properties also make them one of the most difficult-to machine aerospace materials. The properties responsible for the poor machinability of the nickel based super-alloy Inconel 718 are - high work-hardening capacities, maintaining high strength during machining due to its high-temperature properties, hard abrasive carbides in the microstructure, low thermal conductivity and specific heat and high cutting temperature, high chemical affinity for many tool materials leading to diffusion wear, and its strong tendency to weld to form built up edge because of its gummy nature at high temperature [3, 4]. Furthermore, its low thermal conductivity results in heat concentration in the cutting edge [5-7]. This There are some advantages of ceramic tools in machining Inconel 718 has been reported by some researchers [8] however, ceramics are low conductive materials [9] and the heat generated during the machining of Inconel 718 transfers very slowly through them and causes many problems and sometime leads to early tool failure [9]. One approach to overcome the difficulties in machining Inconel 718 is to use an external heat source to soften the work material surface layer in order to decrease its tensile strength and strain hardening [10]. Laser Assisted Machining (*LAM*) of Inconel 718 reported a reduction of tool wear by 40%, cutting force by 18% and increase in metal removal rate by 33% [11]. However, the high costs of high powered lasers and the large power consumption slowed down the implementation of LAM. A new approach of preheating using inducting heating as an economical alternative to LAM for end milling of Inconel 718 is presented in this paper. The experimental results of both conventional and induction heating enhanced machining of Inconel 718 were compared at different speed and feed values in terms of tool life, tool wear morphology and vibration.

Experimental Setup and Procedure

The work-piece material used in all experiments was nickel based super alloy Inconel 718. The cutting conditions for the experimental work are given in table 1.

Table 1 Cutting conditions for experimental work

Trial Number	Cutting speed (m/min)	Feed (mm/tooth)	Axial depth of cut, (mm)	Preheated temperature, (^{0}C)
1	16	0.07	0.57	420
2	28	0.07		
3	50	0.07		
4	28	0.03		
5	28	0.07		
6	28	0.16		

Sandvick TiAlN coated using PVD (4 µm single layer) carbide inserts was used in the experiments. One insert has two cutting edges. The inserts profile and geometry data are presented in Fig. 1. End milling tests were conducted on Vertical Machining Centre with quarter immersion cutting. Work material was Inconel 718. Machining was performed with a 20 mm diameter end-mill tool holder. All of the experiments were run at room temperature and online heating conditions at a temperature of 420 ºC not causing any phase change in Inconel 718. High frequency induction heating was utilized to run the heat assisted machining. Selected cutting conditions for the experimentation are presented in Table 1. Average flank wear value of 0.3 mm was considered as the criteria for tool life calculation. Scanning Electron Microscope (SEM) was employed to investigate tool wear morphology. Vibration/chatter was monitored using an online vibration monitoring system. The experimental setup of the preheated machining is presented in Fig. 2.

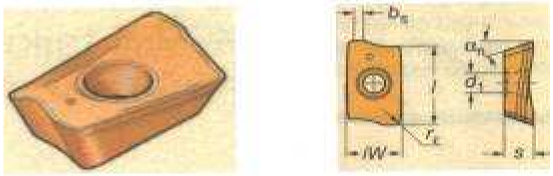
Result and Discussions

3.1 Tool life

Fig. 3 shows the tool life both at room temperature and with preheating (420 ^{0}C). Trials 1-3 in the figure are for variation in cutting speed from 16-50 m/min with feed maintained at 0.07 mm/tooth and trials 4-6 are variation in feed from 0.03-0.16 with cutting speed maintained at 28 m/min. It is observed that tool life is significantly influenced by heating at all the investigated cutting parameters. However, the higher advantage of heating is also found to be dependent on the cutting parameters i.e. cutting speed and feed as shown in Fig. 3. Medium cutting speed gave the best advantage of heat assisted machining with 76 % of increase of tool life. At lower or higher cutting speeds the benefit of heat assisted machining is found to be less significant. With respect to the feed it is found that the best improvement of tool life (by 83%) is achieved at the lowest feed. But an increase in feed reduced the preheating benefit and at the highest feed value the improvement of tool life is only 28%. This may be related to higher cutting temperatures generated at higher speeds and feeds and addition from external source does not play a desired role due to more active diffusion wear rates. Longer tool life achieved in heat assisted machining offers an increase of metal removal per tool life.

3.2 Vibration/Chatter

More intensive chatter results in high dynamic stresses acting on the tool resulting in premature tool failures. Fig. 4 represents the effect of preheating in reducing the amplitude of vibration during machining. Significant amount of reduction of chatter amplitude may be observed from this figure. The highest reduction of amplitude is observed at the intermediate cutting speed of 28 m/min at the intermediate feed of 0.07 mm/tooth (trials 2 and 5) and at the lowest cutting speed of 16 m/min and the lowest feed value of 0.03 mm/tooth (trial 4). Reduction at other conditions is not that significant.



L	iW	d_1	s	b_s	r_ε	α_n °
11	6.8	2.8	3.59	1.2	0.8	21

Fig. 1 Insert Shape and Geometry

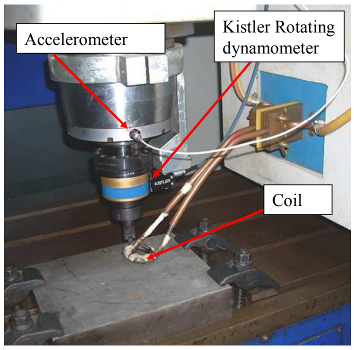


Fig. 2 Experimental setup

It may be observed the FFT plot of vibration that there was one main peak in the range of 4500 – 5000 Hz. The most significant peak during room temperature cutting was at 4510 Hz with amplitude value of 0.095 mV in trial run 2 but preheating reduced its amplitude to 0.015 mV (more than 6.3 times) as shown in (Figure 4). Reduction of the amplitude of machining vibration at other trial runs is shown in Fig. 4. Lower vibration will reduce the dynamic loads on the edge which leads to lower tool wear. Softer workpiece reduces the stress and cutting force acting on the tool resulting in a reduction of tool wear and hence increasing the tool life.

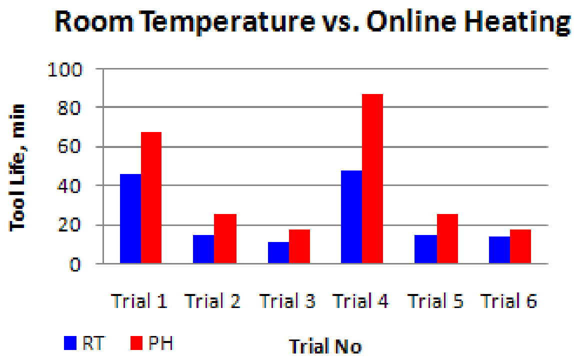


Fig. 3 Comparison between room temperature and preheating in terms of Tool life

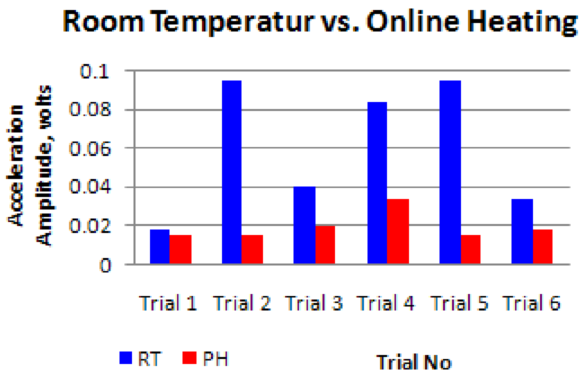
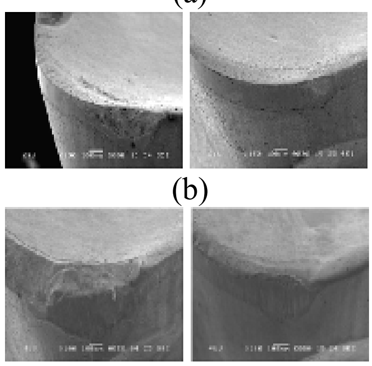


Fig. 4 Comparison between room temperature and preheating in terms of acceleration amplitude

3.2. Tool Wear Morphology

Fig. 6 shows the SEM micrograph of flank wear after end milling at room temperature and with preheating experiments. Though at low speed, room temperature machining caused uniform wear as found in 7(c). However, at higher speed, room temperature end milling caused severe tool wear with catastrophic morphology with cracks as shown in Fig. 7(e). At higher speed, tool wear was found to be uniform in preheated machining if compared with room temperature machining 7(f).

(a)



(b)

(c)

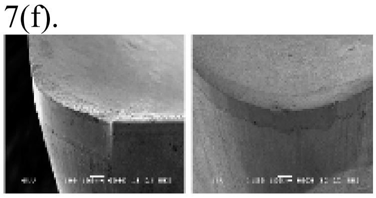


Fig. 5 SEM views of flank wear both for room temperature and preheated machining at feed value of 0.07 mm/tooth different cutting speeds: (a) V = 16 m/min, (b) V = 28 m/min and (c) V = 50 m/min.

It is clear from Fig. 4 and Fig. 6 that application of induction heating is able to reduce tool wear and hence increase tool life. Pictures of the worn tools in Fig. 5 reflect that induction heating could significantly reduce the too wear, hence, lead to increasing in tool life. Elevated temperature in preheated machining leads to an increase in chemical reactivity between chips and the tool materials, and which leads to the formation of built-up-edge (BUE) (Fig. 5(c), which helps in shielding the tool from wearing out quickly. Strain hardening also occurs in machining Inconel 718 which has adverse effect on tool life especially at lower feed rates. Work piece preheating can reduce strain hardening effect considerably and thus facilitate higher tool life. That is why the best improvement of tool life due to preheating was reported at low feed for trial run 4 (with feed value of 0.03 mm/tooth).

Conclusions

The following specific conclusions have been drawn on the work:

1. Induction heat assisted machining helps in substantially increasing tool life during end milling Inconel 718 using TiAlN coated carbide inserts (up to 83%). Maximum benefit is derived at low feed rate and intermediate cutting speeds (28 m/min) at 420 ^{0}C of heating temperature.
2. Heating at 420 0C helps in lowering down acceleration amplitude and the maximum reductions were 600%.
3. Lower rate of tool wear and higher tool life during heat assisted machining due to lower stresses action on the tool and lower strain hardening effects.

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