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High speed machining of Inconel 718: tool wear and surface roughness analysis

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Abstract

Inconel 718 is a Nickel based Heat Resistance Super Alloy (HRSA) widely used in many aerospace applications. It possesses good properties like corrosion resistance, high strength and exceptional weldability. It is considered as one of the most difficult to cut alloy. Recently many researcher have focus in employing many machining strategies to improve machinability of Inconel 718.This paper presents High Speed Machining (HSM) of Inconel 718. Turning trials are conducted at various speed ranging from low to high (60 m/min, 90 m/min, 190 m/min, 255 m/min). Tool wear and surface roughness, which are two major aspects of machinability, have been discussed in this investigation.

Keywords: High speed machining; Inconel 718; Tool wear; Surface roughness;

1. Introduction

Today's aerospace industry demands material with superior properties to respond to the requirements such as weight, reliability and precision in complex environments [1, 2]. Nickel based super-alloys are widely used in the aerospace industry because of their exceptional mechanical resistances to high temperature and corrosion [3, 4]. Nickel-based super-alloys are mainly used for static or rotating components of the hottest sections of aero engines. These rotating parts are the blades and the disks in the high-pressure compressor (HPC) and turbine (HPT) stages [5].

Inconel 718 is one of the Heat Resistant Super Alloy (HRSA) from nickel-chromium group appropriate for many aerospace applications. It is a precipitation-hardenable nickel-chromium alloy which also contains Iron, Niobium and Molybdenum, Aluminium, Titanium, Cobalt, Carbon, Manganese and Silicon. It has a good corrosion resistance and high strength and weldability.

Inconel is considered one of the difficult to cut metals because of the same properties which make it suitable for aerospace applications. Machinability of Inconel 718 is a challenge for many researchers over past many years. Many studies have been undertaken to explore difficulties in machining of Inconel 718.

As Inconel is difficult to cut, cutting tool often gets worn out immediately during its machining so it is very important to select a appropriate cutting for machining of Inconel 718. Devillez et al. [6] found that welding and adhesion of workpiece material onto the rake and flank faces are the dominant wear modes during dry cutting Inconel 718. Flank wear and microchipping found to be the predominant failure modes of cemented carbide tool insert which affects tool performance and tool life in machining Inconel 718 [7].

Altin et al. [8] found that for ceramic tools flank wear, crater, notching and plastic deformation are the main wear mechanisms. Sharman et al. [9] used CrN and TiAlN coated tools while machining Inconel 718. They found extensive BUE and peeling of coating with CrN tools because of higher chemical affinity of CrN for Inconel 718 than that for TiAlN. According to them TiAlN coated tools are better in performance while machining of Inconel 718.

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The high-speed machining technology has become more prevalent in recent years in many industries because of development of tougher, more refractory tool materials and of high-speed machining spindles [10].

This paper presents use of use of high speed machining while turning of Inconel 718. Surface roughness and tool wear are the main issues which have been addressed in this investigation.

2. Experimental details

For the analysis rods of Inconel 718 are used with 30 mm in diameter and 60 mm in length (Fig. 1). The hardness of the material is 45 HRc. From 60 mm length of workpiece, 25 mm length is used for holding and 30 mm length is used for turning. The Carbide CVD coated insert with grade K 05-K25 and specifications WNMA 060408 are used for the machining. The tool holder is MWLNL 2020 - K06. Tool holder with insert fixed on it is shown in Fig. 2.

Continuous turning operation is carried out on CNC turning Centre in wet condition. Four workpieces are machined at four different speeds two of them are conventional turning at 60 m/min and 90 m/min remaining two are high speed turning at 190 m/min and 255 m/min. Throughout the experimentation, depth of cut and feed are kept constant at 0.5 mm and 0.1 mm/rev respectively.

With above mentioned cutting parameters, machining is carried out with 30 mm length of cut and this operation is repeated three times therefore total machining length is 90 mm. After every cut surface finish and tool wear is measured. Surface finish is measured by the Mitutoyo make SJ 210 portable surface roughness tester.

During the surface roughness measurement, cut off length is kept at 0.8 mm and evaluation length is 4 mm with probe speed. The set for surface roughness measurement is shown in Fig. 3. Tool wear is measured by Mitutoyo make Tool Maker's Microscope with L.C of 5µm.

3. Experimental results

3.1 Analysis of Surface Roughness

The graph of surface roughness (Ra) (Fig. 4) against speed reflects that surface roughness values are high at low cutting speeds i.e. at 60 and 90 mi/min and low at higher cutting speeds i.e. at 190 and 255 m / min. This trend is because at high speeds there may a thermal softening of material and also at high speed there is a possibility that surface flaws gets wiped out as mentioned by [11].

Interesting observation made during the investigation is that when cutting speed is changed from 190 to 250 m/min surface finish again deteriorate this is because at high cutting speed due notching of tool gets damaged immediately during the turning which is also visible in insert SEMs and high resolution photographs of tools.

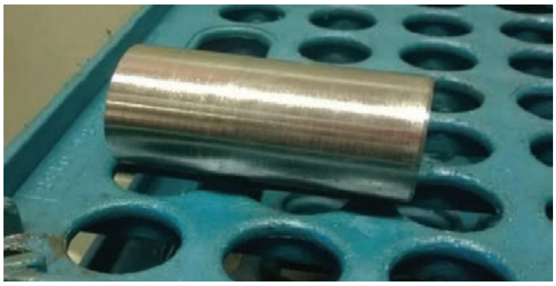


Fig.1 Inconel 718 rod used for Machining.

Fig 2.Tool Holder with Cutting Insert.

Fig. 3 Roughness measurement setup.

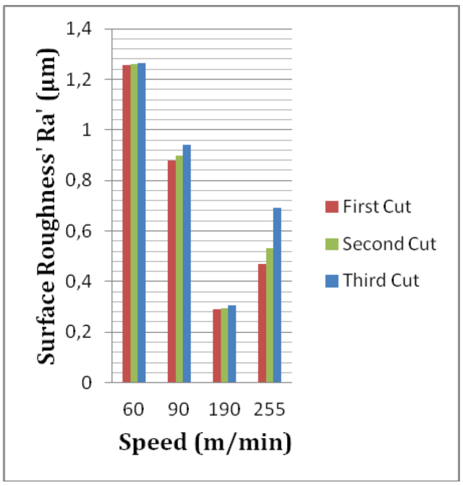


Fig.4 Variation in Surface Roughness for Different Speeds

One more thing must be taken into consideration that during the speeds 60, 90 and 190 m/min surface roughness is approximately same for all three cuts. But for highest speed of 250 m/min it increases with every cut this also because of rapid wear of tool. At lower cutting speeds during initial cuts tool wear is not so significant so with the speeds 60 and 90 m/min there is not much difference between the Ra values. For 60 mi/min speed, the variation in surface roughness is 1.258, 1.259 and 1.264 (Table 1) so it can be concluded that at low speed tool will produce same surface roughness pattern for a longer period.

The similar trend is observed for 90 and 190 m/min speeds also. But for highest speed of 255 m/min it can be seen that roughness value goes on increasing with every cut. For this speed the variation in surface roughness is 0.469, 0.531 and 0.691.Therefore it can be seen from above pattern that though these surface values are very good the increase in roughness value with every cut is on higher side which indicates rapid wear of tool.

The roughness patterns are shown in Fig 5-8. The patterns indicate that though the surface roughness values are high at lower speeds, the pattern is uniform throughout the turning length. At high speed pattern is not uniform at some point it suddenly increases which may be due to either vibration caused because of high speed or may be to instant notching of tool at high speed.

Table 1. Surface Roughness Ra at different speeds and cuts.

Speed m/min	First Cut	Second Cut	Third Cut
60	1.258	1.263	1.267
	1.440	1.447	1.453
	5.106	5.119	5.124
90	0.880	0.887	0.894
	1.02	1.022	1.035
	4.063	4.071	4.073
190	0.290	0.294	0.298
	0.366	0.370	0.373
	1.929	1.930	1.933
255	0.469	0.472	0.488
	0.601	0.605	0.612
	2.935	2.946	2.953

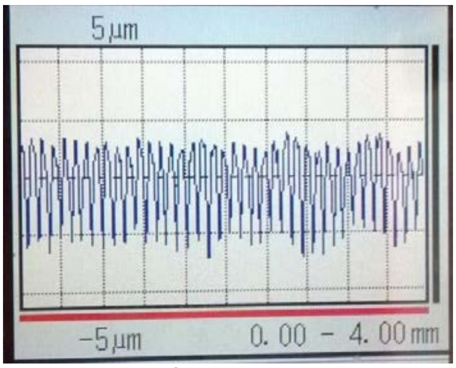


Fig.5 Roughness pattern at 60 m/min

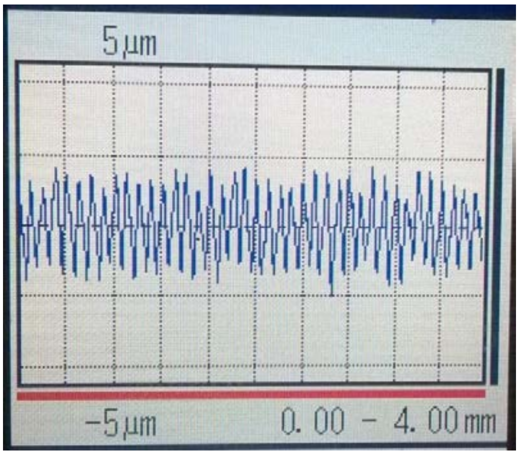


Fig.6 Roughness pattern at 90 m/min

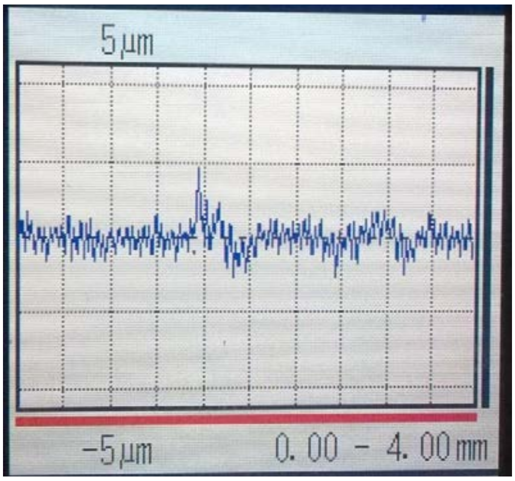


Fig.7 Roughness pattern at 190 m/min

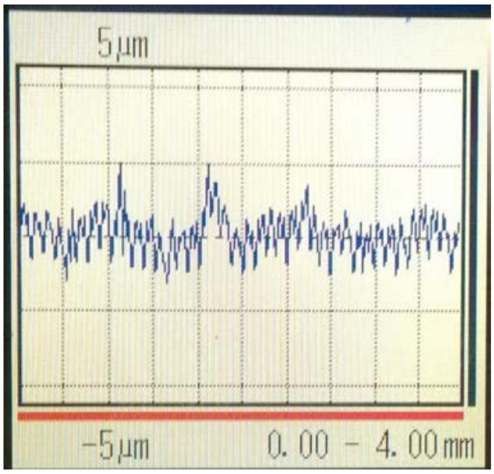


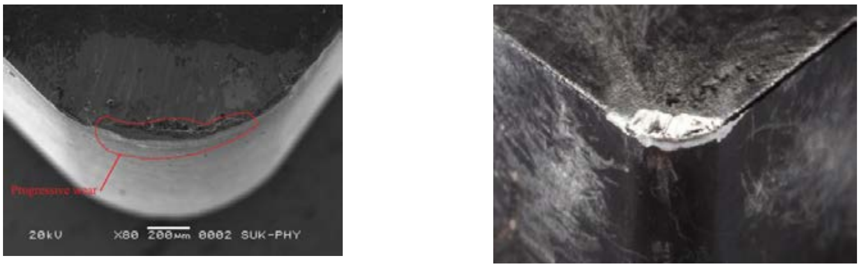
Fig.8 Roughness pattern at 255 m/min

3.2 Analysis of Tool Wear

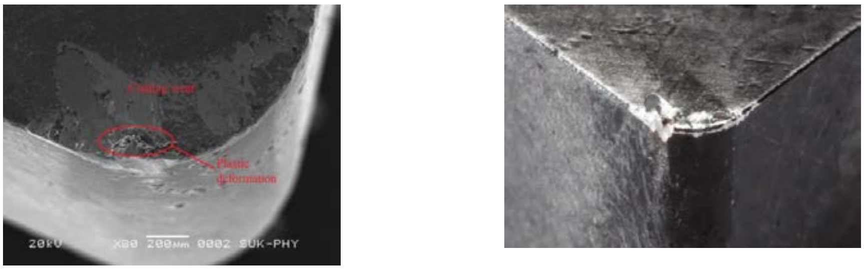
For analysis of tool wear apart from tool wear measure by Tool Maker's Microscope Scanning Electron Microscope (SEM) and High Resolution Photography (HRP) is also used. These techniques are very useful to observe the tool actual wear pattern and damage of tool.

The measured values of tool wear after final cut are given in Table 2. SEM and HRP images are shown in Fig. 9. From Table 2 and Fig. 10, it is clear that, for same cutting parameters, tool wear is highest at cutting speed 255 m/min.

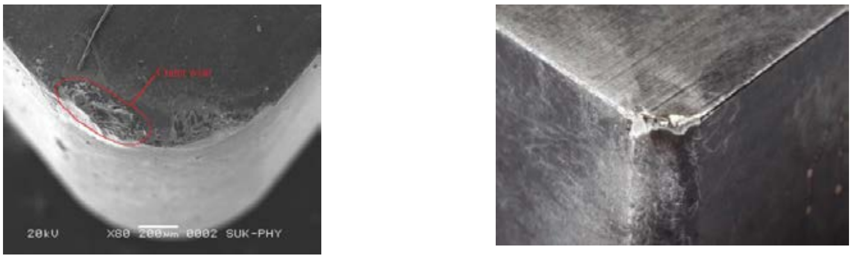
Scanning Electron Microscope Images **High Resolution Photography Images**



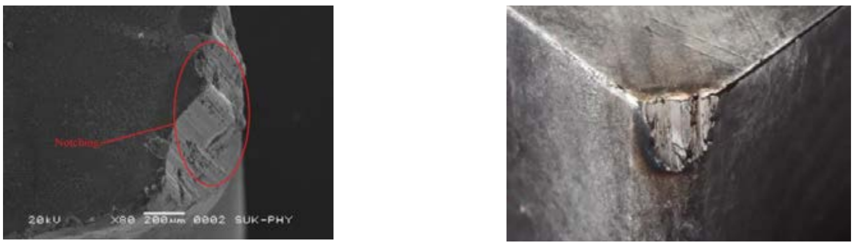
Speed = 60 m/min



Speed = 90 m/min



Speed = 190 m/min



Speed = 255 m/min

Fig. 9 Tool wear pattern at various speeds (SEM and HRP)

At high cutting speeds tool gets worn out at very faster rate with major tool failure patterns like heavy notching. Tool gets worn out almost up to tool life criterion at high speed which can be seen from Table 2 and graph shown in Figure 10. At high speeds burn marks are also visible on tool this is due to large amount of heat is generated during machining of Inconel 718 and most of this heat is diverted to tool because of poor thermal conductivity Inconel 718.Tool wear at 255 m/min is almost twice to that at 190 m/min and 3 to 3.5 times that at 90 and 105 m/min.

Since Inconel 718 is difficult to cut lot of heat is generated while machining it at high speeds. Because of low thermal conductivity of Inconel 718 lot of this heat is transferred to cutting tool which is seems to be the major reason of tool wear.

In conventional low speed machining at 60 and 90 m/min, tool wear rate is very less because of low temperature in cutting zone. At low cutting speeds no major signs of tool damage are observed. Wear observed is uniform along the nose radius along with some traces of peeling coating are also visible. At lowest speed of 60 m/min some traces of crater is observed on the tool.

Table 2 Tool Wear at different speeds

Speed (m/min)	Flank Wear (micron)
60	90
90	105
190	160
255	320

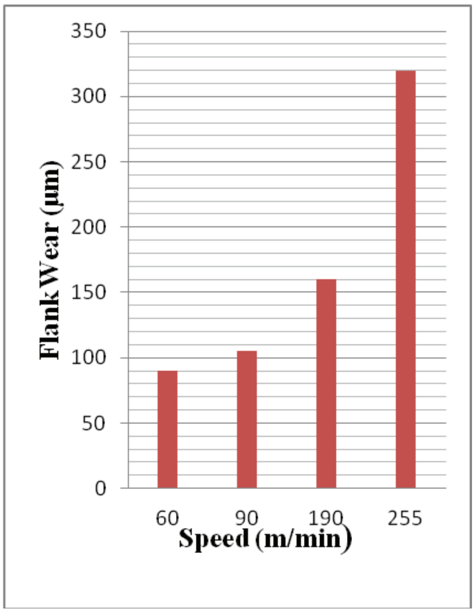


Fig.10 Variation in Tool Wear for Different Speeds

Conclusions

Issues related with surface roughness and tool wear during high speed machining of Inconel 718 has been reported in this paper. Turning trials are conducted at various speed ranging from low to high (60 m/min, 90 m/min, 190 m/min and 255 m/min). It is found during investigation that both speed levels i.e. low speeds and high speeds gives good machined surface as values of surface roughness are low for all the speeds. For fresh inserts surface roughness is almost same at low as well as at high speed. Speed 190 m/min gives best result for surface roughness for the conditions under investigation. While machining Inconel 718 at high speed surface quality may deteriorate because of rapid tool wear rate for subsequent cuts.

During the investigation no major signs of tool damages are observed while machining Inconel 718 at low speeds i.e. at 60 and 90 m/min. Wear patterns observed at these cutting speeds are uniform along the nose radius along with some traces of peeling coating. Comparatively at high cutting speeds tool gets worn out at very faster rate with major tool failure patterns like heavy notching. Also at high speed because of very high amount of heat is generated in cutting zone while machining Inconel 718 burns marks are visible on the tool. This can be one of the major criterion which leads the tool wear. Tool wear during machining of Inconel 718 is complex phenomenon which needs to explored further which may help to improve the machinability of Inconel 718.

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