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Predicting Surface Roughness, Tool Wear and MMR in Machining Inconel 718: A Review

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Abstract- Increasing the productivity and the quality of the machined parts are the main challenges of manufacturing industry, in particular for heat resistant super alloys employed in aeronautic and aerospace applications.Superalloy, Inconel 718 is widely used in the sophisticated applications due to its unique properties. However, machining of such superior material is difficult and costly due its peculiar characteristics. The present article is an attempt to suggest optimization technique to study the machinability of Inconel 718 with respect to cutting parameters (speed feed, depth of cut)on output parameters such as surface roughness(Ra) and material removal rate (MMR) in high speed turning of Inconel 718 using cemented tungsten carbide (K20) cutting tool. Cost effective machining with generation of good speed ,feed depth of cut . The output parameters like surface finish tool wear and metal removal rate can also be optimized for economical production.

Key words- *CNC, MRR, Ra*

1 Introduction

Turning processes comprise a very big portion of metal cutting process in industry. For the determination of ideal machinability properties, those parameters such as mechanical material properties, machine tool rigidity, feed rate, depth of cut, cutting speed and cutting tool geometry play an important role in machining . Cutting speed is the main parameters that affect machinability properties of the material . Although Inconel 718 can be machined by using cemented carbide tools at low cutting speeds, it must be machined by ceramic tools at higher cutting speeds. But the problem of machining inconel 718 is one of ever increasing magnitude due to extreme toughness and work hardening characteristics of the alloy.

Nickel-based alloys account for 80% of the super alloy, with the remainder being iron and cobalt based. Approximately 45–50% of the total material requirements for a gas turbine engine are met using nickel alloys. The properties that make nickel-based super alloys posses high yield strength (retained to approximately 750 ◦C), high ultimate tensile strength, high fatigue strength, retention of corrosion and oxidation resistance up to elevated temperatures and good creep resistance. Nickel and nickel-based alloys especially Inconel 718 is widely used in many industries, owing to its unique properties such as high oxidation resistance, corrosion resistance even at very high temperatures, and retains a high

Tool materials with improved room and elevated temperature hardness like cemented carbides (including coated carbides), ceramics and cubic boron nitride (CBN) are frequently used for machining nickel base superalloys. Despite recent advances in cutting tool materials, machining of nickel base superalloys at high speed conditions generally reduces the hardness and strength of cutting tools Most of the literature advocates that the use of different tool materials such as ceramic tool materials like Al_2O_3/TiC mixed ceramics, Si_3N_4 ceramics:Sialon, latest SiC whiskerreinforced Al_2O_3 ceramics (&25% SiC whiskers), multilayer (TiN/TiCN/TiN) coated carbide tools produced by the physical vapor deposition (PVD) technique, Cubic boron nitride (CBN) cutting tools, etc., appears to give better overall performance than cemented tungsten carbides while machining nickel-based alloys . Though the performance wise for the above mentioned tools are better, their cost limits the use in the engineering applications

Cemented tungsten carbide cutting tools are the oldest among the hard cutting tool materials. Cemented tungsten carbide tools are mainly used for continuous cutting operations. Over the years, the use of carbides for cutting tools has been established. Carbide tools are used to machine Inconel 718 in the speed range of 10–30 m/min.However, with the increasing demand to achieve fast material removal rate and better surface quality, high speed machining was introduced. For nickel-based alloys, the concept of high speed machining refers to speeds approximately over 40 m/min

2 Literature Review

It is essential to understand the past and present status of the machining of Inconel 718 process to suggest future areas of work. Extensive literature survey has been carried out to find the state of machining of inconel 718.

Liao and Shiue (1996) analysed the wear mechanism of two cemented carbide tools K20 and P20 grades in dry turning of Inconel 718. The feed rate and the depth of cut were 0.10 mm/rev and 1.5 mm, respectively. The cutting speed was either 35 or 15 m/min. On the wear surface of the K20 carbide observation found that the sticking layer very close to the cutting edge was observed. Built-up edge was formed at a cutting speed of 35 m/min with chipping of the cutting edge. When P20 carbide was used, the sticking layer also could be found, but comparatively the wear was more irregular, the flank wear length was larger and the groove was deeper.

Rahman *et al*. (1997) revealed the machinability of Inconel 718 subjected to various machining parameters including tool geometry, cutting speed and feed rate. Flank wear of the inserts, workpiece surface roughness and cutting force components have been considered as the performance indicators for tool life. Tool life found to be increased as the SCEA increases from - 5 to 45°. This gives improved heat removal from the cutting edge, distributes the cutting forces over a larger portion of the cutting edge, reduces tool notching and substantially improves tool life. The PVD–TiN coated carbide insert exhibited excellent resistance to depth of cut notch wear at the approach angles of 15° and 45°

Dudzinski *et al.* (2004) in their study taken a review of developments towards dry and high speed machining of Inconel 718 alloy and presented recent work and advances concerning machining of this material. In addition, some solutions to reduce the use of coolants are explored and different coating techniques to enable a move towards dry machining are examined. Cemented carbide tools are largely used for machining nickel-based alloys at very low cutting speeds of 20–30 m/min, the K20 grade appears to be the best for cutting Inconel 718.

Krzysztof Jemielniak (2005) did comparison of cutting performance of several cemented carbide and CBN tools in finish turning (ap=0.2 mm and f=0.08 mm/rev) of Inconel 718 and investigated that cutting forces are not always higher using CBN tools than using carbide tools. On the other hand, tool life of the best carbide tools appeared to be comparable with some of CBN tools. Generally cutting force values obtained using CBN tools were higher than those obtained using carbide tools, which is understandable having in memory special preparation of cutting edge of such tools.

I A Choudhury (1998) In this paper a general review of their material characteristic and properties together with their machinability assessment when using different cutting tools The advantages and disadvantages of different tool materials with regard to the machining inconel are highlighted. Uncoated carbide tool are better than coated tool for machining inconel 718 apparently the coating does not improve the performance of coated tool

Benardos and Vosniakos (2003) presented the various methodologies and practices that are being employed for the prediction of surface roughness. It gave a review of the different approaches that are used for predicting the surface roughness and certain remarks concerning each approach. As is evident- from the referenced papers, in recent years there has been a great deal of research activity in the field and the results that have been produced are good. The trend that is formed encourages more automated systems building for on-line monitoring, measuring or control and is mainly driven by the fact that the processes themselves have been automated to a great extent. All the methodologies that are presented here can exhibit advantages and disadvantages when compared to one another, but given this trend the most promising seem to be the theoretical and the AI approaches. A comparison of these two approaches reveals that AI models take into consideration the particularities of the equipment used and the real machining phenomena, information that is stored in the experimental data used to develop the models

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Abdullah Altin (2007) has study the effect of cutting speed and cutting tool geometry on cutting force metal removing process is carried out for four different cutting speed while constant feed and depth of cut As a result of experiments the lowest mean cutting force which depends on tool geometry is obtain as 672N with KYON2100SNGN120 712 ceramic tool maximum cutting force is determained as 1346 N with the cersmic cutting tool having KYON4300 RNGN120 700 geometry

Ezugwu (2007) revealed the recent improvements in the machining of difficult-to-cut aerospace super alloys. A positive rake cutting edge is recommended for semi finishing and finishing operations whenever possible. Positive rake geometry minimizes work hardening of the machined surface by shearing the chip away from the workpiece in an efficient way in addition to minimising built-up-edge. Using a large nose radius wherever part geometry does not demand otherwise can reinforce the cutting edge.Thakur and Ramamurthy (2009**)** has optimized of high speed turning parameter of Inconel 718 using taguchi technique. The optimal parameters observed were cutting speed 75 m/min, feed 0.08 mm/rev and depth of cut 0.5 mm Thakur *et al.* (2009) attempted to use Taguchi optimization technique to study the machinability of Inconel 718 with respect to cutting force, cutting temperature, and tool life in high speed turning of Inconel 718 using cemented tungsten carbide (K20) cutting tool. It was demonstrated a correlation between cutting speed, feed, and depth of cut with respect to cutting force, cutting temperature, and tool life in a process control of high speed turning of Inconel 718 in order to identify the optimum combination of cutting parameters, It also revealed the effect of high speed cutting parameters on the tool wear mechanism and chip analysis

Thakur *et al.* (2009) did experiments on machining of Inconel 718 on lathe and proposed investigations of high speed turning on Inconel 718 using Taguchi optimization technique for cutting force, cutting temperature, and tool life in high speed turning of Inconel 718 using cemented tungsten carbide (K20) cutting tool. A correlation between cutting speed, feed, and depth of cut with respect to cutting force, cutting temperature also demonstrated in order to identify the optimum combination of cutting parameters. Mathew (2010) introduced aluminum as a versatile and attractive lightweight automotive material with significant cost savings. Standard surface roughness prediction methodologies were explored. Parameters affecting surface roughness of machined surfaces were detailed along with practical recommendations to improve surface quality

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Ahmad Yasir Moh (2011) has focus on the tool performance when finish turning Inconel 718 using single layer PVD coated TiAIN carbide insert at high cutting speed at various cutting speeds, depth of cut and feed rate under dry cutting condition . He concluded that the most significant factor that influences the flank wear or tool life at high cutting speed and dry machining is depth of cut followed by feed rate and cutting speed, respectively. Tool life is significantly influenced by temperature generated at the cutting zone when machining Inconel 718 under dry cutting condition. Increaseing the cutting speed and depth of cut affected the tool life and promoted wear progression..

V Dhanalakshmi (2010) she mainly studies on wear analysis if ceramic cutting tool the experiment result indicate that the cutting speed is the moist signifficient factor to overall performance the co realation with cutting speed and feed with tool wear and surface are obtained by variable linear regration it has been found that the less tool wear and good surface finish are obtained using ceramic tool when finished turning inconel at low speed the optimum cutting condition for good surface finish is 100 mm/min. and 0.1 mm/rev the tool failure are obtained when cutting speed of 200m/mim and feed rate of 0.15mm/rev and has concluded that performance is better at low cutting speed

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Colak (2012) deals with experimental investigation on machinability of Inconel 718 in conventional and alternative high pressure cooling conditions The experiment results have prove that the tool flank wear and cutting forces considerably decrease with the delivery of high pressure coolant to the cutting zone. Moreover, ANOVA results also indicate that high pressure cooling has a significant beneficial effect on cutting tool life

***Tran Minh-Duc (2013*)** In his study, an attempt has been conducted to investigate the effects of cutting parameters on tool wear and surface roughness during hard turning of Inconel 718 material. By taking into account the Analysis of Variance (ANOVA) in accordance to Central Composite Design (CCD); the mathematical model of the flank wear and surface roughness are developed with transformation of the natural logarithm. when machining at higher cutting speed, around 50-75m/min, the surface roughness is significantly improved due to the disappearance of built-up-edge. However, due to the hard particles of the Inconel 718 material against the cutting tool, the abrasive wear increases rapidly at high cutting speed, more than 90m/min. As evidenced from this paper, in order to achieve a high surface quality with low cutting tool wear, a cutting speed in the range of 50- 70 m/min is highly recommended for the hardened Inconel 718 using PVD coated cutting tool

3 Conclusions and discussion

The current work presented a review of the different approaches that are used for predicting the surface roughness tool wear and MRR certain remarks concerning each approach can be found in the respective sections. As is evident from the referenced papers, in recent years there has been a great deal of research activity in the field and the results that have been produced are good. The trend that is formed encourages more automated systems building for on-line monitoring, measuring or control and is mainly driven by the fact that the processes themselves have been automated to a great extent. All the methodologies that are presented can exhibit advantages and disadvantages when compared to one another, but given this trend the most promising seem to be the theoretical and taguchi which gives more advantages and negligible disadvantages

Inconel 718 retain high strength at the temperatures typically encountered during cutting leading to high cutting forces and high temperatures in the shear zone which causes plastic deformation of the cutting tool edge. These alloys also contain inclusions of highly abrasive carbide particles (that improve creep resistance) and show a tendency to work-harden which leads to abrasive wear of the tool, particularly at the leading edge and depth-of-cut positions. These alloys appeared to be difficult to machine because of a tendency of the maximum temperature of tool face existing at the tip of the tool. Due to precipitating the hard secondary phase of (Ni_3Nb) during machining, it makes the cutting condition even worse. All these difficulties lead to serious tool wear and less material removal rate (Rahman et al., 1997; Choudhury and El-Baradie, 1998). Welding and adhesion of worked material onto the cutting tool frequently occur during machining causing severe notching as well as alteration of the tool rake face due to the consequent pull-out of coating and tool substrate. For the coated carbide tools, the right selection of the tungsten carbide cobalt alloy for the substrate, the associated coating materials, the coating procedure and the cutting conditions choice are the main problems.

As Inconel 718 works harden rapidly, hawing low thermal conductivity, high strength and high pressures produced during machining cause a hardening effect that makes further machining more difficult. Severe tool injury usually occurs in cutting this material. Rapid tool wear and its influence on surface quality in machining have long been recognized as a challenging problem. Hence careful machining practices are must.

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