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MACHINING OF NICKEL BASED ALLOYS USING DIFFERENT CEMENTED CARBIDE TOOLS

BASIM A. KHIDHIR*, BASHIR MOHAMED

Department of Mechanical Engineering, Faculty of Engineering,
Universiti Tenaga Nasional, Malaysia
*corresponding Auther: basim@student.uniten.edu.my

Abstract

This paper presents the results of experimental work in dry turning of nickel based alloys (Haynes – 276) using Deferent tool geometer of cemented carbide tools. The turning tests were conducted at three different cutting speeds (112, 152, 201and 269 m/min) while feed rate and depth of cut were kept constant at 0.2 mm/rev and 1.5 mm, respectively. The tool holders used were SCLCR with insert CCMT-12 and CCLNR – M12-4 with insert CNGN-12. The influence of cutting speed, tool inserts type and workpiece material was investigated on the machined surface roughness. The worn parts of the cutting tools were also examined under scanning electron microscope (SEM). The results showed that cutting speed significantly affected the machined surface finish values in related with the tool insert geometry. Insert type CCMT-12 showed better surface finish for cutting speed to 201 m/min, while insert type CNGN-12 surface roughness increased dramatically with increasing of speed to a limit completely damage of insert geometer beyond 152 m/min.

Keywords: Cutting tool, Surface roughness, Tool wear, Nickel based alloys.

1. Introduction

Increasing the productivity and the quality of the machined parts are the main challenges of manufacturing industry. Modern cutting tools allow cutting at high speeds, thus increasing the volume of chips removed per unit time and this objective requires better management of the machining system corresponding to cutting tool-machine tool-workpiece combination to go towards more rapid metal removal rate. Exploring higher cutting speed depends to a greater extend on the cutting tool materials [1]. General information on operating parameters employed

Nomenclatures

C_t	Empirical tool life constant
doc	Depth of cut, mm
f	Feed rate, mm
R_a	Surface Roughness, µm
T	Tool life, min.
V	Cutting speed, m/min.

when turning nickel based alloys are available in both academic [2-5] and industrial literature [6, 7]. From the very beginning, development of an adequate predictive theory of the process was of a major concern for all researchers. In relation to machining operations with defined cutting edges, workpiece surface integrity aspects when turning Inconel 718 with coated carbide cutting tools [8, 9]. Due to their high temperature strength and high corrosion resistance, nickel alloys are used for engines for commercial and military aircraft and space engines. It is considered by machinists one of the most challenging areas. This is due to a complex of material properties [10,11], namely low thermal conductivity leading to increased temperatures at the tool point/rake face; work-hardening tendency during machining; high thermal affinity to tool materials resulting in welding/adhesion of workpiece material to the cutting edge; presence of hard abrasive particles (e.g. carbides, oxides) resulting in intense tool wear [12]. The heat generated during a cutting operation is the summation of plastic deformation involved in chip formation and the friction between tool and workpiece and between the tool and the chip [13]. Metallurgical changes, that have improved superalloys making the metal stronger, tougher or more resistant to oxidation or corrosion, have also made these metals more difficult to machine. For the nickel-based superalloys, high temperature characteristics translate directly to machining challenges. The combination of high cutting force and high temperature when machining these materials leads to edge breakdown of the tool through chipping or deformation. In addition, for the majority of these metals, work hardening takes place rapidly. A hardened surface created during machining can result in depth-of-cut-line notching of the tool and may also compromise the fatigue strength and geometric accuracy of the part [18]. Many nickel alloys are age hardenable, meaning that the hardness of the alloy increases dramatically upon heat treatment. As second phase particles form, the alloy becomes stronger and more abrasive, thus more difficult to machine. Therefore, it's preferable to perform machining in the softer state. Typically, it is best to machine parts to near finish dimensions in the solution-treated condition. After age hardening, only a final finishing operation is performed, providing the desired surface finish while minimizing the risk of distortion caused by heat treatment [19]. The geometry of the tool plays a big part in controlling heat. The geometry of the cutting tool must allow for chip removal in order to take the heat out with the chip. Tool geometry should allow for smoother cutting and less vibration and better chip evacuation. In addition, higher rpm and feed rates with shallow depth-of-cut are typically required to maintain chip flow and heat [20-22].

This study intends to investigate the effect of tool holder geometry on cutting performance in terms of tool life and tool wear when machining of nickel-based alloys - 276.

2. Experimental Procedure

The machining tests were performed by single point, continuous turning of nickel based alloys – Haynes 276, specimens in cylindrical form on a conventional turning machine. The workpiece specimens were 300 mm long and 75.15 mm diameter. The chemical physical compositions of the workpiece materials are given in Table 1and 2 respectively.

Table 1. Chemical Composition (wt. %) of Haynes 276.

Ni	Co	Cr	Mo	Fe	W	V	Mn	C	Others
57	**1.62**	**15.44**	**15.34**	**5.43**	**3.67**	**0.41**	**0.52**	**0.004**	**Si < 0.02** **P - 0.005** **S < 0.01**

Table 2. Physical Properties of Haynes 276.

Density	Electrical Resistivity	Dynamic modulus of elasticity	Thermal conductivity	Specific heat
8.89 g/cm^3	**1.3 μΩ–m**	**229 MPa**	**10.2 W/m.K**	**427 J/Kg.K**

Coolant was not used during the tests. Two different grades of cemented carbide cutting tool inserts CCMT-12 and CNGN-12 were clamped mechanically for two rigid tool holders SCLCR and CCLNR-M12 respectively [23]. As far as possible, the tests were carried out in accordance with ISO 3685. Cutting speeds used were 112, 152, 201, and 269 m/min. Feed rate and depth of cut were kept fixed, 0.2 mm/rev and 1.5 mm, respectively. Surface roughness measurement was carried out on the machined surfaces using a Hand–held Roughness Tester TR200 instrument. Three measurements were made on the each surface. The worn cutting tools were also examined under a Philips XL 30 ESEM type scanning electron microscope (SEM).

3. Results and Discussions

3.1. Workpiece surface roughness

Figure 1 shows the workpiece surface roughness values for nickel based alloy. These values are the averages of three readings. All of the tests resulted in higher surface roughness values. These higher surface roughness values can be explained by the highly ductile nature of Nickel based alloys, which increases the tendency to form a large and unstable, built up edge (BUE). The presence of the large and unstable BUE causes poor surface finish.

It is seen from Fig. 2 that cutting speed had a significant influence on the surface roughness produced. These figures show that the highest surface roughness values are observed at 152 m/min cutting speed using CCMT-12 insert and completely damaged surface with totally ending of tool geometry using CNGN-12 after the cutting speed increased above 152 m/min. The general trend in the curves in Fig. 2 for insert type CCMT -12 is that when cutting speed is increased from 112 to 152 m/min the surface roughness values increase slightly and after increasing the cutting speed beyond 152 m/min decrease until a minimum value is reached beyond which they increase but in same figure for insert type CNGN -12 the curve increasing incrementally with increasing the speeds.

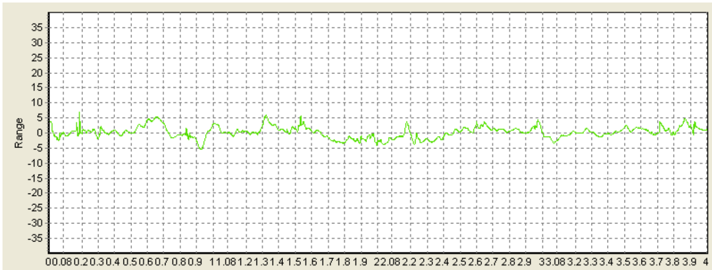

Fig. 1. Surface Roughness Profile Chart, Cutting Speed (*V*=112 m/min), Feed Rate (*f*=0.2 mm), Depth of Cut (doc=1.5 mm), Surface Roughness (R_a =1.509 µm).

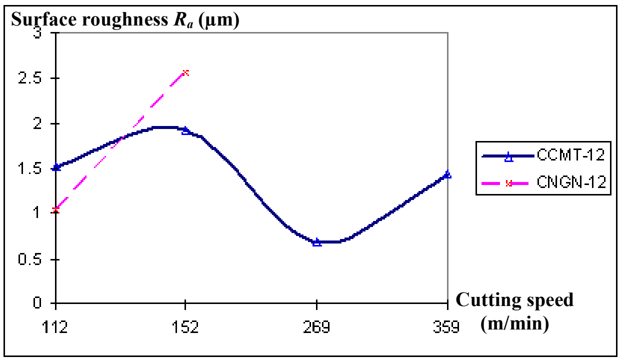

Fig. 2. Cutting Speed vs. Surface Finish for Turning Nickel Based Alloys Haynes -276 Using CCMT-12 and CNGN-12 Inserts at a Feed Rate 0.2 mm/rev and Depth of Cut 1.5 mm.

3.2. Tool wear

The decreases in surface roughness with increasing cutting speed 152 m/min can easily be explained by deferent wears appear in the cutting tool inserts. The worn surfaces of the CCMT-12 and CNGN-12 used to machine the nickel based alloys Haynes-276 workpiece material were examined by The SEM images of the worn cutting edges. It is seen from the images of Figs. 3 (a) to (d) that wear predominantly occurred in two regions during the tests: at the depth of cut line and the nose radius of cutting edge. Wear at the depth of cut line does not have any influence on the machined surface roughness [24]. However, wear at the nose radius of cutting edge directly influences the machined surface roughness since the nose edge is in direct contact with the newly machined surface, Fig. 3(a). In form of nose radius wear for speed 112 m/min with another wear appeared when the speed increased to 152 m/min as a flank wear, Fig. 3(b). In this speed, value of R_a increased due to rubbing of the wear land against the machined surface damages the surface and produce large flank forces which increase deflection and radius dimensional accuracy [25]. Also this could be the effect of chatter or vibration which occurred at this cutting speed, and that explain the increasing of the value of surface roughness with insert CCMT-12 (Fig. 2). When the SEM images in Figs. 3(c) and (d) closely examined, the highest tool wear is seen on the insert type CNGN -12 (Fig. 3(d)) used at the 152 m/min cutting speed compound with highest surface roughness. However, further increasing in the cutting speed increases the extent of tool wear. Furthermore, during chip formation, small fragments break off from the chip and become lodged in the contact area between the workpiece and the tool. Given the high forces in this area, the particles can become pressure welded to the cutting edge. The particles can breakdown the cutting edge, pulling carbide with them to cause rapid tool wear. They can also pick out large pieces of the tool surface to cause flank wear and edge chipping.

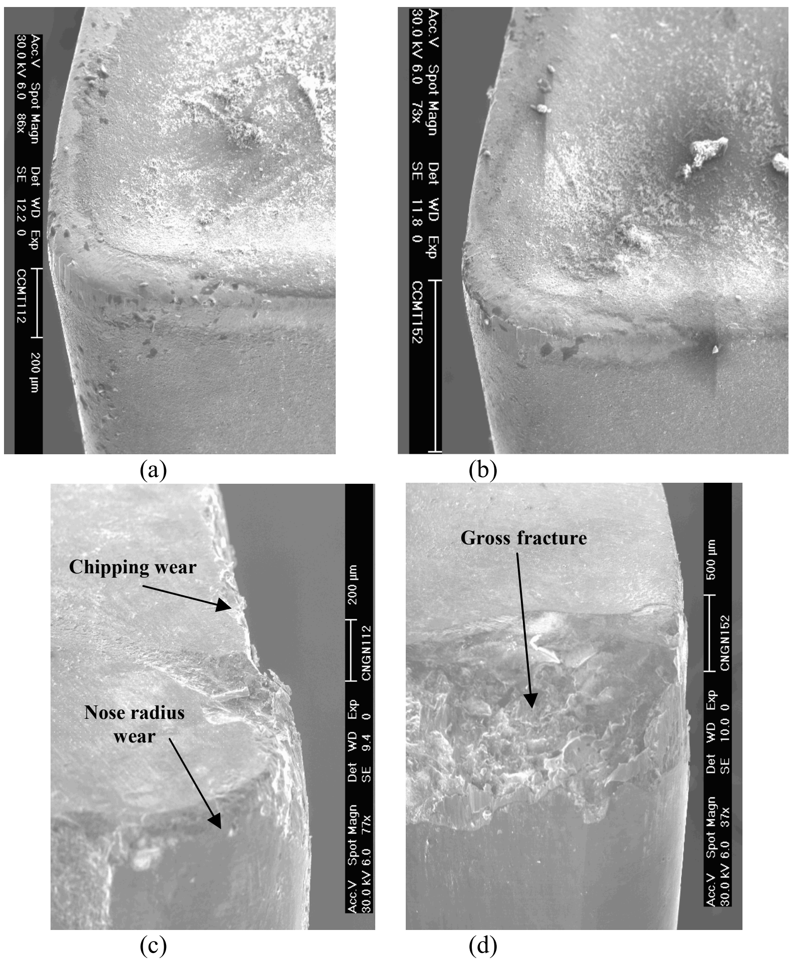

Fig. 3. SEM Images Showing the Wear of the CCMT-12 after Machining Nickel Based Alloys, Haynes-276 at (a) 112 m/min, (b) 152 m/min, and CNGN -12 after Machining Nickel Based alloys, Haynes-276 (c) 112 m/min and (d) 152 m/min Cutting Speeds.

3.3. Tool life

Tool life is often the most important practical consideration in selecting cutting tools and cutting conditions. Tool wear and fracture rates directly influence tooling costs and part quality [25]. An understanding the tool life requires an understanding of the ways in which tools fail. Tool life improvement is essential to reduce the cost of production as much as possible. Cutting tools have a limited life due to inevitable wear and consequent failure, and avenues must be found to increase tool life, the critical parameter of the cutting process. Cutting tools fail either by a gradual and progressive wearing of its edge or due to chipping or plastic deformation [26]. Usually the tool life criterion is defined as a predetermined threshold value of cutting tool wear. Clearly, any development in tool or work material increasing tool life will be beneficial. Continued efforts are being made to find ways of using cutting tool to the greatest possible extent before they fail. The most widely used tool life equation is the Taylor tool life equation which relates to the tool life T in minutes to the cutting speed V through an empirical tool life constant C_t:

$$T^n = C_t/V$$

When cutting speed increasing the tool life decreasing consequently. Figures 4 (a) and (b) shows deferent kind of wears in cutting edge for Insert type CCMT-12 as Chipping wear and gross fracture for deferent cutting speeds 201 and 269 m/min, respectively. Figure 4(a) in spite of chipping but the tool still usable [25] and the surface roughness value was the lowest for the same cutting length of Fig. 2, but when increasing cutting speed the surface roughness increase dramatically with totally ending the tool life.

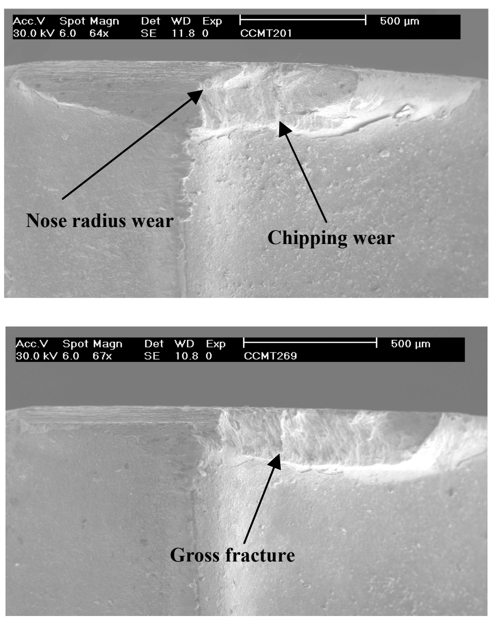

Fig. 4. SEM Images Showing the Wear of the CCMT-12 after Machining Nickel Based Alloys, Haynes-276 at (a) 201 m/min, (b) 269 m/min.

4. Conclusions

Turning tests were performed on nickel based alloys Haynes-276 using two different inserts of cemented carbide cutting tools. The influences of cutting speed, tool inserts type and workpiece material were investigated on the machined surface roughness. Based on the results obtained, the following conclusions can be drawn:

- Insert types was found to have a majority effect on the machined surface roughness.
- Cutting speed was found to have a significant effect on the machined surface roughness values.
- Nose radius wear cutting edges, evidenced by the SEM examinations, were found to be responsible for the surface roughness values.
- Higher surface roughness values as a result of gross fracture cutting edge geometry at higher cutting speeds.
- Increasing cutting speed beyond 112 m/min ending tool life for insert type CNGN -12, while for insert type CCMT -12 the limit of cutting speed increases for the same cutting condition beyond 269 m/min.

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