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An experimental investigation of the effect of coating material on tool wear in micro milling of Inconel 718 super alloy

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ABSTRACT

In this study, milling of the 718 nickel super alloy in micro conditions and the effect of coating material on tool wear are investigated. Within this context, coated and uncoated WC-Co micro milling tools were used for cutting experiments under dry and lubricated (minimum quantity lubrication, MQL) conditions. Tool wear occurred on the micro end mill, and the change in radius of the cutting tool and the side-edge radius were determined in accordance with the processed slot geometry. The results obtained showed that the cutting tools coated with AlTiN, TiAlN+AlCrN, and AlCrN displayed better performances compared to those coated with TiAlN+WC/C and DLC. In addition, DLC and TiAlN+WC/C coated tools showed better performance against built-up edge (BUE) formation. Furthermore, the MQL method used during the cutting process significantly reduced the decrease in the radius.

1. Introduction

Miniaturized products in the dimension of a few micron to a few millimeter, has increased dramatically over the last decade in the fields such as medical, transportation, bioengineering, microelectronics environmental, and communication industries [1]. There are different techniques (micro-layered manufacturing, micro-laser processing, micro-electro discharge machining, microforming and micro mechanical machining) for manufacturing of miniaturized parts. Micro mechanical machining is derived from conventional machining process by downscaling the cutting tool sizes which should lie within the range from 1 to 1000 μm [2,3]. There is a substantial increase in the specific energy required with a decrease in chip size during machining [4].

Due to the capacity of nickel alloys to preserve their mechanical specifications in higher temperatures, they are widely utilized in important fields of industry. Today, these materials are being used in gas turbines, the aviation industry, nuclear reactors, and many applications where high temperatures are used [5,6]. Although these materials are widely preferred, their machinability is not at the desired level. Thermal and mechanical properties of the nickel alloys limit the machinability of these materials. The high resistance of the material, deformation hardening, which occurs during processing and a low thermal conductivity coefficient affects the tool negatively during the cutting process [7]. In order to solve the problems which are encountered during the machining of these materials, researchers have come up with several suggestions. The most significant of these solutions is coating of the cutting tool. According to some researches, materials which are difficult in cutting are more easily machining with the development of coating technology. The hardness values of the coatings, low friction coefficients, and thermal specifications affect the processing performance positively. Therefore, the usage life of the tool, which directly affects the cost of machining and product quality, has been increased [8]. Among the studies conducted within this context, Derrien and Vigneau [9] reported that TiN coated cutting tools have a higher corrosion resistance and a better surface quality compared to uncoated carbide tools.

In conventional machining, it can found a lot of studies that focused on optimizing the cutting conditions of Inconel 718. For this purpose, the performance of different coating materials has been investigated for longer tool life [10]. In addition, Gatto and Iuliano [11] examined the performances of CrN and TiA1N coatings in the processing of super alloys. As a result of their study, the researchers stated that the characteristics of the coatings protect the main layer of the tool from the high temperature that occurs during the milling process. In another study, CrN and TiA1N coatings were compared, and the corrosion resistance of the CrN was observed to be lower than that of the TiA1N coating. The reason for this situation was found to be the low hardness

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value of the CrN coating. In addition, it was also stated that this material was more interactive with Inconel 718 material [12]. The aim of the nano-layers was to give the milling tool an extended tool life. When the TiN/AlTiN and CrN/TiN nano-layer coatings were compared to an uncoated tool, high corrosion endurance and resistance against chip adherence could be observed [13].

The concept of tool wear in the micro milling process generally differentiates it from the conventional milling process. Hard materials, which are particularly used in micro pattern manufacturing, lead to very short tool life. Failures affecting the tool life in micro milling proccesing are generally shown as abrasive wear, chipping on the cutting surfaces, fatigue, and fractures due to overstress [8]. Another study carried out to determine the failure mechanisms of micro-end-mills were studied during the machining of aluminum, graphite electrodes and mild steel workpieces [14]. In this study, the cutting force variation was monitored, i.e. the relationship between the utilization-related changes at the tool wear. Inspection of the cutting force variation patterns indicated that tool failure occurs with chip clogging, fatigue and wear-related excessive stress. The effects of the cutting parameters due to the size of the process also vary compared to the conventional milling process [15,16]. Particularly in cases where the edge radius is very small compared to the chip thickness, a uniform chip formation is not observed. This situation leads to an increase in the cutting forces that affect the cutting tool [17].

Coating of the micro milling tool helped to solve the current problems encountered regarding the tool life. In the studies conducted, it was observed that due to the high corrosion resistance, both TiAlN and diamond coatings were particularly preferred for the micro milling processes [18,19]. Due to the superior mechanical properties provided by the diamond coatings, they stand out as the most commonly preferred coating types in recent years. Their high hardness values significantly reduce tool wear during the metal cutting process. Additionally, they have a low friction coefficient which reduces the cutting force and heat occurrence during the milling process. In addition, the chemically stable structure of diamond coatings is significant in preventing chip adherence during the cutting process [20,21]. Along this, in several studies regarding different coating compositions, TiN, TiCN, TiAlN, CrN, and CrTiAlN coatings were used [22,23]. Aramcharon et al. [23] compared the performances of TiN, TiCN, TiAlN, CrN, and CrTiAlN for the milling of steel. The results obtained showed that the performance of the TiN coating was better in terms of corrosion and the quality of the machined surface than that of the uncoated tools and other coated tools.

In this study, micro milling experiments were carried out to investigate the effect of coating in the machining of Inconel 718 nickel alloy. The most important difference of this study, in contrast to the studies considered above, is that it is focusing on wear behavior of single layer (DLC, AlTiN and AlCrN) and multi-layer (TiAlN+AlCrN and TiAlN+WC/C) coated micro cutting tool. Additionally wear mechanisms and effect of reduction of tool diameter/edge radius increasing on machined slot geometry were discussed. Micro milling tests were carried out under dry cutting conditions. Also, the Minimum Quantity Lubrication (MQL) method was used to investigate the effect of lubrication on tool wear of the AlCrN coated tool. The decrease in diameter and change in radius are investigated in each milling tool with identical cutting lengths.

2. Materials and method

Inconel 718 nickel-based super alloy is used in leading fields of industry (aviation and aerospace, medical, etc.) and because of its prominent superior mechanical properties was chosen as the work material. For the cutting experiments, an ultra-fine grain carbide tool, 768 μm in diameter, of K20-K50 quality (Table 1), and a micro end mill with coatings of different compositions (TiAlN+AlCrN, DLC, AlTiN, TiAlN+WC/C, AlCrN) was used.

Tables 2 and 3 give the geometrical information of the cutting tool. In addition, Table 2 presents some characteristic features of the coatings. The cutting parameters were 20,000 rev/min (Vc=48 m/min), a feed rate of 1.25, 2.5, 3.75, and 5 μm/flute, and cutting depths of 0.1, 0.15, and 0.2 mm. During all the cutting experiments, a constant cutting length of 120 mm was considered (Fig. 1). As a result of the cutting process carried out with each cutting tool, the wear types and mechanisms were analyzed by scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX). Additionally, decreases in terms of the diameter of the tool were evaluated along with the changes in the slot geometry.

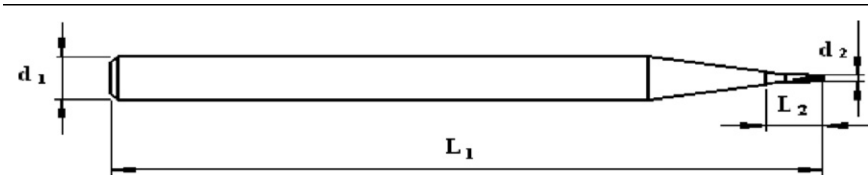
Table 1
Some mechanical properties of WC-Co.

Type	Grain size (μm)	Density (g/cm^3)	Hardness (HV_{30})	Transverse rupture strength (MPa)	Compressive strength (MPa)
K20-K50	0.4	14.2	1680	4300	6500

Table 3
Some characteristics of the coatings used.

	Hardness (HV 0,05)	Friction coefficient	Oxidation temperature (°C)	Coating thickness (μm)
AlCrN	3200	0.35	1100	1.8
AlTiN	3300	0.4	900	3
DLC	2500	0.1–0.2	350	1
TiAlN+AlCrN	3300	0.35–0.4	1100	0.8
TiAlN+WC/C	3000	0.15–0.2	800	1.1

Table 2
Geometrical information on micro mill ends used in the experimental study.



d_2 (mm)	d_1 (μm)	L_1 (mm)	L_2 (mm)	Cutting flute number
4	768	47	1.6	2