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Surface texture characterization and chip morphology in ball nose end milling process of Inconel 718 for turbine blades

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ABSTRACT – Surface texture and chip morphology, during end milling of Inconel 718 were investigated. Due to the complexity of the milled surface profile, variation in gap was detected on the spiral profile. The maximum gap was found to be at the centre of the cutter path and attenuated towards the edge of the cutter path, which possessed a lower surface roughness (Ra) value. Studies shows that the frequency of dislodged chips were affected by notch wear. Severe tool damage occurred was noticed when the accumulated chips welded on the cutting edge greater than 5 pieces.

1. INTRODUCTION

Aerospace industry is the highly upcoming sector with new materials were chosen for the best mechanical properties. The nickel based super alloy, Inconel 718 exhibits best characteristic make it the choice of material with its outstanding characteristics and for the aerospace industry [1].

Fabrication of aerospace parts requires high accuracy with good surface finish. Surface roughness are geometrical measures of surface quality and main criteria for the acceptance of the finished component. In the machining of Inconel 718, [2] reported that the common surface anomalies identified were material drags, white layers, scoring and plucks. Surface roughness is very critical for the machining due to the dependent effect of cutting conditions (feed, cutting speed, depth and width of cut); process kinematics; cutting tool geometry and material orientation; mechanical properties of the machined material; vibrations in the machine tool system; as well as the precision and rigidity of the machine tool and work piece as discovered by [3]. Whitehouse (2011) stated that the complex motion rotational and linear in milling process cause the variation is also observed in the measured surface roughness [4].

Due to the geometry of a ball nose cutter, the machined part will display crescent features or scallop height, which are affected by the feed and pick ratio. [5] reported that that an increases in scallop height is due to an increase in feed rate or the width of cut.

This paper presents a study on the effect of milling parameters and cutting tool wear modes on the surface roughness and chip formation behaviour of aged Inconel 718 when high speed end milling with ball nose PVD coated tools. The issues are analysed in their milling parameters; which are surface roughness and chip morphology.

2. EXMPERIMENTAL PROCEDURES

Machining experiments were performed on a DMC 635V Eco DMG ECOLINE vertical milling machine under MQL at a rate of 20 pulses/min to produce 50 ml/hr. The work material used for the experiment was a 160 × 100 × 50 mm block of aged Inconel 718 AMS 5663 (42 HRc). The chemical composition of the material used was 53% Ni, 18.3% Cr, 18.7% Fe, 5.05% Nb, 3.05% Mo, 1.05% Ti, 0.23% Mn, and C balance (all weight percent). The machining process was conducted with four main cutting parameters; cutting speed (Vc), feed rate (fz), depth (DoC) and width of cut (WoC). The PVD TiALN/CrN insert was a 16 mm diameter ball nose end mill. Four different settings of cutting parameters with three levels were set in this experiment; Vc 100-140 m/min, fz 0.1 – 0.2 mm/tooth, ap 0.5-1.0 mm and ae 0.2-1.8 mm.

3. RESULTS AND DISCUSSION

3.1 Surface roughness

The experimental results showed that end milling using a ball nose can obtain a better surface finish. The roughness of the milled surfaces was found to be between 0.173–0.3 μm, less than the 0.5 μm which is equivalent finish with manual polish.

The influence of feed rate on the surface roughness can be seen during end milling. The cutting test data shows that the surface roughness increases with an increase in feed rate; However, the profile of the milled surface is complex; some variations in gap distance on the spiral profile were detected (Figure 1). The rotational and linear cutter motion causes inconsistent topology profile. Therefore, it was found that the average deviation of Ra value falls within ± 38%. It was common for a variation in the Ra value to be at 40% during milling process as reported by [23]. It was found the maximum gap of the cutter mark was in the middle of the cutter path. The gap reduces and is more attenuated towards the edge of the cutter path. This is because of the reduction of feed groove size and the accumulating swept material causing smearing at the path edge as exhibited in Figure 2.

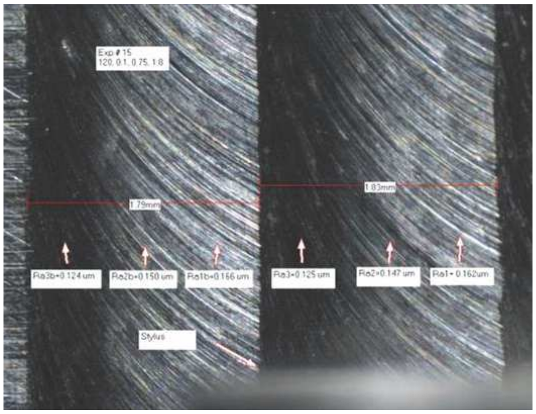

Figure 1 SEM Micrograph of roughness that vary at different locations of cutting path.

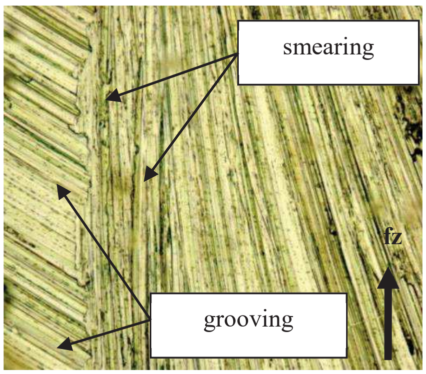

Figure 2 Smearing and grooving occur along cutter locus those effects on Ra reading (20 x).

3.2 Chip formation

The chip was formed due to the shearing action during tool-work piece engagement that shown by lamella shape (corrugated rough surface). The chip generated was in a fragmented form due to an intermittent cutting action during machining. It was thicker at the leading edge (start of cutting) and decreasing towards the trailing edge (end of the peripheral milling cut).

During the initial stage of machining when the cutting edge was in a good condition, chip disposal was in an elemental form. In the absence of notch wear near the DoC line due to the combined effect of mechanical impact and thermal shock, the chip adhered as notch wear occurred and accumulated with the new chip. This welded chip then was dislodged from the cutting edge after several tool rotations. The amount of trapped chip depended on the size of notch wear. At VB_3 = 0.20–0.30 mm, the number of accumulated chips, n, was observed to be between 2–4 pieces, which occurred alternately with loose chips. It indicates moderate notch wear, where the cutting tool is still able to withstand the milling process. As the VB_3 reaches more than 0.3 mm, the number of welded chips increased (n>5) and departed more frequently in the shape of anise-likes (Figure 3). The tool could be used momentarily and soon failed, especially when an audible noise was emitted, with smoke clearly visible from the flying chip and a burnish colour appearing on the back of the chip.

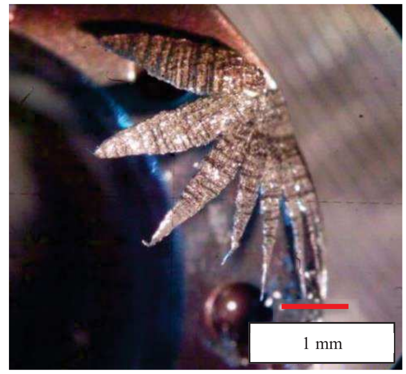

Figure 3 Incomplete segmented anise-like chips appearing during machining, indicating the end of tool life.

4. CONCLUSION

Surface roughness value is complex in milling; the feed mark was weakened on the milling profile; the variation in Ra can be seen. The gap between uncut surfaces in the feed direction is controlled by the feed rate, while the distance between the path intervals that expose the uncut surfaces in the feed direction is determined by the WoC.

The formation of chips can be associated with the tool's condition. When the cutting edge is in good condition, the chip is released in fragmented form. On the other hand, joined chips were generated as notch wear occurred. The number of accumulated welded chips is related to the severity of notching.

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