Archives of Materials Science and Engineering

Volume 39
Issue 1
September 2009
Pages 38-44

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

A study of minimum quantity lubrication on Inconel 718 steel

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Received 28.01.2009; published in revised form 01.09.2009

ABSTRACT

Purpose: Maching of difficult to cut materials like Inconel 718 is a difficult task. The purpose of the research was to machine Inconel 718 nickel based material by milling process applying vegetabled oil by minimum quantity lubrication (MQL). MQL helps to use limited supply of coolant in order to minimise waste and it is environmental free.

Design/methodology/approach: The experiments was carried in a vertical milling machine with super hard cobalt tool. The experiments were carried by various cutting parameters like cutitng speed, feed rate and constant depth of cut. The MQL considered was 12.5, 25 and 37.5 milli litre per hour (ml/hr). The MQL was vegetable oil used for cooking purpose. The experiments were with on MQL and dry milling.

Findings: The supply of 37.5 ml / hour produced low surface roughness than 12.5 and 25 ml/hr. As the length of time was increased, the surface roughness increased due to tool wear. The surface roughness was affected by 32.65 % and tool wear affected by 29.2 % between low and high supply of MQL. The super cobalt tool has given more life by MQL than dry milling. The cutting speed of 20 and 30 m/min produced more flank wear than by 10 m/min for the same feed rate and given depth of cut.

Research limitations/implications: There was no formation of built up edge at tool due to reduction in the heat and flushing of the chips away from the tool edge. The MQL can able to subsidize the heat generataed.

Originality/value: The originality of this paper lies with conducting experiments and finding optimum operating parameters. The other researches can have this as reference

Keywords: Wear resistance; Inconel 718; Surface roughness; MQL

Reference to this paper should be given in the following way:

S. Thamizhmanii, Rosli, S.Hasan, A study of minimum quantity lubrication on Inconel 718 steel, Archives of Materials Science and Engineering 39/1 (2009) 38-44.

MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Minimum quantity lubrication (MQL) is based on the principle that a drop of liquid is split by an air flow, distributed in streaks and transported in the direction of flow of air. In MQL machining, a small amount of vegetable oil or biodegradable synthetic ester is sprayed to the tool tip with compressed air. The consumptions oil in industrial applications are in the range of approximately 10 - 100 ml per hour [1]. In machining, conventional cutting fluid application fails to penetrate the chip-tool interface and thus cannot remove heat effectively. The high pressure jet of soluble oil, when applied at the chip-tool interface, could reduce cutting temperature and improve tool life to certain extent [2-3]. MQL is assisting on the economical front. The present work experimentally investigates the role of MQL on surface roughness, tool flank wear in end milling Inconel 718 at different speed combinations by high speed super cobalt tool. As the length of machining was increased wear by the tool increased. MQL consists of a mixture of pressurized air and oil micro-droplets applied directly into the interface between the tool and chips. However, the question of how the lubricants can decrease the friction under very high temperature and loads is still not answered especially for long engagements times. MQL decreased the contact length compared to dry cutting for both short and long engagement time. MQL machining is nearly equal or often better than the traditional wet machining in tool life and surface finish when cutting steels and aluminum alloys [4].

2. Experimantal procedure

The work piece was Inconel 718 cut from 250 x 250 x 500 mm size material and reduced to 45 x 45 x 225 mm. The end milling cutter used was super hard cobalt tool having four flutes. The operating parameters were 10, 20, 30 m/min with constant feed rate of 0.15 mm/tooth and constant depth of cut of 0.40 mm. The MQL flow was 12.5 ml/hr, 25 ml/hr and 37.5 ml/hr. The lubricant used was vegetable sunflower seed oil for cooking purposes. The machine used was MAZAK C.N.C. milling. The surface roughness was measured using Mitutoyo SJ 400 tester and tool flank wear were measured by tool makers microscope. Figure 1 shows MQL instrument used in milling. The experiments were conducted by dry and MQL with same operating parameters. MQL 12.5 ml per hour operated at cutting speed of 10 m/min, 25 ml per hour at 20 m/min and 37.5 ml per hour at 30 m /min.

Fig. 1. MQL unit used in High Speed Milling

2.1. Inconel 718 material

Inconel 718, which is a nickel based super alloy and different from other alloys, has been widely used in the aircraft, in particular in the hot section of gas turbine, due to their high temperature strength and high corrosion resistance and nuclear industry due to its exceptional thermal resistance and the ability to retain its mechanical properties at elevated temperatures over 700° C. [5-6]. Inconel 718 also used in medical equipments, eg. dentistry uses, prosthetic devices, space vehicles, heat treating equipments, nuclear power systems, chemical and petrochemical industries, pollution control equipments, and coal gasification and liquifaction systems [7]. Nickel based alloys are classified as difficult to cut material due to its their high strength, work hardening tendency, highly abrasive carbide particles in the micro-structure, strong tendency to weld and form built up edge (BUE) and low thermal conductivity [8-9]. They have a strong tendency to maintain their strength at the high temperature that is generated during machining [9]. The chemical and meachnical properties are shown in the Tables 1 and 2 respectively.

Table1.
Chemical composition of Inconel 718

C	Mn	Si	Cr	Ni	Co	Mo	Nb +Ta	Ti
0.04	0.08	0.08	18.37	53.37	0.23	3.04	5.34	0.98

Table 2.
Mechanical properties of Inconel 718

Yield Stress (MPa)	Tensile stress (Mpa)	Strauin (%)	Elastic molulus (Gpa)	Thermal Conductivity (W/m.K)	Density (kg/m3)
1110	1310	23.3	206	11.2	8470

2.2. Advantages of MQL

Minimum Quantity Lubrication (MQL) has many advantages compared with traditional wet machining and dry machining. Many researches have suggested that MQL shows potential competitiveness in terms of tool life, surface finish and cutting forces in turning, milling, drilling, reaming and taping. The advantages of MQL application on machining operations are:

- Provides lubrication on machines set up for flood or high-pressure, high-volume coolant delivery and recovery,
- Reduces mist and spray, therefore, offering an attractive alternative on unenclosed machines like a typical tool room mill or lathe,
- Reduces or eliminates problems associated with thermal shocking of the cutting tool,
- MQL technique produces a significant role in terms of reducing cutting temperature between tool-work piece interfaces.
- MQL can reduce the corner and flank wear more effectively than a solution type of cutting fluid,
- Particularly well suited for tools and operations either generated heat or abrasion to the flank of the tool is the major players to tool failure,
- Reduces both cost of buying and disposing of conventional cutting fluid if all operations can be run with MQL.

3. Results and discussion

3.1. Surface roughness

When machining austenitic stainless steel (difficult to cut materials), smalller feed rate, low surface roughness value can be achieved [11]. Surface roughness is quantiable attributes on a machined surface. The surface roughness plays wider role on the performance of a product. Bad surface make performance vulnerable and product fail well before the expected life. In general, low surface is possible with high cutting velocity, low feed rate without considering any wear that are likely to occur during machining. A surface property such as roughness is critical to the function – ability of the machined components and this is increasing component functionability [12-13]. Many researchers have conducted experiments to determine the effect of parameters such as cutting speed, feed rate, nose radius and depth of cut as the principal parameters on surface roughness and tool wear in hard turning [14-15]. Kamata and Obikawa [1] reported that when the cutting speed was increased to 1.5 m/seconds, the tool lives were drastically shortened. The increase in the quantity of lubricant impoved the tool life. Figure 2 shows the surface roughness against length of milling at 12.5, 25 and 37.5 ml per hour. The surafce roughness value was 0.22 µm for 225 mm length. At 550 mm of length of cutting, surface roughness was 0.23 µm. As the length of cutting was increased, there were increase in surface roughness and it was not consistent. As the length of milling continued, surface roughness was increased at 12.5 ml / hour. It shows that 12.5 ml / hour was not enough to cool the cutting edge and control the wear. The supply of MQL at 25 ml / hour, the surface roughness decreased and was less than 12.5 ml / hour. Low surface roughness obtained at 37.5 ml / hour in all length of milling due to less wear and MQL has reduced the heat at cutting zone. When MQL supplied at 12.5 ml per hour, for length of 3.6 metre and surface roughness was found as 0.44 µm at the end of milling. When supply of MQL increased to 25 ml per at cutting velocity of 30 m/min, surface roughness value was 0.62 µm for the same length as that of 12.5 ml per hour. As the length of milling was increased from 225 mm in multiples of 225 mm, increase or decrease in values were noticed. At the end of 3.60 metre, surface roughness was 0.62 µm. Initial surface roughness value was 0.23 µm at 225 mm length of miliing at 37.5 ml / hour. When experiment concluded at 3.6 metre, roughness was 0.48 µm. When MQL supplied at low rate, the surface roughness values were 0.22 µm at beginning and increased to 0.44 µm at the end of milling. The surface roughness at 25 ml / hour for 30 m/min cutting speed, the initial values was 0.38 µm and obtained a value of 0.62 µm at 3.6 metre milling. The MQL supplied at 37.5 ml per hour at cutting speed of 30 m/min, surface roughness was 0.48 µm at the end of 3.6 metre. There was a difference of 0.18 µm between 12.5 and 25 ml / hour on surface roughness for 3.60 meters length of milling. The difference between 25 and 37.5 ml / hour was 0.14 µm. MQL at 37.5 ml per hour produced low surface roughness than 25 and 12.5 ml per hour. This was due to less wear by cutting edge at high supply of MQL. The surface roughness by dry milling at three cutting speeds were high than MQL milling. Figure 4 shows surface roughness by dry cutting.

3.2. Flank wear

Ezugwu et al [16] investigated the performance of multi-layer coated carbide tools in the machining of martensitic stainless steel without coolant, and found that the predominance failure modes at higher speed conditions were significant nose wear and chipping / fracture of the cutting edges. Several cutting tool wear have been developed taking into account the qualitative and quantitaive effect of their cuases. Wear of the cutting tool edges take place in the complex conditions caused, among others by the mutual interactions of the mechanical and factigue wear, and plastic strain, as well as pehnomena connected with the adhesion, thermal and diffusion oxidation [17]. The flank wear were formed by continuous rubbing of the work material with cutting edges. The extent at which the wear occur is depend upon so many factors such as operating parameters, work material hardness, stability of the machine especially while machining tough materials like Inconel 718, titanium, hard martensitite stainless steel, coolant, properties of cutting edges and low thermal conductivity of materials etc. The low thermal conductive material is tougher to machine due to less softening effect of the work materials. The tough materials wear the cutting tool faster than others due to the presence hard carbides and martensite structure. There would be initial flank wear at the beginning of the machining. This was attributed to very sharp cutting edge. Once the wear started and faster wear takes place or delayed wear would occur. The supply of coolant plays an important role on the tool wear. MQL is sufficient to cool the work material and also the cutting edges. The coolant at 12.5 ml / hour may not able to flush away the chips.

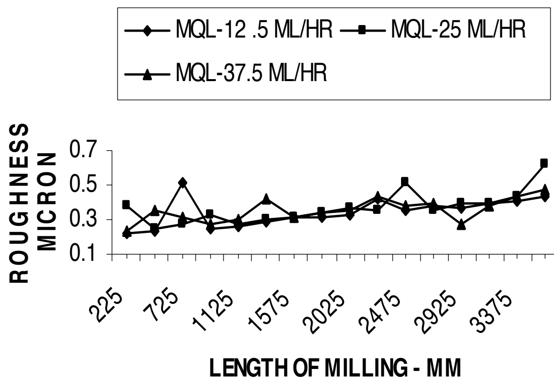

Fig. 2. Length of milling Vs roughness

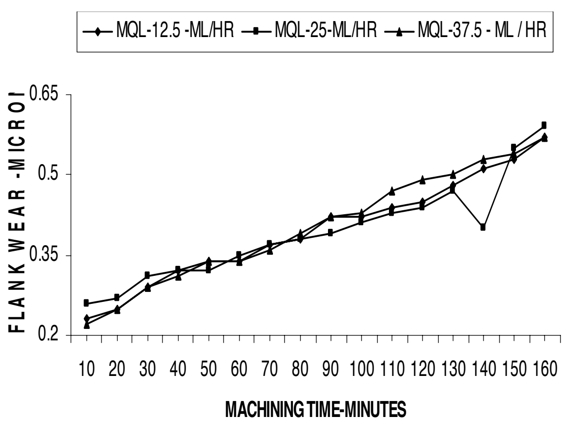

Fig. 3. Length of milling Vs flank wear

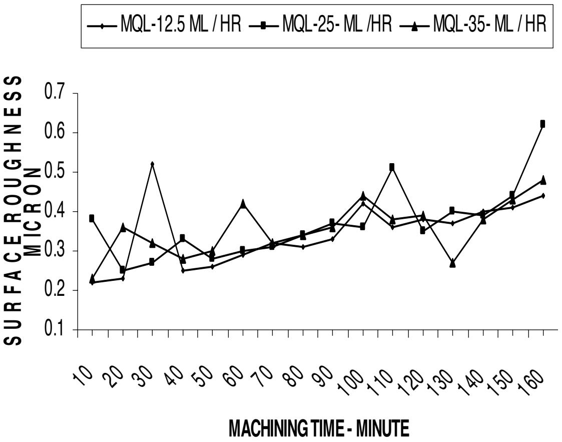

Fig. 4. Length of milling Vs surface roughness -dry milling

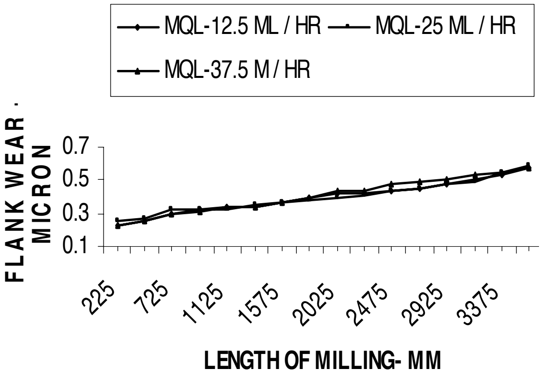

Fig. 5. Milling time Vs flank wear –dry milling

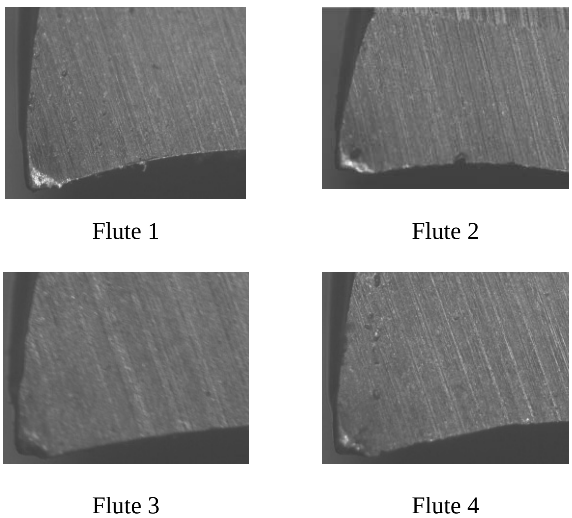

Fig. 6. Flank wear –dry milling – cutting speed 10 m/min for 10 min

Figure 3 shows the length of milling Vs flank wear by dry process.As the machining time and length was increased, there were an increase in flank wear than crater wear. Figure 5 shows flank wear by dry cutting and Figure 5 for flank wear by MQL. The heat generated at tool edge would have softens the cutting edge and flank wear increreased by dry milling. When the milling length increased in multiples of 225 mm, there were corresponding increase in the flank wear. The increase in the flank wear was inconsistent.

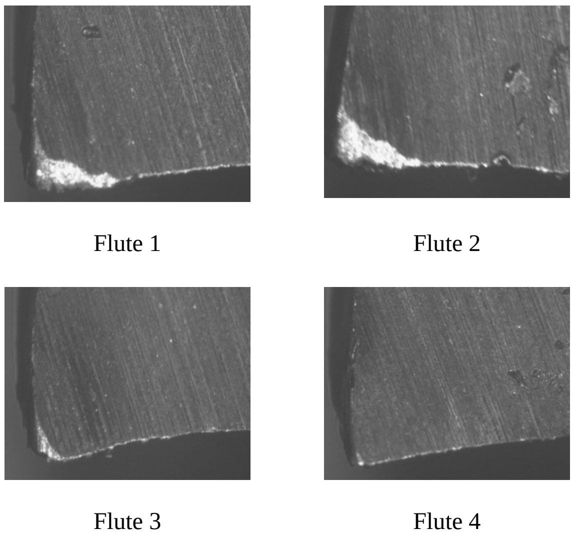

Fig. 7. Flank wear under dry cutting for 50 minute at cutting speed of 20 m/min for 50 min

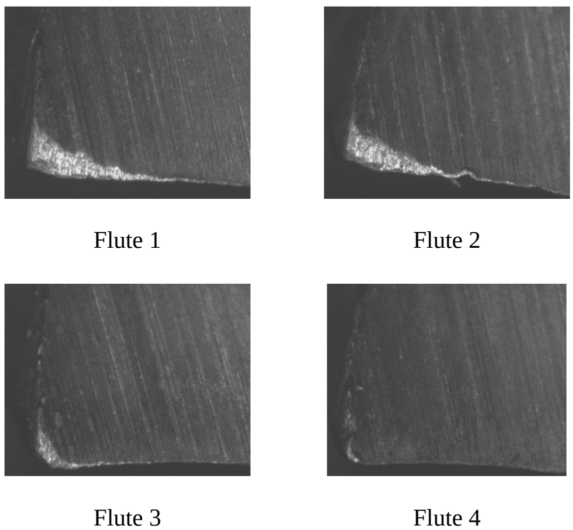

Fig. 8. Flank wear dry cutting at cutting speed of 10 m/min for 90 min

Figure 6 shows flank wear on each flute at cutting speed of 10 m/min. for 10 min.by dry cutting. Formations of flank wear is just formed. When the cutting speed increased to 20 m /min. and machined for 50 min.more flank wear formed and there were differences between flute. This is shown in the Figure 7. Figure 8 is the flank wear formed with cutting speed of 10 m/min and 20 m/ min. The formations of flank wear was not uniform due to the machining and contact in the work material.

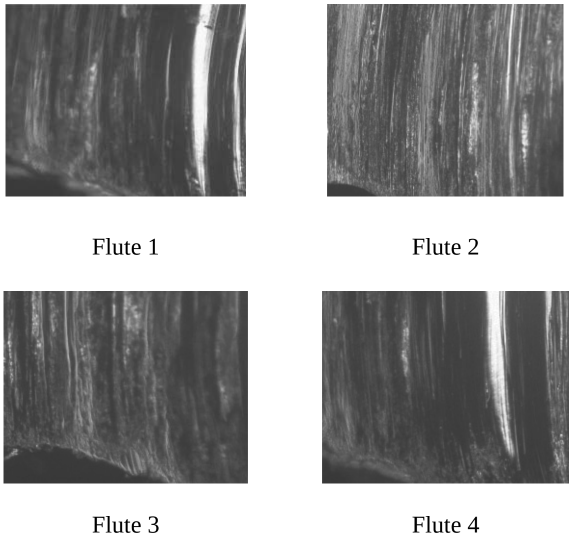

Fig. 9. Flank wear under dry cutting for 10 minute at cutting speed of 20 m/min

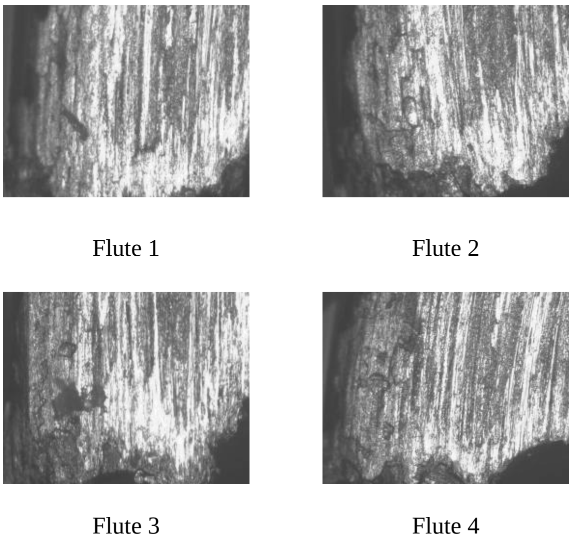

Fig. 10. Flank wear under MQL cutting at cutting speed of 30 m/min

Figure 9 is the formation of flank wear at 90 min at cutting speed of 10 m/min. As the length of milling was increased, the flank wear formation was high with respect to time.

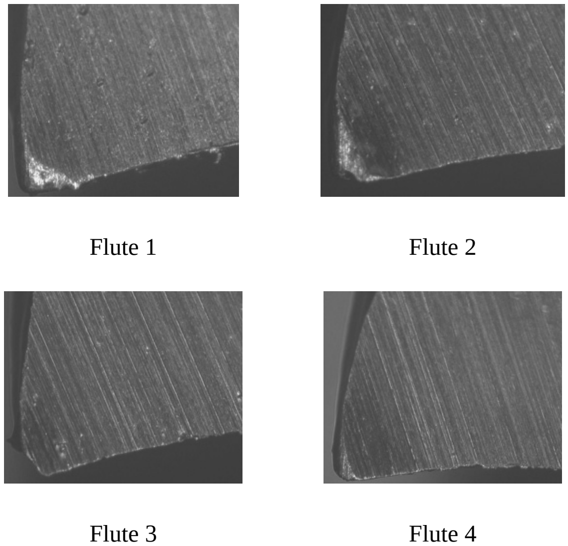

Fig. 11. Flank wear under MQL at cutting speed of 10 m/min for 10 min

Figure 10 is the flank wear formed by dry cutting at 30 min.for 20 m/min cutting speed. The milling time increased with cutting speed, flank wear increased and formation of flank wear between flutes are not consistent. Figure 10, 11, 12, 13, 14, 15 and 16 with different cutting speeds for various milling time.

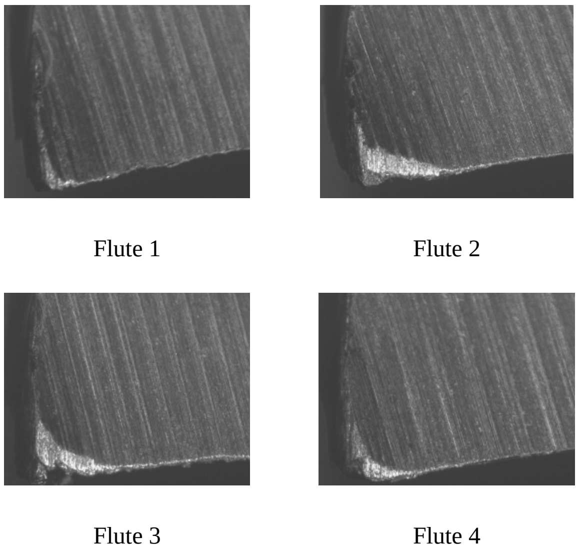

Fig. 12. Flank wear under MQL cutting at cutting speed of 10 m/min 10 min

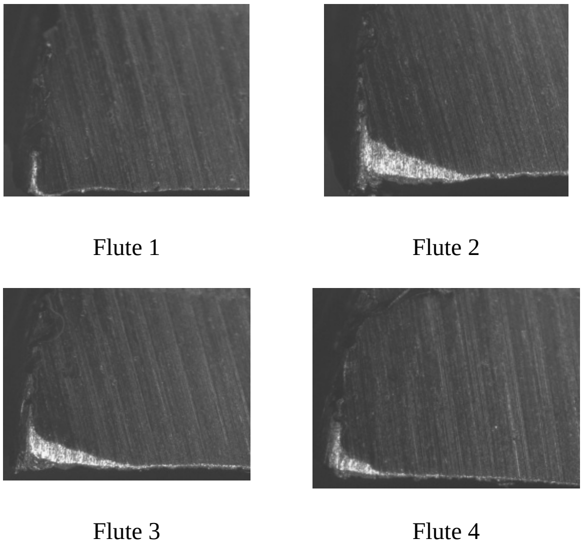

Fig. 13. Flank wear under MQL machining at cutting speed of 10m/min for 90 min

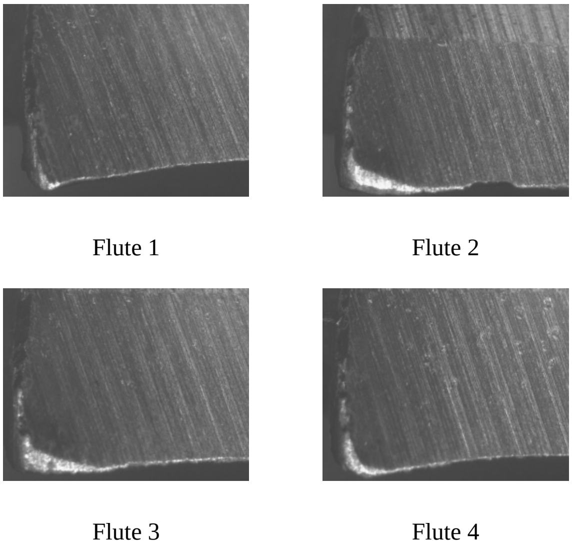

Fig. 14. Flank wear under MQL machining at cutting speed of 10 m/min for 120 min

When the length of time increased, MQL supply at cutting zone have different effect as shown in the Figure 15 and 16 whatever be the supply of coolant.

4. Conclusions

MQL technique offer better results than by dry cutting in terms of surface roughness. The total length of travel by super cobalt cutting tool in MQL condition is higher than that in dry cutting. The end milling process of Inconel 718 with cutting speed of 10 m/min and 20 m/min results in worse machining characteristics both in dry and MQL milling. MQL does not contribute any significant results when milling with low cutting speeds. Super alloy tools show good performance on surface roughness at 30 m/min by MQL than dry milling. There was improvement in surface roughness at 37.5 ml/ hour MQL supply than 12.5 and 25 ml per hour. The flank wear by 37.5 ml / hour by MQL was low. The tool life was increased by 43.75 % by MQL than dry cutting. It is no doubt that dry milling has increased surface roughness and flank wear with all cutting speeds. Beyond the cutting speed of 30 m/min. there would be increase in flank wear and surface roughness.

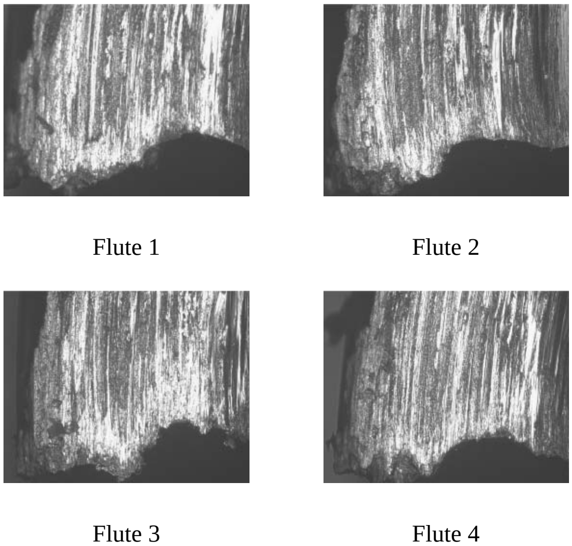

Fig. 15. Flank wear at cutting speed of 20 m/min. with MQL

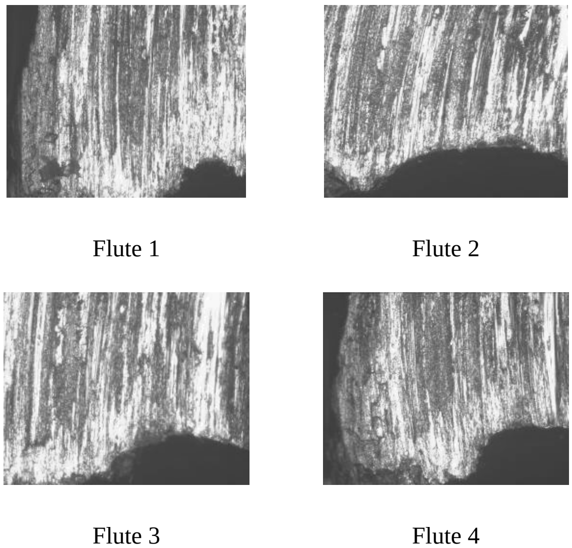

Fig. 16. Flank wear at cutting speed of 30 m/min.with MQL

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