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Exploration of Ti6Al4V surface grinding under dry and MQL environments

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ABSTRACT

Nowadays the use of sustainable/environment friendly methods are rising in surface grinding process. In this work, the surface grinding of Ti-6Al-4V alloy with cubic boron nitride (CBN) grinding wheel under dry and minimum quantity lubrication (MQL) environment was performed. Experiments under MQL condition enhanced the overall grinding performance in terms of surface roughness and tangential cutting forces. Efficient lubrication under MQL environment due to presence of high anti-oxidation mono-saturated fatty acid percentage and lesser poly-saturated fatty acid percentage (easily oxidized) provides excellent lubrication and cooling action at the grinding zone in comparison to dry condition. Under dry grinding as the number of grinding passes increased from 2^{nd} to 8^{th} pass surface roughness increased by 166%. At higher grinding pass (8^{th}) surface roughness decreased by 24% in contrast to 1^{st} pass. Further, cutting force under dry grinding case with 8^{th} pass got increased by 18% in contrast to MQL condition.

Keywords: Ti-6Al-4V, Cubic boron nitride (CBN), Surface roughness, Grinding forces.

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1. INTRODUCTION

Grinding technique in terms of tool geometry, contact area, heat generation at the mating surface is different from other machining processes. In surface grinding wheel having hard abrasive particles are generally used. Cubic boron nitride (CBN) super abrasive grinding wheel has been widely used for grinding of Ti–6Al–4V alloys because of its high hardness, good thermal conductivity and very good thermo-chemical stability (Dogra et al., 2018). But machining of Ti-6Al-4V is very difficult due to its poor thermal conductivity (Singh et al., 2020a). High amount of heat is generated at the cutting zone due to friction generation between workpiece and wheel. The intense heat generated reduced the surface quality by thermal damages like surface burning; surface cracks on workpiece, residual stresses and dimensional distortions (Singh et al., 2019a). In order to remove this heat synthetic cutting fluids also known as petroleum based cutting fluids are used by the machinist. But these fluids have very harmful effects on the environment as well as human health due to synthetic nature (Jia et al., 2014). Researchers throughout the world have been working on developing various other alternatives to remove the harmful impacts. Dry grinding is sustainable option to reduce these dangerous concerns. But under dry grinding in the absence of cutting fluid higher amount of friction generates poor surface finish and high residual stresses at the workpiece material (Sinha et al., 2019). Nowadays, Minimum quantity lubrication (MQL) technique has been widely used by the machinist (Singh, 2020). In most of the works generally vegetable oil were used by the researchers because of excellent viscosity, pour point etc. Under MQL very little quantity of cutting fluid (~100 L/min) therefore disposal issues reduced (Gupta et al., 2016). Further, with the aid of this technique chip collection is easy. Conventional flood cooling consists of mineral based synthetic lubricants is the most economically and efficiently used in the industries for machining processes. But it has the negative effects on operator's health and ecology system (Singh et al., 2020b). So, the effective control of the heat generated at the cutting zone is essential to ensure the lower wheel wear rate and work piece quality in grinding. Researchers are working for reducing consumption of coolants/lubricants during grinding operations because of economic and ecological pressures. There are various causes of environmental degradation by the industry: Emission to air, release of harmful effluents into water, Industrial waste, disposal of emulsion based used cutting fluids (Khanna et al., 2020). Out of these causes use of emulsion based cutting fluids for machining is still at large in industry. So any mean to reduce the use these cutting fluids shall have large impact on the protection of environment. In recent years dry grinding has also been explored by the researchers, where there is no coolant/ lubricant is used to transfer heat from the contact zone of grinding wheel and workpiece (Sadeghi et al., 2010). In the absence of coolant–lubricant on the grinding zone, problems of thermal damages on the workpiece surface, as poor surface integrity, increase in the grinding energy and grinding forces and wear of the grinding wheel frequently occurs compared to wet grinding. Thus, it is critically important to evaluate the performance of dry grinding in the grinding of difficult to grind modern material like Titanium and Inconel (Dogra et al., 2011). From the literature, it is clear that apart from grinding environment like flood, MQL and dry, the wheel material also plays a significant role in enhancing the grinding performance. Lot of work has been reported on surface grinding of Titanium under different cooling/ lubricating environment using CBN wheel (Dogra et al., 2018; Singh et al., 2019a; Singh et al., 2019b). But the work pertaining to comparing the performance of CBN wheel under dry and MQL surface grinding of titanium is scant. Further the performance comparison of this wheel material in terms of grinding forces and surface roughness during grinding of titanium alloy under dry as well as MQL surface grinding is also not much reported. In this study, the performance of CBN wheel under dry and MQL surface grinding of Ti-6Al-4V having grade 5 is evaluated by considering the grinding forces and average surface roughness.

2. MATERIALS AND METHODS

For experimentation, Titanium alloy of grade-5 (Ti-6Al-4V) was used. This alloy has high strength to weight ratio and mostly used in aerospace applications such as landing gear, wing spar etc. (Setti et al., 2014). It is highly hardened material under heat treatment and can achieve high strengths (Balan et al., 2014). Grinding was performed with CBN grinding wheel (B91C75BR5) resin bonded having dimensions 160 x 10 x 31.75 mm. The details of workpiece material are indicated in Table 1.

Grinding performance is measured in terms of average surface roughness and cutting forces. The grinding was performed up to 10th grinding pass with each wheel under fixed set of grinding conditions. The truing and dressing were meted out after employing a diamond dresser of 0.5 carat mounted on the table of the grinding machine whenever required (Hadad and Sharbati, 2016). A CBN grinding wheel uses cubic boron nitride as its grinding material due to super abrasives and stronger than normal abrasives like aluminum oxide and silicon carbide (Kuo et al., 2017). CBN grinding is used for hardened materials like Ti alloys, Ni alloys, cast and wrought irons. It is a second hardness material to the diamond-grinding wheel. Final experimentation settings are indicated in Table 2.

Table 1. Chemical compositions of Ti-6Al-4V

Composition	*Ti*	*Al*	*V*	*C*	*O*	*N*	*H*	*Fe*
Wt (%)	90.5	5.8	3.8	0.1	0.2	0.05	0.0125	0.3

Table 2. Experimental conditions

Grinding parameters	Parameter settings
Grinding wheel	CBN (160x10x31.75 mm)
Grinding mode	Up grinding
Grinding length, (mm)	80
Wheel speed, Vs (m/s)	22
Workpiece speed, Vw (mm/min)	3000
Depth of cut, (µm)	10
Dresser	0.5 Carat single point diamond dresser
MQL parameters	nozzle stand-off distance (60 mm),
nozzle projection angle (15°), air	pressure 5 bar

2.1 Experimental Setup

Experiments were performed on horizontal spindle a precise horizontal spindle surface grinder having 18″×6″ table size (make: Premac limited). All the experiments were performed under standard set of grinding conditions as indicated in Table.2

Fig. 1 shows the experimental set-up. The digital dynamometer of RMS make was used to measure grinding forces. The tangential (Ft) component of grinding forces was measured in every pass and data was recorded. The aim was to check the trend in the grinding forces produced with grinding time; means to check the effect of wheel wear on grinding forces with progression of grinding. Thus, the data of eight grinding passes was recorded and compared in continuous grinding without any redressing under standard set of grinding conditions under dry and MQL grinding. Average surface roughness was measured with surface roughness analyzer (Male: Mitutoyo) under each pass.

Fig. 1. Grinding setup

3. RESULT AND DISCUSSION

In this section, the comparison results related to surface roughness and cutting force under dry and MQL grinding are displayed. The grinding mode was fixed as up grinding and other parameters like wheel speed, workpiece speed and depth of cut were also fixed on the basis of the literature, as the aim was to compare the performance of CBN under dry and MQL grinding of Ti-6Al-4V Grade 5.

3.1 Surface Roughness

Average surface roughness was measured with surface roughness analyzer and is indicted in Fig. 2. It is clearly depicted that surface roughness was decreased significantly under MQL and dry environments. Under dry grinding, due to absence of any lubrication high amount of friction generated and temperature generation also increased. The abrasive particles present on the wheel surface wear off and enhanced the roughness of the workpiece material (Virdi et al., 2020). As the number of grinding passes increased from 2nd to 8th pass, the surface roughness increased by 166%. However, under MQL environment, the surface finish of workpiece material got enhanced in comparison to dry grinding environment. The main reason for low surface roughness is excellent lubrication and cooling action provided by MQL process. The misting action of MQL created lubrication layer between wheel surface and workpiece material and reduced the contact area resulted in lower friction generation. At higher grinding pass (8^{th}), the surface roughness got decreased by 24% in contrast to 1^{st} pass (Oliveira et al., 2012). Fig. 2 indicates the surface roughness produced under dry and MQL grinding process. As expected under MQL surface grinding, surface finish got enhanced in comparison to dry machining (Fig. 3).

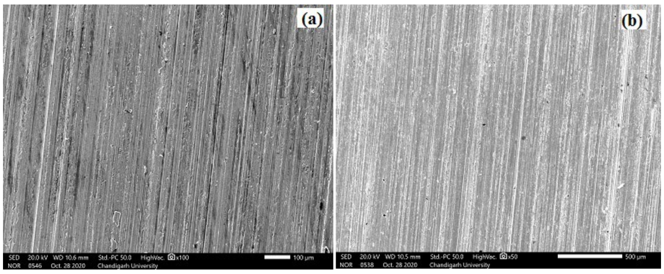

Fig. 2. SEM images of surface roughness under (a) Dry grinding (b) MQL grinding

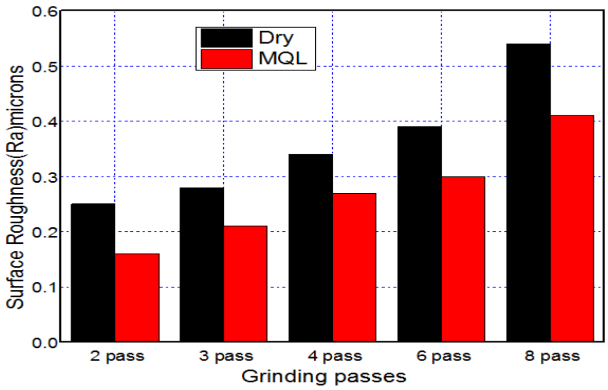

Fig. 3. Average surface roughness under MQL and Dry grinding

3.2 Grinding Force

Grinding forces especially tangential force is very important in surface grinding performance. Fig. 4 depicts the measured values of tangential force under dry and MQL environments. It can be seen that with the rise in grinding passes grinding forces increased under each selected case (Fig. 4). The increment in grinding passes enhanced the friction production between grinding wheel and workpiece material (Li et al., 2016). Cutting force under dry grinding case with 8^{th} pass increased by 18% in contrast to MQL condition. Lowest grinding force under MQL environment shows the efficient grinding performance. Under dry grinding case due to absence of any lubrication, high friction was generated which resulted in clogging of chips at the wheel surface which further enhanced the friction as well as temperature. Therefore, high cutting force was generated under dry condition (Awale et al., 2020). Contrary to this, under MQL case, high pressure of cutting fluid mist flushes the clogging of chips from the contact zone and helps in lowering the friction production (Nguyen and Zhang, 2013). Moreover, in canola oil, the presence of high anti-oxidation mono-saturated fatty acid percentage and lesser poly-saturated fatty acid percentage (easily oxidized) provides good lubrication (Lawal, 2013). This is the main reason of lower grinding forces under MQL environment in comparison to dry grinding.

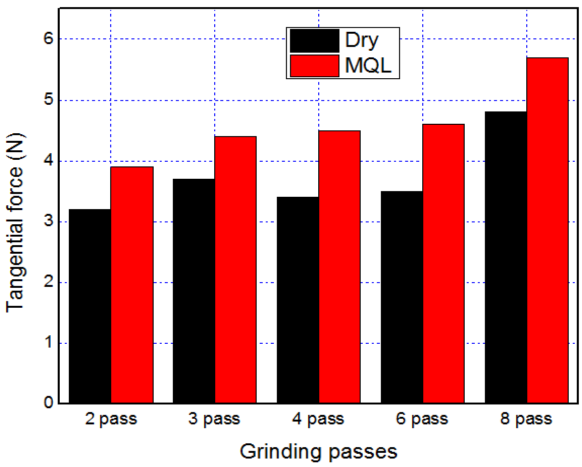

Fig. 4. The variation of Ft with number of grinding passes under Dry and MQL conditions

4. CONCLUSION

Following critical conclusions of surface grinding performance are drawn under MQL and dry grinding of Ti-6Al-4V alloy with CBN wheel:

- The result of the study indicates that MQL grinding can be used as sustainable alternate to dry grinding of titanium alloys.
- Surface roughness under MQL environment produced better grinding performance in contrast to dry grinding. Under dry grinding as the number of grinding passes increased from 2nd to 8th pass surface roughness increased by 166%. But under MQL environment surface roughness is excellent due to better lubrication and cooling action. The misting action of MQL created lubrication layer between wheel surface and workpiece material and reduced the contact area resulted in lower friction generation. At higher grinding pass (8th) surface roughness decreased by 24% in contrast to 1st pass.
- Minimum tangential grinding forces were registered under MQL environment in contrast to dry case. The increment in grinding passes enhanced the friction production between grinding wheel and workpiece material. Cutting force under dry grinding case with 8th pass increased by 18% in contrast to MQL condition.
- The presence of high anti-oxidation mono-saturated fatty acid percentage and lesser poly-saturated fatty acid percentage (easily oxidized) in canola oil provides good lubrication. This is the main reason of lower grinding forces and surface roughness under MQL environment in comparison to dry grinding.

The performances of vegetable oil based eco-friendly cutting fluids and lubricants depend on the machining processes and working conditions. So, it's not possible to rank the different vegetable based cutting fluids and lubricants. By using MQL technique for vegetable based eco-friendly cutting fluids and lubricants in different machining processes offer best alternate to eliminate environmental related problems as posed by other petroleum and mineral oils. Genetically modified and hybridized non-edible vegetable oils are successfully used as cutting fluids in surface grinding for different environmental conditions. The mist particle was investigated and characterized for different machining processes under different environments as the nano particles mixed with mixture of two or more than two vegetable based cutting fluids used for surface grinding, it enhanced the lubrication, cooling and oxidation stability of these oils. The mist of this mixture is not the environmental issue used under MQL technique. Further from the literature, it was observed that the eco-friendly bio based cutting fluids when used with MQL technique stands out among other latest techniques used for surface grinding. The hybrid machining approach also used vegetable-based cutting fluids.

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