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Feasibility Study on Application of Palm Oil as Cutting Fluid in Machining of Aerospace Materials

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Abstract

This paper discusses the effectiveness of palm oil as cutting fluid for machining titanium alloy Ti-6Al-4V. Palm oil could be a good alternative because it is biodegradable and gives minimum effect to the machine operators' health and the environment. The main objective of this study is to compare performances of synthetic oil and palm oil using the MQL (Minimum Quantity Lubricant) method. The cutting fluids were applied into the cutting zone in form of mist. Those performances were also compared to different methods such as dry (without cutting fluid) and flooded (with synthetic oil) machining. Tests were conducted at three different cutting speeds 60, 80 and 100 m/min on CNC (computer numerical control) milling machine. Study showed that the use of palm oil with MQL technique gave better tool life compared to flooded technique and high cutting speed. However, at low cutting speed better tool life was obtained with flooded and the tool life for mist coolant for palm oil and synthetic oil just slightly lower. Dry condition is totally not suitable for machining Ti-6Al-4V at any cutting speed. As conclusion, palm oil possesses great potential to be applied as cutting fluid for machining aerospace materials.

Keywords: palm oil, titanium alloy Ti-6Al-4V, MQL, tool life.

INTRODUCTION

Titanium alloys are widely used in aerospace because of it excellent mechanical properties such as high strength to weight ratio, high corrosion resistance and ability to sustain high strength at elevated temperature. However, these materials are classified as difficult to machine materials because if the high ductility and poor thermal conductivity [1]. The ductility results the chip is difficult to cut and requires cutting tool with high sharpness [2]. Cutting fluids are used in machining as lubricant and coolant to decrease the cutting temperature and prolong the tool life. By decreasing the heat generation at the cutting zone, the phase transformation of the microstructure can be minimized. This microstructure alteration can jeopardize the surface integrity of the machined surface. The surface integrity is very crucial for aerospace component. With regards to titanium alloys where the thermal conductivity is low, the heat generated in the cutting zone is more localized. Hence, the possibility of phase transformation is higher on the machined surface. Minor defect on the machined component in aerospace can cause major catastrophe.

Beside of that, application of cutting can also simplify the chips and metal debris removal from the tool-workpiece interface. The application of cutting fluid at certain pressure can carry away the chip from the cutting zone and avoid disturbance during cutting process. Continuous chip produced especially in turning process can cause damage on the machine surface if the chip penetrates in to the cutting zone. However, the usage of cutting fluid is now being debated due the negative impact on the machine operators' health and also to the environment [3,4,5]. The fume of the cutting fluid when exposed to high temperature can cause cancer. Mishandling of waste cutting fluid can harm our environment especially the water resources.

Furthermore, it has been reported that the total cost associated with the cutting fluid is higher than the cost of buying cutting tool. Nowadays, with the vast advancement in materials, cutting tool can be produced at low cost and the performance improve tremendously [6]. Many researchers had concluded that dry machining is not suitable for machining titanium alloys. The excessive heat generated in the cutting zone not only cause rapid wear growth and result shorter tool life, but also effect the surface integrity of the machined surfaced [7]. The MQL technique in machining titanium was introduced to accommodate these requirements.

The cutting fluid which is sprayed in the cutting zone in form of mist with assistance of compressed air can give better cooling effect and reduce the heat generation. Higher the speed, bigger the centrifugal force created by the rotating milling cutter and thus hinder the lubricant penetrate into the cutting zone. Assisted jet pressure will be required for high speed machining [8].

The aim of this study is to determine if palm oil can be used as cutting fluid for titanium machining in industry. As a matter of fact, cutting fluids that are used nowadays are mostly petroleum based oils and mineral oil-based polymeric materials which are bad for environment and for the workers' health. Indeed, indications must be followed to get rid of these hazardous fluids and they can cause several diseases as skin cancers or breathing problems. Palm oil, which is biodegradable, seems to be a safe and "ecofriendly" alternative.

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Moreover, using this oil could have an economic interest for Malaysia which is the second producer and first exporter of the world [9,10]. The performance of these machining methods will be analyzed based on the tool life.

Palm oil presents the advantage of being produced either under liquid or solid form, which facilitate its industrial transformation. Indeed, it is under solid form under 30°C and liquid for higher temperatures. Its melting point is between 36°C and 40°C. It is composed of a long carbon chain, longer than synthetic ester carbon chain, which increase the durability of contact with the material and improve lubricity [11,12]. Furthermore, the presence of fatty acids and polar carboxyl groups (COOH) reduces the coefficient of friction and product a thin film which increase lubrication. Moreover, it has a high viscosity index (40mm²/s at 40°C) compared to synthetic oils (19mm²/s at 40°C) and an affordable application cost. Palm oil is used in cosmetic industry, which means that it doesn't present danger to human and unlike synthetic oils, will not lead to skin disease. In addition to that, palm oil is biodegradable and doesn't present danger to our planet except from its mass production which is already being executed mostly for food industry [13].

It had been reported that, the chemical property of palm oil is compatible with the titanium and its' alloy. Furthermore, palm oil's chemical compatibility with titanium is excellent at room temperature [14]. Thus it has great potential to be applied as cutting fluid for machining titanium and its alloys.

Palm oil could present a lot of advantage compared to synthetic oil as cutting fluid, mostly regarding environmental issues. As a matter of fact, vegetable oils are more susceptible to degradation by oxidation or hydrolytic reactions than synthetic oils. Moreover, they are less likely to evaporate when exposed to the heat and so produce less mist than petroleum based oils by the evaporation-condensation mechanism.

METHODOLOGY

Performance of palm oil as cutting oil was compared with synthetic oil, dry machining and flooded machining. These four cutting conditions were investigated at 3 different cutting speed; 60, 80 and 100 m/min. Table 1 shows the design of experiment used in this study while Fug 1 explains the factors and levels used in this experiment.

The material used in this study is titanium alloy Ti-6Al-4V. This titanium alloy is from alpha-beta group. Table 2 shows the mechanical properties of Ti-6Al-4V.

Trial was conducted on Haas CNC Machine as shown in Figure 2. The palm oil and synthetic oil are applied in form of mist. This method is also known as MQL. Fig 3 shows the MQL apparatus used in this study. The MQL flow rate used in this study was 100 mL/H. This rate was applied for MQL synthetic oil and MQL palm oil.

Table 1: Design of experiment used in the study.

Run	Cutting speed (m/min)	Method
1	60	Flooded
2	80	Flooded
3	100	Flooded
4	60	MQL Synthetic oil
5	80	MQL Synthetic oil
6	100	MQL Synthetic oil
7	60	MQL Palm oil
8	80	MQL Palm oil
9	100	MQL Palm oil
10	60	Dry
11	80	Dry
12	100	Dry

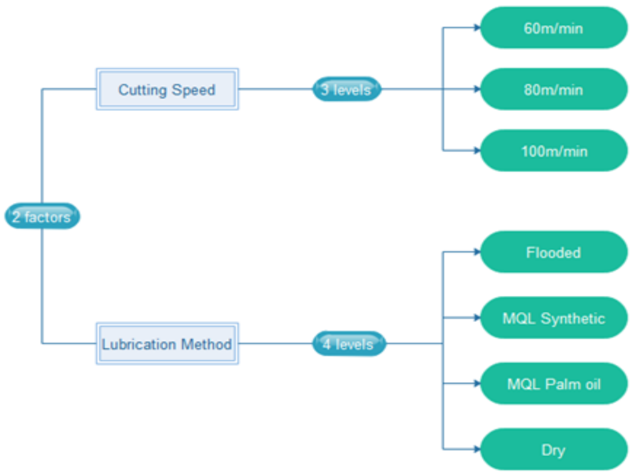

Figure1: Factors and levels in this experiment

Table 2: Mechanical properties of T-6Al-4V.

Tensile strength (MPa)	993
Yield strength (MPa)	830
Elongation (%)	14
Modulus of elasticity (GPa)	114
Hardness (HRC)	36

Figure 2: CNC Hass Milling Machine

The tool used for this experiment was PVD coated tungsten carbide as shown in Figure 4. The wear was measured gradually at the end of each 100 mm travel. The time taken to complete each travel is shown in table 3. Figure 5 shows the measurement of wear on the flank surface of the cutting tool. The equipment used to measure the tool wear was Moticam Toolmaker microscope. Image was analyzed by Moitic Image software. Wear measurement only can be conducted after the calibration. This is to ensure the measurement is correct and reliable. Machining was stop when the wear reach 0.2 mm. The tool life is determined by the total time taken for the machining until the wear reached this point. Machining would be also stopped if there was sudden breakage or catastrophic failure on the tool.

Table 3: Time taken to travel 100 mm at various cutting speed.

Cutting Speed (m/min)	Time of cut for 100 mm (s)
60	35
80	27
100	21

Figure 3: The MQL apparatus.

Figure 4: PVD Coated tungsten carbide insert.

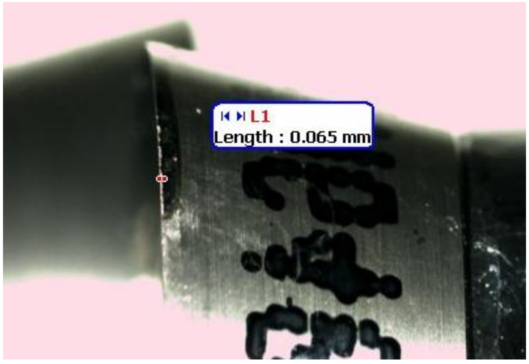

Figure 5: Measurement of tool wear on the flank surface.

RESULTS AND DISCUSSION

The performance of the cutting tool at different cutting conditions and at various cutting speed were evaluated based on the tool life obtained. Table 4 shows the tool life obtained for each trial. Figure 6, 7 and 8 shows the tool wear progression at cutting speed 60, 80 and 100 m/min respectively.

From the result, we can conclude that dry machining is not suitable for any cutting speed. Rapid wear growth was observed in dry machining at all cutting speed. The heat generated at contact point between cutting tool and work material is extremely high. As titanium alloy is not good conductor, almost 80% of the heat generated absorbed by the cutting tool. The excessive heat can cause the cobalt as the binder for the cutting tool loss the bonding strength. It is believed that tool breakage or severe chipping would be observed if we prolong the trial after the wear reached at 0.2 mm.

Flooded cutting condition is more suitable at lower cutting speed. At cutting speed 100 m/min the flooded condition is less effective compared with MQL conditions. It is believed that, the centrifugal force created by the rotating tool is high enough to hinder the cutting fluid from penetrating in to the cutting zone. MQL technique gave better due to effect of high pressure that induce the cutting fluid in form of mist to penetrate in to the cutting zone.

Longer tool life was obtained under palm oil compared with synthetic oil at cutting speed 80 and 100 m/min. Effect of high pressure assistance is similar for both oil because same pressure and same flow rate were applied. Longer tool life was obtained for palm oil might be due to chemical compatibility of the palm oil with titanium alloy. Chemical compatibility between palm oil and titanium alloy might result less chemical reaction and give better lubrication effect. Better lubrication can reduce the friction at the contact surface between cutting tool and work material. Thus, heat generation due to friction can be minimized.

Table 4: Result obtained

Run	Cutting speed (m/min)	Cutting Condition	Tool wear (Vb)	Tool Life (sec)
1	60	Flooded	0,210	700
2	80	Flooded	0,202	567
3	100	Flooded	0,205	273
4	60	MQL Synthetic oil	0,210	630
5	80	MQL Synthetic oil	0,210	432
6	100	MQL Synthetic oil	0,212	315
7	60	MQL Palm oil	0,212	700
8	80	MQL Palm oil	0,212	513
9	100	MQL Palm oil	0,212	315
10	60	Dry	0,210	350
11	80	Dry	0,200	243
12	100	Dry	0,214	189

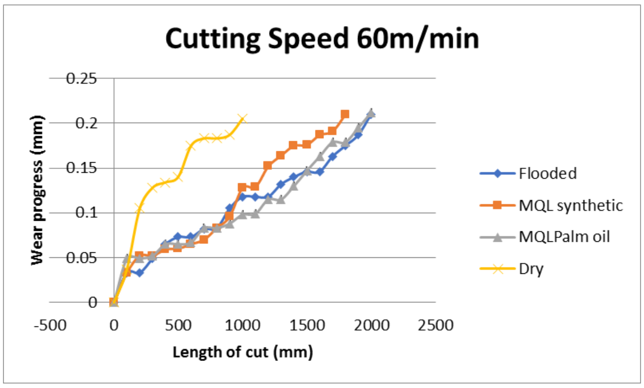

Figure 6: Wear progress at cutting speed 60 m/min

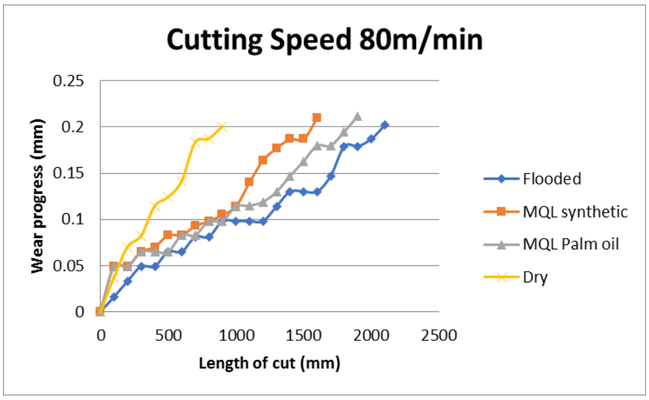

Figure 7: Wear progress at cutting speed 80 m/min

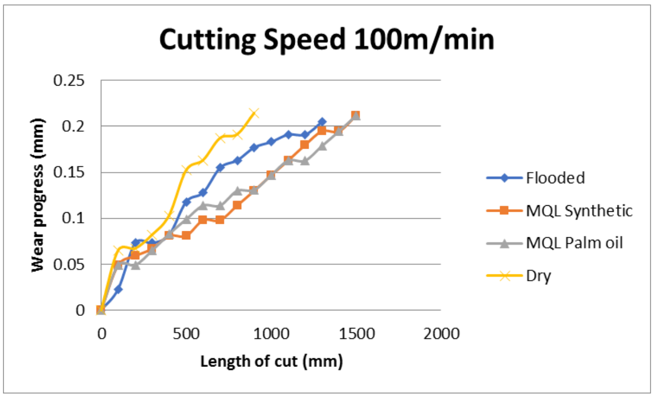

Figure 8: Wear progress at cutting speed 100 m/min

CONCLUSION

Results obtained are encouraging and we can consider exploring the use of palm oil as cutting fluid. The results given by this study are indeed relevant so we can consider that using palm oil with MQL technique can be a great alternative to the use of synthetic oil. As a matter of fact, using palm oil with MQL technique gives a better tool life than the use of synthetic oil with the same technique for all cutting speeds and better results than flooded for high cutting speed (100m/min). Moreover, using palm oil in machining industry can be a cost effective way compared to the use of synthetic oil which is expensive as a product and difficult to get rid of, not to mention that it can be a great opportunity for Malaysia which is already the first exporter and second producer of palm oil. In addition to that, the use of palm oil would be a lot better for environment and worker in contact with it, also reducing costs related to waste disposal and machine operators' health. Nevertheless, there was only no replicate for this experiment. Data was taken based on only 1 experiment. Replication on experiment need to be conducted in order to have higher reliability on the result. Further investigation need to be carried out

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