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Effect of Al_2O_3 nanolubrication with Sodium Dodecylbenzene Sulfonate (SDBS) on surface roughness and tool wear under MQL during turning of Ti-6AL-4T.

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Abstract. The application of coolant reduces the friction and heat generation, which affect the surface finish and tool life, during machining. Recently, nanolubricant opens a new ways of coolant strategy in machining operation. It is well known that suspended nanoparticles without surfactant in base oil tend to agglomerate after a period of time. This paper presents the effects of Al_2O_3 nanolubricant with surfactant, Sodium Dodecylbenzene Sulfonate (SDBS) on surface roughness and tool wear during turning of titanium alloy, Ti-6AL-4T. The comparison of different coolant strategies, dry cutting, flooding, minimum quantity lubricant (MQL), nanolubricant with and without surfactant are also presented. The results showed that Al_2O_3 nanolubricant with surfactant, Sodium Dodecylbenzene Sulfonate (SDBS) under MQL exhibits low surface roughness and tool wear rate compared to others. This proved that the addition of surfactant not only improved nanolubricant stability but also machining performance.

1. Introduction

Titanium alloy (Ti-6Al-4T) is one of the favorable alloys that generally used in modern manufacturing processes due to high strength to-weight ratio at higher temperatures and superior corrosion resistance. Thus, it finds extensive applications in aerospace, automotive, nuclear, chemical, marine and biomedical industries. However, titanium alloys are known to have certain undesired characteristics such as poor thermal conductivity, poor elastic modulus, and high chemical reactivity at elevated temperature which make them difficult to machine material. Due to these characteristics, issues related to rapid tool wear and low surface roughness quality always arises. In overcoming this problem, researchers have proposed several solutions such as promoting cutting process with combination of low feed and high cutting speed, use of coated tool such as carbide coated, polycrystalline diamond (PCB) and cubic Boron Nitride (CBN) and application of lubrication [1-3].

Lubrication effects tool media and surface conditions of the machined workpiece. Lubricant also functions as the heat transfer and chip removal agent during machining. However, the excessive use of lubricants affects the environment and potentially damaging chemical constituents. These fluids are difficult to dispose, expensive to recycle and can cause skin and lung disease to the operators [4]. As a solution, minimum quantity lubricant (MQL) application has been employed or attempted. MQL systems use only a minute amount of cutting fluids typically at a flow rate of 50–500 ml/h [5]. MQL application reduces the machining cost, safe for the environment and produces less occupational

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exposure [6]. In terms of product quality, MQL system promotes direct application of cutting fluid near to the cutting zone with high outlet speeds providing well lubrication and adequately cooling effect. As a result, reduction of friction and heat between the tool and the work material can be observed [7]. On the other hand, the performance of MQL system depends on several factors such as type of lubricants used, droplet size and distribution in terms of nozzle distance and air pressure. For optimum output, all of these factors setting must be carefully considered [8].

Recently, researchers have been exploring the new formulated lubricant known as nanolubricant. The advantages of nanolubricant have attracted considerable attention because of their unique properties and tremendous potentials in a wide range of applications. Nanolubricant is produced by suspended nanoparticles (such as alumina and copper oxide) inside base lubricant (such as water, oil and ethylene glycol). It has been reported that nanolubricant is very effective in reducing friction and heat transfer. Addition of small amount of nanoparticles improves the fluid thermal conductivity and tribological characteristics which are important in mechanical machining especial to enhance the quality of machined product such as surface integrity, cutting force and cutting temperature. Therefore, nanolubricant becomes promising new lubrication, which has important economic value on the friction-energy consumption. However, nanoparticles have a strong tendency to agglomerate and a weak combination with the organic or polymer matrix because of its bad consistent interface. So, the homogeneous dispersion of nanoparticles in lubricating oil is difficult to achieve [9-12]. As a solution to this problem, the use of surfactant is recommended. Surfactant prevents the aggregation and sedimentation of nanoparticles in the nanofluid. The addition of surfactant changes the thermophysical properties, affects the boiling heat transfer characteristics and increases the viscosity of nanolubricant [13]. As far as manufacturers' views are concerned, the nanolubricant without surfactant or additive leads to limited application after a long period of time. There is a limited number of studies on fundamental understanding on the mechanisms and the effects of surfactant on nanolubricant for better quality in machining. Hence, this study proposes experimental investigation on the effect of nanolubricant with surfactant Sodium Dodecylbenzene Sulfonate (SDBS) under MQL on tool wear and surface roughness during machining Ti-6AL-4T.

2. Experimental setup

2.1. *Preparation of Nanolubricant*

Al_2O_3 particle sizes (<50 nm) were suspended (0.1% wt) in soluble cutting oil (SolCut) using ultrasonics liquid processor for 4 hours at 25 % amplitude. The output power was set at 100 W for temperature range of 18–23°C. 1% of SDBS was added to minimize agglomeration in the mixture.

2.2. *Experimental Procedure*

Five different lubrication-cooling conditions were investigated. Those conditions are as follow: (a) without any cooling lubricant (dry cutting), (b) flood lubricant, (c) base lubricant under minimal quantity lubricant (MQL cutting), (d) nanolubricant without surfactant under minimal quantity lubricant (MQL cutting), and (e) nanolubricant with SDBS under minimal quantity lubricant (MQL cutting). A two-channel external supply system was used for the MQL purpose. The present work deals with experimental investigation on the role of Al_2O_3 nanolubricant with SDBS surfactant on surface roughness and tool wear in straight turning of the titanium alloy by a single type of carbide inserts with constant cutting parameter configurations. 5 mm diameter of material was removed for each cutting process to 45 mm length. Cutting process was continued until 30 mm of diameter has been removed. For each cutting process, the surface roughness and tool wear result were acquired using Mitutoyo surface roughness measurer and Leica microscope at magnification of 16 times. Measurement for surface roughness data was taken on four point with range of measurement 4mm. Table 1 shows the details of experimental conditions for the different environment.

Table 1: Experimental conditions

Item	Description
Machine Tool	CHEVALIER FCL-608 CNC Turning Machine
Work specimen:	
Materials	Titanium alloy (Ti-6AL-4T)
Size (mm)	50 mm diameter
Cutting tool (insert):	
Cutting insert	Finishing coated carbide insert (nose radius: 2 mm)
Process parameters:	
Spindle speed (Cutting speed)	541 rpm (85m/min)
Feed rate	0.2 mm/rev
Depth of cut	0.2 mm
MQL supply Air:	6.0 bar, lubricant: 40 ml/h (through external nozzle)
Flood lubricant supply:	60 L/h
Environment:	Dry, flood lubricant, minimum quantity lubrication (MQL) – base oil, pure nanolubricant and nanolubricant with SDBS

3. Results and discussion

Figure 1 shows the stability of nanolubricant with and without surfactant that was left for a period of 1 week. It is expected that the addition of surfactant (SDBS) will able to stabilize the particles for more than 24 hours. After 1 week, it appears that the nanolubricant without surfactant begins to produce sediments. In contrast, the nanolubricant with the addition of SDBS tends to remain stable without any sign of particles sedimentation. This phenomena is due to the aggregation (or flocculation) of particles. Dispersing nanoparticles with base oil is difficult due to the weak combination with the organic or polymer matrix because of its poor consistent interface. Thus, to improve the mixing process, addition of surfactant is required. Surfactant promotes lower surface tension of a liquid, increasing the contact between the liquid and another substance. The mechanism is known as adsorption which will accrete on the surface of the liquid, creating a film that reduces its surface tension. This results in a stable dispersion.

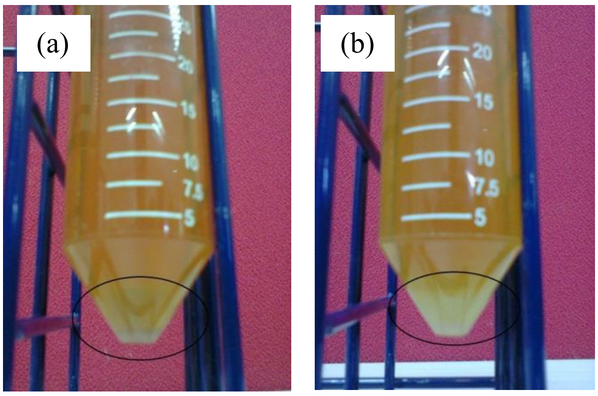

Figure 1: Stability of nanolubricant after 1 week;
(a) Nanolubricant with addition of SDBS,
(b) Nanolubricant without addition of SDBS.

Meanwhile, Figure 2 represents the results of average surface roughness values for five different cutting conditions after 30 mm diameter of material has been removed. As expected, dry cut condition produces the worst surface quality, in which the value of surface roughness is 4.41 μm towards the end of turning process. As the condition of the tool deteriorated, rapid increment of surface roughness value can be observed under this dry cut condition. Meanwhile, the flood lubricant condition produces the best surface roughness which is 4.06 μm as the machining process progresses towards the end of the turning process. It appears that the MQL with nanolubricant added with the SDBS conditions showed improvement in the surface roughness values compare to MQL with nanolubricant and MQL with base oil condition. Although result of MQL with nanolubricant and MQL with base oil is nearly similar but small improvement in terms of surface quality can be observed in MQL with nanolubricant condition. It is believed that lubrication is the main reason to explain the different results produce between the dry cut and other cutting conditions. The results also proved the ability of lubrication in reducing the effect of friction and heat generation at the cutting zone. The observation shows that the MQL system and nanolubrication are capable of improving the surface finish of the machined titanium alloy although the consumption of lubricant is small compared to the flood coolant. It should be emphasized here that the different in surface finish recorded between nanolubricant and nanolubricant with SDBS shows that surfactant has significant effect in reducing the friction and heat generation.

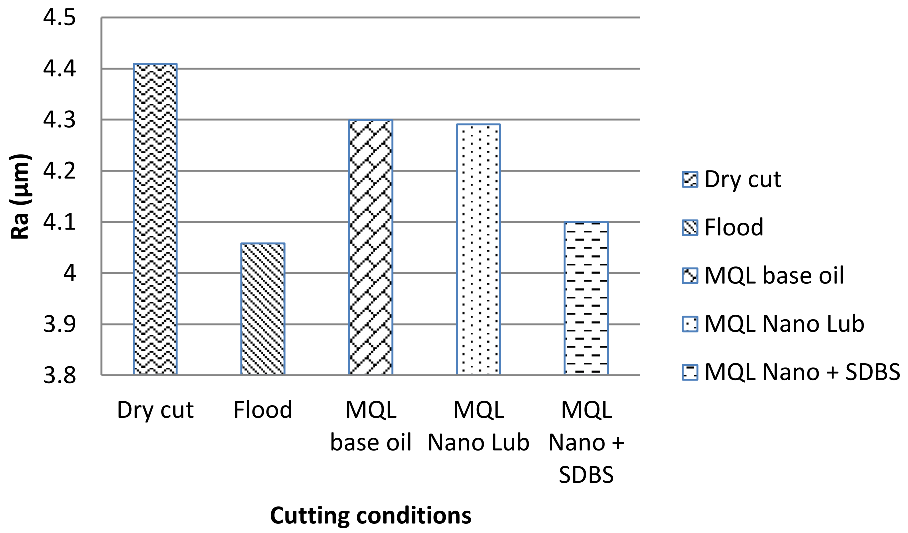

Figure 2: Average surface finish for five different cutting condition; dry cut, flood lubricant, MQL with base lubricant, MQL with nanolubricant, and MQL with nanolubricant added with SDBS.

Figure 3 shows the results of average tool wear for the five different cutting conditions. It is to note that the material has been removed is 30 mm of the bar diameter for each cutting condition. The results show that the wear rate for dry cut, flood lubricant and MQL for the base oil reached the average of VB flank wear of 0.25 mm. The tool wear rates recorded for MQL (nanolubricant) and MQL (nanolubricant with additional SDBS) are 0.21 mm and 0.22 mm, respectively. It is clear that nanolubricant is capable of improving the tool life compared to the dry cut, flood lubricant and MQL for base oil. This may be due to lower fiction between cutting tool and workpiece and low cutting temperature during turning operation. Figure 4 shows the tool wear condition for the different cutting conditions after 30 mm diameter of material being removed. From the images captured, it can be inferred that the wear occurs by mainly abrasion.

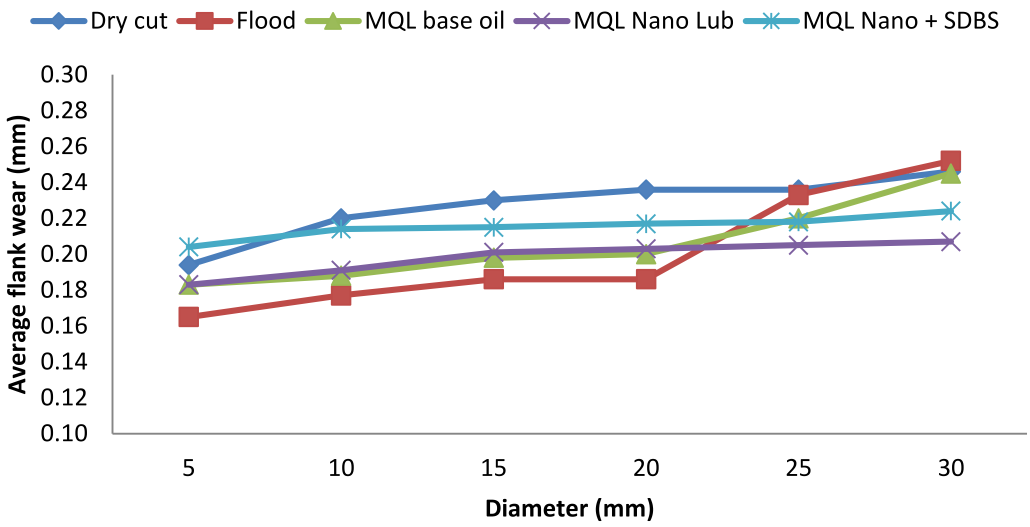

Figure 3: Average tool wear for five different cutting conditions; dry cut, flood lubricant, MQL with base lubricant, MQL with nanolubricant, and MQL with nanolubricant plus SDBS

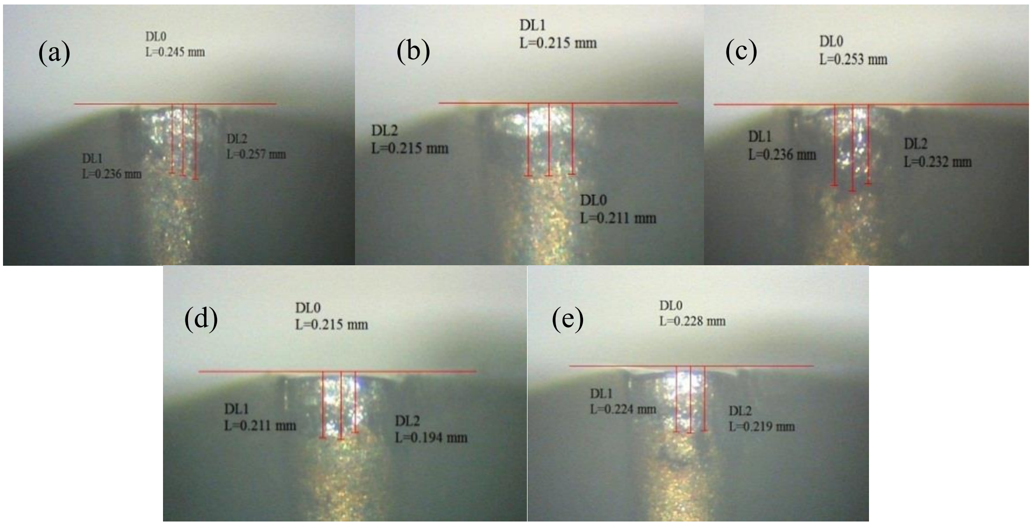

Figure 4: Tool wear condition after 30 mm diameter removal; (a) Dry cut, (b) Flood coolant, (c) MQL with base lubricant, (d) MQL with nanolubricant and (e) MQL with nanolubricant and SDBS

4. Conclusion

The use of nanolubricant promote better lubrication and cooling effect. Importantly, the addition of surfactant (SDBS) not only overcome the problems related to agglomeration of the nanoparticles but also improve the machining performance. It also appears from the experiments that the MQL system enhance the lubrication usage and at the same time improves the cooling and lubrication effects. Combination of the MQL system with nanolubricant and surfactant have significant benefits in improving tool wear rate as well as surface roughness value. However, due to constant machining settings (speed and feed) used during experiment lead to unconfirmed machining effect. Hence, further investigations with different cutting parameter are essential.

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References
[1] J Nithyanandam, S Laldas, and K Palanikumar, Procedia Materials Science 5 (2014) 1–10.
[2] G D Revankar, R Shetty, S S. Rao, and V N Gaitonde, Materials Research 17(4) (2014) 1010–1022.
[3] G Symbols, R & D Journal of South African Institution of Mechanical Engineering 26 (2010) 43–52.
[4] P S Sreejith, Materials Letter 62(2) (2008) 276–278.
[5] I Ansari and B Kotiveerachary, International Journal of Mechanical Engineering and Research 3(5) (2013) 439–448.
[6] M S Najiha, M M., Rahman, A R Yusoff and K Kadirgama, International Journal of Automotive and Mechanical Engineering 6 (2012) 768–776.
[7] M C S Alves, E C Bianchi, P R Aguiar and R C Canarim, Revista Materia 16(3) (2012) 754–766.
[8] K H Park, J Olortegui-Yume, M C Yoon and P Kwon, International Journal of Machine Tools and Manufacture 50(9) (2010) 824–833.
[9] M. A. Kedzierski, International Journal of Refrigeration 36(4) (2013) 1333–1340.
[10] Y Tao, Y Tao, B Wang, and Y Tai, Materials Chemistry and Physics 147(1-2) (2014) 28–34.
[11] T Luo, X Wei, X Huang, L Huang, and F Yang, Ceramic International 40(5) (2014) 7143–7149.
[12] M K Moraveji, M Darabi, S M H Haddad, and R Davarnejad, International Communication in Heat and Mass Transfer 38(9) (2011) 1291–1295.
[13] H Hu, H Peng, and G Ding, International Journal of Refrigeration 36(3) (2013) 1045-1055.