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Environmentally Sustainable Milling operation on Ti-6Al-4V Aerospace grade alloy using Vegetable oil based Nano-lubrication

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ABSTRACT

Due to several regulations imposed by National Green Tribunal (NGT) on emissions from industrial waste, environmentally sustainable machining is becoming essential ingredient among industrial sector using new lubricants. This machining process is capable of significant reduction in waste by remanufacturing, reuse and recycling. This machining process covers an in-depth overview of those operations and practices which are most environmentally sustainable. This paper covers environmently sustainable milling operation on Ti-6Al-4V aerospace grade high temperature alloy using different % weights of Al_2O_3 and TiO_2 nanoparticle suspensions in sunflower oil. Noga-minicool minimum quantity lubrication (MQL) supply system is used for nanolubrication at the machining interface during milling operation. It was found that 0.50% wt of Al_2O_3 nanoparticles suspension in sunflower oil performed better in terms of reduction in tool temperature difference as compared to TiO_2 nanoparticles suspensions. SEM images also showed improvement in microstructure of Ti-6Al-4V alloy workpiece in nano-lubrication condition as compared to dry milling operation.

Keywords: Environmentally sustainable milling, Minimal quantity lubrication, Cutting temperature, Surface finish, Depth of cut, Fluid flow rate

INTRODUCTION

Machining operation consists of material removal from workpiece using a specific HSS cutting tool. In industrial sector, machining plays major role in carrying out different operations. Tremendous amount of heat is generated in case of ferrous and other high strength materials due to their plastic deformation and friction at the machining interface. This heat generated cause several adverse effects on the machining performance and tool life of any material. Therefore urgent release of this heat generated is atmost important. Several conventional lubrication techniques are in practice but they are practically not as effective as required in current industrial scenario. Several new techniques of heat dissipation are underway as shown below:

- Dry machining
- Cryogenic cooling
- Coated tools
- MQL

But apart from that MQL technique is popularly used method in present scenario of machining in a sustainable manner [18, 19, 20]. In this paper, effect of addition of Al_2O_3 and TiO_2 nanoparticles (in different wt %) suspension in sunflower oil during milling operation on Ti-6Al-4V aerospace grade high strength alloy has been studied. The performance was evaluated in terms of cutting tool temperature under different cutting speed, depth of cut and fliud flow rate. This paper will be useful in design and development of a novel ecosystem for Environmently sustainable milling operation using vegetable oil based nanolubrication under different operating conditions.

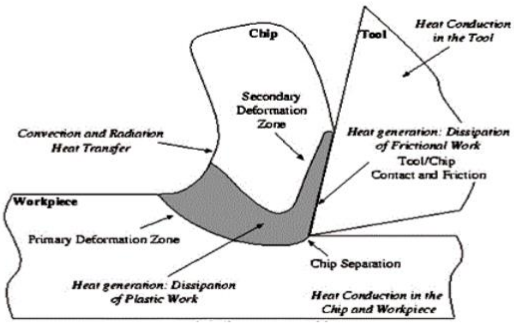


Figure 1. The zones of heat generated during machining [1]

LITERATURE REVIEW

Sachin and Nilesh (2018) conducted machining of M2 Steel using non edible vegetable oil based MQL supply system. A green cutting fluid has been prepared combining aloevera gel and cotton seed oil. It was found that surface roughness decreases by 6.7% as compared to conventional cutting fluid. Tool wear also decreases by 0.14% as compared to conventional cutting fluid.

Mirsadegh et *al.* (2019) conducted graphite nanofluid MQL grinding of Hardened AISI 1045 Steel. 60-66.7% reduction in grinding temperature and 35-50% reduction in surface roughness is obtained in comparison to flood and dry grinding, respectively. Xiao et *al.* (2012) conducted milling operation on Ti–6Al–4V alloy using MQL supply. Significant reduction is found in cutting forces and surface roughness. The coating of the tools also improves under MQL than flood coolant due to decrease in coating delamination. Mehmet et al. (2016) used hexagonal boron nitride (hBN) due to its superior lubrication behavior. hBN is an inorganic artificial material with high heat shock resistance, heat conduction, electrical insulation and chemical stability and therefore used for various important applications in different industry. Jeevan and Jayaram (2018) conducted turning of AA 6061 alloy using two nonedible vegetable oils as Jatropha and Pongamia. It was found that the vegetable oil-based cutting fluids are more effective in reducing the cutting forces, flank wear and surface roughness etc in comparison to mineral oil. Jatropha oil outperformed Pongomia oil and Mineral oil in terms of cutting force while Pongomia oil outperformed Jatropha oil and Mineral oil in terms of surface roughness.

Rahul et *al.* (2019) explored green and sustainable grinding operation using different nanofluids. Al_2O_3 nanofluid MQL gives better lubrication performance in terms of lower surface roughness, specific grinding energy and grinding force ratio as compared to pure SiC nanofluid.

Sidik et *al.* (2017) discussed use of Al_2O_3, CNT, MoS_2, Diamond nanoparticles with different vegetable oils (Coconut/ Jatropha/ Soyabean) during different machining operations. It was found that these nanofluids are very useful in enhancing heat transfer and cooling rate during machining. They also reduce friction and wear at machining interface. But there are some problems associated with them such as poor stability and high production cost. Some new prospects of hybrid nanofluids were also discussed.

Suresh and Amitava (2019) conducted End Milling of AA1050 using Sunflower Oil MQL. The coefficient of friction decreases from 0.5 to 0.1. The uncoated carbide end mill showed better results as compared to diamond coated tools under dry and MQL conditions. The surface roughness by the MCD coated tool was higher as compared to other tools.

Pereiraa, et *al.* (2015) used the hybrid CO_2+MQL in end milling operation. CO_2+MQL hybrid cooling method found more sustainable and environment friendly alternative as compared to other lubrication methods used during machining operations.

Aqilah et *al.* (2021) studied the machining of AISI 4340 steel using green lubrication techniques. Significant improvement was found in tool wear, cutting force, surface roughness and chips formation.

Sharma et al. (2021) studied and reviewed the different aspects of Environmental friendly machining in current scenario. This new sustainable way of machining plays important role in improvising machinability and productivity in terms of improved surface quality and reduced tool wear etc.

SAMPLE PREPARATION

For preparation of samples for nano-lubrication, TiO_2 and Al_2O_3 nanoparticles (Average particle size: 30-50 nm) with 99% purity are used. Cold pressed sunflower oil (viscosity: 0.04914 kg/m*s, density: 918.8 kg/m^3, smoke point: 232°C) is used as base oil. The % composition by weight of nanoparticles is kept as 0.25, 0.50 and 0.75 respectively. For homogenous mixing of base oil and nanoparticles, samples are kept inside a probesonicator for approx 1 hour followed by 30 mins strring action using hot plate magnetic strrirer. The images of prepared samples (in different compositions of TiO_2 and Al_2O_3 nanoparticles) are shown in Figure 2.


2(a)


2(b)

Figure 2. (a) Suspension of TiO_2 in sunflower oil **(b)** Suspension of Al_2O_3 in sunflower oil

EXPERIMENTAL SETUP

An Experimental setup was developed on milling machine using Ti-6Al-4V alloy workpiece to investigate and compare the performance of TiO_2 and Al_2O_3 nanoparticles suspension in sunflower oil during side face milling. Linear slots were cut on the workpiece using HSS milling cutter. A noga mini-cool (Model: MC 1730) is used for supply of nanolubricant at the machining interface (Figure 3). A control valve is inbuilt in this system for supply of compressed air and nanolubricants at different flow rates as shown in Table 2. The cutting temperature is measured by the infrared thermal gun (Range: -50 $^{\circ}$C to +650 $^{\circ}$C), depth of cut is measured by Digital vernier caliper (Accuracy: +0.02 mm, Resolution: 0.01mm) and a digital tachometer (Test range: 2.5-99, 999 rpm**)** is used for measurement of rotating speed respectively. The chemical composition of Ti-6Al-4V workpiece is given in Table 1. The range of machining parameters has been selected based on the previous literature review given in Table 2. The block diagram and milling machine setup is shown in Figure 4.

Table 1: Chemical composition of Ti-6Al-4V alloy

Elements	Composition (wt%)
Titanium	90
Aluminum	6
Vanadium	4
Iron	0.25
Oxygen	0.20

Table 2: Machining parameters and their levels

Factors	Level 1	Level 2	Level 3
Cutting speed	8	20	40
Depth of cut	0.6	1.2	1.8
Type of coolant	Dry condition	Al_2O_3 nanoparticles	TiO_2 nanoparticles
Composition	0.25	0.50	0.75
Flow rate	0.60	0.45	0.30

Figure 3. Noga MC1730 minicool MQL Supply System

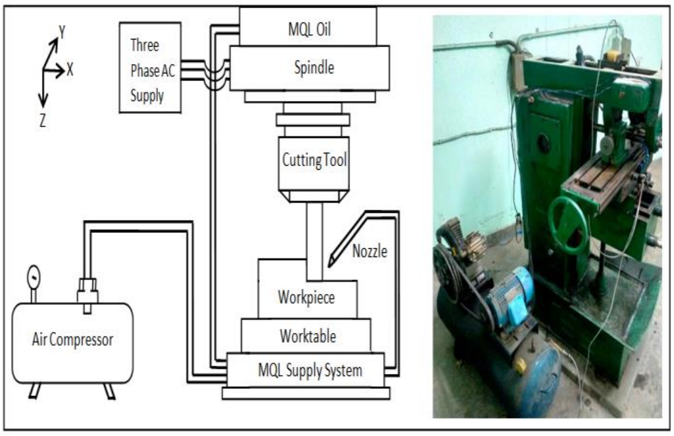


Figure 4. Block diagram of MQL supply based Experimental set-up

RESULTS AND FINDINGS

Following results are obtained in terms of cutting temperature under different operating conditions during environmently sustainable milling operation.

Cutting temperature

Cutting temperature plays major role in influencing the machining performance and tool life of any material. The conventional lubricants don't act effectively in these operating conditions due to breakdown of its protective layer under high speed machining conditions. The addition of nanoparticles enhances their lubricating efficacy due to increase in heat transfer characteristics of base oil. The sunflower oil is largely used as an effective lubricant in various machining operations. This is due to low level of emission of carbon monoxide (CO), CO_2 and other hydrocarbons etc.

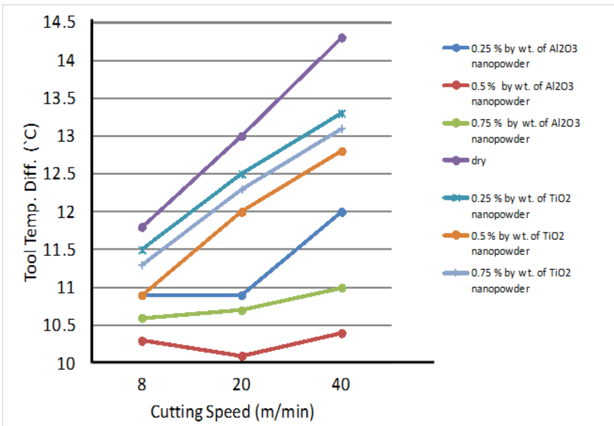


Figure 5. Variation of Tool Temp. Diff. and Cutting Speed (Depth of cut: 0.15 mm, Fluid Flow rate: 0.45 ml/min)

With the increase in cutting speed, the tool temperature goes on increasing as shown in Figure 5. In case of TiO_2 nanopowder suspension, 0.5% wt% shows good result while 0.5% wt% Al_2O_3 nanopowder suspension in sunflower oil shows best results in terms of reduction in cutting tool temperature difference. The 0.25% nanopowder suspension of Al_2O_3 and TiO_2 doesn't show effective results in comparison with other suspensions.

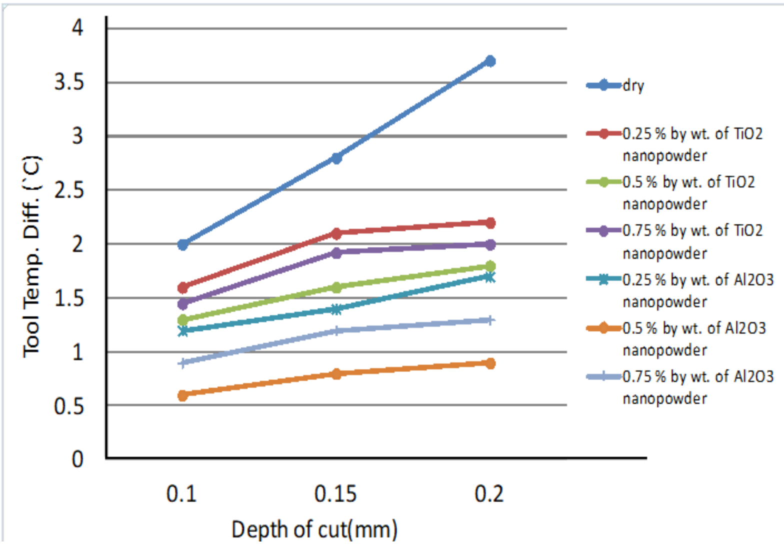


Figure 6. Variation of Tool Temp. Diff. and Depth of cut (Fluid flow rate: 0.45 ml/min)

From the above graph, it is clear that on increasing the depth of cut, there is also an increase in tool temperature (Figure 6). Increasing depth of cut, increases the cutting force required to cut the workpiece which is the root cause of increase in tool temperature. Here also 0.5% nanopowder suspensions of Al_2O_3 in sunflower oil gives the best performance.

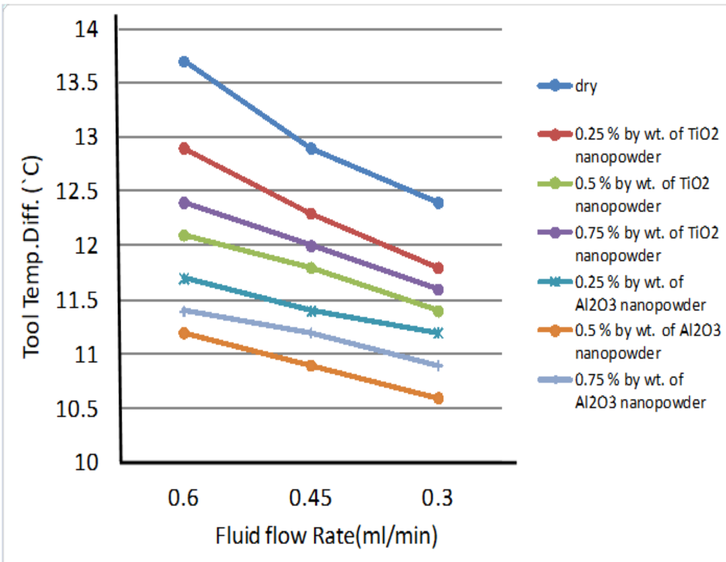


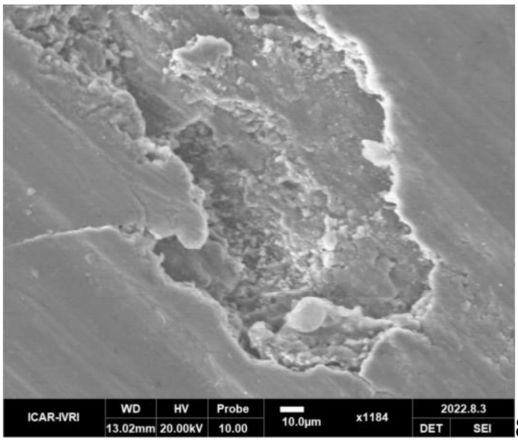
Figure 7. Variation of Tool Temp. Diff. and Fluid Flow Rate (Depth of cut: 0.15 mm)

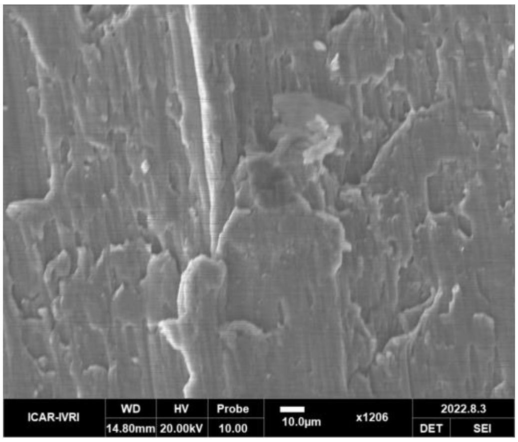
From the above graph, it is clear that with continuous decrease in fluid flow, the tool temperature goes on increasing (Figure 7). The limited supply of fluid reduces the cooling effect of lubricant. Here also 0.5% nanopowder suspensions of Al_2O_3 in sunflower oil give the best performance.

VISUALIZATION STUDY

Few Scanning electron microscope (SEM) images of Ti-6Al-4V high temperature alloy workpiece have been captured to study the indepth behaviour of microstructure of machined workpiece as shown in Figure 8. Heavy wear tracks and cracks found in case of dry milling (Fig. (a) while small amount of wear is obtained in case of vegetable oil based nanolubrication

(Fig. (b).



8(a)


8(b)

Figure 8. SEM images of Ti-6Al-4V workpiece in (a) Dry condition (b) Nanolubrication condition

CONCLUSIONS

Following conclusions are obtained from this work on Environmently sustainable milling operation on Ti-6Al-4V aerospace grade alloy using Al_2O_3 and TiO_2 nanoparticles suspensions in sunflower oil.

1. Tool temperature increases with increase in cutting speed. This is due to decrease in time of heat dissipation at machining zone.
2. Tool temperature increases with increase in depth of cut. This is due to increase in cutting forces acting at the machining interface.
3. Tool temperature increases with decrease in fluid flow rate. This is due to reduction in nanolubricant supply in machining zone which results in increase in cutting tool temperature.
4. Al_2O_3 nanoparticles suspension in sunflower oil showed better performance as compared to TiO_2 nanoparticles.
5. 0.50% by weight of Al_2O_3 nanoparticles suspension in sunflower oil showed maximum reduction in temperature difference at different operating conditions.
6. SEM images of milled Ti-6Al-4V workpiece showed significant improvement in its microstucture in nanolubrication condition as compared to dry milling.
7. These findings will be useful in design and development of Environment friendly and sustainable manufacturing platforms in near future.

REFERENCES

[1] Agarwal S. M and Patil N. G. (2018). Experimental study of non edible vegetable oil as a cutting fluid in machining of M2 Steel using MQL, *2nd International Conference on Materials Manufacturing and Design Engineering*, 20, 207-212.

[2] Cai X J, Liu Z Q, Chen M and Long An Q. (2012). An experimental investigation on the effects of minimum quantity lubrication oil supply rate in high-speed end milling of Ti–6Al–4V, *Journal of Engineering Manufacture*.

[3] Chakule R, Chaudhari S. and Talmale P. (2019). Recent advances in green and sustainable manufacturing grinding process: A review, *Journal of Nanoscience and Technology*, 5, 857-861.

[4] Iyappan S K and Ghosh A. (2019). Small Quantity Lubrication Assisted End Milling of Aluminium Using Sunflower Oil, *International Journal of Precision Engineering and Manufacturing-Green Technology*,2, 337-345.

[5] O. Pereiraa, P. Catalab, A.Rodrigueza, T. Ostrac, J. Vivancosb, A. Riveroc, L. N. Lópezde-Lacalle. (2015). The use of hybrid CO_2+MQL in machining operations, *The Manufacturing Engineering Society International Conference, MESIC*, 492-499.

[6] Seyedzavvar M, Shabgard M. and Mohammadpourfard M. (2019). Investigation into the performance of eco-friendly graphite nanofluid as lubricant in MQL grinding, *Machining science and technology,* 569-594.

[7] Sidik N A C. (2017) Samion S and Ghaderian J, Recent progress on the application of nanofluids in minimum quantity lubrication machining: A review, *International Journal of Heat and Mass Transfer,* 79-89.

[8] Upahdyay, N. (2015). Environmentally Friendly Machining: Vegetable Based Cutting Fluid, *SAMRIDDHI, S-JPSET*: 7, 79-85.

[9] Gupta, K. (2020). A Review on Green Machining Techniques, *Procedia manufacturing*, 51, 1730-36.

[10] Sen. B, Mia. M, Krolczyk. GM, Mandal. UK, Mondal. SP. (2021). Eco-Friendly Cutting Fluids in Minimum Quantity Lubrication Assisted Machining: A Review on the Perception of Sustainable Manufacturing, *International Journal of Precision Engineering and Manufacturing-Green Technology*, 8, 249-280.

[11] Gokce Mehmet, Yapincak Goncu, Nuran AY. (2016). Environmentally friendly material: Hexagonal boron nitride", *BORON* 1 (2), 66-73.

[12] Ahsana Aqilah Ahmad, Jaharah A. Ghani, Che Hassan Che Haron. (2021) Green lubrication technique for sustainable machining of AISI 4340 alloy steel, *Jurnal Tribologi* 28, 1-19.

[13] T. P. Jeevan and S. R. Jayaram. (2018). Performance Evaluation of Jatropha and Pongamia Oil Based Environmentally Friendly Cutting Fluids for Turning AA 6061, *Advances in Tribology*, 1-9.

[14] K.M.Li, S.K. Liang. (2007). Modeling of cutting force in near dry machining, *International journal of machine tools and manufacturing*, 1292-1301.

[15] Y. M. Shashidhara, S.R. Jayaram. (2010). Vegetable Oils as a Potential Cutting Fluid—an Evolution, *Tribology International* 43 **(2010)**, 1073-1081.

[16] Lawal, S. A., Choudhury I. A., and Nukman Y. (2012). Application of Vegetable Oil-Based Metalworking Fluids in Machining Ferrous Metals—a Review, *Int J Mach Tool Manu*. 52, 1-12.

[17] L.D. Lacalle. (2006) Experimental and numerical investigation of the effect of spray cutting fluids in high speed millin. *Journal of materials processing technology*, 172(11), 11-15.

[18] G.C. Nie, X.M. Zhang, D. Zhang, H. Ding, H. (2018). An experimental study of the white layer formation during cryogenic assisted hard machining of AISI 52100 steel, *Procedia CIRP* 77, 223-226.

[19] R. Sharma, B. K. Jha and V. Pahuja. (2020). Impact of environmental friendly machining on machinability: A review, *Materials Today: Proceedings*, https://doi.org/10.1016/j.matpr.2020.12.498.

[20] Sharma, R. Jha, B K and Pahuja, V. (2021). A Comprehensive Review on Evaluation of Environmental Friendly Machinability, Cutting Fluids and Techniques in Metal Cutting Operation, *International Journal of Advanced Research*, 9(04), 223-235.

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