International Journal of Scientific Research & Engineering Trends
Volume 8, Issue 5, Sep-Oct-2022, ISSN (Online): 2395-566X

Productivity Enhancement in Machining of Al6061 alloy Subjected to Dry and Nano-fluid Assisted Minimum Quantity Lubrication Approach

Durgesh Singh, Sankalp Verma
Department of Mechanical Engineering,
Shri Shankaracharya Technical Campus,
Shri Shankaracharya Group of Institutions
Bhilai, Chhattisgarh
durgeshsingh.030.rcet@gmail.com, sankalpv.07@gmail.com

Abstract- Since there is a lot of concern regarding energy wastage in the current world, so it is important to develop alternative methods which can be energy efficient for machining. Dry, minimum quantity lubrication (MQL) and nanofluid MQL-assisted are some of those processes. Investigation of experimental machining process parameters has been on notice for several decades among researchers. Aluminium (Al) 6061 alloys have been widely used in the field of automobile and aerospace industries owing to exceptional characteristics. In this paper, the Al6061 alloy specimen has been employed for the machining investigation subjected to dry, MQL and nanofluid (h-BN and Graphene) MQL-assisted CNC turning operation. The influence of the machining parameter on the wear response in the turning of Al6061 with dry and MQL employing nanoparticles-based nanofluid (h-BN and Graphene) was examined. These Al6061 alloy specimens were machined by varying the cutting speed (CS) (180-200 m/min), feed rate (FR) (0.1-0.3 mm/rev) and depth of cut (DOC) (0.5 mm) their influences on surface finish and tool wear were analyzed. The processes were performed in dry, MQL and nanofluid (h-BN and Graphene) MQL-assisted environments. It was found that machining under the nanofluid MQL-assisted conditions is preferable due to better surface finish and tool wear. Moreover, it was evident that machining characteristics were much more satisfactory in MQL-assisted conditions over the dry and MQL conditions.

Keywords - Composites; Al6061; Minimum quantity lubrication; Machining; Surface finish; Tool wear; Optical microscopy.

I. INTRODUCTION

Today the interest is developing in the manufacturing industry for a good quality product, low cost and high profitability. Aluminium6061 alloy has been widely used because of its wide application range in the field of automobile and aerospace industries. Aluminium is the most utilized metallic alloy because of its high availability, good corrosion resistance, high thermal and electrical properties, low density, and high ductility and malleability making it easy to machine.

Aluminium is among the most suitable materials to manufacture lighter parts for different automobiles because of its high specific mechanical properties, and low density. Their strength and wear resistance are comparable to cast iron, with three times the thermal conductivity and with around 67% less density. With these properties, Aluminium alloys are ideal materials for the manufacture of lightweight machining vehicles and equipment and other materialistic parts. Machining is any of various processes in which a piece of raw material is cut into a desired final shape and size by a controlled material-removal process. Machining is a part of the manufacture of many metal products, but it can also be used on materials such as wood, plastic, ceramic, and composites. Much of modern-day machining is carried out by computer numerical control (CNC), in which computers are used to control the movement and operation of mills, lathes, and other cutting machines. Machining requires attention to many details for a workpiece to meet the specifications set out in the engineering drawings or blueprints. Besides the obvious problems related to correct dimensions, there is the problem of achieving the correct finish or surface smoothness on the workpiece.

The inferior finish found on the machined surface of a workpiece may be caused by incorrect clamping, a dull tool, or inappropriate presentation of a tool. Frequently, this poor surface finish, known as chatter, is evident by an undulating or irregular finish, and the appearance of waves on the machined surfaces of the workpiece. Machining is any process in which a cutting tool is used to remove small chips of material from the workpiece (the workpiece is often called the "work"). To perform the operation, relative motion is required between the tool and the work. This relative motion is achieved in most machining operations employing a primary motion, called "cutting speed (CS) and a secondary motion called "feed". The shape of the tool and its penetration into the work surface, combined with these motions, produce the desired shape of the resulting work surface. The primary functions of a cutting coolant are cooling and lubricating the workpiece in a machining process. Lubrication property in cutting coolant reduces the abrasion and adhesion at low CS as well as greases the contact areas between chips and tool rake face.

Today vast variety of cutting fluids are available and the effectiveness of cutting fluid depends upon various factors such as cutting parameters, strategies for cutting fluid application and types of machining. The properties of cutting fluids should not change within a range of pressure, temperature and time having the same stable chemical composition. For instance, cutting liquids must prevent corrosion between workpiece material and cutting tool as well as lubricating oil of slides and machine bearing. Cooling is one of the most important challenges in the machining process. High adhesion at high CS ranges, high thermal loads as well as the work hardening of the material present some other difficulties in machining. The conventional methods of enhancing the cooling rate have already reached their limits.

The use of novel approaches is essential in order to achieve high-performance cooling and lubrication. Nanofluids provide a potential way to fulfill this requirement. Nanofluids belong to the novel group of potential heat transfer fluids with superior thermo physical properties and heat transfer performance. Results of the latest research with nanofluids in machining show the promising performance of these fluids as a replacement for the conventional metalworking fluids when accompanied with the MQL techniques.

II. LITERATURE REVIEW

The manufacturing practices and technologies adopted as a part of sustainable machining were evaluated, analyzed and optimized for sustainability impacts. Even though sustainable machining is a critical aspect of sustainable manufacturing, the studies carried out to assess the ecological and social effects of sustainable machining are insufficient. Most of the research that has analyzed the effects of sustainability conducted so far is limited to the economic aspects i.e. from discovering the newer techniques of material removal as a substitute to conventional machining as well as to the optimization of various variables contributing to the machining process. Some of the researchers have attempted to analyze the environmental impacts. In a study carried out by, Rotella et al. [1], the milling process of a non-conventional material g-TiAl alloy was analyzed for ecological and environmental effects with three cooling and lubricating conditions i.e., flooded cooling, MQL and dry machining. Shao et al. [2] have proposed a methodology that uses a virtual model of a machining system to analyze the environmental impact of the process.

Nanoparticle inclusion was found to be beneficial in improving the coolant properties in terms of enhanced thermal conductivity and improved heat transfer coefficients up to an inclusion fraction of 6% of the nanoparticles. Improved surface roughness and characteristics of AISI D2 tool steel using carbon nanotubes (CNT) in the grinding process were obtained [3]. The result shows that by utilizing carbon nanotubes, the surface characteristics were improved from the micro level to the nano level. The nanofluid-assisted MQL application results in significant energy savings and costs in a mesoscale grinding process in a miniaturized machine tool system [4].

Nanodiamond particles and paraffin oil are used as nanofluid, and a series of nanofluid MQL mesoscale grinding experiments were carried out. The experimental results show that the nanofluid MQL approach can significantly reduce the grinding forces and surface roughness compared with the dry and pure MQL cases [5]. In addition, smaller nanodiamond particles can be more beneficial to produce better ground surfaces. The utilization of nanofluids MQL results in the reduced magnitudes of average drilling torques and thrust forces [6].

The nodal temperatures that represented the cooling capabilities of the fluid decreased with the CNT content. However, the change was less than 2% of the CNT inclusion, corresponding to the change in thermal conductivity. In another study, nanographene-enhanced vegetable oil fluid provided better results in terms of wettability and a reduced friction coefficient [7]. The improvement was based on the increased thermal conductivity and enhanced heat transfer coefficient. A lot of research on the application of nano-cutting fluids has been reported in the literature about the use of nanoparticles as additives to traditional oil-based lubricants and improved machining performance in terms of reduced wear and decreased friction.

Research on the application of nanoparticles as a water-based cooling/lubricating medium is still very rare [8]. The application of water-based Al_2O_3 and diamond nanofluids in the MQL grinding showed promising improvements in surface roughness, a reduction in the grinding force, and an improved G-ratio with high concentrations of nanofluids as compared to pure water application. Research has been carried out to investigate the wheel wear and the tribological characteristics in wet, dry and MQL grinding of cast iron. The tribological properties and application performance of water-based TiO_2 nanofluid were investigated in the MSR 10D fourball tribotester and bench drilling operation [9]. It was found that the surface modified TiO_2 nanoparticles can effectively reduce the load-carrying capacity, friction reduction and anti-wear properties of pure water. Water-based nanofluids can serve as more sustainable and environment-friendly cutting fluids, given the toxicity and non-biodegradability of the oil-based fluids [10]. Vakkas et al. [11] made efforts to develop the nano-MQL by the addition of hBN particles. This nano-MQL was compared with pure MQL. The results showed that nanofluid with 0.5% vol showed better results than pure MQL.

1. Knowledge Gained from the Literature:

- A lot of research has been conducted in the field of MQL as a sustainable manufacturing technique. This is because the metalworking fluids used as the cooling and lubricating media in the machining operations create many concerns related to the personnel's health and safety as well as a significant increase in the cost of machining operations. However, the most available data is limited to the effects of the dry and MQL on the machining parameters. Research investigation on the machining characteristics of the Al6061 specimen subjected to dry, MQL and nanofluid assisted MQL is seldom found.
- Water-based nanofluids-assisted MQL is a new area of cutting fluids in machining applications replacing the conventional oil-based MQL for increased sustainability of the machining processes as they combine the higher cooling rate of water with the high lubricating effects of the nanoparticles.
- To maximize the efficiency of cutting fluids in machining processes the knowledge of machining conditions and cutting fluid types is critically important. However, misemploy of cutting fluid and nonefficient methods of disposal can raise health issues and environmental impact.
- The inclusion of solid lubricants and nanofluids in lubrication/cooling techniques increases the productivity of the process due to a reduction in friction and heat at the cutting zone.
- High productivity is essentially associated with high CS, DOC and FR resulting in high temperature in the cutting zone. Consequently, the quality of a product, dimensional accuracy and tool life deteriorated. If the FR and CS are reduced just for smoothness of the surface, it is just a waste of resources without significant gains in productivity.
- Minimum quantity lubrication (MQL) and dry machining have been successfully applied in some machining processes and have been classified as environmentally friendly techniques. Nowadays, the advancement in technology has identified solid lubricants, nano-lubricants and ionic fluids increasing the productivity and performance of the product. Most common cooling techniques have been widely used as flood cooling; MQL, dry cutting and cryogenic cooling possess characteristics in terms of efficiency, cost, energy consumption, disposal and environmental hazard.

III. OBJECTIVES

Aluminium is the most utilized metallic alloy as a base matrix element in the development of MMCs because of its high availability, good corrosion resistance, high thermal and electrical properties, low density, and high ductility and malleability making it easy to machine. Owing to the above-stated exceptional characteristics Al alloys found their application in numerous industries. Hence, more in-depth investigations on the machining characteristics are required.

Based on the literature review objectives of the current research work are:

- Investigation of experimental machining process parameters has been on notice for several decades among researchers, owing to the necessity of tool wear and surface finish while performing the advanced machining processes. So, an experimental investigation of machining parameters during CNC turning was performed to investigate the effects of CS (180 and 200 m/min), FR (0.1, 0.2, and 0.3 mm/rev) and DOC (0.5 mm) on the tool wear and surface roughness of the Al6061 alloy dry, MQL and nanofluids (h-BN and Graphene) assisted machining environment.
- Dry and Groundnut oil-based nanofluid MQL (plain, h-BN and Graphene) are used to study the turning response of the Al6061 specimen to minimize the tool wear and surface roughness.
- The machinability studies under the dry and Groundnut oil-based nanofluid MQL (plain, h-BN and Graphene) ambient conditions were conducted to analyze the influence of machining parameters such as CS (180-200 m/min), FR (0.1-0.3 mm/rev) and DOC (0.5 mm) their influences on surface finish and tool wear were analyzed.
- To investigate and measure the tool wear employing a Dino-lite microscope and software.
- To measure the surface roughness induced due to machining of Al6061 subjected to dry, MQL and nanofluid (h-BN and Graphene) assisted MQL ambient environment.

IV. MATERIALS AND METHODS

1. Materials:

The composition of the Al6061 alloy is Ti – 0.15, Mn – 0.15. Si – 0.4-0.8, Cr – 0.04-0.35, Fe – 0.7, Cu – 0.15-0.4, Mg – 0.8-1.2, Zn – 0.25, others – 0.05 and Al – balance. The properties of h-BN nanoparticles used for the experiment are presented in **Table 4.1**. The procured h-BN nanoparticles are 99.8 pure and particles size ranging from 100-200 nm. The appearance of the h-BN

International Journal of Scientific Research & Engineering Trends
Volume 8, Issue 5, Sep-Oct-2022, ISSN (Online): 2395-566X

nanoparticles is white and having thermal conductivity is ~ 120 w.mk^{-1}.

Table 1. Properties of h-BN used for the experiment.

Purity of h-BN	99.8%
Particle Size	100-200 nm
Colour	White
Thermal conductivity	~ 120 w.mk^{-1}

The properties of Graphene nanoparticles (GNPs) used for the experiment are presented in **Table 4.2**.

Table 2. Properties of graphene used for the experiment.

Purity of graphene	>99%
Lateral Dimension (X, Y)	5-10 µm
Thickness	3-8 µm
Special surface area	180 m^{2}g^{-1}
Colour	Black
Thermal conductivity	~ 5000 w.mk^{-1}

2. Machining:
The irregular portion of the procured specimens is removed using simple turning and facing operations, and the samples are converted into clean cylindrical rods. This clean Al6061 cylindrical rod is then clamped in the high-speed CNC lathe to determine the effects of numerous input machining variables on the surface profiles under dry, MQL and nano-fluid machining conditions. First dry machining was performed and then MQL and nano-fluid machining.

All the experiments have been performed under ambient conditions. In this machining process, the various stages of CS and FR were followed, while maintaining the DOC as constant. To determine the effect of FR and CS on the surface roughness under dry, MQL and nano-fluid machining environments, this approach was adopted.

Since Polycrystalline Diamond (PCD) cutting tool inserts are more expensive than necessary, replacing them with tungsten carbide (TC) tools results in higher production rates at lower costs. Hence, in this investigation, TC tool (Grade: KC850 and Price: 550 rs/pcs) was used for the machining process. The lubricant used for MQL is groundnut oil and for nano-fluid MQL machining fluids are groundnut oil/0.25% of h-BN (Nano-fluid-1) and groundnut oil/0.25% of graphene (Nano-fluid-2) nanoparticles. The nanofluid samples are prepared by suspension of h-BN and GNPs in groundnut oil (99.75 % groundnut oil + 0.25 % nanoparticles). Before performing the nano-fluid MQL machining operation, the mixture of Nano-fluid-1 and Nano-fluid-2 was ultrasonicated for 40 minutes to promote its dispersion using ultrasonic sound and hence, increase its solubility so that it gets completely mixed and the solute does not get settled down.

The roughness measurement was noted from 3-6 different locations on the machined surfaces of the metallic rods, and the average value was determined for a particular surface. Based on the literature review, **Table 4.3** has been prepared to investigate the effects of various turning processing parameters on surface roughness and tool wear. **Table 4.3** presented input machining parameters and their levels (FR, DOC and CS), machining environment (dry, MQL, Nano-fluid-1 and Nano-fluid-2) and output variables (surface roughness).

Table 3. Parameters for conducting experiments.

F (mm/rev)	DOC (mm)	CS (m/s)	Material	Machining Environment	Output Variables
0.1	0.5	180	Al6061 cylindrical specimen	Dry	Surface roughness
	0.5	200			
0.2	0.5	180			
	0.5	200			
0.3	0.5	180			
	0.5	200			
0.1	0.5	180		MQL	
	0.5	200			
0.2	0.5	180			
	0.5	200			
0.3	0.5	180			
	0.5	200			
0.1	0.5	180		Nano-fluid-1 MQL	
	0.5	200			
0.2	0.5	180			
	0.5	200			
0.3	0.5	180			
	0.5	200			
0.1	0.5	180		Nano-fluid-2 MQL	
	0.5	200			
0.2	0.5	180			
	0.5	200			
0.3	0.5	180			
	0.5	200			

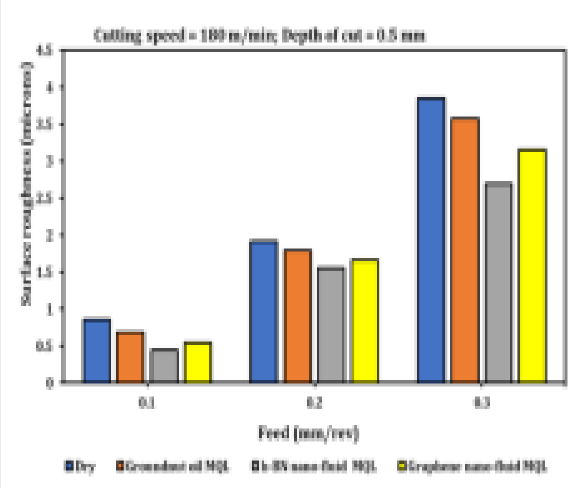
V. RESULT AND DISCUSSION

International Journal of Scientific Research & Engineering Trends
Volume 8, Issue 5, Sep-Oct-2022, ISSN (Online): 2395-566X

Table 5.1 presented input machining parameters and their levels (FR, DOC and CS), machining environment (dry, MQL, Nano-fluid-1 and Nano-fluid-2) and values of the output variables (surface roughness) estimated from the surface roughness tester. As compared to dry, MQL, Nano fluid-2 MQL, less surface roughness were observed during the machining subjected to Nano-fluid-1 MQL (h-BN).

Table 4. Parameters for conducting CNC turning experiments.

Exp. Run	FR (mm/rev)	DOC (mm)	CS (m/min)	Material	Machining Environment	Output Variables
1	0.1	0.5	180	Al6061 cylindrical specimen	Dry	0.8655
2		0.5	200			0.7082
3	0.2	0.5	180			1.9126
4		0.5	200			1.6792
5	0.3	0.5	180			3.8528
6		0.5	200			3.2054
7	0.1	0.5	180		MQL	0.69215
8		0.5	200			0.4468
9	0.2	0.5	180			1.7996
10		0.5	200			1.5457
11	0.3	0.5	180			3.5815
12		0.5	200			3.1005
13	0.1	0.5	180		Nano-fluid-1 MQL (h-BN)	0.44465
14		0.5	200			0.39225
15	0.2	0.5	180			1.5596
16		0.5	200			1.3311
17	0.3	0.5	180			2.69235
18		0.5	200			2.8047
19	0.1	0.5	180		Nano-fluid-2 MQL (Graphene)	0.54465
20		0.5	200			0.4231
21	0.2	0.5	180			1.6596
22		0.5	200			1.4999
23	0.3	0.5	180			3.15235
24		0.5	200			2.9089



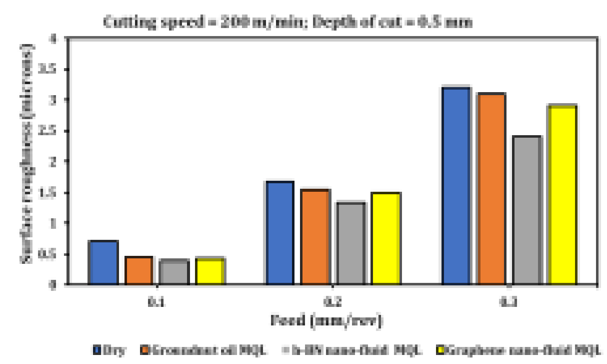


Fig 1. Surface roughness values in different machining environments for the Al6061 specimen.

Figure 5.1 displays the comparison of surface roughness values in different machining environments for the Al6061 specimen. However, the BUE reduces and chip fracture decreases as the speed increases, and hence surface comes out smooth. It was found that with the increase in FR, the surface roughness increased. Under dry machining, the surface profile was found to be smoother at the lower feeds. Generally, the material removal increases with the increase of FR which increases the temperature and forces. Due to this wear in the cutting tool increases and henceforth surface roughness is also enhanced.

In comparison with dry machining, MQL machining shows better surface quality because of the lubricant effect of MQL oil, so at the tool chip interface overrake surface quantity of friction gets reduced. The BUE formation for Al6061 was more severe under dry machining compared to MQL and nanofluid-assisted MQL machining which was observed while microscopic investigations were obtained at the rake surface. High pressure in MQL also results in easy chip removal from the rake surface.

VI. CONCLUSIONS

In this work, an Al6061 alloy specimen has been employed for the machining investigation subjected to dry, Groundnut oil-MQL and Groundnut oil-based nanofluid (h-BN and Graphene) MQL-assisted CNC turning operation. The influence of the machining parameter on the wear response in the turning of Al6061 with dry and MQL employing nanoparticles-based nanofluid (h-BN and Graphene) was examined. The turning operation was performed at different feed rates and cutting speeds, each under both MQL and dry machining.

Based on the investigations the concluding remarks are:

- A substantial lessening in surface roughness while machining Al6061 was evident subjected to Groundnut oil-based h-BN nanofluid MQL machining conditions. This may be because of the lubrication effect of MQL.

- It is found that the surface finish increases as the cutting speed increases.
- Groundnut oil-based h-BN nanofluid MQL machining yields better results as compared to dry and groundnut oil-based graphene nanofluid MQL machining environments

REFERENCES

[1] Rotella G, Priarone PC, Rizzuti S, Settineri L. Evaluation of the Environmental Impact of different Lubrorefrigeration Conditions in Milling of γ-TiAl Alloy. Glocalized Solutions for Sustainability in Manufacturing, Berlin, Heidelberg: Springer Berlin Heidelberg; 2011, p. 365–70. https://doi.org/10.1007/978-3-642-19692-8_63.

[2] Shao G, Kibira D, Lyons K. A Virtual Machining Model for Sustainability Analysis. Volume 3: 30th Computers and Information in Engineering Conference, Parts A and B, ASMEDC; 2010, p. 875–83. https://doi.o rg/10.1115/DETC2010-28743.

[3] Prabhu S, Vinayagam BK. Nano surface generation of grinding process using carbon nano tubes. Sadhana 2010; 35:747–60. https://doi.org/10.1007/s12046-010-0048-3.

[4] Lee P-H, Nam TS, Li C, Lee SW. Environmentally-Friendly Nano-fluid Minimum Quantity Lubrication (MQL) Meso-scale Grinding Process Using Nano-diamond Particles. 2010 International Conference on Manufacturing Automation, IEEE; 2010, p. 44–9. https://doi.org/10.1109/ICMA.2010.27.

[5] Nam JS, Lee P-H, Lee SW. Experimental characterization of micro-drilling process using nanofluid minimum quantity lubrication. Int J Mach Tools Manuf 2011; 51:649–52. https://doi.org/10.1016/j.ijmachtools.2011.04.005.

[6] Park K-H, Ewald B, Kwon PY. Effect of Nano Enhanced Lubricant in Minimum Quantity Lubrication Balling Milling. J Tribol 2011; 133. https://do i.org/10.1115/1.4004339.

[7] Gu Y, Zhao X, Liu Y, Lv Y. Preparation and Tribological Properties of Dual-Coated TiO_2 Nanoparticles as Water-Based Lubricant Additives. J Nanomater 2014; 2014:1–8. https://doi.org/10.1155/2014/785680.

[8] Shen B, Shih AJ, Tung SC. Application of Nanofluids in Minimum Quantity Lubrication Grinding. Tribology Transactions 2008; 51:730–7. https://doi.org /10. 1080/10402000802071277.

[9] Gu Y, Zhao X, Liu Y, Lv Y. Preparation and Tribological Properties of Dual-Coated TiO 2 Nanoparticles as Water-Based Lubricant Additives. J Nanomater 2014; 2014:1–8. https://doi.org/10.1155/2014/785680.

[10] Rahman MM, Kadirgama K, Ab Aziz AS. Artificial Neural Network Modeling of Grinding of Ductile Cast Iron using Water Based SiO2 Nanocoolant. International Journal of Automotive and Mechanical Engineering 2014; 9:1649–61. https://doi.org/10.15282/ijame.9.2013.15.0137.

[11] Yıldırım ÇV, Kıvak T, Sarıkaya M, Şirin Ş. Evaluation of tool wear, surface roughness/ topography and chip morphology when machining of Ni-based alloy 625 under MQL, cryogenic cooling and CryoMQL. Journal of Materials Research and Technology 2020; 9:2079–92. https://doi.org/10.1016/j.jmrt.2019.12.069.