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Evaluation of nano fluids in minimum quantity lubrication hard machining of Monel K500 material for high heat-resistant application

Monica Devendiran[1], Arul Kulandaivel[2], Vinayagam Mohanavel[3,4], Sathish Kannan[5,6]

[1]Chennai Institute of Technology, Department of Mechatronics Engineering. Chennai, Tamil Nadu, India.

[2]Agni College of Technology, Department of Mechanical Engineering. Chennai, Tamil Nadu, India.

[3]Bharath Institute of Higher Education and Research, Centre for Materials Engineering and Regenerative Medicine. Chennai, Tamil Nadu, India.

[4]Chandigarh University, Department of Mechanical Engineering. Mohali, Punjab, India.

[5]Saveetha Institute of Medical and Technical Sciences, Saveetha School of Engineering, Department of VLSI Microelectronics. Chennai, Tamil Nadu, India.

[6]Amity University Dubai, Department of Mechanical Engineering. Dubai, United Arab Emirates.

e-mail: monicaphd6@gmail.com, arulroll7@gmail.com, mohanavel.phd@gmail.com, sathishk.dr@outlook.com

ABSTRACT

In turning, the interaction among target material tool and chip usually causes thermal damage as well as tool wear. High-pressure coolant is an emerging technology that delivers and the tool interface region. High coolant pressure allows better penetration of coolant by enhancing the lubrication effect, and decreasing thermal damage and tool wear through cooling effect at the cutting zone. The manufacturing sector wants to create a lot of goods in a short amount of time as the fourth industrial revolution approaches. Response surface design and the Taguchi L27 orthogonal array methodological paradigm are used in this work. The cutting speed (750, 1000, 1250 rpm), feed rate (0.075, 0.1, 0.125 mm/rev), depth of cut (0.25, 0.50, 0.75 mm), and fluid pressure (2.5, 5, 7.5 bar) represent as the process parameters. The objective of this paper, is to investigate how the surface finish, cutting force, and tool wear mechanism are influenced by coolants under the different coolant pressure, depth of cut, feed and speed in turning of monel using coated carbide tool. Also in this work the performance of cutting coolant (CuO and graphene) were compared with respect to tool wear, cutting force, surface roughness, cutting zone temperature chip morphology and surface modification during turning of monel. The findings showed that, under extreme wear conditions, GO-based nano fluids improved machining performance, as measured by increased cooling and lubrication regime, cutting temperature of 122 °C, and surface roughness of 0.0462 µm and flank wear of 0.2 mm.

Keywords: Machining, Monel K500 Alloy; Nanofluids, Surface Roughness; Tool Wear.

1. INTRODUCTION

In metal cutting operation, the coolants plays a dominate role in achieving consistent surface quality. The main problem arise during the cutting process that is generation of high heat. The heat generation becomes more intensified in the machining of hard materials (i.e Titanium, Inconel and monel). In order to increase machinability throughout the machining process and regulate the temperature at the cutting zone, various coolants and cooling techniques have been created. The machining industry is where the flood/wet cooling technique is most commonly utilized. It offers improved lubrication during cutting operations and debris cleansing. Additionally, it aids in lowering the excessive heat that forms at the cutting contact area [1]. The major disadvantage in flood/wet coolant is that coolant never allowed to penetrate properly into the actual-tool contact area. There is a need to find an alternative coolant for betterment in turning operation.

MQL (Minimum quality lubrication) is a technique in which a small quality of oil is applied with high pressure air. Many researchers have reported the achievement of effective lubrication in the cutting process from MQL by using small quantities of coolants [2–7]. Khan et al stated significant reduction in surface roughness, tool wear and dimensional deviation in turning AISI 1060 steel with the approach of MQL. Liao and Lin reported tool life is improved at the application of MQL in machining of NAK80 hardened steel when cutting parameter are chosen properly. KHANDEKAR *et al*. [8] stated adding different nanoparticles in conventional

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fluid increases the thermal conductivity. SHARMA *et al*. [9] noced with the approach improves the tool life, surface roughness, cutting zone temperature and cutting force in various metal removal process.

The heat transfer capabilities of six distinct types of nano fluid particles—Mos2, ZrO2, CNT, polycrystalline diamond, Al2O3, and SiO2—were compared during the grinding process by CHAN *et al*. [10]. Among all fluids, it was shown that CNT nano fluids have superior heat transmission characteristics. The application of SiO2-mixed cutting fluids in turning operations was examined by SAYUTI *et al*. [11]. It has been noted that improved tool life and surface quality are correlated with reduced cutting fluid usage. MANOJKUMAR and GHOSH [12] used the MQL technique to experimentally study the performance of nano-graphite fluid. In comparison to traditional wet machining, it was observed that cutting temperature, surface roughness, cutting force, and tool wear decreased by roughly 25%, 30%, 54%, and 71%.

OZBEK *et al*. [13] investigated the impact of the eco-friendly Minimum Quantity Lubrication (MQL) system on the turning of Vanadis 10 SuperClean steel in the automotive industry. Results show that MQL significantly improved cutting temperature, tool vibration amplitude, tool wear, average surface roughness, and tool life compared to Dry machining. The cutting environment was found to be the most effective parameter for average surface roughness. The workability of Vanadis 10 SuperClean tool steel, a high vanadium alloyed powder metallurgy tool steel utilized in the automotive sector, is examined in this study in relation to dry, cryo, and cryo MQL cutting conditions. The study discovered that surface roughness, cutting temperature, tool wear, and cutting tool vibration amplitude were all improved by spraying liquid nitrogen into the cutting zone. The best results were obtained with the Cryo MQL cutting environment, which reduced the cutting temperature by 32.77%, the cutting tool vibration amplitude by 42.76%, the flank wear by 56.99%, and the surface roughness by up to 65.03% as compared to dry machining [14].

Sankar Thangavel et al attempted by adding graphene and graphene oxide to enhance the mechanical, thermal, and biocompatibility characteristics of polycaprolactone nanocomposite nanofibers. Graphene and GO were added to the nanofibers in different amounts during their synthesis [15]. Suresh Kumar Ramalingam et al conducted experimental study uses a CNC turning machine equipped with a carbide tool to optimize the machining parameters for turning SAE 8822 alloy steel under green machining. Spindle speed, feed rate, and depth of cut are controlled variables, and roughness (Ra) is the response variable [16]. Deibe Valgas dos Santos et al investigated the behavior of CA6NM super martensitic stainless steel using coated carbide tool and evaluate the effects of cutting fluid pressure and speed on wear processes, tool life, and surface roughness. Results indicate that roughness is not significantly influenced by cutting speed, cutting fluid pressure, or tool material [17]. Verner Petersen Pereira and Marcelo Araujo Camara has confirmed that there is a best cutting temperature for metal machining in order to minimize tool wear and enhance surface quality. The flank, notch, and mass loss of inserts at various cutting speeds were measured in the study using tool wear tests and dry turning of ABNT 1045 steel. Since different temperatures and roughness values vary with temperature and cutting speed, the suggested approaches, however, were unable to establish the existence of an optimal cutting temperature [18]. The surface roughness evolution of Incoloy 825 superalloys during machining operations is examined in this work. A range of high-speed machining parameters were employed, such as feed rates, cutting speeds, and cutting tools. The findings indicate that while cutting tools have little effect on surface roughness, cutting speed and feed rate are important variables [19]. Augusto Moura Martins et al The effects of turning parameters on the fatigue life, residual stress, and surface roughness of hardened AISI 4140 steel are investigated in this work. The most important factor is the feed, and residual stress profiles are influenced by the cutting parameters. After turning at higher cutting speeds and depths in conjunction with lower feeds, longer fatigue lifetimes were noted [20].

Nevertheless, there has been little research in employing nanofluids to determine the impact of MQL. When turning, it can be challenging to comprehend how varying coolant pressures affect the chip's shape. Since the cutting condition and temperature produced at the contact are closely related to the chip production and morphology during turning operations, it is crucial to comprehend these aspects [21–23].

2. EXPERIMENTAL CONDITION

The Kirloskar Turnmaster 35 was used to perform the turning function. This lathe is medium duty, with center heights of 175 mm and a center to center distance of 800 mm. A DC compound motor with 3 HP and 2.2 KW powers the head stock. The workpiece material used in this investigation is Monel K500. Monel is a nickel based alloy of HRC 27 and Ultimate tensile strength of 965 MPa. Monel K500 is comprised of Nickel and Copper as main constituents and some portions of Aluminum, Titanium, Carbon, Manganese, Iron, Sulphur and Silicon. The Carbide tool SNMG 120408 MT TT5080 is used as cutting insert coated with TiAlN- TiN. Utilizing the Plasma Vapour Deposition technique, the tool's HRA value is 93. Using a KISTLER 9257B dynamometer, the cutting force was determined. A fixture that was specifically made the cutting tool to be secured onto the dynamometer. The coolants (CuO and graphene) are delivered to the machining area with different coolant pressure. For every trial, the standoff distance of 40 mm remained constant. The Taylsurf +3 surtronic profilometer, with a transverse length of 4mm and a cutoff length of 0.8mm, was used to determine the Surface Roughness value. The cutting zone temperature was measured using the non-contact type IR pyrometer. The Tayl Surf CCi profilometry equipment was then used to measure the non-contact 3D Surface Roughness value. The evaluation of surface modification and tool wear was conducted using scanning electron microscopy. The workpiece, tool material and process parameters were selected based on the pilot studies [1]. Graphene oxide and Copper oxide nanoparticles have high thermal conductivity. When dispersed in a base fluid, they significantly improve the fluid's ability to dissipate heat generated during the turning process. This reduces the cutting temperature, which is crucial for prolonging tool life and improving the quality of the finished product. The experimental configuration as depicted in Figure 1. To measure the tool's temperature directly, a thermocouple was affixed close to the cutting zone, which is typically at the tool's cutting edge. The thermocouple was inserted into the tool holder and secured to the tool's surface using high-temperature glue. Throughout the turning process, the temperature may be continuously monitored thanks to the K-type thermocouple. The quick response time of the thermocouple is essential for detecting the sudden temperature fluctuations that take place during the turning process.

2.1. Preparation of nano cutting fluid

The cutting fluid used is a mixture of water-soluble cutting oil in a dispersed water with Graphene nano particles. The coolant is prepared by first mixing 10% of water-soluble cutting oil in Water by using Ultrasonic Probe sonicator for 15 mins at 30 KHz frequency. Then after fine mixing of oil in water, 0.5 wt % of nano graphene particles is dispersed in the mixture with the help of ultrasonic probe sonicator for 45 mins at 30 KHz frequency to facilitate homogenous dispersion of particles. The same procedure is followed to prepare the copper oxide based nanofluids. In this research work, sodium dodecyl benzene sulfonate was used as surfactant to avoid agglomeration. Agglomeration of particles will result in the reduction of vital properties such as thermal conductivity, lubricity which in turn affects the machining output responses. Hence homogenous dispersion is advisable [24].

3. RESULTS AND DISCUSSION

3.1. Surface roughness

The quality of the machined surface is based on the Surface Roughness value. In turning operation the Surface Roughness value depends upon the cutting edge of the tool. From the experimental condition, it is observed turning with graphene reduced the surface value in the range of 12% and 34% over CuO and wet coolant condition The variation of the surface roughness is much less at a lower depth of cut for the three cooling environments with increase in depth of cut. The cutting zone temperature rises with increased depth of cut (DOC), weakening the tool and work material in the process. The process of softening encourages material to flow out of the work material. Small particles are thus fed into the tool. The machining zone's temperature is lowered using the graphene method. Figure 1(c) represents the value of surface roughness at different DOC. It is seen when speed increases the surface roughness while the value decreases. From Figure 2(a) it is noticed under CuO and graphene turning condition by increasing the cutting speed, surface roughness value decrease. It is also noted a considerable reduction can be seen in surface roughness value when graphene used as coolant. At increased cutting speed work material are prone to adhesion and built-up-edge, hence leading to worse surface roughness [25]. An increase in the pressure the Surface Roughness value decrease as indicated in the Figure 2(d).

Figure 1: Experimental setup.

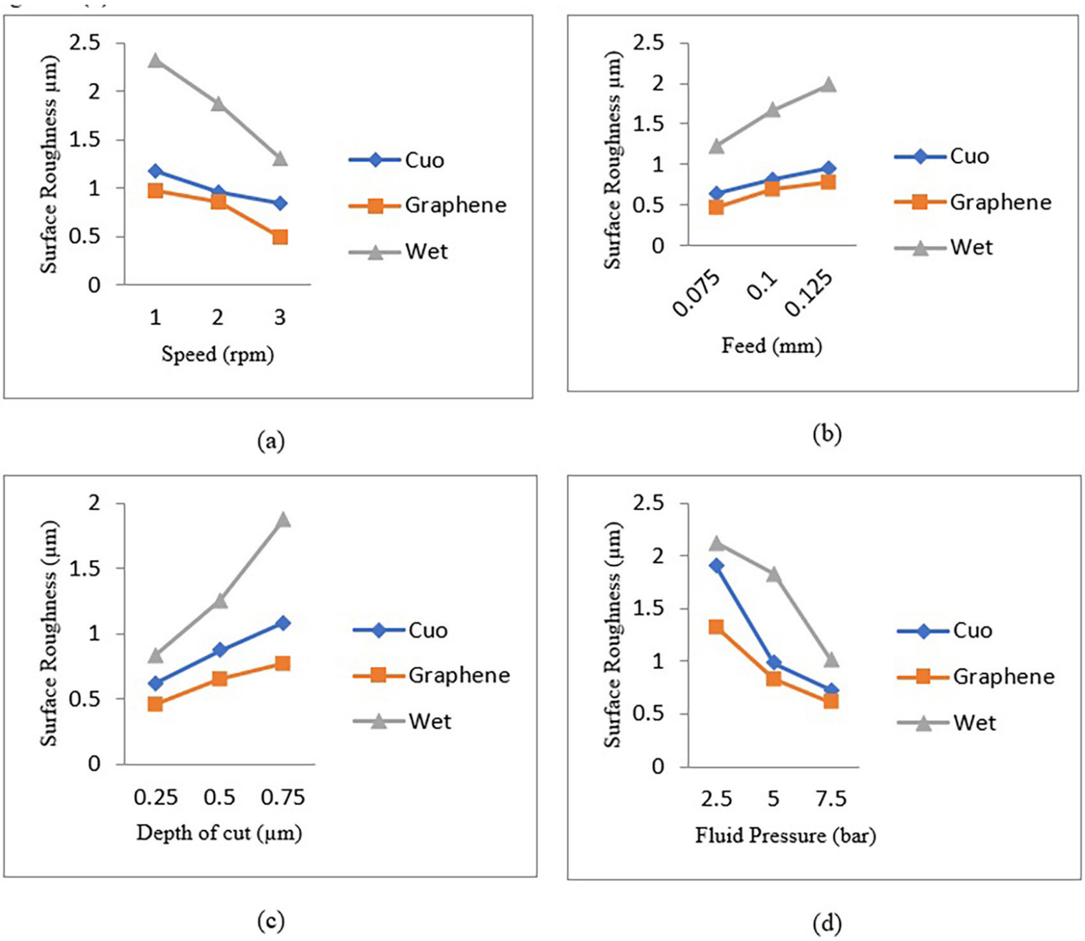
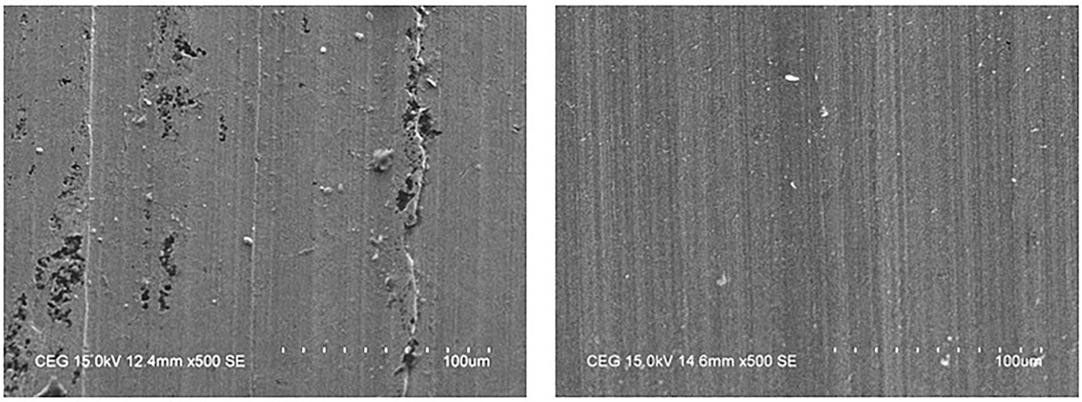


Figure 2: Variation of the surface roughness while turning Monel K500 at different conditions (a) speed (b) feed (c) depth of cut (d) fluid pressure.

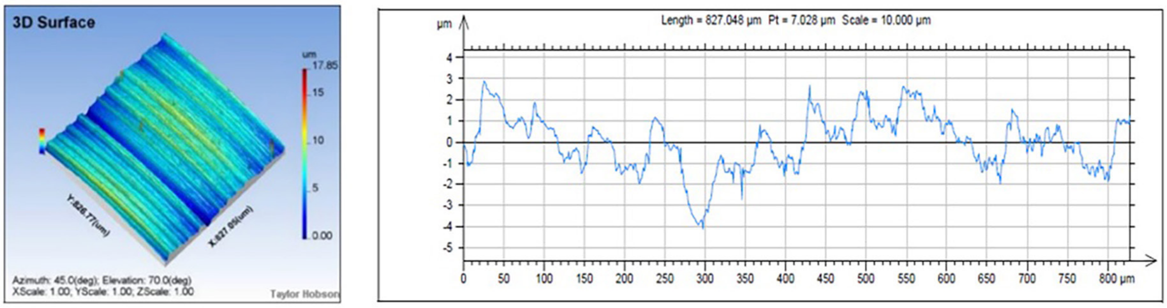


(a) (b)

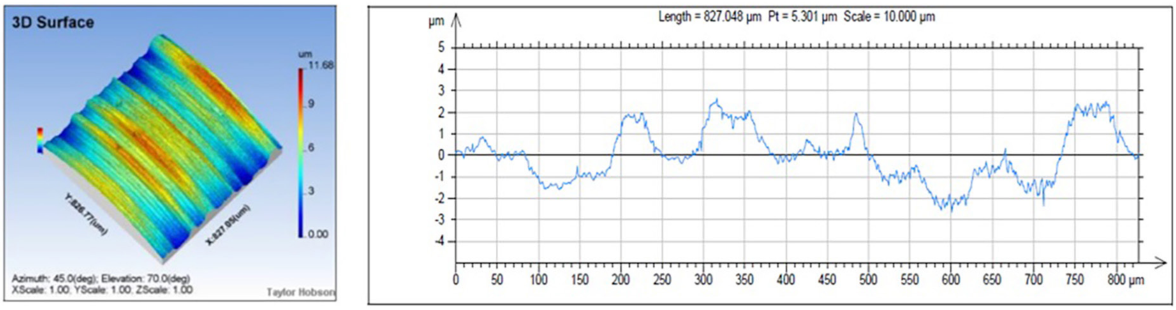
Figure 3: Variation of the surface morphology while turning Monel K500 at different conditions (a) CuO (b) Graphene.

The surface characteristic profiles and associated three-dimensional surface topographies of the machined surface under CuO and graphene turning are displayed in Figure 3. The profile exhibits greater ups and downs due to the dull tool's increased friction. Figure 4 profile makes the surface flaws which are quite evident. Less ups and downs may be seen in the surface roughness profile of the ground component beneath graphene, which leads to less flaws. The temperature at the contact zone drops when graphene coolant is applied.

The cutting force findings for CuO, graphene, and wet turning are displayed in Figure 5. Generally, as feed rates rise, so do the cutting pressures. This is because more chips are being loaded, which raises the cutting force. As it would be predicted that the cutting force result was greatly impacted by the DOC, feed rate, and

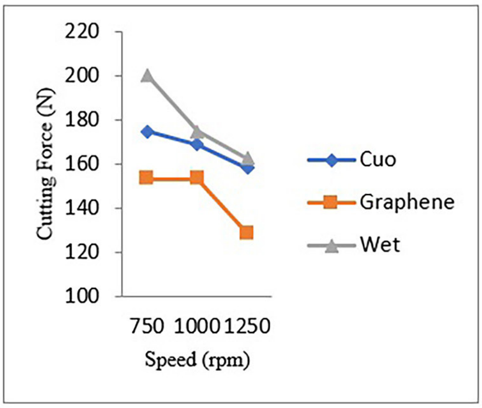


(a)

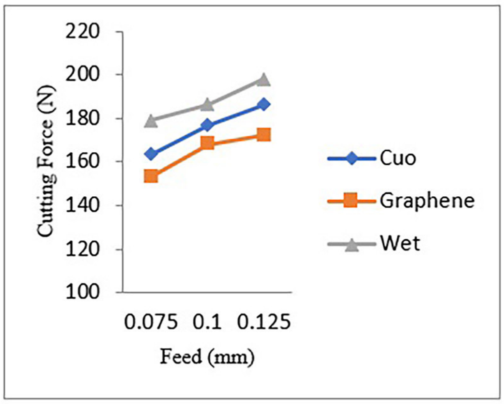


(b)

Figure 4: Variation of the 3D surface topography while turning Monel K500 at different conditions (a) CuO (b) Graphene.



(a)



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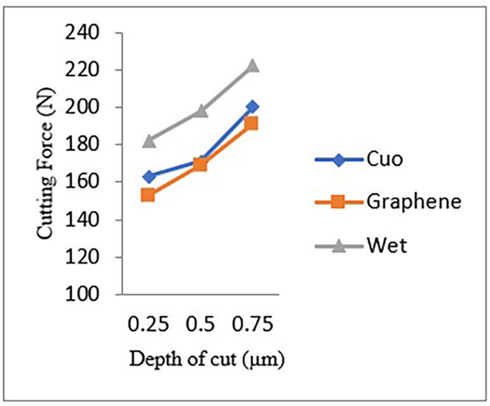
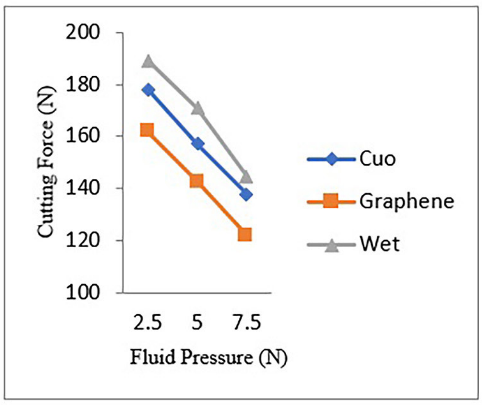


(c)



(d)

Figure 5: Variation of the cutting force while turning Monel K500 at different conditions (a) speed (b) feed (c) depth of cut (d) fluid pressure.

cutting speed. Cutting force tends to decrease as cutting speed increases. Meanwhile higher cutting force was recorded at higher DOC and with higher feed rate [26]. Further, more it is noticeable that the cutting force is decreased under graphene turning over CuO turning. With the approach of graphene the cutting was reduced in the range 17–22% compared to CuO and 17–36% over wet coolant condition. Improved lubrication and penetration are achieved at the tool-chip interface with the use of graphene and CuO coolant. The cooler's benefit is that it lowers friction at the contact between the tool and the chip, improving cushioning. In comparison to the wet cooling state, there was less shearing action and consequently reduced thrust force since the material hardness was preserved in the grapheme and CuO coolant condition.

3.2. Tool wear

The experimental findings demonstrate that the tool wear has developed after cutting the tool with three distinct coolants. The tool's surface was scanned using a 3D Taylsurf probe, as depicted in Figure 6. Because of increased adhesion, wear on the machined tool surface under wet coolant was seen with microchipping and cracks.

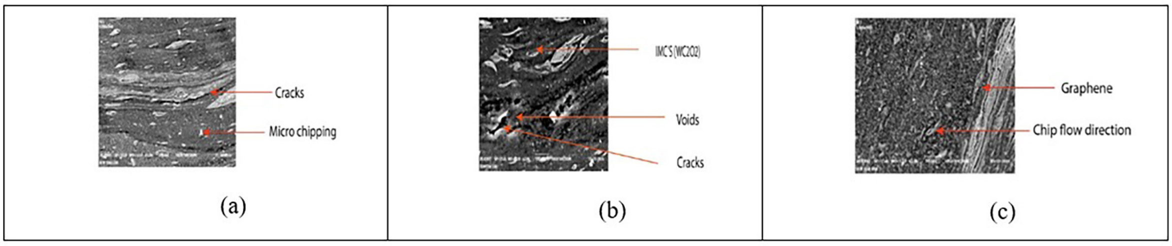


Figure 6: Variation of the tool wear while turning Monel K500 at different conditions (a) CuO (b) wet (c) graphene.

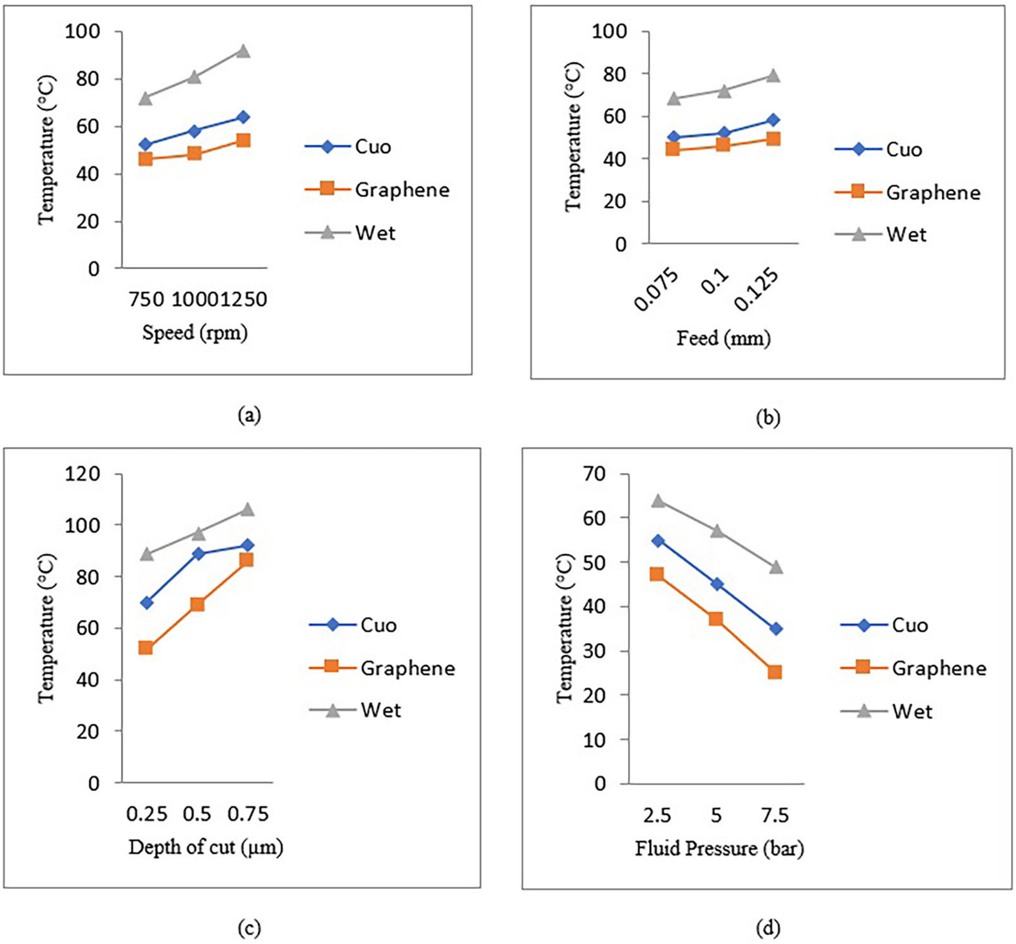


Figure 7: Variation of the cutting temperature while turning Monel K500 at different conditions (a) speed (b) feed (c) depth of cut (d) fluid pressure.

Because of the cooling effects, tool wear was reduced during machining while using graphene coolant. The inclusion of graphene oxide powder enhanced the coolant's thermal conductivity. As a result, the contact area's temperature dropped. Additionally, less wear is produced during machining with CuO coolant, which partially inhibits the formation of adhesion on the tool surface [27]. Furthermore, beneath the CuO coolant, cavities and cracks created by tool/chip abrasion were discovered on the tool surface. However, with graphene cutting, the tool surface's flat contour was visible. This demonstrated that there was reduced friction at the contact area.

3.3. Cutting temperature

The temperature rise in turning is an important attribute, because it can adversely affect its surface properties and may cause residual stress induced under the surface. Because of the relative motion between the tool and the workpiece, the tool is subjected to three different factors during any machining process: cutting force, cutting temperature, and sliding action. These variables will eventually lead to the cutting tool performing below the expectations. Loss of dimensional accuracy, greater surface roughness, and higher power consumption are all consequences of the subpar performance. Tool wear brought on by the metal cutting process's persistently during high temperatures is the cause of the subpar performance. The hardness of the tool decreases with the increase in the cutting temperature, and it becomes too soft thus fails ultimately [28]. Cutting or machining temperatures significantly affect tool wear, tool failure, and hence, tool life. turning with graphene reduces the cutting temperature to maximum of 23% over CuO and 39% over wet coolant. Better lubricating action and penetration in the cutting zone are the attributes of the coolant. Figure 7 illustrates the fluctuation in cutting temperature under various coolant environments.

4. CONCLUSION

The turning process was carried out by machining workpiece materials of Monel K500 with Carbide tool SNMG 120408 MT TT5080 coated with TiAlN- TiN under wet, graphene and CuO cooling conditions at various cutting speed, feed, depth of cut and fluid pressure. On the basis of cutting temperature, cutting force, surface roughness, chip morphology, and tool wear, the effects of graphene and CuO as cutting coolants were investigated and contrasted with wet machining. Given below is a summary of the main findings from the experiment:

i) Graphene coolant application lowers the cutting temperature in comparison to CuO and wet coolant application. When compared to the wet coolant condition, the graphene coolant lowers cutting temperature by roughly 18 to 23% and 19 to 39%. Compared to wet coolant, the cutting temperature dropped by 23% when considering CuO coolant.
ii) Graphene coolant reduces cutting force by a maximum of 36% and proves to be more efficient than the wet coolant.
iii) Graphene coolant reduces surface roughness to 12% and 34% over CuO and wet coolant condition. The CuO coolant reduces the surface roughness in the range of 14–21%.
iv) When graphene coolant is applied, there is decrease in tool wear at all three cutting speeds and feed rates.

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