Effect of Nano-MQL Using Graphene Nanoplatelets as Cutting Fluid on Lubrication During Grinding of Nimonic 90

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The mineral-based metal working fluids are used to reduce the friction and temperature generated during the machining and grinding. However, the metal working fluids are considered as unsustainable during machining and grinding processes due to its high operating and disposal cost, susceptibility to environmental pollution, health-related issues amongst the workers, and high energy consumption. On the other hand, minimum quantity lubrication (MQL) technique is widely used in machining and grinding due to its ability to lubricate and cool the grinding zone by less consumption of cutting fluid. Moreover, the selection of cutting fluid additives for the formulation of water-based nanofluid using graphene nanoplatelets (GnP) under MQL mode is not dangerous in view of environmental and ecological aspects. To fulfil the sustainability criteria, the experiments have been conducted on Nimonic 90 superalloy under dry and MQL environments. Further, the surface integrity of the ground surface has been studied using Surface Profilometer and Stereo Zoom Microscope (SZM). The results obtained during nano-MQL grinding using GnP shows that the grinding forces have been reduced significantly, and the surface quality has been improved compared to dry grinding of Nimonic 90 superalloy.

Keywords: Minimum Quantity Lubrication, Graphene Nanoplatelets, Surface Roughness, Grinding Force.

Introduction

Grinding is a machining process in which abrasives are responsible for material removal in the form of tiny chips. These abrasives are randomly oriented and different in size and shape. Due to this, few of the abrasives are participating in an actual shearing action, while rest are responsible for heat generation by rubbing the workpiece surface [1]. High heat generation is one of the prime suspects of deteriorating the ground surface quality of "difficult to grind materials" like titanium and nickel-based alloys, ceramics, and composites. The adverse effects due to the higher temperature can be minimized by using suitable cutting fluid during grinding. Generally, the mineral based metal working fluids are used to lessen the friction and temperature generated during grinding. However, the metal working fluids are considered as unsustainable during machining and grinding processes due to its high operating and disposal cost, susceptibility to environmental pollution, health-related issues amongst the workers, and high energy consumption. On the other hand, the MQL technique is widely used in machining and grinding due to its ability to lubricate and cool the grinding zone by less consumption of cutting fluid [2]. It has been reported that, although the MQL technique is widely accepted as a sustainable technique in the machining of various advanced materials, MQL is not always found to be effective due to its low capability in cooling the grinding zone [3].

To overcome the above difficulties, nanofluids are being used in MQL mode. Among various nanoparticles, graphene nanoplatelets (GnP) are found competent owing to its inherent ability to offer excellent lubrication and high thermal conductivity [4]. It has also been investigated that the GnP has significantly reduced the grinding force, grinding coefficient, surface roughness, specific grinding energy and temperature as compared to dry and MQL grinding with soluble oil [5]. From the literature, it was found that the GnP has great potential to provide efficient cooling and lubrication during grinding. Hence, the present study focuses on investigating the effect of nano-MQL using GnP as cutting fluid on lubrication during the surface grinding of difficult to grind material Nimonic 90 superalloy.

Experimental Setup and Procedure

The 3 axis CNC surface grinding machine (model: SMART-B818III) with conventional Alumina abrasive wheel (AA60K5V8) has been used to conduct the grinding experiments on Nimonic 90 superalloy. Fig.1 shows the schematic representation of the experimental setup. In this study, the GnP with an average thickness of 15 nm, purchased from Sigma Aldrich has been used for dispersion by a two-step method. GnP water-based nanofluid has been prepared by adding 0.75 vol.% of GnP to the base fluid. Sodium lauryl sulfate (SLS) surfactant was added to improve the stability of nanofluids and followed by sonication for 30 mins [6]. The grinding forces have been measured using Kistler dynamometer (Type: 9257B) attached with charge amplifier. The ground surface roughness has been measured with the help of Talysurf surface profilometer. Stereo zoom microscope has been used to study the ground surface topography by capturing the 2D and 3D images of the ground surface.

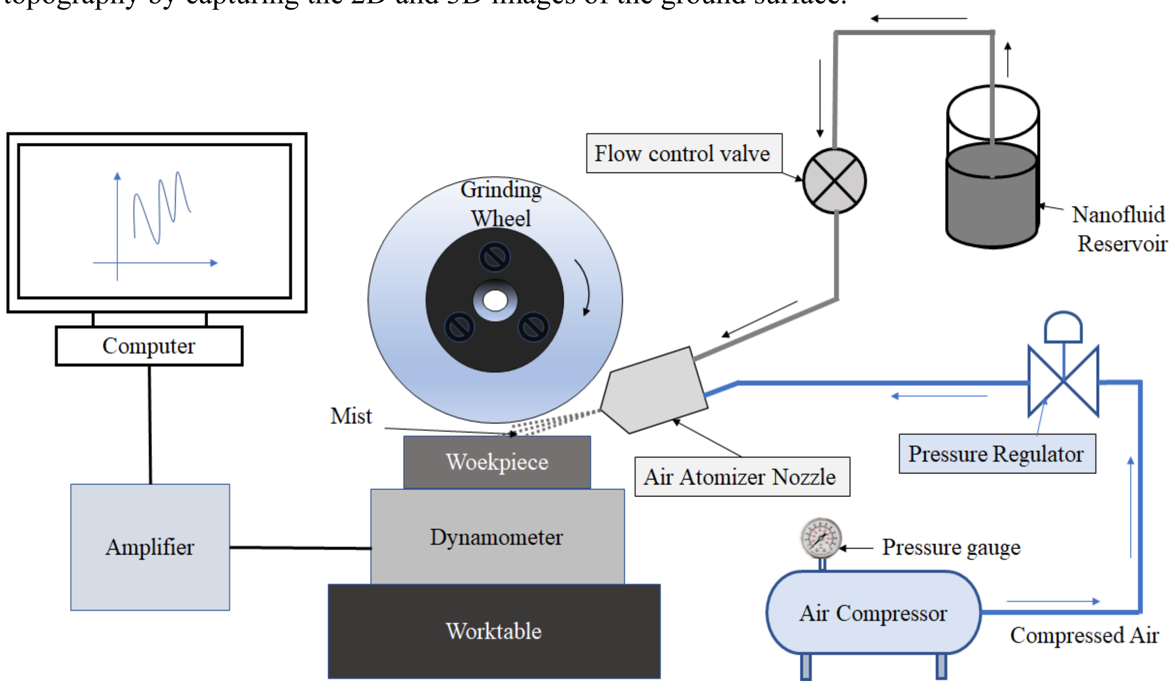

Figure 1. Schematic representation of experimental setup for grinding Nimonic 90 under MQL mode

Results and Discussion

The grinding forces and the average surface roughness (Ra) have been studied to understand the effect of nano-MQL using GnP additives on cooling and lubrication in grinding of Nimonic 90 as compared to the dry grinding.

Grinding Forces

Figure 2(a) shows the tangential and normal forces are decreasing with an increase in cutting speed. Moreover, in case of nano-MQL, the grit sharpness of the grinding wheel has been retained for a longer duration as well as GnP easily slides in between the mating surfaces resulting in lower normal and tangential grinding forces. Figure 2(b) & 2(c) shows the variations in the grinding forces with respect to table speed and depth of cut, which also indicates the significantly lower forces obtained during nano-MQL. The smaller values of grinding forces indicate the efficient cooling and lubrication obtained at the wheel work interface due to the formation of GnP thin film during the process.

a) b) c)

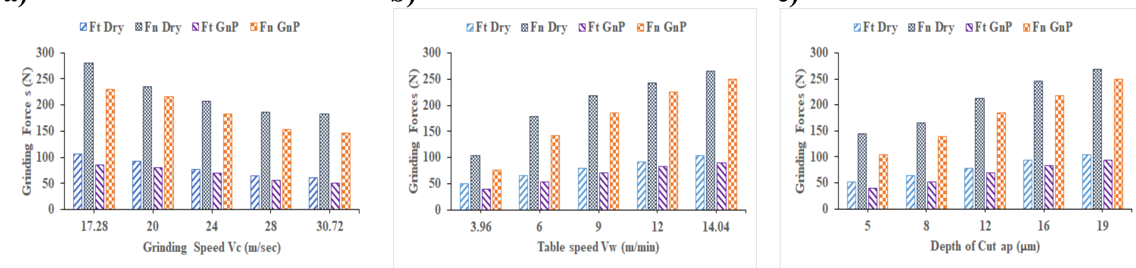

Figure 2. Variation of grinding forces under dry and MQL mode with different (a) grinding speeds, (b) table speeds and (c) depth of cut.

Surface Roughness (Ra)

Figure 3 shows the variation of average surface roughness (Ra) with respect to grinding speed, table speed and depth of cut. It can be seen that the average surface roughness decreases with an increase in grinding speed and increases with the increase in table speed and depth of cut. Moreover, in nano-MQL grinding the surface roughness are observed towards the higher side to that of dry grinding. This is possibly due to the retained sharper grits and splintering of grits during nano-MQL grinding which produces shearing marks on a ground surface resulting in higher values of surface roughness.

a) b) c)

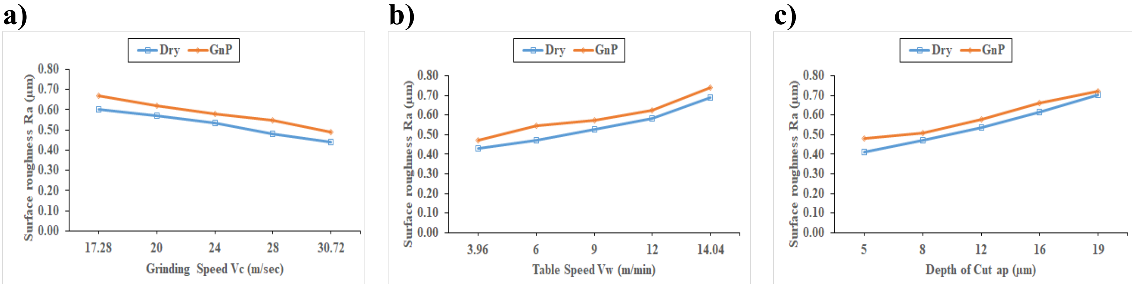

Figure 3. Variation of surface roughness under dry and MQL mode with different (a) grinding speeds, (b) table speeds and (c) depth of cut.

Surface Topography

Figure 4 illustrates the 2D and 3D SZM images of ground surfaces observed under dry and nano-MQL grinding environments. The predominant surface damage was observed in dry grinding due to severe rubbing and chip adhesion over a ground surface. However, negligible surface damage can be seen in nano-MQL grinding which indicates the lesser amount of heat accumulation. Moreover, the non-uniform surface is observed in dry grinding due to the absence of lubrication. Whereas, uniform surface is observed in nano-MQL due to proper cooling and lubrication.

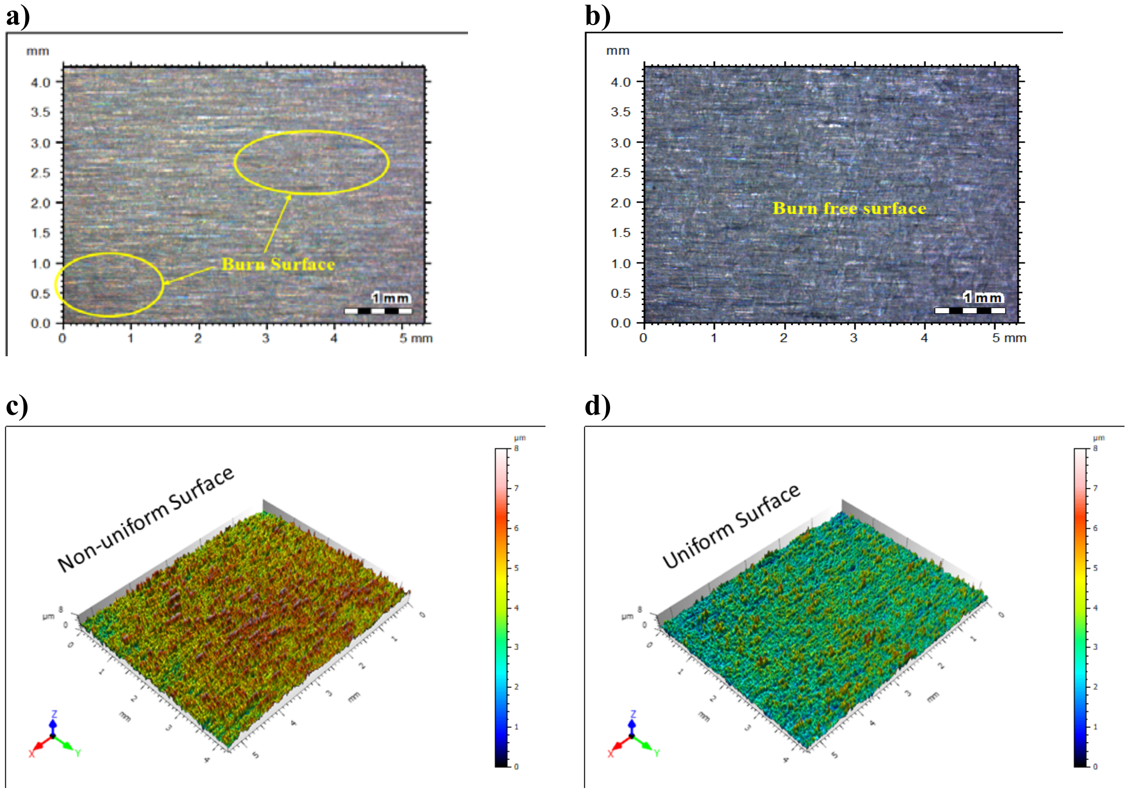

Figure 4. Surface micrographs under (a,c) dry and (b,d) MQL with GnP Nanofluid environment.

Conclusion

1. Lower tangential and normal forces have been observed in nano-MQL griding as compared to dry condition. It is attributed to the efficient cooling and lubrication obtained using GnP nanofluid.
2. SZM images of ground surface using GnP nanofluid shows clear grinding tracks, uniform, and burn-free surface. This is attributed to the grit splintering and retention of the grits sharpness for a longer duration during nano-MQL grinding.
3. Water-based GnP nanofluid has been found suitable for improving the cooling and lubrication during Nimonic 90 grinding and has a great potential for improving the grindability of superalloys.

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