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Novel uses of alumina/graphene hybrid nanoparticle additives for improved tribological properties of lubricant in turning operation

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ABSTRACT

Present work investigates the effect of alumina/graphene (GnP) hybrid nanoparticle additives on tribological properties of lubricant as cutting fluid in turning of AISI 304 steel. The hybrid nano-lubricant has been developed in different volumetric concentrations (0.25, 0.75 and 1.25 vol%). The tribology and wettability testing of lubricants confirm that wear and friction coefficient reduces with an increase of nanoparticle concentration. The hybrid nanofluid has shown the lowest pin wear and friction coefficient. The performance of hybrid nano-lubricant have been compared with the alumina nanofluid. The results establish that mixing of GnP with alumina enhanced its tribological properties. The developed hybrid nano-lubricant significantly reduced the tool flank wear and nodal temperature by 12.29% and 5.79%, respectively compare to alumina based lubricant.

1. Introduction

In manufacturing industry, large amount of heat generated at the machining zone, during dry machining of steels, restricts increase of cutting speed. Furthermore, in high speed machining with dry conditions, desired surface finish and tool life cannot be achieved because high heat generation in cutting zone may affect the hardness and sharpness of cutting tool. This increased temperature may leads to premature breakage of cutting tool. To perform high speed machining, a need of cutting fluid arises. Cutting fluid plays a vital role by cooling the tool-workpiece interface, removing the chips away from machining zone and lubricating the tool-workpiece interface. The conventional way of cooling serves the purpose up to some extent however, the excessive use of the conventional cutting fluid pollutes the environment and may be hazardous for human being. Dry machining could be an alternative approach of machining for cleaner production. Moreover, few researchers [1–3] have adopted dry machining and achieved encouraging results regarding machining performances. However, in most machining situations, dry machining cannot be the preferred method with high depth of cut as it affects tool life [4]. Therefore, to restrict the extravagant consumption of conventional cutting fluid a promising technique MQL can be tried. In this technique, the minimal quantity of any cutting fluid is sprayed into the cutting zone at high pressure for better penetration into machining zone. Maruda et al. [5] found that MQL technique is capable of spraying cutting fluid into cutting zone optimally. Padmini et al. [6] noticed that using MQL a lower cutting-tool wear rate and surface roughness is observed compared to dry machining. Maruda et al. [7] reported almost a threefold reduction in surface roughness with the use of emulsion mist compared to dry cutting. Moreover, Maruda et al. [8] observed that the proper application of MQL has provided significant improvements in cutting tool wear rate and productivity of cutting tool. Furthermore, Behera et al. [9] proposed a model for the local coefficient of friction as a function of MQL parameters and cutting conditions that predicts cutting forces, contact length and chip thickness under MQL environment with reasonable accuracy. Few researchers [10,11] found that use of MQL improves surface finish, tool life and reduces the cutting forces. In their opinion MQL might be a viable alternate to wet machining. Therefore MQL can minimize both, the manufacturing cost and environmental hazards.

The conventional fluids may possess good lubrication properties, however, their poor thermal properties restrict their use as cutting fluid in high speed machining. To overcome this problem, nanometre sized particles are mixed in conventional fluids, which leads to the improved performance [12]. Tiwari et al. [13] observed in their investigations that

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List of symbols

T	Nodal Temperature (°C)
VB	Tool flank wear (μm)
v	Cutting speed (m/min)
f	Feed rate (mm/rev)
d	Depth of cut (mm)
np	Nanoparticle volumetric concentration (vol. %)
θ	Contact angle (Wettability) of liquid droplet (°)

Abbreviations

MQL	Minimum quantity lubrication
MWCNT	Multi walled carbon nano tube
CNT	Carbon nano tube
SQCL	Small quantity cooling lubrication
MoS_2	Molybdenum di sulphide
Al_2O_3	Alumina
GnP	Graphene nanoplatelets
MI	Metal insulated
RSM	Response surface methodology
ANOVA	Analysis of variance
FESEM	Field Emission Scanning Electron Microscope

inclusion of nanoparticles in conventional fluids enhanced their thermal conductivity compare to base fluids. An improvement up to 22.4% in thermal conductivity of conventional fluid at room temperature could be achieved by adding 6% Al_2O_3 in base fluid [14]. Yang [15] and Choi et al. [16] mixed Multi walled carbon nano tube (MWCNT) into base fluid and noticed very high improvement in its thermal conductivity up to 200% and 150% respectively compared to its base fluid.

Sayuti et al. [17] investigated the performance of SiO_2 nanoparticle enriched cutting fluid in turning operation and observed less tool wear with low cutting fluid consumption. Amrita et al. [18] achieved a significant reduction of 71% and 25% in tool wear and temperature, respectively, with the use of nano-graphite based cutting fluid in turning compare to conventional flood machining. Furthermore, Kumar and Ghosh [19] performed grinding with MWCNT nanoparticle enriched sunflower oil based cutting fluid and observed that the atomization of nanofluid at a low flow rate in small quantity cooling lubrication (SQCL) has offered a high degree of cooling and lubrication, leading to an overall improvement in machinability. Albert et al. [20] used graphene enriched mineral oil in grinding and achieved a significant reduction in surface roughness, grinding forces and specific energy consumption. The lower force results in obtaining smaller values of surface roughness parameter [21]. Sharma et al. [22] investigated the water based TiO_2 nanofluid in turning and reported enhanced machining performance over conventional cutting fluid. Sidik et al. [23] reviewed the research work carried out in various investigations based on application of Al_2O_3, CNT, molybdenum di sulphide (MoS_2) and diamond nanoparticles with MQL in machining operations. They reported that significant improvement could be achieved in all the reported investigations.

A lot of work is reported on machining with mono type of nanoparticles enriched cutting fluids. However, to the best of author's knowledge, very few investigations have been performed with hybrid nanofluids (i.e. a colloidal suspension enriched with two different types of nanoparticles). Sarkar and Ghosh [24] reviewed the open literature on hybrid nanofluids and concluded that the proper hybridization might be helpful in making hybrid nanofluids very auspicious for heat transfer enhancement. Tansen et al. [25] observed that a little inclusion of MWCNT nanoparticle into water based alumina solution made it a potential heat transfer fluid. Furthermore, Nine et al. [26] achieved a significant improvement in thermal conductivity by mixing MWCNT nanoparticles into alumina nanofluid. Moreover, Ahammed et al. [27] recorded an enhancement of 88.62% in convective heat transfer coefficient and a reduction of 4.7 °C in equipment temperature by the use of alumina-graphene hybrid nanofluid. In few investigations, hybrid nanofluids has shown improved results relative to base nanofluids. Zhang et al. [28] used MoS_2-CNT hybrid nanofluid in grinding and yielded lower G ratio and surface roughness relative to MoS_2 and CNT nanofluids. Moreover, few researchers have observed an enhancement in thermophysical [29] and tribological [30] properties of base nanofluid

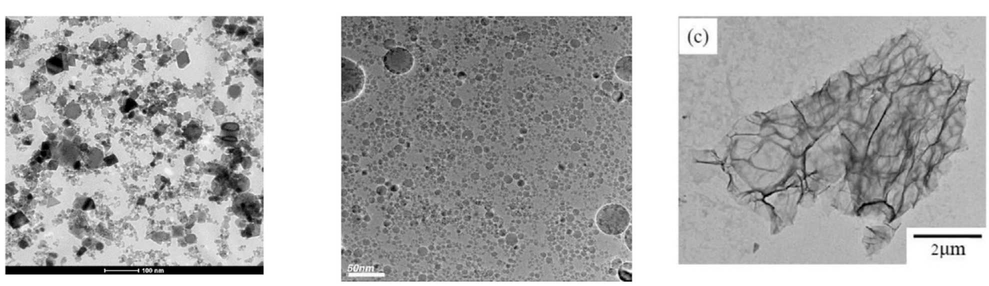

Fig. 1. TEM images of (a) Alumina nanofluid (b) Al-GnP hybrid nanofluid (c) GnP nanofluid [31].

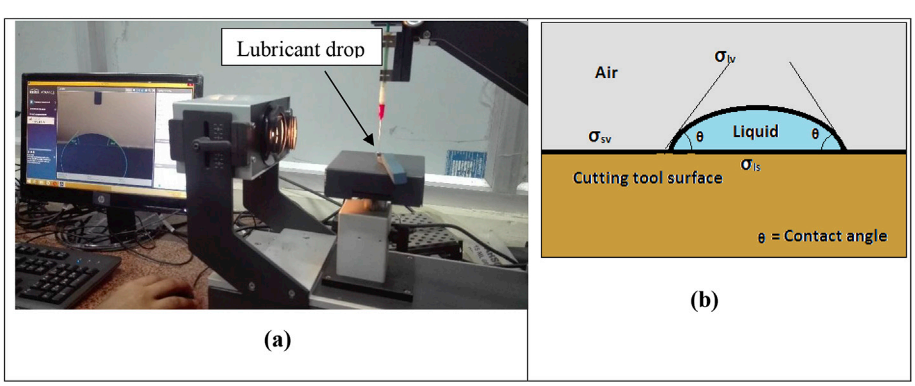

Fig. 2. (a) Contact angle measurement setup (b) Schematic diagram showing a liquid droplet on solid surface.