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Synergism of TiO_2 and Graphene as Nano-Additives in Bio-Based Cutting Fluid—An Experimental Investigation

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ABSTRACT

The present work aims to investigate the synergetic effect of titanium dioxide (TiO_2) and graphene (GnP) nanoparticle additives on the rheological and machining characteristics of biodegradable vegetable oil (rice bran). The rice bran oil has been used in turning of M2 steel using a minimum quantity lubrication (MQL) technique. The effects of varying concentrations by weight (0.5 and 1 wt%) of both mono (rice bran oil/TiO_2) and hybrid (rice bran oil/TiO_2/graphene) nanofluids have been studied. The rheological studies of both mono and hybrid oils revealed an improvement in the viscosity with an increase in nanoparticle concentration. Furthermore, an improvement in viscosity in hybrid fluids at higher temperatures was observed. The experiments revealed that hybrid nanolubricant shows a significant reduction in tool flank wear and surface roughness by 38 and 11%, respectively, compared to TiO_2-based lubricant used alone. The tool wear decreased considerably by about 29 and 32% corresponding to 500 and 1,200 rpm, respectively in the case of hybrid fluid (1 wt% TiO_2+graphene) in comparison to the base oil, which considerably enhanced the tool life. Scanning electron microscopy analysis was conducted to study the mechanisms of tool wear at flank faces and crater faces. Chip morphological analysis was performed for the acceptable chips by analyzing the color and structure, depicting the amount of heat generation at the tool–workpiece interface. The results establish that synergism of GnP with TiO_2 enhances the tribological properties and hence provides a greener and efficient lubrication methodology.

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Introduction

The growing quest for sustainable processes in modern industry *(1)*, poor biodegradability of petroleum-based oils, and various health hazards associated with synthetic oils have necessitated the development of ecofriendly and biodegradable lubricants from renewable sources *(2)*. Flooded and dry lubrication have been extensively adopted by industries on the basis of intended operations *(3)*. Contrary to flooded lubrication and dry cutting, the minimum quantity lubrication (MQL) technique has evolved as a sustainable alternative *(4)*. Bio-based lubricants in conventional machining operations can serve as a potential alternative. However, the performance of these oils has not been extensively explored. Vegetable oils generally possess a high flash point and fire point and better thermophysical properties, which can be further enhanced by using proper additives *(5)*. The properties of vegetable oil mainly depend on the nature, degree of saturation, and composition of fatty acids present in the vegetable oils *(6)*. Considerable research has previously been dedicated to exploring the potential of vegetable oils in machining with and without the introduction of nanoparticles *(7, 8)*. More recently, with the advent of nanotechnology, researchers have used nanoparticles as additives in bio-based cutting fluids *(9–17)*.

For instance, Talib and Rahim *(18)* have reported that the addition of nanoparticles in bio-based vegetable oils resulted in improved tribological performance by reducing the tool wear rate and surface roughness. Padmini et al. *(16)* investigated the effect of $nMoS_2$ in coconut, sesame, and canola oil and reported that 0.5 wt% $nMoS_2$ leads to a 44% reduction in tool wear, 39% reduction in surface roughness, and 37% reduction in the cutting forces. In a related study, Amrita et al. *(19)* reported a 54% reduction in cutting interface temperature, a 25% reduction in tool wear, and a 71% reduction in surface roughness with the addition of 0.3 wt% nano graphite in water-soluble oil. Sayuti et al. *(20)* observed a reduction in cutting forces and an increase in temperature using 0.2 wt% SiO_2 in end milling of aluminum alloy at a nozzle orientation angle of 60°.

Raju et al. *(21)* performed MQL-assisted turning with multiwalled carbon nanotube (MWCNT) nanoparticles and observed a 33.33% reduction in the contact angle of the nanofluid compared to the conventional fluid that enhanced the wear resistance capability of the nanofluid. On mixing

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