Arabian Journal of Chemistry (2023) 16, 104908

King Saud University

Arabian Journal of Chemistry

www.ksu.edu.sa
www.sciencedirect.com

REVIEW ARTICLE

Nanofluids and their application in carbon fibre reinforced plastics: A review of properties, preparation, and usage

Sunday A. Lawal [a], Rasaq O. Medupin [b], Kelvin O. Yoro [c,*], Uzoma G. Okoro [a], Oyewole Adedipe [a], Joseph Abutu [d], Jimoh O. Tijani [e], Ambali S. Abdulkareem [f], Kingsley Ukoba [g], Mohammed B. Ndaliman [a], Patrick T. Sekoai [h], Tien C. Jen [g]

[a] *Department of Mechanical Engineering, Federal University of Technology, Minna, Nigeria*
[b] *Department of Materials and Metallurgical Engineering, Federal University of Technology, Owerri, Nigeria*
[c] *Energy Technologies Area, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720, United States*
[d] *Department of Mechanical Engineering, Taraba State University, Jalingo, Nigeria*
[e] *Department of Chemistry, Federal University of Technology Minna, Nigeria*
[f] *Department of Chemical Engineering, Federal University of Technology, Minna, Nigeria*
[g] *Department of Mechanical Engineering Sciences, University of Johannesburg, Auckland Park, South Africa*
[h] *Biorefinery Industry Development Facility, Council for Scientific and Industrial Research, Durban 4041, South Africa*

Received 19 November 2022; accepted 9 April 2023
Available online 18 April 2023

KEYWORDS

Nanofluids;
Machining;
Manufacturing;
Minimum quantity lubrication;
Carbon fibre reinforced polymer

Abstract Renewed call for the replacement of conventional materials with carbon fibre reinforced plastics (CFRPs) in many high-performance applications is responsible for the current wave of research on minimum quantity lubrication (MQL) strategy in machining. Due to their competitive advantages over conventional materials, polymer matrix composites (PMCs) are now attracting the attention, of researchers, especially in the field of machining. Although most manufacturing methods require less machining, precision machining like milling and drilling call for more research inputs. For this purpose, this review article assesses various aspects of nanofluid preparation and its application in CFRPs. Recent scientific reports on nanofluids with a focus on properties, preparation, and application (including respective methodologies) were analyzed, to contribute to the growing database for future research in this field. This review article shows that cutting temperature and cutting force remain the key determinants of surface finish, while tool wear constitutes a major parameter that machining scientists would like to keep under full control by the use of appropriate

* Corresponding author.
E-mail address: kelvin.yoroo@gmail.com (K.O. Yoro).
Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.arabjc.2023.104908

cutting fluids. Uncertainties around the quality of nanofluids which is scarcely discussed in the literature is raised in this review, while advocating for more research to unravel it. Furthermore, this review article sheds more light on the machining operations of carbon fiber-reinforced plastics using nanoparticle-laden fluids for a safe and sustainable machining experience. Finally, this review assesses the possibility of achieving excellent CFRP processing using a sustainable approach to fill existing gaps identified in literature like wasted cutting liquids, environmental pollution, and exposure of operators to health hazards.

1. Introduction

Researchers have channeled a tremendous amount of energy toward the creation of a safe, sustainable, and effective manufacturing environment; especially for cutting, corrosion control, and machining (Eterigho-Ikelegbe et al., 2021; Medupin et al., 2023). Cutting fluids are important materials that could be used to achieve optimal surface finishes during machining operations. Machinists simply take advantage of an abundant supply of coolants to achieve speedy cooling and lubricating effect as well as a quick removal of chips. However, the need for a high volume of cutting fluids and additional peripheral equipment becomes a huge worry (Madanchi et al., 2019).

Significant effort has been made by scientists in recent times to explore nanofluids and their prospective lubricating potential. Singh et al. (2017) defined lubrication as the process by which wear of either or both surfaces or parts in relative movement to each other is reduced by the abrupt and deliberate introduction of lubricants between the surfaces to remove the pressure generated during the opposing movement. The main objectives of the lubrication were to reduce wear and tear, as well as heat generated due to friction, thereby protecting surfaces against corrosion. Bio-lubricants have been identified as an excellent substitute for synthetic lubricants in the machining of heat-resistive superalloys because they offer the most sustainable mode of machining for both micro and nano-fluids (Sen et al., 2020; Venkatesh et al., 2018). However, of all the lubrication approaches, nano-lubrication has emerged as one of the most sustainable, renewable, and energy-efficient lubrication strategies in machining processes (Zadafiya et al., 2021; Huang et al., 2017; Pal et al., 2021). Different variables, including production time, cost, and energy consumption, are minimized by the use of appropriate cutting fluids (Agapiou, 2018).

While machining quality is said to depend on the speed of cutting, feed rate, properties of materials being cut, and the choice of appropriate cutting fluids also affects the quality of finished surfaces (Rapeti et al., 2016). According to Venkatesh et al (Venkatesh et al., 2018) cutting fluids are effective coolants meant to convey heat away from the tool/workpiece interface during machining. Common coolants (water, mineral oil, synthetic oil, vegetable oil, etc) are used as base oils to perform the same functions. However, they are ineffective in their raw state because of chemical imbalances, and could facilitate the corrosion process (Pimenov et a., 2021). Therefore, nanoparticles-laden base oils are currently investigated to address issues around quick heat removal from the interface between tool and workpiece by leveraging the large surface areas of nanoparticles (NPs).

Nano-cutting fluids are principally fluids containing lower volume concentrations of NPs which are generally used during cutting operations. Pimenov et al (Pimenov et a., 2021) presented findings on the improvements in machining activities achievable with NPs being homogeneously dispersed in base fluids. Given the non-biodegradable nature of most of the conventional cutting fluids currently in use, as well as health-related issues like skin and lung diseases, MQL has emerged as a more environment-friendly option (Padmini et al., 2019). Lubrication failure at higher metal removal and environmental pollution are common problems associated with most conventional coolants. Flood cooling is common with this type of machining. Hence, the machining environment is usually flooded with hazardous chemicals (Ma et al., 2022). This does not align with the SDGs guidelines on responsible production and consumption. In addition, the vibration and noise that often result from certain machinery underscore the need to find suitable alternatives that could help address these challenges. To proffer a solution to these problems, Jia et al. (2020) suggested the use of viscoelastic damping materials for vibratory noise reduction owing to their low densities, high strengths, and high elastic moduli. Furthermore, Feito et al.(2019) identified local delamination as the most challenging impairment associated with machining CFRPs. Zadafiya et al. (2021) reported an approximately 58% reduction in tool wear rate by using a nanofluid of 1% volume concentration in contrast to traditional and dry machining. Other indicators that improve because of the increase in the concentration of NPs include fluid viscosity, thermal conductivity, and density. The challenges encountered with conventional materials in all applications have triggered intense research for the development of both natural and synthetic fiber-reinforced polymer (nano)composite materials to address the aforementioned agelong issues(Abdalla et al., 2010; Arumugam and Ju, 2021; Benzait and Trabzon, 2018; Feldman, 2017; Guo et al., 2020; Guo and Zhang, 2021; Jawahar et al., 2020; Lin et al., 2020; Medupin et al., 2017, 2019; Mensah et al., 2015; Pozegic et al., 2016; Sadare et al., 2022; Salah et al., 2019; Sathyanarayana, 2013; Scholz et al., 2011; Sun et al., 2021; Veeman et al., 2021; Zaaba and Ismail, 2019; Zwawi, 2021; Bokobza, 2019; Kumar et al., 2021; Oleiwi et al., 2022; Wang et al., 2014). Some of these polymer nanocomposites are applied in areas which would require resizing to the design specifications, hence the need for machining with other conventional materials (Mohammed et al., 2015; Jose and Athikalam, 2020).

Furthermore, maintaining the chemical stability of nano-cutting fluids and ensuring its adherence to the sustainable development goals (SDGs) are the major challenge that must be overcome by researchers in the field (Goindi and Sarkar, 2017; Yoro et al., 2021). Zadafiya et al. (2021) have investigated an effective lubrication system that meets sustainability requirements without trading off manufacturing efficiency and product quality. In another study, Wickramasinghe et al. (2021) opined that most vegetable oils have stability issues resulting in poor cooling performance during machining operations. Similarly, Kumar et al. (2023) recently reported that the addition of nanoparticles boosts the lubricating performance of pure oils; adding that the sustainability of machining operations is greatly improved by the reduction of cutting forces, cutting temperature, tool wear, and surface roughness. Despite the recent clamor for a paradigm shift from conventional materials to composites (polymer nanocomposites), there is still a dearth of scientific reports on improving manufacturing activities in polymer structures sectors like housing, and automobile manufacturing.

In this review, we seek to explore insightful information on nano-based cutting fluids for a wide range of applications. We examine the possibility of using non-destructive nano-coolants loaded with NPs in machining operations. Finally, this review explores pioneer and recent research in the field to update stakeholders in the field on machining operations of carbon fiber-reinforced plastics using nanoparticles-laden fluids for safe and sustainable machining experience.