PAPER 94 – SYNTHESIS AND CHARACTERIZATION OF CNTS/TIO₂ NANOCOMPOSITE FOR FORMULATION OF HYBRID NANOFLUID FOR MACHINING CFRPS

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ABSTRACT
Removal of heat from cutting zones raises concerns in machining carbon fibre reinforced plastics (CFRPs). Therefore, this has necessitated increased search for sustainable and cost-effective cooling agents. In this study, carbon nanotubes (CNTs) and TiO_2 were synthesised using sol-gel and Central Composite Design and characterised to form different compositions of TiO_2/CNTs (9:1, 7:3, and 5:5) nanocomposites. The nanocomposites were characterized using Brunauer-Emmett-Teller (BET), HESEM/EDX, XRD and FTIR to investigate their stability as suitable fillers in base-oils. The FTIR spectra for TiO_2/CNTs revealed that the composites have absorption peaks corresponding to C=C and Ti-O bonds; giving rise to peaks assigned to Ti-O-C and C-O bonds. The diffraction peaks of anatase are clearly identified and the diffraction peaks assigned to CNTs are barely seen as a result of overlapping of the main peaks of CNTs with the peaks of TiO_2. The study established that the challenges common to individual NCs are sufficiently addressed with hybrid NCs TiO_2/CNTs (5:5) NC offering an overriding advantage over other nanocomposites as heat removing agent owing to its largest surface area, pore volume and as the most stable nanosuspension. It can, therefore, be concluded that TiO_2/CNTs nanocomposites have high prospect for reinforcing base oils for effective machining.

KEYWORDS: Synthesis, Characterisation, Carbon nanotubes, Titanium oxide, Nanocomposites, Machining

1. INTRODUCTION

Carbon fibre reinforced plastics (CFRPs) have been established as indispensable materials for many applications in engineering. Their outstanding performance in national defence, aerospace and upscale civilian products earns them their current status in manufacturing technology (Zheng et al., 2022). However, until recently, machining of CFRPs has received less attention than they actually deserve as a material with comparative advantages (Erturk et al., 2021). Researchers who have investigated machining of CFRPs with conventional cutting fluids decried the associated challenges and call for more studies to unravel the uncharted waters (Elgnemi et al., 2021; Wang et al., 2018; Zhang et al., 2017). Most of the orthodox cutting fluids are proven to have repeatedly fail to sustain their relevance in the current efforts towards achieving the UN's Sustainable Development Goals on responsible consumption and production (SDG #12).

Quick and easy removal of heat from cutting zones during machining affect the level of success of the process in terms of tool life, speed of cutting as well as surface finish. Sankaranarayanan et al. (2021) reported on the preference of bio-oil-based cutting fluids to proffer solutions to numerous health hazards associated with synthetic cutting fluids in pursuance of sustainable green manufacturing. Even though synthetic and vegetable oil perform excellent momentary cooling functions during machining, chemical imbalance which often triggers corrosion process renders them ineffectual in the present environmentally conscious world (Pimenov et al., 2021). Therefore, nanofluids are currently being advanced to address issues around quick heat removal from tool/workpiece interface by leveraging large surface areas provided by nanoparticles (NPs). This is expected to facilitate quick removal of heat and also help to reduce the quantity of fluids needed for a particular machining process (Patole et al., 2021). The volume of cutting fluids needed as well as the volume released to the immediate environment after being used are also significantly reduced; hence environmental pollution is effectively addressed in the same manner cost is also sufficiently managed (Ni et al., 2021; Haq et al., 2021). It is in line with this principle that the Minimum Quantity Lubrication (MQL) technique was established to further optimize machining parameters (Usha & Srinivasa Rao, 2019). MQL is an environment-friendly and cost-effective alternative to flooding and dry cutting fluid application (Agrawal & Patil, 2018). It is a machining process that is consistent with cleaner and responsible production in the context of sustainable production.

However, more recently, a more excellent way of performing the dual functions of heat removal and lubrication during machining has been launched and is currently receiving more attention from the research world (Gao et al., 2021). While the fluid lubricates the cutting interface, the nanofillers convey heat away from the cutting zone; making machining experience rather seamless and fast; thereby extending tool life and enhancing surface finish (Singh et al., 2021). This is termed nanofluid-MQL (nMQL). Kumar et al. (2023), in a recent study, described nMQL as the novel chapter of sustainable machining. The process involves spraying nanofluids mist on to the tool work interface during machining as the sliding friction between the tool work is converted to rolling friction and reduces friction coefficient significantly; hence giving rise to low cutting forces (Bai et al., 2019; Osman et al., 2020; Jamil MKhan et al., 2020; Lawal et al., 2023). Venkatesan et al. (2020) conducted a comparative study on certain machining parameters under dry and MQL. Their observation on turning operation under nMQL shows that MQL prevents wear mechanism which is a peculiar drawback with dry machining. This indicates that the use of nMQL is a step in the right direction in sustainable machining of difficult-to-machine materials for industrial applications. While also investigating the approach, Gao et al. (2021) observed that the optimization of the nanofluids under high pressure air flow addresses the problem of unsatisfactory heat transfer capacity of MQL in the machining zone and improves the lubrication performance of the interface between the tool and the workpiece. While acknowledging the possibility of taking advantage of different physical and chemical properties of NPs to form hybrid nanofluids, Gao et al. (2020) submitted that the use nMQL technique could lower processing damage such as resin coating, multi-fibre block pull-out, as well as pits. Therefore, it can be concluded that nMQL is the undisputable future of CFRPs machining.

Excellent as nMQL technique may seem, a number of challenges have been identified with the process of producing hybrid nanofluids. Production of standard nanosuspension remains an age-long procedural challenge. Abubakre et al. (2023) agreed with an earlier work by Urmi et al. (2021) on the difficulties associated with the attainment of long-term stability of hybrid nanofluids, which is one of the requirements of hybrid nanofluids applications. This quality of the nanofluids is important in that it improves its thermal behaviour during applications. Therefore, addressing the stability issue is vital to carrying out quality machining. From the literature, external force, stirring and ultrasonication can be deployed to break the bonds that hold NPs together provided the duration for each activity is addressed (Medupin et al., 2019; Ma et al., 2022). Hence the question of time remains a huge gap in the literature. Hence, given the vital role NPs play in the achievement of excellent clean machining via nMQL technique, the processes leading to the production of NPs deserves all the needed attention. It is in keeping with this, therefore, that this study is designed to synthesise and characterise high quality carbon nanotubes (CNTs), TiO_2 and their nanocomposites (NCs) for the development of hybrid nanofluids for CFRPs machining.

2. MATERIALS AND METHODS

All reagents used in this study were of analytical grade with percentage purity in the range of 95%-99.98%. They were sourced from Sigma Aldrich Chemicals Nigeria, a world class distributor of chemicals and other product and used without any further purification. The chemicals used in this experiment include titanium (IV) isopropoxide ($Ti\{OCH(CH_3)_2\}_4$, methanol (CH_3OH), sodium hydroxide pellets (NaOH), hydrochloric acid (HCl) and sodium dodecyl sulfate (SDS) as well as deionized and distilled water.

2.1 Synthesis of TiO_2 nanoparticles

Central Composite Design (CCD) based on Response Surface Method (RSM) was used for biosynthesis of TiO_2 NPs using sol-gel method as shown in Tables 1 and 2. A known volume of titanium isopropoxide was measured into a 250 cm^3 beaker containing a specific volume of extract from plant and stirred on a magnetic stirrer. The mixture was adjusted to the desired pH using NaOH and HCl solution under continuous stirring. The resulting mixture was washed with de-ionized water, dried at 105 °C in an oven for 12 h, and calcined at 450 °C for 3 h.

Table 1: 2^4 factorial design matrices

Coded value	Volume of extract (cm^3)	Volume of precursor (cm^3)	Stirring time (min)	pH
– Level	50	5	100	2
+ Level	80	8	200	12

Table 2: Experimental run for the biosynthesis of TiO_2 nanoparticles

Selected Run	Volume of extract (cm^3)	Stirring time (min)	Volume of precursor (cm^3)	pH	Crystallite size (nm)
3	65	100	6.5	12	18.92
6	50	100	6.5	7	10.20
9	80	150	6.5	12	16.41