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Investigating Corrosion and Surface Hardness of Al6061 in Machining Fluids with Variable CNT Concentrations

Imhade P. Okokpujie[1,2*], Dafe O. Nakpoberuo[2], Darlington O. Emojeya[2], Temitayo M. Azeez[2], Lagouge K. Tartibu[1]

[1] Department of Mechanical and Industrial Engineering Technology, University of Johannesburg, Johannesburg 2028, South Africa
[2] Department of Mechanical and Mechatronics Engineering, Afe Babalola University, Ado Ekiti 360001, Nigeria

Corresponding Author Email: imhadeokokpujie@gmail.com

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ABSTRACT

This project investigates the corrosion tendency of various machining fluids on Al6061 alloy for a sustainable cutting process. Also, the surface of the machining workpiece was analysed to understand the effect of the carbon nanotubes (CNTs) on the surface morphology that assists the cutting conversion of the sliding friction to the rolling process. The study used a two-step process to create machining fluid with CNT nanoparticles at different percentage concentrations. The soluble oil (sample B1), mineral oil (sample B2), 0.2-g/l-CNTs nano-mineral machining fluid (sample B3), 0.4-g/l-CNTs nano-mineral machining fluid (sample B4), and 0.6-g/l-CNTs nano-mineral machining fluid (sample 5) makes up the corrosion study medium. The corrosion study was conducted using polarisation resistance and potentiodynamic corrosion techniques. After the corrosion study, the Vickers micro-hardness machine was employed to evaluate the surface hardness of the normal face region subjected to the corrosion study. The SEM and EDS were also used to investigate the microstructure and elemental composition of the machining fluid impacts on the Al 6061 alloy. The results show that the soluble oil has a high corrosion rate of 0.03590591 (mm/year), with a list polarisation resistance rate of 8,432.83 (Ω) compared to the other machining fluid employed in this study. Furthermore, the 0.6-g/l-CNTs nano-mineral machining fluid has the lowest corrosion rate of 0.0013197 (mm/year) and the highest polarisation resistance of 32,941.67 (Ω). The 0.6-g/l-CNTs presence in the mineral oil increases the rheological and tribological properties, which results in an outstanding performance in the corrosion study. Furthermore, the CNTs hardened the surface of the workpiece due to the carbon element deposition during the implementation of the cutting fluid.

1. INTRODUCTION

In machining, cutting fluid plays a significant role as it reduces friction and enhances surface finishing. However, when applied, not all cutting fluids are sustainable and eco-friendly for the workpiece and end users. Eco-friendly machining fluid is highly needed in manufacturing, primarily in industries that employ computer numerical control (CNC) systems [1]. However, much research has been done on developing biodegradable machining fluid for sustainable machining. Most of this study proved viable, but the study did not consider the study of the corrosion effects of this machining fluid on the workpiece. It is essential to know if the machining fluid is free from elements that can cause the aluminium or any materials involved in the study [2]. The utilisation of aluminium 6061 combinations in modern applications is often restricted by their defencelessness to consumption, which can bring about diminished execution, well-being risks, and monetary misfortunes. Even though machining liquids have been universally used to work on the exhibition of aluminium combinations during machining tasks, their impact on the corrosion conduct of the composites is not indeed known [3]. Subsequently, there is a need to explore the corrosion conduct of aluminium 6061 composites in various kinds of machining liquids and to recognise the variables that influence the consumption opposition of the combinations in these liquids. This study plans to address this examination issue by researching the impact of various machining liquids on the consumption conduct of aluminium 6061 composites and by giving bits of knowledge into the systems that administer the erosion conduct of the amalgams in these liquids. The aftereffects of this study are supposed to add to the improvement of additional viable methodologies for upgrading the consumption opposition of aluminium amalgams in modern applications. According to Maurya et al. [4].

Aluminium and its composites are ideal in aviation, car and marine businesses because of its lightweight and high solidarity to weight proportion. The external bodies of planes, ships, automobiles, and so on are typically made of aluminium and their combinations. The elastic and weakness disappointment of a part is exceptionally impacted by the erosion conduct of the material in various conditions. The surface unpleasantness of the examples is significant in deciding the consumption conduct of material. In circumstances like Coronavirus or while hanging tight for fixing, planes, vehicles, ships and so on stand inactive for quite a long time in stormy conditions. As the downpour is acidic, the metal begins eroding when it reaches out to it. In the current work, erosion because of a corrosive downpour on the cleaned surface of the as-projected Al6061 combination is dissected through a reproduced corrosive downpour climate (pH=4). The impact of surface harshness on the consumption rate was additionally explored. The erosion rate diminishes as the surface completion of the example increases [5].

Samuel et al. [6] examined the impact of machining conditions on the erosion of 6061 aluminium amalgam. The study shows that electrical-release machining gives preferred protection from pitting consumption over the precious stone and carbide turning machine. Boring, turning, and cutting might impact the mechanical qualities of the workpiece by delivering an opening around the low lingering stresses and a little layer of incredibly pushed material on the recently made surface, making it turn out to be more inclined to weakness, break spread and erosion at the focused-on surface. The machining surface honesty has extraordinary effects on the weak lifetime of material since miniature breaks start at the surface. The customary machining methods contrasted with the forward-thinking or non-traditional strategies are more vulnerable to the enlistment of unfortunate surface uprightness because of direct contact between the apparatus and workpiece, which are described by a few harm imperfections, for example, miniature breaks, surface solidifying, harshness and lingering tractable. This paper outlines the classes of aluminium compounds, their applications and the machining of the combinations with a sharp spotlight on 6061 aluminium composites. And different machining strategies with their helpful and non-useful consequences for the workpiece, device life, climate change and corrosion effects [7].

Corrosion is a natural process that causes the deterioration of materials through chemical reactions with the environment. Corrosion is particularly problematic in metals and alloys and is a significant cause of failures in many engineering applications [8]. Dang et al. [9] Bacteria, algae, and fungi quickly colonise most abiotic surfaces of a substance, accelerating material breakdown. The interaction of microorganisms and their metabolic by-products, such as exopolymeric substances (EPS), with an abiotic surface, is called biocorrosion or microbially influenced corrosion (MIC). Therefore, the user's decision to address or resolve the issue of biofouling and biodeterioration of manufactured commodities will have economic and environmental consequences. Even though MIC is often used with metallic materials, freshly created and emerging materials frequently succumb to corrosion, which causes a variety of chemical reactions and transport processes to take place inside the material. This paper reviews current knowledge on microbial and material interactions that contribute to biological corrosion and biofouling, including biofilms, oxygen-deprived and aerobic environments, bacteria assault, and the various roles microorganisms play. It discusses recent research on biocorrosion and biofouling of conventional and novel materials. The authors also demonstrate the most current analytical methods for characterising and identifying MIC on materials, including thermal imaging, Fourier (FTIR), atomic force microscopy (AFM), scanning electron microscopy (SEM), X-ray photoelectron microscopy (XPS), X-ray diffraction (XRD), optical and epifluorescence microscopy, electrochemical impedance spectroscopy, mass spectrometry, and chemometrics.

Despite the significant efforts made in the study of the corrosion behaviour of aluminium 6061 alloys, there is still a lack of understanding of the impact of different machining fluids on the corrosion behaviour of the alloys [10]. Therefore, there is a need to investigate the corrosion behaviour of aluminium 6061 alloys in different machining fluids.

The results of this study will provide valuable insights into the corrosion behaviour of Aluminium 6061 alloy in different machining fluids. This information can be used to optimise the selection of suitable machining fluids for aluminium 6061 alloy based on corrosion behaviour. Resulting in improved quality and reliability of machined components. Furthermore, this study will contribute to understanding the corrosion mechanism of aluminium 6061 alloy, which is essential for developing effective corrosion mitigation strategies. Investigating the corrosion behaviour of Aluminium 6061 alloy in different machining fluids. Also, the study evaluates the effect of CNT Nano-lubricant on the surface morphology of aluminium 6061 alloys.

2. METHODOLOGY

2.1 Materials

This section entails the materials employed for this study. The Al 6061 alloys and their chemical composition are presented in Table 1 and Figure 1(a). The CNT nanoparticles used to develop the machining fluid are presented in Figure 1(b). Also, the mineral oil used as the based fluid is given in Figure 1 (c).

Figure 2(a) and Figure 2(b) show the scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) analyses of the CNTs nanoparticles employed in preparing the nano-lubricant end-milling machining operation of Al6061 alloy. The CNTs is a non-metallic nanoparticle having 98% purity with particle sizes ranging from 10nm±1nm to 4.5±0.5nm with 3-6μm. The EDS analysis of the chemical composition of the MWCNTs nano-powder (characterised under SEM) (Figure 2) revealed the presence of carbon in a high amount based on the percentage weight. The morphology of the MWCNTs is stable based on the SEM micrograph. The significance behind the choice of these materials is that developing machining fluid is a complex situation, and the machining fluid has a significant role to play during the cutting process. The CNTs are biodegradable nanoparticles that are eco-friend, corrosion free and have the tendance to convert the sliding friction into rolling friction during machining.

Table 1. Composition of the aluminium alloy material

Materials	Fe	Si	Mn	Cu	Zn	Mg	Pb	Sn	Al
Wt. (%)	1.27	2.448	0.108	0.434	0.492	0.2	0.112	0.073	94.87

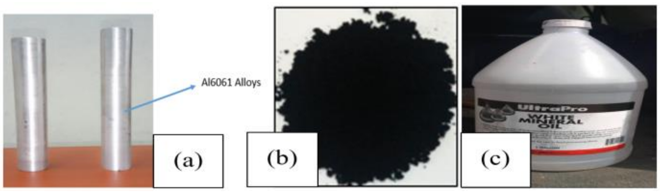

Figure 1. (a) Al6061 alloy, (b) The CNTs nanoparticles, and (c) mineral oil used to prepare the nano-lubricant

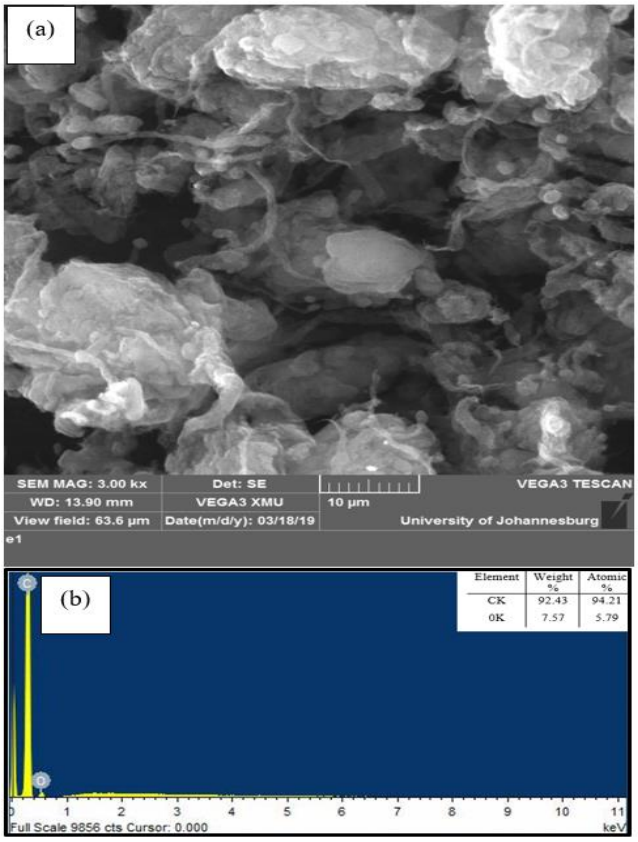

Figure 2. The SEM micrograph of MWCNTs nano-powder used in preparing the nano-lubricant for machining operation

2.2 Method

2.2.1 Procedures of synthesizing the nano-lubricant

When making nano-lubricants, two main methods-bottom-up, the one-step method of preparation, and top-down, sometimes known as the two-step approach-are always considered [11]. The two-step method was used in this project. It is currently the most cost-effective method for mass-producing nano-lubricants [12]. The nanoparticles were created in this process as dry powders using either physical or chemical means. Sigma-Aldrich Corporation manufactures the CNTs used in this study. Using a micro-weighing scale, the different % concentration of the nanoparticles was determined to be 0.2g, 0.4g, and 0.6g MWCNTs. The nanoparticles and mineral oil were homogenised for one hour and five hours using the magnetic stirrer and ultrasonic cleaning device at room temperature (see section Figure 3).

2.2.2 Ultrasonic cleaner machine and the micro scale device

The ultrasonic cleaning machine employed in this study is at the Department of Mechanical Engineering, Covenant University. The machine has a high occurrence of vibration to stir the mixture. The water implementation in the ultrasonic bath assists in eliminating all traces of pollution or impurity from the embedded surface of the lubricant. Water is most frequently used, or a solvent is sometimes employed. The mixture in a beaker must not be placed in the ultrasonic bath alone without a solution. This will create a resistance that will not allow cavitation on the mixture or lubricant during the ultra-sonication process. Figure 3 shows the ultrasonic cleaner and other measuring instruments, including the micro-milling scale used for measuring the weight concentration of CNTs before nano-lubricant preparation.

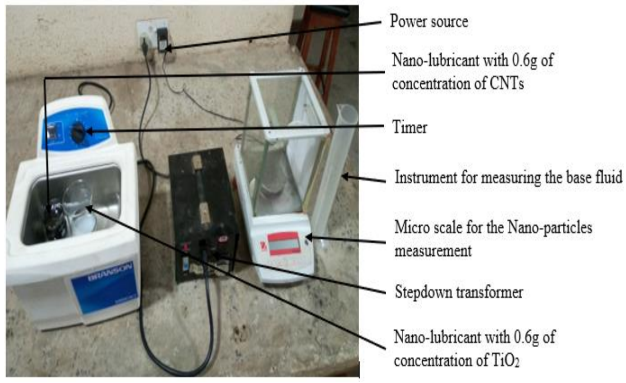

Figure 3. Experimental setup for synthesising the MWCNTs nano-lubrication for the machining operation

2.2.3 Linear polarization resistance

The linear polarisation resistance (LPR) technique is employed to study the effect of the developed nano-lubricant on Al 6061 alloy after machining. This technique is one of the most effective electrochemical processes for corrosion measurement. It gives the corrosion rate by determining the relationship between the generated current and the electrochemical potential. This non-destructive, quick testing technique is commonly used in corrosion studies to capture data [13]. The experimental setup of the LPR consists of three electrodes, a potentiostat regulator, and a computer system. The three electrodes are the working, reference, and counter electrodes. This analysis was conducted to ascertain that the developed nano-lubricant is free from corrosion or resists corrosion during implementations. The experimental setup is presented in Figure 4.

The corrosion studies to gain corrosion rate data were done using the weight-loss method. This method was used because it is quick and non-destructive. The AMMC was sectioned into smaller coupons and well-labelled for corrosion testing, i.e., weight loss check in different environments. The weight-loss method is a quantitative technique used in determining and monitoring corrosion-internal or external, in metallic structures, in which case a metal hybrid composite. It involves taking readings of the differences in the weight of the metal under study over specific time intervals. It is considered the most straightforward corrosion monitoring since it involves only time and weight variables, which are not difficult to obtain. The readings were taken every 24 hours for 5 days. The samples of the AMMC developed were subjected to 5 environments, as shown in Table 2.

Each specimen was removed from the environment it was subjected to after 24 hours and was cleaned with a rag so the difference between their weights upon commencement and time of removal (after 24 hours) could be recorded and measured. The weight measurement was done using the OHAUS Digital Weighing Scale.

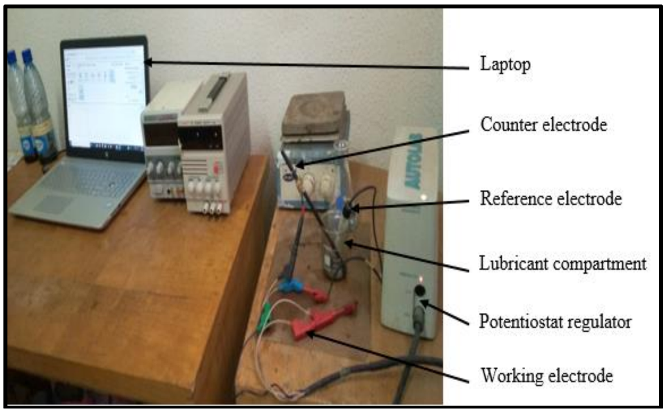

Figure 4. Experimental setup of the surface corrosion test using the linear polarisation resistance method

Table 2. Specimens and their environments

Environment	Specimen
MF Soluble Oil	B1
MF Mineral Oil	B2
MF 0.2g/L CNTs Nanomachining fluid	B3
MF 0.4g/L CNTs Nanomachining fluid	B4
MF 0.6g/L CNTs Nanomachining fluid	B5

Why and how the environments were prepared:

Soluble Oil Machining fluid: The coolant was prepared from 9g soluble oil and 500ml distilled water. This was further divided into

Mineral Oil: Mineral oil was purchased from the market. A coupon of the AMMC was submerged in 100ml of mineral oil to check for the reaction.

The data obtained were entered into an engineering formula to generate the corrosion rates.

Weight loss

$$\Delta W = \text{Initial Weight (Wi)} - \text{Final weight after each time interval (Wo)} \quad (1)$$

The corrosion rate formula is shown below [14]:

$$k = \frac{86.7 * \Delta W}{t * \rho * A} \quad (2)$$

where, k=corrosion rate, ΔW=weight loss, t=time, ρ=density, A=surface area

$$A = l * b * t \quad (3)$$

where, l=length, b=breadth, t=thickness

The Inhibition Efficiency formula is expressed below

Inhibition Efficiency=100xSurface Coverage

The Surface Coverage formula is given as

$$SC = 1 - \frac{\Delta_I}{\Delta_c} \quad (4)$$

where, SC=Surface Coverage, Δ_I=Weight loss of AMMC, Δ_c=Weight loss of Control

2.2.4 The Vickers hardness tester

The Vickers hardness tester was employed in this work for the hardness measurement of the corrosive and non-corrosive Al 6061 alloy. The technique of the Vickers hardness test entails indenting the well-polished Al 6061 alloy with a diamond indenter; the dwell time observed in this study is 15 seconds, with an angle of indentation of 136^o between reverse faces subjected to a load of 1 to 100kg. The well-polished Al 6061 alloy's surface is captured in ranges that are accurately controlled to the correct pyramid with a square base. After eliminating the load, the hardness test result is determined from the diagonal between the two indentations left on the surface of the Al 6061 alloy.

2.2.5 Microstructural analysis

The VEGA3 TESCAN scanning electron microscope (SEM) has an energy dispersive spectrometer (EDS). The VEGA3 TESCAN is a multipurpose tungsten thermionic emission SEM for high and low vacuum processes. The SEM has a wide variety of ports, 7 different chamber sizes, and optimised geometry for EDX with numerous detector methods. The process of obtaining the required image of the nanoparticles (CNTs), the nano-lubricant t, Al 6061 alloy, and the elemental chemical compositions were determined with the application of the energy dispersive spectrometer (EDS). All the samples are placed in the SEM sample holder, fixed to the SEM machine embedded with the EDS and the monitor (the software is installed to regulate the reflective analysis). The interaction between the cathode and anode in the elements present in the samples generates the workpiece's morphology and chemical composition.

Figure 5 shows the X-ray diffraction (XRD) array analysis on the phase transformation for the MWCNTs nano-powder. The result indicates that at 2-theta degree, the sharp peak of 25.7^o and intensity of 8000cps indicate that the MWCNTs nanoparticles are hexagonal graphite. According to Pistone et al. [15], the non-availability of strong spurious diffraction in the XRD plot shows the level of the crystallographic purity of the MWCNTs nanoparticles. The analysis based on this characterisation indicates that the XRD result of the MWCNTs nanoparticle is in good agreement with the specification of the Joint Committee on Powder Diffraction Standards (JCPDS No. 01-0646). The sharp peak in the XRD analysis at 25.7 has a sharp edge [16]. However, it means that the CNTs nanoparticles got oxidised with an acid solvent without any substantial damage to the CNTs nanoparticles. The result of this characterisation is in line with the work of Zhou et al. [17] in a related study.

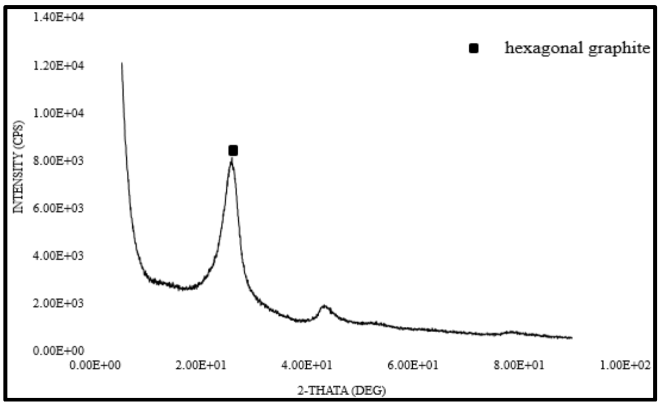

Figure 5. XRD analysis of the CNTs nanoparticles employed in developing the nano-machining fluid

3. RESULTS AND DISCUSSION

This section entails the results obtained from the experimental analysis of the corrosion study of the behaviour of Al 6061 alloys in various developed machining fluids. The section is divided into three (3) section, which contains the analysis of the surface hardness, corrosion rate, and the polarisation resistances of the developed machining fluid towards the Al 6061 alloys after the corrosion study implementing the developed machining fluid to ascertain it levels of eco-friendliness of the machining fluid before using it for manufacturing of mechanical parts.

3.1 Analysis of the machining corrosion and the effects of the nano-lubricant on the surface hardness

After the immersion of the Al 6061 alloys in the developed machining fluid via the linear polarisation resistance (LPR) technique, the hardness of the surface of the workpiece was studied with the Vickers hardness tester. The force of 500N and dwelling time of 15 seconds since the workpiece is made of aluminium alloys. From the developed machining fluid of various volume concentrations of CNTs particles on mineral oil. The study considered the five (5) machining fluids with the received samples to compare the surface hardness study. Sample B1 is the as-received workpiece before the corrosion study. Sample B2 is the sample placed in the control media with soluble oil (the current machining fluid employed in most computer numerical control machines). Sample B3 is the mineral oil environment; sample B4 is the media containing 0.2g/litres of CNTs nanoparticles, and sample B5 media solution with 0.4 g of CNTs nanoparticles. Finally, sample B6 is the media that contains 0.6g/litre of CNTs nanoparticles. The hardness results obtained from the various samples are presented in Figure 6.

Figure 6 shows that the CNTs nanoparticles significantly affected the surface hardness of the Al 6061 alloys after the immersion of the workpiece in the various concentrations of the media. The trend of the results shows that as the CNTs nanoparticles increase, the surface hardness of the Al 6061 alloy increases. Also, from the literature, it was established that the nanoparticles employed for the machining process deposit thin-firm particles on the surface of the workpiece, which assist in converting the sliding friction into a rolling process, thereby reducing the impact of the cutting tools on the workpiece as shown in Figure 7. This result aligns with the work done by Talib and Rahim [18]. From the analysis, it can be seen that the workpiece reacts with the soluble oil, reducing the surface hardness when compared, as received sample B1 has a hardness value of 95.1, and sample B2 (soluble oil) has a surface hardness of 94. The sample's hardness varies differently. From the results, sample B6 has the highest surface hardness of 121.71, followed by 113.83 of the 0.4g/litre sample B5. The carbon element in the CNTs nanoparticles helped harden the Al 6061 alloys' surface via depositing the carbon element on the surface. This process assists in increasing the hardness of the workpiece [19, 20]. It can be seen as a trend in the three (3) machining fluids developed with CNTs nanoparticles for this study.

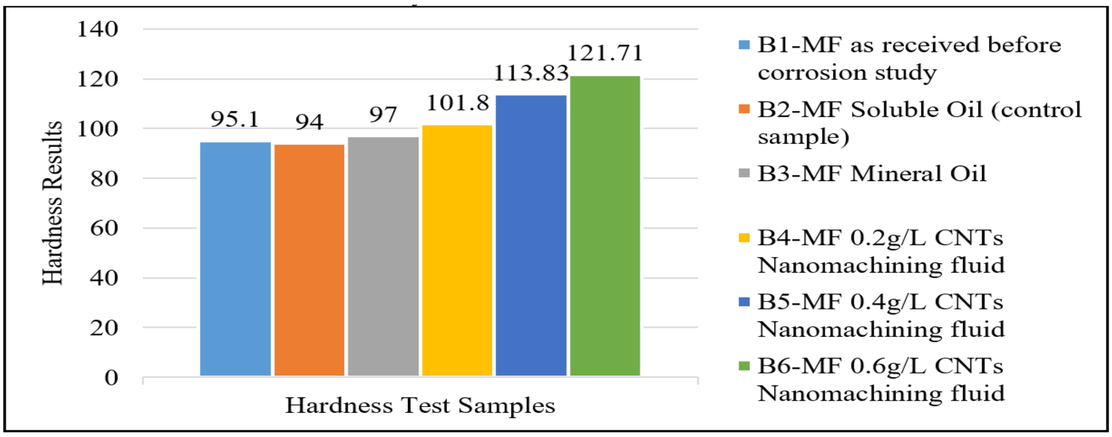

Figure 6. The hardness results of the various samples employed for the study

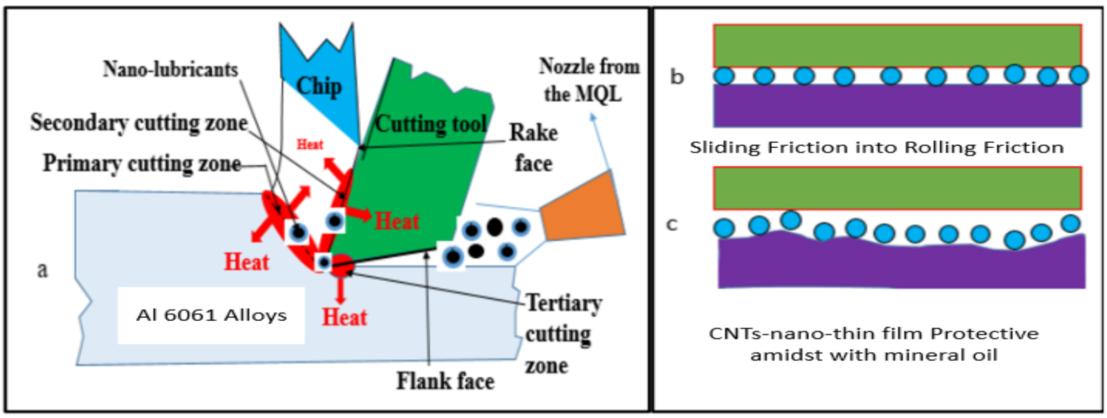

Figure 7. (a) The mechanism of the machining lubrication and cooling process, (b) the rolling effects, and (c) thin-film deposition to protect the workpiece surface

3.2 Microstructural results from the corrosion analysis of the Al 6061 alloy

The six samples used in this study were analysed using the VEGA3 TESCAN scanning electron microscopy (SEM).

Coupled with the energy dispersive spectrometer (EDS) to evaluate the microstructural characteristics of the surface morphology. Figure 8 is the as-received sample for the comparative analysis of the other five samples employed in the linear polarisation study. Figure 9 presents sample B1 immersed in the soluble (control media) oil. The SEM image in Figure 9(a) shows that pit corrosion occurred in the normal face region, which can be seen with the dark spot. Figure 9(b) depicts the EDS analysis of sample B2 in the soluble oil media, which entails the elemental composition of the surface morphology of sample B2. It can be seen that 1.06% chlorine (Cl) and 0.80% sodium (Na) are present, which can be why the pit corrosion occurs. The literature has also established that the machining fluid employed in the manufacturing industries is not ecologically friendly to the operators and the workpiece [21, 22]. Moreover, when deposited in the environment, it causes environmental pollution.

Figure 10 shows both the SEM and EDS of the mineral oil media (sample B2) after the linear polarisation corrosion study. The normal face region shows a high rate of vibration, which can lead to tool wear substitution during the manufacturing process. Also, the EDS analysis proved that the mineral oil, when employed in the machining process, has a meager cooling rate, which causes high heat generation at the cutting region between the cutting tool and the workpiece by having an elemental composition of 3.3% oxygen [23]. It can also be seen that the surface lubrication element is very low due to the presence of 0.61% silicon.

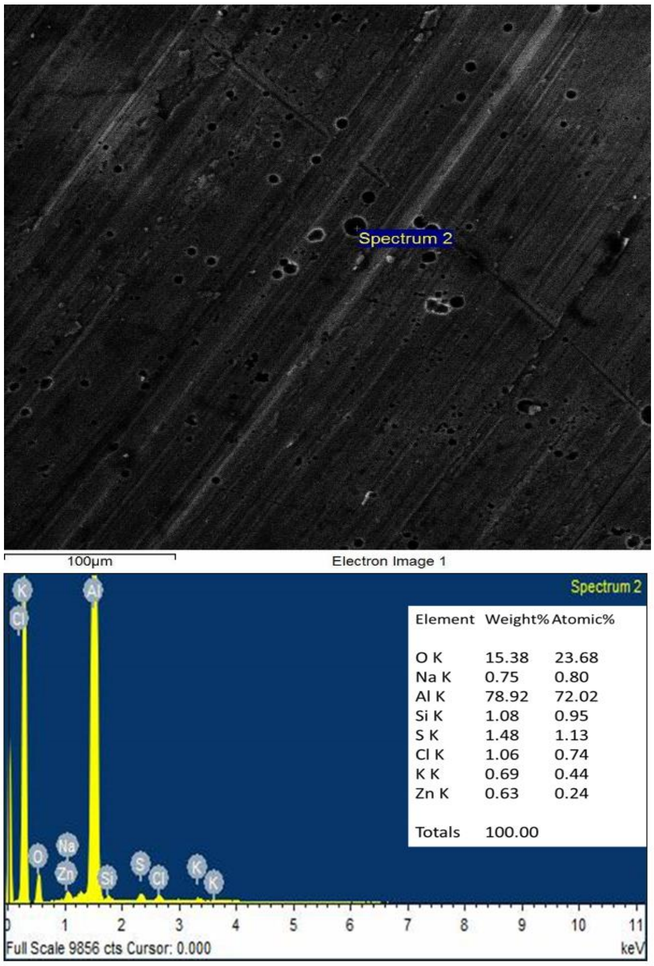

Figure 9. MF control (Soluble oil)

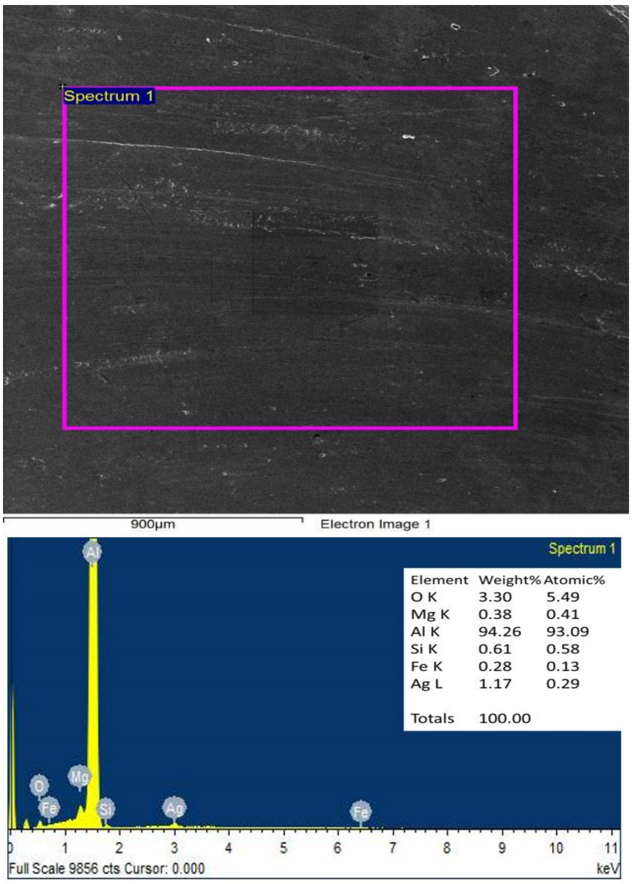

Figure 8. As received samples

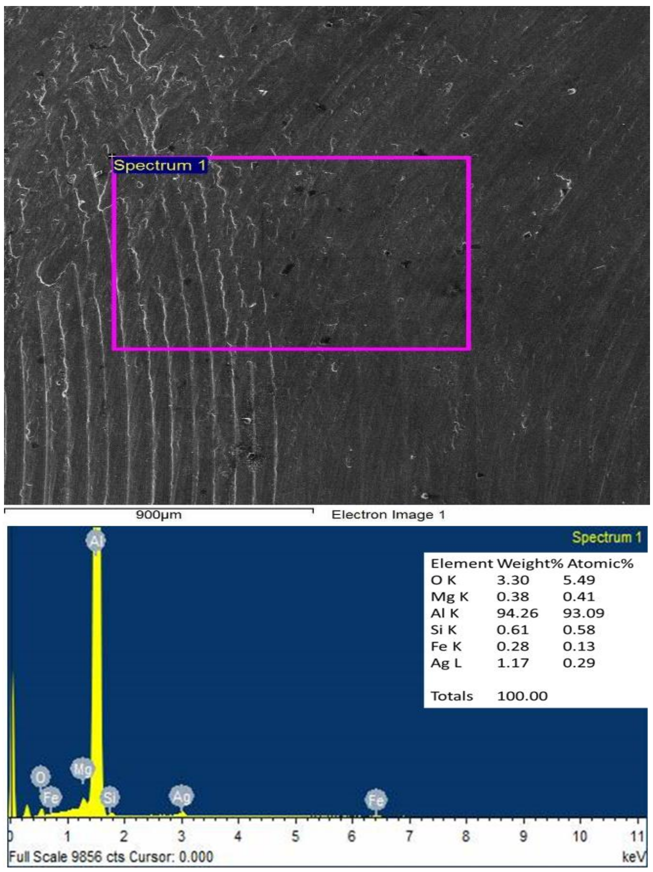

Figure 10. MF mineral oil

Figure 11 shows the SEM and EDS analysis of the NFR (Sample B3) 0.2g/litre CNT lubricant after LPR. There is a trend in Figures 11, 12, and 13, which shows that the CNT nanoparticles are present in the microstructural characteristics of samples B3-A5. From the literature, it has been observed that during the machining process, the CNT nanoparticles are deposited on the surface of the workpiece, thereby leading to converting the sliding friction into rolling friction. The study conducted by Okokpujie et al. [24] shows that applying the CNT nanoparticles reduces the surface roughness, cutting force and temperature and improves the rheological property of the base oil employed in the study.

Figure 11(b) shows that the elemental compositions improve due to the implementation of the 0.2g/l CNT nanoparticles in the mineral oil compared with the pure mineral oil. Sample B3 has 21.14%, Oxygen, 1.69% silicon, 10.17% Carbon, and 67% Aluminium. However, as the CNT nanoparticles increase to 0.4g, the elemental composition of the cooling properties on the normal face region increases except silicon 20.14% Oxygen, 2.69% silicon, 12.67% Carbon and 64.5% aluminium. This analysis is present in Figure 12(a), Figure 12(b) give the SEM and EDS analysis of the NFR (Sample B4) 0.4g/litre nano-lubricant after LPR.

Figure 13 shows the SEM and EDS analysis of the NFR (Sample B5) 0.6g/litre nano-lubricant after LPR. The elemental composition obtained from the surface morphology analysis shows that the Oxygen in 0.4g of CNT media is higher than in 0.6g. The elemental property of the 0.6g CNT is 19.64% Oxygen, 2.69% silicon, 13.67% carbon, and 64% aluminium. This result is supported by observation, and the authors have drawn a colouration study to see that the reason for the increase in the surface hardness properties of sample B5 is a result of the presence of the CNT nanoparticles deposited as a tiny film on the surface of the Al 6061 alloys [25].

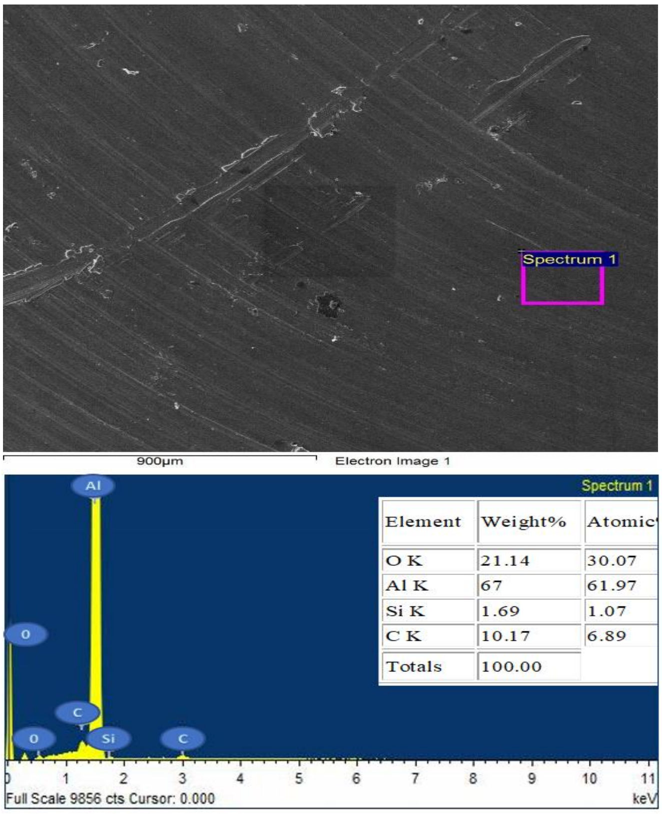

Figure 11. SEM and EDS analysis of the MF 0.2g/l CNTs Nano-mineral machining fluid media

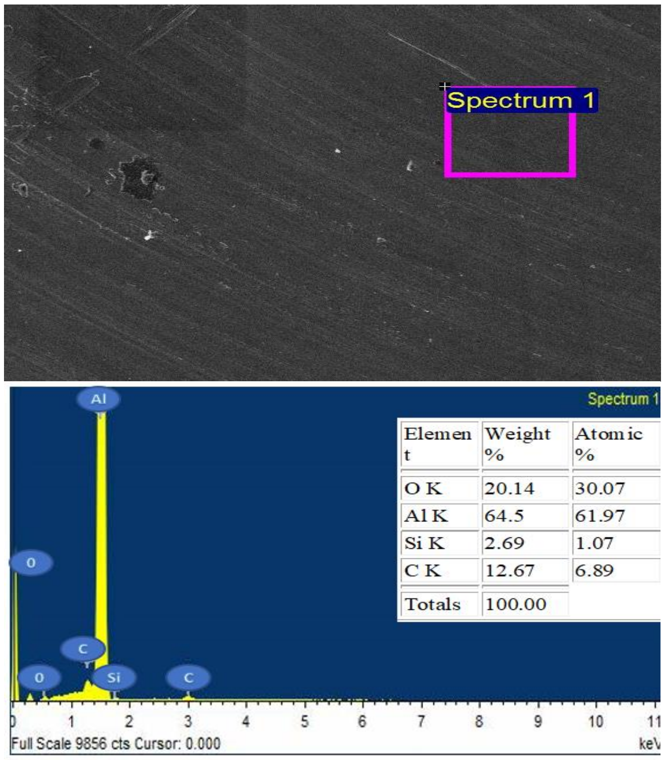

Figure 12. SEM and EDS analysis of the MF 0.4g/l CNTs Nano-mineral machining fluid media

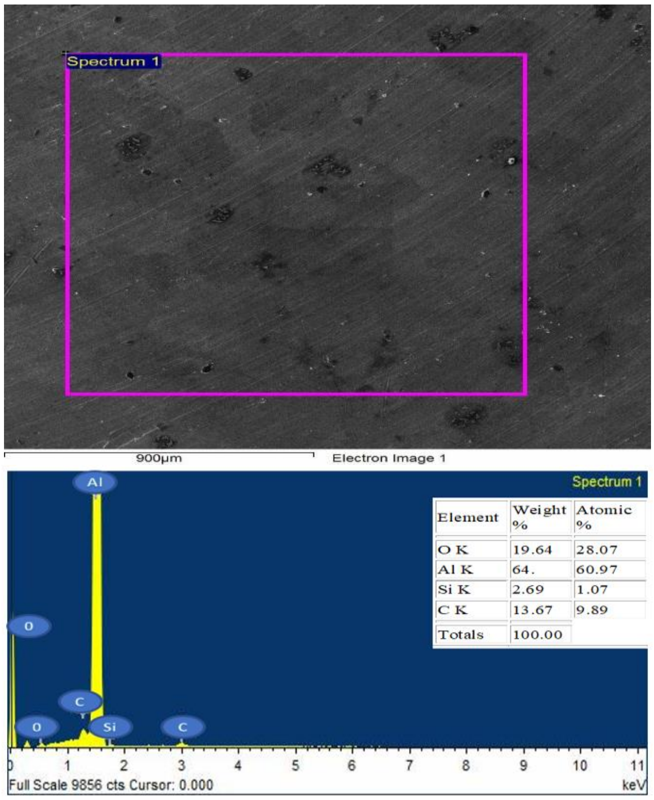

Figure 13. SEM and EDS analysis of the MF 0.6g/l CNTs Nano-mineral machining fluid media

3.3 Polarisation examination of the corrosion outcomes of the Al 6061 alloy in the various developed machining fluid

Table 3 presents the findings related to the six samples' corrosion rate and polarisation resistance. The analysis was conducted using the LSV staircase technique, employing a start potential of-1.5 Vocp, a stopping potential of 1.5 Vocp, a scan rate of 0.01, and steps of 0.0025V. The parameters utilised in this study included a projected number of 1229, an interval time of 0.244 seconds, and anticipated durations of 300.05. Based on the Tafel analysis model, the environment had a density of 7.86g/cm^3, an equivalent weight of 27.925g/mol, and a surface area of 1cm^2. It is evident from Table 3 that significant variations exist in the corrosion rate and polarisation resistance of the generated machining fluid.

Figure 14 and Figure 15 present the corrosion rate results and the linear polarisation resistance of the five (5) different media.

Table 3. The various machining fluids' potentiodynamic corrosion and polarisation resistance in the Al 6061 alloys' machining face (MF)

Medias	Ecorr, Obs (V)	Jcorr (A/cm²)	Icorr (A)	Corrosion Rate (mm/year)	Polarisation Resistance (Ω)
Soluble oil (Control media)	-1.818948843	-3.09002E-06	-3.09002E-06	0.03590591	8432.83
Mineral oil	-3.277702494	1.5734E-10	1.5734E-10	0.0282828	16561.7
0.2g/l CNTs+mineral	-1.647795831	-1.13569E-08	-1.13569E-08	0.0133197	22944.44
0.4g/l CNTs+mineral	-1.447795831	-1.03569E-08	-1.03569E-08	0.0033197	26945.13
0.6g/l CNTs+mineral	-1.247795831	-1.01569E-08	-1.01569E-08	0.0013197	32941.67

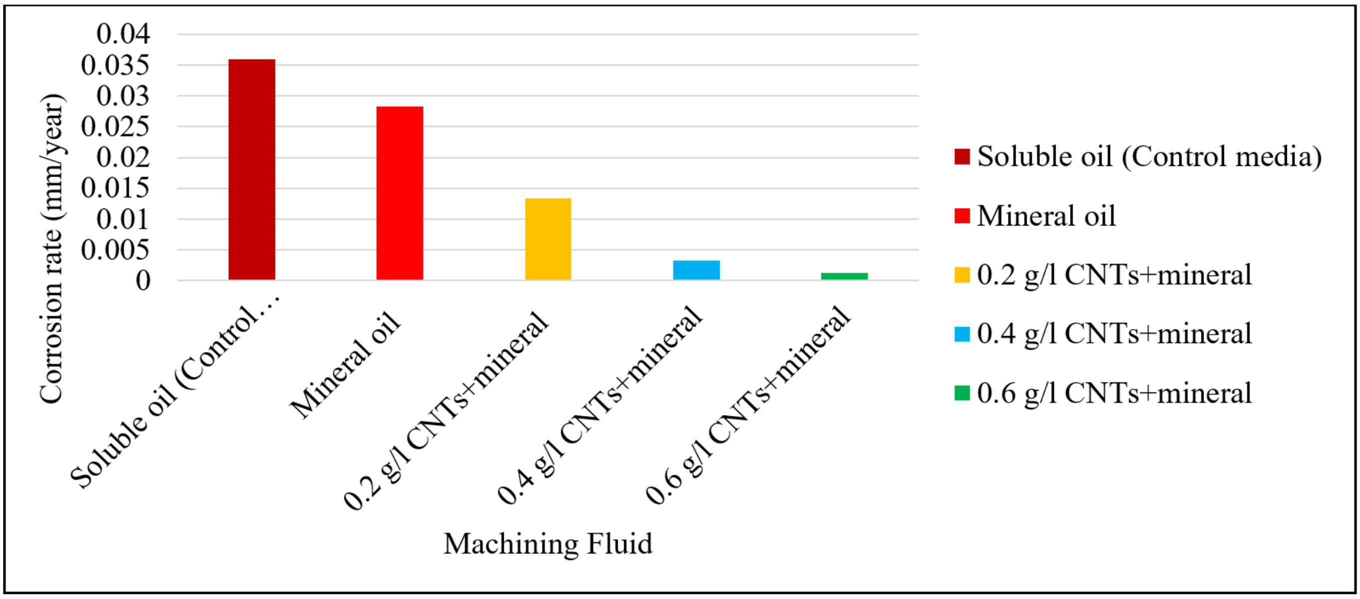

Figure 14. Corrosion rate of the five (5) different media used for the study

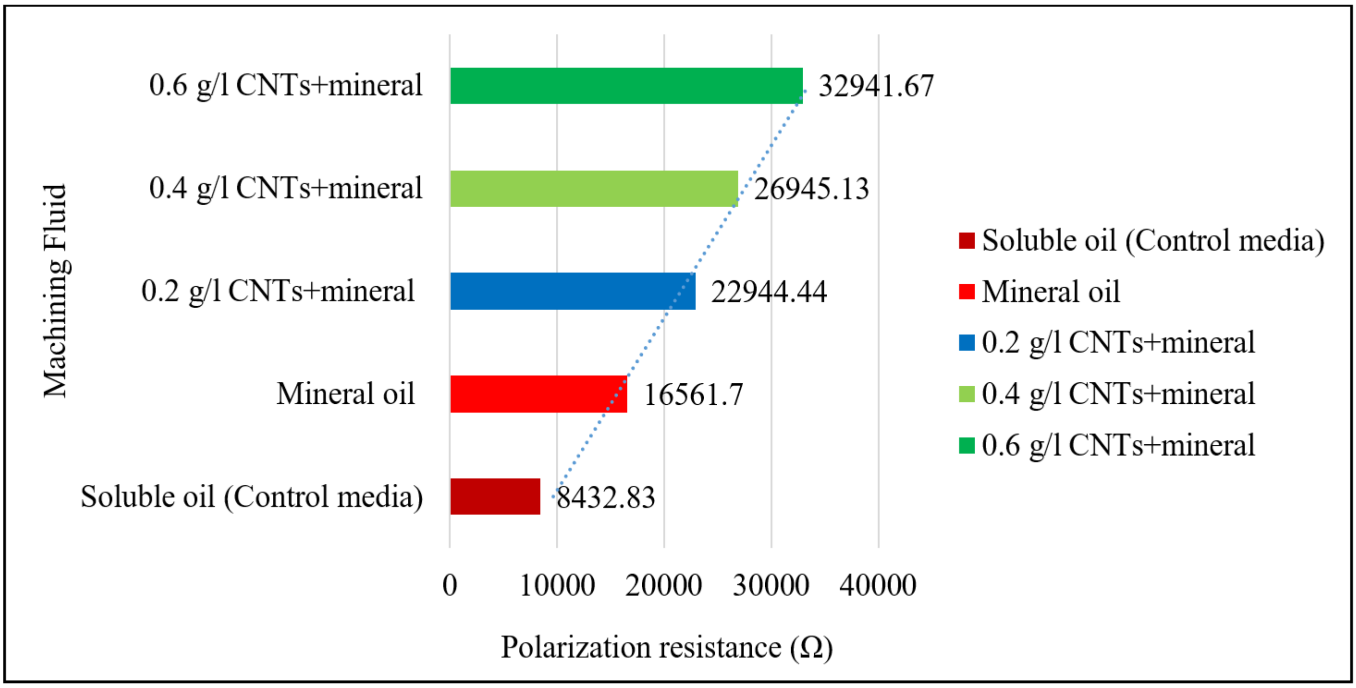

Figure 15. Polarisation resistance of the study’s five (5) different media

Employed for this study. It can also be established that the increment of the CNT nanoparticles in the corrosion analysis reduces the corrosion rate of the Al 6061 alloys [26, 27]. The CNT also function as an inhibitor for the polarisation resistance of the three (3) media that contain it. Corrosion rate (mm/year); 0.03590591, 0.0282828, 0.0133197, 0.0033197, and 0.0013197, respectively. Polarisation resistance (Ω); 8,432.83, 16,561.7, 22944.44, 26,945.13 and 32,941.67 for the five (5) samples, respectively.

4. CONCLUSION AND RECOMMENDATION

This project has successfully conducted an experimental study to analyse the effects of various machining fluids on the surface hardness and corrosion behaviour of Al6061 alloy. This research developed five (5) different machining fluids via the two-step method of the nano-machining fluid process. The five samples are soluble oil (control sample) that is (sample B1), mineral oil (Sample B2), 0.2g/litre CNT nanoparticles (sample B3), 0.4g/litre CNT nanoparticles (sample B4) and 0.6g/litre CNT nanoparticles (sample B5). After the preparation of the machining fluid, the project implemented Potentiodynamic corrosion and polarisation resistance to study the corrosion rate of the machining fluid on the surface of the al6061 alloy, and after the corrosion study, the SEM and EDS to investigate the microstructure and elemental composition of the machining fluid and the Vickers micro-hardness for the hardness measurement, to enable the authors to carry out flexibility study of the behaviours of the various machining fluids on the surface hardness and corrosion rate on the al6061 alloy. Therefore, the project has the following conclusions.

(1) The experimental study shows that adding the CNT nanoparticles to the machining-based fluid increases the surface hardness. The pure sample B1, under the hardness analysis, has a hardness of 95.1, sample B2-94, sample B3-97, Sample B4-101.8, Sample B5-113.83, and sample B6-121.71, respectively.

(2) The results of the corrosion rate and the linear polarisation resistances show that the media with 0.6g of CNT nanoparticles on the base machining fluid has the lowest corrosion rate of 0.0013197 (mm/year), the media of 0.4g CNT nanoparticles has the corrosion rate of 0.0033197 (mm/year), of 0.2g CNT nanoparticles has 0.0133197 corrosion rate. It was also observed that the mineral oil (0.0282828mm/year) has a reduced corrosion rate compared to soluble oil (0.03590591mm/year).

(3) The CNT nanoparticles act as an inhibitor in the developed machining fluid, which affects the linear polarisation resistance of the machining fluid. Polarisation resistance (Ω) 32941.67 (0.6g CNT nanoparticle), 26945.13 (0.4g CNT nanoparticle), 22944.44 (0.2g CNT nanoparticle), 16561.7 (Mineral oil) and 8432.83 (soluble oil) for the five (5) samples, respectively.

This project will recommend further study on the corrosion study by implementing CNT nanoparticles on locally developed machining-based fluid to ensure that these nanoparticles' performance analysis is established.

REFERENCES

[1] Kumar, R., Sharma, S., Kumar, R., Verma, S., Rafighi, M. (2023). Review of lubrication and cooling in computer numerical control (CNC) machine tools: A content and visualization analysis, research hotspots and gaps. Sustainability, 15(6): 4970. https://doi.org/10.3390/su15064970

[2] Sato, B.K., Lopes, J.C., Rodriguez, R.L., Garcia, M.V., Ribeiro, F.S.F., Aguiar, P.R., Bianchi, E.C. (2021). Eco-friendly manufacturing towards the industry of the future with a focus on less cutting fluid and high workpiece quality applied to the grinding process. The International Journal of Advanced Manufacturing Technology, 113: 1163-1172. https://doi.org/10.1007/s00170-021-06650-1

[3] Okokpujie, I.P., Tartibu, L.K. (2022). A mini-review of the behaviour characteristic of machining processes of aluminium alloys. Materials Today: Proceedings, 62: 4526-4532. https://doi.org/10.1016/j.matpr.2022.05.006

[4] Maurya, S.K., Chechi, P., Prasad, R., Susheel, C.K., Manna, A. (2022). Effect of surface finish on corrosion behavior of polished Al6061 alloy in simulated acid rain environment. Materials Today: Proceedings, 64: 755-759. https://doi.org/10.1016/j.matpr.2022.05.208

[5] Okokpujie, I.P., Tartibu, L.K., Sinebe, J.E., Adeoye, A.O., Akinlabi, E.T. (2022). Comparative study of rheological effects of vegetable Oil-Lubricant, TiO2, MWCNTs Nano-Lubricants, and machining parameters' influence on cutting force for sustainable metal cutting process. Lubricants, 10(4): 54. https://doi.org/10.3390/lubricants10040054

[6] Samuel, A.U., Araoyinbo, A.O., Elewa, R.R., Biodun, M.B. (2021). Effect of machining of aluminium alloys with emphasis on aluminium 6061 alloy-a review. In IOP Conference Series: Materials Science and Engineering, IOP Publishing, 1107(1): 012157. https://doi.org/10.1088/1757-899X/1107/1/012157

[7] Akkurt, A. (2015). The effect of cutting process on surface microstructure and hardness of pure and Al 6061 aluminium alloy. Engineering Science and Technology, an International Journal, 18(3): 303-308. https://doi.org/10.1016/j.jestch.2014.07.004

[8] Okokpujie, I.P., Tartibu, L. (2023). Corrosion behaviour of coconut rice and eggshell reinforced aluminium metal matrix composites in 0.4 M H2SO4. Advances in Materials and Processing Technologies, 1-15. https://doi.org/10.1080/2374068X.2023.2192389

[9] Dang, Y.T., Power, A., Cozzolino, D., Dinh, K.B., Ha, B.S., Kolobaric, A., Vongsvivut, J, Truong, V.K., Chapman, J. (2022). Analytical characterisation of material corrosion by Biofilms. Journal of Bio-and Tribo-Corrosion, 8(2): 50. https://doi.org/10.1007/s40735-022-00648-2

[10] Okokpujie, I.P., Ikumapayi, O.M., Okonkwo, U.C., Salawu, E.Y., Afolalu, S.A., Dirisu, J.O., Nwoke, O.N., Ajayi, O.O. (2017). Experimental and mathematical modeling for prediction of tool wear on the machining of aluminium 6061 alloy by high speed steel tools. Open Engineering, 7(1): 461-469. https://doi.org/10.1515/eng-2017-0053

[11] Ali, N., Bahman, A.M., Aljuwayhel, N.F., Ebrahim, S.A., Mukherjee, S., Alsayegh, A. (2021). Carbon-based nanofluids and their advances towards heat transfer applications-A review. Nanomaterials, 11(6): 1628. https://doi.org/10.3390/nano11061628

[12] Okokpujie, I.P., Bolu, C.A., Ohunakin, O.S. (2020).

Comparative performance evaluation of TiO_2, and MWCNTs nano-lubricant effects on surface roughness of AA8112 alloy during end-milling machining for sustainable manufacturing process. The International Journal of Advanced Manufacturing Technology, 108: 1473-1497. https://doi.org/10.1007/s00170-020-05397-5

[13] Barati, M., Abbasi, M., Abedini, M. (2019). The effects of friction stir processing and friction stir vibration processing on mechanical, wear and corrosion characteristics of Al6061/SiO2 surface composite. Journal of Manufacturing Processes, 45: 491-497. https://doi.org/10.1016/j.jmapro.2019.07.034

[14] Okokpujie, I.P., Tartibu, L.K., Babaremu, K., Akinfaye, C., Ogundipe, A.T., Akinlabi, E.T. (2023). Study of the corrosion, electrical, and mechanical properties of aluminium metal composite reinforced with coconut rice and eggshell for wind turbine blade development. Cleaner Engineering and Technology, 13: 100627. https://doi.org/10.1016/j.clet.2023.100627

[15] Pistone, A., Iannazzo, D., Panseri, S., Montesi, M., Tampieri, A., Galvagno, S. (2014). Hydroxyapatite-magnetite-MWCNT nanocomposite as a biocompatible multifunctional drug delivery system for bone tissue engineering. Nanotechnology, 25(42): 425701. https://doi.org/10.1088/0957-4484/25/42/425701

[16] Saleh, T.A. (2013). The role of carbon nanotubes in enhancement of photocatalysis. Syntheses and Applications of Carbon Nanotubes and Their Composites, 479-493.

[17] Zhou, X., Han, H., Wang, Y., Zhang, C., Lv, H., Lou, Z. (2022). Silicon-coated fibrous network of carbon nanotube/iron towards stable and wideband electromagnetic wave absorption. Journal of Materials Science & Technology, 121: 199-206. https://doi.org/10.1016/j.jmst.2022.03.002

[18] Talib, N., Rahim, E.A. (2018). Performance of modified jatropha oil in combination with hexagonal boron nitride particles as a bio-based lubricant for green machining. Tribology International, 118: 89-104. https://doi.org/10.1016/j.triboint.2017.09.016

[19] Sivamaran, V., Balasubramanian, V., Gopalakrishnan, M., Viswabaskaran, V., Rao, A.G., Sivakumar, G. (2020). Mechanical and tribological properties of self-lubricating Al 6061 hybrid nano metal matrix composites reinforced by nSiC and MWCNTs. Surfaces and Interfaces, 21: 100781. https://doi.org/10.1016/j.surfin.2020.100781

[20] Xie, H., Wei, Y., Jiang, B., Tang, C., Nie, C. (2021). Tribological properties of carbon nanotube/SiO2 combinations as water-based lubricant additives for magnesium alloy. Journal of Materials Research and Technology, 12: 138-149. https://doi.org/10.1016/j.jmrt.2021.02.079

[21] Okokpujie, I.P., Tartibu, L.K. (2023). Development and application of nano-lubricant in machining: A review. Modern Optimization Techniques for Advanced Machining: Heuristic and Metaheuristic Techniques, 41-60. https://doi.org/10.1007/978-3-031-35455-7_3

[22] Okokpujie, I.P., Tartibu, L.K. (2023). Cutting fluid and its application with different delivering machining techniques. In Modern Optimization Techniques for Advanced Machining: Heuristic and Metaheuristic Techniques, Cham: Springer Nature Switzerland, pp. 25-39. https://doi.org/10.1007/978-3-031-35455-7_2

[23] Jamil, M., He, N., Gupta, M.K., Zhao, W., Khan, A.M. (2022). Tool wear mechanisms and its influence on machining tribology of face milled titanium alloy under sustainable hybrid lubri-cooling. Tribology International, 170: 107497. https://doi.org/10.1016/j.triboint.2022.107497

[24] Okokpujie, I.P., Chima, P.C., Tartibu, L.K. (2022). Experimental and 3D-deform finite element analysis on tool wear during turning of Al-Si-Mg Alloy. Lubricants, 10(12): 341. https://doi.org/10.3390/lubricants10120341

[25] Arunkumar, T., Pavanan, V., Murugesan, V.A., Mohanavel, V., Ramachandran, K. (2022). Influence of nanoparticles reinforcements on aluminium 6061 alloys fabricated via novel ultrasonic aided rheo-squeeze casting method. Metals and Materials International, 28(1): 145-154. https://doi.org/10.1007/s12540-021-01036-0

[26] Anwar, J., Khan, M., Farooq, M.U., Khan, T.F., Anwar, G.A., Qadeer, A., Arshad, M.A., Irfan, M., Subhani, T. (2023). Effect of B4C and CNTs' nanoparticle reinforcement on the mechanical and corrosion properties in rolled Al 5083 friction stir welds. Canadian Metallurgical Quarterly, 62(1): 1-10. https://doi.org/10.1080/00084433.2022.2054586

[27] Mosleh-Shirazi, S., Akhlaghi, F., Li, D.Y. (2016). Effect of SiC content on dry sliding wear, corrosion and corrosive wear of Al/SiC nanocomposites. Transactions of Nonferrous Metals Society of China, 26(7): 1801-1808. https://doi.org/10.1016/S1003-6326(16)64294-2