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Experimental Study and Finite Element Analysis of Temperature Reduction and Distribution During Machining of Al-Si-Mg Composite Using Deform 3D

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ABSTRACT

Composite materials are promising materials in the manufacturing industry due to the quality of their materials properties. However, in transforming these materials, the machining process experiences a high-heat generation rate, which has led to the study of temperature distribution, and reduction analysis at the cutting region. High-temperature generation during machining operation leads to thermal deformation on the developed component or parts, affecting the operation life span of the component. Thus, this study investigated the effect of mineral oil-based-Multi-walled carbon nanofluid (MWCNTs) compared to pure mineral oil in the turning of aluminum-silicon magnesium metal composite (AlSiMg) on temperature reduction and distribution. The nanofluid was prepared with 0.4g of MWCNT to 1 liter of mineral oil. The study employed the energy dispersive spectrometer to obtain the chemical composition of the developed nanofluid. Furthermore, Finite element software DEFORM 3D v11.0 uses a lagrangian incremental approach to simulate chip formation and temperature distribution on the workpiece. Also, to study the effects of the machining parameters on the temperature distribution. The experiment results showed a significant reduction of 11.9% in temperature when machining with nanofluid compared to pure mineral oil. The simulation results showed that the temperature increases as the cutting speed and feed rate increase. The minimum temperature via the DEFORM 3D Finite Element Model simulation was achieved at spindle speed 870 rpm, feed rate 2 mm/rev, and depth-of-cut 1 mm. In conclusion, the study recommends that the manufacturing industry employ the optimized machining parameters during the turning of AlSiMg metal matrix composite for a sustainable machining process.

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1. Introduction

Machining is cutting or removing bits of material to get the required shape. It removes unwanted parts (chips) of a material to get a defined shape. Therefore, there is a need to employ simulation analysis such as the finite element method to predict and achieve sustainable results for sustainable machining processes. The finite element method **(**FEM) is a sustainable method of analyzing temperature distribution in the machining process, which gives a better understanding of the cutting region and how the temperature is distributed during the machining [1]. Shetty *et al.,* [2] performed a study on the use of FEM in understanding the interactions between the cutting tool and workpiece when machining composite materials. This study examined the lousy surface morphology caused by temperature during machining. Various simulations were done on three machining processes (drilling, orthogonal, and turning) by different researchers and were reviewed using different simulations. Perez *et al.,* [3] investigated the effect different cutting tools have on the cutting edge's temperature during the high-speed dry turning of AISI 1045 steel. The cutting tool used for the investigation is carbide coated cutting tool and uncoated cermet cutting tool. In order to investigate the effect of the cutting tool, DEFORM-2D FEM software was used. The cutting process was simulated three times for adequate investigation of the experiment. For the three simulations, three cutting tools were used: (1) uncoated cermet cutting tool with complete length contact with the workpiece (2) coated carbide cutting tool with complete length contact with the workpiece, (3) coated carbide cutting tool with no condition. The result showed that coating changes the position of the field temperatures, and the highest temperature point is the same for the three cutting tools investigated. It was also observed that there was no significant change in the temperature field when performing high-speed dry turning of AISI 1045 steel with the cutting tools.

The finite element method in simulating the effects of turning parameters is one of the accurate and most recent methods applied in the manufacturing industry [4-5]. Due to the constant study being carried out by many researchers. Umer *et al.,* [6] investigated the finite element method of analysis in analyzing the machining characteristics of aluminum metal matrix composite material. The metal matrix composite material combines aluminum alloy (Al-359) as the base metal and silicon carbide to reinforce the aluminum alloy. The machining was done using a polycrystalline diamond cutting tool at three different speeds and feed rates. The simulation was carried out using ABAQUS software. The results of the simulation were close to that of the experimental. The simulation results showed that the maximum temperature in the tool-chip interface occurs at the tool's tip. It also showed that the temperature field of the cutting area increases with an increase in feed rate and has a decrease in temperature; an increase in the cutting speed leads to the maximum temperature and a reduction in the temperature field. D'Addona and Raykar [7] studied the analysis of temperature distribution during the turning of Inconel 718 using FEM. The workpiece, which is a superalloy with a combination of nickel and chromium, was subjected to four lubricating conditions during the machining process: dry machining, conventional wet machining, and high-pressure coolant at two pressures (50 bar and 80 bar). The FEM software used for the simulation of the turning process was ANSYS. It was used to predict the temperature of the cutting zone under the high-pressure coolant as it was hard to take the temperature measurement. The results of the finite element analysis were close to the experimental results. The cutting temperature was found to reduce with each lubricating condition stated, having 38°C to 31°C temperature drop for the 80bar high-pressure coolant and 35°C to 31°C temperature drop for the 50bar high-pressure coolant. Therefore, the importance of FEM is a key in turning operation via lathe machining.

A lathe machine is a machine tool that uses single-point cutting tools for machining. With this machine tool, five various main types of machining operations can be performed. These are: turning, facing, external threading, boring, and cut off [8]. Turning is the primary operation done on the lathe machine. There are different types of turning operations: straight turning, contour turning, taper turning, and form turning. Performing this machining operation on difficult-to-cut materials also causes friction and increased temperature. Bag *et al.,* [9] performed a study on the turning of hardened steel (AISI 4340 STEEL) and the effects of nano-cutting fluid during the turning process. The study was centered on improving the temperature reduction process during the machining of the hardened steel as the temperature was a crucial factor/parameter for an enhanced quality of the machined part and determination of the tool lifespan. This study included various nano-cutting fluids with different nanoparticles and different base fluids, all to investigate the impact of nano-cutting fluid. The study found that the application of nanofluids under minimum quantity lubrication (MQL) reduced the impact of high temperature during the machining of the hardened steel. Its sizeable thermal conduction property increases the tool's lifespan due to its better cooling and lubrication.

Friction during machining produces heat which, if not dissipated, increases the temperature of the cutting area, reduces the tool life, and affects the surface quality [10-11]. With the effects of friction between the workpiece and work tool taken into consideration, various lubricants have been selected during machining. These lubricants contain properties making them suitable to act as coolants and anti-wear agents [12-13]. Some include soluble oils, synthetic oils, semi-synthetic oils, and straight oils used for machining [14]. Over time these lubricants are hazardous to the environment and machinist, hence the need to improve the lubricant and the application method. This brings about the research of nano lubricants as lubricants during machining. This is a researched method of overcoming the hazardous properties of lubricants in machining. It involves nanotechnology as nanoparticles of size 10 – 100nm are mixed in a base fluid before its application during machining operations [15]. Examples of nanoparticles include CuO nanoparticles, Fe_2O_3 nanoparticles, Al_2O_3 nanoparticles, TiO_2 nanoparticles, and Carbon nanotubes. These nanoparticles are added to base fluids like biodegradable vegetable oil, ethylene glycol, lubricating oil, synthetic oil, and water. When nanoparticles are added to a base fluid, they affect various characteristics of the base fluid. Raja *et al.,* [16] experimented on the effect of nanofluid on tool wear and temperature in the turning of mild steel. Metal oxide-based ZnO nanofluid was utilized for this study using minimum quantity lubrication as the means of application. The experiment showed a reduction in the temperature during the turning process when applying the nanofluid, resulting from the large thermal conductivity of the zinc oxide nanoparticle. It also reduces tool wear, produces a good surface finish, and is eco-friendly.

Rao *et al.,* [17] investigated the effect of nanofluid under the minimum quantity lubrication method of application in the turning of EN-36 steel compared to dry machining. Al_2O_3 nanoparticles added to vegetable oil base fluid were used as the nanofluid for the investigation. They were applied at different volumes of 6% and 8%. The 6% nanofluid contained 6 grams of Al_2O_3 and 100 milliliters of vegetable oil. The 8% nanofluid contained 8 grams of Al_2O_3 and 100 milliliters of vegetable oil. The investigation results showed that the use of nanofluid improved the machining characteristics. It improved the surface roughness to which the dry machining produced a surface roughness of 1.6 µm, while the 6% and 8% nanofluid produced surface roughness of 0.6 µm and 0.1 µm, respectively. The use of the nanofluid also reduced the cutting temperature, having results of 46°C and 44°C for the 6% and 8% nanofluid and 55°C for the dry machining. When comparing the results of the different volumes of nanofluid, the 8% nanofluid had better results in cutting temperature, which helps reduce the surface roughness.

Aluminum metal matrix composite is a new trend of materials employed in the manufacturing industry to produce viable mechanical components for different applications in the engineering industries [18,19]. Due to their quality mechanical and high resistance to corrosion when applied in high altitude and marine applications [20].

However, the raw material needs to be passed through a transformation process before the finished product can be used. This transformation process is via machining operations. Machining comprises lathe, milling, grinding, drilling, and shaping processes. Most cylindrical materials are machined via turning operations. The Al-Si-Mg metal matrix composite is a cylindrical material employed in this machining experimental study. Due to the high strength-to-weight ratio of machining aluminum composite, there is a need to implement biodegradable nono-lubricant to reduce the temperature generated at the cutting region.

However, this research aims to experimentally study the reduction of the heat generated during machining an aluminum-silicon magnesium metal matrix composite (AlSiMg) material using mineral oil-based-Multi-walled carbon nanofluid (MWCNTs). Furthermore, a comparison was made on the experimental results of the two lubrication environments. Also, the DEFORM 3D FEM was used to study the significance of the machining parameters with time variation on the temperature distribution and reduction during the machining process.

2. Methodology

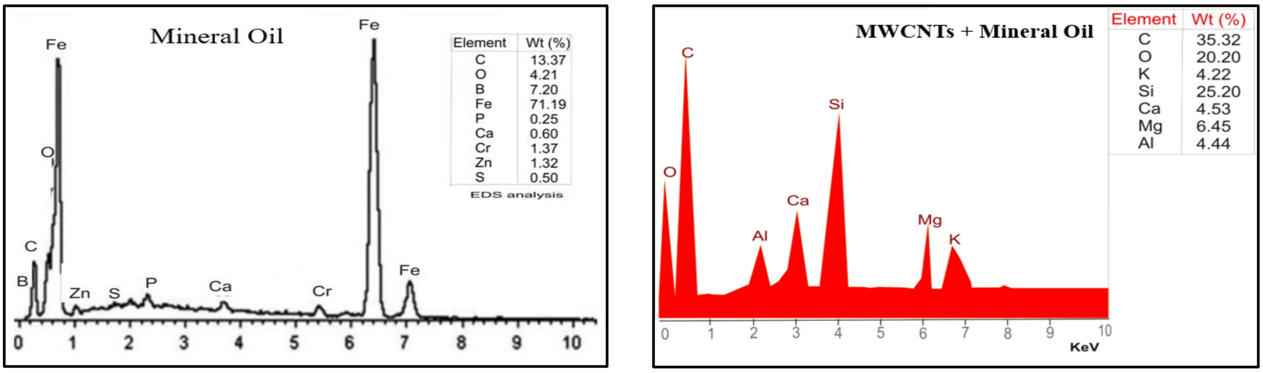
The aluminum metal matrix composite has aluminum as its base metal and the following components: coconut rice, coconut shell, silicon, and magnesium. These components were put in to increase the properties of the base aluminum metal. The aluminum metal matrix was prepared using the stir casting method. This process is economical for casting metals and is mainly used for mass production. The stir casting process starts by melting the base metal in a furnace, preferably a bottom pouring furnace. It reacts with the air and moisture to form Al_2O_3. A mechanical stirrer stirs the molten metal while still in the furnace. At the same time, the other components are preheated. The preheated components are poured into the molten metal while still being stirred. Stirring was done for 1 hour 30 minutes to avoid sedimentation at the bottom of the furnace and to get a homogeneous mixture. The homogeneous mixture is then poured into a mould with the shape of the cylinder. The casted metal matrix was 230mm long and 24mm in diameter. The X-Ray Fluorescence Spectrophotometry was employed to determine the chemical composition of the material, as shown in Table 1. Table 1 shows the chemical properties of the Ai-Si-Mg metal matrix composite used for the machining process.

Table 1
Chemical composition of the Al-Si-Mg metal matrix composite

Material	SiO_2	Al	Fe_2O_3	MnO	CaO	P_2O_5	K_2O	TiO_2	SO_3
w (%)	4.73	84.6	2.35	0.40	1.83	0.70	0.35	0.12	1.0
Material	MgO	Cl	LOI	RbO	ZnO	Cr_2O_3	SrO	NiO	
w (%)	3.07	0.29	0.77	0.01	0.18	0.04	0.50	0.03	

2.1 Preparation of Nano Cutting Fluid

Multi-Walled Carbon nanotubes (MWCNT) nanoparticles are used for the experiment. The nanoparticle size ranges from 10 ± 1nm to 4.5 ± 0.5nm with 3 – 6µm and has a purity of 98%. For making the lubricant, white mineral oil, which is mineral oil, was used as the base fluid. Mineral oil was used as the base fluid to reduce the surface roughness and material loss. It has better lubrication properties than water or dry machining [21]. The white mineral oil was mixed with the nanoparticle at a ratio of 0.4g for 1 liter of mineral oil. The ultra-sonicator ran for 3 hours to prevent particle agglomeration and get a homogeneous mixture [22]. Figure 1 shows the SEM and EDX analysis of the white mineral oil and the nanofluid chemical composition.



Element	Wt (%)
C	13.37
O	4.21
B	7.20
Fe	71.19
P	0.25
Ca	0.60
Cr	1.37
Zn	1.32
S	0.50

EDS analysis

Element	Wt (%)
C	35.32
O	20.20
K	4.22
Si	25.20
Ca	4.53
Mg	6.45
Al	4.44

(a) (b)

Fig. 1. EDX images of (a) White mineral oil and (b) MWCNTs and white mineral oil

2.2 Experimental Setup

This experiment was performed on a WARCO GH-1640ZX gearhead precision lathe machine with a maximum rotational speed of 1800 rpm. High-speed steel was used as the cutting tool. The experiment was carried out with three different depths of cuts, feed rates, and spindle speeds. As shown in Table 2, Mineral oil lubrication and Nanofluid lubrication are under two different cutting environments. The temperature of the tool-chip interface was measured using a K-type thermometer (PM6501). The thermocouple of the K-type thermometer was placed at the tool-chip interface to get an accurate temperature during the machining. In order to achieve optimal machining parameters, the L9 orthogonal array was used. Figure 2 shows the experimental study set up for the turning operations for the nine experimental runs.

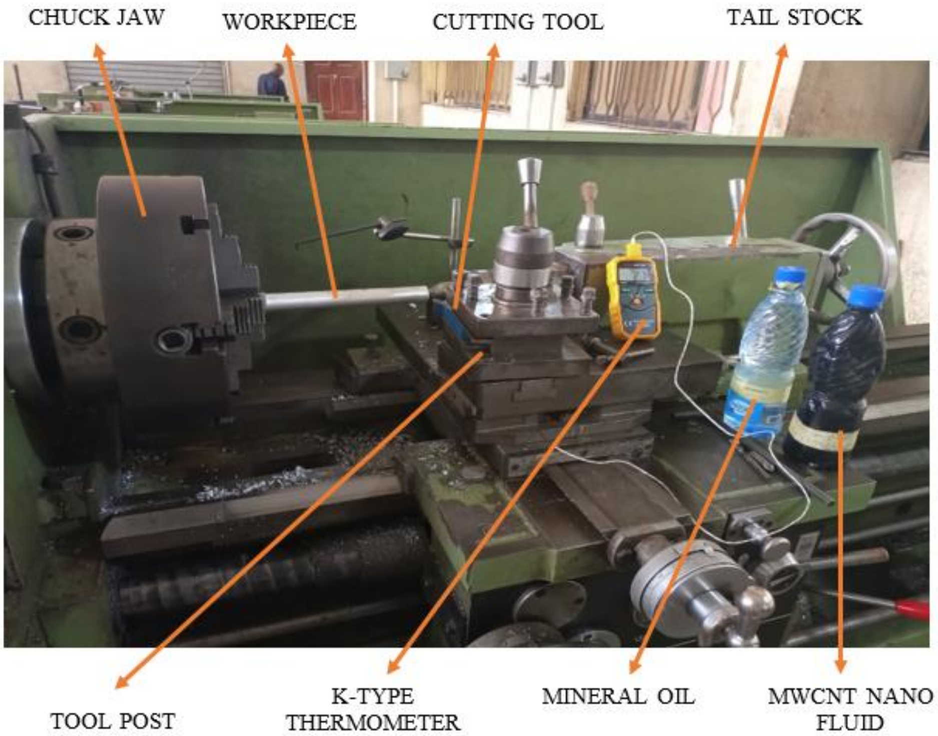


Fig. 2. The experimental study setup for the turning operations

Table 2
Conditions for experimentation

Experimental Conditions	Turning machine
Workpiece	Al-Si-Mg
Cutting tool	High-speed-steel
Environment	Mineral oil lubrication, MWCNTs Nanofluid lubrication
Spindle speed (rpm)	870, 1400, 1800
feed rate (mm/rev)	2, 4, 6
Depth of cut (mm)	1, 2, 3
Length of cut (mm)	170

2.3 Taguchi L9 Array Analysis

Taguchi method operates with orthogonal arrays, which help reduce the large number of experiments to be performed (due to a large number of parameters) to the barest minimum number and still obtain all the information obtained from the total experiments [23]. The L9 orthogonal array is the most used for optimization. It is of three types: larger the better, nominal the better, and smaller the better. For this experiment, the smaller, the better the L9 array shown in Eq. (1) was utilized to optimize the parameter. The experimental design was generated using the Taguchi L9 method of optimization, as shown in Table 3.

$$\frac{S}{N} = -10\log_{10}\frac{1}{x}\sum_{n=1}^{x}\frac{1}{zn^2} \tag{1}$$

where x is the total number of experiments, zn is the experimental results of the n-th experiment.

Table 3
Optimized parameters using Taguchi L9 orthogonal array

Spindle speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)
870	2	1
870	4	2
870	6	3
1400	2	2
1400	4	3
1400	6	1
1800	2	3
1800	4	1
1800	6	2

2.4 Finite Element Modeling

Finite element analysis (FEA) uses numerical techniques to analyze the difficulties encountered during machining processes. It is a method used to analyze modeled engineering objects to predict typical problems like heat transfer, fluid flow, electromagnetic potential, and structural integrity in using the objects. FEA method of analysis functions by converting differential equations added to boundary conditions into linear equations to study the parameters for the turning operation via simulation. It divides the modeled object into smaller pieces called an element. With each element having almost the same geometry, it quickly analyzes each element at nodes where the initial problem and boundary conditions are applied in the degrees of freedom are calculated before combining the elements at the same nodes into a whole known as mesh. The process of scattering the model into elements and assembling them is called discretization. For the Finite element method of analysis to be performed, analytical solutions must be found. This analysis includes

i. Heat balance: The first law of thermodynamics says that the rate of thermal and mechanical energy in and out of the system is equal to the rate of heat generated and stored in the system, as shown in Eq. (2).

$$E_{in} - E_{out} = E_{stored} - E_{generated} \tag{2}$$

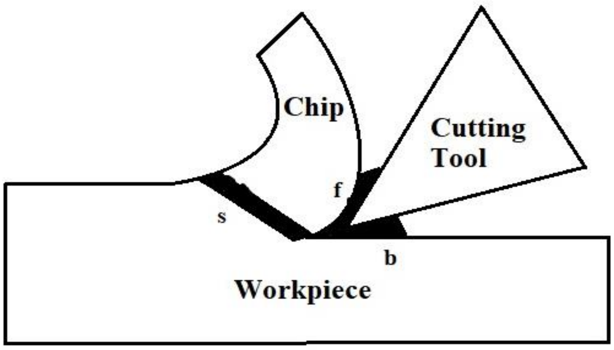
ii. Heat conduction: The thermal conduction of the material also needs to be analyzed in 3-dimension, i.e., dx, dy, and dz. The rate of heat conduction in these directions is presented in equations (3-5).

$$\bar{Q}_x = -k.A\frac{\delta T}{\delta z} = -k.dz.dy\frac{\delta T}{\delta z} \tag{3}$$

$$\bar{Q}_y = -k.A\frac{\delta T}{\delta y} = -k.dx.dz\frac{\delta T}{\delta y} \tag{4}$$

$$\bar{Q}_z = -k.A\frac{\delta T}{\delta x} = -k.dy.dx\frac{\delta T}{\delta x} \tag{5}$$

iii. The heat generated: The heat generated occurs at the point of contact between the cutting tool and work. Chips formulate, and shearing occurs, as shown in Figure 3.



s : Primary shear deformation zone
f : Secondary shear deformation zone
b : Tertiary shear deformation zone

Fig. 3. Heat generation zones during the machining

Neglecting the heat generated in the tertiary shearing zone, the heat generated at the primary and secondary zones are given in Eq. (6) and (7).

$$Q_s = F_s.V_s = \frac{\tau hV\cos(\alpha_n)}{\sin(\alpha_n)\cos(\phi_n - \alpha_n)} \tag{6}$$

$$Q_f = F_f.V_f = \frac{\tau h V \cos(\beta_n)}{\cos(\phi_n + \beta_n - \alpha_n)\sin(\phi_n - \alpha_n)} \tag{7}$$

where, h = thickness of the uncut chip, V = cutting velocity, τ = shear flow stress, ϕ_n = normal shear angle, β_n = normal friction angle and α_n = normal rake angle.

iv. Equations of heat discretization: These are the Eq. (8), (9), and (10) are the representations of the heat conduction equations discredited in time by explicit method.

$$\frac{\delta T}{\delta x} = \frac{T^p_{i+1,j,k} - T^p_{i,j,k}}{\Delta t} \tag{8}$$

$$\frac{\delta T}{\delta y} = \frac{T^p_{j+1,i,k} - T^p_{i,j,k}}{\Delta t} \tag{9}$$

$$\frac{\delta T}{\delta z} = \frac{T^p_{k+1,j,i} - T^p_{i,j,k}}{\Delta t} \tag{10}$$

The finite element method (FEM) analysis is embedded in different software. In order to describe the behavior of the Aluminum metal matrix (workpiece) during the machining process, the Johnson-Cook material model was used, and this is because of its ability to simulate the high strain rates and temperature. Johnson Cook's formula is shown in Eq. (11).

$$\sigma_{jc} = [A + B(\epsilon)^n] \times \left[1 + Cln\left(\frac{\dot{\in}}{\dot{\in}_0}\right)\right] \times \left[1 - \left(\frac{T - T_0}{T_m - T_0}\right)\right] \tag{11}$$

where σ = stress flow, $\dot{\in}_0$ = plastic strain rate reference, $\dot{\in}$ = equivalent plastic strain rate, ϵ = equivalent plastic strain, T = cutting temperature, T_m = melting temperature, T_0 = ambient temperature, A = initial yield strength, B = strain hardening coefficient, C = strain rate effect and n = strain hardening exponent.

Johnson cook's equation shows the temperature change at the tool-chip interface throughout the machining process using Eq. (12) [24].

$$\Delta T = \frac{0.4U}{\rho C}\left(\frac{vt}{\alpha}\right)^{0.333} \tag{12}$$

where ΔT is the mean rise in temperature of the tool-chip in ̊C, t is the chip thickness before cutting in m and is the specific operation energy in Nm/mm^3, v is the cutting speed in m/s, ρc is the volumetric specific heat of the material in J/ mm^3. ̊C and α is thermal diffusivity of the material in m^2/s.

For each simulation step, the damage factor and the fracture strain were estimated using Eqs. (13) and (14).

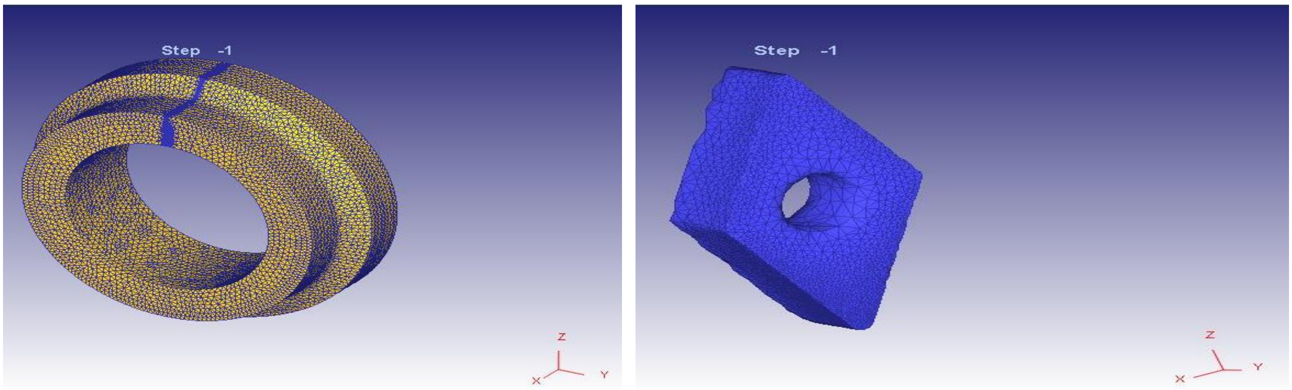
$$C = \sum \frac{\Delta\delta}{\delta_f} \tag{13}$$

where $\Delta\delta$ is the change in plastic strain, C is the damage factor and δ_f is the fracture strain.

$$\delta_f = (A_1 + A_2 \exp(A_3\varphi^*))\left(1 + A_4 \ln\left(\frac{\dot{\epsilon}}{\dot{\epsilon}_0}\right)\right)\left(1 - A_5\left(\frac{T - T_0}{T_m - T_0}\right)^m\right) \quad (14)$$

where, φ^* are the ratio of pressure stress and von mises stress, $A_1 - A_5$ are the damage parameters.

A lagrangian incremental approach was used to perform the simulation using DEFORM 3D simulation software. The workpiece was studied as plastic material, and the cutting tool was rigid. Figure 4(a) and 4(b) show the meshed images of the workpiece and the cutting tool. The workpiece was made to be fixed in all directions and presented in a curved model. At the same time, the cutting tool was set to move in the direction of the imputed depth of cut, the feed rate, and spindle speed. The simulation was performed without using lubrication and set with the procedures of 1000 incremental steps, 10 as the interval number of steps to save, 28°C initial temperature, and a cutting angle of 365 degrees.



(a) (b)

Fig. 4. (a) Meshed workpiece and (b) cutting tool on DEFORM 3D

3. Results

Table 4 shows the results obtained from the experimental runs. A total of 9 samples of the aluminum metal matrix were used, and the length of cut for each operation was 170 mm. Experimenting with two environmental conditions: mineral oil lubrication and MWCNts nanofluid lubrication, 18 experimental runs, nine experimental runs for MWCNTs nanofluid, and mineral oil cutting fluid were conducted for this study, and each experimental run was timed.

Table 4
The Experimental Results from the turning operations

S/N	Spindle speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	Mineral Oil Average Temperature (°C)	MWCNTS Average Temperature (°C)	Mineral Oil Machining Time (sec)	MWCNTS Machining Time (sec)
1	870	2	1	38	34	94	92
2	870	4	2	62	60	81	87
3	870	6	3	74	71	73	74
4	1400	2	2	78	64	59	60
5	1400	4	3	100	73	51	52
6	1400	6	1	65	51	46	47
7	1800	2	3	78	73	44	45
8	1800	4	1	62	56	40	40
9	1800	6	2	73	68	36	36

3.1 Temperature Variation under Mineral Oil Lubrication and MWCNT Nano Lubrication

Figure 5 shows the temperature variation during the turning of the aluminum metal matrix composite material about the time it took for the machine for the length of 170 mm. The results show the temperature increase when using mineral oil as the lubricant during composite material machining. The average temperatures obtained are 38 °C, 62 °C, 74 °C, 78 °C, 100 °C, 65 °C, 78 °C, 62 °C, 73 °C. This variation is due to the difference in the parameters. The time taken to turn the composite material when using mineral oil compared to when using MWCNT nano lubricant was reduced. This is due to the flow rate of the two lubricants employed for the experiment; when the MWCNT nanoparticles were added to the mineral oil, it increased the tribological properties and the viscosity of the fluid flow [25]. This increase in viscosity affects the cut time by increasing it compared with the mineral oil.

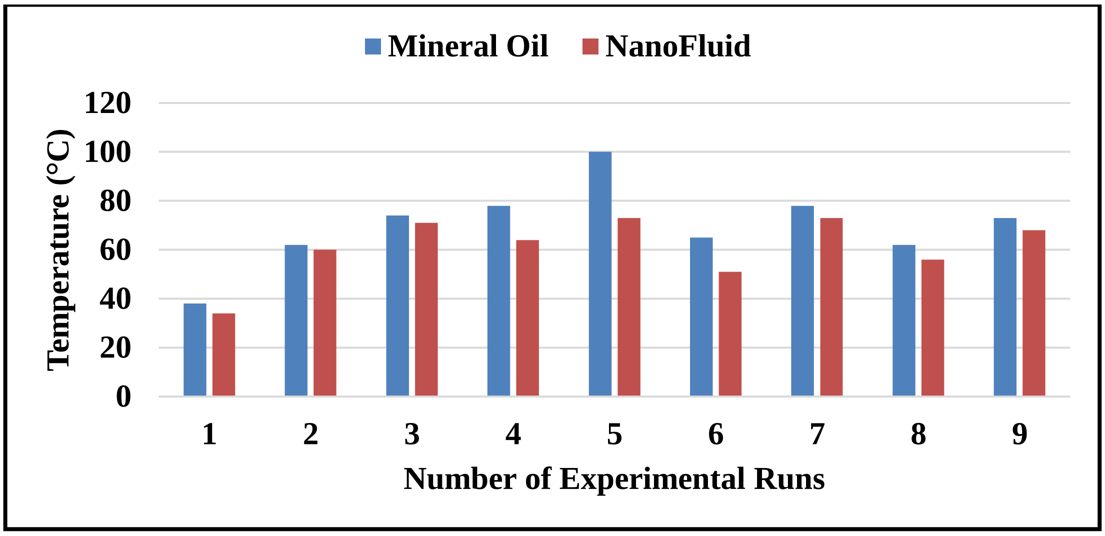


Fig. 5. Comparison of the temperature variation for mineral oil lubrication and MWCNT nano lubrication

The maximum temperature for the mineral oil was 100 °C, and the minimum was 38 °C. Also, Figure 5 shows the varying temperature during the turning of the aluminum metal matrix composite material about the time it took for the machine for the length of 170mm. The average temperatures obtained are 34 °C, 60 °C, 71 °C, 64 °C, 73 °C, 51 °C, 73 °C, 56 °C, 68 °C. The application of the MWCNTs nanofluid reduces the temperature due to the high percentage of oxygen in the nanofluid, which gives the nanofluid excellent cooling properties during the turning operation. The MWCNTs nanoparticles increase the oxygen found in the mineral oil from 4.21% to 35.32%, as shown in the EDX analysis in Figure 1. The result shows a significant drop of an overall average of 11.9% in the tool-chip interface temperature when machining using MWCNT nano lubricant as to when machining with mineral oil, as presented in Table 4. The maximum temperature attained when using the MWCNT nanofluid as the lubricant is 73 °C which is 27% lesser than the maximum temperature for the machining operation under mineral oil lubrication. The minimum temperature is 34 °C which is 10.5% lesser than the minimum temperature gotten when machining under mineral oil lubrication. Figure 5 also shows the side-by-side comparison of the temperature variation under the two environmental conditions. Figure 6 shows the varying temperature for both environmental conditions with time.

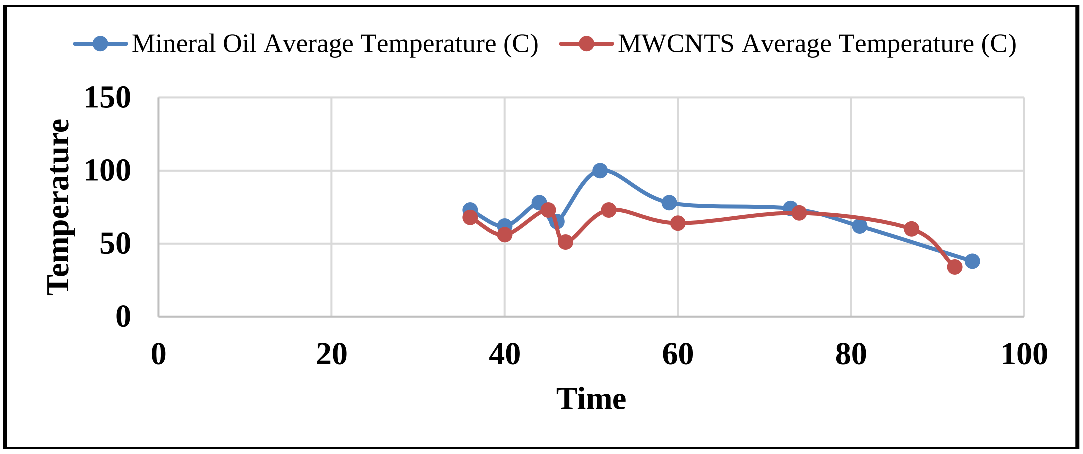
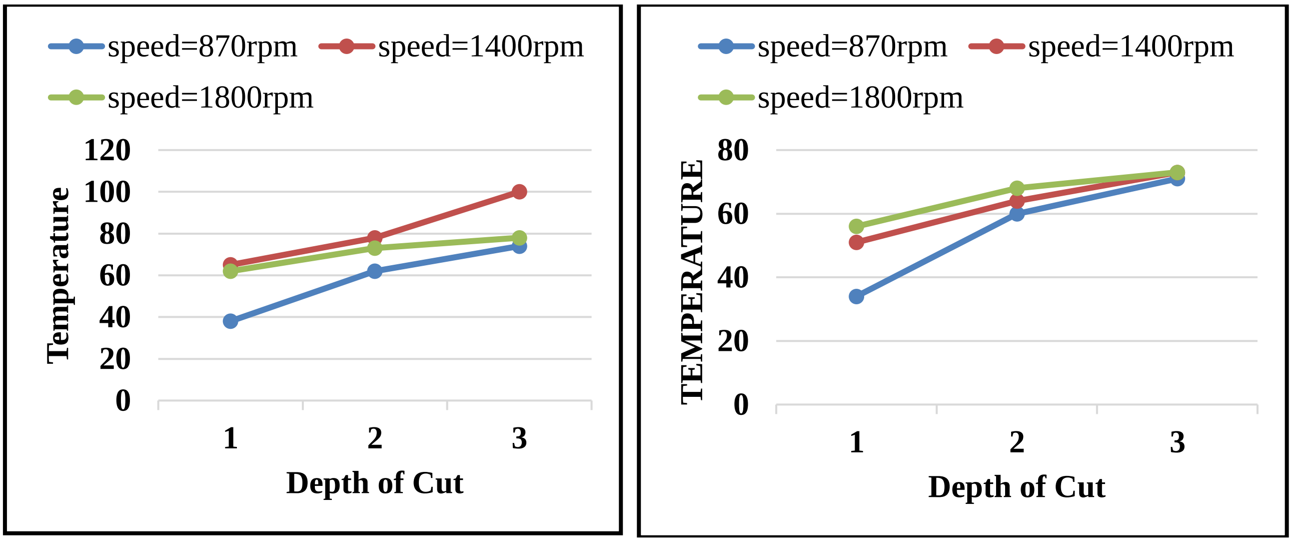


Fig. 6. Comparison of the varying *T*emperature with time for mineral oil and MWCNT

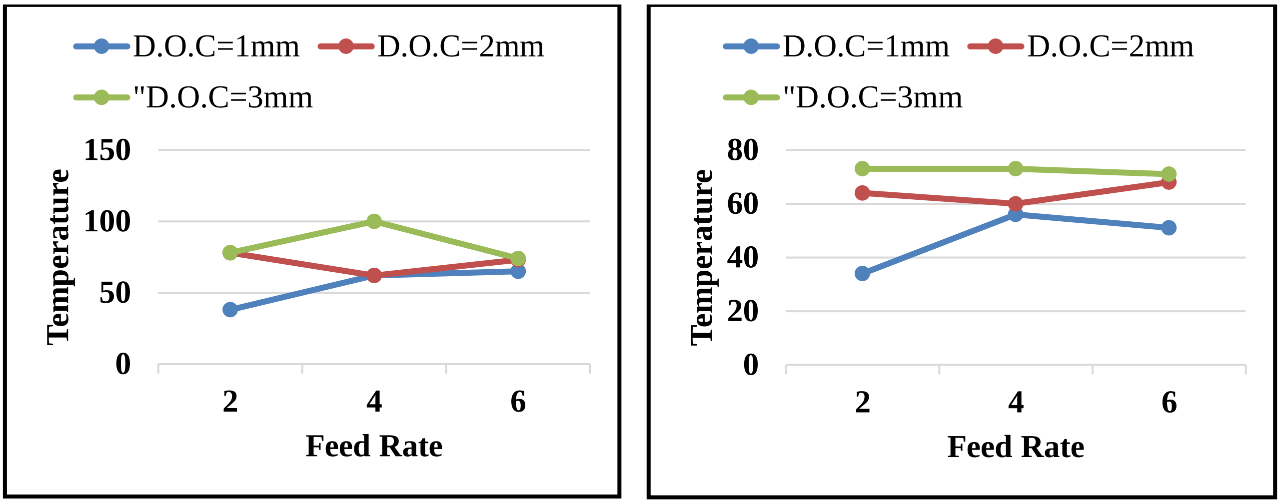
3.2 Effects of the Cutting Parameters on the Temperature

Figure 7 shows the graphical representation of an in the temperature with the increase in the depth of cut. This result is in line with the study carried out by [26] the author's experimental study of the effects of depth of cut on vibration and machining time during machining of Al-1060. The study concluded that depth of cut increase in machining operation leads to high vibration, increasing the friction and machining time. Figure 8 shows the representation of the effect of the feed rate on the temperature, which shows a variety of temperature variations concerning the depths of cut used. Having a gradual increase with the increase in feed rate for 1 mm depth of cut, the higher Temperature at 2 rev/min for 2mm depth of cut, and higher Temperature at 4 mm/rev feed rate for 3mm/rev depth of cut for both the use of mineral oil and nanofluid experiment.



(a) (b)

Fig. 7. Effect of depth of cut on *t*emperature under (a) mineral oil lubrication and (b) MWCNT nano lubrication

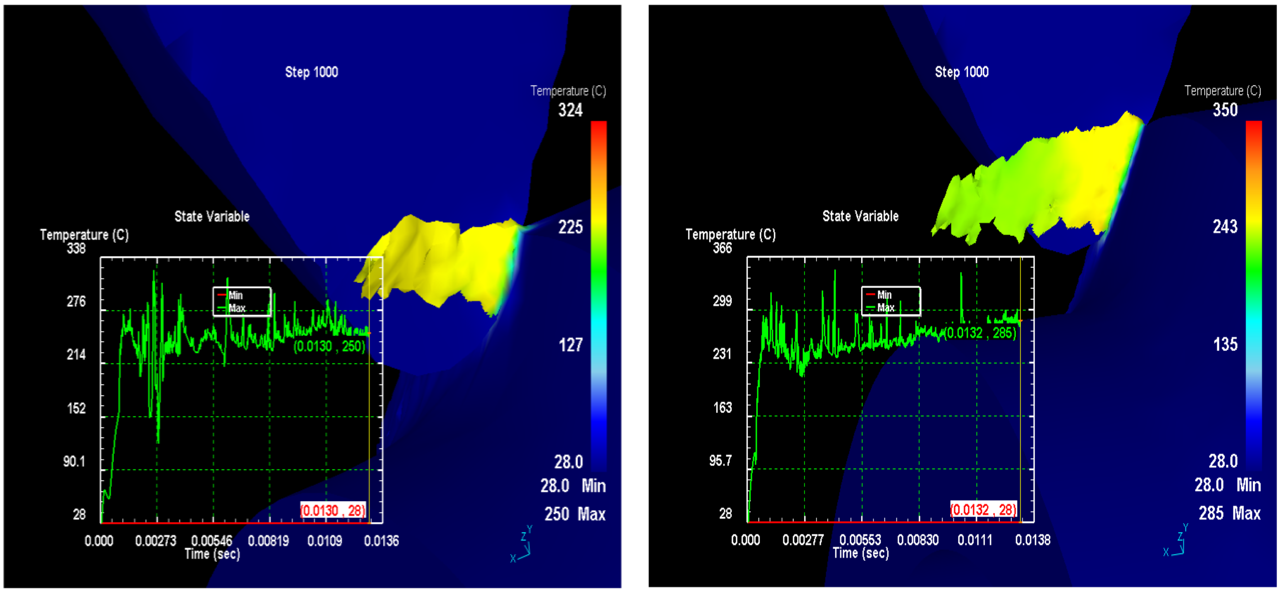


(a) (b)

Fig. 8. Effect of feed rate on temperature under (a) mineral oil lubrication and (b) MWCNT nano lubrication

3.3 Finite Element Results in the Temperature, Chip Formation and Cutting Time

Figure 9 to 14 present the simulation models under the three varying cutting parameters to study the effects of the parameters on the temperature reduction and distribution using the DEFORM 3D software. The FEM also shows the time variation effects on the temperature formulation of the chips generated at the cutting regions. The cutting speed increases with the increase of the temperature. This result confirms the observation of a study carried out by Okokpujie *et al.,* [27]. The temperature distribution was carried out on machining of mild steel. The study concluded that increasing the cutting speed significantly affects the temperature reduction in the cutting region. Nevertheless, at a depth of cut 1 mm, feed rate 2 mm/rev, and spindle speed of 870 rpm, the simulation result recorded 324 °C, which is the minimum temperature of the experiments as shown in Figure 9.



(a) (b)

Fig. 9. (a) Spindle speed 870 rpm, feed rate 2 mm/rev, and depth-of-cut 1 mm (b) spindle speed 870 rpm, feed rate 4 mm/rev, and depth-of-cut 2 mm

In Figure 10 and 11, when compared with Figure 9, it can be seen that the spindle speed is constant at 870 rpm, but the feed rate increase to 4 and 6, also the depth of cut increases to 2 and 3. Whereby the temperature generated increases constantly with the increase of the feed rate and depth of cut. This has proven that the feed rate and depth of cut have significant effects on temperature generation during the machining operation. This result is in line with [26]. The authors studied five machining parameters' effects on the surface roughness. They mentioned that the lubricant reduces the temperature in all machining conditions.

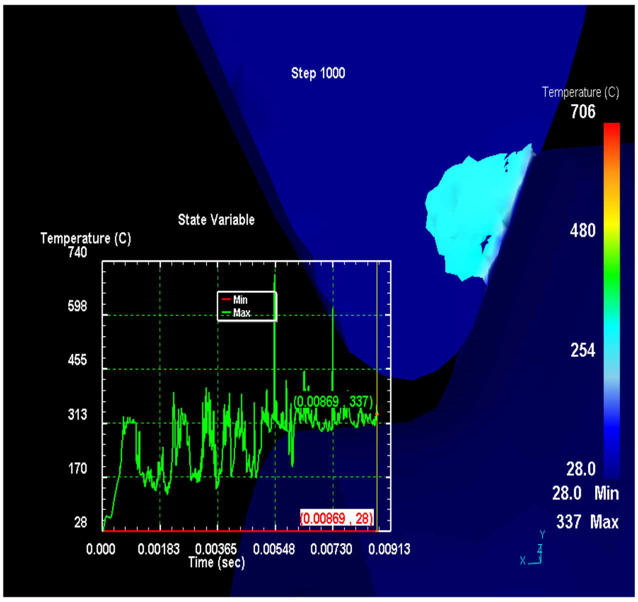


Fig. 10. Finite Element Model for spindle speed 870 rpm, feed rate 6 mm/rev, and depth-of-cut 3 mm

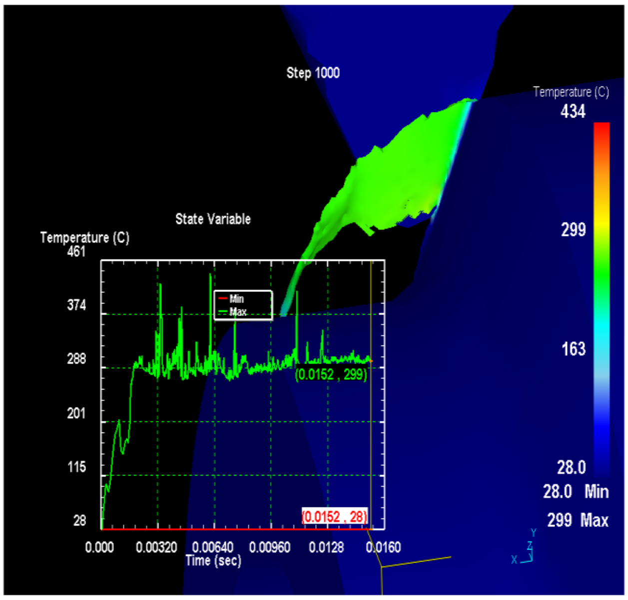
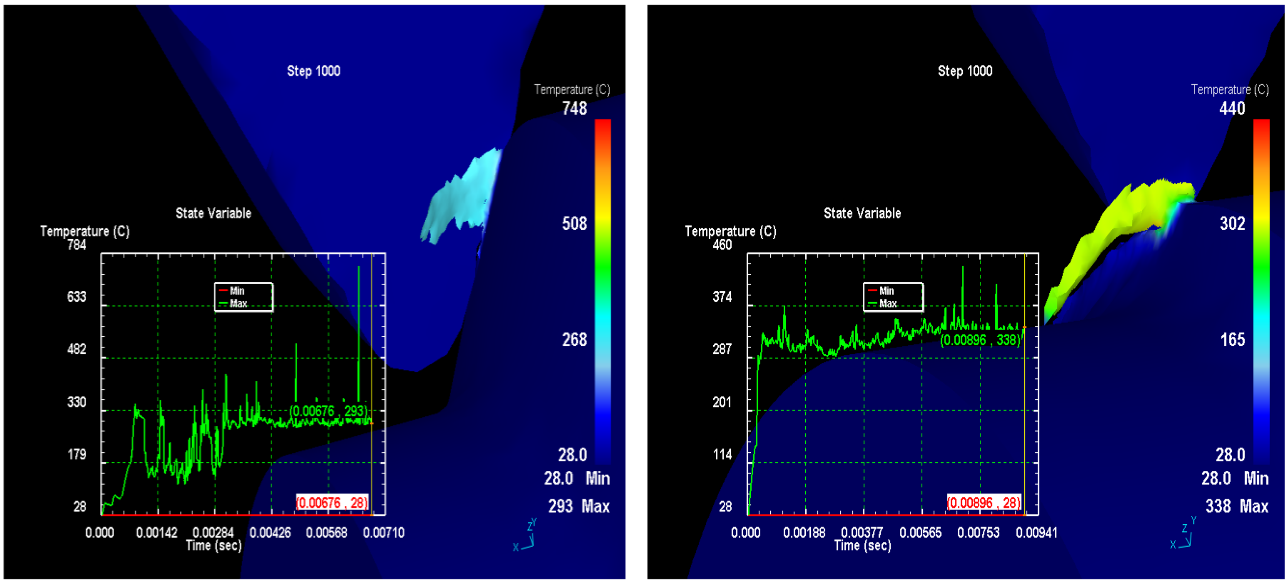
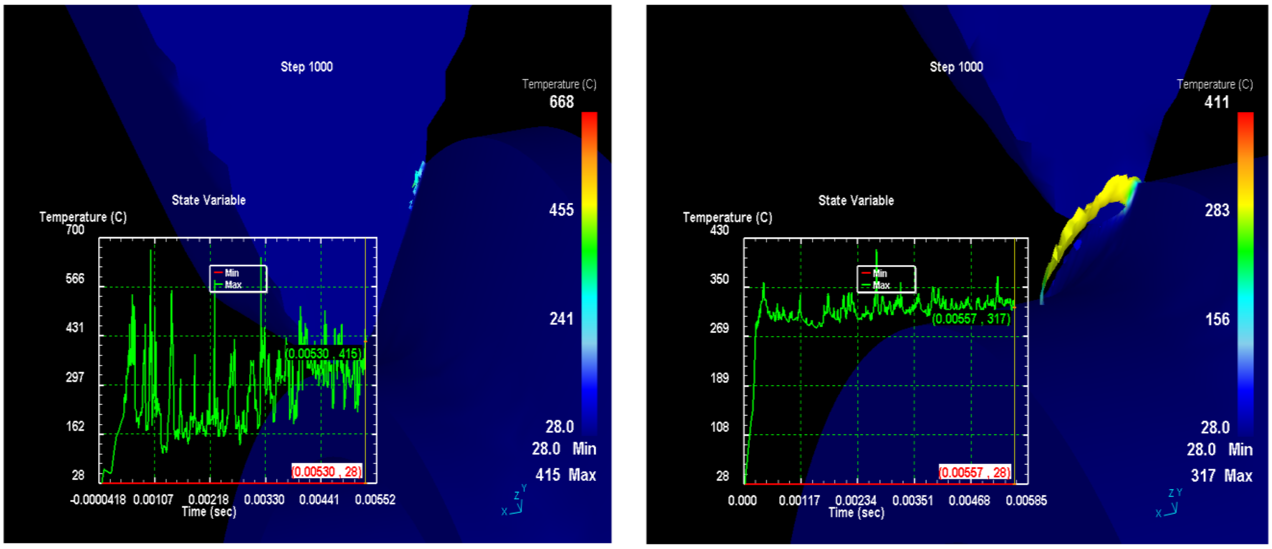


Fig. 11. Finite Element Model for spindle speed 1400 rpm, feed rate 2 mm/rev, and depth-of-cut 1 mm



(a) (b)

Fig. 12. (a) Spindle speed 1400 rpm, feed rate 4 mm/rev, and depth-of-cut 2 mm (b) spindle speed 1400 rpm, feed rate 6 mm/rev, and depth-of-cut 3 mm



(a) (b)

Fig. 13. (a) Spindle speed 1800 rpm, feed rate 2 mm/rev, and depth-of-cut 1 mm (b) spindle speed 1800 rpm, feed rate 4 mm/rev, and depth-of-cut 2 mm

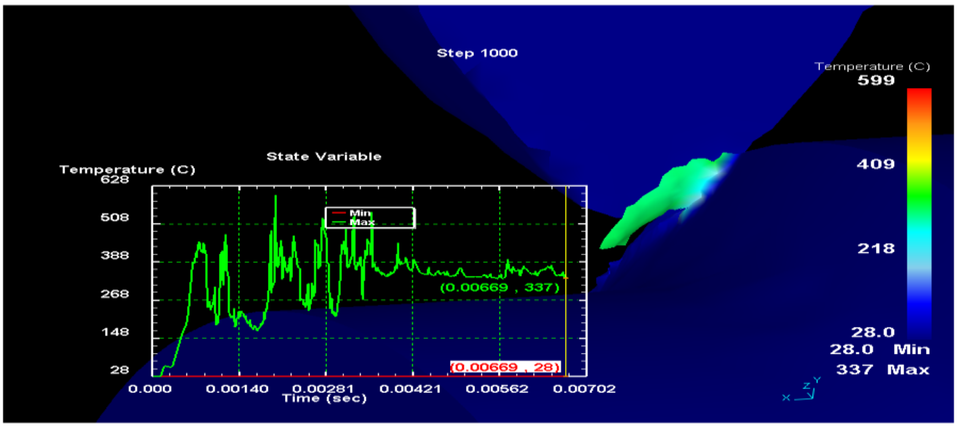
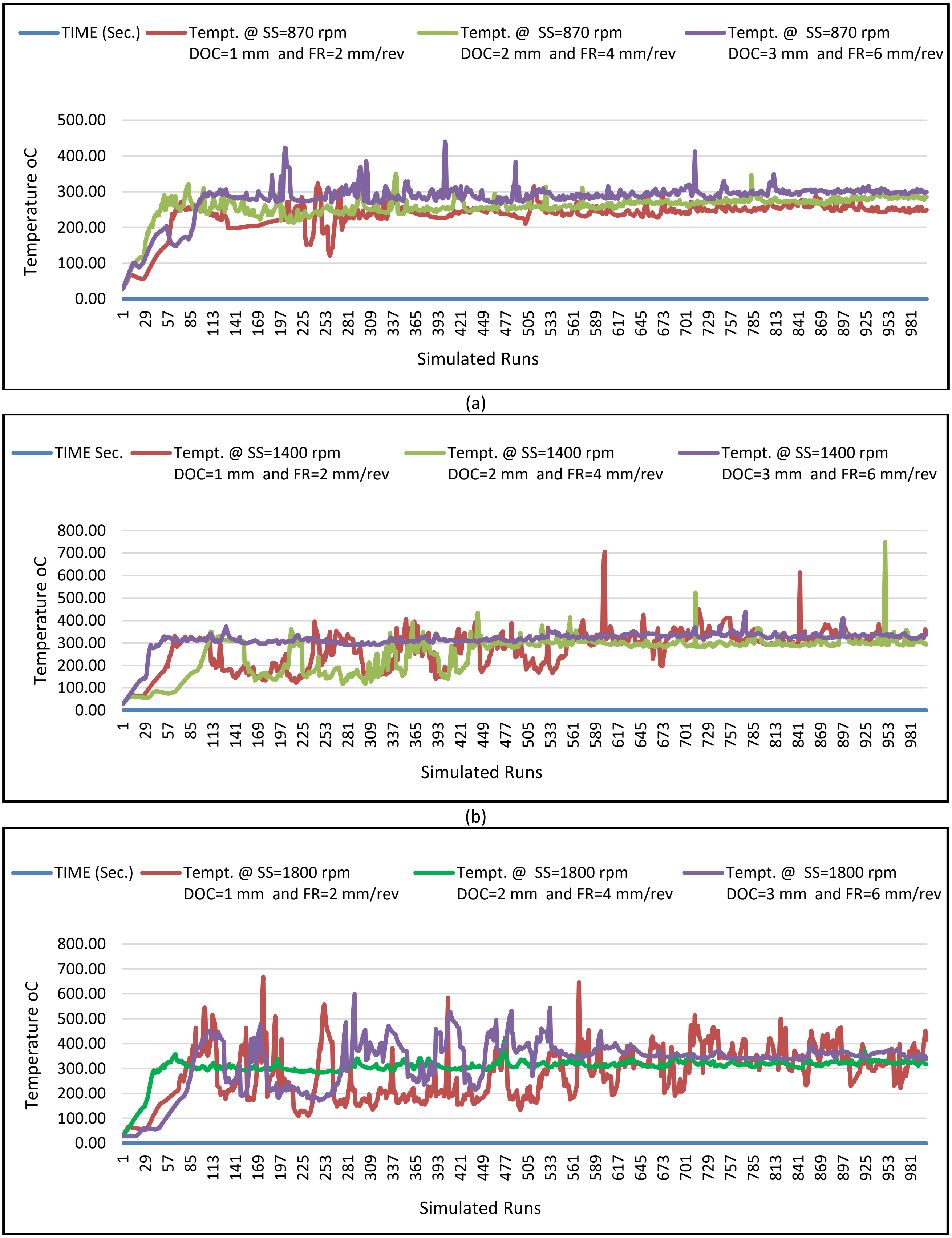


Fig. 14. Spindle speed 180 rpm, feed rate 6 mm/rev, and depth-of-cut 3 mm

The cutting time during the simulation via the DEFORM 3D shows that it constantly increases with the depth of cut. Still, as soon as the feed rate increases from 4 to 6 rev/min, the cut time reduces with the same spindle speed of 870 rpm. This trend is seen in the nine (9) simulation machining environment. The minimum cutting time of 220 seconds was obtained at a spindle speed of 1800 rpm, feed rate of 2 rev/min, and depth of cut 3 mm, as shown in Figure 15(c). This is due to high spindle speed, relatively low feed rate, and the maximum depth of cut. From literature, it has been confirmed that high machining speed eliminates the build-up edge during machining and reduces the manufacturing time and cost. The comparative study of the various machining parameters at each cutting speed of 870 rpm, 1400 rpm, and 1800 rpm was presented in Figure 15.



(c)

Fig. 15. Comparative study of various DOC, FR, and Constant SS on Temperature Distribution (a) 870 rpm, (b) 1400 rpm, and (c) 1800 rpm

The simulated results show that the feed rate and the depth of cut significantly increase the temperature during the machining process [28-32]. The chips formulation has also been affected by the depth of cut. As the depth of cut increases from 1 to 3 mm, the unwanted chips from the workpiece increase. However, the feed rate increases the machining time by increasing the temperature in the cutting regions.

4. Conclusions

The experiment and simulation study carried out on the Al-Si-Mg metal matric composite on temperature reduction and distribution under MWCNT nano-lubricant has the following conclusion from the study.

i. The temperature increased with the increase in cutting parameters with which the machining operation was carried out.
ii. The machining experiment with the mineral oil- MWCNT-nano lubricant reduces the temperature at the tool chip interface by an overall average of 11.9% compared to machining with mineral oil.
iii. The mineral oil machining operation has a lesser cutting time when compared with the machining done with the MWCNT nano-lubricant.
iv. The analysis of the temperatures and machining time via the Deform 3D shows that the machining parameters significantly influence chip formulation and heat generation at the cutting region.

The study has justified that MWCNT nano-lubricant is viable for machining operations and should be implemented in the manufacturing industry for machining of Al-Si-Mg metal metric composite for the sustainable manufacturing process.

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