A Study of the Effect of the Nano MoS_2 Concentrations in MQL on Grinding CFRPs

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Abstract. To investigate the effect of the nano MoS_2 concentration in minimum quality lubrication (MQL) on grinding carbon fiber reinforced plastics (CFRPs), grinding experiment for CFRPs with various concentrations (0%, 3%, 6%, 9%, and 12%) of nano MoS_2 added into palm oil MQL was carried out. The surface roughness and the surface morphology of the CFRPs were detected by the Olympus optical microscopy. Grinding forces were measured by dynamometer and the coefficient of friction was calculated and analyzed. Also, the mechanism of CFRPs grinding with various nano MoS_2 concentrations MQL was explained. The results show that when the concentration of nano MoS_2 is up to 9%, the coefficient of friction reaches the lowest value of 0.0632, also the quality of surface roughness with R_a value of 1.86μm and surface morphology of CFRPs are both better than these of other concentrations. It could be concluded that different concentrations of nano MoS_2 MQL grinding affect the quality of CFRPs profoundly.

1. Introduction

Recently, many species of composite materials have been created to compensate the defects of the physical or chemical properties of the single conventional material, such as metal matrix composites (MMC), fiber reinforced polymers (FRP), ceramic matrix composites (CMC) and carbon fiber reinforced plastics/polymers (CFRPs) etc[1-3]. CFRPs as a widely used material in aerospace , transportation, military industry with an appropriate workpiece shape and quality possesses merits of high modulus-to-weight ratio, strength-to-weight ratio, damping ability, good dimensional stability, fabulous damage tolerance, good corrosion and fatigue resistance[3]. On the other hand, CFRPs recently is considered as a kind of difficult-to-machined material due to the heterogeneous, fragility in behavior and thermal damage after processing[2, 3]. The contradiction between the increasing needs for CFRPs and limitation of the CFRPs processing triggers on academic and industrial research on the conventional machining approaches for CFRPs[1]. One of the efficient ways to machine CFRPs is grinding, which the high accuracy of CFRPs could be achieved. Soo et al.[4] conducted an investigation about edge grinding of CFRPs with D76, D151, D252 grinding head respectively. D76 grinding head produced 3.0 μm Ra, which the satisfaction of industrial needs could be reached. Sasahara et al.[5] operated CFRPs grinding with inner coolant end grinding wheel, which the surface roughness was enhanced 50% compared to milling with no delamination. Wang et al.[6] introduced rotary ultrasonic machining to the end grinding of CFRPs, the results showed that lower ultrasonic power, or higher tool rotation speed, could produce better surface roughness of CFRPs. Also, Hu et al.[7] investigated surface grinding CFRPs with various orientations (-45°, 0°, 45°, 90°), and proposed that the worst damage could be observed when the orientation was -45°. Also, burning of CFRPs could be usual under dry grinding condition.

Nanofluid MQL as the improvement of MQL, which not only possesses the advantages of the MQL such as environment friendly, low cost, increasing the tool life, good surface finish with appropriate MQL parameters, reducing the machining temperature, and cutting force, but also enhances these merits and strengthens the lubrication and cooling effects due to the enhancing of the heat transfer property in the grinding zone[8-10]. In this case, nanofluid MQL grinding has been utilized by researchers to produce better workpiece and prolong the life of the grinding wheels.

As the problems of CFRPs grinding has not been tackled effectively, in the present research, a novel CFRPs grinding method was introduced. The effect of various concentrations of nano MoS_2 added in MQL on grinding CFRPs was investigated. Grinding forces generated during CFRPs grinding with nano MoS_2 in MQL were tested by the dynamometer. In addition, the surface roughness, surface morphology of ground CFRPs with 0%, 3%, 6%, 9%, and 12% concentrations of nano MoS_2 in MQL was analyzed by Olympus optical microscopy. The mechanism of the effect of the increase concentrations of nano MoS_2 in MQL grinding CFRPs was explained.

2. Materials and experimental procedures

The ground CFRPs with the dimension of 5mm×60mm×30mm was placed on the YDM-III99 3D dynamometer, which the orientation of carbon fibers was 0° when grinding conducted by K-P36 precise CNC grinding machine. And the grinding parameters including nanofluid MQL transfer system parameters are shown in table 1. The grinding wheel containing 80 mesh SiC grits as the size of $20\text{mm} \times \emptyset 76.2\text{mm} \times \emptyset 300\text{mm}$ was engaged in the grinding CFRPs. The experimental set-up was shown in Fig. 1. The concentrations of nano MoS_2 as the mean size of 50 nm added into the palm oil as the nanofluid MQL are shown in table 2. After grinding, the surface morphology and surface roughness of CFRPs were detected by Olympus optical microscopy DXS510.

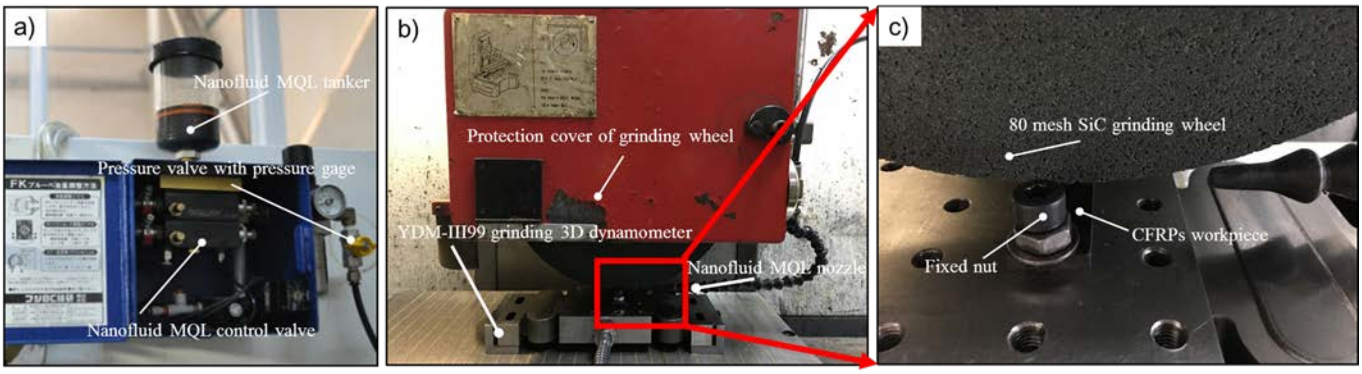

Fig. 1 a) nanofluid MQL transfer system; b) grinding operation setup; c) local magnification of grinding area

Table 1 Grinding parameters with nanofluid MQL transfer system

Grinding parameters	value
Wheel speed v_s(m/s)	30
Feed speed v_w(mm/min)	3000
Cutting depth a_p(μm)	15
MQL flow rate (mL/h)	50

MQL gas pressure (MPa)	0.6
MQL nozzle distance (mm)	12
MQL nozzle angle (°)	15

Table 2 Concentration of nano MoS_2 to the palm oil

Experiment number	Concentration of nano MoS_2 to the palm oil (g)
1	0%
2	3%
3	6%
4	9%
5	12%

3. Results

3.1 Grinding forces

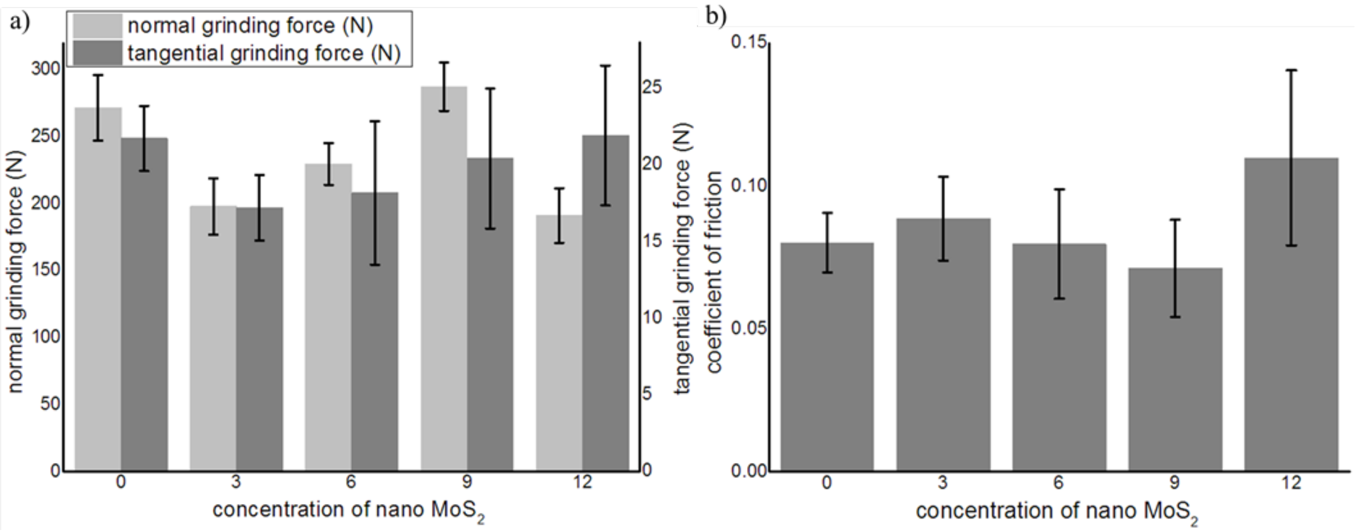

Fig. 2 Schematic of a) average normal grinding force and average tangential grinding force and b) coefficient of friction

Figure 2 a) shows schematic of the value of the average normal grinding force and the average tangential grinding force simultaneously calculated through 20 grinding passes for each grinding force with the specific nano MoS_2 content from 0% to 12%. It can be seen that the average normal grinding force decreases first, then increases, and decreases in the end. And the standard error of average normal grinding force is from 15.62 to 24.45. The lowest value is when nano MoS_2 is 12%, which is 191.04N. The highest is when nano MoS_2 is 9%, which is 287.23N. On the other hand, the tangential grinding forces are all lower than that of free nano MoS_2 MQL grinding. And the average tangential grinding force increases with the nano MoS_2 concentration increase from 3% to 12%. And the standard error of average tangential grinding force is from 2.12 to 4.68. It is easy to see that when the concentration of nano MoS_2 is 0%, the tangential grinding force gets highest value of 21.72N. And the lowest value is 17.21N, when nano MoS_2 concentration is 3%.

Figure 2 b) shows the changed coefficient of frictions with the nano MoS_2 increase, which is the ratio of the average tangential grinding force to the average normal grinding force based on the data from Fig.2 a). Interestingly, the trend of coefficient of friction as the nano MoS_2 concentration increase changes against to that of normal grinding force, that is increase first, decrease then, and increase in the end. And the standard error of coefficient of friction is from 0.0104 to 0.0336. The lowest coefficient of friction is 0.063, when the concentration of nano MoS_2 is 9%. And the highest value is 0.107 when the concentration of coefficient of friction is 12%.

3.2 Surface roughness

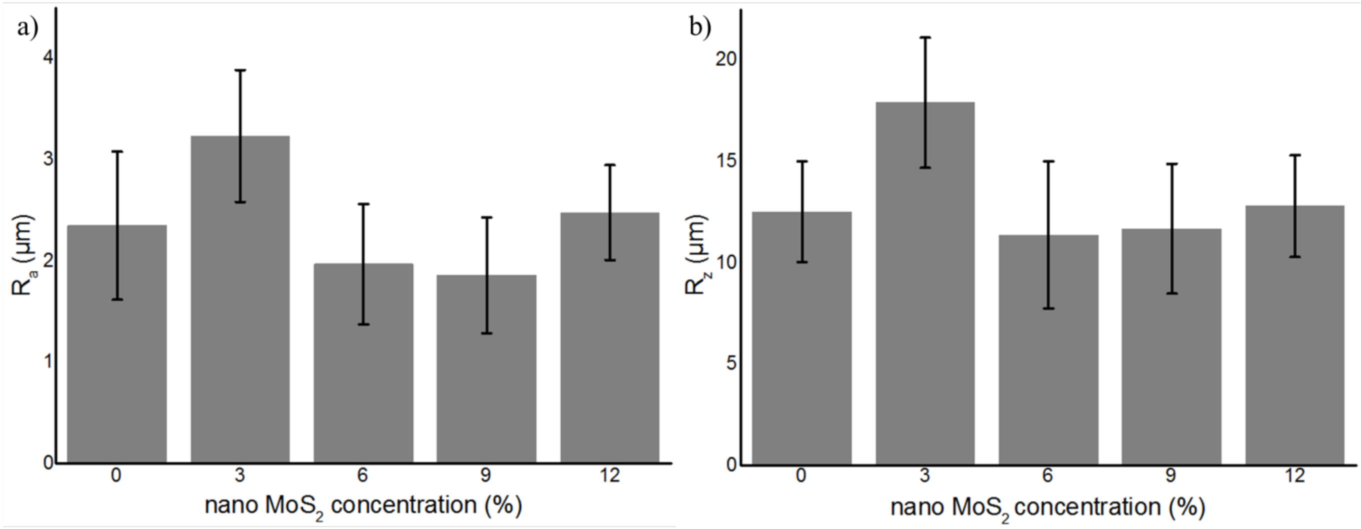

Fig. 3 Schematic of surface roughness under various nano MoS_2 concentrations in MQL grinding a) R_a b) R_z

Figure 3 shows the surface roughness of ground CFRPs under different nano MoS_2 concentrations MQL measured by Olympus optical microscopy. Interestingly, the tendency of the surface roughness changing with the nano MoS_2 additive increase is similar to that of the coefficient of friction. It also shows that the standard error of R_a is from 0.47 to 0.73, and the standard error R_z is from 2.49 to 3.64. The R_a and R_z of 3% are both in the highest value in all the concentrations, the value are 3.23μm of R_a and 17.90μm of R_z respectively. And also R_a of concentration of 3% is higher than that of R_a of 0% about 37.35% and the R_z of concentration of 3% is higher than that of R_z of 0% about 43.0%. In contrast the concentration of 9% owes the lowest R_a value, which is 1.86μm. And concentration of 6% has the lowest R_z value, namely, 11.37μm. Compared to surface roughness of concentration of 3%, the R_a of concentration of 9% decreases to 42.55%, and R_z decreases to 34.74%. This phenomenon is similar to the research of Zhang et al. [11] that when the coefficient of friction is in the lowest point, the surface condition achieves the ideal quality. And the grinding state is better than any other concentrations in this investigation.

3.3 Surface morphology

In the present experiment, the ground fiber orientation was 0° which was parallel with the grinding direction. Olympus optical microscopy collected the processed CFRPs surfaces under various nano MoS_2 concentrations MQL grinding shown in fig. 4. It can be seen that there is no burning, burrs, delamination, or fiber pullout phenomenon of the samples during the grinding. In fig. 4 a), there is no nano MoS_2 particle maintained on CFRPs surface with some shorn out randomly placed on the ground CFRPs surface. In fig. 4 b), there are severe shorn out phenomenon with the cashed CFRPs residues. In fig. 4 c), the clear CFRPs are shown with slightly shorn out phenomenon and CFRPs residues. In fig. 4 d), the CFPRs is sound after grinding, no chip off on the surface of CFRPs and hard to detected severe shorn out displayed on the CFRPs ground surface. In fig. 4 e), the shorn out is severe again similar to that of the concentration of 3%, the carbon fibers were damaged with the high volume of nano MoS_2 particles.

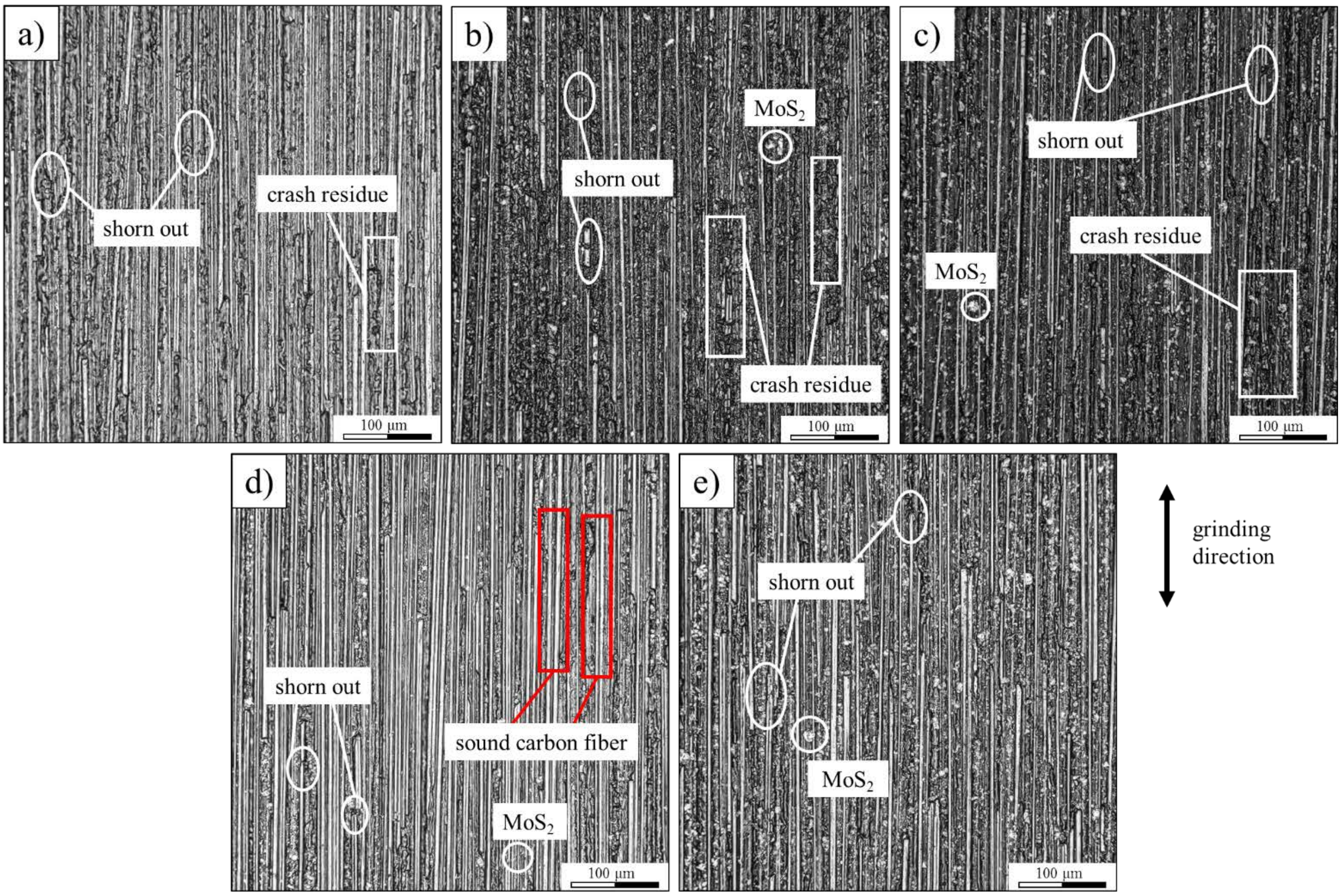

Fig. 4 Schematic of the surface morphology of ground CFPRs with concentration of a) 0% b) 3% c) 6% d) 9% e) 12% nano MoS_2 MQL grinding

4. Discussion

In this section, the mechanism of CFRPs grinding with various concentrations of nano MoS_2 was explained according to the results illustrated above. During the grinding process, the micro cutting process could be regarded as single grit unidirectional cutting process with various concentrations nano MoS_2 MQL, shown in Fig. 5 When the nano MoS_2 concentration is 3%, the tribofilm formation is inhibited, attributed to these limited amount of nano MoS_2 particles accumulate in front of the cutting edge of the grit[12], shown in Fig. 5 b). In this case, the ground CFRPs surface morphology gets worse than that of MQL grinding shown in fig. 5 a), the coefficient of friction becomes higher, and the CFRPs surface roughness is higher than that in MQL grinding condition. In addition, the contact state between grits and CFRPs surface is changed from sliding to rolling, which the normal grinding force and tangential grinding force decrease rapidly than that of the MQL grinding, shown in fig. 2 a) and fig. 5 a) and b).

When the concentration of nano MoS_2 reaches to 6%, which is a transition phase between 3% concentration of nano MoS_2 MQL CFRPs grinding and 9% concentration of nano MoS_2 MQL CFRPs grinding. The surface roughness and the grinding forces containing the normal grinding force and tangential grinding force of concentration of 6% nano MoS_2 MQL grinding are both in the middle status compared with 3% concentration and 9% concentration. This is because, in this condition, small amount of nano MoS_2 particles are pushed into the contact zone between grits and CFRPs due to the over accumulation of the nano MoS_2 particles in front of the cutting edge, the tribofilm is promoted by these nano MoS_2 particles to some extent[12], shown in Fig. 5 c).

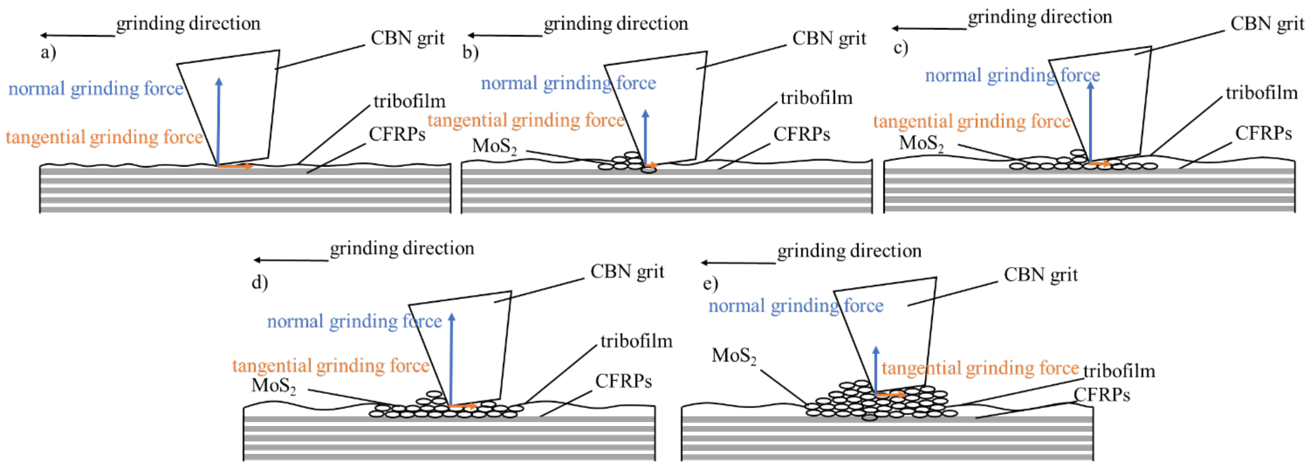

Fig. 5 Schematic of CFRPs grinding with a) 0% b) 3% c) 6% d) 9% e) 12% nano MoS_2 concentrations MQL grinding

When the concentration reaches to 9%, the coefficient of friction is lowest, the normal grinding force is the highest, and the tangential grinding force are higher than these in the concentration of 6% and little bit lower than these of 12% concentration of nano MoS_2 MQL grinding. The surface morphology is better than any other concentration of nano MoS_2 MQL grinding. This is because, the grinding efficiency could be promoted by the tribofilm that combined with adequate amount of nano MoS_2 and palm oil in the contact area[12], shown in Fig.5 d).

When the concentration of nano MoS_2 particles is up to 12%, excessive nano MoS_2 particles aggregated in the contact zone and near the cutting edge break the fibofilm between grit and CFRPs, shown in Fig. 5 e). In this circumstance, grinding condition is disturbed leading to the highest coefficient of friction, the tangential grinding force increasing based on that of 9% concentration because of the damaged tribofilm by over volume of nano MoS_2[12] in the contact zone and the inner friction of nano MoS_2 particles increasing with the nano MoS_2 particles increasing, which caused by the enhancing of viscosity of tribofilm[11].

Based on the analysis mentioned above, it can be speculated that in the same grinding condition, the value of grinding forces, i.e. tangential grinding force and normal grinding force, and coefficient of friction calculated from the ratio of grinding forces, the quality of surface of CFPRs and surface roughness of CFRPs could be changed even promoted under nano MoS_2 MQL grinding.

5. Summary

In the present paper, MoS_2 nanofluid MQL grinding CFRPs with various nano MoS_2 concentrations was conducted. The grinding forces were detected by dynamometer. The surface roughness and surface morphology were both detected by Olympus DSX510 optical microscopy. And the mechanism of MoS_2 nanofluid MQL grinding CFRPs was discussed. The conclusions can be drawn as follows:

1. The trend of tangential grinding force decreases first, and increases with the nano MoS_2 concentration increase. And the tendency of normal grinding force decreases first, increases then and decreases in the end. The coefficient of friction of various concentrations changes opposite to that of the normal grinding force. The 9% concentration of nano MoS_2 MQL grinding has the lowest value of 0.063.

2. The R_a of the 9% concentration nano MoS_2 MQL ground CFRPs reaches the lowest value of 1.86 μm. And the R_z of the 6% concentration nano MoS_2 MQL ground CFRPs owns the lowest value of 11.37 μm.

3. The concentration of 9% gets the highest surface condition, which the carbon fiber is sound and has the most slightly shorn out phenomenon without any crashed carbon fiber residues.

4. Based on the mechanism of nano MoS_2 MQL grinding CFPRs, as the concentration of 9% of nano MoS_2 prompts the integrity and friction property of tribofilm, the surface roughness and surface condition could be a better quality than other these of concentrations.

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