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ORIGINAL PAPER

Experimental Evaluation of the Lubrication Performance in MQL Grinding of Nano SiC Reinforced Al Matrix Composites

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Abstract

Metal matrix composites (MMCs) are materials which have been extensively used in the aerospace and automobile industries and have been categorized as hard-to-machine materials.Lubricants participate a significant role in machining, particularly in the grinding process. As a effect of the rising require for environmental safety and the growing number of health problems faced by workers, traditional lubricants are gradually being replaced. This research evaluate the performance of MQL grinding of nano SiC reinforced Al matrix composites using SAE20W40, Cashew nut shell oil and nano Tio_2 filled Cashew nut shell oil as base oils. Experiments for grindability study were approved on a horizontal spindle cylindrical grinding machine using Response Surface Methodology. In this research, the influences of n grinding parameters including wheel speed, work piece speed, depth of cut and wt% nano SiC have been considered on the basis of the grinding forces and temperature to develop optimum grinding narration such as lubrication, high biological and ecological safety. The result shows that the application of nano fluid leads to the reduction of tangential forces and grinding zone temperature. Surface integrity of machined surface were studied using Scanning electron microscopy (SEM).

Keywords Minimum Quantity Lubrication (MQL) · Grinding · Cashew nut shell oil · Nano SiC particles · Nano TiO_2 · Variable frequency drive · Infra-red thermometer

1 Introduction

Metal matrix composites (MMCs) are a moderately new group of composite materials that consist of a ductile metal matrix reinforced by tough particles, fibres or whiskers [1, 2]. Further development in MMCs has led to the conceptualization of metal matrix nano composites (MMNCs). At present, MMNCs advanced significantly in several engineering areas [3]. New processing techniques like deformation processing, solidification processing, Spray forming, vapour phase processing and powder metallurgy have been developed for the production of MMNCs [4]. Definite characteristics of MMNCs [5] during cutting have given ascend to differing reports which normally consent that MMNCs are very difficult to machine [6].

Grinding is one of the most essential machining approaches. In particular, it secures the absolute precision and surface quality of parts [7]. A well-built specific grinding energy is formed by grinding than by cutting and milling [8]. Most of the heat generated transmits to the grinding wheel and work piece. Grinding declines the service life and consistency of parts, as well as the machining accuracy of grinding wheels [9]. Grinding zone is frequently lubricated by conventional cooling via hammering and lubrication However, hammering grinding cannot fulfil with green manufacturing and sustainable development [10]. Therefore cooling lubrication technique for grinding should be improved, and optimized by considering various parameters energy conservation, emission reduction, eco-friendliness, and high efficiency [11].

The cost of waste liquid handling can be incredible, getting up to 54% of total grinding fluid costs [12]. Dry grinding demands high needs for grinding wheels, work piece materials, and machines, but it lean to result in deprived work piece surface quality [13]. MQL grinding is a green machining technique as an alternative for conventional coolant supply

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method [14]. In MQL Grinding, an air–oil mixture is supplied into the grinding contact zone and significantly improves cutting performance in terms of increasing wheel life and getting better the surface quality of the machined parts [15]. In MQL 30–100 mL coolant is used per unit width of the grinding wheel which is significantly lesser than that of pouring grinding (60 L/h) [16]. Amiril SahabAbdul Sani et al. [17] showed MQL based Jatropha-based lubricant mixtures exhibits enhanced cutting performance with reduction of cutting forces and specific cutting energy by 4%, cutting temperatures by 10%. Alumina with graphene nano platelets incorporated hybrid nano fluid shows better performance during turning of AISI 304 steel under MQL [18]. Mao et al. [19] proved that MQL parameters can improve the lubrication and cooling properties of the oil film and enhance the milling characteristics of TC4 alloy. Thermal conductivity of the lubricant can be improved by incorporating nano size metallic particles [20]. Nano fluids have lower Reynolds numbers and consequently the favours in increasing the heat transfer [21].

The design of experiments can be used to identify the individual contributions of the parameters along with their intricate relationship [22]. The Response Surface Methodology (RSM) and artificial intelligence are used to find the optimal response [23]. Rajmohan et al. [6] studied the drilling performances on hybrid metal matrix composites to employed four factor RSM based D-optimal design. Baskar et al. [24] predicted pressure of the oil-film in journal bearings that are lubricated by different nano-based bio-lubricants using RSM based D-optimal design.

On the basis of associated literature review very few articles are available in the area of sustainability of the machining of MMNCs. Therefore this research evaluate the performance of MQL grinding of nano SiC reinforced Al matrix composites using SAE20W40, Cashew nut shell oil .and nano Tio_2 filled Cashew nut shell oil as base oils. The influences of n grinding parameters including wheel speed, work piece speed, depth of cut and wt% nano SiC have been considered on the basis of the grinding forces and temperature to develop optimum grinding narration such as lubrication, high biological and ecological safety. The result shows that the application of nano fluid leads to the reduction of tangential forces and grinding zone temperature.

2 Materials and Methods

2.1 Material Used

Aluminium billets are obtained from M/s Micro Fine Chemicals, India and the SiC nanoparticles are purchased from M/s US Research Nanomaterials Inc., USA. The Vacuum based solidification process is used to fabricate Aluminium matrix composites reinforced with SiC nanoparticles [23]. The SEM with EDX of Nano SiC reinforced Aluminium matrix composites is shown in Fig. 1 indicating the uniform distribution of SiC nanoparticles in metal matrix nanocomposites.

SAE20W40, Cashewnut based vegetable oil and nano TiO_2 were acquired from M/s Ganapathy traders, India. The nanotubes of 10–30 μm long have a mean diameter of 10–20 nm. Synthesis of nanofluids were carried out by mixing 10 g of nano TiO_2 in 500 ml vegetable oil using ultrasonic processor. The processed samples were kept ideal for 24 h earlier to the measurements. The measured properties of the nano fluids are presented in the Table 1. The heat cropping ability of the nanofluid is increased as indicated by the increase in flash and fire point [24].

2.2 Material Preparation

MMNC specimens were prepared by gravity die casting in which themould is preheated to 300 °C for aiding the flow of the metal melt and decrease the thermal defects of the casting. The mould cavity is cover with a layer of refractory material to prevent the casting adhering to the mould and extend the life of the mould. Nano SiC is pre heated around 300 °C for 30 min and the Aluminium is melted in the furnace at 650 °C. Nano SiC is added at different weight percentage (1%, 2% & 3%) into the furnace along with simultaneous stirring of 400 to 450 rpm. At the time of pouring the mixture of Al and Nano SiC, the air present in the mould will be sucked out with the help of a vacuum pump to reduce the porosity effect. The casted material isremoved from the mould and allowed to cool for 15 to 20 minutesin normal conditions. The specimens are prepared in the size of300mm length and 20 mm diameter.

2.3 Experimental Design

The RSM based D-optimal design is used to model experiments and examine the responses in MQL based grinding of composites [25]. In the present investigation, the models are examined by D-Optimal design for which the quadratic effects of the quantitative factors are interacted by the qualitative factors and Table 2 shows the experimental design. Based on the literature study analysis and trial on number of experiments, four numerical and one categorical factor are varied over three levels.

2.4 Experimental Procedure

The experiments are done using horizontal spindle cylindrical grinding machine (HMT Make, Type G13P). In the present investigation, the cylindrical MMNC specimens were ground with the selected aluminium oxide grinding wheel

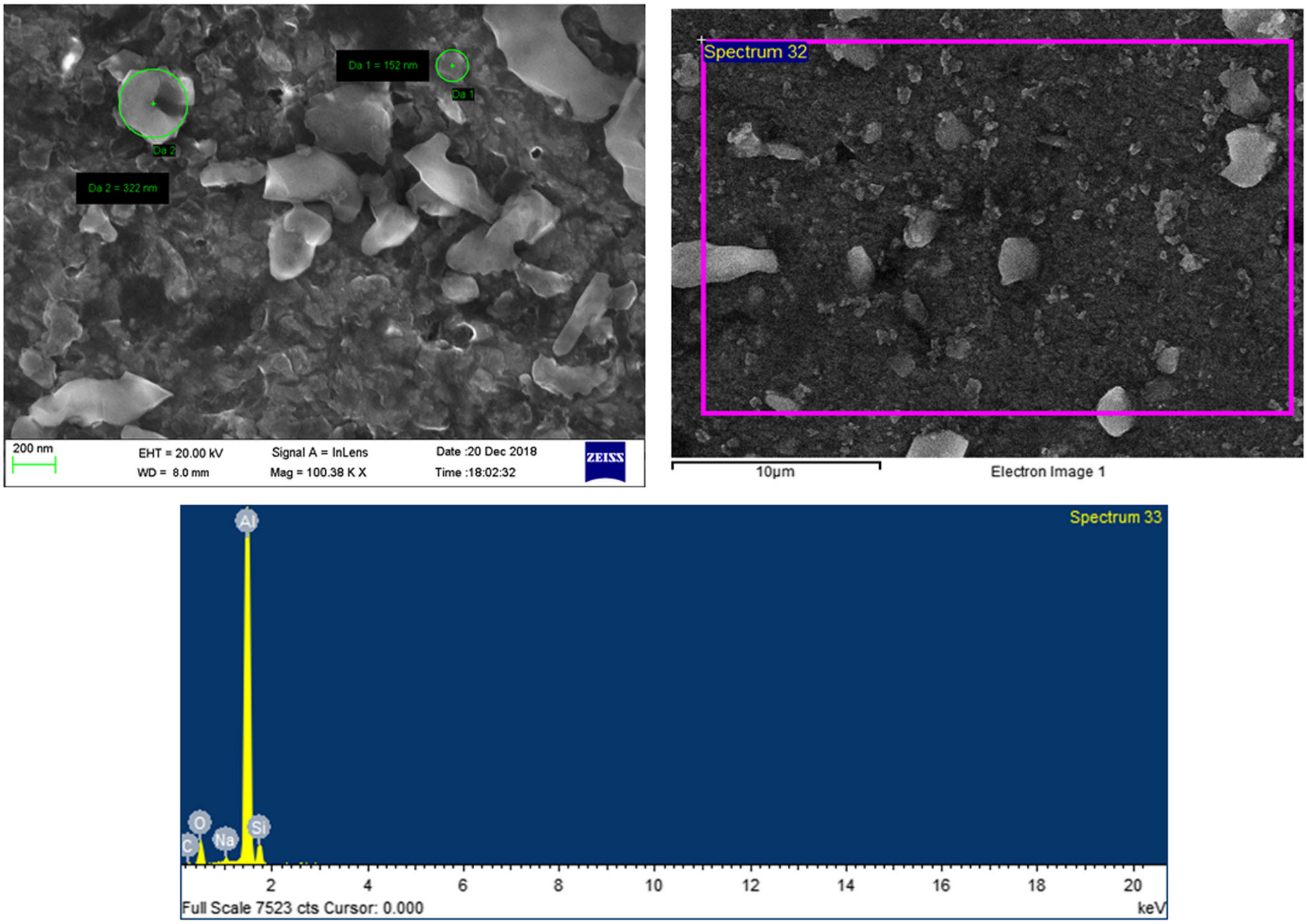


Fig. 1 SEM with EDX of Nano SiC reinforced Aluminium matrix composites

(AA60K5V8). Figure 2 shows the schematic arrangement of setup containing MQL system, work piece and grinding wheel.

The wheel speed can be changed by a Variable Frequency Drive (VFD) attached to the grinding wheel motor which varies the frequency of the motor running at constant speed. The power used by the operation is determined by the following equation

$$P = \frac{(F_t \times V_s)}{94535} \quad (1)$$

Where, P is the power in Kilo Watt, Ft is tangential grinding force in Newton, V_s is wheel speed in m/min to a constant. The temperature generated during cylindrical grinding is measured using non-contact infra-redlaser thermo meter. A single-point diamond dresser is used to dress the grinding wheel before each and every experiment. The parametric study experiments are planned using Response Surface Method (RSM). Table 3 shows the details of 36 experiments totally based on RSM in which the parameters are varied over different levels.

Table 1 Properties of lubricants used

Properties	Flash point (°C) [ASTM D92]	Thermal Conductivity Watt/mK	Viscosity @100 °C (cSt) [ASTM D445]	Viscosity index [ASTM D2270]
SAE20W40	200	0.152	15.2	120
Vegetable Oil (Cashew nut shell Oil)	214.27	0.161	15.48	126
Vegetable Oil (Cashew nut shell Oil + TiO2)	190.2	0.169	16	158

Table 2 Grinding parameters and their levels

Sl.No	Parameters	Notation	Unit	Levels		
				1	2	3
1	Wheel speed	*n*	rpm	900	1200	1500
2	Depth of cut	*d*	µm	10	20	30
3	Work piece speed	*v*	rpm	80	150	270
4	Wt% nano SiC	*w*	%	1	2	3
5	Type of MQL	–	–	SAE 20 W40	VEG OIL	VEG OIL + TiO_2

3 Results and Discussions

3.1 Development of RSM Based D-Optimal Design Models

The experiments are designed and analysis is carried out using RSM technique. RSM is a combination of mathematical and statistical approaches to model and analyse quandariesin which response is influenced bylimited variables. The main purpose of RSM is to optimize this response [26]. The designs generated by the general optimal design planner have additional investigations more than that of the acceptable limit. The general optimal design is replaced by D-optimal design when the categorical factors are involved. The variance

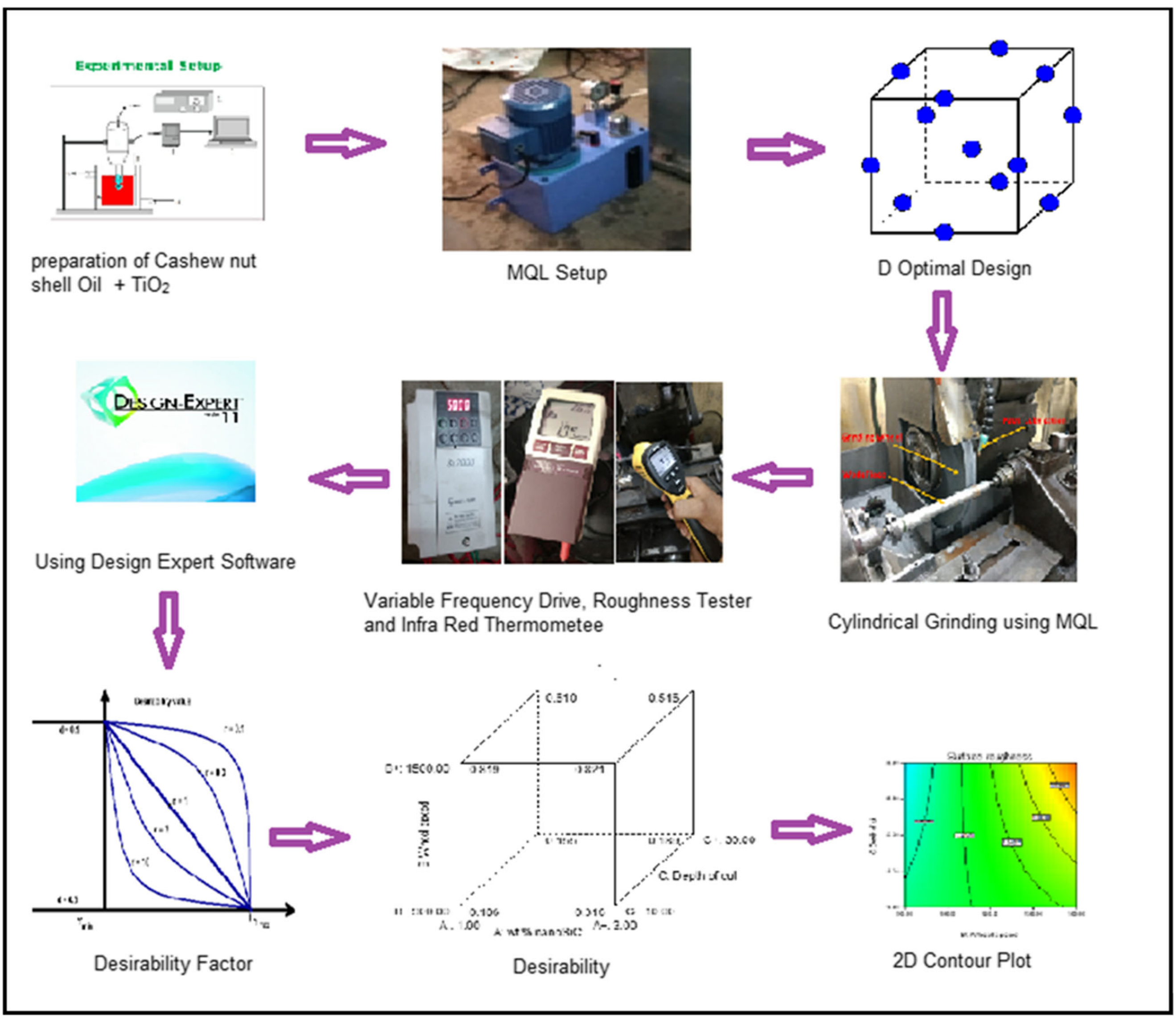


Fig. 2 Schematic arrangement of experimental Setup

Table 3 Experimental results

Sl No	Material	Wheel Speed	Depth of Cut	Work piece Speed	MQL	Temperature	Cutting Force
1	3	1500	30	270	VEG OIL + TiO2	36.7	37.45
2	1	900	10	80	VEG OIL + TiO2	37.5	52.96
3	1	1500	30	270	veg	39.9	37.14
4	3	1500	10	270	veg	36.7	37.03
5	3	900	10	80	SAE 20/40	38	53.38
6	1	1500	10	270	VEG OIL + TiO2	35.7	37.55
7	3	1500	10	150	SAE 20/40	37.4	37.13
8	3	900	10	270	VEG OIL + TiO2	36.8	52.75
9	1	1500	30	80	VEG OIL + TiO2	40.9	37.14
10	3	900	20	270	SAE 20/40	35.4	53.11
11	1	900	30	270	VEG OIL + TiO2	34.3	52.54
12	1	900	30	150	SAE 20/40	48.6	52.54
13	1	1500	20	80	SAE 20/40	39.1	37.24
14	1	900	10	270	veg	38.2	52.54
15	3	900	30	270	veg	36.8	52.75
16	1	1500	10	80	veg	40	36.93
17	2	1200	30	150	SAE 20/40	55.6	54.38
18	3	1200	20	150	veg	38.9	52.49
19	3	1500	10	80	VEG OIL + TiO2	36.7	24.83
20	3	900	30	80	VEG OIL + TiO2	41.6	52.96
21	1	900	10	270	SAE 20/40	37.8	52.75
22	2	900	20	150	VEG OIL + TiO2	34.8	52.75
23	1	900	30	80	veg	39.3	52.75
24	3	1500	30	80	veg	42	39.09
25	1	1500	30	270	SAE 20/40	37.4	36.93
26	1	1200	20	150	veg	41.8	52.17
27	2	1500	20	150	VEG OIL + TiO2	36.6	35.07
28	2	1200	15	150	SAE 20/40	42	52.64
29	2	900	10	80	veg	44	53.15
30	1	1200	10	80	SAE 20/40	37	52.01
31	1	900	30	270	VEG OIL + TiO2	38.5	52.96
32	3	1500	10	270	veg	36.4	37.65
33	3	1500	10	150	SAE 20/40	39.8	31.6
34	3	1500	10	80	VEG OIL + TiO2	38.3	37.14
35	3	900	30	270	veg	38	52.75

associated with the evaluations of specified model coefficients is minimized by selecting the design points using D-optimal criterion [21]. In many RSM problems, the relation between the independent variable and the response is unknown. Hence, accurate approximation for the set of involved independent variables and the functional relation ship between y is set primarily in RSM. The value of y can be obtained by a second order model as follows,

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{12} x_1 x_2 + \beta_{11} {x_1}^2 + \beta_{22} {x_2}^2 + \varepsilon \quad (2)$$

Tables 4 and 5 represent the quadratic models of Temperature and Cutting Force respectively, for different MQL systems such as SAE20W40, Cashew nut shell Oil and Cashew nut shell Oil+ NanoTiO_2.

3.2 The Analysis of the Quadratic Mathematical Model

The design matrix was established using Design-Expert 8.0, to fit the experimental data and examine the experimental data to a second-order polynomial. The performance of the models was ensured using lack-of-fit test, sequential F test and other adequacy measures. While the significance of input parameters is evaluated byanalysis of variance (ANOVA). Based on the result, the model terms are significant since Prob>F value

Table 4 FI Model for temperature

Sl. No.	Type of MQL system	2FI model for Temperature
1	SAE 20 W40	−3.062979632 + 10.62426481w + 0.067016686n −1.693744789d + 0.127320097v-0.000320013wn +0.034747693wd-0.00188762wv + 0.000107471nd −2.2877E-05n v-0.000846345dv-2.428640759w^2 −2.84315E-05 n^2 + 0.053423424 d^2–0.000302874v^2
2	Vegetable Oil (Cashew nut shell Oil)	−0.302815999 + 9.107482115w + 0.071791943n −2.148470111d + 0.140210894v-0.000320013wn +0.034747693wd-0.00188762wv + 0.000107471nd −2.2877E-05nv-0.000846345dv-2.428640759w^2 −2.84315E-05n^2 + 0.053423424d^2–0.000302874n^2
3	Cashew nut shell Oil + TiO_2	−3.914685495 + 9.987990277w + 0.070692812n −2.085190016d + 0.139824802v-0.000320013wn +0.034747693wd-0.00188762wv + 0.000107471nd −2.2877E-05nv-0.000846345dv-2.428640759w^2 −2.84315E-05n^2 + 0.053423424d^2–0.000302874v^2

is between 0.05 and 0.1. Furthermore, the two-factor interaction (2FI) model was selected in responses due to considerable curvature [27].

Tables 6 and 7 reveals the ANOVA table for responses, where MQL type, in whichWheel speed, Depth of cut, interaction amongWheel speed and Depth of cut, Wheel speed and MQL type are significant model terms. The F-value of model is11.36968, conforming the significance of the model. The result of responses shows that an R-squared value which comes close to 1 is desirable. In addition to this, there are minor variation between Adj R-squared and Pred R-squared, so that the models have sufficient transaction between the input and output parameters. The signal-to-noise ratio is attractive and the Adeq precision valve is larger than 4. The lack-of-fit sufficientlydefine the functional relationship between the response variable and the experimental factors.

The $\beta_0$values for SAE20W40, Cashew nut shell Oil and Cashew nut shell Oil+ NanoTiO_2 0.1% in temperature are 3.41,5.46 and 5.55 and in cutting force are 3.41, 5.46 and 5.55 correspondingly. The $\beta_0$value is a mean response value of all the carried-out experiments and cut-off of the plane [21]. The $\beta_0$values respondto the key grinding factorsand also to the investigationalanomaliessuch as surface finish, machine vibrations andenvironmental conditions. It is clearly observed from the coefficient β_0 and the experimental results, the

Table 5 FI Model for cutting force

Sl. No.	Type of MQL system	2FI model for Cutting Force
1	SAE 20 W40	−34.17015817 + 2.025307399w + 0.17559284n −0.174358632d-0.034140933v-0.000855875wn +0.054260311wd + 0.00240328wv + 0.000167673nd +1.25877E-05nv-0.000596958dv-0.539060645w^2 −8.62179E-05n^2 + 0.001554197d^2 + 6.09565E-05v^2
2	Vegetable Oil (Cashew nut shell Oil)	−36.4919234 + 1.968939669w + 0.178095052n −0.235380715d-0.031037011v-0.000855875wn +0.054260311wd + 0.00240328wv + 0.000167673nd +1.25877E-05nv-0.000596958dv-0.539060645w^2 −8.62179E-05n^2 + 0.001554197d^2 + 6.09565E-05v^2
3	Cashew nut shell Oil + TiO_2	−33.52179178 + 0.901474909w + 0.174498643n −0.192324176d-0.020835496v-0.000855875wn +0.054260311wd + 0.00240328wv + 0.000167673nd +1.25877E-05nv-0.000596958dv-0.539060645w^2 −8.62179E-05n^2 + 0.001554197d^2 + 6.09565E-05v^2

Table 6 ANOVA for temperature

Source	Sum of Squares	df	Mean Square	F Value	*p* value Prob > F	
Model	476.9079	24	19.87116	2.757124	0.0489	significant
A-wt% nanoSiC	0.390997	1	0.390997	0.054251	0.8205	
B-Wheel speed	1.506825	1	1.506825	0.209072	0.6573	
C-Depth of cut	69.74305	1	69.74305	9.676847	0.0110	
D-Work piece speed	52.0606	1	52.0606	7.223407	0.0228	
E-MQL type	31.92035	2	15.96017	2.214474	0.1599	
AB	0.159702	1	0.159702	0.022159	0.8846	
AC	2.192653	1	2.192653	0.304231	0.5934	
AD	0.663137	1	0.663137	0.09201	0.7679	
AE	7.9417	2	3.97085	0.550955	0.5929	
BC	2.006266	1	2.006266	0.278369	0.6093	
BD	9.149493	1	9.149493	1.269492	0.2862	
BE	8.724129	2	4.362064	0.605236	0.5648	
CD	13.38623	1	13.38623	1.857339	0.2028	
CE	66.89932	2	33.44966	4.64114	0.0375	
DE	5.210375	2	2.605187	0.36147	0.7054	
A^2	13.33661	1	13.33661	1.850455	0.2036	
B^2	15.30138	1	15.30138	2.123066	0.1758	
C^2	79.92975	1	79.92975	11.09025	0.0076	
D^2	13.08231	1	13.08231	1.81517	0.2076	
Residual	72.07208	10	7.207208			
Lack of Fit	58.32708	5	11.66542	4.243513	0.0693	not significant
Pure Error	13.745	5	2.749			
Cor Total	548.98	34				

performance of Cashew nut shell Oil+ NanoTiO_2reinforced composites based MQL system is better in comparison with other systems. When the coefficient values are greater than 0, the response value of the composite increase with the related variables while an inverse effect is observed when the coefficient value is lesser than 0.

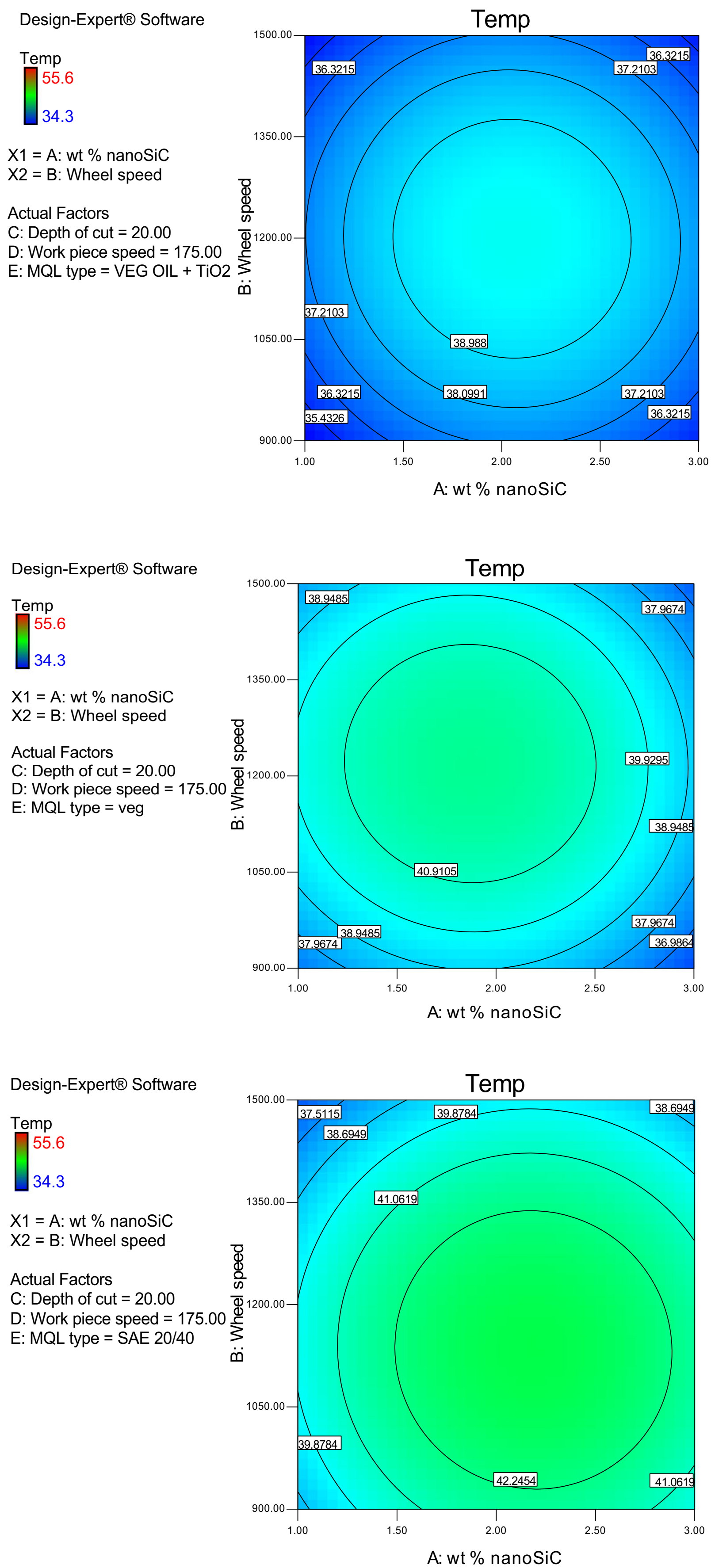
3.3 Effect of Grinding on Temperature

The 2FI models built-in for temperature on grinding parameters is presented as 2D contour plots in Fig. 3. The temperature decreases with the increase in wt.% of nano SiC irrespective of the grinding settings since the heat resistance, hardness and

Table 7 ANOVA for cutting force

Source	Sum of Squares	df	Mean Square	F Value	p value Prob > F	
Model	2509.29	24	104.5537	11.36968	0.0002	significant
A-wt% nanoSiC	0.086829	1	0.086829	0.009442	0.9245	
B-Wheel speed	1756.98	1	1756.98	191.0626	< 0.0001	
C-Depth of cut	5.749812	1	5.749812	0.625263	0.4474	
D-Work piece speed	0.520288	1	0.520288	0.056579	0.8168	
E-MQL type	4.273491	2	2.136745	0.23236	0.7968	
AB	1.142343	1	1.142343	0.124224	0.7318	
AC	5.34666	1	5.34666	0.581422	0.4634	
AD	1.074935	1	1.074935	0.116894	0.7395	
AE	6.787324	2	3.393662	0.369043	0.7004	
BC	4.883518	1	4.883518	0.531058	0.4829	
BD	2.770051	1	2.770051	0.301229	0.5952	
BE	5.600618	2	2.800309	0.304519	0.7441	
CD	6.659652	1	6.659652	0.724203	0.4147	
CE	1.327265	2	0.663633	0.072167	0.9309	
DE	6.489569	2	3.244784	0.352854	0.7111	
A^2	0.657044	1	0.657044	0.07145	0.7947	
B^2	140.71	1	140.71	15.3015	0.0029	
C^2	0.067648	1	0.067648	0.007356	0.9333	
D^2	0.529907	1	0.529907	0.057625	0.8151	
Residual	91.95836	10	9.195836			
Lack of Fit	0.619458	5	0.123892	0.006782	1.0000	not significant
Pure Error	91.3389	5	18.26778			
Cor Total	2601.248	34				

Fig. 3 2D contour plots for Temperature on Different MQL system



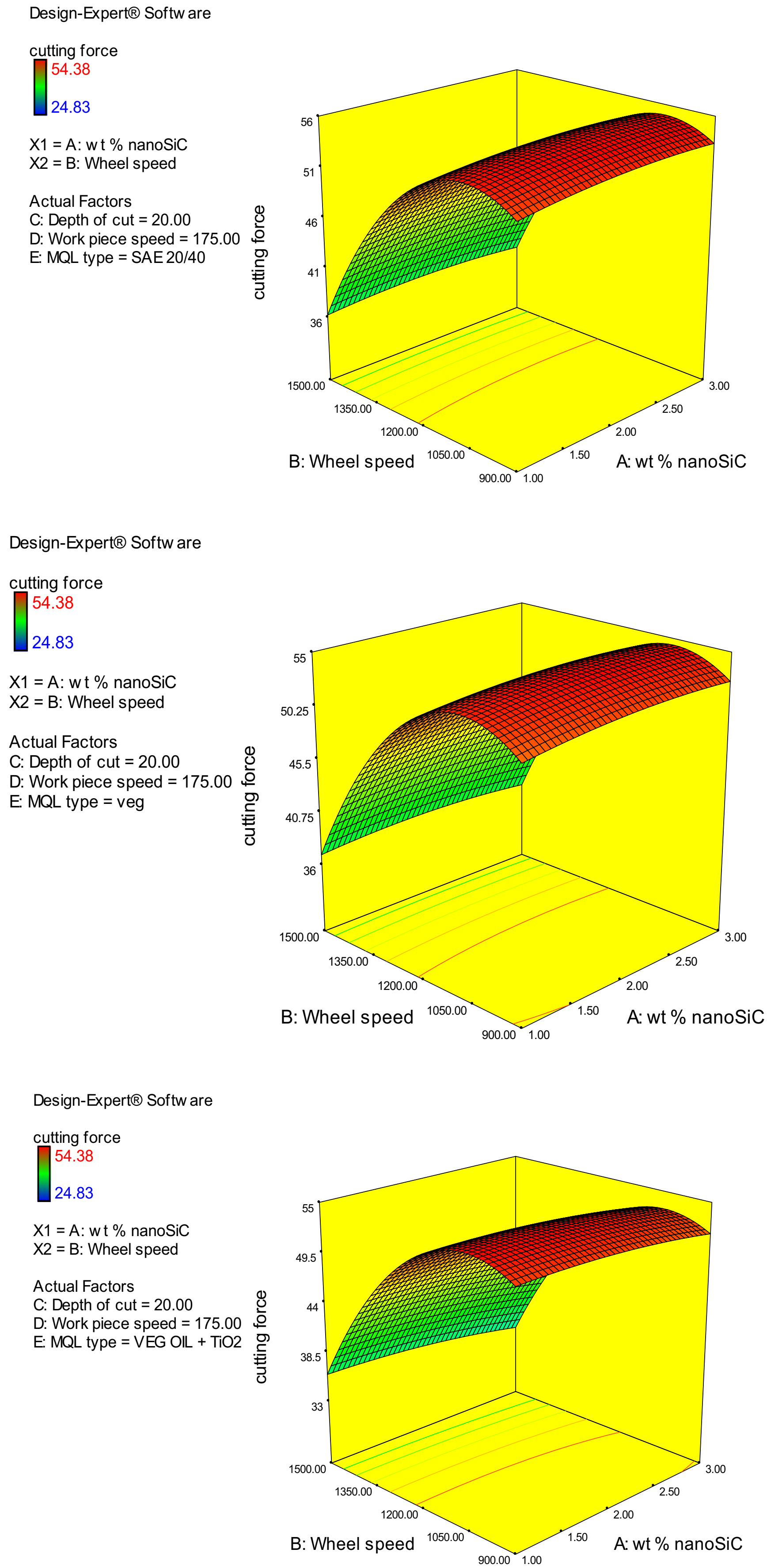


Fig. 4 3D surface plots for cutting force on Different MQL system

tensile strength are influenced by the addition of nano SiC in Al matrix [28]. When compared to dry grinding, the MQL grinding process results in better surface roughness, reduced grinding forces and prevented workpiece burning. The grinding temperature could be lowered remarkably in MQL grinding [29]. The experiments revealed that the grinding temperature decreases with the increase in wt.% of nano SiC [9]. The best performance is obtained by Cashew nut shell Oil+ NanoTiO_2 based MQL which is primarilydue to the decrease in the grinding temperature and the lubricity of the employed fluid indicating the increased heat collecting ability of nano fluid [17]. In actual grinding process, the quality of nano fluids play an important part in transporting heat throughoutthe grinding process along with the improvement in the surface finish.

3.4 Effect of Grinding on Cutting Force

The 2FI models built-in for Cutting Force on grinding parameters is presented as 3D surface plots in Fig. 4. One of the most important parameters is tool life which regularly decrease with the increase in the depth of cut and cutting force due to increased stress and contact of the workpiece. More cutting force is generated with the rapid tool advancement and vibrations resulting in increase of the surface roughness [30]. It is observed from the experiments that the increase in the workpiece speed and wheel speed resulted in the decrease of the tangential grinding force while the increase in depth of cut increases tangential grinding force and surface roughness [28]. The best performance is obtained by Cashew nut shell Oil+ NanoTiO_2 based MQL, since the lubricant of MQL system penetrate into the workpiece and the wheel interface contact zone [31].

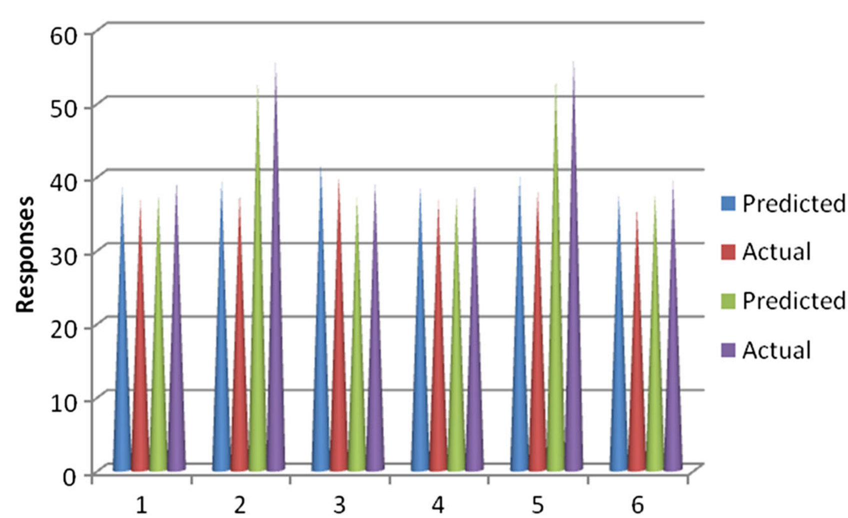
3.5 Effect of MQL Systems on Responses

The effect of different MQL on responses were presented in Figs. 3 and 4. The experimental results showed that nano filled MQL could significantly reduce grinding forces and enhance surface quality. Tio_2 filled MQL shows better performance compare to other MQL systems due to decrease in friction and a rise in load bearing capacity of friction parts. Nano fluid revealed better tribological and thermophysical properties and reduced the cutting forces and surface roughness, cutting zone temperature and tool wear [32]. Tiwari et al. [33] observed that an increase of nanoparticle volume concentration increased thermal conductivity, viscosity and density of fluid, which, in turn, increased the heat extraction capability of cutting fluid and reduced the cutting zone temperature. Peng et al. [34] showed different mechanisms like rolling action of nano-sized spherical particles,surface protective film,sewing effect and compressive stress concentrations of nano particles for anti-wear and friction reduction by mixing nano particles into ordinary cutting fluid. Therefore the nano filled MQL improves the overall performance of sustainable grinding process.

3.6 Confirmation Experiment

The usefulness of the model has been chequered by confirmation with experimental results. In order to verify the adequacy of the model developed, five confirmation run experiments have been carried out (Fig. 5) at different cutting conditions. The predicted values are very close to the experimental results, and hence, the developed model is appropriate for predicting the responses in sustainable grinding of nano SiC composites.

Fig. 5 Conformation test



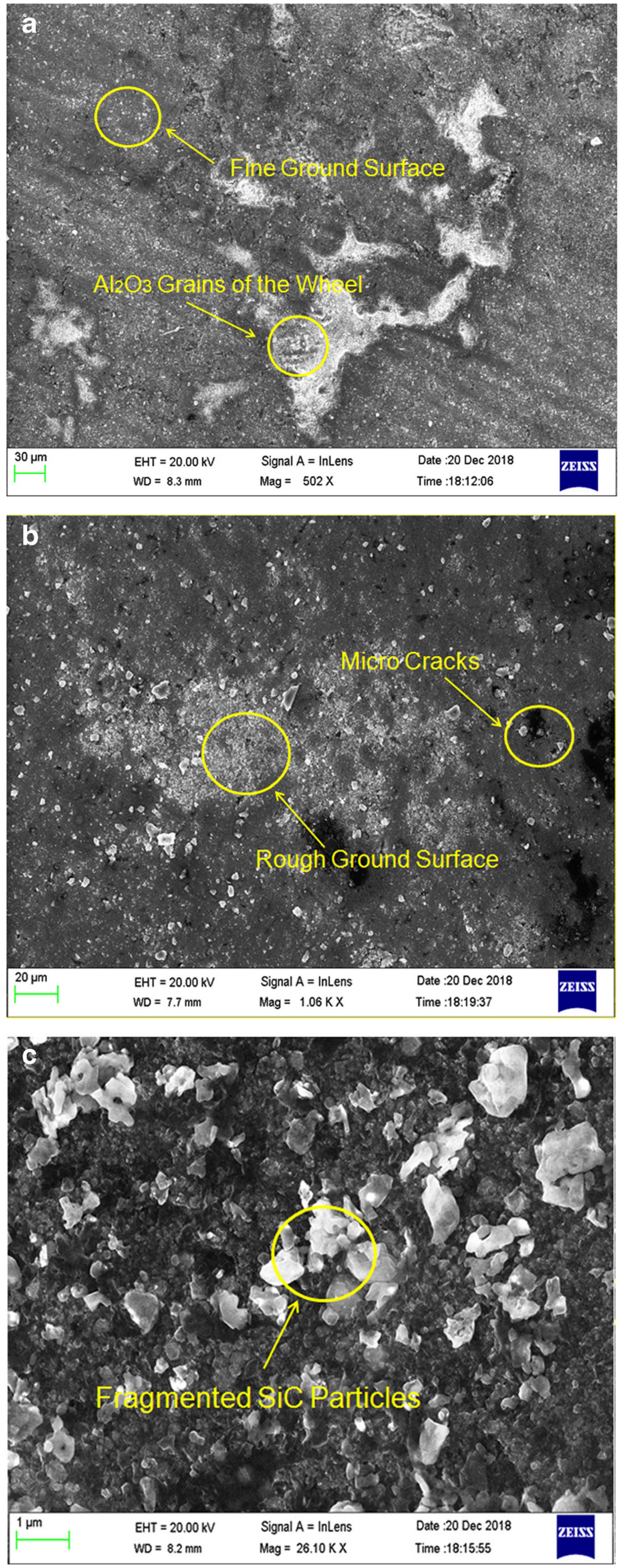


Fig. 6 Microstructure of machined surface at (a) n = 1500 rpm, d = 30 μm, v = 270 rpm, w = 2% and SAE20W40 (b) n = 1500 rpm, d = 10 μm, v = 270 rpm, w = 3% and VEG Oil + TiO_2 (c) n = 1500 rpm, d = 20 μm, v = 270 rpm, w = 3% and VEG OIL

3.7 Surface Morphology of Machined Surface

The machined surface is observed and analyzed using scanning electron microscope (SEM) and the micrographs are presented in Fig. 6. The machined surface of the workpiece revealed poor surface finish and grinding wheel marks owing to the high depth of cut of the grinding wheel. Higher depth of cut, lower workpiece and wheel speed pull the SiC particle by fragments from the surface of the workpiece rather than grinding it [28]. The higher depth of cut and cutting force resulted in the workpiece surface breakup while the Al_2O_3 wheel grains are embedded on the surface. SEM micrograph clearly revealed crack and defect free fine surface [35] but the variance in the thermal expansion of Al and SiC nanoparticles generate heat which may lead to micro crack propagation on the ground surface.

4 Conclusion

Based on the results of the present experimental investigation, the following conclusions for MQL grinding of MMNC can be drawn

- Nano SiC reinforced Al matrix composites were fabricated successfully by Vacuum based solidification process
- The influences of n grinding parameters including wheel speed, work piece speed, depth of cut and wt% nano SiC have been considered on the basis of the grinding forces and temperature to develop optimum grinding narration such as lubrication, high biological and ecological safety.
- Quadratic models of Temperature and Cutting Force were developed using RSM based D-optimal design for different MQL systems such as SAE20W40, Cashew nut shell Oil and Cashew nut shell Oil+ NanoTiO_2.
- The most significant parameters that influence the responses are MQL type, Wheel speed and Depth of cut.
- The machined surface of the work piece revealed poor surface finish and grinding wheel marks owing to the high depth of cut of the grinding wheel.
- The best performance is obtained by Cashew nut shell Oil+ NanoTiO_2 based MQL, since the lubricant of MQL system penetrate into the workpiece and the wheel interface contact zone
- The quality of nano fluids play an important part in transporting heat throughout the grinding process along with the improvement in the surface finish.

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