

Analysis of Cutting Forces and Surface Roughness in Machining Al2219, Unhybrid and Hybrid Metal Matrix Nano Composites using CCD Design of Experiment

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Received: 4 March 2021, Revised: 7 June 2021, Accepted: 7 July 2021

Abstract

Nano Composites (nano MMCs) exhibit outstanding engineering properties like wear resistance, better stiffness, low density, and excellent ratio of strength to weight and so on. Unhybrid and hybrid nano MMC composites were fabricated using liquid metallurgical stir casting technique. Turning of Al2219 through TiN coated carbide tool was carried out to investigate surface roughness and cutting forces, by considering the cutting parameters like feed rate and speed. Response surface methodology (RSM) was used to design the experiments and to analyze the obtained results. The obtained results indicated that the cutting forces and surface roughness increases with increase in feed rate and decreases with increase in cutting speed. RSM displayed model and measured values are truly close to each other, which shows that created model can be effectively used to predict the cutting force and surface roughness on turning of MMCs. The predicted model values and obtained experimental values were close to each other with minimal error of 5 %, so the model is adequate.

Keywords: Unhybrid, Hybrid nano MMCs, Surface roughness, Cutting force, RSM

Introduction

Composites classified under the advanced materials. These materials have good weight to strength ratio, so they are suitable to use in the fields like automotive, aerospace, etc. The properties of matrix (toughness, ductility, etc.) and the properties of reinforcement (high modulus, high strength, etc.) will determine the overall properties of the composite materials [1,2]. Particulate reinforced metal matrix composites will result in less cost, homogeneous properties and can be synthesized by using conventional techniques. Also, they exhibit good hardness, higher strength and wear resistance properties. So, they found wide applications in areas like automobile, structural applications, aerospace and so on [3]. The excellent properties of MMCs such as low weight, high strength, low or high thermal expansion and thermal conductivity can be achieved with the help of appropriate matrix, reinforcement and interface. The MMCs will have the density roughly equal to 1/3rd of steel, results in high-specific strength and stiffness [4].

In this present scenario, there is a scope in fabricating new materials with high strength, less in weight, stiffer, good wear resistance and high fatigue strength. Generally used reinforcements are (Al₂O₃) Alumina and (SiC) Silicon Carbide. And commonly used matrices are aluminum, magnesium and titanium alloys. Better properties of these matrices can be obtained by incorporating reinforcements like Al₂O₃, B₄C, SiC, TiB₂, TiC and so on [5]. Compared to other ceramic particles, B₄C is the harder and less dense (2.51 g/cm³) reinforcing material. Other properties include high impact strength, high wear resistance and also high melting point makes B₄C as suitable reinforcement for MMCs [6]. In MMCs normally used solid lubricants are MoS₂, Graphite, Cu₂S, Sb₂S₃ and H-BN due to their higher wear resistance. Among these solid lubricants MoS₂ is having density of 5.02 g/cm³ [7]. Mechanical alloying, squeeze casting, spray deposition, stir casting and powder metallurgy processes are employed to

synthesize the aluminium based MMCs. These synthesizing processes will also be treated as one of the important factors to determine the final properties of the composites. The raw materials can be mixed either in liquid or solid state. Among them liquid state fabrication methods are easy to follow as well as results in high volume production [8]. MMCs have combination of attractive qualities assumes an imperative part in different industries. But, strengthening of reinforcing particles with hard and abrasive nature brings serious tool wear and surface roughness in machining [9]. The applications of MMCs are deficient due to their poor machinability. This prompts to extraordinary cutting tool wear and poor surface finish, thus MMCs have higher hardness and superior reinforcement strength. Subsequently by method of conventional machining it is hard to machine [10]. Turning is the essential manufacturing operation which is utilized in numerous industries. This operation needs great surface finish, so the machine supervisor will make utilization of their own insight with experience to create better surface finish with amid turning operation. The procedure ought to be performed utilizing legitimate information parameters and appropriate input parameters to decrease the restrictions [11]. Therefore, more research is going ahead in understanding the machinability factors [11].

To contend with manufacturing industries in worldwide level, MRR (material removal rate) and surface roughness assumes a vital part in choosing the efficiency of the organization. Proficient turned component will bring about lesser tool wear, with outstanding tolerance, fatigue strength and so on. For expanding profitability and to decrease machining time Computer Numerical Control (CNC) machine apparatus is the better choice. With a specific end goal to accomplish least MRR and least surface roughness the selection of parameters is essential in turning process [12]. Because of advancement in coating technology, carbide cutting tool are sheltered with ceramic particles to enhance the properties like hardness, wear resistance, fracture strength, thermal shock and toughness. The coated carbide cutting tools surface shows good resistance to abrasion. These cutting tools can have one or additional thin layers of coatings and these coatings will have the ability to oppose the wear. The normally utilized coated layers are aluminum oxide (Al_2O_3), titanium nitride (TiN) and additionally titanium carbide (TiC) [13]. The necessities for machining is due to complex design of component and dimensional tolerance cannot be disposed of totally. As of the current literature, information on PMMCs gives a thought regarding the weight percentage, volume fraction, distribution and morphology of reinforcement and matrix properties, which are the main parameters that impact the general cutting procedure [14]. In recent days, the applications of DOE methods are used for assessment of machining parameters. CCD (Central Composites Design) scheme of DOE is extremely successful and efficient experimental technique which uses huge number of factors. Two level factorial experimental designs make use of K factors in 2 levels with every factor. Three or high-level experiments are used when nonlinear relationship is required and this method increases the cost and time of testing. When compared to factorial experimental designs and 3k, CCD is the efficient and capable method. To study the various factors at 5 levels by reducing the number of tests CCD technique can be used [15].

Recent analysts illustrates that the properties of MMCs with small volume fraction of nanoparticles particularly mechanical properties is superior to that with micro size particles. It was found that the enhancement in strength can be basically credited to the grain refinement since of nucleation and sticking made a difference by the expansion of nanoparticles support [10]. With the addition of nanoparticle enhancers, the mechanical properties of AMMC are knowingly enhanced. Though they are more convenient for the mechanism of hardening nanoparticles, rather than MMC reinforced with micron-sized particles. Kady *et al.* [1] and Vijayraj *et al.* [16] a similar study was showed on a nano SiC particles reinforced Al MMCs [1], and it was found that tool wear was mainly affected by feed rate and cutting speed. When the tool on the MMC wears, the depth of cut can be ignored. According to them, the addition of nano-SiCp improves flank wear due to the presence of the hard abrasive phase. This will scratch the cutting tool on the flank surface. Furthermore, Manohar *et al.* [17] reported that the grooves in the chip flow direction formed in the cutting insert are parallel to the movement of the workpiece. In addition, they observed 2- and 3-body wear due to the presence of nano clay particles. Lin *et al.* [18] also reported on this type of observation for micron particles of SiC.

Literature review

The studies on the turning characteristic of metal matrix composites by means of particulate reinforcement have been reported by researchers. Machining performance of Al_2O_3 reinforced MMC by response surface methodology was studied and identified the lower cutting force and lower surface roughness for 0.10 mm depth of cut, cutting speed of 100 m/min and feed rate of 0.1 mm/rev. Excellent surface roughness was accomplished by enhancing cutting speed, however worse/inferior surface

roughness was seen by increase in feed rate. Cutting force was affected by the interactions of depth of cut and feed rate [4]. Results of TiC reinforced metal matrix composite by L_{25} Taguchi technique showed that surface roughness increases with increase in TiC reinforcement content. The surface roughness and cutting force was less at higher cutting speed, whereas increases in cutting speed increases the surface roughness and cutting force [5]. Surface roughness is significant parameter to assess the quality of a machined part. Further, the surface roughness also has influence on the factor called as sustainability during machining, which in turn influences the parameters and machining process selection [19]. The aim of the study is to obtain the arithmetic mean surface roughness i.e. R_a in turning operations. R_a is an important parameter which is commonly used to describe the surface deviation at ideal level [15]. Results of the turning of Al/SiC/Graphite hybrid MMCs using GFA was found that, Al-10 % SiC-Graphite hybrid composites gives superior machinability with a least flank wear. Surface roughness and highest MRR was obtained for all cutting conditions in contrast to 5 and 7.5 % of SiC-Graphite aluminium metal matrix composites [20].

Studies on the effect of cutting speed in machining of MMCs found that during cutting process debonding mechanisms and crack initiation can alter by changing the cutting speed subsequently [10]. Investigation on micro-machinability of nano TiB_2 and Ti reinforcing Mg-based metal matrix composites found that, surface roughness mainly depends on depth of cut and spindle speed. At lower feed rate the noticeable surface quality (0.15 to 0.5 μm) was obtained. The cutting force obtained for MMC is roughly 2 times larger than Mg/ TiB_2 [2]. Analysis of temperature and tool stress at the time of machining MMCs found that, on tool face high stress was created. This is due to contact of hard particles in matrix in the region of the tool face. The high stress region increases by increase in feed rate. Also, at the tool tip the stresses were increased. During the action of rolling and sliding the presence of hard particles enhances the cutting speed and size, as a result high tool stresses are induced [21]. The formation of chips is connected to segmentation mechanism and it begins at a crack on surface of the work piece [22]. The effect of various parameters using CCD for turning of hybrid nanocomposite (Al/6061/SiC/Graphite) were evaluated. Cutting force and roughness were mainly influenced by depth of cut and feed rate. In addition, results reported that, tool wear for nanocomposite is negligible because the sizes of particles are too small and also existence of Graphite solid lubricant minimizes the tool wear [23].

However, from literature survey it is found that, the data are insufficient on parametric studies on turning characteristics of aluminium metal matrix with nano particles reinforced hybrid composites. Moreover, adequate investigations have not done to determine the machinability of Unhybrid and Hybrid nano MMCs (Al2219+2% n- B_4C and Al2219+2% n- B_4C +2% MoS_2). With a specific end goal to meet the expanding requests/demands for the small components and high precision components with predominant machining and mechanical properties, as a rising machining process in nano MMCs, drawing a consideration from industry, scholarly world and academia. In this current research work, an effort is made to investigate the influence of n- B_4C and MoS_2 particulates on the machining characterization of Al2219 alloy, Unhybrid and hybrid nano MMCs. The CCD scheme of DOE is used for analyzing the experimental results of machining performances.

Materials and methods

In this present study, Al2219 was chosen as matrix material and its elemental composition of Al2219 in weight % is Zr: 0.1 - 0.25, V: 0.05 - 0.15, Mg: Max 0.02, Fe: Max 0.30, Si: Max 0.20, Ti: 0.02 - 0.1, Mn: Max 0.10, Zn: Max 0.10, Cu: 5.8 - 6.8 and Remaining Al. Nano Boron carbide (n- B_4C) with 30 - 60 nm average particle size was chosen as primary reinforcement material and solid lubricant Molybdenum disulfide with typical particle size of 600 - 900 nm was added as secondary reinforcement. From the literature it was known that wettability between Al and B_4C was poor below 1100 $^{\circ}C$. So, in this present work, K_2TiF_6 halide salt was used to improve the wettability between Al and B_4C in the ratio of 0.4Ti/n- B_4C . The nano MMCs were prepared by stir casting method by means of resistance furnace connected with stain less steel stirrer [24,25]. From the casting, 3 different types i.e. Al2219, Unhybrid and Hybrid nano MMCs ingots with 250 mm length and 42 mm diameter cylindrical rod were obtained. The casted ingots were examined using FESEM. **Figure 1(a)** shows FESEM image of Unhybrid and Hybrid nano MMCs. This shows n- B_4C as well as MoS_2 particles are uniformly distributed in Al matrix.

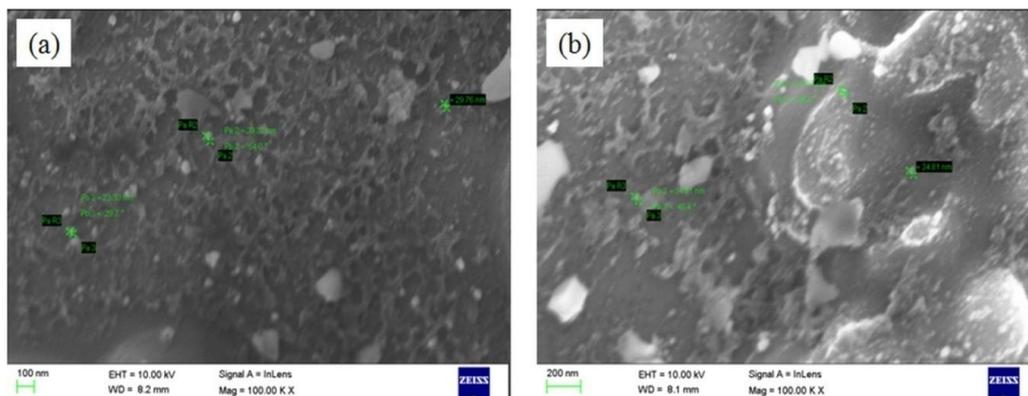


Figure 1 FESEM image of (a) Unhybrid and (b) Hybrid nano MMCs.

Plan of experiments

In the DOE (Design of Experiment), the tests are planned based on CCD. Experiment was conducted by considering feed rate (*f*) and cutting speed (*v*) as factors. CCD is extremely useful experimental technique and is most capable method. It is substitution for the 3k or more factorial experimental designs. Depth of cut, cutting speed and feed rate are some of the factors which influence turning characteristics of Al matrix as well as prepared composites. In the present work experimentation was carried out to find out the effects of cutting speed and feed rate and at constant depth of cut (0.5 mm). The experimental data was analyzed soon after the completion of test. By considering the hardness of Al2219, Unhybrid, Hybrid nano MMCs and its chemical composition, the cutting parameters are selected.



Figure 2 Experimental setup used for turning operation (a) CNC turning machine (b) Amplifier interfaced to personal computer.

Table 1 shows the plan of experiment based on CCD and the design matrix of experiment for various runs and factors by their actual and coded values. In design matrix of experiment for various runs and factors by their actual values, the experiment consists of 13 tests and the 1st column was allocated to run order, 2nd column was allocated to feed rate, 3rd column was assigned to cutting speed. The experiments were conducted as for run order. Using TiN Coated Carbide inserts the turning experiment was conducted for Al2219, Unhybrid and Hybrid nano MMCs work piece material in dry condition. TiN coated carbide TNMG 160408 HT TT5100 inserts were used during investigation, which was of ISO geometry with nose radius of 0.8 mm, Entry angle -60° , Clear angle -7° , and Rake angle -0° . Order of layer of Multilayer coating of TiN coated insert are TiN, TiCN, Al_2O_3 , TiN and Carbide Substrate respectively. The WTJNL2525-M16 steel grade type of tool holder was used in this work. For each operation, new cutting inserts with new edges were used for turning operation.

ACE CNC (Computer Numerically Controlled) lathe with FANUK control system was used for turning operation. Figure 2 shows experimental setup used to measure cutting force. During turning operation, the cutting force (*F_c*) was noted with the help of dynamometer. After completion of every experiment, surface roughness (*R_a*) was measured at 3 different positions by the help of Mitutoyo surface roughness tester.

Results and discussion

Cutting forces

The obtained cutting force from experimental results of Al2219 is analyzed by means of ANOVA and the results are shown in **Table 1**. From the obtained results it is clear that the factor f and v are significant for Al2219 and their p -value is < 0.05 . The interaction of $f \times v$ is also significant. The significant factors of percentage (%) contribution are deliberated by Eq. (1).

Table 1 Design of Experiment for various runs and factors by their actual values.

Run order	f (mm/rev)	v (m/min)	Cutting force-Fc (N) (Al2219)	Cutting force-Fc (N) (Al2219+2%n-B4C) Unhybrid nano MMCs	Cutting force-Fc (N) (Al2219+2%n-B4C +2%MoS2) Hybrid nano MMCs	Surface Roughness-Ra (µm) (Al2219)	Surface Roughness-Ra (µm) (Al2219+2%nB4C) Unhybrid nano MMCs	Surface Roughness-Ra (µm) (Al2219+2%nB4C+2%MoS2) Hybrid nano MMCs
1	0.300	200.00	103	218	251	4.22	5.16	5.96
2	0.441	185.35	117	246	279	5.55	6.92	7.81
3	0.300	150.00	126	261	296	5.82	6.79	7.76
4	0.300	150.00	134	275	304	5.9	6.49	7.25
5	0.441	114.64	176	316	328	7.95	9.44	10.52
6	0.300	100.00	140	290	319	6.39	8.54	8.99
7	0.300	150.00	121	266	291	5.99	7.14	7.45
8	0.300	150.00	130	270	297	5.33	7.92	7.28
9	0.300	150.00	136	271	302	5.26	6.98	7.08
10	0.100	150.00	85	211	228	2.32	3.24	3.86
11	0.158	185.35	107	205	233	3.58	3.62	4.68
12	0.500	150.00	159	299	315	7.46	9.20	5.96
13	0.158	114.6	92	251	278	3.44	5.13	6.39

From **Tables 2 - 4** the significant factor of % contribution is calculated using [sum of square (Seq ss)/ (Total sum of square)]. While for Unhybrid nano composite, the ANOVA results were seen in **Tables 2 - 4**. Factors f and v , $v \times v$ and $f \times v$ are significant whereas the factor $f \times f$ are not significant. Similarly, for Hybrid nano MMCs the ANOVA result shows the factors f and v , $f \times f$ is significant. The factors $v \times v$, $f \times v$ is not significant whose values are > 0.05 . For both Unhybrid and Hybrid nano MMCs feed rate is highest contribution followed by cutting speed. From the main effect plot (**Figure 3**), it is clear that by increase in feed rate increases cutting force and it decreases by increasing cutting speed. This is due to reduction in chip tool contact length [26]. From **Figures 3(a) - 3(c)**, it is evident that for Al2219 the cutting force is lower and by adding 2% n-B4C the cutting force increases mainly due to its higher hardness. Since the hard ceramic n-B4Cp performs as an abrasive grain and also it offers high resistance, thus the cutting force increases. **Figure 3(b)** clearly shows increase in cutting force may be due to increase in frictional force. The cutting force is maximum for nano hybrid composite; cutting force is some extent increases with addition of 2% MoS₂. On the cutting edge of cutting insert, MoS₂ particles forms lubricating film. This film tends to slip on the shear plane of cutting tool. Hence the cutting force increases in Hybrid nano MMCs and this can be seen in **Figure 3(c)**.

Table 2 Analysis of variance for cutting force (N) of Al2219 for the coded values.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
<i>fI</i>	1	4932.82	4932.82	4932.82	199.39	0.000	63.347
<i>vI</i>	1	1159.83	1159.83	1159.83	46.88	0.000	14.89
<i>fI</i> × <i>fI</i>	1	60.05	79.83	79.83	3.23	0.110	0.77
<i>vI</i> × <i>vI</i>	1	92.04	92.04	92.04	3.72	0.095	1.182
<i>fI</i> × <i>vI</i>	1	1369.00	1369.00	1369.00	55.34	0.000	17.58
Pure Error	4	147.20	147.20	36.80			
Total	12	7786.2					

R-Sq = 97.78 %, R-Sq (pred) = 94.67 %, R-Sq (adj) = 96.19 %.

$$\text{Percentage (\%) contribution} = \frac{\text{sum of squares of a factor}}{\text{total sum of squares factor}} \tag{1}$$

Table 3 Analysis of variance for cutting force (N) of Unhybrid nano MMCs for the coded values.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
<i>fI</i>	1	6638.4	6638.4	6638.45	256.91	0.000	49.14
<i>vI</i>	1	5930.9	5930.9	5930.88	229.53	0.000	43.91
<i>fI</i> × <i>fI</i>	1	242.0	321.7	321.67	12.45	0.110	1.791
<i>vI</i> × <i>vI</i>	1	370.7	370.7	370.71	12.45	0.095	1.744
<i>fI</i> × <i>vI</i>	1	144.0	144.0	144.00	5.57	0.050	1.067
Pure Error	4	113.2	113.2	28.30			
Total	12	13506.9					

R-Sq = 98.66 %, R-Sq (pred) = 95.13 %, R-Sq (adj) = 97.70.

Table 4 Analysis of variance for cutting force (N) of Hybrid nano MMCs for the coded values.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
<i>fI</i>	1	23.6296	23.6296	23.6296	265.62	0.000	77.46
<i>vI</i>	1	3.5496	3.5496	3.5496	39.90	0.000	11.63
<i>fI</i> × <i>fI</i>	1	0.8908	0.9881	0.9881	11.11	0.013	2.92
<i>vI</i> × <i>vI</i>	1	0.1996	0.1996	0.1996	2.24	0.178	0.65
<i>fI</i> × <i>vI</i>	1	1.6129	1.6129	1.6129	18.13	0.004	5.28
Pure Error	4	0.4610	0.4610	0.4610			2.04
Total	12	30.5051					

R-Sq = 97.96 %, R-Sq (pred) = 93.87 % and R-Sq (adj) = 96.50 %.

In turning process, the material undergoes very high plastic deformation and strains, thus the entire energy is transformed into heat. The rate of temperature generation is higher at higher cutting speed; at the cutting zone the high temperature generation makes material soft [26]. In between work piece and tool, the contact area enhances by increase in feed rate for Al2219 matrix as well as nano composites. The value of the cutting force is mainly affected by its turning conditions like feed rate, cutting speed *v*, and cutting depth of cut. The easiest way in turning to control cutting force is to change the cutting conditions.

By increasing the cutting speed in turning will some extent reduce the cutting force. The reduction in force depends on the condition, type of the material used for turning and the range of cutting speeds. More complex dependencies for the material in the low range of cutting speed have a tendency to form a (BUE) Built-Up Edge. For most materials to be turned, increasing the cutting speed will decrease the cutting force.

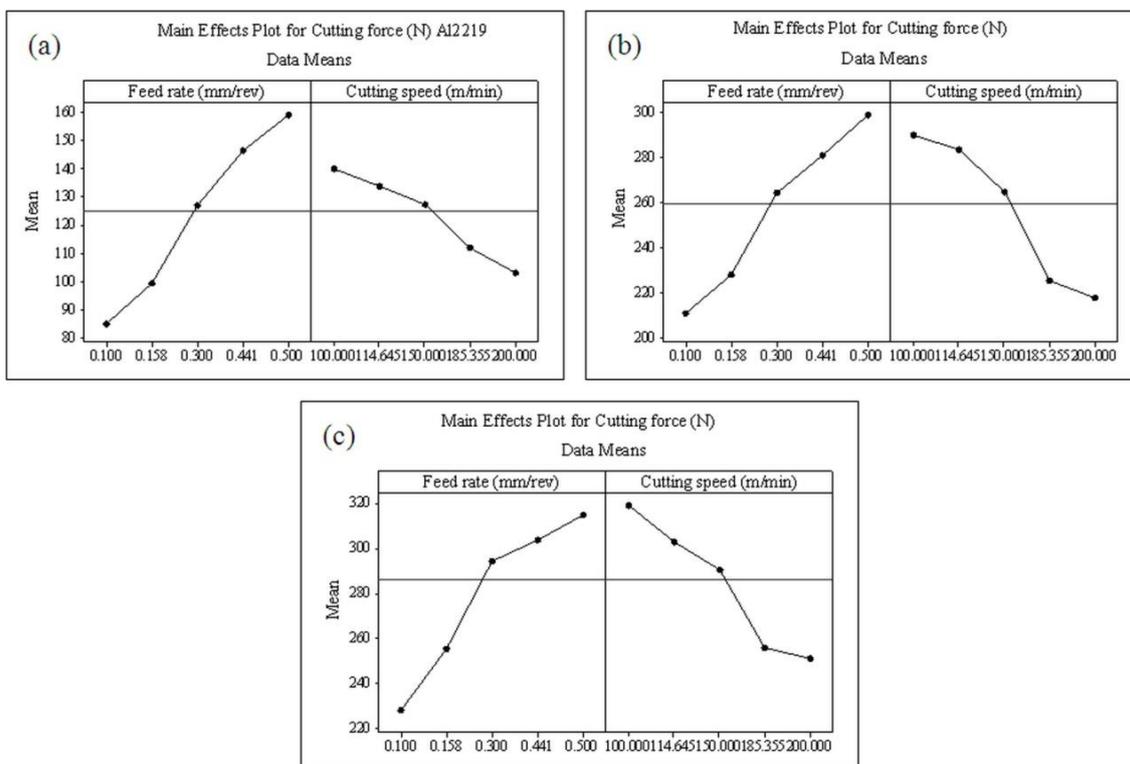


Figure 3 factors on cutting force in main effect plot of (a) Al2219, (b) Unhybrid and (c) Hybrid nano MMCs.

The cutting speeds as well as feed rate are the 2 factors consider for contour plots. **Figure 4** shows the contour plots of (a) Al2219, (b) Unhybrid and (c) Hybrid nano MMCs for cutting force. The contour plots assist to know the influence of factors on cutting force. For all the 3 composition the contour plots shape is almost similar. From plots it is noticed that the hybrid composite (Al2219+2% n-B₄C+2% MoS₂) has higher cutting force followed by Unhybrid and Al2219. The cutting force above the feed rate 0.4 mm/rev is huge for Unhybrid but for Hybrid nano MMCs is above at 0.3 mm/rev feed rate. Among Al2219 alloy and nano composites, the cutting force is less for Al2219, but there are no distinctions in contours seen for the chosen factors. However, by increases in cutting speed the cutting force decreases. It is evident from figures the hybrid composite contain MoS₂ is more pronounced than Unhybrid and Al2219. The reason for increase and decrease in cutting force is discussed in main effect plot of cutting force. By means of coded values the regression model is signified by Eqs. (2) - (4).

$$F_c(\text{Al2219}) = 129.400 + 24.83 * (f_1) - 12.04 (v_1) - 3.388 (f_1 * f_1) - 3.63 (v_1 * v_1) - 18.500 (f_1 * v_1) \tag{2}$$

$$F_c(\text{un hybrid}) = 268.600 + 28.806 (f_1) - 27.228 (v_1) - 6.800(f_1 * f_1) - (v_1 * v_1)7.300 - 6.00 (f_1 * v_1) \tag{3}$$

$$F_c(\text{hybrid}) = 298.000 + 27.380 (f_1) - 23.771 (v_1) - 12.938 (f_1 * f_1) - 6.187 (v_1 * v_1) - 1.000 (f_1 * v_1) \tag{4}$$

Where $v1$, Fc , and $f1$ represent the cutting speed, cutting force and feed rate correspondingly for the coded values.

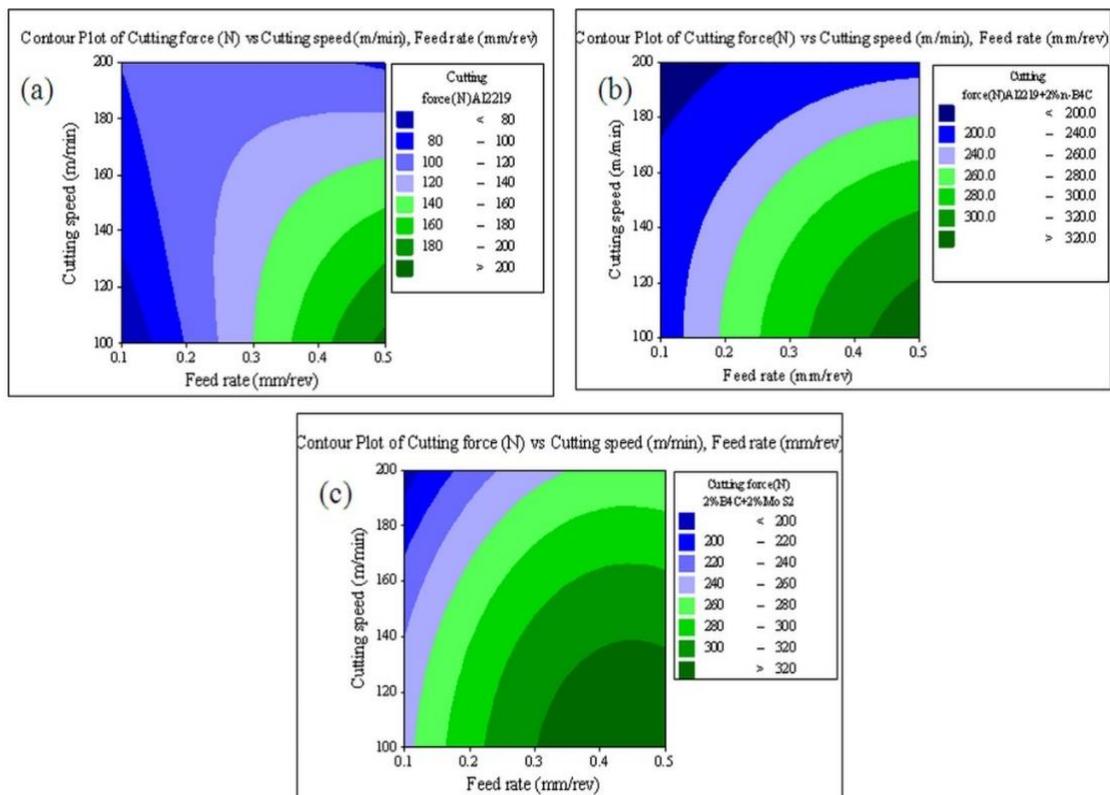


Figure 4 Contour plots on cutting force of (a) Al2219, (b) Unhybrid and (c) Hybrid nano MMCs.

Surface roughness

The significant factor influences on the surface roughness for Al2219 and nano composites were analyzed. ANOVA results of surface roughness for Al2219, Unhybrid and Hybrid nano MMCs are given in **Tables 5 - 7** respectively. From the Tables, the p -values < 0.05 are significant. The significant factor influences among the cutting speed and feed rate in interaction between cutting speed on surface roughness. The most significant factor for both Al2219 and nano composite is feed rate, in addition to this cutting speed subsequently influences on surface roughness.

Table 5 Analysis of variance for surface roughness (μm) of Al2219 for coded the values.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
$f1$	1	33.1407	33.1407	33.1407	345.79	0.000	75.79
$v1$	1	9.4723	9.4723	9.4723	98.83	0.000	21.66
$f1 \times f1$	1	0.1492	0.1270	0.1270	1.33	0.287	0.341
$v1 \times v1$	1	0.0416	0.0416	0.0416	0.43	0.531	0.095
$f1 \times v1$	1	0.2500	0.2500	0.2500	2.61	0.150	0.571
Pure Error	4	0.2649	0.2649	0.0662			1.53
Total	12	43.7248					0.313

R-Sq = 97.96 %, R-Sq (pred) = 93.87 % and R-Sq (adj) = 96.50 %.

Table 6 Analysis of variance for Surface roughness (μm) of nano MMCs for coded the values.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
<i>fI</i>	1	33.1407	33.1407	33.1407	345.79	0.000	75.79
<i>vI</i>	1	9.4723	9.4723	9.4723	98.83	0.000	21.66
<i>fI</i> \times <i>fI</i>	1	0.1492	0.1270	0.1270	1.33	0.287	0.341
<i>vI</i> \times <i>vI</i>	1	0.0416	0.0416	0.0416	0.43	0.531	0.095
<i>fI</i> \times <i>vI</i>	1	0.2500	0.2500	0.2500	2.61	0.150	0.571
Pure Error	4	0.2649	0.2649	0.0662			1.53
Total	12	43.7248					0.313

R-Sq = 96.83 %, R-Sq (pred) = 91.53 % and R-Sq (adj) = 94.56 %.

Table 7 Analysis of Variance for Surface roughness (μm) of Hybrid nano MMCs for coded the values.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
<i>fI</i>	1	32.1550	32.1550	32.1550	156.65	0.000	71.01
<i>vI</i>	1	9.7021	9.7021	9.7021	47.27	0.000	21.42
<i>fI</i> \times <i>fI</i>	1	1.5238	1.6456	1.6456	8.02	0.025	3.36
<i>vI</i> \times <i>vI</i>	1	0.2043	0.2043	0.2043	1.00	0.352	0.45
<i>fI</i> \times <i>vI</i>	1	0.2550	0.2550	0.2550	1.24	0.302	0.56
Pure Error	4	1.1501	1.1501	0.2875			3.17
Total	12	45.2771					0.03

R-Sq = 98.47 %, R-Sq (pred) = 92.45 % and R-Sq (adj) = 97.37 %.

The main effect plot indicates that, increase in cutting speed for Al2219 reduces the surface roughness (R_a) value, also similar results obtained for Unhybrid and Hybrid nano MMCs. From **Figures 5(a) - 5(c)** that the value of surface roughness is least for Al2219 matrix, but for Hybrid nano MMCs it is higher. The BUE formed on the tool at lower cutting speed in Unhybrid nano composite is due to high temperature, pressure and the strain hardening of 2 phases. Moreover, this can evidently see from FESEM image in **Figure 6(a)** at constant 0.5 mm depth of cut, lower cutting speed of 114.64 m/min and at feed rate 0.1 mm/rev. However similar kind of observation reported in previous work of Manna and Bhattacharayya [27] for lower cutting speed. During higher cutting speeds there is fast removal of material in short duration and hence lowers the tendency of advancement of Build-up edges (BUE), although from **Figure 6(b)** for higher cutting speed there is no formation of BUE on the tool surface and this can clearly see from the figure. Thus, from **Figure 5(b)** the surface roughness is been improved in Unhybrid at 0.5 mm constant depth cut, higher cutting speed of 200 m/min and at the feed rate 0.3 mm/rev.

While **Figure 5(c)** turning Hybrid nano MMCs, adding MoS_2 particles acts as solid lubricant and from work piece surface. The elimination and scattering of MoS_2 results in higher surface roughness. From **Figures 5(a) - 5(c)**, one can see increase in feed rate surface roughness increases. In higher feed rates the surface roughness is increases because of increased friction between cutting tool and work piece, while in cutting zone the temperature increases. On high temperature the material acts as ductile behavior because of decrease in shear strength [9]. The superior chips formed at higher feed rate will have a tendency to clog on the tool tip because of its high temperature. At higher feed rates these tend to increase in surface roughness. The cutting speed and the interactions between feed rates, cutting speed have less influence for all compositions on surface roughness.

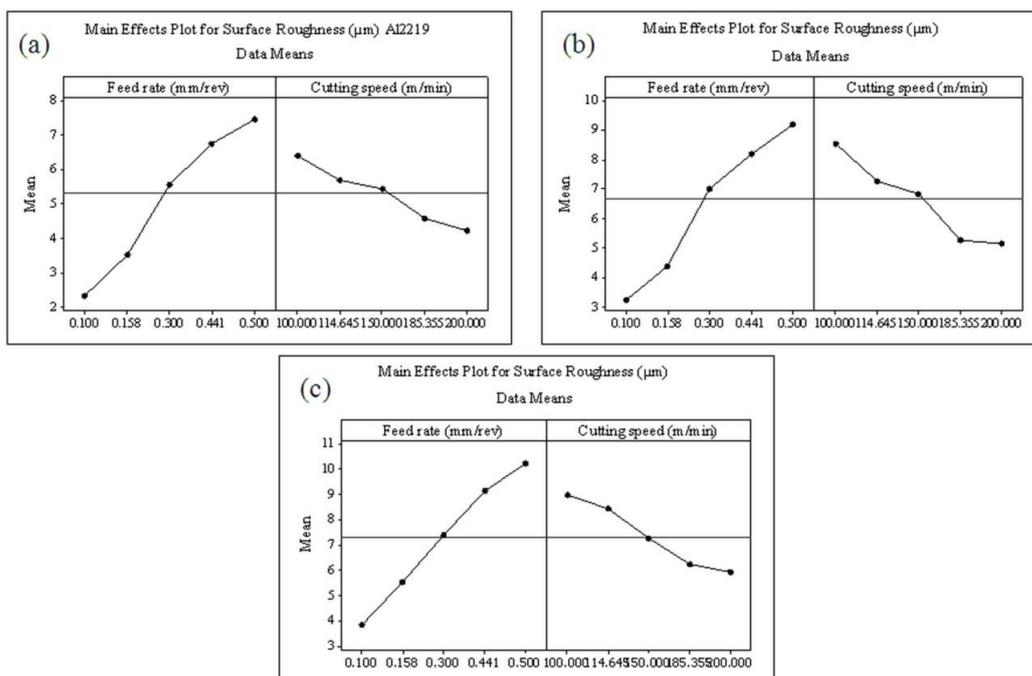


Figure 5 Effects of factors on surface roughness in main effect plot of (a) Unhybrid and (c) Hybrid nano MMCs.

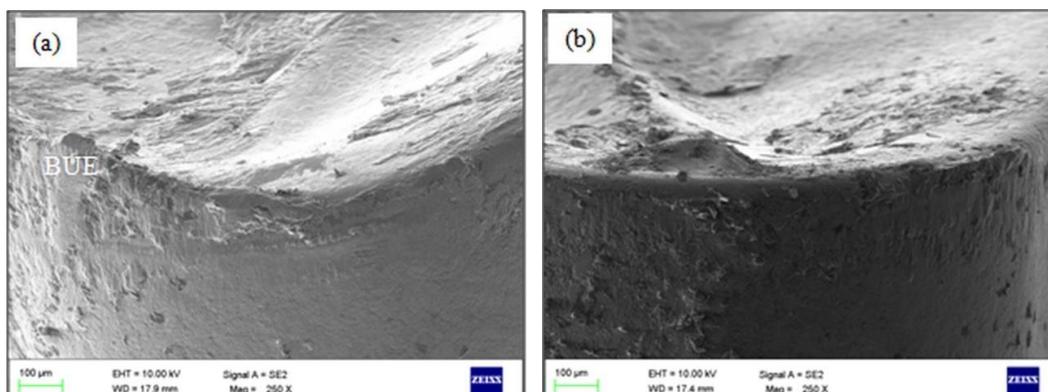


Figure 6 Built-Up Edge created at (a) lower cutting speed of 114.64 m/min, feed rate of 0.441 mm/rev and constant depth of cut of 0.5 mm and (b) higher cutting speed of 200 m/min, feed rate of 0.3 mm/rev and constant depth of cut of 0.5 mm for Unhybrid nano MMCs.

It is evident from surface topography using FESEM turned surface of Al2219, Unhybrid and Hybrid nano MMCs. Where there is no feed mark were observed in **Figures 7(a) - 7(c)** for all 3 compositions, at 0.5 mm constant depth of cut, higher cutting speed of 200 m/min cutting speed and at 0.3 mm/rev feed rate. Hence the cutting speed has no influence on turned Al2219 and prepared nano composite. As we come to know that from **Table 1** and from **Figure 5** surface roughness is low at the lower feed rate and surface roughness increases by increase in feed rate. Though the roughness values of Al2219 is lesser than that of Unhybrid and Hybrid nano MMCs. From the % contribution **Tables 5 - 7** for all the 3 composition the feed rate is higher influence than of cutting speed and their interactions. Thus, for examination of FESEM turned surface topography we have selected the higher feed rate (0.5 mm/rev) for better comparison with **Figure 7** (higher cutting speed 200 m/min). However, for Al2219 at 0.5 mm constant depth of cut, at higher cutting speed of 150 m/min and at 0.5 mm/rev higher feed rate.

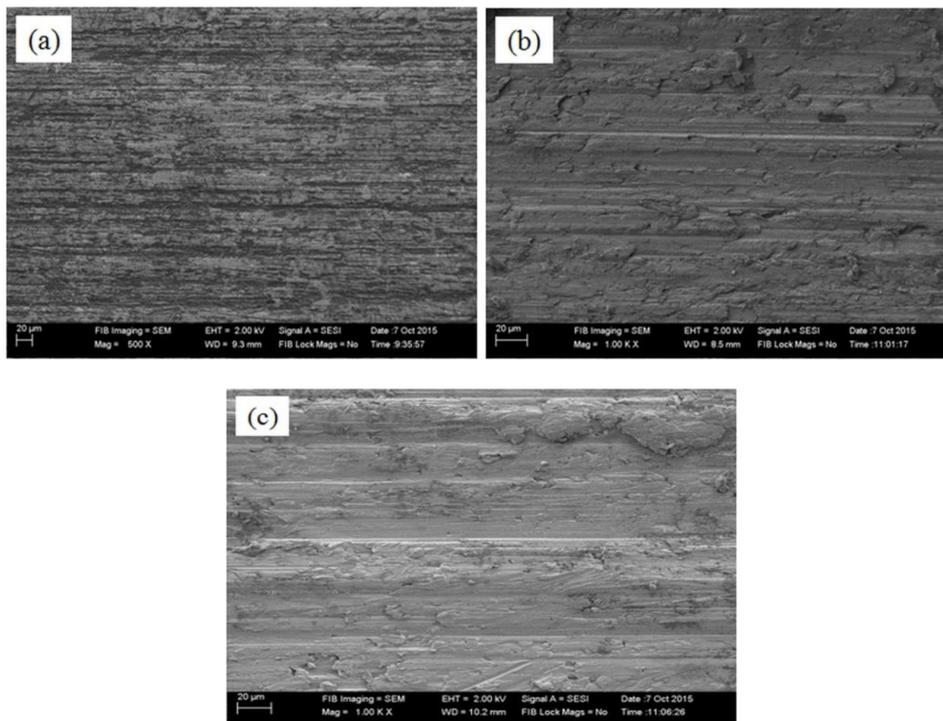


Figure 7 FESEM images of turned surface at cutting speed of 200 m/min, feed rate of 0.3 mm/rev and at constant depth of cut of 0.5 mm for (a) Al2219, (b) Unhybrid and (c) Hybrid nano MMCs.

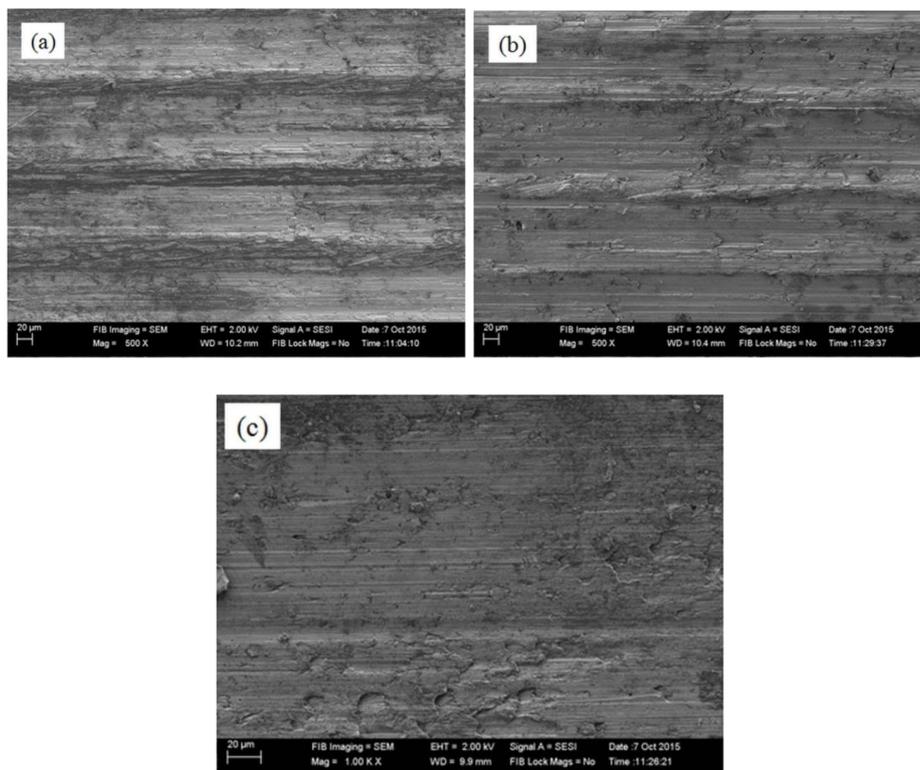


Figure 8 FESEM images of turned surface at cutting speed of 150 m/min, feed rate of 0.5 mm/rev and at constant depth of cut of 0.5 mm for (a) Al2219, (b) Unhybrid and (c) Hybrid nano MMCs.

Figure 8(a) clearly shows the feed marks and grooves formed on the surface. Since Al2219 is softer in nature, the deformation and micro cracks in the Al2219 alloy appears to be increases at the dislocation pile-up regions. Hence the surface roughness values of Al2219 are less as compared to Unhybrid and Hybrid nano MMCs. **Figure 8(b)** shows the surface topography of Unhybrid where the hard ceramic nano B₄C particles roll above the turned surface and form the abrasive grooves. Because of ploughing on the turned surface the grooves are formed. So, the surface roughness is more in Unhybrid as compared to Al2219. But for Hybrid nano MMCs from **Figure 8(c)**, the feed marks are clearly visible with abrasive grooves and solid lubricant MoS₂ particles are smeared and spread on the surface. This forms the scratch marks and crates, there by surface roughness increases as compared to Al2219 and Al2219+2%*n*-B₄C. In case of Al2219 alloy **Figure 8(a)** at higher feed rate, the feed mark and their ridges are formed because of materials side flow on the surface due to higher ductility. Where as in Unhybrid and Hybrid nano MMCs, this may not come in to existence because of its lower ductility. Moreover, the nano MMCs has a tendency of fracture, thus the prepared nano composites have higher surface roughness. Eqs. (5) - (7) are for regression model of coded values.

$$Ra (Al2219) = 5.660 + 1.7186 (f1) - 0.661(v1) - 0.3769 (f1 * f1) - 0.1694 (v1 * v1) - 0.2525 (f1 * v1) \quad (5)$$

$$Ra (un hybrid) = 7.0640 + 2.0048 (f1) - 1.1013 (v1) - 0.4864 (f1 * f1) - 0.1714 (v1 * v1) - 0.2525 (f1 * v1) \quad (6)$$

$$Ra (hybrid) = 7.3640 + 2.03534 (f1) - 1.08813 (v1) - 0.13513 (f1 * f1) + 0.07737 (v1 * v1) - 0.25000 (f1 * v1) \quad (7)$$

Where *Ra*, *v1* and *f1* represent the surface roughness, cutting speed and feed rate correspondingly for the coded values. The contour plots shape is exactly similar for Al2219, Unhybrid and Hybrid nano MMCs.

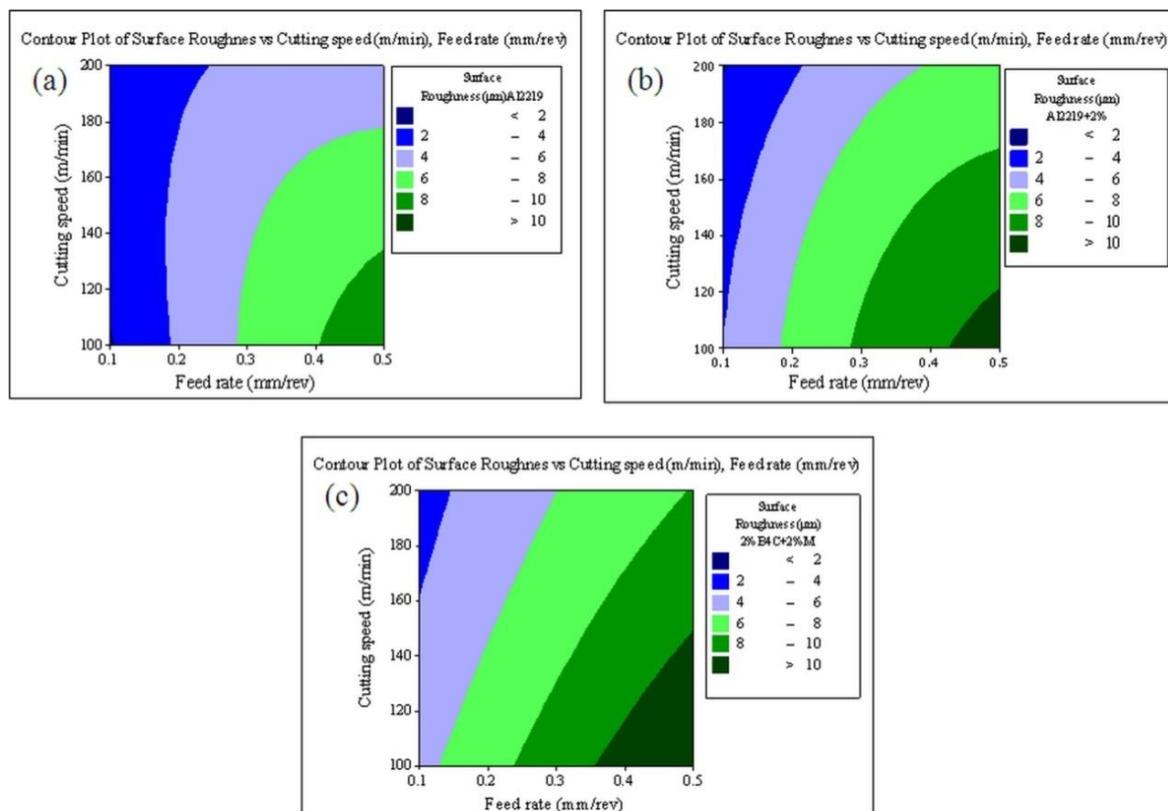


Figure 9 Contour plots on surface roughness of (a) Al2219, (b) Unhybrid and (c) Hybrid nano MMCs.

From plots the hybrid composite (Al2219+2%*n*-B₄C+2%MoS₂) has higher surface roughness next to Unhybrid and Al2219. The surface roughness above the feed rate 0.4 mm/rev is huge for Unhybrid but for Hybrid nano MMCs the feed rate above 0.3 mm/rev. Between the Al2219, Unhybrid and Hybrid nano MMCs, the surface roughness is less for Al2219, but there is no difference in contours can clearly see in **Figures 9(a) - 9(c)**. It is clear from figures the Hybrid nano MMCs contain MoS₂ is more pronounced than Unhybrid and Al2219. The cause for increase and decrease in surface roughness is discussed in main effect plot of surface roughness.

Confirmation test

The model was assessed through turning operation on Al2219, Unhybrid and Hybrid nano MMCs at various coded values of factors like feed rate (*fI*), cutting speed (*vI*). As the response equation for the model is gotten from quadratic regression fit, so to affirm their legitimacy affirmation test was done. The confirmation tests should exist within the range for the derived equations by choosing the independent variables. The 3 confirmation investigations were carried out for surface roughness and cutting force on the state of route parameter (independent) give through quadratic model. Confirmation test was carried for 3 replicates for the similar testing condition and average of those was taken for probable surface roughness and cutting force values. Confirmation test parameters are given in **Table 8**. The calculated error is less than 5 % for all the 3 compositions is as shown in **Table 9**. The error values among the experimental and regression model values are little which affirms the experimental conclusion. Therefore, it is showed that the analytical power of the regression equation is adequate with a reasonable accuracy within the experimental domain.

Table 8 Confirmation test parameters for cutting force and surface roughness in actual and coded value.

Exp.no	Feed rate- <i>f</i> (mm/rev)	Cutting speed- <i>v</i> (m/min)	Feed rate- <i>fI</i> (mm/rev)	Cutting speed- <i>vI</i> (m/min)	Composition
1	0.3	114.64	0	-1	Al2219
2	0.441	150	1	0	Al2219+2% <i>n</i> -B ₄ C
3	0.158	200	-1	1.4121	Al2219+2% <i>n</i> -B ₄ C+2%MoS ₂

Table 9 Confirmation test results of cutting force, surface roughness along with their assessment by regression model for coded values.

Sl. No.	Cutting Force in N					Surface Roughness (Ra) in microns				
	Rep.1	Rep.2	Avg.	Reg. Model	% of Error	Rep.1	Rep.2	Avg.	Reg. Model	% of Error
1	148	122	135	137	1.45	4.85	4.15	4.475	4.3	4.06
2	326	304	315	290	8.62	8.21	8.28	8.25	8.58	3.84
3	248	273	260	245	6.12	4.56	4.31	4.43	4.11	7.78

Conclusions

Aluminium metal matrix nano and nano hybrid composites reinforced (*n*-B₄C and *n*-B₄C/MoS₂) was developed using stir casting technique successfully. The investigation was done to evaluate the effect of cutting speed and feed rate (parameters) on turning characteristics like surface roughness and cutting force using CCD design of experiment. The subsequent conclusions from the experimental results and analysis are drawn:

1) The Al2219, Unhybrid and Hybrid nano MMCs were developed using stir casting technique successfully. The addition of 0.4 % of K₂TiF₆/B₄C ratio for both compositions in to melt improves the

wettability of composites. The distributions of particles ($n\text{-B}_4\text{C}$ and $n\text{-B}_4\text{C}/\text{MoS}_2$) in Al2219 matrix are uniform and excellent bonding between Al matrix and a nano particle right through the matrix.

2) Feed rate is the major influencing factor and the cutting speed had little influence on surface roughness, cutting force and tool wear in turning Al2219 and Unhybrid and Hybrid nano MMCs. The addition of ($n\text{-B}_4\text{C}$ and $n\text{-B}_4\text{C}/\text{MoS}_2$) particles increases the surface roughness and cutting force in nano composites.

3) The development of BUE (Built up Edge) created at 114.64 m/min lower cutting speed and at 0.441 mm/rev feed rate of in turning Unhybrid nano MMCs, further the cutting speed enhances to 200 m/min at 0.3 mm/rev feed rate there is no formation of BUE on the flank face of cutting insert.

4) The modeled values and obtained measured values are genuinely near to each other, which demonstrates that created model can be successfully make use to predict the surface roughness, cutting force and tool wear on turning Al2219, Unhybrid and Hybrid nano MMCs with 95 % certainty interims inside the scopes of parameters considered.

5) The predicted modeled and obtained experimental values are acceptably near to each other with % error is under 5 %, then the model is adequate.

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