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Analyze the Effect of Crater Cutting Tool Wear Modeling in the Machining of Aluminium Composite

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The present investigation is used to analyze the effect of crater wear modeling in the machining of aluminium composite. Response surface methodology (RSM) is one of the best optimization technique used to bring out the optimal values of speed, feed and depth of cut for attain minimum surface roughness, cutting tool temperature and tool wear. AA7075 alloy with 15wt% of silicon carbide has been investigated in the dry machining condition. The double layered TiCN/Al_2O_3 coated tool was preferred. The worn surface analysis in coated tool was concentrated. The outcomes of the machining conditions were expected to improve surface finish. Novel approach of this investigation is to analyze the surface morphology to visualize the surface peak and valley profile of the coated tool and analyzed with various surface parameters that decide the surface roughness of the profile.

Keywords: *Aluminum, tool wear, cutting tool temperature, coating, surface morphology, surface roughness.*

1. Introduction

Owing to better mechanical and physical properties, metal matrix composites are extensively used in many industries. Many researchers focused on the material reinforced with boron, silicon carbide, titanium carbide, alumina for their research studies. Silicon carbide based aluminium alloy has outstanding material properties and quality characteristics. It's also providing the high thermal conductivity and coefficient of thermal expansion. It is used in aerospace, automotive, electronics and thermal applications. Microstructure, wear and corrosion resistance was enhanced due to the addition of SiC particles to the aluminium alloy[1,2].Interfacial bonding strength between the layers was mainly depends on the wt% of reinforcement[3]. Silicon carbide (SiC) reinforced with aluminum attracts most of the researchers for their research work, due to their superior quality of refractoriness and abrasion resistance property. Sahoo et al.[4] examined the tool wear behavior of coated tool and uncoated tool while machining of AA7075 alloy. It is well known that the coated tool experiences very less tool wear compared with uncoated tool. Chip morphology was investigated under different conditions and the performance of uncoated insert and cutting profile was also analyzed. Bhushan[5] presented the microscopic behavior of SiC reinforced with AA7075. AA7075 with 5% SiC to 15% SiC composites were employed in varying four different size of 0%, 5%, 10% and 15% SiC particles were used to make the composites. SiC reinforced with aluminum having more hardness of 272 MPa compared with other composites. Results revealed that maximum improvement of 9.67% in tensile strength compared with other composites. Bhushan[6] has conducted the experimental investigation on AA 7075 alloy with 10 wt % SiC to get optimized values of cutting force during machining process. In this method, comparative analysis was made in between desirability approach to genetic algorithm and the results showed that the percentage deviation was found more in cutting speed in calculating tangential force. It was observed that the 12% varies in genetic algorithm compared with desirability approach in feed force. In machining cutting force generated in AA7075 with 15 wt% SiC composite is more than AA7075 with 10 wt% SiC composites.

Wear is a process of interface between surfaces, which causes the deformation and removal of metal on the surfaces due to the effect of applied load. Wear was mainly depends on the plastic deformation which it causes the deterioration of metal surfaces. The wear behavior of the aluminium composite was enhanced by the accumulation of different size of the silicon carbide particles[7]. Tool wear, chip formation and tool tip temperature was analyzed in steel under different cutting speed and feed[8]. Tool wear study was deeply investigated and reported by Szczotkarz et al.[9] and Usca et al.[10] Increase in sintering input constrains automatically increases the density as well as hardness value reported. Tool wear studies were deeply examined and reported by Suresh et al.[11], Kumar and Sehrawat[12], and Musavi et al.[13]. The performance of cutting tool on wear formation and surface roughness was investigated in steel and aluminium composite [14,15]. Low wear rate was achieved in titanium carbide coated based alloy steel. Tribological behavior was improved by coating layers[16]. Uddin et al.[17] performed three different types of tool such as TiN, TiAlN, PCD coated tools are used to study wear analysis

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of the cutting tool material. The developed model was used to predict the response variables such as cutting forces, surface roughness and tool wear in machining of steel using TiN coated cutting tool[18]. Titanium based multilayered and carbide coatings were used to provide better wear resistance[19]. Agari [20] discussed about the behavior of Inconel 718 steel turning with tungsten carbide tool. Two layered coated material of $TiCN/Al_2O_3$ was preferred. The results depicted that maximum chip tool contact length was detected at the cutting speed of 95 m/min. Consequently surface roughness is also seems more at the same speed. Kumar et al.[21] deliberated the effect of TiAlCrN coating on WC-CO cutting tool in the machining of AISI 1045 steel. Coated tools were effectively performed to decrease the machining forces compared with uncoated tool cutting speed act as a dominant factor in tool tip temperature. The research was more beneficial to study about the chip behavior. nano layered

Surface roughness is defined as the indiscretions which are inherent in the fabrication process. The profilometer or laser scanner is used to measure the surface roughness. The friction and wear of the metal is mainly depends on the surface texture. Different factors were used to measure the surface roughness. Average surface roughness was measured from peak and valleys of the metal surface. The surface roughness was investigated under different input constrains in SiC reinforced aluminum composite[22]. Francis Xavier et al.[23] conducted turning experiments on Nimonic C263 by using Cubic boron nitride (CBN) insert. Parametric optimization technique was efficiently applied to evaluate the surface roughness and wear parameters. The surface profile of the work piece was affected by higher feed rate. It was interested to record that Scanning electron microscope (SEM) analysis confirms the lengthy grooves and feed marks. Bhushan[24] concluded that the surface roughness in machined part is drastically increased within an increase in of flank wear in carbide insert tool. Crater wear is found utmost in the cutting speed of 90 m/min. Abrasion is the most dominant wear due to interface in between tool and work piece at high speed.

Statistical methods are the mathematical models and techniques which are used to evaluate the quality characteristics of the processes. The optimal solution and its effect is mainly depends on the statistical analysis. Response surface methodology investigates the interaction between several descriptive variables and response variables. The optimal factor and their effect was attained in turning process of aluminium composite using RSM[25]. Quadratic model and optimization was used to evaluate the cutting forces in turning of SiC based Al composite[26]. Gupta and Singh[27] attempted to study about the machining behavior of Al6061-T6 using carbide insert by different ways. Signal acquisition process was effectively done with microphone equipped with lathe. Local mode decomposition technique was used to analyze the vibration signal during machining. Novel approach of investigation was carried out in this study, multi objective genetic algorithm and artificial neural network was effectively implemented. At last it was concluded that the surface finish was seems to be better in between the speed range of 1400-1490 revolutions per minute (rpm) and feed rate of 37-37.35 mm/min. Design of experiments (DOE) of L27 orthogonal array was developed in this study to minimize the number of experiments. Novelty approach of nano indentation and scratch test were conducted in proper manner to the cutting tool, results show that Polycrystalline Diamond (PCD) based tools has higher hardness compared to other tools. Gopal[28] uses the RSM model to predict temperature rise in the machining of AA6061 using coated tool material of Al_2O_3 bonded with carbide tool. Mane and Kumar[29] attempted a novel technique which was applied in cutting fluid application in the machining of AISI 52100 grade steel. RSM approach model was mathematically applied to achieve optimum value of surface roughness. Desirability approach model was designed and the value shows that confirms with the optimal values of velocity 139.937 m/min, feed of 0.081 mm/rev and depth of cut 0.192mm in minimizing the surface roughness. More concentration was given for Ramp function graph which shows the optimal values. Karim et al.[30] summaries the result of surface roughness and the tool temperature of Al-Mg-Zr alloy in the minimum quantity lubrication method by using PCD tool. Desirability function analysis approach was very essential to found the optimal values. This research mainly focuses on the sustainability approach of machining. From the results, it is very understandable to know that the values of experimental method are very nearer to the predicted model. Laghari et al.[31] analyses the cutting force by involving second order model incorporate with response surface methodology. Bhushan[32] presented a deep investigation on AA7075 with 15 wt% of SiC composite aims to find out the optimized parameters among the response variables. Desirability approach was suited in this method and it was used for multi response optimization. Results showed that the optimum speed was found to be 95.39 m/min, feed of 0.16 mm/rev and depth of cut of 0.4mm to diminish flank wear. Response surface methodology was preferred by Bhushan[33] to optimize the surface roughness and tool life in the machining of AA7075 contains up to 10 wt% of silicon. Cutting speed of 209 m/min, feed of 0.18 mm/rev and depth of cut of 0.20 mm was chosen from this investigation to minimize the surface roughness value. Desirability value 0.776 was attained from this combined optimization.

The environmental pollution of the cutting fluid and total machining cost was reduced by dry machining process. Kharka et al.[26] was concluded that dry machining improves the working environment of the operator, product quality, durability and reliability of the tool. Javidikia et al.[34] conducted experiments on AA6061-T6 alloy in three different categories such as dry, wet, and minimum quantity lubrication (MQL) method. In all machining conditions lowest feed rate significantly decrease the value of surface roughness. Syafiq et al.[35] examines the SiO_2 mixed fluid in the machining of Al319 aluminum alloy. Eco friendly technique like MQL method was adopted in this research. Karim et al.[36] presented the research work based upon the prediction of responses in SiC reinforced aluminum alloy. Taguchi method was employed to calculate the optimal values. Aljinović et al.[37] tested the machining factors and it was interesting to note that cutting plan of experiment was clearly noted and executed to evaluate the response parameters. Feed rate plays a most important role to judge the surface roughness. Srivastava et al.[38] attempted to make an effort to evaluate the output constraints in the machining of $A359/B_4C/Al_2O_3$. The results reported that the roughness values lies between 1.15 µm to 2.58 µm. Dennison and Umar[39] examines the machinability study on steel using green cutting fluid. In this study palm oil and peanut oil was used as the metal cutting fluid and found that maximum cutting tool temperature was observed in machining with palm oil, subsequently surface roughness was calculated and it was marginally lesser values compared with other cutting fluid.

The objective of the work is to improve the machining performance and surface roughness with less tool wear. The current investigation, dry machining process was involved to investigate the effect of cutting speed, feed and depth of cut of the doubled layered coated tool towards to reduce the tool tip temperature, wear and surface roughness for the aluminium reinforced with 15 wt% of silicon carbide. Response surface methodology was used to predict the optimal input constrains. Worn surface of the cutting tool was characterized by Atomic force microscopy (AFM). Crater cutting tool wear modeling was also analyzed in the machining process.

2. Materials and Methods

AA7075 with 15 wt% SiC composites were prepared by using stir casting process. Samples used in this investigation with a dimension of 120 mm x 30 mm diameter solid rod. Cutting tool tip temperature has been recorded with the help of infrared thermometer equipped with all geared lathe. Single laser infrared thermometer with an accuracy of ± 2% was used. Temperature range was specified in between -20°C to 2200°C with an optical resolution of 50:1. The temperature was taken at 3 points around the workpiece and the average value was considered. A total set of 20 experiments were conducted by using Response surface methodology in order to get the accurate results of the output response parameters. 20 experiments were arranged with 6 central points, 8 factorial points, and 6 axial points. Twenty cutting tools were involved in the experimental work. The machining environment condition was set as dry machining. At the end each machining tool wear was deliberated by via tool maker's microscope and deep investigation was carried out by scanning electron microscope image (SEM).

2.1. Microscopic analysis

Figure 1 represents the clear SEM image of AA7075 alloy with 15% SiC (20-40µm), and in the image it was noticeable SiC particles are evenly dispersal among the specimen. Most of the places the dot spots noted that the SiC particles and evenly spread over the place. The stir casted SiC based AA 7075 was machined by lathe. Worn surface characterization of the cutting tool was analyzed by AFM.

Figure 2 shows the EDX profile for the AA7075 with 15% SiC content along with the elements of Al, Si, C, Cu, Mg, Zn, and O. Most dominant elements are aluminium, silicon, carbon and the other elements evenly distributed. AA7075 with 15 wt% of silicon particle size limited with (20-40 µm) was mixed and fabricated by using stir casting process, recommended by the researcher[33] from his research studies. AA7075 with 15 wt% SiC composites were produced

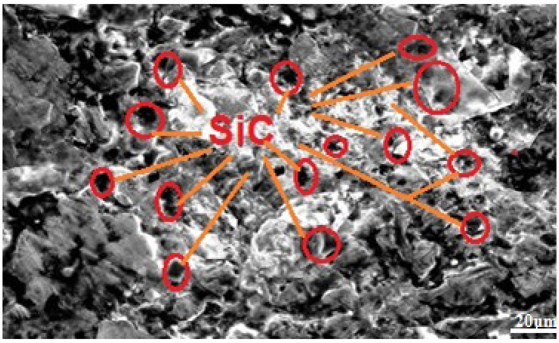

Figure 1. Microstructureof AA7075 with 15 wt % SiC.

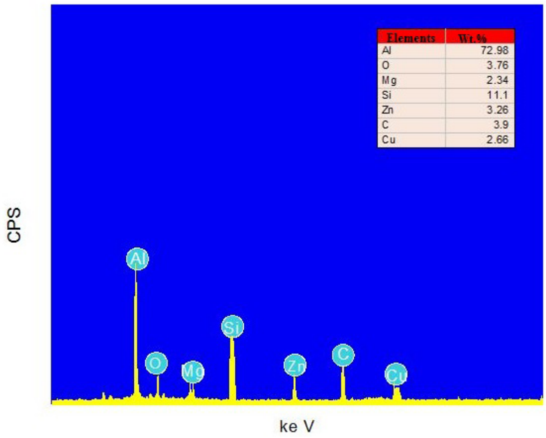

Figure 2. Energy dispersive X-Ray (EDX) profile of AA7075 with 15 wt % SiC.

with the dimension of 100 mm length and 30mm diameter referred[6]. Commercial composition of AA7075 alloy was tabulated in Table 1.

2.2. Experimentation work

Based upon the literature review cutting parameters and their levels were selected. The values of cutting parameters are exhibited in Table 2. Referred from the research study[20], the cutting tool insert was selected for this investigation, and it was presented in Table 3. Tungsten carbide as a tool material and it is coated with two layers, which consists TiCN as a first layer and Al_2O_3 as a second layer. Al_2O_3 has preferred as the second layer to minimize the high temperature developed in between cutting tool and work piece and TiCN as a top layer to endure more cutting forces and to lessen the tool wear[40]. Dry machining method was preferred to enhance clean and healthy operating conditions, at the same time elimination of coolant reduces human hazard problems.

The experimental setup on turning of AA7075 with 15 wt% SiC was shown in Figure 3. Tool wear was measured experimentally by optical microscope and in statistical analysis it was predicted by RSM with quadratic model. For each specimen, surface roughness was measured at 3 distinct points of the circumference and its average value was considered. It was measured by surface roughness tester with measuring

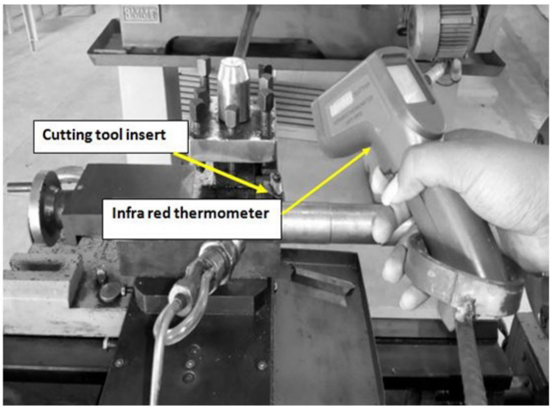

Figure 3. Experimental setup.

Table 1. Elemental composition of AA7075.

Alloy	Zn	Mg	Cu	Cr	Si	Fe	Al
7075	5.62	2.52	1.63	0.22	0.06	0.18	89.77

Table 2. Cutting parameters.

Input variables	Level 1	Level 2	Level 3
Speed (m/min)	100	150	200
Feed (mm/rev)	0.15	0.20	0.25
Depth of cut (mm)	0.20	0.40	0.60

Table 3. Cutting tool insert specification.

Corner radius	0.8 mm
Clearance angle in Degree	0^0
Rake angle in Degree	6^0
Cutting edge length	13 mm
Position angle (Kr)	45^0

range of 0.05-15 µm, tracing length of 6mm and its speed of 1mm/sec.ISO 3685: 1993 experimental standards were used to evaluate the response variables.

3. Response Surface Methodology (RSM)

Design of experiments based RSM was achieved by using design expert version11. It was successfully utilized for quadratic interaction. Second order quadratic model was formed to predict the response parameters. Main objective of involving RSM technique was used to minimize the response variables. Central composite design type was preferred in RSM to create quadratic model for this optimization. Experiment was designed by using response surface methodology and it was tabulated in Table 4. Predicted RSM values of the response variables are listed in Table 5.

4. Results and Discussion

Analysis of Variance (ANOVA) was performed to investigate the relationship between input variables to the response variables in statistical method. It was also given importance to test the Importance and fitness of the model developed. The level of confidence was found to be 95%. Table 5 and 6, shown that cutting speed was the dominant factor on tool tip temperature and tool wear. From Table 7, depth of cut was the powerful factor on surface roughness.

4.1. Effect of cutting speed, feed and depth of cut in tool tip temperature

Figure 4a, 4b and 4c clearly shows the effect of cutting speed, feed and depth of cut in affecting tool tip temperature. It was undoubtedly that the tool tip temperature was seems high at maximum cutting speed and low in minimum speed

Table 4. Experimental outcome and optimized results.

Experiment runs	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)	Tool tip temperature (°C)		Tool wear in millimeters (mm)		surface roughness in microns (µm)	
				Exp	RSM	Exp	RSM	Exp	RSM
1	200	0.15	0.6	84.5	88	0.075	0.079	2.01	2.14
2	100	0.15	0.6	74.9	78	0.048	0.051	2.48	2.64
3	150	0.20	0.4	75.9	79.1	0.053	0.056	2.02	2.15
4	150	0.20	0.4	76.4	79.6	0.054	0.057	2.03	2.16
5	200	0.15	0.2	78.0	81.2	0.063	0.066	1.21	1.29
6	100	0.25	0.2	68.4	71.2	0.036	0.038	2.02	2.15
7	200	0.25	0.2	78.0	81.3	0.057	0.06	1.55	1.65
8	150	0.15	0.4	75.7	78.9	0.055	0.058	1.87	1.99
9	150	0.20	0.4	74.1	77.2	0.046	0.048	1.99	2.12
10	150	0.20	0.4	76.8	80.0	0.053	0.056	2.32	2.17
11	150	0.25	0.4	76.1	79.3	0.050	0.053	2.47	2.31
12	150	0.20	0.2	72.7	75.7	0.047	0.049	1.83	1.71
13	100	0.25	0.6	78.7	82.0	0.044	0.046	3.18	2.97
14	100	0.15	0.2	71.1	70.5	0.039	0.038	1.80	1.78
15	200	0.20	0.4	85.1	84.3	0.070	0.069	2.02	2.00
16	150	0.20	0.6	83.1	82.4	0.063	0.062	2.59	2.56
17	150	0.20	0.4	79.8	79.1	0.058	0.057	2.18	2.16
18	200	0.25	0.6	89.8	89.0	0.082	0.08	2.64	2.61
19	100	0.20	0.4	78.7	78.0	0.046	0.045	2.41	2.39
20	150	0.20	0.4	80.7	80.0	0.057	0.056	2.19	2.17

Table 5. ANOVA for prediction of tool tip temperature.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	368.75	9	40.97	34.80	< 0.0001	significant
A-Cutting speed	194.48	1	194.48	165.17	< 0.0001	51%
B-Feed	3.84	1	3.84	3.26	0.1009	1%
C-Depth of cut	156.03	1	156.03	132.51	< 0.0001	41%
AB	1.62	1	1.62	1.38	0.2680	
AC	1.81	1	1.81	1.53	0.2439	
BC	2.21	1	2.21	1.87	0.2011	
A^2	7.82	1	7.82	6.64	0.0275	
B^2	0.36	1	0.36	0.30	0.5906	
C^2	0.47	1	0.47	0.39	0.5415	
Residual	11.77	10	1.18			
Lack of Fit	6.32	5	1.26	1.16	0.4376	not significant
Pure Error	5.45	5	1.09			
Cor Total	380.53	19		R^2= 96.9	Adj R^2 =94.12	Predicted R^2=82.68%

Table 6. ANOVA for prediction of tool wear.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.2360	9	0.0262	30.06	< 0.0001	significant
A-Cutting speed	0.1850	1	0.1850	212.00	< 0.0001	75%
B-Feed	0.0023	1	0.0023	2.58	0.1394	1%
C-Depth of cut	0.0449	1	0.0449	51.45	< 0.0001	18%
AB	0.0000	1	0.0000	0.0000	1.0000	
AC	0.0018	1	0.0018	2.0600	0.1814	
BC	0.0001	1	0.0001	0.0573	0.8156	
A^2	0.0008	1	0.0008	0.9404	0.3550	
B^2	0.0000	1	0.0000	0.0163	0.9010	
C^2	0.0000	1	0.0000	0.0163	0.9010	
Residual	0.0087	10	0.0009			
Lack of Fit	0.0027	5	0.0005	0.4541	0.7967	not significant
Pure Error	0.0060	5	0.0012			
Cor Total	0.2447	19		R^2= 96.4	Adj R^2 =93.3	Predicted R^2=76.75%

Table 7. ANOVA for prediction of surface roughness.

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	2.74	9	0.3040	355.80	< 0.0001	significant
A-Cutting speed	0.5018	1	0.5018	587.18	< 0.0001	18.3%
B-Feed	0.3422	1	0.3422	400.52	< 0.0001	12%
C-Depth of cut	1.88	1	1.88	2204.22	< 0.0001	69%
AB	0.0021	1	0.0021	2.47	0.1470	
AC	0.0021	1	0.0021	2.47	0.1470	
BC	0.0006	1	0.0006	0.71	0.4170	
A^2	0.0032	1	0.0032	3.74	0.0819	
B^2	0.0003	1	0.0003	0.38	0.5498	
C^2	0.0018	1	0.0018	2.16	0.1724	
Residual	0.0085	10	0.0009			
Lack of Fit	0.0068	5	0.0014	3.88	0.0814	not significant
Pure Error	0.0017	5	0.0003			
Cor Total	2.74	19		R^2= 98.41	Adj R^2 =96.41	Predicted R^2=96.4%

and depth of cut of 0.2 mm. Minimum tool tip temperature was initiated and it was observed from the Figure 4b. Severely change in tool tip temperature related to cutting speed exhibited in Figure 4a and 4b. But in Figure 4c

3D surface plat appears flat shape, consequently there is marginally increase in temperature at the maximum depth of cut. Due to plastic deformation more wear created in between tool and work piece evidenced strengthening in temperature cited in Manimaran et al.[41]. Cutting speed and depth of cut contributes more in the prediction of cutting tool tip temperature exhibited in ANOVA Table 5.

4.2. Effect of cutting speed, feed and depth of cut in tool wear

Figure 5a, 5b and 5c illustrates the effect of cutting speed, feed and depth of cut in tool wear. From the Figure 5a tool wear provokes at the minimum speed and depth of cut and attains utmost at maximum speed and depth of cut. Cutting

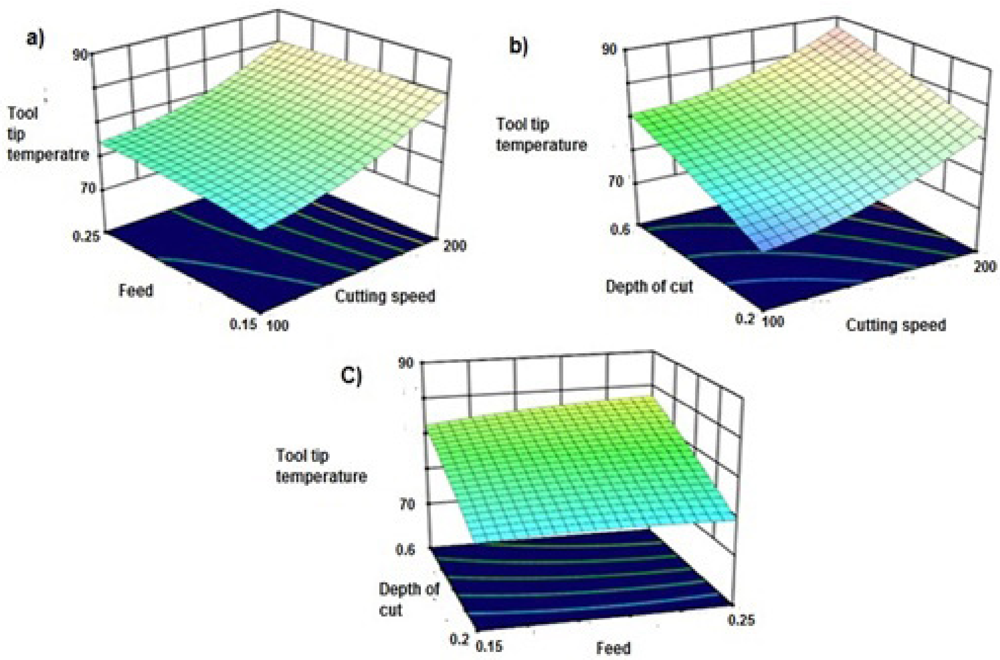

Figure 4. Effect of tool tip temperature with a) cutting speed and feed b) cutting speed and depth of cut c) feed and depth of cut.

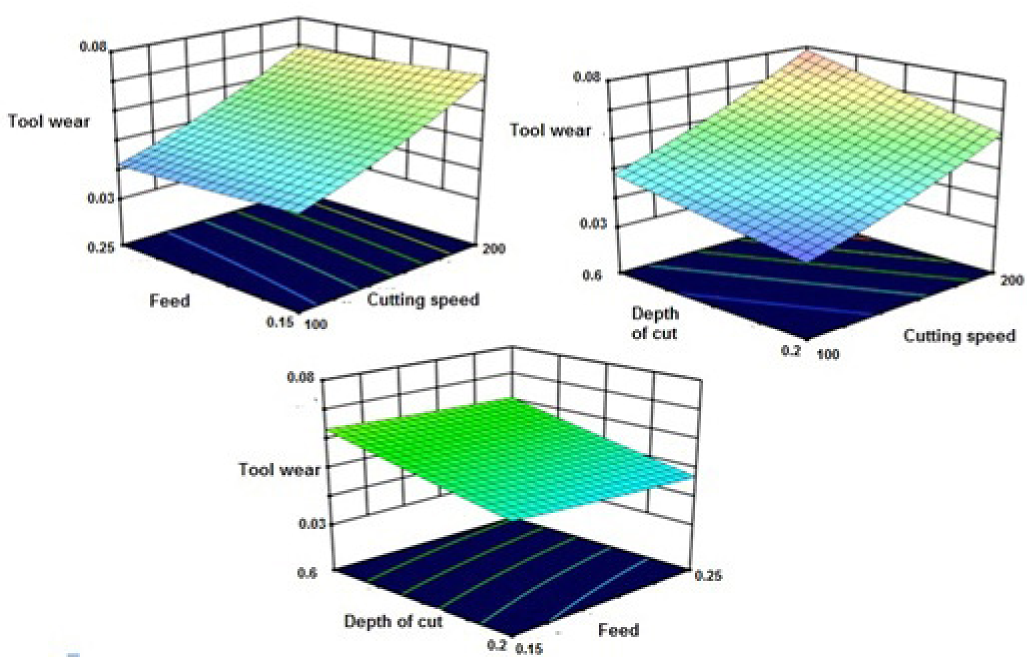

Figure 5. Effect of tool wear with a) cutting speed and feed b) cutting speed and depth of cut c) feed and depth of cut.

speed contribution is more and clearly observed from the ANOVA Table 6. Due to high thermodynamic load on the insert ensuing to increase wear. Subsequently crater wear slightly developed and gradually increased, because of increase in feed and cutting speed[32].

4.3. Effect of cutting speed, feed and depth of cut in surface roughness

Figure 6a, 6b and 6c clearly show the effect of cutting speed, feed and depth of cut in the prediction of surface roughness of the work piece. It was evidently noted from the Figure 6a, there is no reasonable impact from the cutting speed and feed in surface roughness. Depth of cut is the foremost factor affect surface roughness. The surface roughness has been increased due to chattering effect on the work piece. It was found at maximum depth of cut condition[42]. From the Table 4, it was interested to know that the minimum feed rate and depth of cut improves the surface finish.

4.4. Desirability approach

Desirability approach was carried out by using response surface methodology. It was most important to optimize the response variable for the objective function. In this investigation, desirability approach was more versatile to find out the best optimal values. Table 8 shows the response variable with constraints. Multi set of optimal solutions was generated in the desirability approach. The major objective is to minimize the output variables. There are 62 optimal solutions were generated. From the 62 optimal solutions, best of 5 optimal solutions were selected and it was tabulated in Table 9. Average surface roughness was considered as the roughness parameter.

Generally desirability value lies in between 0 and 1. Desirability value of '0' indicates the function in unacceptable and '1' indicates the response variable exactly with the target value[32]. From Table 8 importance value 3 indicates

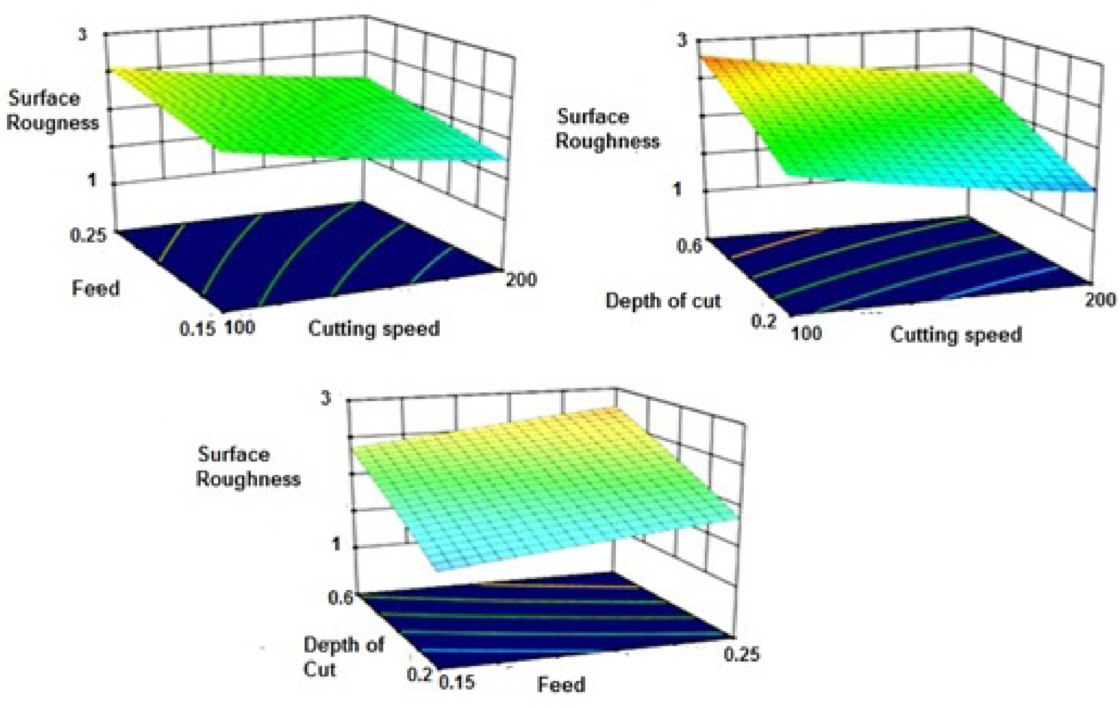

Figure 6. a) Effect of surface roughness with a) cutting speed and feed b) cutting speed and depth of cut c) feed and depth of cut.

Table 8. Constraints and response variables of multi objective optimization.

Response	Constraint	Lower bound	Upper bound	Lower weight	Upper weight	Importance
Cutting speed	In range	100	200	1	1	3
Feed	In range	0.15	0.25	1	1	3
Depth of cut	In range	0.20	0.60	1	1	3
Tool tip temperature	Minimize	70.50	89.0	1	1	3
Tool wear	Minimize	0.03	0.08	1	1	3
Surface roughness	Minimize	1.29	2.97	1	1	3

Table 9. Multi set of optimal solutions.

Number	Cutting speed(m/min)	Feed (mm/rev)	Depth of cut(mm)	Tool tip temperature Deg c	Tool wear (mm)	surface roughness microns	Desirability	
1	100.000	0.150	0.200	70.815	0.0402	1.801	0.865	Selected
2	100.399	0.150	0.200	70.830	0.0403	1.798	0.865	
3	101.166	0.150	0.200	70.863	0.0404	1.794	0.865	
4	101.891	0.150	0.200	70.891	0.0406	1.789	0.865	
5	102.589	0.150	0.200	70.921	0.0407	1.784	0.864	

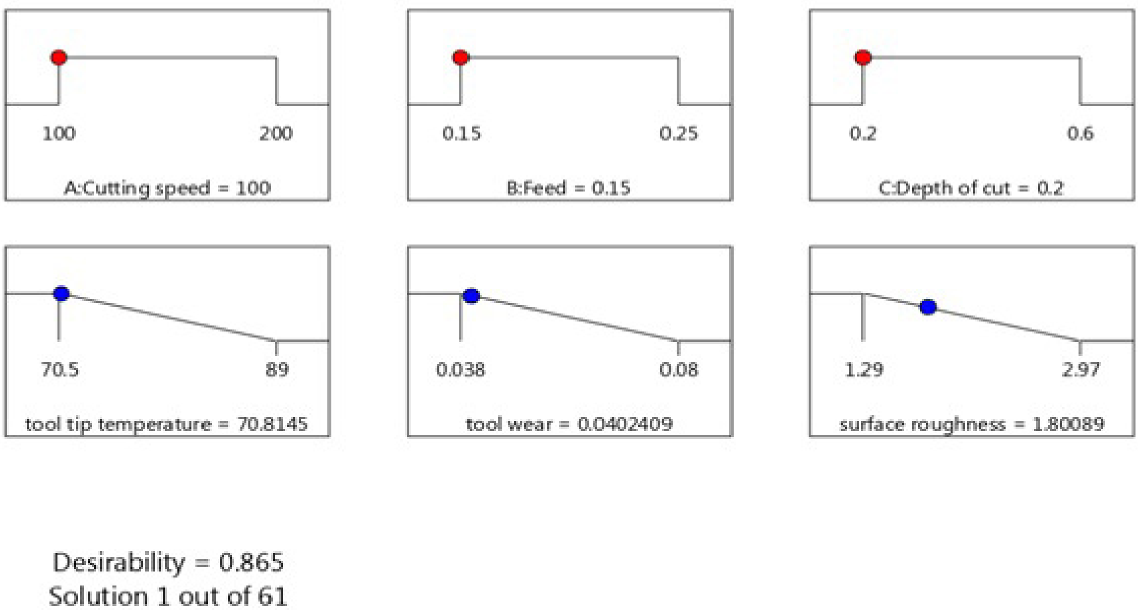

Figure 7. Ramp diagram.

the level of prediction towards the response factors. In this investigation desirability value of 0.865 was found and it is satisfactory, observed from Table 9. Ramp diagram illustrated in Figure 7, it was clearly noticed that the optimum values was selected for cutting speed, feed and depth of cut are 100m/min, 0.15mm/rev, and 0.2mm respectively. It was found that the optimum value of tool tip temperature, tool wear and surface roughness are 70.81m/min, 0.402 mm/rev, and 1.8 respectively. From Table 9, optimal set 1 was chosen because of tool tip temperature and tool wear values are found to be minimum compared with other optimal solutions. Figure 8 portrays the bar graph of desirability of multi objective function. From that graph, the values of desirability of response variables closer to 1 and it was acceptable, the combined objective desirability value of 0.8651 was noticed and it was very significant.

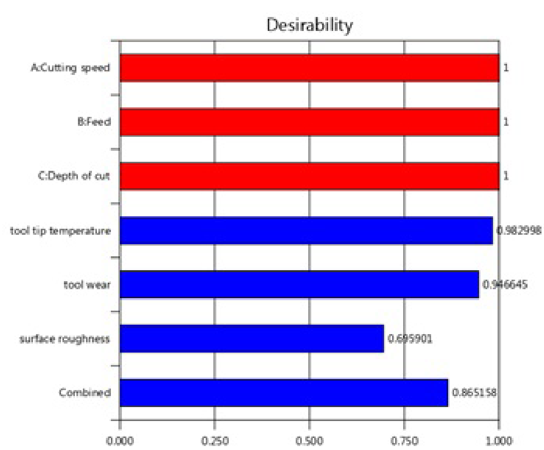

Figure 8. Bar graph of desirability of multi objective function.

4.5. Tool wear analysis

In order to examine the crater wear evolution and determine the effect of cutting tool with varying parameters of speed, feed and depth of cut. Figure 9(a-f) illustrates the formation of crater wear during turning with double layered $TiCN/Al_2O_3$ coated tool with varying machining condition. Due to abrasion between tool and work piece, more friction was occurred at the cutting zone and in the result, different wear patterns was developed. In this investigation, more concentration was given for crater wear investigation. Due to coated tool used in this investigation, more wear pattern occurred in crater portion of the tool studied in literature

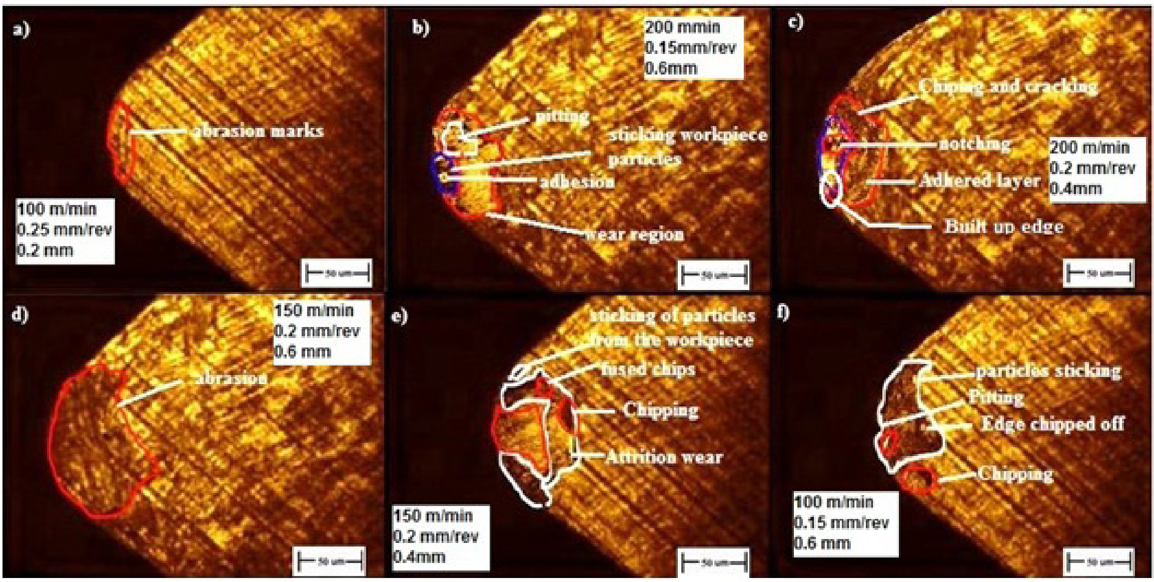

Figure 9. wear formation on cutting tool under different cutting speed, feed and depth of cut.

study, so the importance is given for crater wear modeling Figure 9a Wear pattern was produced at the tool tip, because of abrasion generates in between tool and work piece. Tool wear formation was noticed less due to low cutting speed of 100 m/min. But in Figure 9b crater wear was developed with various wear patterns[20]

Due to increase in cutting speed, the wear region was found wider, pitting of coated tool was occurs due to maximum depth of cut of 0.6 mm. More amount of heat generated during turning, thermal softening was takes place resulting adhesion of particles was observed[20]. Owing to severe rubbing action between the tool and work piece, resulted sticking work piece particles embedded on the tool surface. However Al_2O_3 act as a bottom layer in the coated tool reduces crater wear[20]. TiCN as a top layer due to its lower coefficient of friction develops thermal crack in the tool face was obviously noticed in Figure 9b. Thermal softening was formed on the wear region resulted in creation of built up edge and adhered layer was clearly noted in Figure 9c. Sudden formation of adhered layer due to maximum force, weldments of chips formed over the tool surface due to high cutting speed and feed rate[31]. While using carbide based tools, brittle particles contact with work material generates more abrasion due to force variability and it was reflected in Figure 9d. Due to presence of Si particles and at maximum speed creates more abrasion takes place[9] and it was observed in Figure 9e. From the Figure 9f it was interested to note that there are so many factors affecting tool face and develops crater wear[20]. Because of high temperature in the cutting zone, chips flows over the surface of the tool and adhesion on the surface. Due to coating delamination formed at moderate cutting speed and minimum depth of cut creates fusion chips and chip sticking on the tool face. Friction is created due to pressure and relative motion at the chip/tool interface. Material adhesion on the tool exit surface is mainly depends on the effect of machining depth. Adhesion of Al/SiC particles on the tool was observed at cutting speed of 100m/min and 0.6mm depth of cut. This type of wear patterns increases, it tends to create pitting, edge chipped off on the tool face and uneven crater wear region was developed[24].

4.6. Tool surface morphology

To perceive the surface roughness after cutting process, surface morphology seems to very important to visualize the surface roughness parameters in worn out region. In Figure 10 it shows the atomic force microscopic images of the cutting tool after machining. Tool was scanned at the size of 88 X 116 µm, 80 X 109 µm and 78 X 103 µm respectively. Before AFM analysis, tool tip was cleaned by acetone ethanol. Considering the tool images of cutting tool insert at 200m/min, 150m/min and 100 m/min are illustrated in Figure 10 surface profile was drastically changed after machining process compared with the profile of before machining process. In the deep investigation of cutting tool in Figure 10a, hill like profile was profound in the 3D image profile, due to severe crater wear it also reflected in surface roughness of the workpiece with the maximum value of 0.075 mm shown in Table 4. From the deep study of cutting tool profile found in Figure 10a, surface has more peaks and valley due to maximum tool nose radius of 0.8 mm, when the nose radius was increases initiate more abrasive action resulted wear in the tool profile. Cutting speed plays a most important role to create more wear due to excessive force developed in between tool and work piece. Due to the high cutting speed with 200 m/min, the tool profile was totally damaged and it was resembled in Figure 10. Abrasion marks creates lot of peaks and valley profile due to maximum feed of 0.2 mm/rev and also it relates with the SEM image and AFM image presented in Figure 10b. Depth of cut with an increase of cutting speed develops surface crack on the tool profile evident of high peak and valley profile was developed in the cutting tool at 100m/min showed in Figure 10c.

Figure 11 indicates the waviness, texture and surface roughness of the cutting tool was efficiently indicated by the

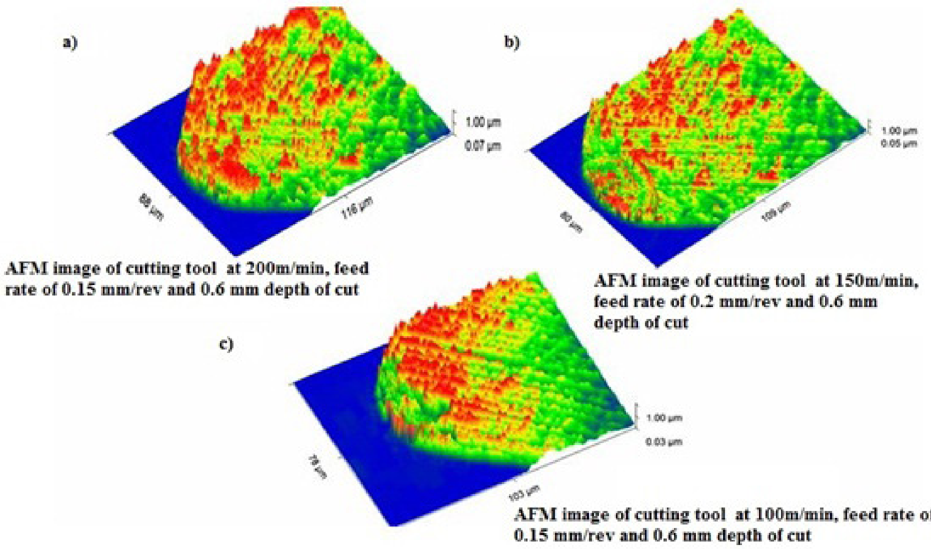

Figure 10. Tool surface morphology at different cutting speed.

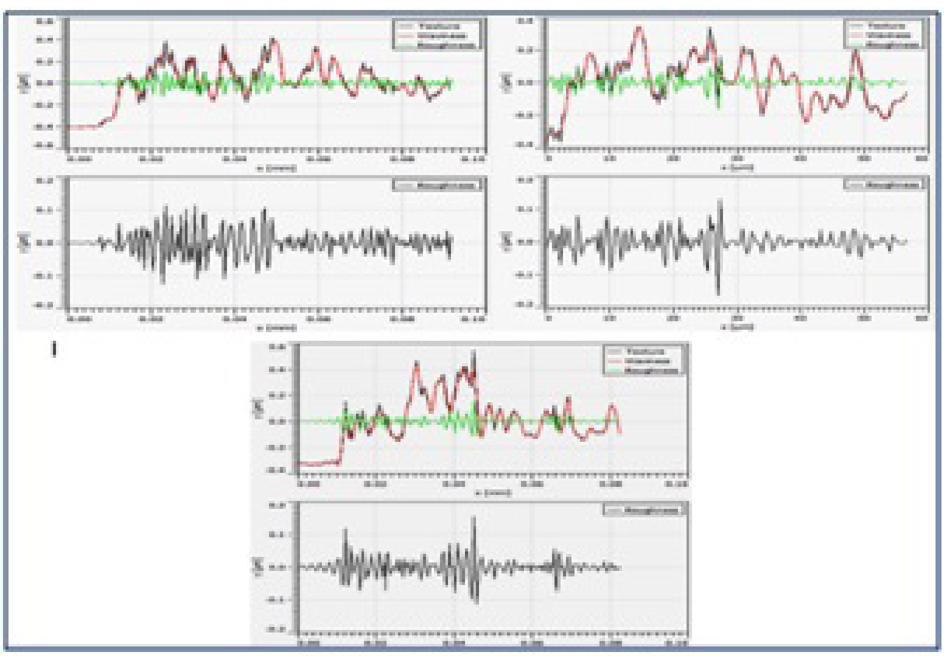

Figure 11. Surface profile graph at different cutting speed.

use of imaging software. From the Figure, it was obviously stated that the tool at maximum cutting speed has more surface roughness on the tool profile. Maximum surface roughness value was found. The graph indicates more peak and valley profile for the entire cutting tool after machining. The various surface parameters were analyzed using surface profile plot and it was shown in Table 10. The surface roughness was mainly depends on the cutting speed and depth of cut. Tool wear and its surface morphology under different input constrains were observed in AFM and SEM of the tool wear. The surface roughness of the tool has been increased with increase of cutting speed from 100 to 200 m/min. Wear surface of the cutting tool was also increased with increase of average roughness.

From the Table 10, it shows the tool surface parameter value for the tool profile at three different cutting speed conditions. Comparing three tool surface profile, it was keenly observed that the roughness average value of maximum 51.32 nm noticed at the cutting speed 200 m/min, and also valley depth value is more than other two profile

Table 10. Tool surface parameters value at different cutting speed.

S.No	Surface parameters	Cutting speed of 200m/min, feed rate of 0.15 mm/rev,and 0.6mm depth of cut	Cutting speed of 150m/min, feed rate of 0.2 mm/rev, and 0.6mm depth of cut	Cutting speed of 100m/min, feed rate of 0.15 mm/rev, and 0.6mm depth of cut
1	Roughness Average (R_a)	51.32	16.59	30.90
2	Maximum height of the roughness (R_t)	570	206.6	187.6
3	Root mean square	77.96	24.52	39.96
3	Maximum roughness Valley depth (R_v)	227.1	105.8	73.26
4	Maximum roughness Peak height (R_p)	153.2	45.70	78.43
5	Skewness (R_{sk})	0.6780	0.3505	0.3924
6	Kurtosis (R_{ku})	7.164	7.261	3.072

Table 11. Confirmation result.

Response variables	Optimal values			Predicted values by desirability approach	Experimental value	Percentage of deviation
	Cutting speed (m/min)	Feed (mm/rev)	Depth of cut (mm)			
Tool tip temperature (^{0}C)	100	0.15	0.20	70.81	72.0	1.65
Surface roughness (µm) in microns				1.80	1.71	5.00
Tool wear (µm) in microns				0.04	0.04	4.70

was 227.1 nm, it means that the tool was affected more with the crater wear. Maximum height of the roughness value of 92.21 nm was found in the tool profile at the cutting speed at 150 m/min. From the reference cited in Gopal[28] summarize the importance of kurtosis parameter in the investigation of surface profile. The kurtosis value for the tool surface at three different cutting speeds, value is more than 3.0, indicates high spiky profile like hill profile was observed in the 3D image shown in Figure 10. It was well known that the skewness and kurtosis values are very important to define the shape of the profile. The value of kurtosis was pointed in the Table 10. Root mean square value and maximum height of the roughness value for the tool profile was 77.96nm, 570 nm respect to the cutting speed of 200m/min, 24.52 nm, 206.6nm related to the cutting speed of 150 m/min, 39.88 nm, 187.6 nm was observed at 100 m/min stated that the profile was rough witnessed with the study[43]. Value of skewness is also plays a vital role in the evolution of surface profile. Negative and positive skewness values, describes the probability of distribution of peaks and valleys in relation to the midline of the roughness profile[44].

Table 11 exhibits the confirmation experiment carried out in this investigation. The optimal values of cutting speed= 100 m/min, feed =0.15 mm/rev, depth of cut = 0.2mm obtained by the desirability approach, predict the optimal values of response parameters stated in the Table 11. For finding the significance of the results, experiment was carried out in this machining condition and the results are noted in the Table 11. It was very acceptable that the percentage deviation error for all the response variables within the limit of 5%[44].

5. Conclusions

From the literature review, only few researchers are concentrated to investigate the tool profile by using surface morphology technique. Novel approach of surface morphology was applied in this investigation to visualize the surface profile. The following findings have been concluded based on the effect of crater wear modeling of aluminum composite.

- The developed RSM model was validated and good agreement with the confirmed values obtained by experimental investigation
- Crater wear morphology was deeply investigated; more number of wear patterns was analyzed
- Chipping, abrasion marks, adhered layer, were found in the coated tools during the turning of aluminum composite
- Cutting speed plays a most imperative role, which affects the surface roughness of the profile and drastically increases the cutting tool tip temperature. Even though depth of cut initiates the crater wear was observed.
- By implementing ANOVA test, it is confirmed with the values shows the cutting speed is the most dominant factor compared with feed and depth of cut.
- Optimization of surface roughness, tool wear, and cutting tool tip temperature was obtained with by using desirability approach at cutting speed of 100 m/min, feed of 0.15 mm/rev, and depth of cut of 0.2mm.
- Atomic force microscope analysis was carried out to identify the hill valley profile in the tool surface.

skewness and kurtosis parameters was observed at the significant level from that it was observe that there is chances of developing spiky profile in the tool surface at different cutting speed.

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