ANALYSIS AND OPTIMIZATION OF MACHINING PARAMETER DURING TURNING OF A356/10% SiCp MMC USING RESPONSE SURFACE METHODOLOGY APPROACH

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ABSTRACT

In this study, an effort has been made more complex multi performance optimization using Response Surface Methodology (RSM) based desirability approach while machining of Al/10\%SiC Particulate Aluminum Metal Matrix Composite (PAMMC) produced through stir cast method. The effect of main cutting parameters like Cutting speed (V), Feed rate (F), Depth of cut (D) and Machining time (T) on the output responses of Tool flank wear ($V_{Bmax}$) and Surface roughness (Ra) were investigated. The most significant machining parameters were ascertained using analysis of variance (ANOVA). The contour plots are drawn for study effect cutting parameters and their interactions. From the study found that developed numerical model for tool flank wear and surface roughness is found to be adequate and used for predict the parameters within this experimental range.

Keywords: Particulate Aluminum Metal Matrix Composite (PAMMC); Response surface methodology (RSM); Analysis of Variance (ANOVA); Tool flank wear ($V_{Bmax}$); Surface roughness (Ra); Contour plots.
1. INTRODUCTION

Metal matrix composites (MMC’s) are one among the commonly well-known composites material due to their superior mechanical and chemical properties such as high hardness, strength, toughness, wear resistance and corrosion resistance. Silicon carbide particulate (SiCp) reinforced aluminium metal matrix composites are most widely used MMC and commercially available ones due to their cost-effective production processes [1]. Mostly the products made out of composite materials are near-net shaped processes, but the need for machining cannot be completely eliminated, since, in modern engineering, high demands are being placed on components made of composites in relation to their dimensional precision as well as their surface quality [2]. Therefore, there is a great need to understand the questions associated with machining of this type of composite material.

Progressive technologies need materials with different exceptional combinations of properties that cannot be met by the conventional metal, alloys, ceramics, and polymeric materials. This is especially true in the case of materials that are needed for aerospace and space industries, where the product performance requirement is quite complex. The demands made on materials for better overall performance are so great and diverse that no single material can satisfy them. Hence, new materials have to be synthesized, which ultimately result development of advanced composite materials [3].

The industrial application Al/SiC particulate MMC still inadequate this mainly due difficulty in machining presence of abrasive nature of hard SiC particles leads to excess wear on tool. From the published research found that only PCD tool gives the use full tool life while machining Al/SiCp MMC due their high hardness and chemical propensity. But considering cost of machining carbide and ceramic cutting tools are not completely eliminated. The carbide cutting tools have useful tool life in lower cutting speeds less than 75 m/min. So many researcher recommend cemented carbide cutting tools for rough cutting operation and PCD tool for finishing in order to minimizing machining cost [4].

However, a limited quantity of research are stated on the machining A356 Al/SiCp MMC with uncoated carbide cutting tools respect to output responses of tool flank wear and surface roughness using response surface methodology with different cutting conditions [5, 6, 7 & 8]. Moreover, the significant number of studies has been reported on machining different
other alloys of aluminium as matrix and SiC has been used as reinforcement using carbide, CBN and PCD cutting tools [9, 10, 11, 12, 13,14, 15, 16 &17 ]. Hence the main objective of the present work is to optimize tool wear and surface roughness while machining LM25 Al/SiCp metal matrix composite using uncoated cemented carbide cutting tools (K10) with Response surface methodology (RSM) based desirability approach.

2. EXPERIMENTAL STUDY

Turning experiments were performed on a center lathe (PSG 141) which is having a spindle speed range of 50-1750 rpm with feed range 0.05-3.5 mm/rev with adequate spindle control. A356 equivalent of British grade LM25 Al alloy chemical composition as shown in Table 1 is reinforced with 10% SiC particles with an average grain size of 25µm was produced by stir casting method is used for conduct the turning trials. The dimensions A356/SiC/10p MMC rod used for experiment was 275 mm length and 100 mm diameter. The uncoated fine grain cemented carbide cutting tool ISO grade of K10 grade WIDIA make used for experiment. The turning trials were conducted as per DOE (Design of Experiment) matrix at random manner to eliminate logical mistakes.

To measure the tool flank wear the maximum width of flank (VBmax) land was measured in this study which is widely used in manufacturing applications in the industry. The maximum width of flank (VBmax) and Build up Edge (BUE) formation quantified using CLEMAX optical microscope with following specification: Working distance: 1 to 5 mm, Magnification: 50 to 1000X, Illumination: 12V, 100W. The Scanning Electron Microscope (SEM) was used for analyzing tool flank wear mechanism at various machining parameters.

| Elements of A356 Al alloy |
|--------------------------|
| Elements     | Si | Fe | Mn | Mg | Ti | Ni | Cu | Al |
| A356 Al alloy  | 7  | 0.5| 0.3| 0.33| 0.2| 0.1| 0.1| Bal |

3. DESIGN OF EXPERIMENTS BASED ON RESPONSE SURFACE METHODOLOGY

In this study, main cutting conditions like Cutting speed (V), eed rate (F), Depth of cut (D) and Machining time (T) was considered as important design factors in the turning process. To study the performance of the tool flank wear (VB\text{max}) and surface roughness (R\text{a}) were considered as out responses.
The experiments were designed using full factorial face centered CCD (Central Composite Design) mixing of all factors of cutting parameters in two levels high (+1) and low (-1) consist of eight star points and seven center points (mid-point level 0). This design named face centered CCD mainly due star points of $\alpha=1$ is in the face of cubic part in the design. The cutting parameters and their levels used in this study as shown in Table 2. The experimental results of face centered CCD developed using MINITAF software consist of 31 trials in coded and actual factors along with output responses of tool flank wear and surface roughness are shown in Table 3.

Table 2 Machining parameters and their levels

| Machining parameters | Units     | Symbol | Levels  |
|----------------------|-----------|--------|---------|
|                      |           |        | -1      | 0   | +1   |
| Cutting speed        | m/min     | $V$    | 50      | 100 | 150  |
| Feed rate            | mm/rev    | $F$    | 0.05    | 0.15| 0.30 |
| Depth of cut         | mm        | $D$    | 0.5     | 1.0 | 1.5  |
| Machining time       | min       | $T$    | 2       | 4   | 6    |

Response surface method (RSM) was adopted to model the process parameters with the response variables. RSM is the procedure for determining the association among machining parameters and responses and explain influence of process parameters on desired responses. Based on RSM numerical correlation among output responses and input machining parameters expressed as

$$Y = f(V, F, D, T)$$

Where $Y$ is required output response and $f$ is called response function (or response surface). In the investigation procedure, the estimation of $Y$ was adapted using the second-order polynomial regression equation; this generally named the quadratic model. The quadratic model of $Y$ expressed as given below:

$$Y = a_o + \sum_{i=1}^{4} a_i \cdot X_i + \sum_{i=1}^{4} a_{ii} X_i^2 + \sum_{i<j}^{4} a_{ij} X_i X_j$$

Where $a_o, a_i, a_{ii}$ and $a_{ij}$ indicate constant, coefficients of linear, quadratic and cross product terms correspondingly. $X_i$ Express cutting variables in the coded form.
The coded variables $X_i$, $i = 1, 2, 3, 4$ are obtained from given below transformation relationship equation:

$$X_1 = \frac{V - V_0}{\Delta V}$$  \hspace{1cm} (iii)

$$X_2 = \frac{F - F_0}{\Delta F}$$  \hspace{1cm} (iv)

$$X_3 = \frac{D - D_0}{\Delta D}$$  \hspace{1cm} (v)

$$X_4 = \frac{T - T_0}{\Delta T}$$  \hspace{1cm} (vi)

### Table 3 Experimental results for machining of Al/10%SiCp MMC using K10 tool

| Sl. No | Coded | Actual | Output Responses |
|--------|-------|--------|------------------|
|        | $X_1$ | $X_2$  | $X_3$ | $X_4$ | $V$ | $F$ | $D$ | $T$ | $Y_1$ (VB$_{max}$, mm) | $Y_2$ (Ra, $\mu$m) |
| 1      | -1    | 0      | 0     | 0     | 50  | 0.15 | 1.0 | 4    | 0.09                          | 2.71                          |
| 2      | 1     | 0      | 0     | 0     | 150 | 0.15 | 1.0 | 4    | 0.25                          | 2.27                          |
| 3      | 0     | -1     | 0     | 0     | 100 | 0.05 | 1.0 | 4    | 0.23                          | 1.92                          |
| 4      | 0     | 1      | 0     | 0     | 100 | 0.25 | 1.0 | 4    | 0.21                          | 2.95                          |
| 5      | 0     | 0      | -1    | 0     | 100 | 0.15 | 0.5 | 4    | 0.18                          | 2.41                          |
| 6      | 0     | 0      | 1     | 0     | 100 | 0.15 | 1.5 | 4    | 0.22                          | 2.48                          |
| 7      | 0     | 0      | 0     | -1    | 100 | 0.15 | 1.0 | 2    | 0.17                          | 2.35                          |
| 8      | 0     | 0      | 0     | 1     | 100 | 0.15 | 1.0 | 6    | 0.25                          | 2.53                          |
| 9      | -1    | 1      | 1     | 1     | 50  | 0.25 | 1.5 | 6    | 0.15                          | 3.25                          |
| 10     | 1     | -1     | -1    | -1    | 150 | 0.05 | 0.5 | 2    | 0.30                          | 1.59                          |
| 11     | -1    | -1     | 1     | 1     | 50  | 0.05 | 1.5 | 6    | 0.17                          | 2.22                          |
| 12     | 1     | 1      | -1    | -1    | 150 | 0.25 | 0.5 | 2    | 0.22                          | 2.63                          |
| 13     | -1    | -1     | -1    | 1     | 50  | 0.05 | 0.5 | 6    | 0.15                          | 2.16                          |
| 14     | 1     | 1      | 1     | -1    | 150 | 0.25 | 1.5 | 2    | 0.24                          | 2.69                          |
| 15     | -1    | -1     | -1    | -1    | 50  | 0.05 | 0.5 | 2    | 0.11                          | 2.01                          |
| 16     | 1     | 1      | 1     | 1     | 150 | 0.25 | 1.5 | 6    | 0.38                          | 2.93                          |
| 17     | -1    | 1      | -1    | 1     | 50  | 0.25 | 0.5 | 6    | 0.13                          | 3.18                          |
| 18     | 1     | -1     | 1     | -1    | 150 | 0.05 | 1.5 | 2    | 0.31                          | 1.65                          |
| 19     | -1    | 1      | -1    | -1    | 50  | 0.25 | 0.5 | 2    | 0.08                          | 3.00                          |
| 20     | 1     | -1     | 1     | 1     | 150 | 0.05 | 1.5 | 6    | 0.40                          | 1.84                          |
| 21     | -1    | 1      | 1     | -1    | 50  | 0.25 | 1.5 | 2    | 0.09                          | 3.04                          |
| 22     | 1     | -1     | -1    | 1     | 150 | 0.05 | 0.5 | 6    | 0.37                          | 1.79                          |
| 23     | -1    | -1     | 1     | -1    | 50  | 0.05 | 1.5 | 2    | 0.10                          | 2.06                          |
| 24     | 1     | 1      | -1    | 1     | 150 | 0.25 | 0.5 | 6    | 0.34                          | 2.86                          |
| 25     | 0     | 0      | 0     | 0     | 100 | 0.15 | 1.0 | 4    | 0.20                          | 2.45                          |
| 26     | 0     | 0      | 0     | 0     | 100 | 0.15 | 1.0 | 4    | 0.19                          | 2.44                          |
| 27     | 0     | 0      | 0     | 0     | 100 | 0.15 | 1.0 | 4    | 0.21                          | 2.46                          |
| 28     | 0     | 0      | 0     | 0     | 100 | 0.15 | 1.0 | 4    | 0.20                          | 2.44                          |
| 29     | 0     | 0      | 0     | 0     | 100 | 0.15 | 1.0 | 4    | 0.21                          | 2.45                          |
| 30     | 0     | 0      | 0     | 0     | 100 | 0.15 | 1.0 | 4    | 0.20                          | 2.44                          |
| 31     | 0     | 0      | 0     | 0     | 100 | 0.15 | 1.0 | 4    | 0.20                          | 2.46                          |
Where $X_1, X_2, X_3$ & $X_4$ are the corresponding coded values of machining parameters of $V, F, D$ & $T$ correspondingly and similarly $V_0, F_0, D_0$ & $T_0$ are the values of $V, F, D$ & $T$ at zero condition. In further $\Delta V, \Delta F, \Delta D$ & $\Delta T$ are the intervals of variation in $V, F, D$ & $T$ correspondingly. The tool flank wear ($VB_{\text{max}}$) and average work piece surface roughness (Ra) denoted in $Y_{VB_{\text{max}}}$ and $Y_{Ra}$ correspondingly is evaluated as the output responses. The main objective of using quadratic model is not only examining the whole factor space and also identify area anywhere responses approach it optimum or near optimum value.

4. EMPIRICAL MODELING

4.1. Development of empirical model

The empirical correlation among output responses and cutting variables ($V, F, D$ & $T$) is given in Equations (vii) & (viii) is obtained by experimental results are shown in Table 3. Tool flank wear ($VB_{\text{max}}$) and surface roughness (Ra) regression coefficient and P-value are shown in Table 4. From the Table 3 observed that P-values of tool flank wear ($VB_{\text{max}}$) clearly show that linear, square effect of cutting speed, feed rate and machining time, cutting speed interaction with feed rate and machining time, feed rate interaction with machining time are most significant, whereas other effects are not so significant. Similarly, from surface roughness (Ra) P-values from table shows that liner effect of cutting speed, feed rate and machining time, square effect of cutting speed and feed rate, cutting speed interaction with feed rate and machining time, feed rate interaction with machining time are significant whereas other effects are not so significant since the P-values are more than 0.05.

$$VB_{\text{max}} = 0.04816 + (0.00351V) - (0.93627f) - (0.05175d) - (0.03224t) - (0.00001V^2) + (2.56533f^2) + (0.02261d^2) + (0.00391t^2) - (0.00150Vf) + (0.00010Vd) + (0.00013Vt) + (0.02500fd) + (0.03125ft) + (0.00375dt) \quad \text{(vii)}$$

$$Ra = 2.38802 - (0.00720V) + (5.34311f) + (0.14201d) + (0.06380t) + (0.00001V^2) - (2.27333f^2) - (0.05093d^2) - (0.00443t^2) + (0.00275Vf) + (0.00005Vd) + (0.00010Vt) + (0.02500fd) + (0.05000ft) + (0.00250dt) \quad \text{(viii)}$$

Table 5 gives the values of estimated standard deviation (S) about the regression line, $R^2$ statistic and adjusted $R^2$ statistic. Since the S-value indicates error smaller is good for better model. From the Table 4 observe that S-Value of $VB_{\text{max}}$ is smaller than Ra that indicates $VB_{\text{max}}$ minor amount differed from regression line compared to Ra. Further the $R^2$ value of Ra higher than $VB_{\text{max}}$, so the coefficients of empirical equation of Ra more
effective than that of VBmax. Furthermore R² and adjusted R² closeness decides fitness of the model, in this both models R² and adjusted R² are very close to each other. From the Tables 4 & 5 it can be concluded that developed empirical model clearly model the relationships between the process parameters and output responses VBmax and Ra in turning of particulate metal matrix composite.

| Table 4 Regression coefficient and P-value of VBmax and Ra |
|-----------------------------------------------------------|
| Symbol | VBmax Coefficient | VBmax P-value | Ra Coefficient | Ra P-value |
|--------|-------------------|---------------|----------------|-----------|
| Constant | 0.04816 | 0.156 | 2.38802 | 0.000 |
| v -m/min | 0.00351 | 0.000< | -0.00720 | 0.000< |
| f -mm/rev | -0.93627 | 0.001< | 5.34311 | 0.000< |
| d -mm | -0.05175 | 0.397 | 0.14201 | 0.087 |
| t -min | -0.03224 | 0.045< | 0.06380 | 0.005< |
| v² | -0.00001 | 0.003< | 0.00001 | 0.003< |
| f² | 2.56533 | 0.002< | -2.27333 | 0.026< |
| d² | 0.02261 | 0.434 | -0.05093 | 0.187 |
| t² | 0.00391 | 0.041< | -0.00443 | 0.073 |
| v f | -0.00150 | 0.018< | 0.00275 | 0.002< |
| v d | 0.00010 | 0.391 | 0.00005 | 0.741 |
| v t | 0.00013 | 0.000< | 0.00010 | 0.016< |
| f d | 0.02500 | 0.665 | 0.02500 | 0.741 |
| f t | 0.03125 | 0.042< | 0.05000 | 0.016< |
| d t | 0.00375 | 0.205 | 0.00250 | 0.511 |

| Table 5 Summary of regression analysis |
|----------------------------------------|
| Responses | S-value | R² | Adjusted R² |
| Flank wear (VBmax) | 0.0113420 | 99.05% | 98.22% |
| Surface roughness (Ra) | 0.0148850 | 99.94% | 99.88% |

5. RESULTS AND DISCUSSION

5.1. Influence of cutting parameters on flank wear (VBmax)

During machining of heterogeneous material like Al/SiC MMC cutting tools exposed higher wear and cyclic load mainly due to presence of higher hardness SiC particulate in the Al matrix. The developed empirical equation based on experimental using RSM given the Equation- (vii). In the study examine the effect of four different cutting parameters on output
response of tool flank wear ($V_{B_{\text{max}}}$). The contour plots are developed for different cutting combinations; numbers in the pols denote the amount tool flank wear in mm.

The study of the influence of process parameters on the generation of flank wear and tool wear characteristics creates a basis for understanding the machinability and reducing or preventing tool wear in order to ensure the integrity of the product. This is more important in the case of advanced materials like SiCp reinforced aluminium MMC. Fig.1 illustrates the influence of cutting speed and feed rate on $V_{B_{\text{max}}}$. It is seen that cutting speed increases from lower value 50 m/min to higher values of 150 m/min the flank wear also increases. At lower cutting speed of 50 m/min, possible formation of unstable larger BUE protects the cutting wedge from the propagation of wear, but this is eliminated when the cutting speed is increased to 150 m/min, thus resulting in higher tool wear at higher cutting speed. Also, when the cutting speed is increased, the cutting temperature increases and there is linear relationship between the two. Work done in machining is converted into heat that eventually leads to increase in cutting temperature, which not only reduces the BUE but also softens the tool thus leading to higher tool wear [18]. This is further accelerated by the interaction between the harder SiC particles and carbide cutting tool. Fig.2 shows the BUE formation at low and higher cutting speed.

From Fig.1 with increase in feed rate, a decrease in flank wear ($V_{B_{\text{max}}}$) is seen up to around 0.20 mm/rev of feed rate. At lower feed rates the contact time between tool - work and tool - chip is more which leads to higher abrasion of SiCp present in the work on cutting edge thus also leading to greater heat concentration and thus resulting in more tool wear [19]. However, with increase in feed rate beyond 0.20 mm/rev increase in flank wear ($V_{B_{\text{max}}}$) is seen. With higher feed rate, consequent larger cross- sectional area of the un-deformed chip and resistance to chip deformation leads to higher change in the geometry of tool wedge. The changes in the geometry further lead to thermal induced tool wear thus resulting in higher flank wear.
Fig. 1 BUE formation during machining of Al/10% SiCp MMC using K10 tool

Fig. 3 illustrates the influence of machining time and depth of cut on flank wear. The flank wear generally increases with increase in machining time, due to degradation of cutting tool and alteration in the form of tool wedge [20]. The effect of depth of cut on flank wear is less seen from the Figure. This result correlates results of P value given in Table 4 wherein the depth of cut is observed as the least influence factor compared to cutting speed, feed rate and machining time on tool flank wear in machining of Al/SiC MMC [21]. But depth cut increased in to above 1 mm, the higher tool flank wear observed this mainly due increases in work-tool contact area, normal cutting force and friction its leads to rises interfacial cutting temperature. The higher interfacial temperature further leads to softening of work material its increases tool flank wear.
Fig. 2 Influence of cutting speed \((V)\) and feed rate \((F)\) on Tool flank wear

Fig. 3 Influence of Depth of cut \((D)\) and Machining time \((T)\) on Tool flank wear

Several types of wear mechanisms can influence the tool geometry. The worn cutting edges of K10 grade cemented carbide cutting tool observed under scanning electron microscope (SEM) while turning at low cutting speed of 50 m/min is shown in Fig. 4. From the Fig. 4 distinct abrasive wear grooves can be seen at the work flow direction of primary cutting edge of flank, due to two bodies and three bodies abrasive action of hard reinforced SiC particles [21]. The two body abrasive wear is produced through the roughing action of SiC particulates presents in Al matrix moving at higher cutting speed against the cutting tool. The three body abrasive wear is caused by the released hard SiC particles, entrapped between the tool and the work piece [22].

The wear of cutting tool at a cutting speed of 150 m/min is shown in Fig. 5. At higher cutting speed, in addition to abrasive wear, triangular wear on nose region and wear in the chip flow direction on the rake face is also seen. This is mainly due to higher sliding of flow of chips with hard particles at higher cutting speed. This sliding of chips combined adhesion–abrasion of work material on the rake face away from the cutting edge could have resulted in degradation of tool over the flank portion [23].

Fig. 4 SEM of Cutting tool (K10) at \(V=50\) m/min, \(F=0.05\) mm/rev, \(D=1.5\) mm and \(T=6\) min
The abrasive wear in work flow of flank face and chip flow direction rack face, combined adhesion-abrasive wear observed during 100 m/min is shown in Fig.6. The main wear mechanism observed K10 tool during machining Al/10%SiCp MMC is purely abrasion at low cutting speed of 50 m/min, combination of abrasion and adhesion observed at higher cutting speed [24]. The worn cutting edges observed from SEM also reveal the triangular and grooved wear in the cemented carbide cutting tools.

Fig.5 SEM of Cutting tool (K10) at \( V=150 \) m/min, \( F=0.05 \) mm/rev, \( D=1.5 \) mm and \( T=6 \) min

(a) Tool flank wear  
(b) Magnified circle area
5.2. Influence of cutting parameters on surface roughness (Ra)

The Fig.7 shows effect of cutting speed (V) and feed rate (F) on the out response of surface roughness (Ra). From Fig.7 observed that the surface roughness (Ra) increases as the feed rate increases. Higher feed rates increase the temperature in cutting zone causing decrease in bonding effect between SiCp and Al matrix, thus leading to pull out of SiC particles from the softened aluminum matrix leaving a cavity on the machined surface resulting in poor surface finish [122]. We know that at higher feed rate the cusp height is more which also leads to higher values of surface roughness. From Fig. 2 at low cutting speed, larger size unstable BUE formed this break the chips frequently this leads the poor surface roughness. But increases cutting speed higher interfacial temperature eliminate unstable BUE this reduce the chip fracture leads to good surface finish [23]. The finest required surface morphology of work piece is attained at lesser feed rate and higher cutting speed cutting combinations during machining Al/10%SiCp MMC using K10 tool.
The effect of depth of cut and machining time on the surface roughness is shown in Fig. 8. The depth of cut is lower influencing machining parameter on surface roughness compared to cutting speed, feed rate and machining time [21], which is seen from the observed ‘P’ values given in Table 4. From the illustration it is observed that the surface roughness increases with machining time because tool geometry gets altered.

6. ANALYSIS FOR OPTIMIZATION OF THE RESPONSES

Apart from the study of interaction between process parameters and their effect on desired response variables, it is necessary to optimize the process parameters for the multiple responses of tool flank wear and average surface roughness. One useful approach to optimize the multi-objective simultaneous optimization method procedure developed by researches Derringer and Suich [13]. Their procedure introduces the concept of desirability functions. The general approach is to first convert each response $Y$ into an individual desirability function $d_i$ that varies over the range.

$$0 \leq d_i \leq 1 \quad \text{(ix)}$$

When the response $Y$ is at its goal or target then $d_i = 1$ and if the response is outside an acceptable region then $d_i = 0$. The weight of the desirability function for each response defines its shape. For each response, one can select a weight ($r_i$) to emphasize or de-emphasize the target. Finally the individual desirability functions are combined to provide a measure of the composite or overall desirability of the multi-response system [10]. This measure of
composite desirability is the weighted geometric mean of the individual desirability of the responses. The optimal operating conditions can be determined by maximizing the composite desirability [11]. In the present investigation, the response parameters are chosen to maximize the overall desirability as follows:

$$D = (d_1^{i_1} d_2^{i_2})^{1/(i_1+i_2)}$$

Where $d_1$ and $d_2$ denote VBmax and Ra desirability functions respectively and $i_1$ and $i_2$ is parameters of transformed responses of $d_1$ and $d_2$. Generally the compact gradient algorithm has various starting points it is used for maximize/minimize the compound desirability to identify the optimal input parameter combination. Many standard statistical software tools like Minitab, Design expert, etc. are used to optimize the responses. In this study Minitab is used to optimize the response parameters.

The Fig. 11 shows the single desirability of optimization plot for minimizing tool flank wear. The upper and target values for optimization is chosen from experimental results as showed in Table 3 as 0.39 mm and 0.07 correspondingly. The optimized cutting parameters for attaining minimum tool flank wear of 0.07 mm from optimization plot as follows Cutting speed ($V$) = 50 m/min, Feed rate ($F$) = 0.18 mm/rev, Depth of cut ($D$) = 1.0 mm and Machining time ($T$) = 4 min. All the machining parameters are within range, the desirability of optimization is 100%.

![Fig.9 Optimum results for minimum flank wear (VBmax)](image)

Similarly optimization plot for minimum surface roughness (Ra) is shown in Figure 12. From Table 3 the target and upper values chosen for optimization are 1.59 µm and 3.18 µm correspondingly. The optimized cutting parameters for attaining minimum surface roughness of 1.59 µm from optimization plot as follows Cutting speed ($V$) = 150 m/min, Feed
rate \( F = 0.05 \text{ mm/rev} \), Depth of cut \( D = 0.6 \text{ mm} \) and Machining time \( T = 2 \text{ min} \). All the machining parameters are within range, the desirability of optimization is 100%.

$$\text{rate } (F) = 0.05 \text{ mm/rev}, \text{ Depth of cut } (D) = 0.6 \text{ mm}, \text{ and Machining time } (T) = 2 \text{ min.}$$

| New Low | High Cut | Low Cut |
|---------|----------|---------|
| 1.0000  | 1.5000   | 0.5000  |
| 50.0    | 0.250    | 0.050   |
| 1.50    | 1.50022  | 0.50    |
| 5.0     | 2.00     |         |

### Fig. 10 Optimum results for minimum surface roughness (Ra)

The goal was to minimize \( V_{B_{max}} \) and Ra while both are considered at a time. As the desirability is close to one, it can be concluded that the parameters are within their working range. Optimization plot for the both responses is shown in Fig. 11. The optimum values from the plot are \( V_{B_{max}} = 0.18 \text{ mm} \) and \( Ra = 2.36 \mu m \) and the corresponding parameters of Cutting speed \( (V) = 80 \text{ m/min} \), Feed rate \( (F) = 0.05 \text{ mm/rev} \), Depth of cut \( (D) = 0.50 \text{ mm} \) and Machining time \( (T) = 2 \text{ min} \) respectively.

$$\text{Optimum results for minimum surface roughness (Ra)}$$

![Optimum results for minimum surface roughness (Ra)](image)

### Fig. 11 Optimal chart of minimum \( V_{B_{max}} \) and Ra obtained through RSM for Al/10%SiCp MMC using K10 tool

$$\text{Optimal chart of minimum } V_{B_{max}} \text{ and } Ra \text{ obtained through RSM for Al/10%SiCp MMC using K10 tool}$$

![Optimal chart of minimum \( V_{B_{max}} \) and Ra obtained through RSM for Al/10%SiCp MMC using K10 tool](image)
7. CONCLUSIONS

The response surface methodology based disability approach optimization and effect of machining parameters on tool flank wear and surface roughness during machining composite machining are analyzed in this study. From analyze, the following conclusions are made.

1. From the empirical models found that cutting speed and feed rate more dominant when compared to other parameters. The suggested numerical models for tool flank wear and surface roughness is found to be suitable and used for predict the parameters within this experimental range.

2. The BUE formation adversely affects tool flank wear especially at low cutting speeds whereas higher cutting speeds and feed rates work material thermal softening reduce BUE formation. Surface topographies of the tool indicate that the main wear mechanism of cemented carbide tool is abrasive and adhesive wear.

3. The BUE formations at low cutting speeds produce poor surface finish. The better surface roughness achieved at lower feed rates and high cutting speed combination. Depth of cut increases the increase in surface roughness.

4. The optimized combination cutting parameter found from RSM based desirability approach such as Cutting speed (V) = 80 m/min, Feed rate (F) = 0.05 mm/rev, Depth of cut (D) = 0.50 mm and Machining time (T) = 2 to attain the minimum Tool flank wear (VB_{max}) and surface roughness (Ra) of 0.18 mm and 2.36 \mu m respectively.

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