

MODEL DEVELOPMENT FOR SURFACE ROUGHNESS PREDICTION OF AL 1050/SiCp MMCs MACHINED PARTS

A. M. Easa and Abeer S. Eisa

*Production Engineering and Mechanical Design Department, Faculty of Engineering
Minoufiya University, Shebin Elkom, Egypt*

ABSTRACT

The utilization of Al 1050/SiC particulate materials in many different engineering fields has undergone a tremendous increase. Accordingly, the need for accurate machining of this type of metal matrix composites has been increased enormously. In the present research, an attempt has been made to examine the effect of cutting parameters (cutting speed, depth of cut, feed rate) and two parameters of composite reinforcement; volume fraction and particle size on the machined part surface roughness through the investigated mathematical model developed by using the results gathered from a series of milling experiments. For this purpose, the experimental were reported for five of the maintained parameters. Twenty-five workpieces were fabricated to cover these investigations. A vertical milling machine was used in machining of Al 1050 / SiCp MMCs. The surface roughness (Ra) results were reported with different cutting parameters. The results of research indicated that ; the investigated procedure can be used to predict the surface roughness (Ra) for milling Al 1050 /SiCp MMCs, the experimental results and the predicted data by developed model indicate a good correlation, the surface roughness (Ra) decreases with the increase of cutting speed up to 140 rpm, but the surface roughness increases with the increase of ; depth of cut up to 1.5 mm, feed up to 1.25 mm/rev, volume fraction up to 25% and practical size up to 25 μ m. Also, the use of high cutting speed (140 rpm) , depth of cut 0.25mm, feed 0.4 mm/rev , volume fraction 5% and practical size 7.0 μ m gives a good surface roughness (Ra) as compared with other values of the parameters used in this research.

من الدراسات المتأنية لاستخدام المؤتلفات المعدنية المصنعة من الالومنيوم وحببيات كريد السيلكون Al /SiCp (MMCs) في المجالات الصناعية المختلفة- نجد أنه وبوضوح قد ازدادت زيادة عظيمة في السنوات الأخيرة- ومن هنا أصبحت هناك ضرورة ملحة لمزيد من الأبحاث للحصول وتوكيد دقة عالية في مجال تشغيل هذه المؤتلفات. ويعتبر هذا البحث أحد المحاولات الجادة في هذا الاتجاه. ولقد تم في هذا البحث دراسة تأثير عناصر القطع التالية علي خشونة السطح الناتج أثناء التشغيل علي ماكينة التفرزيز (A vertical Milling machine). وهذه العناصر هي- سرعة القطع- عمق القطع والتغذية. بالإضافة إلي عنصرين آخرين هامين لم ينالا اهتماما كافيا في الأبحاث السابقة وهما نسبة كريد السيلكون (SiC) المستخدم وأيضا حجم حببيات كريد السيلكون المستخدمة. ولقد تم ذلك من خلال نموذج رياضي تم تحسينه للتنبؤ بخشونة السطح الناتج وذلك بالاستعانة والمقارنة بنتائج التجارب العملية التي تم إجراؤها. وتم تصميم التجارب بطريقة حديثة للحصول علي أقصى استفادة وأعلى دقة وأقل وقت مستخدم. ولقد تم تصنيع العينات من هذا المؤتلف باستخدام خمسة نسب من كريد السيلكون- وأيضا خمسة أحجام من حببيات كريد السيلكون. ولقد أظهرت المناقشة العميقة للنتائج أن النموذج الرياضي المقترح قادراً علي التنبؤ بنتائج خشونة الأسطح في عمليات التفرزيز للمؤتلف Al 1050/SiCp - واتضح أن هناك توافقاً جيداً بين النتائج العملية والنتائج من خلال النموذج المقترح.

ويمكننا من خلال نتائج البحث أن نوصي بما يلي:

- أن قيمة خشونة السطح (Ra) تقل مع زيادة سرعة القطع حتى 140 لفة/دقيقة- وأنها تزداد مع عمق القطع حتى 1.5 مم والتغذية حتى 1.25 مم/لفة ومع نسبة إضافة (SiC) حتى 25% ومع حجم حببيات (SiC) حتى 25 ميكرون.

وأيضاً أوضحت النتائج أنه عند استخدام سرعة القطع 140 لفة/دقيقة وعمق قطع 0.25 مم وتغذية 0.4 مم/لفة ونسبة إضافة (SiC) 5% وحجم حببيات (SiC) 7 ميكرون- يؤدي ذلك إلي الحصول علي أقل خشونة (Ra) مقارنة بجميع القيم الأخرى للعناصر المستخدمة في هذا البحث.

Keywords: Surface roughness, Metal matrix, Composites, ANOVA, Taguchi Technique

1. INTRODUCTION

Particulate metal matrix composites (PMMCs) have found wide applications in some industrial fields in which the parts are required to be light and heat resistant or wear resistant. Particularly, non-continuously reinforced materials such as aluminum matrix composites reinforced by silicon carbide particles have become practical engineering materials [1]. End milling is the most metal removal operation encountered, it is widely used in a variety of manufacturing industrial including the aerospace and automotive sectors [2]. In machining of parts, surface quality is one of the most specified customer requirements where major indication of surface quality on machined parts is surface roughness. The quality of the surface plays a very important role in the performance of milling as a good quality milled. Surface significantly improves fatigue strength, corrosion resistance or creep life. Surface roughness also affects several functional attributes of parts, such as; contact causing surface friction, wearing light reflection, heat transmission, ability of distributing and holding a lubricant coating, or resisting fatigue [3]. There fore, the desired finish surface is usually specified and the appropriate processes are selected to reach the required quality. Surface roughness is mainly a result of process parameters such as tool geometry (edge geometry, rake angle ... etc) and cutting conditions (cutting speed, depth of cut, feed rate ... etc) [4, 5].

The mechanism behind the formation of surface roughness is very dynamic, complicated and process dependent It is very difficult to calculate its value through theoretical analysis. Therefore, machine operators usually use (trial and error) approaches on set-up milling machine cutting conditions in order to achieve the desired surface roughness [6]. It is obvious that, trial and error method is not effective and efficient and the achievement of a desirable value is a repetitive and empirical process that can be very time consuming. The dynamic nature and widespread usage of milling operations in practice have raised a need for seeking a systematic approach that can help to set-up milling operations in a timely manner and also to help achieve the desired surface roughness quality [7].

Using gene expression programming (GEP) [8], surface roughness prediction has been done using a few experimental data. GEP is coming from its ability to generate mathematical equations that can be easily programmed even into programming for use in monitoring of surface quality. The parameters, which are used in this study are; spindle speed, feed rate, depth of cut and Ra for CNC end milling.

In [9], the development of models based on feed forward neural networks in predicting accurately both surface roughness and tool flank wear in finish dry hard turning was presented. Neural network

modes with cutting force inputs and a single output yielded better results than neural networks with two outputs, which predict surface roughness and tool wear together. In [10], 3D surface roughness prediction technique in end milling using regression analysis is investigated. From this work, regression analysis can be used trusty to find relationships between surface roughness parameters (S_a) and technological parameters (V , a , f). This work gives more realistic view of surface roughness. Also, from this work the technological parameters range plays a very important role on forming surface roughness.

In [11], the development of a response model for turning macro utilizing factorial design of experiment and response surface methodology are investigated. First order predicative model covering the cutting speed of 15-60 m/min, has been developed at 95% confidence interval. The surface roughness model is developed in terms of cutting speed, rate of feeds and depth of cut. In [12], data dependent systems analysis DDS method is used to characterize the surface generation in ultra-precision machining of AL/SiC MMCs. The metal cutting dynamics are characterized by the natural frequency, the damping ratio, and the relative contribution of the central wavelength components which make up the roughness profile of the workplace. From the experimental work and the analysis of this research, the cutting dynamics of the surface roughness possess a strong correlation with the surface generation mechanisms of MMCs. Moreover, the DDS analysis method provides an effective way to characterize quantitatively the effect of cutting phenomena such as the cut through and pulled out mechanisms on the surface generation in ultra-precision machining of AL/SiC MMCs. In [13], down milling machining process of Alumic-79 is modeled using the adaptive neuron fuzzy inference system (ANFIS) to predict the effect of machining variables (spindle speed, feed rate, depth of cut and number of flutes) on the surface roughness. Optimum surface roughness is achieved for four flutes at the specific machining variables.

In the present research, a mathematical model has been developed to predict the surface roughness of machined Al /SiCp workpiece using response surface method(RSM). Five parameters are used in this work; cutting speed, depth of cut, feed rate, fraction ratio and particle size.

2. EXPERIMENTAL WORK

2.1. Design of Experiment

The present investigation has been planned for achieving the desired prediction model of surface roughness on Al 1050 /SiCp composite machined parts. In order to achieve the desired aim, the investigations are planned in the following sequence; identifying parameters which are having influence on

surface roughness, conducting the experiments as per the design matrix, developing the experimental design matrix, developing the mathematical model, calculating the coefficients of model and testing the significance of the coefficients, checking the adequacy of the developed model and analyzing the effect of different parameters on surface roughness.

During machining, many factors affect the surface roughness. Feed rate and cutting speed are the important factors which affect the quality of surface roughness [14]. Depth of cut is another important factor affecting the finish of machined surfaces. It is found that, surface roughness and profiles are highly dependent on the depth of cut [15]. Therefore, the independently controllable predominant machining parameters that are having large influences on surface roughness of Al /SiC (MMC) specimens have been identified. They are; i) cutting speed; ii) feed rate, iii) depth of cut. Also, in this work volume fraction ratio and particle size are investigated. The chosen parameters, units and their levels chosen are summarized in Table (1).

2.2. Conducting the Experiment

2.2.1. Matrix material

Aluminum alloy 1050 is used in this work. This alloy is popular grade of aluminum for general applications where moderate strength is required. Al 1050 is known for excellent corrosion resistance, high ductility and highly reflective finish. The physical and mechanical properties of Al 1050 are listed in Table (2). And also the chemical composition of Al 1050 is listed in Table (3).

2.2.2. Reinforcement materials

Silicon carbide particulate (SiCp) is used as reinforcement material in this work. The physical and mechanical properties of SiC are listed in Table (4) and chemical composition is listed in Table (5).

3. CASTING OF SPECIMENS

The following steps are used for fabrication the Al 1050/SiCp composites;

- 1- Determination the volume of Al 1050 alloy depending on the dimensions of specimen and the quantity,
- 2- Determinations the volume of silicon carbide (SiCp), these volumes are related to the ratios of volume fraction used in this research. These ratios are; 5, 10, 15, 20 and 25%.
- 3- The particle size which used are; 7, 10, 14, 20 and 25µm
- 4- The reo-cast method is used for fabricating the specimens.

4. MACHINING OF SPECIMENS

Four teeth, ten-millimeter diameter, HSS end mill cutting tool is used. A new cutter is used after each of experiment. The cutter is used for only five pieces of specimens to eliminate tools wear effect at the dry cutting. Therefore, five new cutters are used in this work, also, five of; cutting speed, feed rate, and depth of cut are used in these investigations.

The machining operations are carried out as per the condition given by the design matrix (Table 6) at random to avoid systematic errors.

Table 1, The levels used of identified factors

Parameters	Levels used					Range of par,	
	(-2)	(-1)	(0)	(+1)	(+2)	Min	Max
Cutting speed, rpm	28	45	90	112	140	28	140
Depth of cut, mm	0.25	0.5	1.0	1.25	1.5	0.25	1.5
Feed, mm/rev	0.4	0.6	0.8	1.0	1.25	0.40	1.25
Volume fraction %	5	10	15	20	25	5	25
Particle size µm	7	10	14	20	25	7	25

Table 2, Physical and mechanical properties of Al 1050

Property	Value
Proof stress -2%	35 MPa
Tensile strength	80 MPa
Shear strength	50 MPa
Elongation, A5	42 %
Hardness Vickers	20 HV
Density	2.71 gm/cm ³
Melting point	650°C
Modulus of elasticity	71 GPa
Electrical resistivity	0.0282x10 ⁻⁶ -Ωm
Thermal conductivity	222 w/m.k
Thermal expansion	24 x 10 ⁻⁶ /k

Table 3, Chemical composition of Al 1050

Element	% Present
Cu	0.05%
Mg	0.05%
Si	0.25%
Fe	0.4%
Mn	0.05%
Zn	0.07%
Ti	0.05%
Al	Balance

Table 4, Physical and mechanical properties of SiC

Property	Value
Density	3.1 gm/cc
Porosity	0.0 %
Flexural strength	550 MPa
Elastic modulus	410 GPa
Poisons ratio	0.14
Compressive strength	3900 MPa
Hardness	2800
Fracture toughness	4.6 MPa
Max use temperature (no-load)	1650 °c
Thermal conductivity	120 w/m.°k

5. SURFACE ROUGHNESS MEASUREMENT

The machined parts are prepared accurately for measurements. The instrument which used is SJ-20ip. After measuring operations, the results are tabulated for every specimen and classified into groups related to the following parameters 1) volume fraction, 2) particle size, 3) cutting speeds, 4) depth of cut, and 5) feed rate.

Table 5, Chemical composition of SiC

Normal abrasive practical size range (µm)	1180 ~ 1000 to 180 ~ 150	150 ~ 125 to 90 ~ 63	75 ~ 53	63 ~ 50 to 20 ~ 14	14 ~ 10 to 10 ~ 7	7 ~ 5 to 5 ~ 3.5
Chemical composition % (by weight)	≥ 99.0%	≥ 98.5%	≥ 97.5%	≥ 97.0%	≥ 95.5%	≥ 94.0%

Table 6, Design matrix at random to a void systematic error

Code No.	Cutting speed rpm (V)	Depth of cut, mm (d)	Feed rate mm/rev (f)	Vol. fraction% age (Vf)	Particle size µm (ps)	Ra µm
1	28	0.25	0.40	5.0	7.0	2.1
2	45	0.25	0.40	5.0	7.0	1.9
3	90	0.25	0.40	5.0	7.0	1.3
4	112	0.25	0.40	5.0	7.0	1.15
5	140	0.25	0.40	5.0	7.0	0.6
1	28	0.50	0.60	10	10	2.5
2	45	0.50	0.60	10	10	2.2
3	90	0.50	0.60	10	10	1.5
4	112	0.50	0.60	10	10	1.2
5	114	0.50	0.60	10	10	0.8
1	28	1.0	0.8	15	14	4.0
2	45	1.0	0.8	15	14	3.0
3	90	1.0	0.8	15	14	2.5
4	112	1.0	0.8	15	14	2.0
5	140	1.0	0.8	15	14	1.5
1	28	1.25	1.0	20	20	4.5
2	45	1.25	1.0	20	20	3.9
3	90	1.25	1.0	20	20	3.0
4	112	1.25	1.0	20	20	2.6
5	140	1.25	1.0	20	20	2.2
1	28	1.5	1.25	25	25	5.2
2	45	1.5	1.25	25	25	4.0
3	90	1.5	1.25	25	25	3.5
4	112	1.5	1.25	25	25	3.0
5	140	1.5	1.25	25	25	2.6

6. DEVELOPING THE EXPERIMENTAL DESIGN MATRIX

Central composite rotatable designs of second order have been found to be the most efficient tool in response surface model (RSM) to establish the mathematical relation of the response surface using the smallest possible number of experiments without losing its accuracy. The identified factors, lower and upper limits are discussed before and shown in Table (1). Table (7) shows the 32 set of coded conditions used from the control composite rotatable design matrix. It comprises of full replication of $2^5=32$ factorial design.

All the chosen variables at intermediate level (0) constitute the center points and the combination each of the variable at either its lowest (-2) or highest (+2) with the other three variables of the intermediate levels constitute the star points.

Thus, the 32 experimental runs allowed the estimation of the linear, quadratic and two ways interactive effects of the variables on the surface roughness. The method of designing such a matrix is dealt in [11]. For the convenience of recording and processing the experimental data, the upper and lower levels of the parameters are coded as (+2) and (-2). The coded value of any intermediated levels can be calculated by using the following expression;

$$Xi = \frac{[2x - (x_{max} + x_{min})]}{[x_{max} - x_{min}]} \cdot \frac{1}{2}$$

Where, x_{max} is the upper level of the parameter, x_{min} is the lower level of the parameter and xi is the required coded values of the parameter of any value of x from x_{min} to x_{max} .

Table 7, Layout of central composite rotatable design matrix.

S	A	B	C	D	E	A ²	B ²	C ²	D ²	E ²	AB	AC	AD	AE	BC	BD	BE	CD	CE	DE
1	-1	-1	-1	1	1	1	1	1	1	1	1	1	1	-1	1	1	-1	1	-1	-1
2	1	-1	-1	-1	-1	1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	1
3	-1	-1	-1	-1	-1	1	1	1	1	1	-1	+1	1	1	-1	-1	-1	1	1	1
4	1	1	-1	-1	1	1	1	1	1	1	1	-1	-1	1	-1	-1	1	1	-1	-1
5	-1	-1	1	-1	-1	1	1	1	1	1	1	-1	1	-1	-1	1	1	-1	-1	1
6	1	-1	1	-1	-1	1	1	1	1	1	-1	1	-1	1	-1	1	1	-1	-1	1
7	-1	1	1	-1	1	1	1	1	1	1	-1	-1	1	-1	1	-1	1	-1	1	-1
8	1	1	1	1	-1	1	1	1	1	1	1	1	1	1	1	1	-1	1	1	-1
9	-1	-1	-1	1	-1	1	1	1	1	1	1	1	-1	-1	1	-1	-1	-1	1	-1
10	1	-1	-1	1	1	1	1	1	1	1	-1	-1	1	1	1	-1	-1	-1	-1	1
11	-1	1	-1	1	-1	1	1	1	1	1	-1	1	-1	-1	-1	1	-1	-1	1	-1
12	1	1	-1	1	1	1	1	1	1	1	1	-1	1	1	-1	1	1	-1	-1	1
13	-1	-1	1	1	-1	1	1	1	1	1	1	-1	-1	1	-1	-1	1	1	-1	-1
14	1	-1	1	1	-1	1	1	1	1	-1	1	-1	1	-1	1	-1	1	1	-1	-1
15	-1	1	1	1	1	1	1	1	1	-1	-1	-1	-1	1	1	1	1	1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17	-2	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	2	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	-2	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	2	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	-2	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	2	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	-2	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	2	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	-2	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	2	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	2	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

7. DEVELOPING THE MODEL

Representing the surface roughness of Al /SiCp (MMC) (Ra), the response function can be expressed as:

$$Ra = f(A, B, C, D, E)$$

The chosen model is a second-degree response surface and can be expressed as follows;

$$Ra = C_0 + C_1(A) + C_2(B) + C_3(C) + C_4(D) + C_5(E) + C_6(AB) + C_7(AC) + C_8(AD) + C_9(AE) + C_{10}(BC) + C_{11}(BD) + C_{12}(BE) + C_{13}(CD) + C_{14}(CE) + C_{15}(DE) + C_{16}(A^2) + C_{17}(B^2) + C_{18}(C^2) + C_{19}(D^2) + C_{20}(E^2)$$

The values of the coefficients have been calculated and after determining the significant coefficients, the final model is developed in coded values and is given as follows:

Surface roughness (Ra)=
 $-4.506 + 0.065(A) + 4.56(B) - 2.07(C) - 0.005(D) - 0.63(E) - 0.008(AB) - 0.004(AC) - 0.001(AE) + 0.183(BC) + 0.312(BD) - 0.312(CD) - 0.17(CE) - 0.039(DE) - 0.008(DE) - 4.78(B^2) - 0.358(C^2) - 0.004(E^2)$

8. CHECKING THE ADEQUACY OF THE DEVELOPED MODEL

By using the analysis of variance technique, the adequacy of the model is checked. As per this technique, if the calculated value F ratio of the developed model does not exceed the standard tabulated value of ratio for a desired level of confidence, then the model is considered to be adequate within the confidence limit. In Table (8), ANOVA test results are presented. The experimental results and predicated data are presented in Table (9) and plotted as shown in Fig. 1.

Table 8, Analysis of variance for surface roughness

Source	DF	SEQ SS	Adj SS	Adj MS	F-ratio	P%
Regression	20	21.939	21.939	1.0969	0.71	75
Linear	5	9.323	7.757	1.5513	1.01	4.5
Square	5	5.421	4.913	0.9832	0.64	6.7
Interaction	10	7.195	7.195	0.7195	0.47	8.8
Residual error	11	16.921	16.921	1.5383		
Lack of fit	4	12.316	12.316	3.0790	4.68	3.7
Pure error	7	4.605	4.605	0.6579		
Total	31	38.860				100

Table 9, Experimental and predicted results of surface roughness

Experimental	Predicted
2.1	2.35
1.9	1.89
1.3	1.4
1.15	1.14
0.6	0.69
2.5	2.05
2.2	2.83
1.5	1.53
1.2	1.31
0.8	0.79
4	3.8
3	3.1
2.5	2.05
2	2
1.5	1.41
4.5	4.64
3.9	3.81
3	2.98
2.6	2.62
2.2	2.20
5.2	5.32
4	3.92
3.5	3.41
3	3.01
2.6	2.65

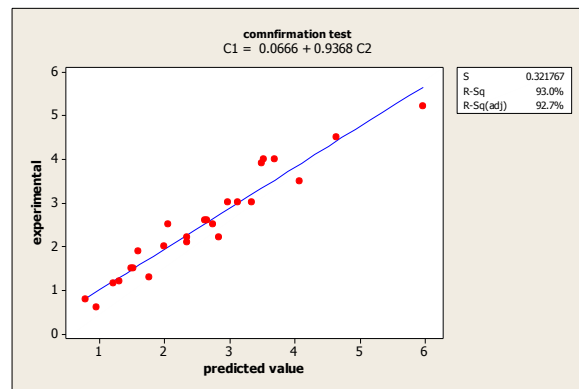


Fig. 1 The correlation between experimental and predicated results

9. DISCUSSIONS

9.1 Microstructure of Al / SiCp MMCs

Figures 2 to 11 show the microstructures of the composites with 5,10,15,20 and 25 % of volume fraction of SiC particles reinforcement. From these figures, it can be seen that, for all ratios of fraction, the SiC particles are distributed uniformly in the Al 1050 matrix. Pores generally co- exist with the SiC particles, which indicate that, the interfacial cohesion between the SiC particles and matrix is relatively weak.

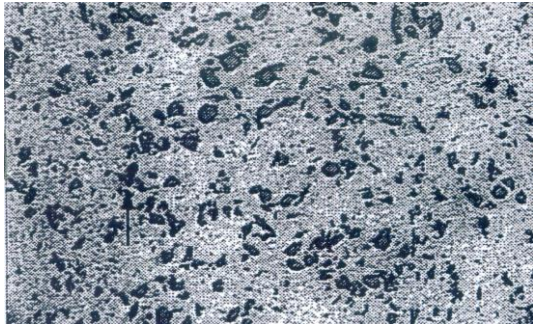


Fig. 2 Microstructure of Al 1050 /SiCp composite
($V_f=5\%$, $P_s=7\mu\text{m}$),(X200)

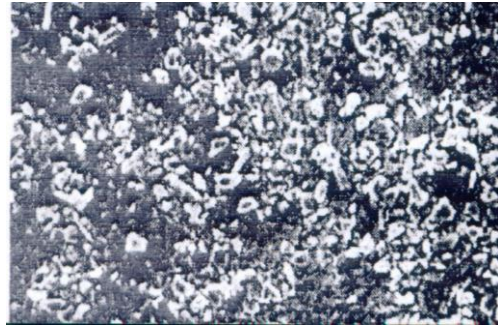


Fig. 6 Microstructure of Al 1050 /SiCp composite
($V_f=25\%$, $P_s=7\mu\text{m}$),(X200)

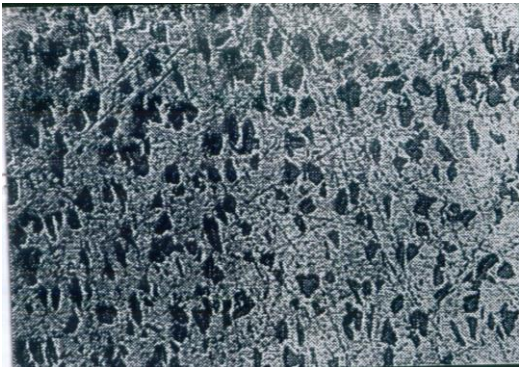


Fig. 3 Microstructure of Al 1050 /SiCp composite
($V_f=10\%$, $P_s=7\mu\text{m}$),(X200)

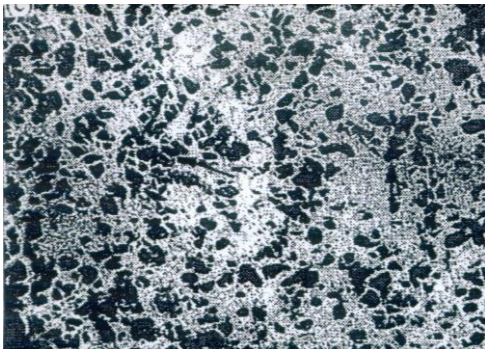


Fig. 4 Microstructure of Al 1050 /SiCp composite
($V_f=15\%$, $P_s=7\mu\text{m}$),(X200)

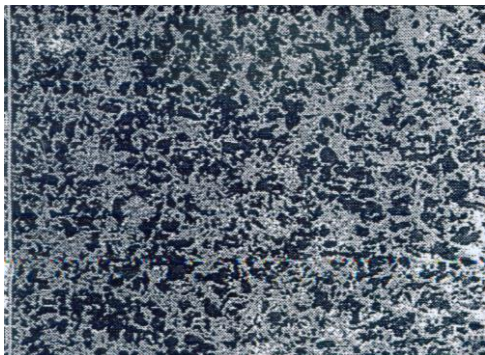


Fig. 5 Microstructure of Al 1050 /SiCp composite
($V_f=20\%$, $P_s=7\mu\text{m}$),(X200)

9.2. Microstructure of Machined Surface

The microstructure of machined surface for Al 1050/SiCp MMCs reinforced with five different V_f ratios of SiC particles are shown in Figs 7 to 11. From these figures, it is clear that, during machining of these composites, cracking and de bonding are typical damage mechanisms that greatly affect the integrity of produced surface. The particles pulled out by the cutter during cutting process leaved behind large pit holes, voids and craters that facilitate the formation of fatigue cracks. Sever damage to the machined surface can be generated due to high temperature gradients during the cutting process. This may be due to residual stress along with micro and macro cracks on the aluminum matrix that was plastically deformed causing severe hardness alterations and metallurgical transformations in the material of MMC. Also during cutting MMCs, the ductile aluminum matrix is subjected to high compressive stress by the cutter, leading to non homogenous plastic deformation. Subsequently, small pieces of the workpiece material adhere to the cutter and are welded firmly due to high temperature and pressure during cutting process. As the cutting progresses, the conglomeration of workpiece material becomes larger and unstable and when they shear off with the chip they create micro defects on the new surface. It is obvious that, the machined surface of aluminum matrix will be different when measured very close to or away from the SiC particles and proper care was taken in this regard. In addition to volume fraction ratio and particle size and the cutting parameters play a vital role in the resultant surface. The increase in cutting speed corresponds to an increase in strain, strain rate and temperature. The kinetics of plastic flow of the aluminum matrix is highly dependent on the cutting conditions. Consequently, the hardness changes are expected in the aluminum matrix due to plastic deformation and material volume changes associated with thermal gradients.

At lower cutting speeds, the heat generated is lower and higher mechanical stresses are imposed on

the surface layer due to higher cutting forces generated. As a result, the effect of work hardening of the matrix dominates the loss of strength due to thermal softening of the matrix material. From figures 7 to 11, the microstructure analysis revealed highly work hardened aluminum grains in the surface layer at lower cutting speed.



Fig. 7 Machined surface of Al 1050/15% SiCp ($V=28$ rpm, $\delta=0.25$ mm, $f=0.4$ mm/rev, $V_f=5\%$, $P_s=7.0\mu\text{m}$), (X200)

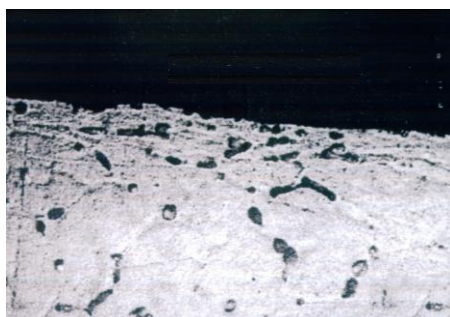


Fig. 8 Machined surface of Al 1050 SiC ($V=45$ rpm, $\delta=0.5$ mm, $f=0.6$ mm/rev, $V_f=10\%$, $P_s=10\mu\text{m}$), (X200)



Fig. 9 Machined surface of Al 1050/ SiC ($V=90$ rpm, $\delta=1$ mm, $f=0.8$ mm/rev, $V_f=15\%$, $P_s=14\mu\text{m}$), (X200)



Fig. 10 Machined surface of Al1050/SiC ($V=112$ rpm, $\delta=1.25$ mm, $f=1.0$ mm/rev, $V_f=20\%$, $P_s=20\mu\text{m}$), (X200)

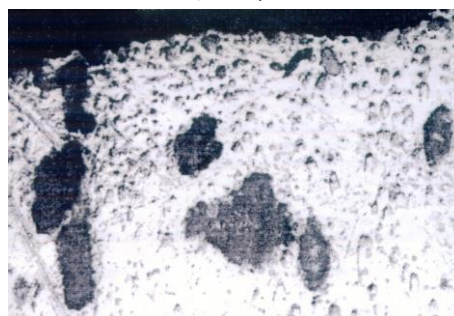


Fig. 11 Machined surface of Al 1050/ SiC ($V=140$ rpm, $\delta=1.5$ mm, $f=1.25$ mm/rev, $V_f=25\%$, $P_s=25\mu\text{m}$), (X200)

9.3 Effect of Cutting Speed on the Resultant Surface Roughness

The cutting speeds used in the machining of Al 1050/ SiCp MMCs are 28, 45, 90, 112 and 140 rpm. Figure 12 shows the influence of the cutting speed on the resultant surface roughness (Ra) with five different depth of cut at fixed feed rate 0.4 mm/rev, volume fraction 5% and particle size 7.0 μm

From this Figure, it can be seen that, as cutting speed increases, Ra decreases. The increase in the depth of cut leads to increase in the roughness of machined surface. The increase in cutting speeds and decreases the depth of cut lead to better surface roughness. Normally higher cutting speed and low depth of cut is suitable for machining Al /SiCp MMCs for getting a good surface finish, but the higher cutting speed should not be more than 140 m/min. More studies must be done for the use of cutting speed more than 140 rpm.

Figure 13 illustrates the variation of surface roughness (Ra) with respect to different cutting speeds (28, 45, 90, 112 and 140 rpm) at different feed rates (0.4, 0.6, 0.8, 1.0 and 1.25 at fixed depth of cut (0.25 mm), particle size (7 μm) and volume fraction 5%). From this Figure the surface roughness (Ra) decreases nonlinearly with the increase of cutting speed. The surface roughness (Ra) reduces in a proposed manner up to a cutting speed of around

120rpm. It is clear that, the increase in feed rate leads to the increase in the surface roughness (Ra). In the case of feed rate (0.4 mm/rev), the values of surface roughness (Ra) are less in all of different speeds as compared with the other values of feed rates. In this part of results, it is obvious that, the surface roughness (Ra) increases with the increase of feed rate, but it fluctuates with different feed rates. It may be due to the imperfection and uneven distribution of SiC particles.

Figure 1 shows the influence of the cutting speeds with different volume fractions (5, 10, 15, 20 and 25% of SiCp) at depth of cut 0.25mm, particle size 7 μ m and feed rate 0.4 mm/rev. From this Figure, the surface roughness decreases nonlinearly with the increase of cutting speed. The surface roughness increases with the increase of fraction ratio. It may be due to the increase of hard particles which had a large effect on the cutter teeth. It is also may be due to un-even distribution of the SiC particles in manufacturing and particle pull-out during the machining operation. From this Figure, the values of (Ra) are larger than that of the previous results, it is due to the increase of fraction ratio and respectively the increase in the number of hard grains.

Figure 15 illustrates the variation of surface roughness (Ra) with respect to different cutting speed and different particles sizes (7, 10, 14, 20 and 25 μ m) at feed rate 0.4 mm/ rev, depth of cut 0.25 mm and volume fraction 5%.

From this Figure, the resultant surface roughness (Ra) decreases non-linearly with the increase of cutting speed. The increase in the particle size leads to an increase in the values of surface roughness (Ra). In this Figure, the values of surface roughness (Ra) are very large as compared with the previous results. It is may be due to the increase of particle size of SiC reinforcement. Also, part of machined surface is composed of pits and voids where SiC is pulled out. This led to bad surface and respectively led to an increase of (Ra).

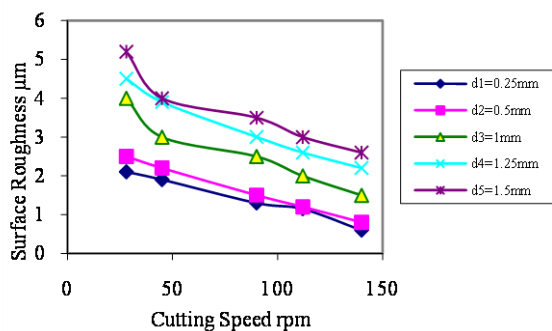


Fig. 12 Cutting speed –Ra relations with varying depth of cut at (f = 0.4mm/rev, Ps= 7 μ m and Vf= 5%)

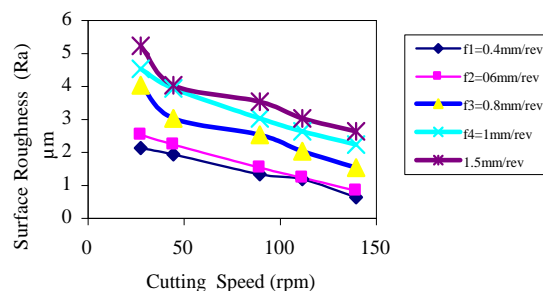


Fig. 13 Cutting speed –Ra relations with varying feed rates at (d = 0.25mm, Ps= 7 μ m and Vf= 5%)

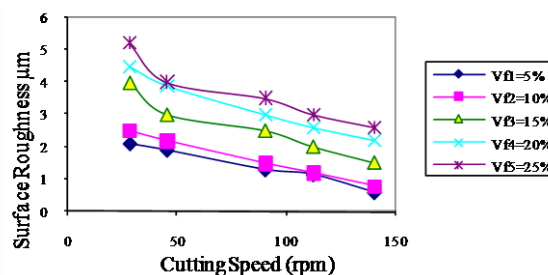


Fig. 14 Cutting speed –Ra relations with varying fraction ratio at (d = 0.25mm, Ps= 7 μ m and f= 0.4mm/rev)

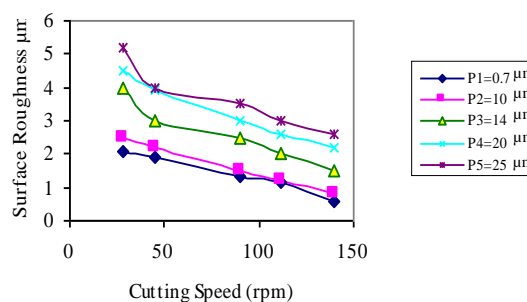


Fig. 15 Cutting speed –Ra relations with varying particle size at (f = 0.4mm/rev, d= 0.4mm and Vf= 5%)

9.4. Effect of Depth of Cut on the Resultant Surface Roughness

The depth of cut used in the machining of Al 1050 SiCp MMCs are, 0.25, 0.5, 1.0 1.25 and 1.5 mm. Figure 16 shows the influence of the maintained depth of cut with five cutting speeds, 28, 45, 90, 112 and 140 rpm on the resultant surface roughness. The previous conditions of cutting are used with fixed feed rate 0.4 mm/rev, particle size 7 μ m and volume fraction 5%. From this figure, the surface roughness increases with the increase of depth of cut for various cutting speed. But, the increase of cutting speed leads to better surface roughness. The increase of depth of cut, results dusty chips, which were easy to fall into

the spacing between the workpiece and the flank face of the cutter. It might be cut once again or pressed into the matrix by cutting tool.

In Fig. 17 the relations between depth of cut and (Ra) are presented with varying feed rates ,0.4,0.6 ,0.8 ,1.0 and 1.5 mm/rev and fixed values of , particle size $7\mu\text{m}$, volume fraction 5% and cutting speed 28 rpm.

From this figure, the surface roughness (Ra) increases with the increase of depth of cut. On the other hand, the increase of feed rate leads to increase of surface roughness (Ra). In the small values of both depth of cut and feed rate, the surface roughness (Ra) is better as compared with the large values of the two parameters. As example, in the case of depth of cut equal 0.5mm and feed rate 0.4mm/rev, the value of Ra is less than $1.0\mu\text{m}$, but in the case of depth of cut equal 0.5mm and feed rate 1.5mm/rev, the Ra value is more than $2.0\mu\text{m}$. The increase of Ra values in the previous cases, is due to the increase in the shearing cutting part as compared with the small values of depth of cut and feed rate.

The increase in the depth of cut, results an increase of the defects in the resultant surface, such as grooves and scratches. These defects are induced by SiC particles which plowed through the machined surface for some distance. The surface roughness is become badly and respectively the values of Ra are increased.

In Fig. 18 the relations between depth of cut and Ra with varying volume fraction are presented. The ratios of volume fraction are, 5, 10, 15, 20 and 25% of SiC particulates. These are plotted with fixed values of feed rate 0.4mm/rev, particle size $7\mu\text{m}$ and cutting speed 28 rpm.

From this figure, it can be seen that, as depth of cut increases, Ra values are increased with all value of fractions ratio. In the range of small values of depth of cut and volume fraction , the surface roughness is better than that of any other values of the two parameters.

The increase of volume fraction from 5% to 25% lead to dramatic increase in the resultant surface roughness from nearly, ($2\mu\text{m}$ at 0.5mn depth of cut to $6\mu\text{m}$ at the same depth of cut) . The increase of volume fraction, hard particles of SiC have a large effect on the cutting edge of cutter , and some of these particles are pulled out and adopt the values of surface roughness (Ra) are increased.

Figure 19 illustrates the variation of surface roughness (Ra) with respect to different depth of cut. The particle size used are, 7, 10, 14 ,20 and $25\mu\text{m}$). Feed rate, volume fraction and cutting speed are fixed and their values are 0.4mm /rev., 5% and 28 rpm respectively.

From this figure, the resultant surface roughness (Ra) increases with the increase of depth of cut at different particle sizes. The values of (Ra) ranged between $2.8\mu\text{m}$ nearly to $7.0\mu\text{m}$ when the particle size is changed from $7.0\mu\text{m}$ to $25\mu\text{m}$. The increase of the particle size of SiC reinforcement increases in the friction between the machined surface and the cutter edges. In this case, the cutter is pressed the SiC particles and embedded into the softer matrix. The large values of (Ra) and the badness of surface is the result of the previous case.

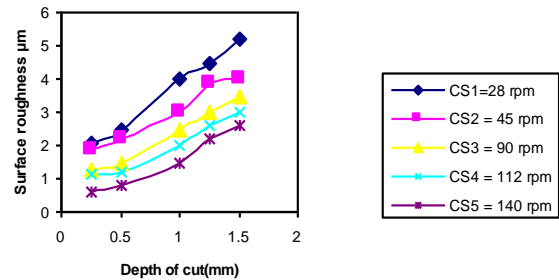


Fig. 16 Depth of cut-Ra relations with varying cutting speed at ($f=0.4\text{ mm/rev}$, $P_s=7\mu\text{m}$, and $V_f=5\%$)

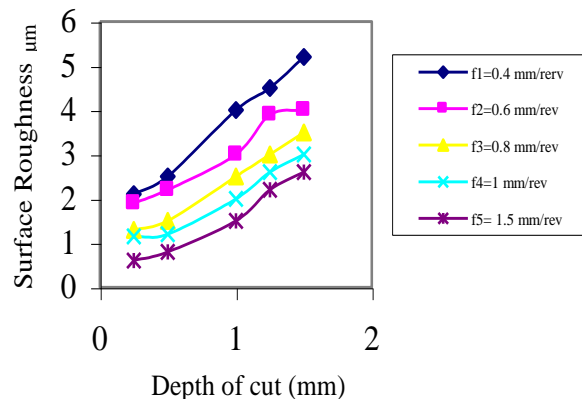


Fig. 17 Depth of cut-Ra relations with varying feed rate at ($P_s=7\mu\text{m}$, $V_f=5\%$ and cutting speed =28rpm)

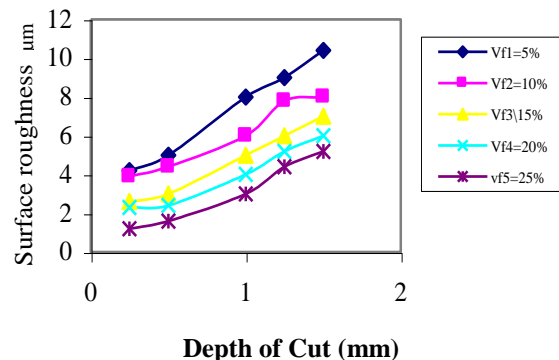


Fig. 18 Depth of cut-Ra relations with varying fraction ratios at ($f=0.4\text{ mm/rev}$, $P_s=7\mu\text{m}$ and cutting speed = 28 rpm)

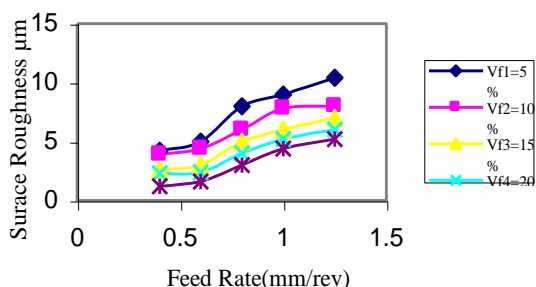


Fig. 19 Depth of cut-Ra relations with varying practical size at ($f=0.4$ mm/rev, $V_f=5\%$ and cutting speed =28 rpm)

9.5. Effect of Feed Rate on the Resultant Surface Roughness

The feed rates used in the machining of Al 1050/SiCp MMCs are, 0.4,0.6,0.8,1.0and 1.25 mm/rev, The fixed values of particle size , volume fraction and cutting speed are, $7\mu\text{m}$, 5% and 28 rpm respectively .

From Fig. 20 it can be seen that, as feed rate is increased the surface roughness (Ra) increase. Also, the increase in depth of cut leads to an increase in surface roughness values with various values of feed rate .In the case of smallest value of feed rate (0.4mm/rev) and (0.25mm) depth of cut, the Ra value is nearly $0.5\mu\text{m}$, but when the feed rate is equal 1.25mm/rev and the same depth of cut , the (Ra) value is become more than $0.2\mu\text{m}$. It obvious that, (Ra) is increases with the increase of feed rate and depth of cut. The increase of feed rate leads to an increase the micro cracks which are formed either due to part of the SiC reinforcement detached from the matrix or due to the rotation of the SiC reinforcement in order to adapt the deformation of the matrix around it.

Figure 21 illustrates the variation of surface roughness (Ra) with respect to different feed rates as mentioned in the previous figure with five cutting speeds (28,45,90,112 and 140 rpm), at fixed particle size $7\mu\text{m}$, volume fraction 5% and depth of cut 0.25mm .It is clear that, the surface roughness increases with the increase of feed rate and decreases with the increase of cutting speed.

At feed rate 1.0 mm/rev, rapid increase of (Ra) in all values of cutting speeds is observed. But the large value of cutting speed 140m/min gives a better surface roughness for all values of feed rates. The bad surface is clear in the large values of feed rates and small values of cutting speed. The increase of feed rate at lower cutting speed leads to the SiC reinforcement pressed into the soft matrix by the flank face of cutter. In this way, the groove created on the machined surface is wider and deeper towards the end and getting bad surface.

In Fig. 22, the relations between feed rate and surface roughness are presented with varying volume fraction (5,10,15,20 and 25%) at fixed values of particle size $7\mu\text{m}$, depth of cut 0.25mm and cutting speed 28 rpm. From this Figure, the surface roughness (Ra) increase with the different values of feed rates and all value of volume fractions. At 0.8 mm/rev feed rate, the surface roughness is increased suddenly for all values of volume fraction. It is may be due to the fracture parts or a pulled out reinforcements fell into interspaces between the flank face and machined surface and give a bad surface finish.

Figure 23 illustrates the variation of surface roughness (Ra) with respect to different feed rates at fixed depth of cut 0.25mm, volume fraction 5% and cutting speed 28 rpm . From this Figure, the resultant surface (Ra) increases with the increase of feed rate and particle size. The increase of particle size from $7\mu\text{m}$ to $25\mu\text{m}$ lead to increase in surface roughness value from 1.5mm to 6.0mm at feed rate equal 0.4 mm/rev. Also, the change of feed rate from 0.4 mm/rev to the maximum value 1.25mm/rev, leads to an dramatic increase in the values of surface roughness. From this Figure it is obvious that, the particle size plays a vital role in the resultant surface roughness. It is may be due to the increase of friction between the tooth of cutter and the particles of SiC reinforcement. Some of particles are sheared or pulled out, and matrix is tearing also. The fracture parts are pressed into the tearing matrix and give a bad surface roughness.

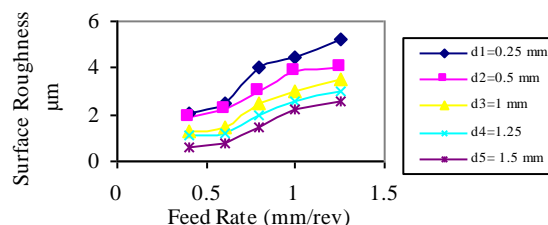


Fig. 20 Feed rate –Ra relations with varying depth of cut at ($P_s=7\mu\text{m}$, $V_f=5\%$ and cutting speed = 28rpm)

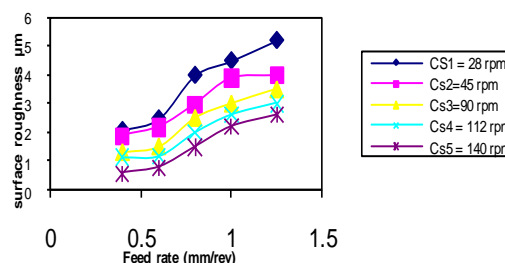


Fig. 21 Feed rate –Ra relations with varying cutting speed at ($P_s=7\mu\text{m}$, $V_f=5\%$ and $d=0.25\text{mm}$)

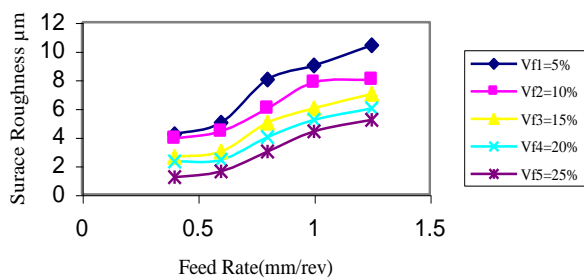


Fig. 22 Feed rate –Ra relations with varying fraction ratios at ($P_s=7\mu\text{m}$, $d=0.25\text{ mm}$ and cutting speed =28 rpm)

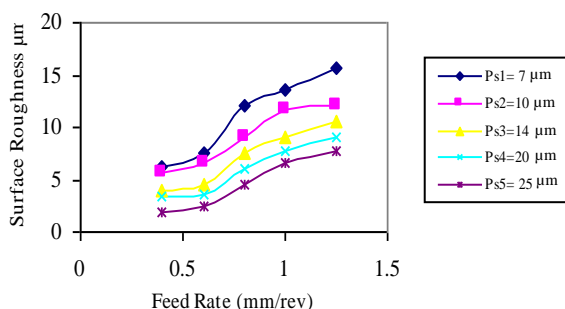


Fig. 23 Feed rate –Ra relations with varying practical size at ($d=0.25\text{mm}$, $V_f=5\%$ and cutting speed = 28rpm)

9.6. Effect of Volume Fraction on the Resultant Surface Roughness

Figure 24 shows the influence of volume fractions with different depths of cut values on the resultant surface roughness (Ra) for the machined parts of Al 1050/SiCp. In these experiments, the particle size is equal $7.0\mu\text{m}$, feed rate 0.4 mm/rev , and cutting speed 28 rpm .

From this figure, it can be seen that, as the volume fraction of reinforcement is increase the resultant surface roughness (Ra) increase for all values of depth of cut. At low levels of Vf (5%)and ($d=0.25\text{ mm}$), the resultant surface is better as compared with any other values. It must be noted that, in this case the particle size and depth of are small also. The bad surface in these results is due to the increase in both volume fraction and depth of cut. The increase of volume fraction leads to increase of particles number. This increase the friction between the cutting edge and particles at the machined surfaces. Also, the increase of friction leads to increase of defects on the resultant surface, such as, grooves and scratches induced by the SiC particles.

Figure 25 shows the relations between volume fraction and the resultant surface roughness (Ra) at different feed rates ($0.4, 0.6, 0.8, 1.0$ and 1.25 mm/rev), with fixed values of particle size $7.0\mu\text{m}$, depth of cut 0.25mm and cutting speed 28 rpm . From

this figure, the surface roughness increases with the increase of volume fraction at all values of feed rate. At the low level of volume fraction and feed rate (5% and 0.4 mm/rev), the surface roughness is small as compared with other values of volume fraction and feed rate used in this investigation. Figure 26 shows the influence of the volume fraction on surface roughness (Ra) with varying cutting speed ($28.45.90.112$ and 140 rpm) at fixed values of particle size $7.0\mu\text{m}$ depth of cut 0.25 mm and feed rate 0.4 mm/rev .

From this Figure, the increase of volume fraction leads to an increase in surface roughness (Ra) for all values of cutting speed. But at small value of volume fraction (5%) and large cutting speed (140 rpm), the surface roughness is better as compared with other ratios of volume fraction and all values of cutting speed used in these experiment. The use of large values of volume fraction and small values of cutting speed leads to an increase in the resultant surface roughness (Ra). It is may be due to the increase of particles numbers, and number of particles pulled out specially at low cutting speed, leave behind large bit holes and voids.

In Fig. 27 the relations between volume fraction and surface roughness (Ra) at varying particle size ($7.10.14.20$ and $25\mu\text{m}$) are presented at fixed values of feed rate 0.4 mm/rev , depth of cut 0.25 mm and cutting speed 28 rpm . From this Figure, the surface roughness increases with the increase of volume fraction at different particle size. At 5% volume fraction and particle size $7.0\mu\text{m}$ the resultant surface roughness is small as compared with other all volume fraction and particle size. The bad surface is clear at volume fraction ratio 25% and particle size $25\mu\text{m}$. It is may be due to the increase in the friction between the edge of cutter and the large number of particles. This lead to high temperature gradients during the cutting which generate residual stresses along with micro and macro cracks on the aluminum matrix and produce bad surface.

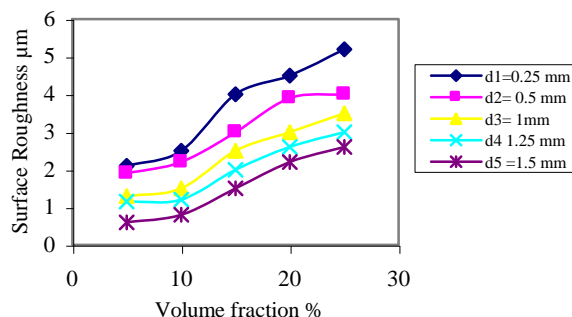


Fig. 24 Fraction ratio –Ra relations with varying depth of cut at ($P_s=7\mu\text{m}$, $f=0.4\text{ mm/rev}$ and cutting speed = 28rpm)

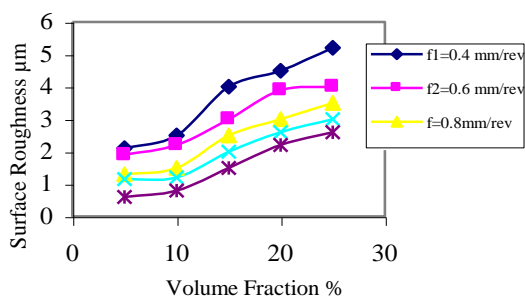


Fig. 25 fraction ratio –Ra relations with varying feed rate at (Ps= 7µm, d=0.25mm and cutting speed=28 rpm)

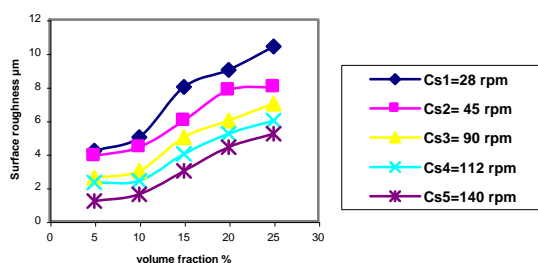


Fig. 26 Fraction ratio-Ra relations with varying cutting speed at(Ps= 7µm, d= 0.25 mm and f= 0.4 mm/rev)

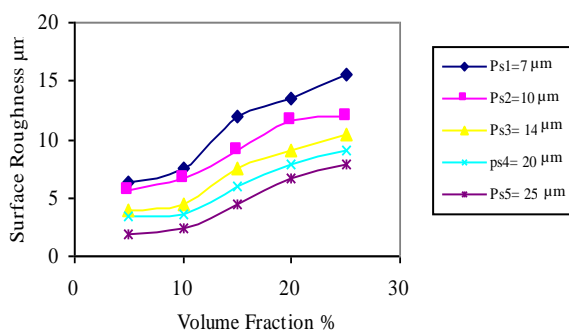


Fig. 27 Fraction ratios –Ra relations with varying particle size at (f= 0.4 mm/rev, d=0.25 mm and cutting speed = 28 rpm)

9.7. Effect of Particle Size on the Resultant Surface Roughness

The particle sizes of SiC particulates used in this work are, 7,10,14,20 and 25µm. Fig 28 shows the influence of the particle size on the resultant surface roughness (Ra) at different volume fraction (5,10,15,20 and25%) of SiC reinforcement at fixed values of feed rate 0.4 mm/rev , depth of cut 0.25mm and cutting speed 28 rpm . From these results, the surface roughness (Ra) increases with the increase of

particle size for all values of volume fractions. But at the small values of particle size 7µm and fraction ratio 5%, surface roughness value is small as compared with the other values of particle size and volume fraction. The increase of particle size and volume fraction results in an increase in the friction between the edge of cutter and the particles on the machined surface. This leads to deformation on the surface finish as mentioned before in the previous parts.

In Fig 29 the relation between the particle size and surface roughness (Ra) at varying cutting speeds (28, 45, 90,112 and 140rpm) with fixed values of feed rate 0.4 mm/rev, depth of cut 0.25mm and volume fraction 5%.

From this figure, it is clear that, the surface roughness increases with the increase of particle size for all values of cutting speed .At the small value of particle size (7µm) and cutting speed (140rpm) , the surface roughness is better as compared with other values of the parameters used in this experiment . At low cutting speed and large volume fraction ratio, the surface roughness is very bad .It is may be due to the increase of hard particles and respectively the increase of the friction between the edge of cutting tool and the machined surface. As mentioned before, this leads to various types of defects which are shown in the resultant surface.

Figure 30 shows the relation between the particle size and surface roughness (Ra) with varying depth of cut (0.25,0.5 1.5,1.25and1.5mm) at fixed values of feed rate 0.4 mm/rev volume fraction5% and cutting speed 28rpm. From this Figure it is obvious that, the increase of particle size leads to an increase of surface roughness (Ra) at the different values of depth of cut. The values of (Ra) are small when the depth of cut is (0.25mm) and particle size is equal (7µm).

On the other hand , the increase of particle size and depth of cut to 25µm and1.5mm , leads to dramatic increase in the value of surface roughness (Ra) .It is may be due to the increase of hard particles numbers of the SiC reinforcement and also the increase of chip thickness due to the increase of depth of cut. This causes some defects which affecting the resultant surface of the machined part.

Figure 31 shows the relation between particle size and surface roughness (Ra) with varying feed rate (0.4,0.6,0.8,1.0and 1.25mm/rev.) at fixed values of depth of cut 0.25mm, volume fraction 5% and cutting speed 28 rpm.

From this figure, it is clear that, the particle size and feed rate are play a vital role in the resultant surface roughness (Ra) . The increase of particle size leads to an increase of surface roughness (Ra) for all values of feed rate, particle size and feed rate, (7.0µm

and 0.4mm/rev). The surface roughness is better as compared with other values of particle size and feed rate. The surface roughness is very bad at the large values of particle size and feed rate. The increase of particle size and feed rate, lead to increase in friction between the edge of cutter and the SiC reinforcement. So, a little number of particles may be pulled out and the matrix may be tearing also. This lead to increase of Ra for the machined surface.

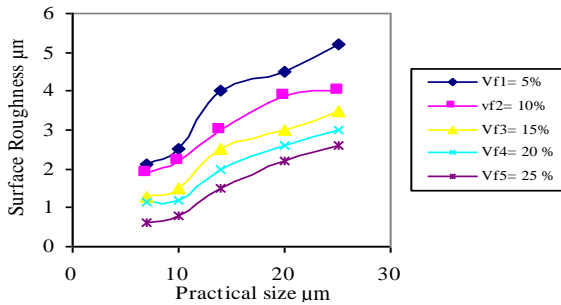


Fig. 28 Particle size–Ra relations with varying fraction ratio at (d=0.25mm, f=0.4 mm/rev and cutting speed = 28 rpm)

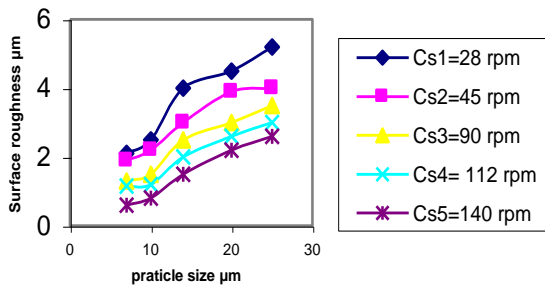


Fig. 29 Particle size–Ra relations with varying cutting speed at (f= 0.4mm/ rev, d= 0.25 mm and Vf=5%)

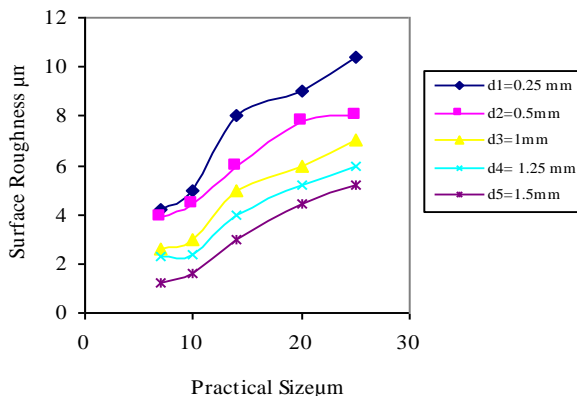


Fig. 30 Particle size –Ra relations with varying depth of cut at (f= 0.4 mm/rev, Vf= 5% and cutting speed =28 rpm)

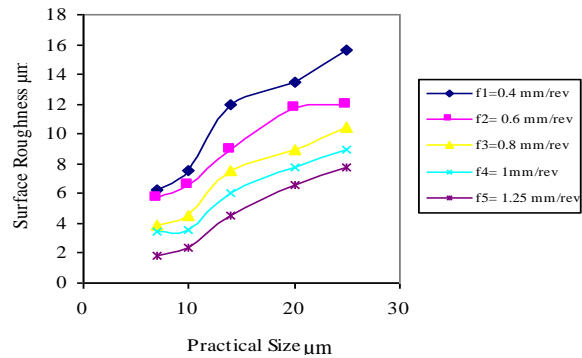


Fig. 31 Particle size –Ra relations with varying feed rate at (d= 0.25 mm, Vf= 5% and cutting speed =28 rpm)

10. CONCLUSIONS

The surface roughness model has been developed to correlate five important machining parameters in machining of Al 1050/SiCp MMCs. The rotatable central composite is used for the experimental design. The five parameters are; cutting speed, depth of cut, feed rate, volume fraction and particle size of SiC reinforcement. May be that is the first time these parameters are studied together. The effect of these parameters on the machined part surface roughness has been analyzed based on the developed mathematical model. Form this work; it can be concluded that;

1. The surface roughness (Ra) decreases with the increase of cutting speed up to 140 rpm.
2. The surface roughness (Ra) increases with the increase of depth of cut up to 1.5mm.
3. The surface roughness (Ra) increases with the increase of feed rate up to 1.25 mm/rev.
4. The surface roughness (Ra) increases with the increase of fraction ratio up to 25%.
5. The surface roughness (Ra) increases with the increase of practical size of SiC particles up to 25µ m.
6. The use of high cutting speed (140 rpm), depth of cut 0.25 mm, feed rate (0.4)mm/rev, volume fraction 5% and practical size (7.0µm) gives a good surface roughness (Ra) as compared with other values of parameters used this work.
7. The experimental results and the predicted values of (Ra) by using the developed model are indicate a good correlation.
8. The procedure followed in this work can be used to predict the surface roughness (Ra) for milling Al 1050 /SiCp MMCs within the ranges of studied parameters.

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