Application of Statistical Tool for Optimisation of Specific Cutting Energy and Surface Roughness on Surface Grinding of Al-SiC_{35p} Composites.

Dayanand Pai pai.dayanand@gmail.com
Dept. of Aero and Auto Engineering,
Manipal Institute of Technology,
Manipal University, Manipal.
India

Shrikantha S. Rao ssr_csr@gmail.com
Dept. of Mechanical Engineering,
National Institute of Technology Karnataka,
Suratkal, Karnataka.
India

Raviraj Shetty rrshetty2@rediffmail.com
Dept. of Aero and Auto Engineering,
Manipal Institute of Technology,
Manipal University, Manipal. India
India

Abstract

In this paper, the effects and the optimization of machining parameters on surface roughness and specific cutting energy during surface grinding of 6061Al-SiC_{35P} composites under different process parameters such as Vol% of SiC, feed and depth of cut were investigated using response surface methodology (RSM). The specific cutting energy and surface roughness are considered as performance characteristics. Experiments are conducted using standard RSM design called Central composite design (CCD). A second order response model was developed for specific cutting energy and surface roughness. The results identify the significant influence factors to minimise the specific cutting energy and surface roughness. Derringer's desirability function was then used for simultaneous optimization of specific cutting energy and surface roughness. The confirmation results demonstrate the practicability and effectiveness of the proposed approach.

Key words: Metal Matrix composites; Specific cutting energy; Surface Roughness; ANOVA; Response surface methodology; desirability function

1. INTRODUCTION

Discontinuously reinforced aluminium composites(DRAC's) is one of the important composites among the metal matrix composites, which have SiC particles with aluminium matrix is harder than tungsten carbide , which pose many problems in machining[1-2]. The aluminium alloy reinforced with discontinuous ceramic reinforcements is rapidly replacing conventional materials in various automotive, aerospace and automobile industries. But DRAC's grinding is one of the major problems, which resist its wide spread engineering application [3].

A fundamental parameter derived from the force measurements is the specific grinding energy, which is the energy per unit volume of material removal. Any proposed mechanisms of abrasive workpiece interactions must be consistent with the magnitude of the specific cutting energy and its dependence on the operating parameters [4]. While Al/SiC-MMC specimen slides over a hard cutting tool edge during grinding, due to friction, high temperature and pressure the particles of Al/SiC-MMC adhere to the grinding wheel which affects the surface quality of the specimen [5]. This also results in decreased uncut chip thickness and hence the increased specific cutting energy for grinding. Rowe et. al. Investigated the creep feed grinding of Nickel-based alloy and found that specific cutting energy is as high as 400 J/mm^3 for 150 mm^3 per mm width of metal removal [5]

A Di Ilio et.al [6] investigated the machining characteristics of Al2009-SiC-15P, Al2009-SiC-20P and Al2009-SiC-25P, concluded that composite shows better surface finish than the pure aluminium. They developed a model of the grinding process based on empirical relations and observed that workpiece surface roughness can be related with the equivalent chip thickness through a power relationship; it shows a decreasing linear trend as the hardness of workpiece material increases. Sanjay Agarwal et.al [7] conducted a study on surface and subsurface of the ground ceramic material and concluded that cutting force and specific cutting energy can considerably be reduced due to dislodgement of individual grains, resulting from microcracks along the grain boundaries. Brinksmeier et. al. [8] made an attempt to quantify the size effect and possibility of using this in grinding for controlled subsurface work hardening of metals. It is observed that, Main physical quantity characterizing the size effect is specific grinding energy which increases with decreasing chip thickness. Lowering cutting speed at a constant chip thickness shifts the chip formation mechanism towards micro-ploughing and thus additionally increases the specific grinding energy. Li et.al [9] investigated the effects of wheel wear on process responses and ground ceramic quality, particularly the flexural strength. Strong relationships between the wheel surface conditions and the process responses are found. During the initial stage of wheel wear, the surface density of diamond grits, surface roughness and flexural strength decreased, and the specific normal force, specific tangential force, force ratio, and specific cutting energy increased. Ren et.al [10] demonstrated the correlation of specific cutting energy with the grinding process parameters and the material property parameters for the tungsten carbides. The study also examines material-removal mechanisms and surface finish in grinding of such materials. Their study revealed that specific cutting energy is related not only to grinding process parameters, but also to the physical–mechanical properties of the workpiece material

Matheiu Barge et.al.[11] conducted scratching experiment on flat surface of AISI4140 steel and found that hardening and softening of the workpiece is key for the study of force and energy. Hwang et.al.[4] found that under a feed of 500 mm/min and for all the wheel speeds used, an increase in the wheel depth of cut from 0.1–2 mm slightly improved the ground surface finish, but greatly prolonged the wheel life. This increase did not deepen the subsurface damage layer for the alumina and alumina–titania, but resulted in a slightly deeper damage layer for the zirconia. Zhong et.al [12] conducted experiments on grinding of Al_2O_3 composites using SiC wheel and diamond wheel and found that SiC wheel is suitable for rough grinding and diamond wheel for finish grinding. Hood et.al.[13] used two separate L_9 taguchi fractional array for grinding of γ-TiAl alloy and BuRTi alloy and found that former require 10% less power and 25% less specific cutting energy compared to the later. They also observed that, high wheel speed, low depth of cut and low feed will result in improved surface roughness. Seeman et.al.[14] developed a second order response surface model for surface roughness and tool wear of Al/SiC composites. They concluded that formation of BUE will affect the tool wear and surface roughness. Krajnik [15] compared RSM and Genetic algorithm for centreless grinding of 9SMn28. Kwak and Kim [16] developed a second order response surface model for surface roughness and grinding force on grinding of Al/SiC/mg composites. They investigated that optimum content of SiC and Mg in AC8A aluminium alloy is 30vol% and 9vol% respectively. Kwak [17] presented the application of Taguchi and RSM for the geometric error. A second-order response model for the geometric error was developed and the utilization of the response surface model was evaluated with constraints of the surface roughness and the MRR. Box and Draper [18] proposed central composite rotatable design for fitting a second order response surface based on the criterion of rotatability.
From the above literature review it is evident that less amount of work is done to investigate the combined effect of specific cutting energy and surface roughness in grinding of Al-SiC composites. Hence in this study an attempt is made to optimise the specific cutting energy and surface roughness during grinding of Al-SiC_{35p} composites using desirability function in response surface methodology.

2. DESIGN OF EXPERIMENT BASED ON RESPONSE SURFACE METHODOLOGY

In order to investigate the influence of various factors on the Specific cutting energy (SE) and surface roughness (Ra), three principal factors such as the volume percentage of SiC (X_1), feed (X_2) and depth of cut (X_3) were taken. In this study, these factors were chosen as the independent input variables. The desired responses were the specific cutting energy (SE) and surface roughness (Ra) which are assumed to be affected by the above three principal factors. The response surface methodology was employed for modeling and analyzing the machining parameters in the grinding process so as to obtain the machinability performances of responses [2].

In the RSM, the quantitative form of relationship between the desired response and independent input variables is represented as $y = F(X_1, X_2, X_3)$

Where y is the desired response and F is the response function (or response surface). In the procedure of analysis, the approximation of y was proposed using the fitted second-order polynomial regression model, which is called the quadratic model. The quadratic model of y can be written as given in equation (1) [19-22]:

$$\hat{y} = a_0 + \sum_{i=1}^{n} a_i X_i + \sum_{i=1}^{n} a_{ii} X_i^2 + \sum_{i-1}^{n} \sum_{j=1}^{n} a_{ij} X_{ij} ------(1)$$

Where a_0 is constant, a_i, a_i, and a_{ij} represent the coefficients of linear, quadratic, and interaction terms respectively. X_i reveals the coded variables that correspond to the studied factors.

The necessary data for building the response models are generally collected by the experimental design. In this study, the collections of experimental data were adopted using central composite design (CCD). The factorial portion of CCD is a full factorial design with all combinations of the factors at two levels (high, +1 and low, −1) and composed of the six axial points and six central points (coded level 0) which is the midpoint between the high and low levels[23]. The star points are at the face of the cubic portion on the design which corresponds to a value of α =1 and this type of design is commonly called the face-centered CCD.

3. DESIRABILITY FUNCTION

The desirability function approach to simultaneously optimizing multiple equations was originally proposed by Harrington (1965) and later improved by Derringer and Suich (1984) [24]. Essentially, the approach is to translate the functions to a common scale ([0, 1]), combine them using the geometric mean and optimize the overall metric. The method involves transformation of each predicted response, ŷ, to a dimensionless partial desirability function, di, which includes the researcher's priorities and desires when building the optimization procedure. One or two-sided functions are used, depending on whether each of the n responses has to be maximized or minimized, or has an allotted target value. If the response is to be minimised the response di can be defined as:

$$d(y) = \left[\frac{H - \hat{y}}{T - H}\right]^{wt} \rightarrow T < \hat{y} < H ------(2)$$

$$1 \rightarrow \hat{y} < T$$

$$0 \rightarrow \hat{y} > H$$

In Eq. (2), L, H and T are, respectively the lowest, highest and the target values and wt is the weight. The value of wt can be varied between 0.1 and 10. The value of one creates a linear ramp function between the low value, goal and the high value. Increased wt moves the result towards the goal or its decrease creates the opposite effect. The partial desirability function d_i ranges between 0, (for a completely undesired response), and 1, (for a fully desired response).

The partial desirability functions are then combined into a single composite response, the global desirability function D, defined as the geometric mean of the different d_i-values:

$$D = (d_1^{v}{}_1 * d_2^{v}{}_2 * d_n^{v}{}_n)^{1/n} \quad (0 \leq D \leq 1) \text{ --------------(3)}$$

In equation (3) v_i is the relative importance assigned to the response i. The relative importance v_i is a comparative scale for weighting each of the resulting d_i in the overall desirability product and it varies from the least important (v_i = 1) to the most important (vi = 5). It is noteworthy that the outcome of the overall desirability D depends on the v_i value that offers users flexibility in the definition of desirability functions.

4. EXPERIMENTAL PROCEDURE

Al-SiC specimens having aluminum alloy 6061 as the matrix and containing 8 vol.%,10 vol.% and 12 vol.% of silicon carbide particles of mean diameter 35µm in the form of cylindrical bars of length 120mm and diameter 20mm. The specimens were manufactured at Vikram Sarbhai Space Centre (VSSC) Trivandrum by Stir casting process with pouring temperature 700-710℃, stirring rate 195rpm. The specimen were extruded at 457℃, with extrusion ratio 30:1, and direct extrusion speed 6.1m/min to produce length 120mm and Ø22mm cylindrical bars. The extruded specimens were solution treated for 2 hr at a temperature of 540°C in a muffle furnace; Temperatures were accurate to within ±2°C and quench delays in all cases were within 20s. After solution treatment, the samples were water quenched to room temperature. Further the specimen is machined to 17mm square cross-section. Table-1 shows the chemical composition of Al 6061 alloy. Grinding method as machining process was selected. Experiments were conducted on 5 HP, 2880rpm, conventional surface grinding machine (Bhuraji make) with automatic (hydraulic) table-feed and Norton make diamond grinding wheel ASD76R100B2 with outer diameter 175mm, width of 12.5mm, thickness of 5mm and inner diameter of 31.75 which is generally used for finishing operation. The honing stick having specification GN0390220K7V7 is used for dressing the wheel. The experiments conducted under dry conditions.

Table-1: Chemical composition of Al 6061 alloy

Element	Cu	Mg	Si	Cr	Fe	Al
Volume %	0.25	1	0.6	0.25	0.2	Balance

The levels and factors selected for the experimentation are given in Table-2. Selection of factors for optimization was based on preliminary experiments, prior knowledge of the literature, and known instrumental limitations. The time required for machining the each specimen is measured. The volume of metal removed per unit time gives the metal removal rate. The surface roughness of the specimen is measured using Taylor/Hobson surtronoic 3+ surface roughness measuring instrument

TABLE 2: Levels of independent Factors

Factors	Levels		
	L	M	H
Vol % Percentage SiC (X_1)	8	10	12
Feed (mm/	60	70	80

s) (X_2)			
Depth of Cut (μm) (X_3)	8	12	16

5: RESULTS AND DISCUSSION

5.1 Development of Mathematical Model

The mathematical relationship between responses and grindingparameters were established using experimental test results from planned set of experiments; face-centered CCD. Table-3 and Table-4 Below shows coefficients of response surface regression and the corresponding p-value for specific cutting energy and surface roughness.

TABLE 3: Regression analysis for Specific cutting energy

Term	Coeffficients	P-value
Constant	543.669	0.020
X_1	18.469	0.424
X_2	-11.125	0.086
X_3	-37.725	0.001
X_1^2	- 1.587	0.148
X_2^2	0.089	0.053
X_3^2	0.948	0.004
X_1X_2	0.030	0.807
X_1X_3	0.628	0.060
X_2X_3	0.098	0.129

TABLE 4: Regression analysis for Surface roughness

Term	Coefficient	P-value
Constant	2.1966	0.003
X_1	- 0.2542	0.002
X_2	0.0078	0.643
X_3	- 0.0088	0.703
X_1^2	0.0095	0.008
X_2^2	0.00003	0.789
X_3^2	- 0.0001	0.874
X_1X_2	- 0.001	0.025
X_1X_3	0.0019	0.048
X_2X_3	0.00013	0.462

It is observed from Table-3 for the response surface regression analysis of specific cutting energy that, linear and square of depth of cut and square of feed are more significant as their P-value are less than 0.05. Similarly regression analysis of surface roughness from Table-4 shows that, linear and square of SiC volume percentage and interaction of SiC vol percentage with feed and depth of cut are more significant. Equation (4) and (5) represent the developed response surface regression equation for specific cutting energy and surface roughness respectively.

Regression equation for specific cutting energy

$$\hat{y}_1 = 543.669 + 18.469X_1 - 11.125X_2 - 37.725X_3 - 1.587X_1^2 + 0.089X_2^2 + 0.984X_3^2 + 0.03X_1X_2 + 0.628X_1X_3 + 0.098X_2X_3 \quad ----(4)$$

Regression equation for surface roughness

$$\hat{y}_2 = 2.1305 - 0.2204X_1 + 0.00576X_2 - 0.0147X_3 + 0.00874X_1^2 + 6.61E-05X_2^2 - 1.08E-04X_3^2 - 0.00117X_1X_2 + 0.00209X_1X_3 + 0.000168X_2X_3 \quad ------(12)$$

Where $\hat{y}_1$ and $\hat{y}_2$ are the responses for specific cutting energy and surface roughness respectively. X_1, X_2 and X_3 represents the decoded values of SiC volume percentage, Feed (mm/s) and depth of cut (microns) respectively.

5.2 Analysis of the Developed Mathematical Model

The ANOVA and F- ratio test have been performed to justify the goodness of fit of the developed mathematical models.

The calculated values of F- ratios for lack-of-fit have been compared to standard values of F- ratios corresponding to their degrees of freedom to find the adequacy of the developed mathematical models. Table-5 and Table-6 shows the ANOVA for specific cutting energy and surface roughness respectively. The standard percentage point of F distribution for 95% confidence level ($F_{0.05,5,5}$) is 5.05. Since the F-value for lack of fit is less than the standard value, both the models are adequate at 95% confidence level. R^2-value the measure of fitness of the model for specific cutting energy and surface roughness are 95.45% and 99.3% respectively. It indicates that model fits well with the experimental results

TABLE 5: Analysis of variance for specific cutting energy

S	D	S	A	F	P
R	9	1	1	2	0
Li	3	8	4	9	0
S	3	1	5	1	0
I	3	3	1	2	0
R	1	5	5		
L	5	4	8	4	0
P	5	9	1		
T	1	1			

.

TABLE 6: Analysis of variance for Surface roughness

S	D	S	A	F	P
R	9	0	0	1	0
L	3	0	0	6	0
S	3	0	0	7	0
I	3	0	0	4	0
R	1	0	0		
L	5	0	0	1	0
P	5	0	0		
T	1	0			

Based on the response surface equation (4) and (5) contour plots for specific cutting energy and surface roughness are plotted. Fig-1 and Fig-2 shows the contour plot for specific cutting energy and surface roughness respectively. From Fig-1 it is observed that, specific energy increase with increase in feed. It is mainly due to the reason that increase in feed will decrease the contact time between the wheel and the workpiece which results in ploughing of wheel on the workpiece. Increased ploughing will increase the surface temperature and hence specific cutting energy [25]. Higher the specific cutting energy higher will be the heat dissipated and poor will be the surface finish [26].Moreover increase in feed will increase the cutting force which results in increased specific cutting energy. It is also observed that with depth of cut up to 13 to 14 microns specific cutting energy decreases. But increase in depth of cut beyond 14microns will results in increase of specific cutting energy. The initial decrease was, due to the increase in the maximum chip thickness with the increase in depth of cut, which resulted in decrease in specific cutting energy. The increase in specific cutting energy beyond certain value of depth of cut could be due to the reduction in friction between the wheel and the work and brittle fracture of the material [6]. Fig-2 shows the contour plot for surface roughness. It is observed from the figure that surface roughness improves with decrease in depth of cut and also with increase in volume percentage of SiC. It may be due to the reason that material becomes harder with increased volume percentage of SiC, which results in improved surface roughness.

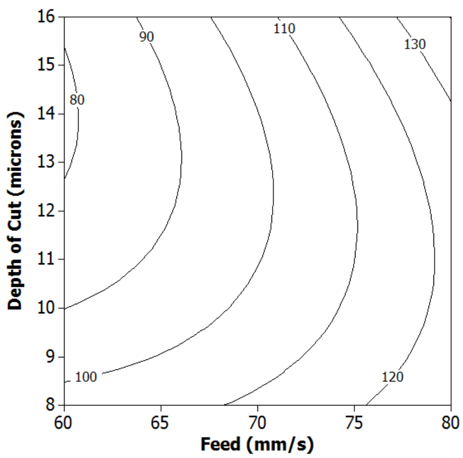

FIGURE 1: Contour plot for Specific energy

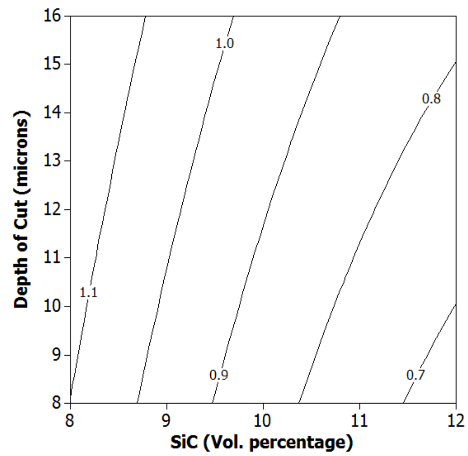

FIGURE 2: Contour plot for Surface Roughness

5.3 Analysis for the Optimisation of Response

Desirability function method popularised by Derringer and Suich [27] is used for the optimisation of specific cutting energy and surface roughness. The general approach is to first convert each response Y into an individual desirability function d_i that varies over the range. $0 \leq d_i \leq 1$

Where, if the response Y ^ is at its goal or target, then d_i=1, and if the response is outside an acceptable region, d_i=0.

The weight of the desirability function for each response defines its shape. The individual desirability functions are combined to provide a measure of the composite or overall desirability of the multi response system. This measure of composite desirability is the weighted geometric mean of the individual desirability for the responses [28]. The optimal operating conditions can then be determined by maximizing the composite desirability.

Fig-3 Shows the optimisation plot for of specific cutting energy and surface roughness. The goal is to minimise specific cutting energy and surface roughness. The upper value and target value for specific cutting energy have been fixed at 150 and 70 respectively. Similarly for the surface roughness the upper and target values are fixed at 1.3 and 0.65 respectively. Both the responses are assigned a weight of 3 and importance of 3. The optimisation plot shows that composite desirability is almost nearer to 1. The optimum value of specific cutting energy and surface roughness are 69.99J/mm^3 and 0.6505 microns respectively for machining Al-6061 SiC12 vl% specimen with feed 60mm/s and depth of cut 9.05 microns.

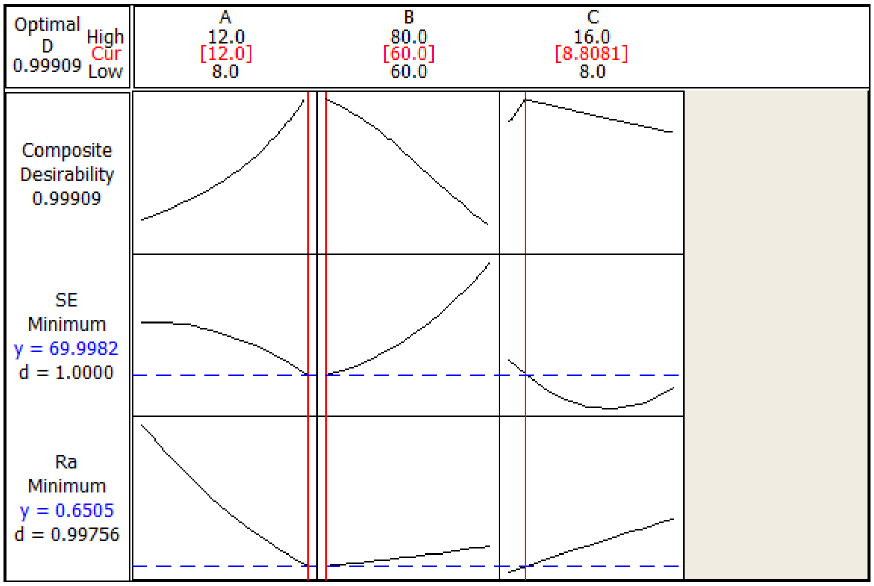

FIGURE 3: Optimum results for minimum specific cutting energy and minimum surface roughness

6. MODEL VALIDATION RUN

The response surface model developed in equation (4) and (5) were validated by the set of test runs. Table-7 gives the results obtained from experimental test, and the results obtained by the developed response surface model. The parentage error for specific cutting energy is within 9.5% and for surface roughness is within 2.5%. Hence it can be concluded that fitted model agrees very close to the experimental results.

TABLE 7: Validation of the results

			Experimental value		Response Surface model value		Percentage error	
	[illegible]	[illegible]	Specific energy (J/mm^3	Surface roughness (mic	Specific energy (J/mm^3	Surface roughness (mic	Specific energy	Surface roughness

		)	rons)	)	rons)		
		84.65	0.65	93.359	0.653	9.33	0.46
		77.17	1.07	71.813	1.083	6.94	1.21
		129.6	1.24	126.833	1.214	2.166	2.1
		76.436	77.47	0.62	0.6305	1.33	1.69

7. CONCLUSION

In this study, the Response surface methodology was applied for analyzing Specific cutting energy and surface roughness in the surface grinding of DRACs. Based on experimental results, following conclusions were drawn from the above experimental work.

i. It is observed that specific cutting energy increase with increase in feed. It may be due to the reason that all the cutting energy is dissipated in to heat at increased feed.

ii. Specific cutting energy is lower with increase in SiC weigt percentage of the specimen. This phenomenon is attributed to the fact that specific cutting energy associated with the ductile material removal process is much higher than that with a brittle removal mode.

iii. Surface roughness improves with increased SiC volume percentage of specimen and decrease in depth of cut. It is mainly due to the fact that, increase in vol% of SiC will increase the hardness of the specimen, which results in decrease ploughing of the wheel during grinding.

iv. Response surface regression is used to develop a second order equation for specific cutting energy and surface roughness. For 95% confidence level, it is observed that fitted value is very close to the experimental value.

v. Desirability function approach is applied to find the optimal cutting condition for minimum specific cutting energy and minimum surface roughness. Maintaining the feed at 60mm/s and depth of cut at 9 microns while machining Al6061-12%volSiC will produce a minimum specific cutting energy of 69.99J/mm^3 and a minimum surface roughness of 0.6505 microns.

8.0 REFERENCES

[1] Raviraj Shetty, R.B. Pai, S.S. Rao, B.S. Shenoy, "Study of tool wear in turning 15% SiCp reinforced 6061 aluminium metal matrix composite with steam as coolant", In: Proceedings

of International conference on Advanced Material processing and characterization, (AMPC 2006), August 28-30, 2006,Chennai, India (CD-ROM).

[2] Dayananda Pai, Shrikantha Rao, Raviraj Shetty, Rajesh Nayak “Application of response surface methodology on surface roughness in grinding of aerospace Materials (6061al-15vol%SiC)”, ARPN Journal of Engineering and Applied Sciences 5,(6), 2010

[3] H. Huang, Y.C. Liu, “Experimental investigations of machining characteristics and removal mechanisms of advanced ceramics in high speed deep grinding” International Journal of Machine Tools & Manufacture 43, 811–823, 2003

[4] S. Malkin and T. W. Hwang, “Grinding Mechanisms for Ceramics”, Annals of the CIRP, 45, 2, pp. 569 – 580, 1996

[5] W.B Rowe, “Principles of Modern grinding technology” Elsiveir Inc publications, pp 74, 2009

[6] Di ilio, A. Paoletti, D. Addona,”Characterisation and modelling of grinding process of metal matrix composites,” CIRP annals, Manufacturing technology 58, 2009

[7] Sanjay Agarwal, P. Venkateswara Rao “Experimental investigation of surface/subsurface damage formation and material removal mechanisms in SiC grinding” International Journal of Machine Tools & Manufacture 48, 698–710, 2008

[8] E. Brinksmeier, A. Giwerzew “Characterization of the size effect and its influence on the workpiece residual stresses in grinding” 1st Colloquium Processscaling, , October 28.-29, 2003 Bremen, Germany.

[9] Li et al, “Wear of diamond wheels in creep-feed grinding of ceramic materials II-Effects on process responses and strength” Wear 211, 104-112, 1997

[10] Y.H. Ren, B. Zhang, Z.X. Zhou “Specific energy in grinding of tungsten carbides of various grain sizes” CIRP Annals - Manufacturing Technology 58, 299–302, 2009.

[11] Matthieu Barge, Jo¨el Rech, H´edi Hamdi, Jean-Michel Bergheau “Experimental study of abrasive process” wear 264,(5-6), 382-388, 2008

[12] Zhaowei Zhong et al.”Grinding of Alumina/Aluminium Composites”, Journal of Materials Processing Technology,123, 13-17, 2002

[13] R. Hood, F. Lechner, D.K. Aspinwall, W. Voice “Creep feed grinding of gamma titanium aluminide and burn resistant titanium alloys using SiC abrasive” International Journal of Machine Tools & Manufacture 47 1486–1492, 2007

[14] M. Seeman & G. Ganesan & R. Karthikeyan & A. Velayudham “Study on tool wear and surface roughness in machining of particulate aluminum metal matrix composite-response surface methodology approach” International Journal of Advanced Manufacturing Technology 48, 613–624, 2010.

[15] P. Krajnik , J. Kopac, A. Sluga, “Design of grinding factors based on response surface methodology”, Journal of Materials Processing Technology 162–163, 629–636, 2005

[16] J.S. Kwak, Y.S.Kim, “Mechanical properties and grinding performance on aluminum-based metal matrix composites”, Journal of Materials Processing Technology, 201, 2008

[17] Jae-Seob Kwak, “Application of Taguchi and response surface methodologies for geometric error in surface grinding process”, International Journal of Machine Tools & Manufacture 45, 327–334, 2005

[18] G.E. Box., N.R.Draper, “Response surfaces, mixtures and Ridge Analysis”, Wiley 84- 98, 2007

[19] L. Zhang, G. Subbarayan, B.C. Hunter, D. Rose, “Response surface models for efficient, modular estimation of solder joint reliability in area array packages”, Microelectronics Reliability 45, 623–635, 2005.

[20] Raviraj Shetty, R.B.Pai, S.S.Rao, R.Nayak Taguchi’s Technique in Machining of Metal Matrix Composites Journal of the Brazilian Society of Mechanical Sciences and Engineering Vol. 31, No. 1, 2009

[21] Raviraj Shetty, Raghuvir Pai, Srikanth S. Rao, and Vasanth Kamath ,”Machinability study on discontinuously reinforced aluminium composites (DRACs) using response surface methodology and Taguchi’s design of experiments under dry cutting condition” Maejo International Journal of Science and Technology. 2(01), 227-239 2008

[22] Dayanand Pai, Shrikantha S. Rao, Raviraj Shetty, Studies on Application of Response Surface Methodology for the analysis of Specific Energy during grinding of DRAC’s Proceedings of the National conference on advances in Mechanical Engineering-2011, January 3-5,2011 Manipal, India

[23] Montgomery D.C.”,Design and Analysis of Experiments”,5th edition John Wiley and Sons, 2001.

[24] S. Raissi, and R- Eslami Farsani “Statistical Process Optimization Through Multi-Response Surface Methodology”, World Academy of Science, Engineering and Technology 2009, 51 267-271

[25] Ken Jones, Mark Johnson, J.J. Iiou “The Comparison of Response Surface and Taguchi Methods for Multiple-Response Optimization Using Simulation” IEEE/CHMTI International Electronics Manufacturing Technology Symposium 1992.

[26] S. Malkin, “Grinding Technology Theory and Applications of Machining with Abrasives”. Ellis Horwood, Chichester 1989.

[27] G.Derringer, and R. Suich, “Simultaneous Optimization of Several Response Variables”, Journal of Quality Technology, 12 (4), 214 –219, 1980.

[28] T. Gulati et al.: “RSM and ANN/GA for Optimization of Soybean”, Food Technology Biotechnology. 48 (1) 11–18, 2010