OPTIMIZATION OF CUTTING PARAMETERS OF AL-ZrO₂-SiC_p AND GRAPHITE HYBRID METAL MATRIX COMPOSITES

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Abstract: Paperwork deals with fabrication, cutting parameter optimization as well as the effect of Zirconia on surface roughness and cutting force of hybrid-composites such as Al/7%SiC/1.75%Gr/2.75%ZrO₂, Al/7%SiC/1.75%Gr/4.5%ZrO₂ and Al/7%SiC/1.75%Gr/6%ZrO₂. Considering Depth of cut (d.o.c), Feed and vol.% of ZrO₂ as input parameters. Taguchi experimental design of L27, S/N ratio and ANOVA were conducted. Optimal parameters for cutting force were observed at feed 0.0599 mm/rev, d.o.c 1mm with 6% ZrO₂ and for Surface roughness at feed rate 0.0143 mm/rev, d.o.c 0.5 mm with Zirconia 2.75 %. Relation among the parameters were presented by regression-equation. 3D and contourplots were used to analyse effect of two factors on responses.

Key words: Hybrid Al MMC, tool dynamometer, optimization of cutting parameters, Taguchi design of experiment

Optimizacija parametara rezanja Al-ZrO₂-SiC_p i grafitnih hibridnih kompozita metalnih osnova. Rad se bavi proizvodnjom, optimizacijom parametara rezanja, kao i efektom cirkonije na hrapavosti površine i snage rezanje hibridnih metalnih kompozita kao što su Al/7%SiC/1.75%Gr/2.75%ZrO₂, Al/7%SiC/1.75%Gr/4.5%ZrO₂, i Al/7%SiC/1.75%Gr/6%ZrO₂. Kao ulazni parametri uzeti su obzir dubina rezanja (d.o.c), pomak i težl.% ZrO₂. Izveden je Taguchi eksperimentalni dizajn L27, S/N i ANOVA analiza. Optimalni parametri za silu rezanja su pomak 0.059 mm/o, d.o.c 1 mm sa 6% ZrO₂ i za hrapavost površine pri pomaku 0.0143mm/o, dubinom rezanja 0.5 mm sa cirkonijom 2.75 %. Veza između parametara predstavljena je regresionom jednačinom. 3D i konturni dijagrami korišćeni su za analizu uticaja dva faktora na izlazne veličine.

Ključne reči: Hibrid Al MMC, dinamometar za alat, optimizacija reznih parametara, Taguchi dizajn eksperimenta

1. INTRODUCTION

There is a growing interest worldwide in manufacturing hybrid metal matrix composites which possesses combined properties of its reinforcement resulting enhanced physical, mechanical and tribological properties.

Tailor-ability of properties, higher ratio strength to density and stiffness, better fatigue resistance, higher electrical and thermal conductivity, better radiation resistance and lower creep rate, wear rate, co-efficient of thermal expansion makes metal matrix composite superior than monolithic materials, common structural materials and polymer matrix materials.. Having desirable attributes of metals and ceramics hybrid metal matrix composites find vast area of application in the field of aerospace, defence, recreation sector, atomic reactor and automobile sector

Al matrix provide better support and distributes the loads homogeneously upon the reinforcement resulting stabilized composite material due to its unique properties i.e. good damping capability, low density, corrosion resistance, non-magnetic nature, thermal conductivity. Earlier researchers have worked on reinforcement of SiC_p, Al₂O₃, Gr, TiB₂ and ZrO₂ on Al matrix individually and in combined form and has found enhancement in mechanical and physical properties of the material. Graphite in the form of fibres or particulates, has long been recognized as a high strength, self-lubricating low density materials. Wettability was found to be increasing with addition of

Silicon, Manganese Iron and elements of IVA, VA and VI groups with susceptibility for Carbide formation. SiC improves the tribological properties and chemical inertness of composite. ZrO₂ forms an intermetallic disperse of Al₃Zr resulting better wettability, grain refinement, good bonding and corrosion resistance.

The final conversion of composite into engineering products is associated with machining and in production and manufacturing optimal use of resources is a prime issue. This justifies the severe need of optimisation of machining parameter which would affect the production rate, quality and cost of component. The major cutting parameters for cutting force on tool are speed, feed, depth of cut, material, nose radius, lubricants used etc. As hybrid MMCs contain certain amount of hard and abrasive ceramic reinforcement it becomes more difficult for machining leading to severe tool wear and work piece damage. Machining parameters table offered by the manufacturer does not provide data for recent developed material. Hence the parameter for new materials need to be optimized. Improving the machinability of MMCs and developing machining data are the most promising ways to convince designer and manufacturers to use MMCs in their application.

Under above circumstances it has been thought proper to investigate the machinability of composites of Al with SiC, Gr, and Zirconia as reinforcements. The cutting parameters are optimized to give desired surface finish and dimensional stability using cutting force measurement by tool dynamometers and Taguchi

experimental design.

2. LITERATURE REVIEW:

Muthukrishnan and Davim [1] studied the surface roughness of Al-SiC 20 wt % by turning the composite bars using coarse grade polycrystalline diamond (PCD). Experimental data collected were tested with the analysis of variance (ANOVA) and artificial neural network (ANN) techniques. Depth of cut, cutting speed and feed were considered as input parameters. Multilayer perception model was constructed with back propagation algorithm to analyse surface roughness. In ANOVA it was revealed that feed rate has highest statistical as well as physical influence on the surface roughness (51% to 30 %) followed by the cutting speed (12%).

Radhika [2] optimized the tribological data to find the parameters affecting wear and friction properties. Design of experiment was followed by L_{27} orthogonal array for analysis of parameters i.e applied load, sliding speed and sliding distance on wear rate as well as coefficient of friction. The influence of parameter was carried out using ANOVA and regression equations for each response as smaller gives better characteristics. Results showed that sliding speed has minimal effect preceded by load and sliding distance.

Rajmohan et al. [3] employed Taguchi method with grey rational analysis to optimise the machining parameters with multiple performance characteristics in drilling hybrid metal matrix Al356/SiC-mica composite. L_{18} orthogonal array was chosen for experiment with input parameters as spindle speed, feed rate, drill type and mass fraction of mica. The parameters were optimized and found that feed rate and type of drill are the most affecting parameters in drilling process. Grey rational analysis is considered more advantageous than the statistical regression analysis.

Tamizharasi and Karthireshan [4] investigated the influence of different cutting parameters on surface roughness during turning of the Al/SiCp/B₄C hybrid composite. Multiple performance analysis (DFA) was performed to combine the multiple performance characteristics followed by ANOVA. The average composite desirability was derived by combining the desirability result of surface roughness, power consumed and cutting force.

Puhan et al. [5] investigated the machinability characteristics of aluminium silicon carbide composite on an electrical discharge machine. To optimize multiple responses simultaneously principal component analysis (PCA) and fuzzy inference system were coupled with Taguchi method. Response parameters selected were material removal rate, tool wear rate, surface roughness and circularity with four influential parameters i.e. discharge current, pulse duration, duty cycle and flushing pressure. Using ANOVA influence of parameters on response were duty cycle, discharge current and flushing pressure.

Sahoo et al. [6] developed composite of Al/SiCp-MMC using stir casting. Experimental investigations were carried out for analysing the flank wear and

surface roughness parameters using multilayer coated carbide insert under experimental design consideration of Taguchi L_9 orthogonal array. Regression model and grey relational analysis were carried out for response optimization. It was observed from the analysis that cutting speed acts as the most influential parameter. Flank wear and feed was found to be most significant parameters for surface roughness.

Mahamani [7] studied the influence of machining parameters on cutting force and surface roughness in turning of AA219-TiB₂/ZrB₂. L_{27} orthogonal layout was used with cutting speed, feed rate and depth of cut as machining parameters. From Minitab package Response graph and analysis of variance showed feed rate has strongest effect on cutting force and surface roughness. Regression model was also developed between machining parameter and response. It was observed that feed rate has the strongest factor with 76.94% contribution.

Kishore et al. [8] performed turning operation on 0 wt. % 2 wt. % and 4 wt. % TiC reinforced in Al6061 composite to analyse the effect on cutting force. Process parameters were speed, feed rate and depth of cut on response to cutting force, flank wear and surface roughness. Using 5 levels for 3 parameters Taguchi design of L_{25} orthogonal array for design of experiment was followed. From analysis of means of responses at all levels it was observed that addition of TiC reinforcement raises surface roughness. Also increase in feed rate and depth cut results in enhanced responses.

Kumar and Rajendran [9] performed turning operation with opted parameters as cutting speed, feed rate and depth of cut to find the optimum machining parameter i.e. low surface roughness and high material removal rate of CNC turning centre on AL-HMMC reinforced with SiC and Graphite. Design of experiment was followed by Taguchi L_{27} orthogonal array. To analyse the effect of cutting parameter on surface roughness and MRR signal to noise ratio and analysis of variance (ANOVA) were used. Feed followed by cutting speed and depth of cut were found to be the most significant parameters.

Singh et al. [10] presented an experimental investigation on the effect of cutting force during turning of Al/SiC/Gr hybrid MMC with weight fraction of 10% SiC and 5% Graphite prepared by stir casting method. The experimental design was reported by Taguchi L_9 orthogonal array plan for concluding the experiments. The cutting forces were measured with variation of parameters of cutting speed, feed and depth of cut. Results showed that change in depth of cut has the maximum effect on the cutting force than feed and speed.

Kumar et al. [11] considered the process parameters as cutting speed, depth of cut and feed rate during turning of EN19 material for achieving optimum surface finish by the help of Taguchi L_{27} orthogonal array followed by analysis of variance. Feed rate was having the highest contributing factor followed by depth of cut and speed.

Parihar et al. [12] analysed cutting force by changing spindle speed, depth of cut and feed

performed on conventional HMT lathe using Lathe tool dynamometer. The analysis was done by finite element method using a 3D solid model in ABAQUS/explicit simulator. The study showed that depth of cut has major impact on cutting force.

M. Ay and Altunpak [13] surveyed the drilling of Al/20%SiC/7.5%Gr, Al/20%SiC/10%Gr and Al/20%SiC/5%Gr using Taguchi's L9 orthogonal array, S/N ratio and ANOVA for optimal process parameters for cutting force and surface roughness. Rate of graphite and feed rate was found to have significant impact on surface roughness. The rate of graphite has most significant effect on cutting force i.e. 79.72% followed by feed rate.

Kishore et al. [14] studied the machinability on Al6061-TiC MMC to know the effect of cutting speed, feed, and depth of cut on surface roughness and cutting forces using Taguchi L-27 orthogonal array. To investigate the contribution of parameters on response ANOVA was used. The contribution of depth of cut is high on the cutting force. In case of surface roughness the contribution of feed is high followed by cutting speed and depth of cut.

Kosaraju and Chandraker [15] investigated the effect of process parameters during turning of MDN350 steel using cemented carbide tool by optimization using Taguchi method with L9 orthogonal array. Speed, feed, and depth of cut were process parameters whereas cutting force and surface roughness were selected as responses. The degree of influence of parameters on response was derived by the help of Analysis of variance. Cutting speed was the most influential parameter in cutting force and for surface roughness feed rate was found to be most influential.

Ahmed et al. [16] carried out experiment on efficient turning of high performance mild steel material using HSS tool. The process parameters chosen were cutting speed, feed rate and depth of cut to minimise the response i.e. Surface roughness, feed and radial forces. Experimental design and analysis was followed by Taguchi's L9 orthogonal array, signal to noise ratio and analysis of variance with the help of Minitab-16 statistical software. Prediction models were developed with the help of regression analysis method. Depth of cut and cutting speed were found to be the most affecting parameters against variation of feed and radial forces.

Shekar et al. [17] studied the effect of variation in machining parameters like speed, feed, depth of cut and nose radius on Al6063T6 using L9 configuration of Taguchi technique. 4 factors and 3 levels for parameters were chosen to develop relation between response and control parameters. Response parameters were surface roughness, material removal rate, machining force and power consumption. From signal to noise ratio analysis for each parameter was done to find the optimum parameter setting. Minimum value for surface roughness were observed with low speed i.e. 500rpm high nose radius of 0.8mm, feed of 10mm/min and depth of cut 0.8mm.

The cutting condition which influence the cutting force and surface roughness in terms of spindle speed, feed rate, axial, radial depth of cut and weight

percentage of SiCp in milling operation was investigated by Subramanian et al. [18] using Taguchi L32, followed by ANOVA. Response surface methodology has been employed to create the mathematical model. The adequacy of the model has been verified using analysis of variance. Direct and interaction effects of process parameters on different cutting forces were plotted to examine the effect of parameters. Feed rate was found to be the most significant parameter which affect cutting force and surface roughness.

3. SCOPE

- In the present investigation turning experiments are to be conducted on the newly developed Al hybrid composite with SiCp-Graphite and different vol % of ZrO₂ by stir casting method.
- The cutting forces are to be measured using lathe tool dynamometer with the help of strain gauge dial indicator.
- To implement Taguchi's 3 factor 3 level design of experiment technique in the measurement of cutting forces and surface roughness in machining of various vol. percentage of ZrO₂.
- To study the direct and interaction effect of process parameters through contour plots analysed through ANOVA for cutting force and surface roughness.
- To generate mathematical model for cutting force (F_z) and surface roughness (Ra) as response with controllable factors as % of Zirconia, Depth of cut and Feed rate using regression analysis.
- Finally optimum cutting parameters are to be decided based on the results available from both theoretical and experimental investigations

4. MATERIALS AND METHODS

4.1 Materials

Aluminium (AA 6061) was used as matrix material to develop hybrid metal matrix composites. The reinforcement added in the hybrid were SiCp, Graphite, and Zirconia (ZrO₂). The particle size of SiCp and Graphite powder were 63µm at an average and that of Zirconia (ZrO₂) was 40µm at an average. The composition of composite was varied by vol. % of reinforcements. Three specimens of different composition i.e. Al/7%SiC/1.75%Gr/2.75%ZrO₂, Al/7%SiC/1.75%Gr/4.5%ZrO₂, Al/7%SiC/1.75%Gr/6%ZrO₂. Aluminium was collected from National Aluminium Company Ltd. Angul, Odisha. Silicon Carbide and Graphite were collected from Suvidhinath Laboratories, Vadodara, Gujrat. Zirconia was collected from High purity laboratory chemicals Pvt Ltd, Sarigam, Gujrat.

4.2 Fabrication of hybrid composite

All composites were fabricated under similar conditions through vortex method followed by conventional casting. The volume percentage and density of raw material were calculated using rule of mixture (Tab.1). Al-the matrix material was placed in the graphite crucible inside muffle furnace and heated

up to its molten state i.e. 750°C. Reinforcement materials were pre heated up to 450°C in muffle furnace to remove surface impurities and assist in the adsorption of gases. Constant stirring was done to ensure homogeneity of mixture. The crucible was heated above liquidus temperature up to 1000°C. Then the molten material was poured in to the prepared sand cast mould. The above process was followed for three different variation of composition of reinforcement. After solidification of the composites (Fig.1), these were machined for required specimen size

Fig. 1. Cast specimens

Specimen No	Total Volume in cm ³	Volume Fraction In cm ³				Density ρ_c (gm/c)
		SiC	Gr	ZrO ₂	Al	
S1	333.367	0.0598	0.022962	0.01205	0.90457	2.7542
S2	330.226	0.06037	0.023181	0.021325	0.89512	2.7801
S3	327.932	0.06079	0.023343	0.03006	0.8857	2.8

Table 1. Constituents of the composites

4.3 Composite properties

Three different specimens were produced and were subjected to tensile and hardness test with ASTM E8M standard specimen under UTM and micro Vickers hardness tester machines. The properties obtained experimentally are indicated in Tab.2. It is seen that with increased % of ZrO₂ the hardness and tensile strength were found to be increasing.

Specimen	Micro Vickers Hardness	Tensile Strength
Al/7%SiC/1.75% Gr/2.75%ZrO ₂	80.25VHN	91 MPa
Al/7%SiC/1.75% Gr/4.5%ZrO ₂	103.22VHN	121MPa
Al/7%SiC/1.75% Gr/6%ZrO ₂	103.77VHN	132MPa

Table 2. Mechanical properties of composites

4.4 Experimental procedure

To study the effect of Zirconia percentage on cutting force and surface roughness the turning process was carried out using a conventional lathe machine of 2.25 KW (spindle speed 54-1200rpm) motor drive. Entire process was operated at constant speed i.e. 360 rpm. The cutting tool used in the study was HSS(10%) ½ inch x 1/2 inch x 2 inch length with positive rake angle. The work piece used for experiment were with varied % of ZrO₂ (1.75%, 4.5%, and 6%) with fixed 7% SiC and 1.75% Gr content by volume. They were in the form of cylindrical bar of diameter 20mm and length 75mm. Experimental trials were carried out in 1 min duration. The cutting force was measured by the Lathe tool dynamometer (Fig.2) connected with the single point cutting tool (SPCT) by the help of a strain gauge dial indicator. The average surface roughness was measured from three different places in the direction of the tool movement using Mitutoyo SJ-210 Surface roughness tester with cut-off and transverse length of 0.8 and 2.5 mm respectively.

4.5 Design of experiment

In order to simplify the parameter design, Taguchi method which is a powerful tool in this regard was used for conducting the experiment for systematised optimization along with quality and cost [11]. Considering the 3 factor and 3 levels L27 orthogonal array with 27 rows (corresponding to the no of experiments) was used for experiment. The opted parameters are presented in Table 3. The experimental results were then transformed into signal to noise (S/N) ratio i.e. the ratio of controlled parameter with the mean of uncontrolled parameters. As recommended by Taguchi the S/N ratio is used to measure the quality characteristics deviating from nominal values. Analysis using S/N ratio has been found to be producing more accurate results for optimisation of parameters [13]. The S/N ratio of responses cutting force (Fz) and surface roughness (Ra) were calculated by considering smaller-the-better characteristics. Optimal condition of the cutting parameter levels can only be determined by analysing the significant effect of the parameters which can be obtained by Analysis of variance (ANOVA). The analysis was carried out within 95% of confidence interval along with the frequency test (f-test). The statistical calculations and analysis were made using Minitab Ver.15 software package.

Fig. 2. Machining on lathe with tool dynamometers

Machining Parameters	Unit	Level 1	Level 2	Level 3
% of ZrO ₂	Volume Fraction %	1.75%	4.5%	6%
Depth of Cut (D.o.C)	mm	0.5	0.75	1
Feed	mm/Rev	0.0142	0.0313	0.0592

Table 3. Machining parameters and Levels

5. EXPERIMENTAL INVESTIGATION

The turning operation was carried out in conventional lathe machine. The resultant force developed during turning is recorded by the help of lathe tool dynamometer connected with a strain gauge dial indicator. As per the design of experiment the experiments were conducted varying the parameters according to Taguchi L27 orthogonal Array for tabulating the responses resultant force and surface roughness as mentioned in Table 4.

6. RESULTS AND DISCUSSION

Basic purpose of the work is to discuss the influence of cutting parameters and the effect of Zirconia on

Cutting force (Fz) and surface roughness during Turning of a Hybrid Al/SiC/Gr/ZrO₂ MMCs.

6.1 Analysis of S/N ratio and ANOVA for resultant cutting force and surface roughness

By considering smaller the better characteristics the S/N ratio for cutting force and surface roughness were calculated to study the control levels produced by each factor on the responses i.e. cutting force and surface roughness as shown in Table 5 and Table 6. It is observed that Feed acts as a prime contributor for both cutting force and Surface roughness. Table 5. Suggests for contribution in cutting force depth of cut and % of zirconia are followed by feed rate. Also from Table 6. It is clear that feed leads the contribution factor followed by % of Zirconia and depth of cut. The experimental results were analysed using ANOVA (analysis of variance). The significant effect of parameters are listed in the Table 7 and Table 8 for cutting force and surface roughness respectively. Table 7 lists the numerical values of ANOVA results with the average values of cutting force (Fz). Present results in Table 7 shows that Zirconia % has least impact on the cutting force. The major significant factor is feed with proportion of 64.4% followed by depth of cut.

Exp. No.	ZrO ₂ %	D.O.C	Feed	Fz	SNRA	Ra	SNRA1
1	1.75	0.5	0.0142	4.47	-13.0062	1.011	-0.09502
2	1.75	0.5	0.0313	6.726	-16.5551	1.236	-1.84037
3	1.75	0.5	0.05592	11.661	-21.3347	2.023	-6.11992
4	1.75	0.75	0.0142	13.453	-22.5764	1.075	-0.62817
5	1.75	0.75	0.0313	15.3236	-23.7072	1.45	-3.22736
6	1.75	0.75	0.05592	23.2647	-27.3339	2.611	-8.33614
7	1.75	1	0.0142	10	-20	1.023	-0.19751
8	1.75	1	0.0313	14.038	-22.9461	1.836	-5.27745
9	1.75	1	0.05592	23.2594	-27.332	2.323	-7.32098
10	4.5	0.5	0.0142	9.185	-19.2616	1.106	-0.8751
11	4.5	0.5	0.0313	12.469	-21.9166	2.056	-6.26046
12	4.5	0.5	0.05592	15.212	-23.6437	2.569	-8.19528
13	4.5	0.75	0.0142	12.041	-21.6133	1.168	-1.34886
14	4.5	0.75	0.0313	15.453	-23.7803	2.185	-6.78903
15	4.5	0.75	0.05592	22.186	-26.9216	2.658	-8.4911
16	4.5	1	0.0142	12.747	-22.1082	1.236	-1.84037
17	4.5	1	0.0313	14.866	-23.4439	2.209	-6.88391
18	4.5	1	0.05592	24.186	-27.6713	2.956	-9.41409
19	6	0.5	0.0142	10.63	-20.5307	1.056	-0.47328
20	6	0.5	0.0313	14.689	-23.3398	2.569	-8.19528
21	6	0.5	0.05592	18.62	-25.3996	2.896	-9.23597
22	6	0.75	0.0142	9.65	-19.6905	1.569	-3.91246
23	6	0.75	0.0313	11.661	-21.3347	2.365	-7.47662
24	6	0.75	0.05592	23.124	-27.2813	2.964	-9.43756
25	6	1	0.0142	9.87	-19.8863	2.035	-6.17129
26	6	1	0.0313	12.083	-21.6435	2.778	-8.87464
27	6	1	0.05592	27.318	-28.729	3.025	-9.61451

Table 4. L27 orthogonal array with S/N ratio of responses

Levels	Depth of cut (mm)	% of Zirconia (ZrO ₂)	Feed (mm/rev)
1	-4.588	-3.671	-1.727
2	-5.516	-5.566	-6.092
3	-6.177	-7.044	-8.463
Delta	3.25	1.73	6.33
Rank	3	2	1

Table 5. Mean response for S/N ratio of cutting Force (Fz)

.Levels	Depth of cut (mm)	% of Zirconia (ZrO ₂)	Feed (mm/rev)
1	-20.55	-21.64	-19.85
2	-23.80	-23.37	-22.07
3	-23.75	-23.09	-26.18
Delta	3.25	1.73	6.33
Rank	2	3	1

Table 6. Mean response for S/N ratio of Surface roughness (Ra)

Factors	Degree of Freedom	Sum of Square	Mean Square	F value	P value	% of contribution
ZrO ₂ %	2	18.517	9.259	9.05	0.009	2.13
D.O.C	2	141.082	70.541	68.95	0.000	16.24
Feed	2	560.038	280.019	273.69	0.000	64.4
ZrO ₂ %*D.O.C	4	71.729	17.932	17.53	0.001	8.25
ZrO ₂ %*Feed	4	16.074	4.018	3.93	0.047	1.8
D.O.C*Feed	4	53.058	13.265	12.96	0.001	6.11
Error	8	8.185	1.023			1.07
Total	26	868.684				100

Table 7. Anova results based on resultant Cutting Force (Fz)

Factors	Degree of Freedom	Sum of Square	Mean Square	F value	P value	% of contribution
ZrO ₂ %	2	2.4745	1.2372	28.01	0.000	19.13
D.O.C	2	0.4673	0.2337	5.29	0.014	3.61
Feed	2	9.1045	4.5522	103.07	0.000	70.41
Error	20	0.8833	0.0442			6.85
Total	26	12.9295				100

Table 8. Anova results Based on resultant Surface roughness (Ra)

The ANOVA result of the average values of surface roughness are summarized in the Table 8. Feed with the contribution factor of 70.41 % has the most significant effect followed by Zirconia % with 19.13% contribution factor on the Surface roughness (Ra). However, Depth of cut has little impact on surface roughness. From the interaction plot of control parameters (Fig.3) for the response cutting force it is observed that with increase in feed rate the cutting force increases homogeneously. Depth of cut is not as effective as feed rate for cutting force. Experimental results reveal that when depth of cut is increased to 1mm along with feed from 0.03130 mm/rev to 0.05592 mm/rev marginal increase in cutting force is seen.

Fig. 3. Interaction plot for Ra

Fig. 4. Interaction Plot for Fz

However, all parameters of surface roughness increases with elevated feed rate as observed from interaction plot for surface roughness (Ra) i.e. Fig.4. With Higher % of ZrO₂ the feed rate is seen to traverse the work piece rapidly increasing chatter, deteriorating the surface quality. The results prove that surface roughness is highly influenced by feed. It is also observed that Ra value is low with lower % of ZrO₂.

6.2 Analysis of combination of two factors

Analysis for combination of any two factors helps to check the change in effect due to combination of input factors. Comparing the 3-D response surface graph and contour plot for cutting force (Fig.5) against

the two factors % of Zirconia and feed , it is evidently clear that feed is the prime factor for development of cutting force. $ZrO_2\%$ has minor effect though highest value for cutting force is observed with high feed i.e. 0.050-0.055 mm/rev

Depth of cut is the primary key for increment of cutting force and $ZrO_2\%$ increment ceases to act as a propellant beyond 5% as the insights on Fig.6 suggests. This might be due to inhomogeneity, casting defect in specimen, machine alignment and strain guage calibration. However, for surface roughness Zirconia % was found to be prominent after feed. The 3D- surface plot and contour plots for surface roughness vs the two factor % of ZrO_2 and feed (Fig.7) depicts the even distribution of contribution of each parameter with increase in value. Feed above 0.030 mm/rev with % of ZrO_2 above 3% showed high surface roughness value. Hence for better surface finish low feed in % of ZrO_2 should be preferred. Depth of cut along with percentage of Zirconia were analysed with two factor plot for Surface roughness in Fig. 8. It is observed that Depth of cut has very less impact on the surface roughness resulting minute amount of variation in graph. High depth of cut with high percent of Zirconia is producing higher value for surface roughness

6.3 Regression model for Surface roughness and cutting force

Regression model was formed to formulate a predictive equation among the control factors during

turning i.e. feed, Zirconia percentage, and depth of cut for different responses. The equation developed for surface roughness (Ra) for this experiment is given below.

$$Ra = -0.182 + 0.165 ZrO_2\% + 0.545 D.O.C + 32.6 Feed = 90.6\%$$

Again to produce a predictive equation among the control factors during turning for Cutting force was defined by the below equation as predicted by regression analysis.

$$Fz = -3.44 + 0.354 ZrO_2\% + 10.4 D.O.C + 277 Feed = 80.9\%$$

Overall lack of fit test is significant at $P = 0.032$ the regression equation is found to have 80.9% efficient result. Fig. 8 displays the normal probability plot for surface roughness (Ra) which determines whether the model meets the assumptions of the analysis or not. Verses order and verses fit are found to be in random order. Histogram proves that the data are normally distributed it shows nearly bell-shaped normal distribution. Figure 10 displays the normal probability plot for Fz contributing to form the regression equation with random order of versus fit and order. An un-even order of histogram suggests the fluctuation of cutting force resulted due to error during machining which lead to the efficiency of residue equation to 80.9%.

Fig. 5. 3-D response Graph and contour plot for cutting force vs $ZrO_2\%$, Feed

Fig. 6. 3-D response graph and contour plot for cutting force (Fz) vs $ZrO_2\%$, Depth of cut

Fig.7 3-D response graph and contour plot for surface roughness (Ra) vs ZrO₂%, Feed

Fig.8 3-D response graph and contour plot for surface roughness (Ra) vs ZrO₂%, Depth of cut

7. CONCLUSIONS

In the present work experimental investigation of turning of

Al/7%SiC/1.75%Gr/2.75%ZrO₂,

Al/7%SiC/1.75%Gr/4.5%ZrO₂,

Al/7%SiC/1.75%Gr/6%ZrO₂

hybrid-metal-matrix composite was carried out at different parameters to study the effect of percentage of Zirconia and machining parameter on resultant cutting force and surface roughness. Taguchi L27 orthogonal array, S/N ratio and ANOVA were used for finding the optimal process parameters for surface roughness and cutting force. Linear regression model was developed to check the adequacy. Two factor 3-D surface plots and contour plots were used for better illustration of contribution of parameters. The following conclusions can be drawn from the analysis of results.

1. From S/N ratios obtained, the optimal cutting parameters for cutting force were observed at feed=0.0599 mm/rev, depth of cut = 1 mm with 6 % ZrO₂. For better Surface roughness recommended parameters were feed rate 0.0143 mm/rev, depth of cut 0.5 mm with Zirconia 2.75 %.
2. Feed rate was found to be the most significant parameter from ANOVA for cutting force with 64.45% followed by depth of cut and zirconia percentage. Also for surface roughness feed rate stood as the most significant parameter with

70.41% contribution followed by % of Zirconia content with 19.13% contribution. Depth of cut has insignificant effect on cutting force.

3. The values obtained from Taguchi analysis and ANOVA analysis are supporting each other justifying the significance of the model.

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