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Procedia Materials Science 6 (2014) 1178 – 1186

Procedia Materials Science

www.elsevier.com/locate/procedia

3rd International Conference on Materials Processing and Characterisation (ICMPC 2014)

Influence of Process Parameters on Cutting Force and Surface Roughness During Turning of AA2219-TiB_2/ZrB_2 In-situ Metal Matrix Composites

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Abstract

Optimization of machining parameters is valuable to maintain the accuracy of the components and obtain cost effective machining. Force signals are highly sensitive carriers of information about the status of machining process. The measure of uneconomic machining like excessive friction in the machining interface and machining with worn out tool can be identified by means of cutting force. Surface finish is an important measure for the quality of the machined surface. Taguchi method was used to optimize the machining parameters. The objective of the paper is to study the influence of machining parameter on cutting force and surface roughness in turning of AA2219-TiB_2/ZrB_2 in-situ metal composites. The contribution of the paper is to study the effect of TiB_2 and ZrB_2 reinforcements, which are formed by in-situ chemical reaction in machining this composite. Cutting speed, feed rate and depth of cut selected as machining parameters. L27 orthogonal layout was used for experimentation. The response graph and analysis of variance shows that the feed rate has strongest effect on cutting force and surface roughness. Regression model also developed between the machining parameters and responses. The confirmation experiments reveal that the good agreement with the regression models.

Selection and peer review under responsibility of the Gokaraju Rangaraju Institute of Engineering and Technology (GRIET)

Key words : In-situ composites, Turing, Cutting force , Surface roughness, Taguchi method, Analysis variance

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1. Introduction

Aluminum matrix composites widely used in aerospace, automotive and structural application because of their improved mechanical properties, wear resistant, damping capacity and reduced density (Kunz and Bampton 2001). The composites manufactured by ex-situ process are limited in application due to poor wetting between the matrixand reinforcement, cluster of reinforcement, heterogeneous microstructure, coarse reinforcement and non uniform distribution of reinforcements (Cui et al. 2000).

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Selection and peer review under responsibility of the Gokaraju Rangaraju Institute of Engineering and Technology (GRIET)
doi:10.1016/j.mspro.2014.07.191

Nomenclature

A Cutting speed (m/min)
B Feed rate (mm/rev)
C Depth of cut (mm)
SR Surface roughness (µm)
CF Cutting force (N)
ANOVA- Analysis of variance

These limitations affect the workability and machinability of the composites. Difference in mechanical property at matrix, reinforcement and, interface between the matrix and reinforcement causes the uneven deformation while forming the components. Presence of coarse reinforcement causes excessive tool wear and poor surface finish in machining the ex-situ composites (Quan et al 1999). In-situ composites may be the suitable candidates to overcome the above said complexity. In in-situ synthesis, the reinforcements are formed by exothermic chemical reaction. Hence, in -situ composites have fine and small reinforcements, strong interfacial bonding between the matrix and reinforcement, homogeneous microstructures and thermodynamic stability (Hsu et al.2005). These advantages offer improved mechanical properties and homogeneously distributed reinforcement, which promotes the machinability and formability. Optimization of cutting parameters becomes more important to control dimensions of work piece without compromising the productivity.

Flex assisted synthesis is a very cheap and easy route for making in-situ composites. This method is best suited for manufacturing TiB_2, ZrB_2 and TiC reinforced composites (Mahamani 2011). Turning is a basic machining operation to shape component in to a desired shape. Cutting force is essential to study the dynamics of cutting process. Friction between the tool and work piece, and the indication of tool wear can be assessed by using cutting force. Surface finish is a quality measure for the components which made machining. Cutting tool vibration occurred when cutting edge is shifted from matrix to reinforcement, which is reflected on the surface finish and tool life.

Machinability of in-situ metal matrix composites was well documented in literatures. Ozcatalbas (2003) carried out an experimental investigation on the chip and buildup edge formation in machining of the in-situ $Al\text{-}Al_4C_3$ composites. The result shows that the small size particle and high hardness of the composite cause discontinuous chip formation and increasing the chip cutting ratio. Rai et al. (2006) conducted a machinability study on Al-TiC in-situ composite. They evaluated the pattern of chip formation and cutting force during shaping operation. The analysis of the result shows that the high volume fraction of the TiC particles causes discontinuous and promotes the favorable chip formation without any build up edge. The cutting force was minimized due to the propagation of micro cracks at particle-matrix interface. Anandakrishnan and Mahamani (2010) investigated machinability behavior of the in-situ $Al6061\text{-}TiB_2$ composites. The effect of speed, feed and depth of cut on flank wear, cutting force and surface roughness are analyzed. Presences of small and fine TiB_2 particles promoted the significant improvement on machinability. Mahamani et al (2012) proposed an approach to optimize the machining parameters in turning of Al 6061-6% ZrB_2 in-situ metal matrix composite with multiple performance characteristics by using grey relational analysis. The result and discussion indicate that the feed rate has the strongest effect. The confirmation experiment indicates that there is a good agreement between the estimated value and experimental value of the Grey relational grade.

Mahamani (2011) aimed to understand the machinability behavior of the $Al\text{-}5Cu\text{-}TiB_2$ in-situ metal matrix composites. The objective of this study is to investigate the effect of the cutting speed and feed rate on flank wear, cutting force, and surface roughness. It was observed that the increase in cutting speed causes increase in flank wear, reduction in cutting force, and minimized the surface roughness. The increase in flank wear, cutting force and surface roughness are observed at higher feed rate. Senthil et al (2013) attempted to investigate the machinability characteristics of homogenized $Al–Cu/TiB_2$ in-situ metal matrix composites. They observed that better surface finish is obtained at higher cutting speed and low feed. The chip breakability is improved due to the presence of reinforcement. Anandkumar et al (2013) presented a study on dry turning characteristics of in-situ Al-4.5%Cu/TiC metal matrix composites using uncoated ceramic inserts. They found that, the acceptable surface finish can be achieved by using uncoated ceramic inserts. Mahamani et al (2010) synthesized AA2219-TiB_2/ ZrB_2 in-situ metal matrix composite by flux assisted synthesis. Quantitative elemental analysis report confirms the presence of reinforcements and Al_2Cu phase with the proposed contribution. In this study, the effect cutting speed, feed rate and depth of cut on cutting force and surface roughness in turning of AA2219-TiB_2/ ZrB_2 in-situ metal matrix composite was experimentally investigated using Taguchi method. An L27 orthogonal array, response graph and analysis of variance were employed to investigate the effect of turning parameters.

2. Materials and method

AA2219 was selected as a matrix material for this study. The chemical composition of the matrix was shown in Table 1. AA2219 alloy was reinforced with TiB_2 and ZrB_2 reinforcement particles. Flux assisted synthesis method was followed to fabricate the composites. Three types of halide salt, namely potassium hexa-fluoro-titanate (K_2TiF_6), potassium hexa-fluoro-zirconate (K_2ZrF_6) and potassium tetra-fluro-borate (KBF_4) were used to synthesize the composites. Energy Dispersive X ray spectroscopy(EDAX) spectra of AA2219- 6 % TiB_2/ZrB_2 is shown in Fig.1, which shows the detection of various elements like Aluminum, copper, Titanium boride and zirconium boride. The quantative elemental analysis report (Table 1) confirms the presence of 4.31 % TiB_2 and 2.42 % ZrB_2. Microstructure for the fabricated material was shown in Fig.2. It is observed from the microstructure the Al_2Cu and reinforcements are in grain boundaries.

Table 1. Chemical composition of AA2219 alloy

Elements	Cu	Mn	Fe	Zr	V	Si	Ti	Zn	Al
Wt. %	6.33	0.34	0.13	0.12	0.07	0.06	0.04	0.02	Bal

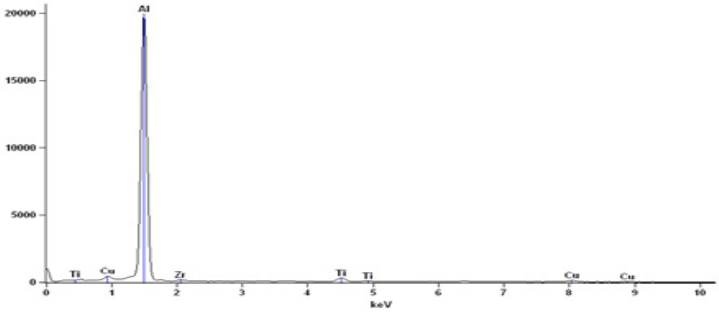

Fig. 1 EDAX spectra of AA2219- 6 % TiB_2/ZrB_2

Table 2. Quantitative Elemental Analysis of AA2219- 6 % TiB_2/ZrB_2

Elements	Net counts	Weight %	Atom %
Al	210739	88.20	94.33
Ti	4226	4.31	2.60
Cu	2175	5.07	2.30
Zr	1941	2.42	0.77

100	100

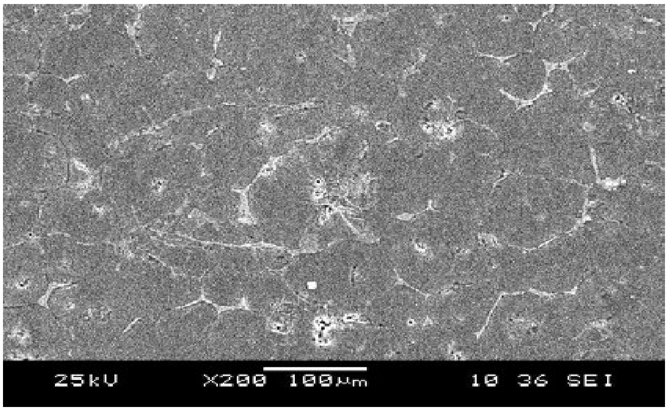

Fig.2 Microstructure of AA2219- 6 % TiB_2/ZrB_2 composite

Taguchi method has been used to optimize the cutting force in machining the composites. L27 orthogonal array lay out was used for the experimental investigation. Speed, feed rate and depth cut are considered as considered as machining parameters. The response to be studied is the cutting force and surface roughness. The level of the machining parameters is given in the Table 3. A smaller better characteristic is used for the experimental work. Kistler dynamometer is with dynoware software was used to measure the cutting force.

Table 3. Factors and levels of experimental work

Factor Notation	Factor	**Levels**		
		1	2	3
A	Cutting speed(m/min)	100	125	150
B	Feed rate(mm/rev)	0.05	0.1	0.2
C	Depth of cut(mm)	0.5	1.0	1.5

3. Experimental Work

Turn master-35 lathe (Kirloskar make) was used to conduct experimental work. The uncoated tungsten carbide insert was clamped with the tool holder to carry out this work. The specification for insert and tool holders are SNMG120408 MTTT5100 and PSBNR-2525M12. The clearance angle, cutting edge angle and nose radius are maintained by 7º, 75º and 0.8 mm respectively. The length of turning is 110mm. No chip breaker was used in the experiment. All the experiments are conducted in dry condition. L_{27} experimental lay out was used to carry out this experimental work. Surface roughness and cutting force is for the each run is measured and reported in the Table.4. Response graph for cutting force and surface roughness are generated by Minitab 14 software and shown in Fig. 3 and 4.

Table .4 Experimental results for cutting force and surface roughness

Trail No	Levels			Response		S/N Ratio for	
	A	B	C	Cutting force (N)	Surface Roughness (µm)	Cutting force	Surface Roughness
1	1	1	1	64.23	2.63	-36.15	-8.39911
2	1	1	2	67.24	2.72	-36.55	-8.69138
3	1	1	3	69.53	2.83	-36.84	-9.03573
4	1	2	1	67.56	2.98	-36.59	-9.48433
5	1	2	2	73.42	3.12	-37.32	-9.88309
6	1	2	3	74.65	3.14	-37.46	-9.93859
7	1	3	1	76.65	3.23	-37.69	-10.1841
8	1	3	2	79.25	3.35	-37.98	-10.5009
9	1	3	3	84.35	3.56	-38.52	-11.029
10	2	1	1	63.78	2.45	-36.09	-7.78332
11	2	1	2	65.69	2.52	-36.35	-8.02801
12	2	1	3	67.64	2.58	-36.60	-8.23239
13	2	2	1	64.53	2.72	-36.20	-8.69138
14	2	2	2	66.74	2.81	-36.49	-8.97413
15	2	2	3	67.83	2.93	-36.63	-9.33735
16	2	3	1	65.87	3.12	-36.37	-9.88309
17	2	3	2	66.91	3.26	-36.51	-10.2644
18	2	3	3	68.48	3.31	-36.71	-10.3966
19	3	1	1	58.65	2.08	-35.37	-6.36127
20	3	1	2	62.52	2.15	-35.92	-6.64877
21	3	1	3	64.23	2.32	-36.15	-7.30976
22	3	2	1	63.40	2.72	-36.04	-8.69138
23	3	2	2	65.26	2.83	-36.29	-9.03573
24	3	2	3	67.60	2.91	-36.60	-9.27786
25	3	3	1	65.69	3.12	-36.35	-9.88309
26	3	3	2	67.80	3.19	-36.62	-10.0758
27	3	3	3	68.92	3.25	-36.77	-10.2377

4. Analysis of results

4.1 Effect of machining parameters on cutting force

Generally lower cutting force desired for setting optimal machining parameter. Cutting force response graph for the L27 experimental lay out was generated by Minitab 14 package and shown in Fig.3. It is seen from the Fig .3 the feed rate has strongest effect on cutting force than cutting speed feed. Higher feed rate will increase the area of cut, which increase the friction between the cutting edge and work piece. This effect increase cutting force when increasing feed rate. Increase in feed rate also increases the chip load which cause excessive cutting force. At lower cutting speed build up formation will be more. Build up edge formation will increase the contact area of the cutting edge, which increases the cutting force. Higher cutting speed breaks the buildup edge formation. Therefore cutting force is minimized when operating with higher cutting velocity. Depth of cut has less effect when compared to feed rate and cutting speed. However increase in depth of cut increases the cutting force. Contact area and radial force is increased when increasing the depth of cut, which increases the cutting force. The response graph for the cutting force (Fig.3), shows $A_3B_1C_1$ have lowest response value. Hence, optimal level of parameters in turning of AA2219- 6 % TiB_2/ZrB_2 in-situ metal matrix composite for obtaining the lower cutting force can be given as $A_3B_1C_1$.

Analysis of variance is performed to find out the level of significance of influencing factors using the Minitab 14 and presented in the Table 5. Percentage of contribution of each factor on the cutting force also estimated. It is observed from the Table 5 the contribution of feed rate has 50.78 % and identified as most significant factor than cutting speed (41.54 % contribution). Depth of cut is the less significant factor and it has 1.35 % contribution on the cutting force within the given levels of factor.

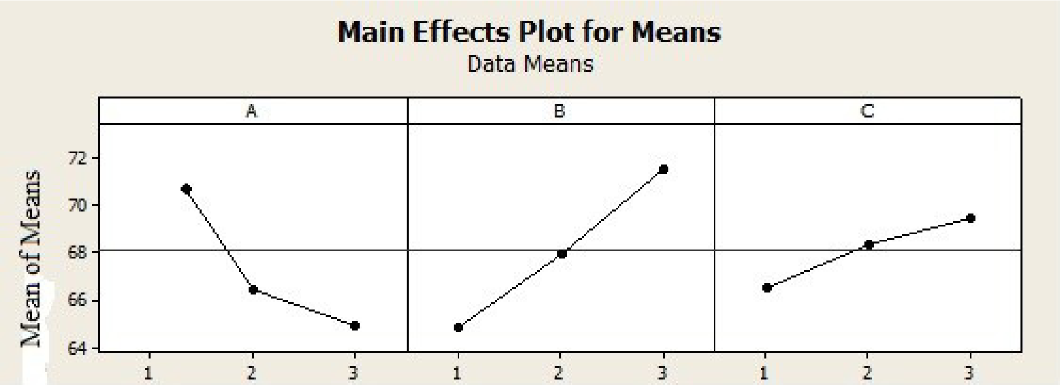

Fig.3 Response graph for the cutting force

Table 5.Result of ANNOVA for Cutting force

Factor notation	Control factors	DOF	Seq SS	AdJ SS	Adj MS	Percentage of contribution
A	Speed	2	657.04	657.04	328.52	41.54
B	Feed	2	803.34	803.34	401.67	50.78
C	DOC	2	21.32	21.32	10.66	1.35
Error		20	100.18	100.18	50.09	6.33
Total					790.94	100.00

4.2 Effect of machining parameters on surface roughness

The lower value of surface roughness is considered for setting optimal parameter. Response graph for the given experimental lay out was generated by Minitab 14 package and shown in Fig.4. It is observed from the Fig 4. the feed rate has extremely strong effect on surface roughness when compared to the cutting speed and depth of cut. Higher surface roughness was recorded at higher feed rate. Increase in feed rate increase the tool vibration. This will be attributed to the tool contact shift from matrix to reinforcement at higher rate of feed, which causes high value surface roughness. Higher feed rate is increase the friction as well as the temperature between tool cutting edge and work piece. This effect will soften the matrix material and allows to remove the reinforcement from the matrix easily and causing higher value of surface roughness. The Fig.4 shows that increase in cutting speed, decrease the surface roughness value. The build up edge formation will be eliminated at higher cutting speed. Therefore, build up edge deposition on surface is minimized, which reduce the surface roughness. The chip tool contact length is less at higher cutting speed, which promotes to reduce the surface roughness value. As seen from the Fig.4 the significance of depth of cut within the given level is very minimal.

Analysis of variance is performed to identify the significant factor by Minitab 14 package and tabulated in the Table 6. The percentage of contribution of the factors on the surface roughness also estimated and presneted in the Table 6. It is seen from the Table 6, feed rate has the strongest factor and has 76.94 % contribution on the surface roughness. Cutting speed has 13.83 % contribution followed by depth of cut has 2.84 % contribution on the surface roughness.

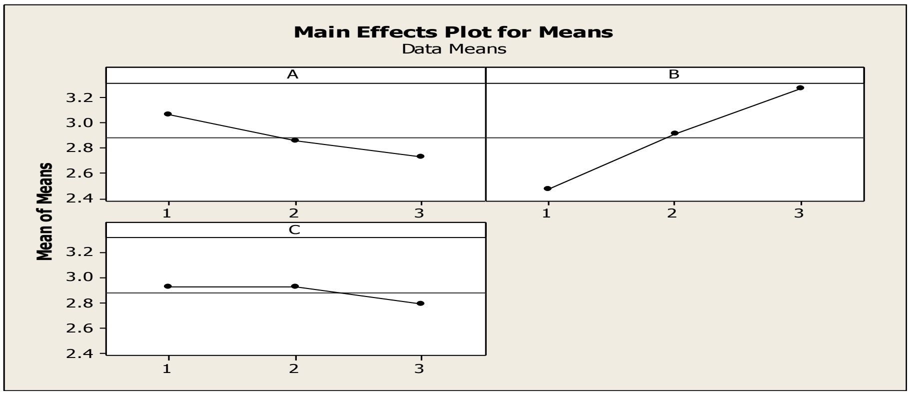

Fig. 4 Response graph for surface roughness

Table 6. Result of ANOVA for surface roughness

Factor notation	Control factors	DOF	Seq SS	AdJ SS	Adj MS	Percentage of contribution
A	Speed	2	0.51	0.51	0.25	13.83
B	Feed	2	2.82	2.82	1.41	76.94
C	DOC	2	0.10	0.10	0.05	2.84
Error		20	0.23	0.23	0.12	6.39
Total					1.83	100.00

5. Correlation and confirmative Test

Correlation between the cutting speed, feed rate and depth of cut, and the responses was developed by Minitab14- Linear regression model. At the optimal condition, the cutting force and surface roughness equations obtained was as follows.

$$\text{Cutting force(CF)} = 62.2 - 4.05^{*}\ \text{Speed} + 3.36\ \text{Feed rate} + 1.46\ \text{DoC} \quad ---- \quad (1)$$

$$\text{Surface roughness(SR)} = 2.43 - 0.182^{*}\ \text{Speed} + 0.195\ \text{Feed rate} + 0.07\ \text{DoC} \quad ---- (2)$$

Confirmative test was performed to verify the improvement of characteristics at the optimal level of selected parameters. The optimal parameter for the turning operation was set and two trails were conducted and tabulated in Table 7. It is observed from the Table 7, 1.3 % is error is found between the predicted value (62.49 N) and observed value (63.28N) of cutting force. Table 7 also indicates that, 1.25 % error is observed between the predicted value (2.51 µm) and experimental value (2.58 µm) of the surface roughness .There is a 2.8 % improvement on the cutting force and 4.6 % improvement on surface roughness are obtained by setting optimal parameter ($A_3B_1C_1$) when compared to the initial parameters(A_1 B_1 C_1). The chip formation for initial parameters and optimal parameter was shown in Fig.5 and Fig.6 respectively. Fig.6 indiactes that the favouable chip formation at the optimal machining parameters. Hence, the equations 1 and 2 correlates the evaluation of cutting force and surface roughness with a reasonable degree of accuracy.

Table 7. Result of confirmative test

Level	**Initial**	**Optimal parameters**	
	Machining Parameters	**Prediction Eqn. 1/ Eqn .2**	**Experiment (Average of Trail 1& 2)**
Setting level	$A_1B_1C_1$	$A_3B_1C_1$	$A_3B_1C_1$
Cutting force	64.23 N	62.49N	63.28N
Surface roughness	2.63µm	2.51 µm	2.58 µm

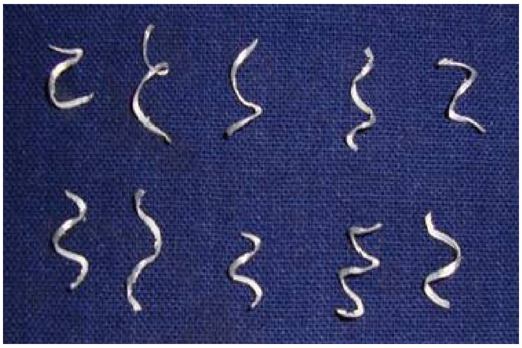

Fig.5. Chip formation at initial parameters (100m/min, 0.05 mm/rev and 0.5mm DoC)

Fig.6. Chip formation at optimal parameters (150m/min, 0.05 mm/rev and 0.5mm DoC)

Conclusion

The optimal parameters to obtain lower cutting force and surface finish in turning of turning of AA2219-TiB_2/ ZrB_2 in-situ metal matrix composite was identified using Taguchi method. The following level of factors provide optimal responses in machining, A_3(cutting speed of 150 m/min) B_1(Feed rate of 0.05 mm/rev)and C_1(Depth of cut of 0.5mm). Response graphs show that feed rate offers greater influence on cutting force and surface roughness. Analysis of variance indicated that the significance of feed rate has 50.78 % contribution on cutting force and 76.94 % contribution on surface roughness. The influence of the depth of cut on the both responses was found be very least when compared to the cutting speed. Linear regression model was developed between the factor and responses. The regression equation for cutting force and surface roughness are found good agreement with confirmation experiment. Therefore this experimental study and regression model guides to select machining parameter to achieve an optimal response in turning of AA2219-TiB_2/ ZrB_2 in-situ metal matrix composite.

Acknowledgement

The author acknowledges the financial support rendered by AICTE under MODROBS scheme 8024 / RID / BOR / MOD / 831/9/10, Dt 21/12/2009. The author also thank the under graduate mechanical engineering students Mr.A.Karthik, Mr S.Karthikeyan, Mr.P.Kathiravan and Mr.Y.Praveenkumar from Sudharsan Engineering College,Pudukkottai,Tamilnadu,India for their help to carry out this research.

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