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-TiB₂/ZrB₂ in-situ metal composites. The contribution of the paper is to study the effect of TiB₂ and ZrB₂ 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.

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 matrix and reinforcement, cluster of reinforcement, heterogeneous microstructure, coarse reinforcement and non uniform distribution of reinforcements (Cui et al. 2000).
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 into 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-Al$_4$C$_3$ 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-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-5Cu-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-TiB₂/ZrB₂ in-situ metal matrix composite by flux assisted synthesis. Quantitative elemental analysis report confirms the presence of reinforcements and Al₂Cu 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-TiB₂/ZrB₂ 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 TiB₂ and ZrB₂ reinforcement particles. Flux assisted synthesis method was followed to fabricate the composites. Three types of halide salt, namely potassium hexa-fluoro titanate (K₂TiF₆), potassium hexa-fluoro-zirconate (K₂ZrF₆) and potassium tetra-fluro-borate (KBF₄) were used to synthesize the composites. Energy Dispersive X ray spectroscopy (EDAX) spectra of AA2219-6 % TiB₂/ZrB₂ is shown in Fig.1, which shows the detection of various elements like Aluminum, copper, Titanium boride and zirconium boride. The quantitative elemental analysis report (Table 1) confirms the presence of 4.31 % TiB₂ and 2.42 % ZrB₂. Microstructure for the fabricated material was shown in Fig.2. It is observed from the microstructure the Al₂Cu 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 % TiB₂/ZrB₂](image)

Table 2. Quantitative Elemental Analysis of AA2219-6 % TiB₂/ZrB₂

| 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   |
Taguchi method has been used to optimize the cutting force in machining the composites. L27 orthogonal array layout was used for the experimental investigation. Speed, feed rate and depth cut are 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 Description | Levels   |
|-----------------|--------------------|----------|
| 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 7°, 75° 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. L27 experimental layout was used to carry out this experimental work. Surface roughness and cutting force is for 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 | 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 A1B1C1 have lowest response value. Hence, optimal level of parameters in turning of AA2219- 6 % TiB2/ZrB2 in-situ metal matrix composite for obtaining the lower cutting force can be given as A1B1C1.

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.

![Main Effects Plot for Means](image)

**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 presented 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.

![Main Effects Plot for Means](image.jpg)

**Fig. 4** Response graph 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           |                 | 20  | 0.23   | 0.23   | 0.12   | 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.

\[
\text{Cutting force(CF)} = 62.2 - 4.05 \times \text{Speed} + 3.36 \times \text{Feed rate} + 1.46 \times \text{DoC} \quad (1)
\]

\[
\text{Surface roughness(SR)} = 2.43 - 0.182 \times \text{Speed} + 0.195 \times \text{Feed rate} + 0.07 \times \text{DoC} \quad (2)
\]

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 \((A_1B_1C_1)\). The chip formation for initial parameters and optimal parameter was shown in Fig.5 and Fig.6 respectively. Fig.6 indicates that the favourable 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 Parameters | Optimal parameters | Experiment (Average of Trial 1 & 2) |
|----------------|--------------------|--------------------|-----------------------------------|
| Machining Parameters | \(A_1B_1C_1\)    | \(A_3B_1C_1\)    | \(A_3B_1C_1\)                 |
| Cutting force   | 64.23 N          | 62.49 N          | 63.28 N                          |
| Surface roughness | 2.63 \(\mu\)m | 2.51 \(\mu\)m | 2.58 \(\mu\)m                  |

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\textsubscript{2}/ZrB\textsubscript{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\textsubscript{2}/ZrB\textsubscript{2} in-situ metal matrix composite.
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