Optimization of machining parameters using Entropy-VIKOR method in drilling of A356-TiB$_2$/TiC in-situ composites

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Abstract. This study presents the multi-performance analysis in drilling of A356-TiB$_2$/TiC in-situ composite produced through stir casting route. A novel Entropy-VIKOR approach is adopted for the optimization of parameters in drilling like spindle speed, drill diameter and % of reinforcement over the MRR, delamination and surface roughness. Experiments were conducted on vertical machining centre by using of carbide drills followed by Taguchi L$_{27}$ orthogonal array. The Entropy weight measurement method was used to evaluate individual weights of each response. For the multi responses optimization VIKOR indexing method was adopted. In this paper, the multi-objective responses are converted as a single VIKOR index, and the ANOVA was performed for VIKOR index to determine the influence parameter for drilling. Finally, confirmation experiment was performed and validated using the regression equation to recognize the effectiveness of proposed method. Result of ANOVA indicates that reinforcement ratio has strongest influence on VIKOR index.

1. Introduction

Aluminium particulate metal matrix composite has wide spread attention to the researchers because of these composites exhibits the promising mechanical and metallurgical properties. As a result, many current applications for AMMCs are in aerospace, automobile components [1]. In in-situ method of fabrication the reinforcement material was synthesized by using inorganic salts through an exothermic reaction which creates the amalgamation of liquid matrix metal results the thermo-dynamically stabled, uniformly distributed ceramic particles are generated during the fabrication [2]. Drilling of composites has received wide-range of attention because of poor machinability. The abrasive natured ceramic reinforcement present in composites causes the deterioration of machining responses in all manufacturing processes [3]. Taguchi orthogonal array was followed to conduct the drilling experiments by considering cutting velocity and cutting time on drilling of composites with 5 mm drill against responses like tool wear, surface roughness and specific cutting pressure are correlated by regression equation [4]. It also observed that when feed rate and point angle increases the delamination increases [5]. The multi-objective characteristic optimization was conducted by using grey relational analysis to optimize the machining responses by considering the input parameters as speed, feed rate
and drill point angle [6]. The present work deals the optimisation of machining parameters to optimize the material removal rate, delamination and surface roughness in drilling of A356-TiB2/TiC composites. Taguchi L27 array was followed to conduct experimentation. The Entropy -VIKOR was performed to combine multiple responses into one desired value that is VIKOR Index. Therefore, the trail with Minimum VIKOR Index is identified as optimal machining parameters. Analysis of variance (ANOVA) also performed to identify the significant influential parameter to affect the combine responses.

2. Experimental procedure

2.1 Work material
In the present work A356 alloy was selected for drilling study, the chemical composition of A356 alloy is Si -6.5%, Fe-0.15%, Cu-0.03%, Mn-0.10%, Mg-0.4%, Zn-0.07%, Ni-0.05 and Ti-0.1%. A356-TiB2/TiC composites fabricated with various volume fractions through mixed salt reaction system. A measured quantity of halide salts namely potassium hexa-flouro-titanate (K2TiF6), potassium hexa-flouro-borate (KBF4) and graphite(C) are used to synthesis the composites. TiB2 and TiC reinforcements are formed by exothermic chemical reaction. The energy dispersive X-Ray (Hitachi S-300 Ha model) spectra of A356-TiB2/TiC composite are recorded by lithium drift silicon analyzer with operating voltage 20 KV and displayed in the Figure 2. This spectrum confirms the various elements presence in composites like titanium, carbon, copper and aluminium. Microstructure analysis was conducted by using scanning electron microscope (JEOL 6360 LV model) and presented in Figure 1. The Figure 1 depicts the presence of homogenously distributed and cluster free TiB2 and TiC reinforcements present in the fabricated composites. L27 orthogonal array was used to conduct the experiments by considering cutting speed, diameter of drill, and % of reinforcement as parameters.

2.2 Experimental work
The drilling experiments were carried out on CNC Vertical Machining Center (VMC) as shown in Figure 3. For the experimentation samples were prepared in the form of 150×50×10 mm by cutting in milling machine. Experiments were performed by using orthogonal L27 array considered machining parameter namely drill diameter, spindle speed and % of reinforcement of material and their levels shown in Table 1. The carbide drill bits are used for conducting experiments. The surface roughness was measured by using of SJ210 stylus type surface roughness tester (Mitutoya Make, 0.001µm). Electronic Top Loading Balance (Shimadzu) was used to measure the work piece weights before after machining processes to evaluate MRR. The delamination was measured by using Metallurgical microspore (Metzer Optical Instruments Private Limited, Mathura, India). The mathematical relation shown in below is used to evaluate the MRR and delamination.

\[ \text{MRR} = \frac{W_b - W_a}{t} \text{mg/min} \]

Where \( W_b \) = weight of work piece before machining (mg) \( W_a \) = weight of work piece after machining (mg) and \( t \) = drilling time.

\[ \text{Delamination factor} = \frac{D_{\text{max}}}{D} \] (mm) where \( D_{\text{max}} \) = Measured Diameter (mm) \( D \) = Diameter of drill in (mm)

Figure 1. A356- TiB2/ TiC composites
Figure 2. EDAX spectra of A356- TiB2/ TiC

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### Table 1. Drilling parameters and their levels

| Factor                  | Processes parameter | Unit | Level 1 | Level 2 | Level 3 |
|-------------------------|---------------------|------|---------|---------|---------|
| A                       | Spindle speed       | rpm  | 795     | 1250    | 1980    |
| B                       | Drill diameter      | mm   | 2.5     | 5       | 10      |
| D                       | % of Reinforcement  | %    | 2.5     | 5       | 7.5     |

![Figure 3. Drilling on Vertical Machining Center](image)

#### 2.3 Entropy weight measurement

The entropy weight method the number of alternatives and various criterions considered to evaluate multi parameter optimization by considering a relative decision matrix. If numbers of alternatives are spindle speed, drill diameter and % of reinforcement considers as ‘M’ and numbers of criteria are assumed MRR, delamination and surface roughness considers as ‘N’ then decision matrix having an order of M×N.

\[
D = \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1n} \\ x_{21} & x_{22} & \ldots & x_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \ldots & x_{mn} \end{bmatrix}
\]

\[
r_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \quad (1)
\]

\[
r_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \quad (2)
\]

Where \(i=1,2,3,\ldots,m \) & \(j=1,2,3,\ldots,n \) in equations

The decision matrix is normalized by maximum values (i.e. beneficial attribute) and minimum values (non-beneficial attribute). The normalized values calculated by following mathematical equations 1 and 2 and values are tabulated in Table 4

#### 2.4 Entropy weight generation model

In this stage the various criterion are resolve by the entropy method projection values (\( T_{ij} \)) are evaluated by equation (4) and the projection of alternative is used to determine the entropy index (\( e_{ij} \)) using equation (5). The projection and entropy indexed values tabulate in Table 4

\[
T_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \quad (4)
\]

\[
e_{ij} = -\frac{1}{\ln m} \sum_{i=1}^{m} T_{ij} \ln T_{ij} \quad (5)
\]

#### 2.5 VIKOR optimization method

The VIKOR method is applicable for multi parameter optimization to find a final solution. In this method statistical procedure to adopt to find the solution close to ideal positive solution (\( f^* \)) and the ideal negative solution (\( f^- \)) were identified by following equations 6 and 7.

\[
f^* = f^- = \left( \left\{ \min_{f_{ij} \in J} f_{ij} \right\} \bigcup \left\{ \max_{f_{ij} \in J} f_{ij} \right\} \right) \quad (6)
\]

\[
f^- = \left( \left\{ \min_{f_{ij} \in J'} f_{ij} \right\} \bigcup \left\{ \max_{f_{ij} \in J'} f_{ij} \right\} \right) \quad (7)
\]

Where \( J= \{ j=1, 2, \ldots, n \} \), \( f_{ij} \) if desired responses is large. \( J'= \{ 1, 2, \ldots, n \} \), \( f_{ij} \) if desired responses is small.

For the calculation of utility and regret measure for each response calculated by the following equation 8 and 9 respectively and tabulated in Table 4

\[
s_{i} = \sum_{j=1}^{n} w_{j} \frac{(f^*-f_{ij})}{(f^*-f^-)} \quad (8)
\]

\[
R_{i} = \max_{j} \left[ w_{j} \frac{(f^- - f_{ij})}{(f^- - f^-)} \right] \quad (9)
\]

Where \( s_i \) utility measure, \( R_i \) is the regret measure \( w_{j} \) is the corresponding weight of the \( j \)th attribute. The individual weight calculated by entropy weight method and finally the VIKOR index calculated by equation 10 and presented in Table 4 and to determine rank of VIKOR indexed values the least index value treated as first rank.

\[
Q_{i} = \left[ \frac{\left( Q_{i}^L - Q_{i}^R \right)}{\left( Q_{i}^L - Q_{i}^L \right)} \right] + \left[ \frac{\left( R_{i}^L - R_{i}^R \right)}{\left( R_{i}^L - R_{i}^L \right)} \right] \quad (10)
\]
Where, $Q_i$ is the VIKOR index of the $i^{th}$ result of alternatives and $v$ is the higher weight of the group utility. In general the value of $v$ considers as 0.5. In the above equation $s^+ = \max_j s_{ij}$, $s^- = \min_i s_{ij}$, $R^+ = \max_i R_i$ And $R^- = \min_i R_i$ are the maximum and minimum values of utility measure and regret measure. The following condition must be satisfied to compromise the solution of the consider weight of given alternative. The alternative $A^1$ is considered lower VIKOR index values by measure Q (minimum) and $A^2$ is the second lowest VIKOR index in list.

a) Acceptable advantage is $Q(A^2)-Q(A^1) \geq DQ = \frac{1}{(m-1)}$ where m is the number of experiments

b) Acceptable decision making stability

The alternative $A^1$ is the lowest VIKOR index ranked by S or/ and R the solution is stable in decision making. This could be the strategy of maximum of utility value $v$ is more than 0.5 needed or equal to 0.5 or with veto less than 0.5 if one condition not satisfied the following must be followed.

1. The alternatives $A^1$ and $A^2$ if only second condition is not satisfied.
2. The first condition not satisfied $A^n$ is calculated by the following relation $Q(A^n)-Q(A^1) < DQ$ for maximum of $n$

From the above equation Q value is minimum, which results the least rank which compromise the better results for multi optimization problem.

3. Results and discussion

This study reveals the combination of Entropy weight measurement and VIKOR method to evaluate the decision matrix D $m \times n$ is represent by the experimental results as shown in Table 4. For the calculation of Entropy weight of each response equation 1 and 2 are used. For the material removal rate beneficial attribute, and the surface roughness and delamination non beneficial attribute equation was used. After calculation the entropy method projection values ($T_{ij}$) are calculated by equation (4). The projection of alternative is used to determine the entropy index ($e_{ij}$) using equation (5). The projection and entropy indexed values tabulated in Table 4. Finally the VIKOR method was adopted for multiresponse optimization. From the individual matrix is analyze $f^+$ and $f^−$ possible best solution values (14.735, 1.3389, 8.948) and worst solution values (2.9278, 1.3046, 2.471) were analyzed by equation 6 and 7.

The values of utility measure and regret measure is by equation 8 and 9, respectively. The maximum and minimum utility and regret measure are (0.9909, 0.0246 and 0.07029, 0.0156) respectively. The lowest VIKOR index calculated using equation 10 and lowest index values ranked as 1 as shown in Table 4. The validation of experiment calculated acceptable advantage equation is satisfied with the value (0.0253) is less than DQ value (0.146). Therefore condition is acceptable.

3.1 optimal level selection and analysis of variance

To find the optimum level machining parameter the main effect parameter are evaluated on the basis of each level of VIKOR index as shown in Table 3. From the table 3 it is found that the 7.5 % of reinforcement, spindle speed at 1980 rpm and diameter of drill is 10 mm the optimal parameter for the multi character machining. Also table 3 shows the difference value of maximum and minimum values and their rank among the processes parameter for the selective model. The results of ANOVA test for VIKOR index shown in Table 2. From the table it has been observed that contribution each parameter on output response. And finally the interaction process parameters are significant at 95% confidence.

**Table 2** ANOVA for VIKOR Index

| Source          | DF  | Adj SS  | Adj MS  | F Value | contribution |
|-----------------|-----|---------|---------|---------|--------------|
| % of Reinforcement | 2   | 0.9826  | 0.49130 | 90.09   | 61.72        |
| Spindle speed   | 2   | 0.3699  | 0.184972| 33.92   | 23.23        |
| Drill Diameter  | 2   | 0.1304  | 0.065196| 11.95   | 8.19         |
| Error           | 20  | 0.1091  | 0.005454| 0.685   |              |
| Total           | 26  | 1.5920  |         | 100     |              |

**Table 3** Main effect factor on VIKOR level

| Parameter        | Level 1 | Level 2 | Level 3 | Max-Min Rank |
|------------------|---------|---------|---------|--------------|
| % of Reinforcement | 0.7246  | 0.3695  | 0.2840  | 0.4406 1     |
| Spindle speed    | 0.6133  | 0.4352  | 0.3297  | 0.2836 2     |
| Drill diameter   | 0.5262  | 0.4884  | 0.3636  | 0.1626 3     |

For the validation of experiments showed acceptable advantage equation is satisfied with the value (0.0253) is less than DQ value (0.146). Therefore condition is acceptable.
| Machining Parameters | Speed | Feed | Depth of cut | Experiment results | Energy index (Ei) | Regret measure values | VIKOR index (Vi) |
|----------------------|-------|------|--------------|--------------------|------------------|---------------------|------------------|
| A1                   | 2.5   | 7.5  | 1.5          | 2.91               | 0.0111            | -0.0611             | 0.0044           |
| A2                   | 2.5   | 7.5  | 2.5          | 2.71               | 0.0201            | -0.0701             | 0.0061           |
| A3                   | 2.5   | 7.5  | 3.5          | 3.51               | 0.0301            | -0.0801             | 0.0081           |
| A4                   | 2.5   | 7.5  | 4.5          | 4.51               | 0.0401            | -0.0901             | 0.0101           |
| A5                   | 2.5   | 7.5  | 5.5          | 5.51               | 0.0501            | -0.1001             | 0.0121           |

Table 4. Taguchi L9 orthogonal array with machining parameters, experimental results, projected values, individual weighted Entropy Index values, utility values, regret measure values and VIKOR index of alternative with their rank.
Conformation test

To verify the model the conformation experiments is analyzed. The predicted value of conformation experiment is obtained by regression equation. From the confirmation test the percentage of error with experiments value and evaluated by regression equation with correspond processes parameter of lowest VIKOR index. The results are shown in Table 5.

Regression equation for VIKOR index = 0.4594 + 0.2652 % of reinforcement_2.5 - 0.0899 % of reinforcement_5.0 - 0.1754 % of reinforcement_7.5 + 0.1539 speed_795 - 0.0242 speed_125 + 0.1297 speed_1980 + 0.0668 dia_drill_2.5 + 0.0290 dia_drill_5.0 - 0.0958 dia_drill_10.0

| Numerical Index | Lowest main effect level of VIKOR Index | Predicted Value | Experimental results | % of Error |
|-----------------|---------------------------------------|----------------|---------------------|------------|
| Spindle speed=1980 | Drill Diameter=10 | 0.0732 | 0.0758 | 0.0026 |

Table 5 Results of conformation experiment

Conclusions

In this study, the machinability of A356-TiB₂/TiC composites produced by K₂TiF₆-KBF₄-Graphite reaction was investigated and the following conclusions are drawn.

A356-TiB₂/TiC composites are successfully produced by K₂TiF₆-KBF₄-Graphite reaction with different reinforcement ratio and characterization report from scanning electronic microscopy and EDAX analysis confirms presence of TiB₂ and TiC reinforcements and their uniform distribution. From the analysis of results exhibits the % of reinforcement is most influential machining parameter followed by spindle speed and diameter of drill.

The Entropy-VIKOR index analysis of the experimental results of material removal rate, delamination and surface roughness can convert the multi characteristics performance optimization of the single performance characteristic is called composite VIKOR index.

From the ANOVA of VIKOR index reveals the moderate reinforcement (5%), higher spindle speed (1980 rpm) and larger diameter of drill (10 mm) is the optimum parameters for machinability of A356-TiB₂/TiC composites. Finally it has been concluded that the VIKOR index of predicted and experiment values are attained with less error value. As a result, the optimization of multiple performance characteristics can be greatly simplified.

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