Optimization of Process Parameters of Drilling in Ti-Tib Composites using Taguchi Technique

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Abstract: Titanium and its alloys exhibit excellent combination of mechanical and thermal properties, which have made them material of choice in various aerospace, defence and corrosion, resistant application. The Ti composite is processed through powder metallurgy route namely by Spark Plasma Sintering, Hot Isostatic Pressing and Vacuum Sintering process. Two different targets volume percentages of TiB(20vol% &40vol%) have been prepared. The present work focuses on finding the drilling characteristics of the Ti-TiB composite produced by the above three process. The drilling tool dynamometer are to be used for finding the thrust force, overcut, taper and circularity of the composites. The Taguchi's experimental design and Analysis of Variance (ANOVA) techniques have been implemented to understand the effects, contribution, significance and optimal machine settings of process parameters, namely, spindle speed, feed rate, process, and drilling material. The performance characteristics of the drilling were evaluated through thrust force, overcut, circularity and taper. The outcome of this project revealed that spindle speed and feed rate have the most significant impact on the dimensional accuracy of the hole, spindle speed and feed rate controls the thrust force. Drilling material, process influences less contribution on drilling of Ti-TiB composites.

Keywords: Ti-TiB composites, drilling, Taguchi method, Anova, Optimization

I. INTRODUCTION

Titanium is a chemical element with the symbol Ti and atomic number 22. It has a low density and is a strong, lustrous, corrosion-resistant (including sea water, aqua regia and chlorine) transition metal with a silver colour.

Titanium can be alloyed with iron, aluminum, vanadium, molybdenum, among other elements Ti produce strong lightweight alloys for aerospace (jet engines, missiles, space craft), military , industrial process (chemicals and petro chemicals, desalination plants, pulp and paper), automotive , agri-food, medical prostheses, orthopedic implants ,dental and endodontic instruments and files, dental implants, sporting goods and jewelers, mobile phones and other applications.

The two most useful properties of the metal form are corrosion resistance and the highest strength-to-weight ratio of any metal. In this unalloyed condition, titanium is as strong as some steels, but 45% lighter. There are two allotropic forms and five naturally occurring isotopes of this element, 46Ti through 50 Ti, with 48Ti being the most abundant (73.8%). Titanium’s properties are chemically and physically similar to zirconium, as both of them have the same number of valence electrons and are in the same group in the periodic table.

1.2 TITANIUM COMPOSITES

Titanium and an alloy comprising mainly of titanium have inherent excellent properties such as lightweight property, high strength (high specific strength) and corrosion resistance, titanium materials are used in various fields for application not only as industrialized materials such as fuselage materials and component materials for aircraft , materials for heat exchangers and electrode materials, but also as building materials such as roof materials and wall materials, and materials for goods of livelihood such as materials for decoration articles, sporting goods and equipment for leisure time amusement.

However, titanium materials are expensive compared with other materials for use (e.g. about 10 times higher in cost than stainless steel generally used as a corrosion resistant materials) and are poor in process ability. For these drawbacks, titanium materials are not replacing other materials and unlikely to be used in increasing amounts despite their excellent properties as described above. To reduce the costs of expensive titanium materials, an attempt was made to provide a “composite material” which comprises an inexpensive material covered with a thin sheet of titanium material by means of a metallurgical or mechanical process. The attempt was partly realized for commercial products.

1.3 TITANIUM DIBORIDE

TiB2 is the most stable of several titanium boron compounds. The material does not occur in nature but may be synthesized by carbothermal reduction if TiO2 and B2O3.
As with other largely covalent bonded materials, TiB2 is resistant to sintering and is usually densified by hot pressing or hot isostatic pressing. Pressure less than sintering of TiB2 can achieve high densities but liquid forming sintering aids such as iron, chromium and carbon are required.

TiB2 is resistant to oxidation in air up to 1000°C. It is also resistant to HCl and HF but reacts with HNO3. It is readily attacked by alkalis. Hot pressing of TiB2 (with small additions of metallic or carbide sintering aids) is carried out at 1800-1900°C and achieves close to theoretical density. Pressure less sintering requires higher levels of sintering aids and sintering temperatures in excess of 2000°C.

1.4 Ferro Molybdenum

It is a beta-stabilizing agent. It has been added to the titanium composites in order to improve the ductility of the product.

The volume fraction which we used was 15%.

II. RELATED WORKS:

Many reviews were done to know more about titanium composites. The journals and the content were as follows:

J. Prasanna et al. [1] concluded that thrust force decreased with the increase in feed rate. The spindle speed and the feed rate had almost equal contribution towards minimizing the thrust force for Ti-6Al-4V plate of thickness 0.4 mm. Even though low feed rate produced good circularity, it impaired overcut and produced higher thrust force. The increase in feed rate plays a predominant role in the drastic reduction of overcut. Higher spindle speed engendered to lesser thrust force and produced holes with good circularity and lesser taper angle.

Researchers have proved Taguchi’s experimental design and ANOVA techniques as an effective tool in analyzing the effect of process parameters in drilling [13,14]. This literature survey of project works in drilling has highlighted the dearth of information available to understand the effect of process parameters on the performance of drilling (3 mm) in Ti-TiB composites by conventional dry drilling process.

K.S.Ravichandran and S.S.Sahay [15] fabricated Ti-TiB composites with different volume fractions of TiB by hot pressing Ti-powders. In all the composites, TiB was the predominant boride phase. The composites with relatively high TiB content also revealed the presence of an unreacted phase TiB. The measured x-ray integrated intensities of various planes of Ti, TiB2 phases agreed reasonably well with the computed data. The volume fraction of TiB phase in the composites were determined from the integrated intensities by the direct comparison method. A mechanism on the basis of crystallography of TiB preferential diffusion of TiB in the axial direction of TiB whiskers and the bimodal packing arrangement of Ti and TiB2 Particles in the starting mixture were suggested for formation of varied morphologies in different composites.

III. SELECTION OF COMPOSITES:

The first step was to select the suitable titanium composite. The suitable titanium composition selected was Ti(70%), FeMo(15%), TiB2(15%) .

The next step was to mix the titanium powders and the composites with the help of ball milling. This process will take around 20 hrs for the perfect binding. The steel balls are used for mixing the powders. The blended titanium was then fabricated into titanium specimens by means of sintering. Ferro Molybdenum is a beta-stabilizing agent. It has been added to the titanium composites in order to improve the ductility of the product.

The next process is to fabricate the titanium by means of Hot Isostatic Pressing, Spark Plasma Sintering and Vacuum Sintering. After fabricating, the titanium pieces are subjected to wire cut EDM to get the required shape.

Ti+TiB2 2TiB

Compositions Selected

<table>
<thead>
<tr>
<th>Ti (Wt%)</th>
<th>FeMo (Wt%)</th>
<th>TiB (Wt%)</th>
<th>Target Volume of TiB (Wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>15</td>
<td>15</td>
<td>40</td>
</tr>
</tbody>
</table>

Wire Cut EDM process was conducted at New G.M. Automations, Coimbatore. Ti-TiB Composites produced by the three processes were cut into coin shape to a thickness 1.5mm and diameter 9mm. Fig.1 shows the work piece before and after wire cut EDM process.

IV. DESIGN OF EXPERIMENTS

Taguchi Method

Taguchi has envisaged a new method of conducting the design of experiments which are based on well-defined guidelines. This method uses a special set of arrays called orthogonal arrays. These standard arrays stipulate the way of conducting the minimal number of experiments which could give the full information of all the factors that affect the performance parameter. The crux of the orthogonal arrays method lies in choosing
4.1 Orthogonal array

While there are many standard orthogonal arrays available, each of the arrays is meant for a specific number of independent design variables and levels. For example, if one wants to conduct an experiment to understand the influence of 4 different independent variables with each variable having 3 set values (level values), then an L9 orthogonal array might be the right choice. The L9 orthogonal array is meant for understanding the effect of 4 independent factors each having 3 factor level values. This array assumes that there is no interaction between any two factors. While in many cases, no interaction model assumption is valid, there are some cases where there is a clear evidence of interaction.

The Table 1 shows an L9 orthogonal array layout using Minitab software. There are totally 9 experiments to be conducted and each experiment is based on the combination of level values as shown in the table. For example, the third experiment is conducted by keeping the independent design variable 1 at level 1, variable 2 at level 3, variable 3 at level 3, and variable 4 at level 3.

5.1 EXPERIMENTAL SETUP

The input and output parameters for the drilling of Ti-TiB composites are given below.

5.2 Input Parameters
- Speed
- Feed
- Process
- Drilling material

5.3 Output Parameters
- Thrust force
- Overcut
- Taper
- Circularity

<table>
<thead>
<tr>
<th>Input parameters</th>
<th>Minimum</th>
<th>Mean</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed rate(mm/rev)</td>
<td>0.05</td>
<td>0.07</td>
<td>0.08</td>
</tr>
<tr>
<td>Speed(rpm)</td>
<td>600</td>
<td>800</td>
<td>1000</td>
</tr>
</tbody>
</table>

5.4 MACHINING SETUP

The drilling experiments were conducted on a three axis Computer Numerical Control (CNC) vertical machining centre. Fig:2 shows the CNC machine during drilling process. The thrust force measurements were made using a Kistler dynamometer and simultaneously the values were sent to Kistler charge amplifier and stored in a personal computer. The hole quality assessment was done by Video Measuring Device.

5.5 MEASUREMENT PROCEDURE

5.5.1 Overcut

Overcut is the difference between the radius of the machined hole and the drill bit radius. Since the periphery of the machined hole may not be a perfect circle, the average radius of the machined hole was considered for calculating the overcut. As the entry hole radius was found to be the larger compared to the exit hole radius, the entry hole was considered for the overcut measurements. Using VMS, twelve points were located on the circumference of the hole to obtain the average radius of the entry hole.
5.5.2 Circularity
The roundness error of the machined hole is proposed in terms of circularity. The error of circularity is defined as the distance between the minimum circumscribing circle diameter and the maximum inscribing circle diameter. The circularity error exists both at the entrance and the exit of the machined hole, their maximum value was used for evaluating the circularity of the machined hole.

5.5.3 Taper
Taper angle between the entry and exit surface was calculated by using the formula given below
\[ \tan \theta = \frac{D - d}{2L} \]
where D is the average diameter of the entry surface, d is the average diameter in exit surface. L is the depth of cut.

5.6 OPTIMIZATION AND MODELING
The experiments were conducted using Taguchi L9 design approach. The optimal parameters were determined by using S/N graphs. The significance and contribution of each process parameter on the performance characteristics were found out using ANOVA method. The objective of this project was to determine the process parameters required to achieve minimum thrust force, overcut, circularity and taper.

Therefore, the quality characteristic of ‘smaller is better’ for all performance characteristics were engaged in this study. The ANOVA results were developed by using the statistical software MINITAB. Work pieces after drilling is shown Fig.5.

VI. RESULTS AND DISCUSSIONS

6.1 ANOVA FOR THRUST FORCE
Analysis of Variance Thrust force (N) with respect to Spindle speed

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>% of contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (rpm)</td>
<td>2</td>
<td>1266.63</td>
<td>1266.63</td>
<td>633.31</td>
<td>35.81</td>
<td>92.27%</td>
</tr>
<tr>
<td>Error</td>
<td>6</td>
<td>106.13</td>
<td>106.13</td>
<td>17.69</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>1372.75</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Analysis of Variance for Thrust force (N) with respect to Feed rate

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>% of contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed (mm/rev)</td>
<td>2</td>
<td>64.3</td>
<td>64.3</td>
<td>32.1</td>
<td>0.15</td>
<td>4.68%</td>
</tr>
</tbody>
</table>

Analysis of Variance Thrust force (N) with respect to Drilling material

Analysis of Variance Thrust force (N) with respect to process

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>% of contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td>2</td>
<td>14.4</td>
<td>14.4</td>
<td>7.2</td>
<td>0.03</td>
<td>1.05%</td>
</tr>
<tr>
<td>Error</td>
<td>6</td>
<td>1358.4</td>
<td>1358.4</td>
<td>226.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>1372.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
VII. CONCLUSIONS

Ti-TiB composites (1.5mm thickness) are drilled by 3mm diameter of drilling tool such as solid carbide, diamond coated high speed steel, cobalt coated high speed steel and the hole quality was analyzed in terms of overcut, circularity and taper angle for various settings of feed rate, spindle speed, process and drilling material. The following conclusions were made

1. Thrust force decreased with the increase in spindle speed.
2. The increase in spindle speed plays a predominate role in the drastic reduction of overcut.
3. Higher feed rate engendered to lesser taper angle.
4. Spindle speed had the predominant contribution towards improving circularity when compared to the other three process parameters.

REFERENCES


