Experimental Investigations on the Drilling of Titanium Metal Matrix Composite

Arun Rajesh M\textsuperscript{1, a}, Bala Kumar S S \textsuperscript{1, b}, Ashok R \textsuperscript{1, c} & Vijay Sekar K S \textsuperscript{2, d}

\textsuperscript{1}Final Year Student of BE, Department of Mechanical Engineering, SSN College of Engineering, Kalavakkam - 603 110, Tamil Nadu, India

\textsuperscript{2}Associate Professor, Department of Mechanical Engineering, SSN College of Engineering, Kalavakkam - 603 110, Tamil Nadu, India

\textsuperscript{a}arun16020@mech.ssn.edu.in, \textsuperscript{b}bala16026@mech.ssn.edu.in, \textsuperscript{c}ashok16021@mech.ssn.edu.in, \textsuperscript{d}vijaysekarks@ssn.edu.in

ABSTRACT

Titanium Metal Matrix Composites have high specific strength and offer high stiffness compared with Nickel alloys and steel. While maintaining equivalent strength, it can reduce 50% weight relative to other super alloys. In this work, preparation of Silicon Carbide reinforced Titanium Metal Matrix Composite by powder metallurgy and drilling of the composite to evaluate the drilling forces are discussed and the effect of drilling process parameters on thrust force, surface finish and chip formation is studied.

Key-words: Titanium Metal Matrix Composite, Si-C particles reinforced Titanium MMC, Powder Metallurgy, Machinability, Drilling, chip Morphology.

INTRODUCTION

A Metal Matrix Composite (MMC) is a material with minimum two constituent parts, one being a metal while the other may be of any other metal or material, such as a ceramic or organic compound. The two distinctive constituents of a composite material are the matrix and the reinforcement. The matrix is a continuous monolithic material in which the reinforcement material is embedded. Structural applications demand light weight high strength materials such as titanium, magnesium, or aluminium. These materials are commonly used as matrix in MMC, as they provide a compliant support for the reinforcement. Cobalt and cobalt-nickel alloy matrices are used for high temperature applications. The reinforcement materials are either continuous or discontinuous and are used to enhance physical properties such as friction coefficient, conductivity, wear resistance. A variety of material is used as reinforcing material
in composites like aluminium oxide, titanium oxide, silicon carbide, titanium carbide, boron carbide, titanium boride, zirconium boride, aluminium nitride, silicon nitride, etc. In the current industrial scenario, the need for light weight and high-performance material has risen. Thus, MMCs have emerged as the strongest contenders against their monolithic alloys. MMCs are used in aerospace, marine and automotive industries. Titanium MMC is very relevant in Industries such as aerospace sector where high strength materials coupled with low weight is required. Many researchers have worked on MMCs by powder metallurgy (PM) routes to improve the mechanical, thermal, and electrical properties of monolithic alloys. Titanium MMC has potential for high strength, corrosion protection, and excellent heat resistance [1].

In drilling of the Titanium Composite, thrust force and surface roughness are largely influenced by the feed rate and the processing technique [2]. Powder Metallurgy processes are commonly used for Titanium Metal Matrix Composite components used for automotive, aerospace and motorcycle industries [1].

In this work, Titanium Metal Matrix Composite reinforced with Silicon Carbide particles is prepared and the drilling on the MMC is conducted. In addition, the drilled surface and chips obtained during drilling are examined using Scanning Electron Microscope (SEM).

**METHODS**

[Following paragraphs explain in brief the 3 adopted methods in sequence: 1.Fabrication of MMC 2.Experimentation]

**1. Fabrication of MMC:**

The Metal Matrix Composite is fabricated through Powder Metallurgy route. *Figure 1 and Figure 2* shows the images of the Titanium and Si-C powders respectively. The Titanium and Si-C powder are taken in the ratio 85:15 by volume [3]. The powder mixture is ball milled for 1hour at 300 rpm with tungsten carbide balls [4]. *Table 1 and Table 2* shows the specifications of Titanium and Si-C powders.

| Table 1 Specifications of Ti powder | Table 2 Specifications of Si-C powder |
|-------------------------------------|--------------------------------------|
| **Purity**                          | **Purity**                            |
| High purity (99%)                   | Highly pure (99%)                     |
| **Size**                            | **Mesh size**                         |
| 40-50 microns                       | 220 mesh                              |
| **Density**                         | **Density**                           |
| 4.506 g/cm³                         | 3.21 g/cm³                            |
| **Melting Point**                   | **Melting point**                     |
| 1668°C                              | 2730°C                                |
Few (3-4) drops of polyvinyl alcohol is used as a binder. Figure 3 and Figure 4 shows the powder before and after ball milling respectively. The powder is compacted at 160 bar using 10 tonne hydraulic press. The dimension of the die is 32×32 mm² with 8 mm thickness (Figure 5). The compacted powders (Figure 6) are loaded on a tubular furnace under controlled atmosphere (Argon) and sintered at a temperature of 1300 degree Celsius for a holding time of 1 hour [5].

The heating and cooling rate are maintained at 5 degree Celsius per minute [5]. Table 3 shows the heating and cooling temperature and time taken. The sample is kept at 1300 °C for a holding time of 1 hour. Figure 7 shows the samples after being sintered in the furnace.
Table 3

| Heating (°C) | Time (Hours) | Cooling (°C) | Time (Hours) |
|--------------|--------------|--------------|--------------|
| 30 - 600     | 3            | 1300 - 400   | 4.5          |
| 600 - 1300   | 3            | 400 – 30     | 6            |

Fig 7 composite samples after sintering

2. Experimentation:

The Titanium MMC samples prepared are drilled using solid carbide tool (φ10mm). At different drilling speeds, 7 holes are drilled (Figure 10). The thrust force and the torque for drilling of the MMC composite are measured using dynamometer (Figure 10) and multicomponent force indicator (Figure 11). Figure 8 shows the drilling machine and Figure 9 shows the drill bit (dia 10 mm) on the wise.
The drilling is carried out on the four samples. Figure 10 shows the blind holes with the numbers.

**RESULTS AND DISCUSSION**

(The abridged form of results is being given here.)

The data collected during experimentation are given in the Table 4 and the figure 11 is plotted between Cutting speed versus Thrust and Cutting speed versus Torque. It can be seen in figure 12 that the change in torque with cutting speed is relatively less. The variation of thrust force with respect to the cutting speed is shown in figure 11.
The SEM Macrograph of the drilled specimen and SEM images of the chips formed during drilling are shown in figures. The SEM images of drilled surface of drilled workpieces and the chips formed are taken at two different speeds (103rpm and 720rpm). The chips formed are powdery and this concludes the poor ductility property of the material. This can be explained on the basis of the powder metallurgy technique that is used for the fabrication. The burrs formed during drilling are of negligible size.

| S.NO | Speed (RPM) | Thrust Force (N) | Torque (Kg-m) |
|------|-------------|-----------------|---------------|
| 1    | 515         | 960             | 0.2           |
| 2    | 720         | 1270            | 0.1           |
| 3    | 103         | 1030            | 0.1           |
| 4    | 1152        | 1090            | 0.1           |
| 5    | 164         | 950             | 0.1           |
| 6    | 257         | 960             | 0.2           |
| 7    | 73          | 1730            | 0.3           |

**Fig 11: Cutting Speed Vs Thrust**

**Fig 12 Torque vs cutting speed**
From the above shown SEM images, it can be seen that the surface layer is highly sheared due to the drilling process. Titanium and Si-C particles are severely fragmented during drilling operation. Silicon Carbide particles present in the Titanium matrix are shattered on the surface of the workpiece (Figure 11 & 12). Titanium is a hard material, in addition to which the abrasive nature of the Si-C particle makes the MMC even harder for machining. Silicon carbide particles are unevenly dispersed in the Titanium Matrix. Moreover, the presence of pores can be noticed from SEM image. Due to porous nature of the material, application of more thrust force will result in the failure. Figure 13 shows the sample drilled at 720 rpm.
Fig 14 SEM micrographs of chips produced during drilling at 103 rpm

Fig 15 SEM micrographs of chips produced during drilling at 720rpm

*Figure 14 and Figure 15* shows the SEM images of the powdery chips formed during drilling.

**CONCLUSIONS**

The following are the conclusions drawn from the experimentation,

1. Reductions of thrust force improve the surface finish and reduce the power consumption in drilling. From 100 to 500 rpm the thrust force is least. At this speeds the tool wear will be less and the power consumed will also be less relatively.

2. Surprisingly no solid chip is formed during machining instead powders were formed which is because of the powder metallurgy preparation process.

3. The chips formed are discontinuous and segmented in nature. They are powdery and this concludes the poor ductility property of the material.

4. Due to presence of Silicon Carbide in the Titanium matrix, it makes it hard to drill the workpiece and abrasive action of Si-C particle causes considerable wear of the Tool.

5. Due to the increased porosity nature of the workpiece, the workpiece gets damaged on applying more force on it. All MMC that are fabricated through Powder metallurgy route shows porosity.

6. Burr formation is negligible when Composite prepared by powder metallurgy.
REFERENCES

[1] Kondoh K. Titanium metal matrix composites by powder metallurgy (PM) routes. InTitanium Powder Metallurgy 2015 Jan 1 (pp. 277-297). Butterworth-Heinemann.

[2] Ramkumar T, Selvakumar M, Mohanraj M, Chandrasekar P. Experimental investigation and analysis of drilling parameters of metal matrix (Ti/TiB) composites. Journal of the Brazilian Society of Mechanical Sciences and Engineering. 2019 Jan 1;41(1):8.

[3] Poletti C, Balog M, Schubert T, Liedtke V, Edtmaier C. Production of titanium matrix composites reinforced with SiC particles. Composites Science and Technology. 2008 Jul 1;68(9):2171-7.

[4] P.S. Kulkarni and S. Ratnaparkhi Fabrication of Ti-CNT composites through powder metallurgy. International Engineering Research Journal Page No 1724-1726

[5] Bolzoni L, Ruiz-Navas EM, Gordo E Understanding the properties of low-cost iron-containing powder metallurgy titanium alloys. Materials & Design. 2016 Nov 15;110:317-23.