An experimental study of drilling parameters and determination of ovality during the drilling of grade 5 titanium alloy with TiN coated carbide drill tools

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Abstract. Titanium is particularly a hard to cut element. Alloys of Titanium are also regarded as hard-to-machine materials. Out of many machining operations on Titanium, drilling is treated as very important operation as it is crucial in many applications. Drilling is normally considered among the final steps of fabrication of parts and has critical economic importance. Hence it is desirable to develop an economical and feasible drilling process for Titanium alloy and improve the effectiveness of current methods since even a small mistake in the drilling operation can lead to throwing away the entire part and having to replace the entire part. On account of above facts, an experimental trial has been made to study the machining aspects during drilling of the Ti-6Al-4V alloy. The primary aim of this research paper is to study various issues in drilling holes on grade 5 Titanium alloy with Titanium Nitride (TiN) coated carbide tool. Drill bits are selected in varying diameters and drilling procedure is carried out under different feed rates and speed. The output responses measured are temperature, thrust force and torque which are analyzed and studied. Also, the hole quality is studied by measuring the Hole Ovality on a profile projector. FESEM of drill bits is carried out to analyze the pattern of wear occurred on drill bits while drilling.

Keywords: Drilling, Ti-6Al-4V, Carbide drill, Temperature, Force, Torque, Coating, Ovality, FESEM.

1. Introduction
Titanium is one of the very hard metal that has been found on the Earth. It has some excellent material properties making it a good choice of material suitable for many critical applications. Titanium is bio compatible and more importantly corrosion resistant which makes it a suitable material choice for medical implants [1] and aerospace applications [2] respectively. Previous researches point out that Titanium machining is a tedious task [3][4][5] resulting in a time and money wasting scenario. This is still an ongoing research where researchers try to develop an optimized approach in machining of Titanium and its alloys [6]. One main drawback in Titanium machining is the development of enormous temperature at the drill zone. This temperature will negatively affect the drilling procedure by gradual wear of drilling tool [7]. So, it is really a necessity to develop an optimized model of drilling of Titanium alloy by suitably selecting the right drilling parameters, right material of drill bit so as to minimize the negative effects that may occur during the drilling operation.
2. Experiment - Materials and Methods

2.1. Base Materials
The base material Ti-6Al-4V alloy required for the experiment was procured in plate form. Table 1 displays the chemical composition of the plate used.

| TITANIUM % | ALUMINIUM % | VANADIUM % | CARBON % | Fe % |
|------------|-------------|------------|----------|-----|
| 90.100     | 5.7100      | 3.200      | 0.590    | 0.2660 |

The drilling experiment is carried out on a conventional vertical machining center [VMC] available at Karunya University, Coimbatore with table size of 1280 x 240 mm. The thrust force values and torque values are measured using a three-component Kistler dynamometer. Coated Carbide tool coated with TiN (Titanium Carbide) is selected as the tool. The drilling tools are selected with different diameters of 6 mm, 8 mm and 10 mm.

2.2. Input Parameters
The input parameters chosen for the experiment is shown in Table 2. The experiments are planned based on the design of experiments using Taguchi’s approach (Taguchi and Konishi, 1987). Three factors have been identified as process parameters, viz. Spindle Speed, Drill Diameter and Feed Rate each at three levels that affect the quality of holes produced in drilling as per Taguchi’s orthogonal array of experiments.

| Drilling Parameters | A   | B   | C   |
|---------------------|-----|-----|-----|
| Speed (rpm)         | 500 | 1000| 1500|
| Diameter of Tool (mm)| 6  | 8   | 10  |
| Feed Rate (mm/min)  | 20  | 40  | 60  |

2.3. Drilling Operation
As the experiment pattern has been devised based on L9 orthogonal array, 9 holes out of which 3 each hole for each drill bits were drilled and the corresponding output parameters like Force, Torque and Temperature were recorded. A Ti-6Al-4V plate of 150 mm x 80 mm x 5 mm size was drilled using carbide drill bits coated over with Titanium Nitride and diameters of 6 mm, 8mm, 10 mm diameters. The Ti-6Al-4V plate and rill bits used in the experiment is shown in Figure 1.

Figure 1. Ti-6Al-4V plate and TiN coated Carbide drill bits used in the drilling experiment
3. Result and Discussion

3.1. Measurement of Thrust Force and Torque

Thrust force values and torque values measured while carrying out the drilling experiment are recorded with Kistler dynamometer interface. The plate is mounted on the dynamometer which sends the pulses to the computer interfaced with it and plots the graphs for Force and Torque. In this experiment drilling of a Ti-6Al-4V plate of 150 x 80 x 5 mm dimensions is carried out. Carbide drill bits coated with Titanium Nitride (TiN) of different diameters 6 mm, 8 mm, 10 mm are used for drilling titanium plate. The force graphs and torque graphs obtained from the interfaced computer helps in studying the variations of force and torque developed during drilling of Titanium. Sample graphs obtained during the drilling experiment are shown in Figure 2.

The values obtained for Force, Torque while drilling operation has been devised according to a L9 array and is shown in the Table 3 below:

| SL.No | SPEED (RPM) | FEED (mm/min) | DRILL DIA. (mm) | THRUST FORCE (N) | TORQUE (Nm) |
|-------|-------------|---------------|-----------------|------------------|-------------|
| 1     | 500         | 20            | 6               | 210              | 86.36       |
| 2     | 750         | 60            | 6               | 258.9            | 92.09       |
| 3     | 1000        | 40            | 6               | 179.2            | 88.88       |
| 4     | 500         | 40            | 8               | 382.5            | 139.80      |
| 5     | 750         | 20            | 8               | 246              | 120.2       |
| 6     | 1000        | 60            | 8               | 329.10           | 137.6       |
| 7     | 500         | 60            | 10              | 810              | 245.7       |
| 8     | 750         | 40            | 10              | 581.5            | 168.1       |
| 9     | 1000        | 20            | 10              | 381.7            | 241.1       |

Figure 2. Sample graphs obtained during drilling
3.2. Temperature Measurement
During the machining of hard to cut elements like Titanium, temperature plays a crucial role. While machining enormous quantity of temperature is produced. This temperature will affect the tool and result in tool failure. Hence developing a model to survive this amount of temperature is an important task inorder to protect the tool and have an extended tool life with less wear. Coating the drill bits with Titanium Nitride (TiN) helps to an extend in protecting the drill bits to withstand the wear and erosion of drill bits as a result of machining.

Temperature values measured during the drilling experiment is shown in Table 4.

**Table 4.** Temperature values measured during drilling experiment

| SLNo | SPEED (RPM) | FEED (mm/min) | DRILL DIA. (mm) | TEMPERATURE (°C) |
|------|-------------|---------------|-----------------|------------------|
| 1    | 500         | 20            | 6               | 40               |
| 2    | 750         | 60            | 6               | 39.8             |
| 3    | 1000        | 40            | 6               | 44.3             |
| 4    | 500         | 40            | 8               | 72               |
| 5    | 750         | 20            | 8               | 61               |
| 6    | 1000        | 60            | 8               | 44               |
| 7    | 500         | 60            | 10              | 36               |
| 8    | 750         | 40            | 10              | 77               |
| 9    | 1000        | 20            | 10              | 72               |

3.3 Measurement of Hole Ovality
Hole Ovality may be described as the deviation from perfect circularity. In short it shows how far the drilled hole is circular in shape. Measurement of Ovality is carried out after the drilling experiment on a profile projector. Profile projector was calibrated as per DOLG - NLQM/001/07 with metric traceability. Hole ovality is measured at Hole entry and hole exit.

The profile projector in which the experiment was carried out is shown in Figure 3.
The following parameters were set on the profile projector:

- Least count = 0.1
- Range = 0-25mm
- Magnification = 10x

The following readings are taken by using profile projector at Hole Entry:

| SL.NO | DRILL DIA (mm) | INITIAL READING (mm) | FINAL READING (mm) | ACTUAL READING (mm) |
|-------|----------------|----------------------|--------------------|---------------------|
| 1     | 6              | 3.36                 | 9.89               | 6.53                |
| 2     | 6              | 4.51                 | 11.16              | 6.65                |
| 3     | 6              | 9.45                 | 15.55              | 6.10                |
| 4     | 8              | 15.25                | 23.80              | 8.65                |
| 5     | 8              | 22.70                | 14.25              | 8.55                |
| 6     | 8              | 14.64                | 6.70               | 8.06                |
| 7     | 10             | 0.90                 | 11.22              | 10.32               |
| 8     | 10             | 10.45                | 20.99              | 10.54               |
| 9     | 10             | 14.40                | 25                 | 10.60               |

The following readings are taken by using profile projector at Hole Exit:

| SL.NO | DRILL DIA (mm) | INITIAL READING (mm) | FINAL READING (mm) | ACTUAL READING (mm) |
|-------|----------------|----------------------|--------------------|---------------------|
| 1     | 6              | 24.90                | 18.38              | 6.52                |
| 2     | 6              | 18.34                | 24.99              | 6.64                |
| 3     | 6              | 24.09                | 18.12              | 6.03                |
| 4     | 8              | 17.24                | 9.06               | 8.19                |
| 5     | 8              | 17.06                | 9.15               | 8.09                |
| 6     | 8              | 8.22                 | 16.75              | 8.530               |
| 7     | 10             | 11.35                | 21.77              | 10.35               |
| 8     | 10             | 21.15                | 10.60              | 10.55               |
| 9     | 10             | 11.36                | 21.24              | 10.12               |
3.4 FESEM Analysis of Drill Bits Before and After Drilling
In order to analyze the wear that has happened on the drill bits during the drilling experiment FESEM analysis was carried out on the drill bits before and after the drilling experiment. This helps in comparing the drill bit morphology that happens during the machining process.

![Figure 4. FESEM analysis of 6 mm TiN coated carbide drill bits before and after drilling](image)

![Figure 5. FESEM analysis of 8 mm TiN coated carbide drill bits before and after drilling](image)

![Figure 6. FESEM analysis of 10 mm TiN coated carbide drill bits before and after drilling](image)

3.5 Chip Formation
As a result of Titanium drilling chips are formed and those were collected. These chips enable the study of drilling parameters during the progression of drilling experiment.

The chips collected during the drilling experiments is shown in Figure 7.
In comparison to other metals the formation of chips while drilling of Titanium alloys is fairly complex. Generally, there are three types of chips formation like continuous, continuous with build-up edge and discontinuous chips. In our experiment at the end of drilling of holes we were able to get only two types of chip types - continuous chips and discontinuous chips. After closer examination it was found that when the feed rate was low long and continuous chips were formed. And in contrast, when there was high feed rate the chips formed were non continuous chips as seen in the above figure. It was also observed that with the increase in speed and feed the chips were fragile and broken.

4. Conclusion
In the present work we have tried to make a small contribution to the area of drilling of Titanium alloy. We have carried out drilling in Grade 5 alloy of Titanium with carbide tools which is coated with Titanium Nitride (TiN). During drilling experiment the output responses like temperature, thrust force and torque were measured and analyzed. Measurement of Ovality was also carried out to determine the hole quality. FESEM analysis was carried out to study the wear pattern of the drill tool. Chips formed were collected.

The following observations were made from the experiment:

- There was considerably high heat production throughout the drilling process which eventually affected the tool. There was increase in drilling temperature at higher speed and feed rates.

- Titanium Nitride (TiN) coating on the drill bit slowed down the tool wear to some extent.

- Feed rate is the key parameter affecting the output responses in the drilling experiment. Also, with respect to increment in feed rate, there is gradual increment in tool wear.

- At higher speed the holes were found to be more circular which was found through the Ovality test.
• The chips formed were collected and at higher feed rates the chips were fragile and broken.

• From the FESEM analysis carried out on the drill bits before and after drilling, it is seen that there is considerable parent material deposition happening on the tool.

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