

# Designing and Conducting Experiments for Optimization of satisfactory Cutting conditions in Micro Turning by using Titanium Alloy

S.Selvakumar, R.Ravikumar, K.Raja

**Abstract:** Micromachining is the basic technology for the production of miniaturized parts and components, which plays an important role in today's manufacturing technology. Miniaturization of industrial products had been the trend of technological development. Micro-component fabrication requires reliable and repeatable methods with accurate tools. Many common methods of manufacturing miniature components have been established in semi-conductor processing techniques, usually in large batch production. Therefore in this work, an attempt is made to machine Titanium Alloy by micro turning using mechanical micro machine tool. Micro turning is similar to that of conventional turning process but operating at the micron scale of parameters to produce micro components. In this work the cylindrical work piece of Titanium Alloy is planned to micro turned with the cutting speed of (51, 61 and 71 m/min), depth of cut (1, 2 and 3  $\mu\text{m}$ ) and feed (5, 10 and 15  $\mu\text{m}/\text{rev}$ ) using the Cermet tool. Full factorial experiments were performed by using a programmable multi-purpose micro machine tool (make Mikrotols DT110). For every set of experiments the output parameters such as the Tool wear and the Surface roughness were measured by using the video measuring system and the Surface roughness tester. Signal to Noise ratio and Analysis of variance are to be employed to investigate the performance characteristics in turning of Titanium Alloy using Cermet tool.

**Keywords:** ANOVA, Full factorial Experiment, Micro turning, Surface Roughness, Signal to Noise Ratio, Tool wear.

## 1 INTRODUCTION

Optimization of machining conditions in Microturning of Titanium Alloy is the aim of this project. At the present stage, I carried out the following.

- ◆ Code generation in microturning.
- ◆ Experimental set-up and Determination of machining performance.
- ◆ Experimental procedure.
- ◆ Experimental Design.

Among the twenty seven, nine experiments were done at various levels of micro-turning parameters.

In future, the remaining 18 experiments are to be carried out and based on that result, the cutting parameters were to be optimized.

Z.Lu, T.Yoneyama,<sup>1</sup> et al (1999), revealed that, if the applications of these conventional machining methods become available for the micro manufacturing process, the production process for micro parts will be advanced as an extension of the traditional material process. Therefore, the control of the reacting force during cutting is one of the important factors in improvement of machining accuracy. The value of the cutting force must be low and that causes plastic deformation of work piece.

T.Masuzawa, et al <sup>2</sup> (2000), Microturning has the capacity to produce 3D structures an Micro scale. As solid cutting tool is used in Microturning and it can produces definite 3D shapes. In order to accurately and precisely control of cutting tool motions during machining, cutting path generation by CNC programming is employed. The major drawback of micro turning process is that the machining force influences machining accuracy and the limit of machinable size. Nabhani, F.,<sup>3</sup> (2001), For example, Titanium alloy components make up 20-30% of the dry weight in a jet engine. However, because of their high strength and low thermal conductivity. M.Azizur Rahman<sup>4</sup> ., (2005) If the cutting tool performance in Microturning was investigated while machining of brass PCD and cermets inserts. During this machining, abrasive wear of cermet insert was observed on the flank face while PCD insert showed groove wear in the flank face. D.I.Lalwani et al <sup>5</sup> (2008), the Cutting speed has no significant effect on cutting forces and surface roughness. The feed rate provides primary contribution and influences most significantly on the surface roughness. The interaction between the feed rate and the depth of cut, quadratic effect of feed rate and interaction effect of speed and depth of cut provides secondary contribution to the model. Q.Wu N.Fang<sup>6</sup> (2009) were derived one experimental analysis under the same cutting conditions, the cutting force and the thrust force in machining Inconel 718 was higher than those in machining Ti-6Al-4V. From this analysis, as the feed rate increases, the cutting, thrust, result forces and force ratio all increases. Ulvi Sekar et al<sup>7</sup> (2004), The Surface roughness values were found to be decreased with the increasing

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cutting speed. This can be attributed to the presence of built-up-edge at the lower cutting speed. In homogeneous distribution of chip thickness at the lower cutting speed may also indicates the variation in the cutting forces and this may be another reason for poor surface finish due to the force fluctuations.

## 2 IMPORTANCE OF MINIATURE COMPONENTS

Miniaturization components play an important role in various applications, such as aerospace, automotive, electronics, biomedical, communications, and environmental. Miniature components provide low power consumption and high heat transfer, since their surface-to-volume ratio is very high. However miniature components fabrication requires reliable and repeatable methods with accurate tools. The common method of manufacturing miniature components is by micromachining, which is mostly used for semi-conductor processing for a large batch production. The majority of these methods are slow and limited to a few silicon-based materials.

The miniature components are used in the following applications:

- In biotechnology and medicine, where micro size machines would be needed to work inside the cells and tissues.
- In harsh environments, such as in vacuum, under pressure and ionizing radiation where traditional machines could not be operated.
- In narrow spaces or narrow channels where conventional machines cannot reach.
- Micro actuators and micro fittings could be used to assemble the small instruments and soft machines.

## 3 MICROTURING

Microturning is a conventional material removal process that has been miniaturized. Microturning has the capacity to produce 3D structure on micro scale.

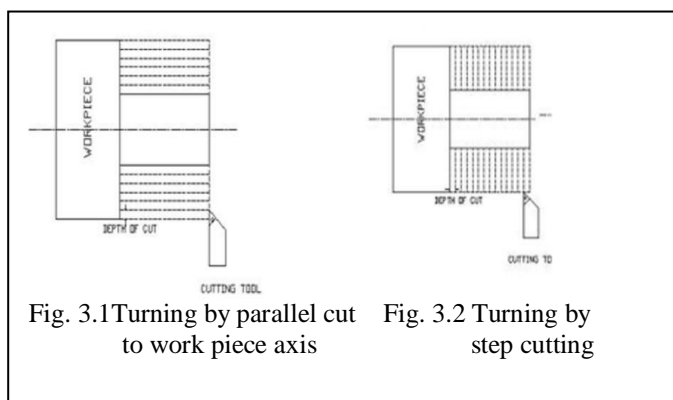


Fig. 3.1 Turning by parallel cut to work piece axis      Fig. 3.2 Turning by step cutting

As solid cutting tool is used in microturning can produce the definite 3D shapes. In order to accurately and precisely control the cutting tool motions during machining, cutting path generation by computer programming is employed.

For carrying out the process of microturning, the workpiece and the cutting tool must be moved relatively to each other in order to separate the excess layer of material in the form of chips. Hence the motion of the cutting tool with respect to the workpiece is important. In this respect, the cutting path generation has been given emphasis. A microshaft with a high aspect ratio and micron range diameter cannot be machined by a cut, parallel to the axis of the job as in conventional machining as shown in Fig.3.1. As the machining on the shaft tends to deflect because the diameter reduces and the unsupported length of the workpiece increases. The Fig. 3.2 describes one possible way of the fabrication of miniature shafts by the step cutting process. Unlike the conventional parallel cut turning, in this work, turning is carried out in a step wise manner, which will help in minimizing the deflection of the shaft. The major drawback of micro turning process is that the machining force influences machining accuracy and the limit of machinable size. Therefore the control of the reacting force during cutting is one of the important factors in improvement of machining accuracy. To overcome the workpiece deflection in microturning, the value of the cutting force must be low and it causes the plastic deformation of the workpiece.

### 3.1 APPLICATIONS OF MICROTURING

The need for microturned component possessing three-dimensional micro/mesoscale features and sub-micron surface finish keeps increasing rapidly in the fields of optics, semiconductor, biomedical devices and precision molds etc. Specific applications include micro scale pumps, valves and mixing devices, micro-fluidic systems, micro-molds, micro-holes for fiber optics and micronozzels for high-temperature jets. These applications require very close tolerances and high quality surface finish. The functional and structural requirements of these devices demand the use of various engineering materials including aluminium alloys, stainless steel, titanium, brass, plastics, ceramics and composites. The typical samples of micro-turned parts are shown in fig.3.3. The Fig.3.3 (a) shows the typical micro electronics packaging elements and Fig.3.3 (b) shows a high aspect ratio Medical application parts with diameter of 0.1mm and length of 15mm. This high aspect ratio could be achieved by using the microturning with minimized step size of less than 0.5 mm. The Fig.3.3 (c) shows microgears with different diameter and feature. The shafts are being used as main shaft for the ultrasonic micro motors.

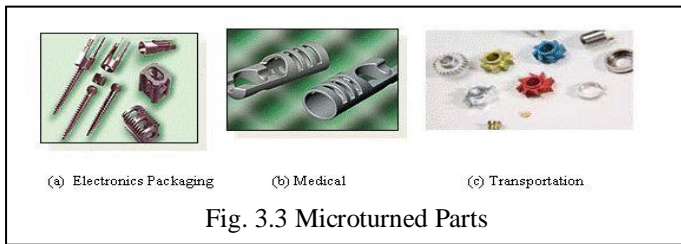
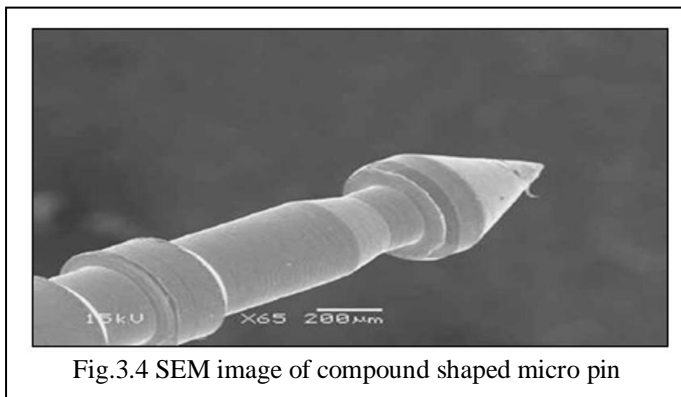


Fig.3.4 shows a compound micropin produced by a microturning which is used for the micro surgical operations.



The present analysis is concentrated on microturning of cylindrical parts of commercially available Titanium Alloy with Cermet cutting tools in a micromachining machine tool setup.

#### 4 MOTIVATION AND PROBLEM STATEMENT

The major limitation of microturning process is that the machining force influences the machining accuracy and the limit of the machinable size. Therefore, the control of the reacting force during cutting is one of the important factors in improvement of machining accuracy. The value of the cutting force must be low and it causes the plastic deformation of the workpiece. This is an effective method of overcoming workpiece deflection in microturning process. With the availability of Micro machining centre (Micro tools DT 110, Singapore Make), no cutting data regarding selection of cutting parameters is available. Hence it has been decided to carry out the detailed experimental analysis is required to arrive the proper machining condition for the standard work pieces. The effects of the depth of cut, feed rate, and spindle speed were to be considered for this analysis.

#### 5 EXPERIMENTAL DETAILS

The detail of the equipments used for performing the micro turning is given in the following section.

#### 5.1 Machine Tool



##### 5.1.1 Machine Specifications

Make: Micro tools DT 110, Singapore.

Model: Multipurpose Micro machine.

##### 1. Travel

i. X-axis: 200mm

ii. Y-axis: 100mm

iii. Z-axis: 100mm

2. Table Working Surface: 350 × 200 mm

3. Spindle Head: AC Servo; 100W

(1-5000rpm)

4. Machine Accuracy: ± 1 Micron

5. Resolution: 0.00025 mm

6. Table: Granite Base;

600 × 600 × 130 mm

##### 5.2 Material selection

From the literature survey it has been observed that there is no attempt is made to machine Titanium Alloy in microturning, however it is required for many applications. Therefore in this work an attempt is made to perform microturning of Titanium Alloy. Titanium is the 22<sup>nd</sup> element on the periodic table. Its atomic weight is 47.867amu. It is a low density element (4510kg/m<sup>3</sup>); approximately less dense than that of steel. It is nonmagnetic, and transfers heat well. Its melting point (1933K [3020 degrees F and 1650 degrees C]) is also higher than that of steel. Its usability lies in its many benefits. Titanium Alloy may be heat treated to increase its strength. It can be used in welded construction at service temperature of up to 600° F. This alloy offers its high strength at a light weight, useful formability and high corrosion resistance.

Titanium Alloy is heat treatable, high strength, low weight material. The most commercially available Titanium Alloy is known as the “workhorse” of the titanium alloys, Titanium

Alloy, or Grade 2 Titanium, is the most commonly used of all the titanium alloys. It accounts for 50 percent of total titanium usage the world over.

Titanium Alloy usability makes it the best alloy for the usage in several industries, like the aerospace, medical, marine and chemical processing industries. It can be used in the creation of such technical things as:

- Aircraft turbines
- Engine components
- Aircraft structural components
- Aerospace fasteners
- High-performance automatic parts
- Marine applications
- Sports equipments

The composition and their level of Titanium Alloy is given below:

| Element  | Ti       | C       | Fe      | H         | N        | O        |
|----------|----------|---------|---------|-----------|----------|----------|
| Weight % | Min 99.2 | Max 0.1 | Max 0.3 | Max 0.015 | Max 0.03 | Max 0.25 |

### 5.3 Cutting Tool for Micro turning

The turning operation involves cutting using a Cermet single point cutting tool (Fig.5.2) to machine Titanium Alloy. The cutting tool details are listed in Table 5.2. Sumitomo type STGCR 1010-09 mini tool holder was used for holding the tool shank.

| ISO Cat. No.: TCMT090204 |     | Grade and Make :ACZ310 (PVD Coated)- SANDWIK |     |
|--------------------------|-----|--|-----|
| Dimensions in mm         |     |  |     |
| Insert Shape             | 60° | Nose Radius(r)                               | 0.4 |
| Relief Angle             | 7°  | Insert Hole Dia. (d <sub>1</sub> )           | 2.5 |

### 5.4 Microturning Parameters

Similar to the conventional turning process, the factors influencing microturning of a work material are tool material, tool geometry, tool coating, coolant, vibration, cutting speed, feed, and depth of cut. Among these factors, the parameters which are planned to vary in this work are

- Cutting Speed (m/min)
- Feed (µm / rev)
- Depth of cut (µm)

Microturning involves less feed and depth of cut usually in the range of few microns whereas in normal turning operation these parameters are in the few millimeters range.

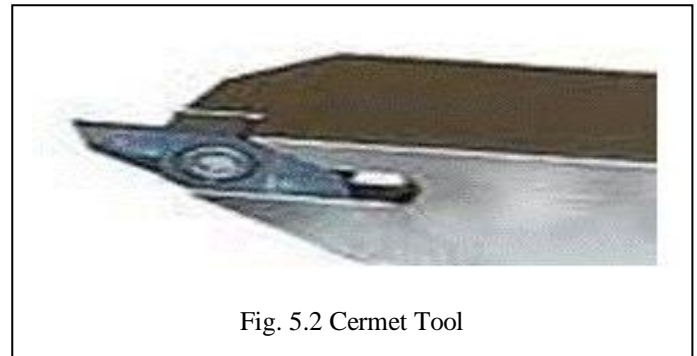


Fig. 5.2 Cermet Tool

#### 5.4.1 Cutting Speed

Speed refers to the spindle and the workpiece rotating speed, where it is stated in revolution per minute (rpm) or the surface speed, the speed at which the work piece material is moving past the cutting tool. Surface speed is the product of the rotating speed and the circumference of the workpiece before the cut is started. It is expressed in surface meter per minute (m/min) and it refers only to the work piece. The formula for speed in m/min from rpm is given in Equation-1.

$$V = (\pi \times D \times N) / 1000 \quad \text{Eqn. (1)}$$

Where V – Cutting Speed in m/min  
D – Workpiece diameter in mm  
N – Spindle Speed in rpm

Every different diameter on a work piece will have a different cutting speed, even though the rotating speed remains the same. The spindle speed range available in the DT 110 machine tools is 0-5000 rpm with safe operating limit restricted to 4000 rpm in the upper limit.

#### 5.4.2 Feed

Feed refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. The feed rate is directly related to the spindle speed and is expressed in microns per revolution (of the spindle). The machine tool has a minimum feed rate of 1 µm/min.

$$F = f \times N \times 1000 \quad \text{Eqn. (2)}$$

Where F – Feed in mm / min  
f – Feed in µm / rev  
N – Spindle Speed in rpm



### 5.4.3 Depth of Cut

The Depth of Cut is the thickness of the layer being removed from the work piece or the distance from the uncut surface of the work to the cut surface and it is expressed in microns ( $\mu\text{m}$ ).

$$t = ((d_1 - d_2) / 2) \quad \text{Eqn. (3)}$$

Where  $t$  = Depth of cut in  $\mu\text{m}$

$d_1$  – Diameter of uncut surface in mm

$d_2$  – Diameter of cut surface in mm

### 5.5 Code Generation in Microturning

Borland C++ Builder 6.0 is used for generation of the NC codes. The typical turned component is shown in Fig. 5.3.

One sample program is explained below

```
0 , 6.5, - 15.0 , 6.5, 0 , 0
1 , 4.5, -15.0 , 4.5 , -10.0 , 0
2 , 1, -10.0 , 1, -5.0, 0
3 , 0.5, -5.0, 0.5, 0.0, 0
```

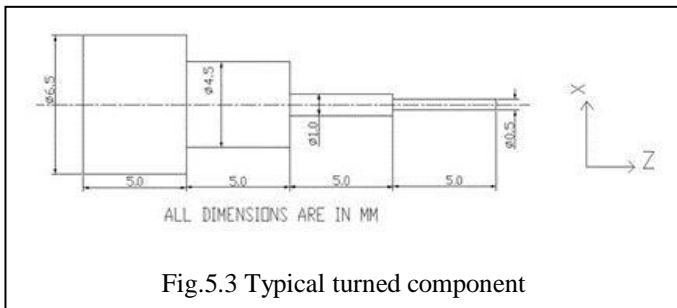


Fig.5.3 Typical turned component

The first digit in each row indicates the block numbers. In '0' block, the initial diameter of the bar and the machining length is specified. In '1' block, the largest diameter of bar to be machined and its machining length is specified. In '2' block, the next largest diameter and the machining length of that diameter is specified. Like these blocks are specified and these files are saved in '.txt' format. The next step is importing this file to 'SLICER'.

### 5.6 Determination of Machining Performance

To determine the machining performance, the output parameters such as tool wear and surface roughness of the work piece were measured.

#### 5.6.1 Tool Wear Measurement

The tool wear on the flank side of the tools was measured using a non contact video measuring system (Fig.5.4) at interval of 10 minutes after machining. The specification of the video measuring system is shown in Table 5.3.

| S.No. | Model                | VMS-2010F                                |
|-------|----------------------|--|
| 1.    | Work table dimension | 354 × 228                                |
| 2.    | Resolution           | 0.001mm                                  |
| 3.    | Magnification        | 34-220X                                  |
| 4.    | Video Aiming system  | CCD color camera,<br>0.7-4.5 X zoom lens |
| 5.    | Lighting System      | Adjustable surface lighting              |

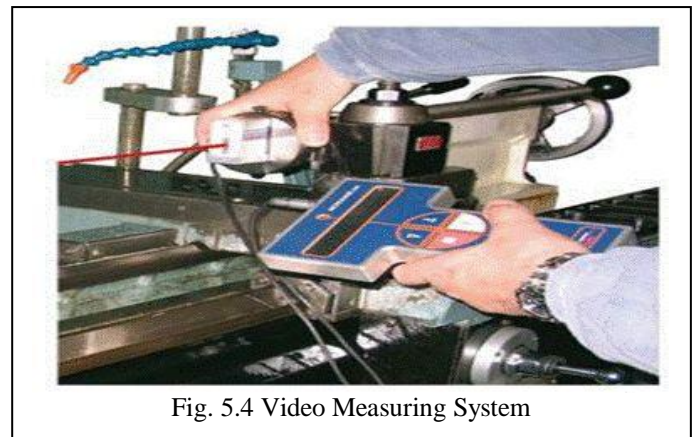


Fig. 5.4 Video Measuring System

#### 5.6.2 Surface Finish Measurement

The surface roughness parameters such as  $R_a$ ,  $R_z$  and  $R_t$  were measured by using stylus based surface roughness tester (Surfcorder SE3500) is shown in Fig.5.5.

1.  $R_a$ : Arithmetic average of the absolute values of the roughness profile ordinates, also known as Arithmetic Average (AA), Center Line Average (CLA). The average roughness is the area between the roughness profile and its mean line, or the integral of the absolute value of the roughness profile height over the evaluation length.

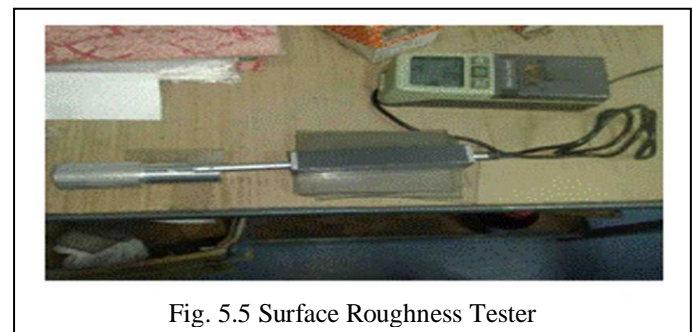


Fig. 5.5 Surface Roughness Tester

2.  $R_z$ : Arithmetic mean value of the single roughness depths of consecutive sampling lengths.  $Z$  is the sum of the height of the highest peaks and the lowest valley depth within a sampling length.

3.  $R_t$ : Maximum height of the profile.

Roughness measuring conditions are

- Cutoff length 0.25 mm
- Evaluation length 0.50 mm
- Sampling length 0.80 mm
- Measuring speed 0.05 mm/s
- Vertical magnification 1000
- Horizontal magnification 2000

Table 5.4 Specification of Surface Tester

|                         |  |
|-------------------------|--|
| Measuring Range         | 600 μm for Z axis  |
| Measuring Length        | λc ×1 to ×10 or free length  |
| Straightness Accuracy   | 0.2 μm / 100 mm or less  |
| Stylus                  | R2 μm diamond  |
| Skid                    | R40 mm (measuring direction) × R2 mm (sapphire)                      |
| Measuring Speed         | 0.05, 0.1, 0.2, 0.5, 1, 2 mm/s, Traverse Speed: 5, 10 mm/s or manual |
| Measuring Magnification | 50-500,000 for Z axis,<br>1- 5,000 for X axis                        |

### 5.7 Experimental Design

The experimental design involves the selection of suitable levels for the machining parameters i.e. speed, feed and the depth of cut. Based on the machine tool, cutting tool and work piece capacity selection of the parameters were made as listed in Table 5.5. The parameters each at three levels result in 27 combinations and full factorial experiments were conducted (Table 5.6).

Table 5.5 Parameters and their Levels

| S.No. | Parameters            | Low Level | Medium Level | High Level |
|-------|-----------------------|-----------|--------------|------------|
| 1     | Cutting Speed (m/min) | 51        | 61           | 71         |
| 2     | Feed (μm / rev)       | 5         | 10           | 15         |
| 3     | Depth of cut (μm)     | 1         | 2            | 3          |

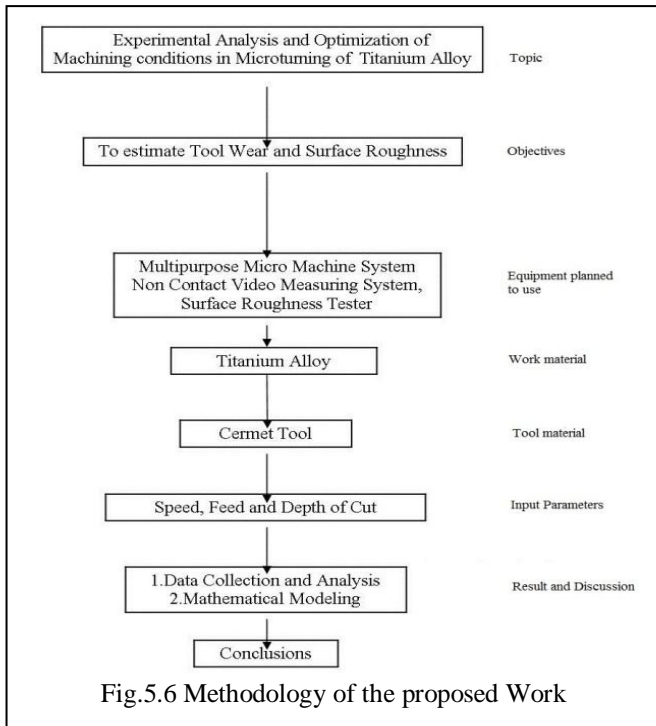
### 5.8 Experimental Procedure

The flank wear was considered as the direct indicator of tool status. Fresh Cermet was used to turn the Titanium Alloy rods under different cutting conditions (Table 5.6). At each cutting condition, the wear of the tool at every 10 minutes interval and the surface finish of the components were measured. No coolant was used during micro turning process.

Table 5.6 Full factorial Experiment

| Exp. No | Cutting Speed (m/min) | Feed (μm / rev) | Depth of cut (μm) |
|---------|-----------------------|-----------------|-------------------|
| 1       | 51                    | 5               | 1                 |
| 2       | 51                    | 10              | 1                 |
| 3       | 51                    | 15              | 1                 |
| 4       | 61                    | 5               | 1                 |
| 5       | 61                    | 10              | 1                 |
| 6       | 61                    | 15              | 1                 |
| 7       | 71                    | 5               | 1                 |
| 8       | 71                    | 10              | 1                 |
| 9       | 71                    | 15              | 1                 |
| 10      | 51                    | 5               | 2                 |
| 11      | 51                    | 10              | 2                 |
| 12      | 51                    | 15              | 2                 |
| 13      | 61                    | 5               | 2                 |
| 14      | 61                    | 10              | 2                 |
| 15      | 61                    | 15              | 2                 |
| 16      | 71                    | 5               | 2                 |
| 17      | 71                    | 10              | 2                 |
| 18      | 71                    | 15              | 2                 |
| 19      | 51                    | 5               | 3                 |
| 20      | 51                    | 10              | 3                 |
| 21      | 51                    | 15              | 3                 |
| 22      | 61                    | 5               | 3                 |
| 23      | 61                    | 10              | 3                 |
| 24      | 61                    | 15              | 3                 |
| 25      | 71                    | 5               | 3                 |
| 26      | 71                    | 10              | 3                 |
| 27      | 71                    | 15              | 3                 |

The methodology adopted for this project is illustrated in Fig.5. 6.



### 5.9 Experiments Conducted at various Levels of Microturning Parameters

The following Fig. 5.7 shows the turned piece of a particular material and the Table 5.7 shows the proposed experimental level by using the cermet insert.

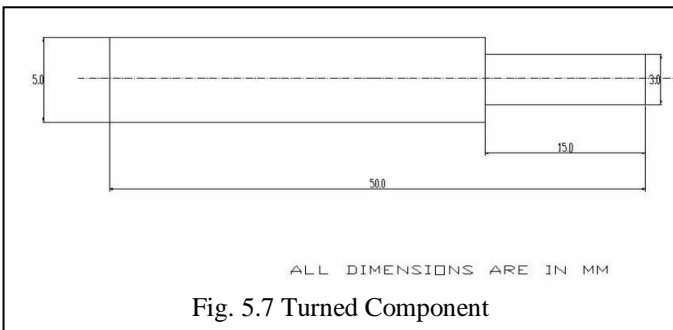


Table 5.7 Experiments conducted at various levels

| Experiment Number | Cutting Speed (m/min) | Feed ( $\mu\text{m} / \text{rev}$ ) | Depth of cut ( $\mu\text{m}$ ) |
|-------------------|-----------------------|-------------------------------------|--------------------------------|
| Experiment 1      | 51                    | 5                                   | 1                              |
| Experiment 2      | 51                    | 10                                  | 1                              |
| Experiment 3      | 51                    | 15                                  | 1                              |
| Experiment 4      | 61                    | 5                                   | 1                              |
| Experiment 5      | 61                    | 10                                  | 1                              |
| Experiment 6      | 61                    | 15                                  | 1                              |
| Experiment 7      | 71                    | 5                                   | 1                              |
| Experiment 14     | 61                    | 10                                  | 2                              |
| Experiment 27     | 71                    | 15                                  | 3                              |

### 5.10 Result of the above Experiments

The following Table 5.8 shows the measured values of a particular experimental level by using the video measuring system and the Table 5.9 shows the output measured surface roughness responses by using the surface tester.

#### 5.10.1 Tool Wear Measurement

Table 5.8 Tool Wear Measure for every 10<sup>th</sup> min. Interval

| Exp. No. | Cutting Speed (m/min) | Feed ( $\mu\text{m} / \text{rev}$ ) | Depth of cut ( $\mu\text{m}$ ) | 10 min. mm | 20 min. mm | 30 min. mm | 40 min. mm | 50 min. mm | 60 min. mm | Tool Wear (mm) |
|----------|-----------------------|-------------------------------------|--------------------------------|------------|------------|------------|------------|------------|------------|----------------|
| 1        | 51                    | 5                                   | 1                              | 0.099      | 0.097      | 0.099      | 0.096      | 0.100      | 0.096      | 0.098          |
| 2        | 51                    | 10                                  | 1                              | 0.114      | 0.116      | 0.112      | 0.110      | 0.109      | 0.108      | 0.112          |
| 3        | 51                    | 15                                  | 1                              | 0.144      | 0.145      | 0.146      | 0.145      | 0.146      | 0.143      | 0.145          |
| 4        | 61                    | 5                                   | 1                              | 0.207      | 0.209      | 0.208      | 0.210      | 0.208      | 0.210      | 0.209          |
| 5        | 61                    | 10                                  | 1                              | 0.218      | 0.219      | 0.218      | 0.219      | 0.218      | 0.220      | 0.219          |
| 6        | 61                    | 15                                  | 1                              | 0.230      | 0.231      | 0.232      | 0.230      | 0.231      | 0.229      | 0.231          |
| 7        | 71                    | 5                                   | 1                              | 0.232      | 0.231      | 0.234      | 0.235      | 0.232      | 0.231      | 0.233          |
| 14       | 61                    | 10                                  | 2                              | 0.428      | 0.429      | 0.430      | 0.429      | 0.430      | 0.428      | 0.429          |
| 27       | 71                    | 15                                  | 3                              | 0.358      | 0.360      | 0.359      | 0.361      | 0.359      | 0.360      | 0.360          |

### 5.10.2 Surface Roughness Measurement

Table 5.9 Measured Surface Roughness (Ra)

| Exp. No. | Cutting Speed (m/min) | Feed ( $\mu\text{m} / \text{rev}$ ) | Depth of cut ( $\mu\text{m}$ ) | Surface Roughness (Ra) ( $\mu\text{m}$ ) |
|----------|-----------------------|-------------------------------------|--------------------------------|--|
| 1        | 51                    | 5                                   | 1                              | 1.90                                     |
| 2        | 51                    | 10                                  | 1                              | 1.00                                     |
| 3        | 51                    | 15                                  | 1                              | 2.00                                     |
| 4        | 61                    | 5                                   | 1                              | 0.94                                     |
| 5        | 61                    | 10                                  | 1                              | 2.86                                     |
| 6        | 61                    | 15                                  | 1                              | 2.53                                     |
| 7        | 71                    | 5                                   | 1                              | 1.50                                     |
| 14       | 61                    | 10                                  | 2                              | 3.62                                     |
| 27       | 71                    | 15                                  | 3                              | 2.80                                     |

## 6 CONCLUSION

### 6.1 Work done

1. Extensive literature survey has been carried out in the following areas such as

- Micromachining.
- Microturning of various combination of workpiece material and tool.

2. Selection and procurement of materials

- Titanium Alloy is selected as workpiece material.
- Cermet is selected as tool material.

3. Design of Experiments

- Microturned parameters such as Cutting speed, feed rate and depth of cut and their levels are selected.
- Trail run have been carried out to familiarize in the microturning process. Based on the experimental design nine experiments were conducted.

### 6.2 Work to Be Done

- The remaining experiments (18Nos.) have to be conducted as per the full factorial method.
- During each experiment the Tool wear and the Surface roughness of work piece has to be measured by using Video measuring system and Surface Roughness tester respectively.
- Regression analysis has to be carried out to predict the Tool Wear and the Surface Roughness.
- Taguchi analysis has to be carried out to find out the optimum parameters to get the lower tool wear and better Surface roughness.

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