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Fabrication of Tibial Component of Knee Joint

Minku[1], Alakesh Manna[2]

[1]ME Research Scholar, Department of Mechanical Engineering, Punjab Engineering College (Deemed to be University), Sector-12, Chandigarh-160012, India.
[2]Professor, Department of Mechanical Engineering, Punjab Engineering College (Deemed to be University), Sector-12, Chandigarh-160012, India.

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Abstract - *This paper is concerned with the fabrication and analysis of machined surface texture of Tibial component. In present study, explained the fabrication processes of Tibial component of knee prosthesis which includes design to establish geometry in solid works, selection of material, machining process and machining of Tibial implant. The TI6AL4V material is selected because of its good modulus of elasticity, corrosion resistance and biocompatibility. Machining is done on CNC vertical machining centre with uncoated carbide inserts. The machining of implant is very challenging due to the complex shape of Tibial component of the knee implant and the associated restrictive geometrical and dimensional requirements. To achieve the required surface finish, the input cutting parameters is optimized based on Taguchi design of experiment. Furthermore, it is vital to ensure that the surface integrity of Tibial component of the knee implant is not brutally affected, in order for the implant to be durable and wear resistant. In this study various machining challenges are described during machining of TI6AL4V. The SEM images of cutting tools after single continuous pass were taken to inspect and analysed the tool wear during machining. The surface roughness heights, R_a (μm) and R_t (μm) of fabricated Tibial implant were measured and analysed.*

Key Words: **Knee, Tibial, TI6AL4V, CNC Machining, Taguchi Method, Surface Roughness.**

1. INTRODUCTION

Knee joint is one of the most complex joint both from a medical and an engineering point of view. It is made up of four bones: femur, tibia, fibula and patella. The knee joint is a pivot hinge joint because with the help of knee joint different motion as be performed by the leg like straightening and bending of legs (Himanshu and Manna 2018). Only in United States, over 500,000 knee replacement surgeries are reported each year which are mostly for patients between 50 and 80 years old (Angelos et al. 2018). Knee joint is held in place by four large ligaments, these are medial condylar ligament (MCL), Lateral collateral ligament (LCL), front cruciate tendon (ACL) and posterior cruciate ligament (Lee1 et al. 2010). The stability of the knee joint is achieved by a system of ligaments, strong muscles, and by a strong but elastic joint capsule. The knee anatomy of a human knee joint is shown in the Fig. 1.

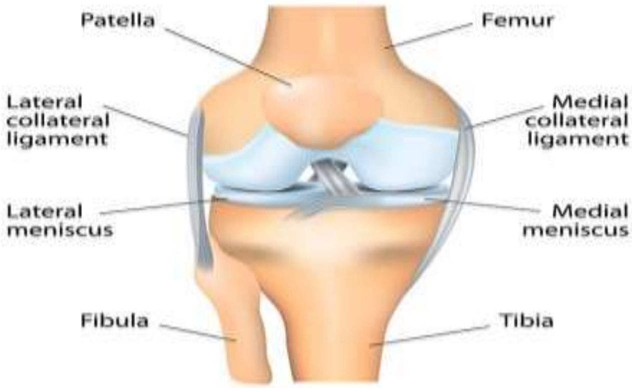

Fig. 1 The human knee (source: https://mobility-health.com)

The basic principle behind the knee replacement technique is to remove defective and damaged joint parts and surfaces of knee and replacing it with an implant made of metal and plastic (Angelos et al. 2018). The main knee parts that are replaced the femoral and tibia surfaces near the knee joint. Knee implants are made up of suitable metals or non-metallic materials and properly machined in order to resemble the natural shape of the knee (Li et al. 2017). In this paper, main focus is given on the design and manufacturing of Tibial component of knee joint. In initial stage, it is crucial to study the design of the whole knee implant at the initial stage in order to determine the appropriate dimensions.

Different steps were undertaken for fabrication of Tibial component of knee joint such as:

- Design Tibial component of knee joint in SOLIDWORKS
- Select the raw material and appropriate fabrication process for manufacturing of femoral component of knee joint.
- Select CNC Vertical Milling Centre COSMOS CVM 800 for machining of Tibial component.
- Machined surface roughness heights R_a (μm) and R_t (μm) were measured utilized Surfcom 130A surface roughness measuring instrument.
- Optimize the input parameters based on Taguchi design of experiment for surface roughness heights R_a (μm) and R_t (μm) and analysis of test results.

2. DESIGN OF TIBIAL COMPONENT

SOLIDWORKS is used to design the component. Tibial component has different geometries at its outer and inner surface. Hence, the detail design of Tibial component is completed in two steps. In first step design the outer surface of the Tibial component. In second step design the inner surface of the Tibial component. The design of the tibial component includes the design of two different structural elements, a stem and a platform. The stem is intended to aid to the fixation of the tibial component to the tibia and the platform is essential for the connection of the tibial component to the tibial articulating surface. Fig.2 shows the design of the Tibial component in Solidworks.

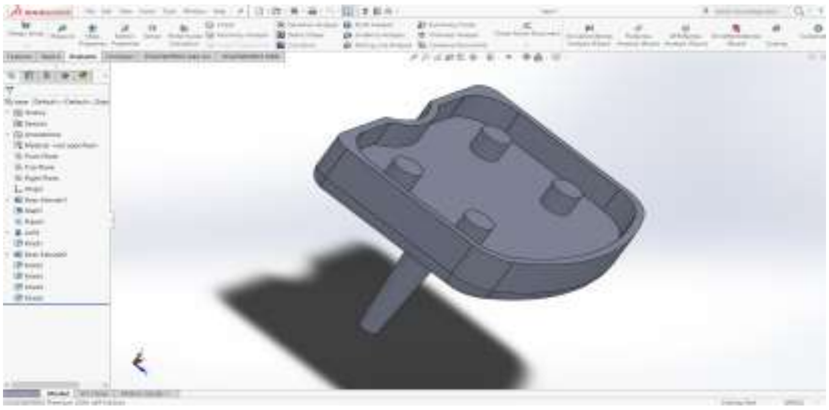

Fig. 2 Design of the Tibial component in Solidworks

3. SELECTION OF MATERIAL

It is very important to select the appropriate material for tibial component. Material selected should be biocompatible for knee implants. Titanium alloys TI6AL4V is selected because of its properties match with the biocompatible materials (Bahraminasab et al. 2011). Table 1 represents the chemical composition and physical properties of TI6AL4V considered for fabrication of tibial component (Veiga et al. 2012).

Table 1 Chemical composition and physical properties of TI6AL4V

Chemical Composition of TI6AL4V		**Physical properties of TI6AL4V**	
Pure Titanium	90%	Density	**4.5g/cm^3**
Aluminum	6 %	Melting point	1670^{0}C
Vanadium	4%	Elastic Modulus	115 GPa
Iron	Max 0.25%	HRC	32
Oxyzen	Max 0.2%	Thermal conductivity	15– 22 W/mK

4. FABRICATION OF TIBIAL COMPONENT

Based on review of literature and study on fabrication of knee joint it is identified that the most suitable process for fabrication of Tibial component of knee joint is CNC Milling. The tibial component was machined on CNC Vertical Milling center COSMOS CVM 800. Fig.3 shows the CNC Vertical Milling center COSMOS CVM 800 used for machining of Tibial component. Fig.4 shows the machined tibial component.

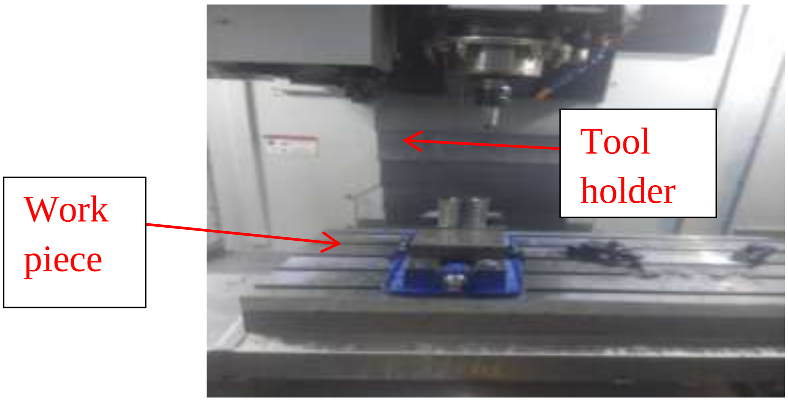

Fig. 3 TI6AL4V workpiece hold on CNC vertical milling center COSMOS CVM 800

Fig. 4 Fabricated tibial component

5. RESULTS AND OPTIMIZATION OF MACHINING PARAMETERS

The selection and setting of cutting parameters are of great important for machining of TI6AL4V alloy because of high tool wear. Keeping in view, few trail experiments were carried out to identify the setting level of the cutting parameters but not explained in the present paper. Utilized the identified setting level and employed Taguchi design of experiments detail experiments were carried out and optimized the machining parameters for minimum surface roughness heights, R_a (µm) and R_t (µm). Table 2 represents the machining parameters and their levels considered for experiments.

Table 2 Machining parameters and their levels considered for experiments.

Sr. no.	Symbol	Input Machining parameters	Levels			Units
1.	A	Rotational speed of cutter	1000	2000	3000	rpm
2.	B	Feed	0.5	0.6	0.7	mm/rev
3.	C	Depth	0.4	0.5	0.6	mm

Taguchi design of experiment L_9 (3^3) orthogonal array is employed and according to this array total of 27 experiments were carried out i.e. 9 experiments with three replications for machining of femoral component. To calculate the S/N Ratio (dB) for minimum surface roughness heights utilized 'Smaller-the-Better (LB)' criteria relation as follows:

S/N Ratio for $(LB) = \eta = -10 \log_{10}[\frac{1}{n}\sum_{i=1}^{n} y_i^2], i = 1,2 \ldots \ldots n$ Eqn.1

Utilized the above mathematical relation equation 1, experimentally acquired results and MINITAB 19 software the S/N ratio (dB) was calculated and drawn the S/N ratio graphs. Fig. 5 and Fig.6 show the S/N ratio (dB) graphs for surface roughness heights R_a (μm) and R_t (μm) respectively. Table 3 represents the Taguchi method based L_9 (3^3) orthogonal array, test results and calculated S/N ratio (dB) for surface roughness heights R_a (μm) and R_t (μm).

Table 3 Taguchi method based L_9 (3^3) orthogonal array, test results and S/N ratio (dB) for R_a (μm) and R_t (μm)

Sr. no.	Rotational speed of cutter(rpm)	Feed rate (mm/rev)	Depth of cut(mm)	Surface roughness height R_a(μm)	S/N ratio of R_a	Surface roughness height R_t(μm)	S/N ratio of R_t
1	1000	0.5	0.4	0.325	9.7623	1.112	- 0.922
2	1000	0.6	0.5	0.576	4.7916	1.491	-3.4695
3	1000	0.7	0.6	0.662	3.5828	2.157	- 6.677
4	2000	0.5	0.5	0.224	12.995	1.067	-0.5632
5	2000	0.6	0.6	0.291	10.0063	1.118	-0.9688
6	2000	0.7	0.4	0.352	7.6810	1.191	-1.5109
7	3000	0.5	0.6	0.176	15.0897	0.768	-1.1356
8	3000	0.6	0.4	0.212	13.4733	1.214	-1.6843
9	3000	0.7	0.5	0.376	8.4962	1.256	-1.9797

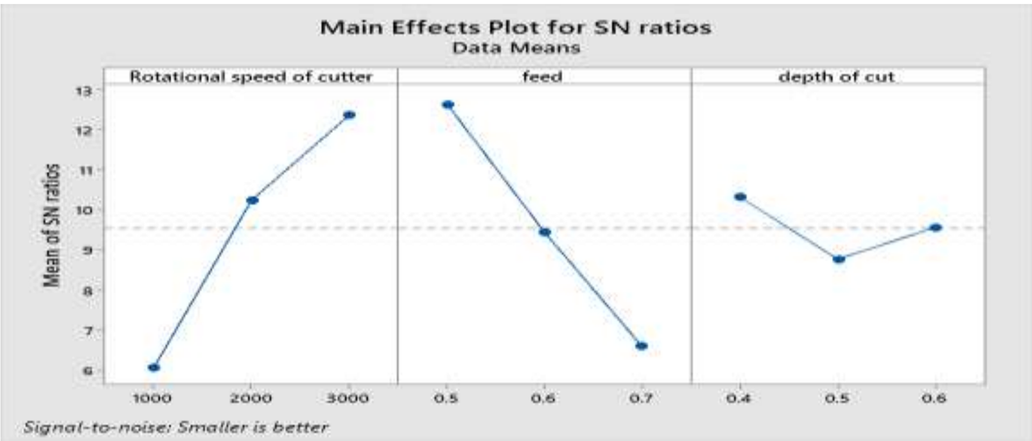

Fig. 5 Variation of input parameters with S/N ratio for R_a (μm)

From Fig. 5 and Fig.6, identified the optimum level of parameters for lowest surface roughness heights, Ra (μm) and Rt (μm) is 3000 rpm rotational speed of cutter, 0.5mm/rev feed rate and 0.4mm depth of cut.

The validity experiments were carried out at optimal parameter setting i.e. 3000 rpm rotational speed of cutter, 0.5mm/rev feed rate and 0.4mm depth of cut and measured the surface roughness heights. The measured values of the machined surface roughness heights Ra (μm) and Rt (μm) are 0.133 μm and 0.623μm respectively. From the validity test results it is clear that the machining of TI6AL4V alloy at optimal setting parameter with carbide tool on CNC vertical machining centre the surface roughness heights were minimum. Hence, tibial component can be machined at 3000 rpm rotational speed of cutter, 0.5mm/rev feed rate and 0.4mm depth of cut with EPNW0603TN8065041 carbide tool.

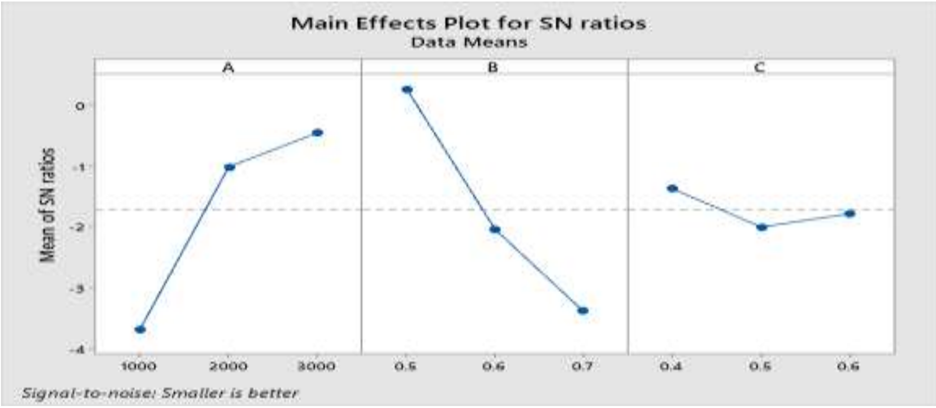

Fig. 6 Variation of input parameters with S/N ratio for R_t (μm)

6. ANALYSIS OF TOOL WEAR

The tool material used in the fabrication of this tibial component is cemented carbide of specification EPNW0603TN8065041. Tool wear is one of the most important problems faced during machining of titanium alloys, it is due to high-cutting temperature and strong adhesion of the metal chips with flank face of the cutting tool. The extent of cutting tool wear depends on the tool material and geometry, work piece material, cutting parameters, cutting fluids and machine-tool characteristics.

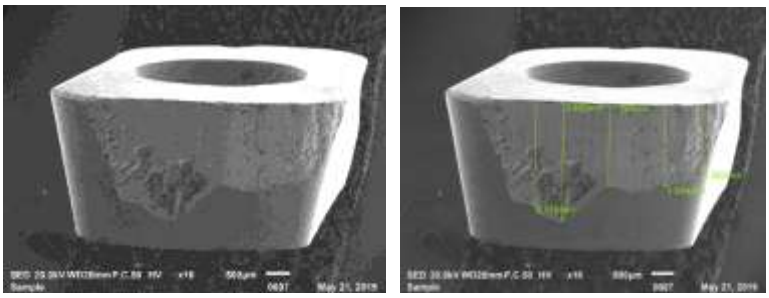

Fig. 7 SEM images of tool inserts used

The average flank wear width of cutting tool EPNW0603TN8065041 was 1.884 mm which shows the very high tool wear during machining of titanium alloys.

7. CONCLUSIONS

In present experimental research investigation, various stages of the manufacturing of tibial component of knee prosthesis are investigated and explained. These stages include design of geometry in solid works, selection of material for knee implants components, selection of machining operation and actual machining of knee implants. Based on the experimental results during fabrication of tibial component of knee implant by CNC vertical milling machine the following conclusions are drawn and listed as follows:

(i) The titanium alloy TI6AL4V may be one of the materials can be used for fabrication of knee implants.

(ii) The CNC vertical machining centre COSMOS CVM 800 can be used for machining of knee implants.
(iii) The tibial component can be machined at optimal machining parameter i.e. 3000 rpm rotational speed of cutter, 0.5mm/rev feed rate and 0.4mm depth of cut with EPNW0603TN8065041 carbide tool. The combination of optimum input parameters gives lowest surface roughness heights Ra (μm) and Rt (μm) i.e. 0.133 μm and 0.623 μm respectively.
(iv) The SEM images of tool wear were taken after each pass of machining operations. The average flank wear width of cutting tool EPNW0603TN8065041 was identified as 1.884 mm that represents very high tool wear.

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