International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 17 (2015) pp 37763-37767


# The parametic study of Titanium alloy (Ti6%Al4%V) cutting process by Finite Element Analysis

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**Abstract**
Titanium alloy (Ti6%Al4%V) is biocompatibility material that can pretend cultivate parts (impant) in medical surgery
One of the appropriated application is the prosthesis implant of total knee arthroplasty (TKA). The titanium alloy has a very high hardness scale so the process of manufacturing requires high techniques such as the selective of cutting tools, cutting characteristics parameters, cutting speed and etc. To study the influent parameters of cutting process, Finite element method was to use for modeling of cutting process. The cutting tools material are TiN and TiAIN, The speed of tools at 10,000 12,500 15,000 17,500 rpm and the angle of blade 5$^{o}$ 10$^{o}$ 15$^{o}$ on vertical are established for the important parameters such as the maximum stress, the force acting on the cutting tools, the heat transfer and temperature rise, as well as the characteristics of cutting chips (chip deformation)
When the various parameters have been investigated, some appropriated values can be commerce to perform an experimental work on 5-axis high speed CNC machine.

**Keyword:** Titanium alloy, Cutting process, Finite element

## Introduction

Titanium alloys are widely employed in aircraft and aerospace industry. They are also used as materials for transplantation and knee prosthesis because of their superiority in mechanical, chemical properties and biocompatibility.
However, titanium alloys have some properties which are hard for transition such as temperature of cutting, toughness of surface which make tool erosion a significant problem and it increases production costs.
In this consideration, cutting process work is mechanical procedures that need machines since it is largely used in creatioan of free 3D work with using iron, ceramic, polymer material and so on.
Titanium alloy cutting process is experimentally studied by a vertical cutting process such as shaping with a lathe or milling.
Haron [1] said that useful life of tools or blades will be shorter when using it with Ti-6AI-4v. The use of fine particles tools will last longer.
Haron and Jawad [2] said that the effects of machining on Microstructures of Ti-6AI-4v and Micrihardness of work piece surface increases due to Microstructure change.
Pitala and Mono [3] said that the surface of work piece that has been done by milling process is a simulation that separates sectional cutting into circle shapes. In 2D simulations permit results in the prediction of temperature and forces of the work piece cutting process.
Su [4] has studied the refrigerants in order to increase the useful life of cutting tools and fatigue from heating in the test.
Afazov [5] has modified milling tools to be finite element and calculated part by part of milling tools by simulating into 2D and calculated them separately then combined all together to find milling process forces.
Patil [6] has created simulation of the effects from vibration within Ti-6AI-4v cutting process.
Sima and Ozel [7] have proposed to modify material forms to notice fragments from cutting Ti-6AI-4v with 2D simulation by using the material forms of Johnson-cook(JC) to explain occurrence of cutting's fragments.
This research aims to study results of heat dissipation with movement of titanium alloy cutting process simulation by using behavior forms of materials of Johnson-cook plasticity model from Johnson [8] which considers annealing –plastic behavior and the loss of materials under forces of cutting tools. According to the research, set up blade angles at 5$^{o}$,10$^{o}$,15$^{o}$ on vertical, the speed of tools is at 10,000, 12,500, 15,000, 17,500 rpm and the depth of milling is at 5 mm.

## Finite Element Method(FEM)

FEM program utilized is ANSYS Workbench 15.0 and it is employed in simulation of 3D cutting process. Figure 1 displays flowchart which describes methods of simulation by FEM principles that can explain computation in agreement with FEM principle procedures. The computation of Flowchart has a geometry formulation, boundary condition, material model, initial boundary condition and enters into iteration process because collected data need to re-collect over and over again in order to approach the closet answer.
The material model of JC are utilized in behavior finding under FEM boundary condition process.

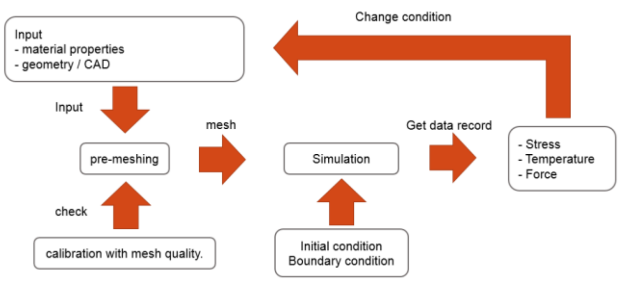


**Figure 1 Overall image of 3D FEM simulation**

### Material model and Chip formulation

JC material model is elements of behavior forms of applied materials to find changes in material forms. JC material model can describe stress strain value and temperature based on material properties.

The equivalent stress can be found from JC's forms as follows.

$$\bar{\sigma}_{jc} = [A + B(\bar{\varepsilon}^P)^n]\; x \left[1 + Cln\frac{\dot{\bar{\varepsilon}}^P}{\dot{\bar{\varepsilon}}_0^P}\right] x \left[1 - \left(\frac{\theta_w - \theta_0}{\theta_m - \theta_0}\right)^m\right]$$

By A, B, n, C and m material constants, $\dot{\bar{\varepsilon}}^P$is strain, $\dot{\bar{\varepsilon}}_0^P$ is strain rate and $\theta_i$ is temperature

Material loss forms are from deformation or element separateness within Mesh process.

### Numerical Formulation

From figure 2, it indicates material forms and blades with 3D vertical cutting simulation.

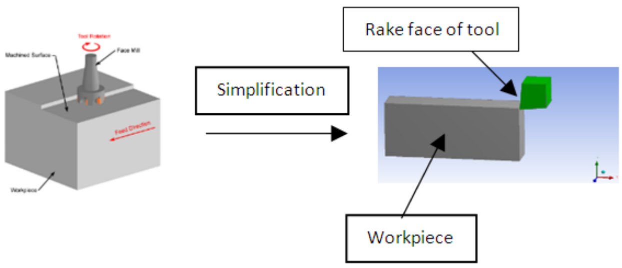


**Figure 2 milling simulation in 3D vertical cutting.**

Figure 3 indicates initial state and boundary condition in simulation which will be both considered blades and materials. Blade will be used to limit movement in 3 directions moving axis and requires material moving towards blades. The friction coefficient formulation between materials and blades by Ozel and Sima [9] has divided the surface of blade into 3 areas at shear friction, 1, 0.5, 0.7-0.8. The first area was a tough area which was not considered in this test but two areas were combined together and balanced out to coefficient of friction equaled 0.6

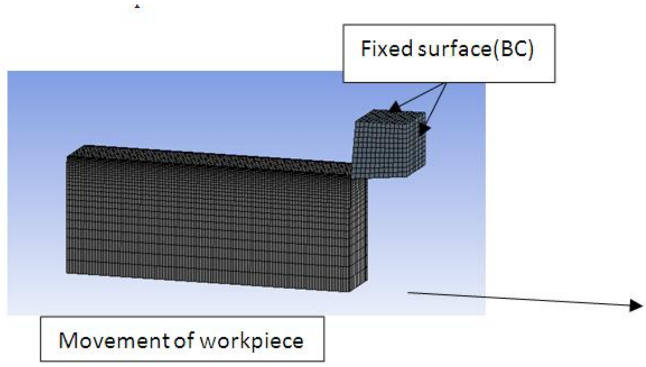


**Figure 3 boundary condition of simulation**

### Simulation and Chip Formation

Features of simulation formation determine parameters as table 1 with conditions, 4 cases of speed value and 3 cases of blade angle value so there will be 12 cases in simulation as follows

**Table 1 parameters used in milling simulation**

| Case | Blade Angle (On Vertical) | Revolutions per minute(rpm) |
|---|---|---|
| 1 | 5° | 10,000 |
| 2 | 5° | 12,500 |
| 3 | 5° | 15,000 |
| 4 | 5° | 17,500 |
| 5 | 10° | 10,000 |
| 6 | 10° | 12,500 |
| 7 | 10° | 15,000 |
| 8 | 10° | 17,500 |
| 9 | 15° | 10,000 |
| 10 | 15° | 12,500 |
| 11 | 15° | 15,000 |
| 12 | 15° | 17,500 |

### Experimental Results

12 cases of simulation that have been made can indicate the results in the program as figure 4 which is a blade angle test with milling 15° at 10,000 rpm etc.

From figure 4-a, it indicates the value of von-Mises stress in total

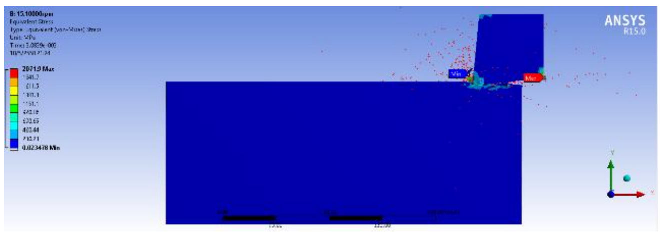


**Figure 4-a**

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 17 (2015) pp 37763-37767
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From figure 4-b, it indicates the value of von-Mises stress only for work piece materials

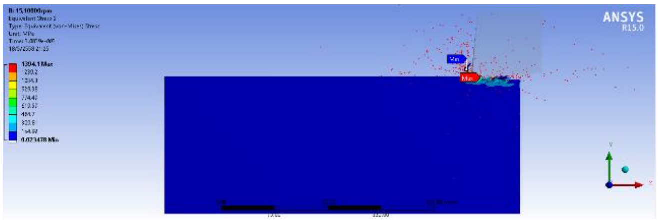


**Figure** 4-**b**

From figure 4-c, it indicates the value of von-Mises stress only for blades

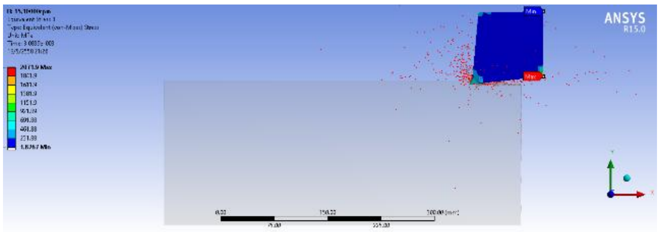


**Figure** 4-**c**

From figure 4-d, it indicates the value of total deformation only for blades

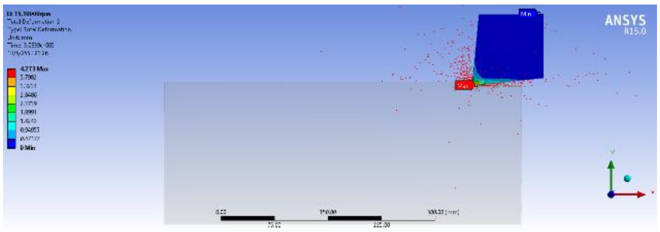


**Figure** 4-**d**

From figure 4-e, it indicates the value of total deformation only for work piece material

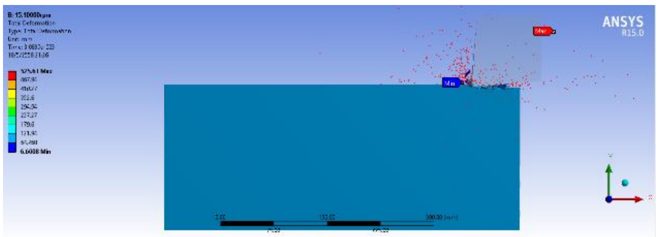


**Figure** 4-**e**

From figure 4-f, it indicates the value of temperature only for blades

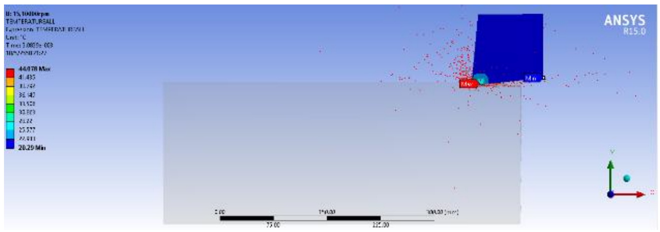


**Figure** 4-**f**

From figure 4-g, it indicates the value of temperature only for work piece materials

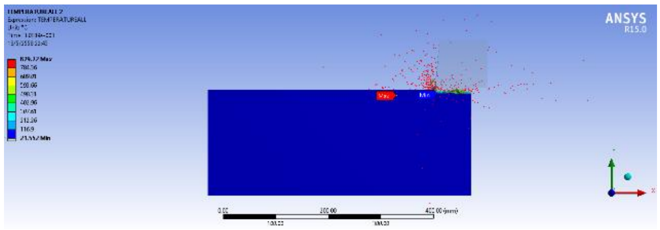


**Figure** 4-**g**

**Analysis the results**

When all results comes out, they need to be analyzed all 12 cases with plot graph indication of contour surface by x-axis displaying value of cutting speed and y-axis displaying the von-Mises stress, forces (total deformation) and temperature.

From figure 5, it displays values of von-Mises stress which takes place within blade. The highest value of von-Mises stress is at 2209.7 Mpa which is in a case of 10$^{o}$ blade angle at cutting speed 12,500 rpm and the lowest value of von-Mises stress is at 1168.9 MPa which is in a case of 10$^{o}$ blade angle at cutting speed at 15,000 rpm.

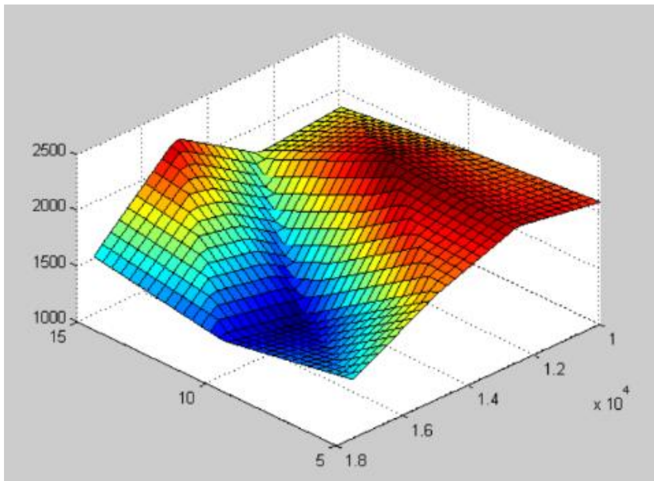


**Figure 5 stress that takes place within blade**

From figure 6, it displays the value of von-Mises stress that occurs in work piece. The highest value of von-Mises stress is at 1406.1 MPa which is in a case of 10$^{o}$ blade angle at cutting

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speed 15,000 rpm. The lowest value of von-Mises stress is at 1361.1 MPa which is in a case of 15$^o$ blade angle and cutting speed at 10,000 rpm.

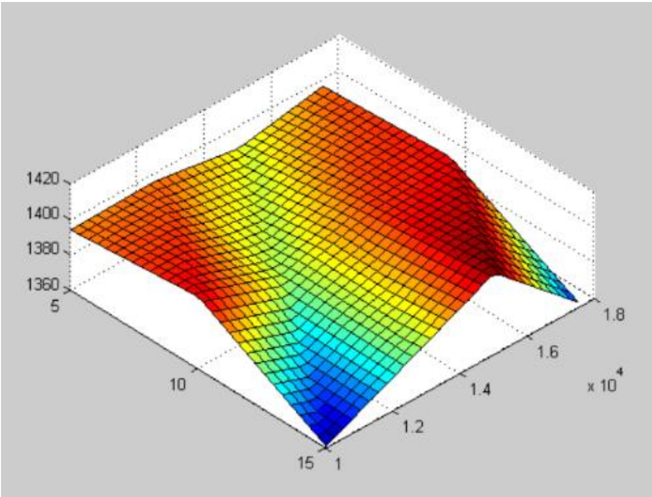


**Figure 6 stress that occurs within TI6%AL4%V material**

From figure 7, it displays the value of temperature which takes place within blade. The highest temperature value is 75.3 $^o$C which is in a case of 10$^o$ of blade angle at cutting speed 15,000 rpm and the lowest temperature is at 28.3 $^o$C which is in a case of 15$^o$ at cutting speed 17,500 rpm.

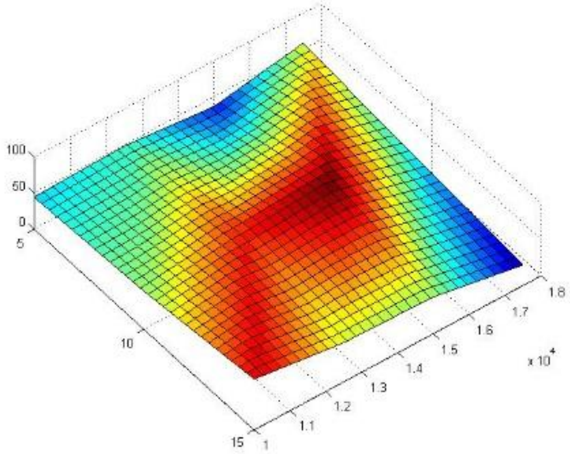


**Figure 7 temperature that takes place within blade**

From figure 8, it displays value of temperature which occurs in work piece. The highest value of temperature is at 1371.4 $^o$C which is in a case of 10$^o$ of blade angle at cutting speed 17,500 rpm and the lowest temperature is at 879.7 $^o$C which is in a case of 5$^o$ of blade angle at cutting speed 10,000 rpm.

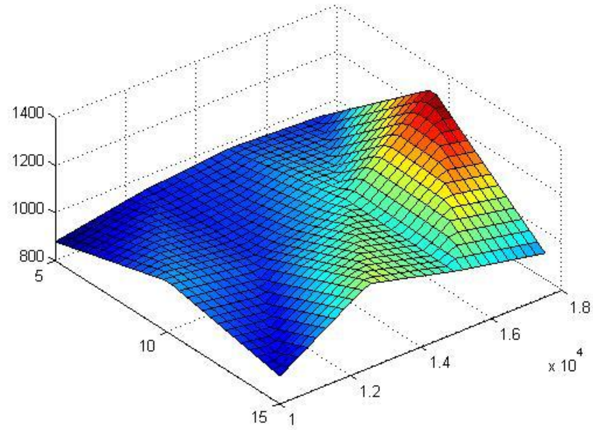


**Figure 8 temperature that occurs within TI6%AL4%V material**

From figure 9, it displays force value that takes place within blade. The highest force value is at 4.3 N which is in a case of 5$^o$ of blade angle at cutting speed at 10,000 rpm and the lowest force value is at 0.5 N which is in a case of 15$^o$ of blade angle at cutting speed 17,500 rpm.

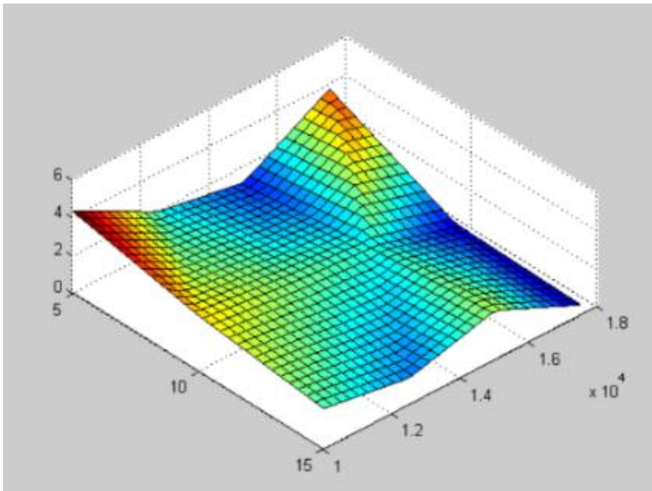


**Figure 9 force that takes place within blade**

From figure 10, it displays force value that takes place within work piece. The highest force value is at 155,650 N which is in a case of 15$^o$ of blade angle at cutting speed 17,500 rpm and the lowest force value is at 76.9 N which is in a case of 10$^o$ of blade angle at cutting speed 12,500 rpm.

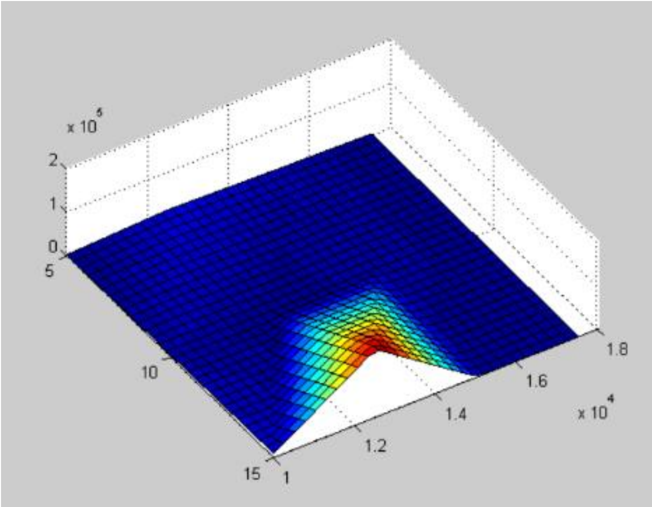


**Figure 10 force that takes place within TI6%AL4%V material**

## Conclusion and Discussion

We found that value of Von-Mises stress that took place within blade was the lowest at $10^o$ of blade angle at cutting speed at 15,000 rpm. The value of von-Mises stress that took place within workpiece was at the lowest $15^o$ of blade angle at cutting speed 10,000 rpm. The lowest temperature value of workpiece was at $15^o$ of blade angle at cutting speed 17,500 rpm. The lowest temperature value of blade was at $5^o$ of blade angle at cutting speed 10,000 rpm. The lowest force value of blade was at $15^o$ of blade angle at cutting speed 17,500 rpm and the lowest force value of workpiece was at $10^o$ of blade angle at cutting speed at 12,500 rpm. According to this data, the lowest values would increase tool life of blades and make materials withstand erosion within processing most.

This data was from simulation process which has not been confirmed with real experiment but at least it shows that we can apply these values in later experiment and decide which value would be the best one.

## Acknowledgment

The author gratefully to thank the TRF-MASTER RESEARCH GRANTS for financial support of this project.

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