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Finite Element Simulation for Cutting of Ti6AI4V

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Abstract: ***Titanium Ti6AI4V alloy is considered difficult to machine especially at higher cutting speeds, because of inherent properties such as low thermal conductivity, high chemical reactivity with cutting tool materials at elevated temperature, this leads to shorten the tool life and poor quality of the surface finishing of the workpiece being machined. By the use of Finite Element (FE) simulations have reduced the burden of extensive experimental trials in understanding the deformation behavior and optimize the cutting process. In this paper the finite element analysis (FEA) of machining for Ti6AI4V is presented. In this particular case the FEA is applied for both workpiece material and cutting tool material. Then at the end of this paper will be able to model and simulate, thereafter to study the influence of Cutting forces, cutting temperature and tool wear.***

Keywords: Titanium Alloys (Ti6AI4V), Finite Element Analysis (FEA)

1. Introduction

Titanium and its alloy are an important class of aerospace engineering material due to their excellent combination of strength of fracture toughness as well as low density. However these material are regarded as difficult to machine because of their low thermal conductivity and high chemical reactivity with cutting tool materials [1]

The Manufacturing of titanium components is however often challenging. High speed machining of titanium alloys are particularly challenging. The machining process (metal cutting) induces large plastic deformations and high temperatures, which induces the surface integrity changes in the workpiece. This process may affect the material properties and residual stress state of the workpiece at the surface or near to the surface. The increased speed of cutting as found in high speed machining may result in significant generation of residual stresses. This is further exacerbated by the low thermal conductivity, high temperature toughness as well as the high chemical reactivity of titanium in general.**[2]**. Several researches have tried with different coated tools to minimize the tool wear and improving the accuracy of the components, Finite Element Model is used to prediction of the cutting forces, cutting temperature, tool wear in advance to eliminate problem during actual machining process that leads to reduce the experimentation cost[3]

2. Methodology

2.1 Material Behavior of the Titanium alloys

At a room temperature, titanium(an allotropic element)has hexagonal close parked(hcp)crystalline structure known as(alpha)α-Ti but forms a body centered cubic(bcc) crystalline structure around 900 °C known as (Beta) β-Ti.typical,6% of Aluminium and 4% vanadium are used as phase stabilizers to obtain an α+ β alloy phase. During the machining of titanium alloys, it has been found that plastic instability and adiabatic shearing chip serration occurs. Workpiece materials often under goes secondary shearing after primary shearing zone and saw-tooth shape chip segment forms.[2]

Consider the Tables Below show the Chemical Specifications and Mechanical Properties of the Titanium alloy Ti6AI4V.

Table 2.1.1: Chemical specifications

	Arcam Ti6AI4V Typical	*Ti6AI4V Required**	*Ti6AI4V Required***
Aluminium,Al	6%	5.5-6.75%	5.5-6.75%
Vanadium, V	4%	3.5-4.5%	3.5-4.5%
Carbon, C	0.03%	<0.1%	<0.08%
Iron, Fe	0.1%	<0.3%	<0.3%
Oxygen, O	0.15%	<0.2%	<0.2%
Nitrogen, N	0.01%	<0.05%	<0.05%
Hydrogen, H	0.003%	<0.015%	<0.015%
Titanium, T	Balance	Balance	Balance

*ASTM F11089 (cast material) **ASTMF1472 (wrought material)

Table 2.1.2: Mechanical properties

	Arcam Ti6AI4V Typical	Ti6AI4V Required**	Ti6AI4V Required***
Yield Strength(Rp0.2)	950 Mpa	758Mpa	860Mpa
Ultimate Tensile Strength (Rm)	1020 Mpa	860Mpa	930Mpa
Elongation	14%	>8%	>10%
Reduction of Area	40%	>14%	>25%
Fatigue Strength*@600Mpa	>10000000 cycles		
Rockwell Hardness	33 HRC		
Modulus of Elasticity	120Gpa		

After Hot Isostatic pressing ** ASTM F1108 (cast material)(ASTM F1472(wrought material)**

2.2. Material Modeling

There are three formulations used in the Finite Element model of machining process: Lagrangian, Eulerian, or Arbitrary Lagrangian Eulerian. Material being removed from the workpiece is exposed to severe plastic deformation and it causes distortion of elements during the FEM simulation. Therefore mesh regeneration in the workpiece is needed.[3]

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2.2.1 Finite Element Modeling and Simulation.

The Finite element modeling was performed by using the commercial FEA software DEFORM 3D; where by the following parameters were used to build up the model as shown in the Fig 1 below.

Cutting speed 70m/min
Depth of cut 0.4 mm
Feedrate 0.3mm/rev
Shear Friction coefficient 0.1
Heat Transfer coefficient 15
Ambient temperature 20℃
Insert DNMA 432
Tool holder DDJNL
Material Ti6AI4V

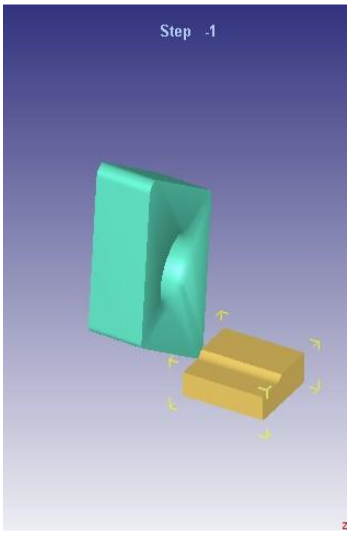

Figure 1: Tool and workpiece

2.2.2. Simulation

From the above model the simulation started from step no 1 and end up at step no 300, whereby the number of solid mesh insert Elements used are 50000 and the number of workpiece mesh generated are 80000, after the completion of pre processor, the run followed then the post processor performed in order to be able to conduct the analysis. The analysis was conducted and the results obtained.

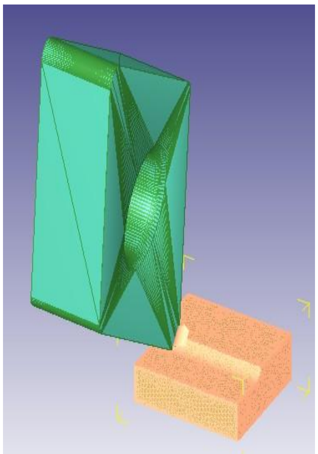

Figure 2: Meshed tool and workpiece.

3. Results and Discussion

3.1 Cutting forces simulation

The cutting force is the basis for determining the cutting and tool parameters design, it is observed that from the simulations results we have three kinds of cutting forces in the directions of x, y and z with speed as shown in the graphs below

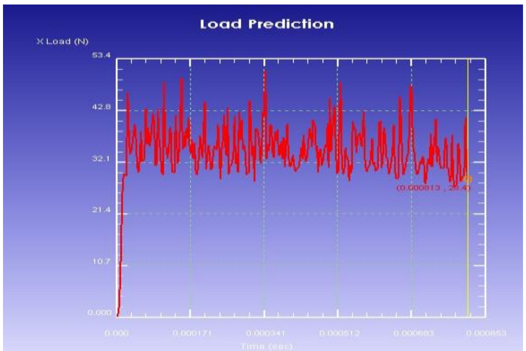

Figure 3: Feed force Vs Cutting time

From Fig3 above, x load corresponds to the feed force, from the simulation results as shown in the graph above, it seems that when the cutting tool starts the cutting, the initial feed force is zero, but as soon as the cutting starts, the feed force will keep on increasing for some seconds, there after the feed forces will be constant (stable) until the cutting tool finishes all the cutting steps.

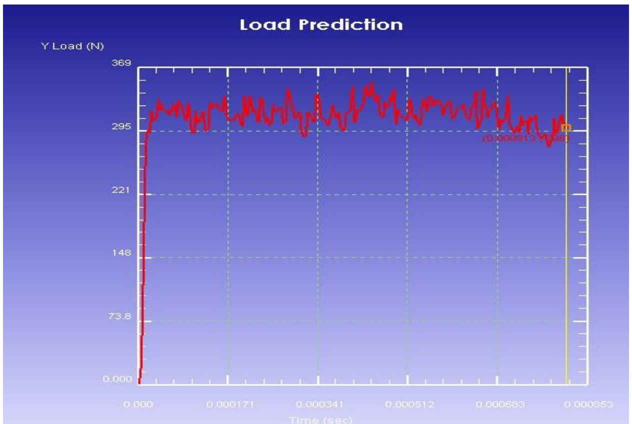

Figure 4: Cutting force Vs Cutting time

From Fig4 above, y load corresponds to the cutting force, from the simulation results as shown in the graph above, it seems that when the cutting tool starts the cutting, the initial cutting force is zero, but as soon as the cutting starts, the cutting force will keep on increasing for some seconds, there after the feed forces will be constant (stable) until the cutting tool finishes all the cutting steps.

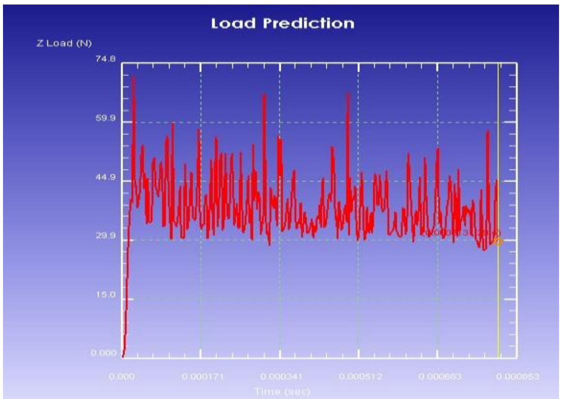

Figure 5: Radial force Vs Cutting time

From Fig5 above, z load corresponds to the radial force, from the simulation results as shown in the graph above, it seems that when the cutting tool starts the cutting, the initial radial force is zero, but as soon as the cutting starts, the feed force will keep on increasing for some seconds, there after the feed forces will be constant (stable) until the cutting tool finishes all the cutting steps.

3.2 Cutting temperature

The Figures below from fig 6-9 shows the variations of cutting temperature during cutting the material Ti6AI4V

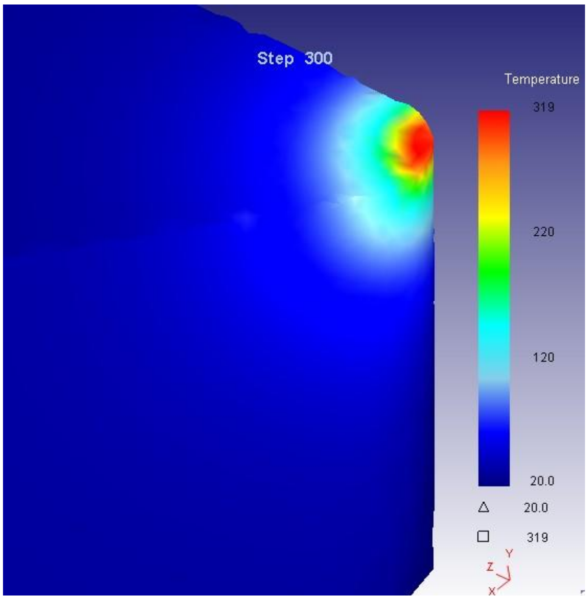

Figure 6

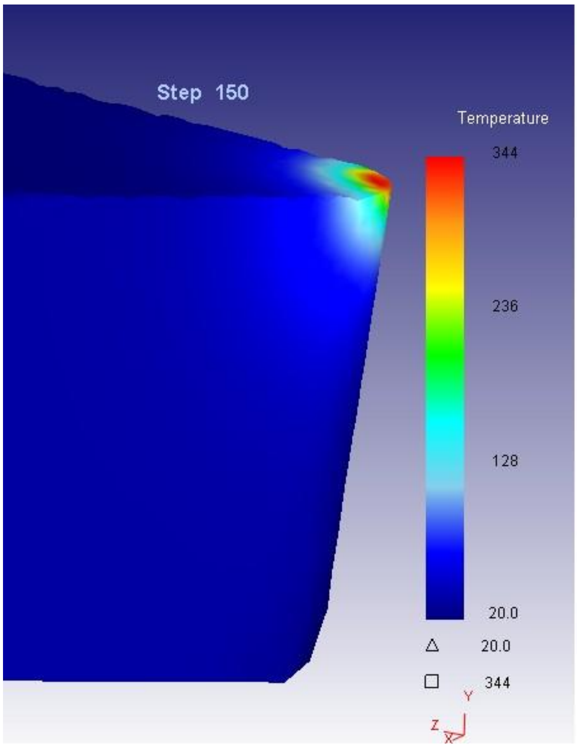

Figure 7

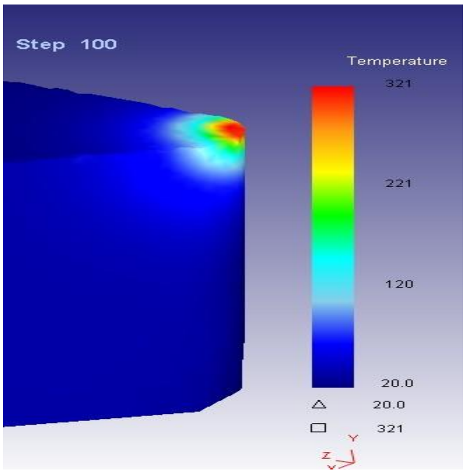

Figure 8

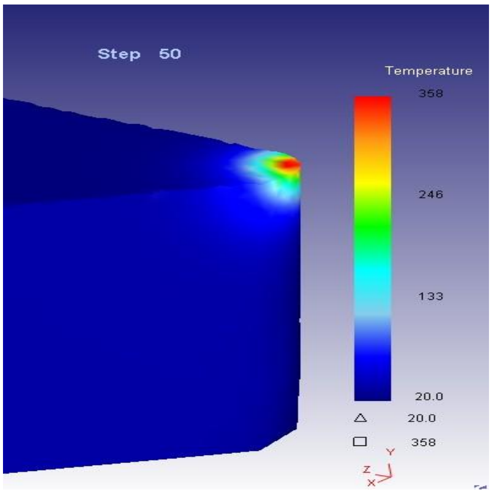

Figure 9

From Figure 6-9 show as per simulation results above, it seem that before starting cutting, the initial temperature is zero 0℃ ,thereafter the temperature will keep on increasing for sometime then it will be constant(stable) though the cutting steps.

3.3. Tool wear

The figures below from fig 10-13 show the effect of the tool wearing when cutting this material Ti6AI4V.

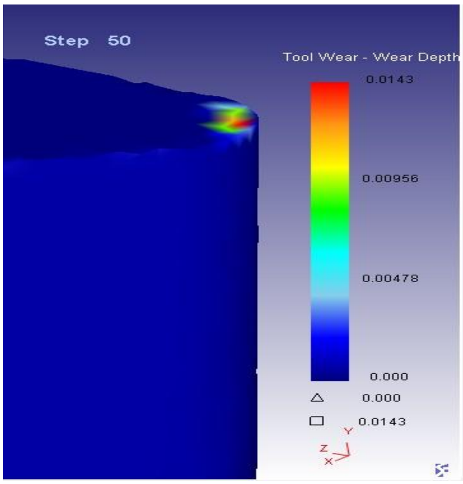

Figure 10

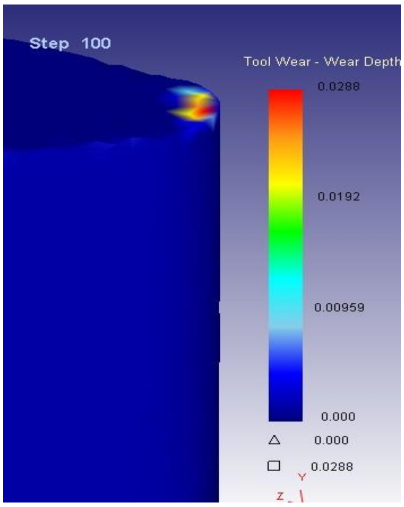

Figure 11

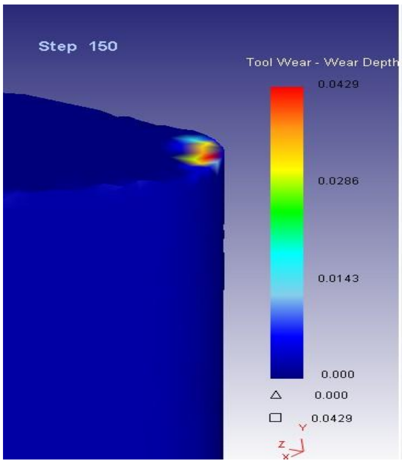

Figure 12

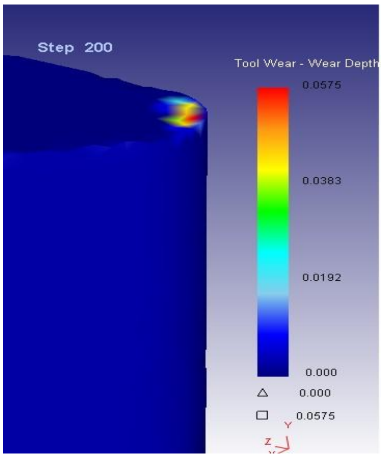

Figure 13

4. Conclusion

A FEA of Machining for Ti6AI4V is presented, where by the cutting tool used to cut the work piece material Ti6AI4V, since we discovered that from the abstract that this kind of material is difficult to be machined. So we can conclude that by the use of this commercial software 3D-Deform it is useful in modeling and simulating this material Ti6AI4V before the actual machining, also it will help to determine the amount of tool wear, so that you might be able to know how to choose the correct cutting tool with the proper cutting angles such as rake angle, clearance angle face angle etc, to predict the cutting forces and cutting temperature, so that you will be able to choose the correct cutting speed, federate and feed.

Therefore it can be concluded that from the obtained correct simulation results and can be employed for the actual cutting (machining) of this material Ti6AI4V..

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