

# Simulation of Turning with Finite Element Thermal Modeling of Aerospace Alloy of Titanium -Ti-6Al-4V using DEFORM 10.2:

Mrs. Shraddha S. Adewar

Assistant Professor, Dept. of Mechanical Engineering, Zeal college of Research & Technology, Pune, Maharashtra, India

\*\*\*

**Abstract** - Titanium alloys are considered as super alloys. Nowadays Titanium alloys are currently used in modern aerospace, automotive, marine, nuclear reactors, chemical industry and medical instruments because of their strength to weight ratio which can be maintained at higher temperatures, better resistance to fracture and corrosion and low modulus of elasticity. But the machining of titanium alloys can be considered very difficult because of its higher chemical reactivity and tendency to weld to the cutting tool, which causes edge chipping and hence rapid tool failure. Machining of Ti-6Al-4V is high temperatures and that is why thermal aspects of machining process strongly affects the accuracy of the output. Temperatures generated during machining processes highly affects the rate of tool wear, tool life, integrity of work piece surface, and hence contribute to the thermal deformation of the cutting tool. We are assurance of the most extreme temperature and its conveyance along the rake face of cutting instrument is a direct result of its controlling impact on apparatus execution, device life and furthermore on the nature of the machined part. An overview on machinability of Ti-6Al-4V Titanium based aerospace alloy. After review a model of machining of this alloy for FEM of temperature distribution on tool has been proposed. A detailed methodology for the modeling & Simulation has been discussed in this paper.

**Key Words:** Modelling, Finite Element Modelling, simulation, Titanium alloys, Temperature

## 1. INTRODUCTION

Titanium alloys are mostly used in components which require higher reliability and therefore components having great surface integrity. During machining though, the surface of titanium alloys gets easily damaged because of its poor machine ability. There are various failures related with machining of titanium alloys like low tool life, inferior surface finish etc. which leads to higher costs. As we know, cutting fluid facilitates to improve the surface finish and enables chip flushing and also performs lubricant function simultaneously

[1]. Reduction in temperature in cutting zone can be seen because of the coolant effect and required cutting forces reduces because of the lubrication action of the coolant fluid.

Citing the reasons given above, lot of research and development has taken place with the aim of optimizing the cutting conditions. We know that machining capability is differentiating and controlling factor, but we also should understand that it is also a major cost contributor. The primary focus in process development flow in the aerospace industry is high performance machining of aluminum alloys [2]. It results into significant gap between the material removal rates of titanium alloys and that of aluminum. Figure 1.1 relates Ti-6Al-4V's machinability in a graphical format against machinability of some other materials along with 1018 steel as a benchmark. Poor machinability is result of characteristics which make the material suitable and desirable for its exclusive use in difficult - to-survive application areas.

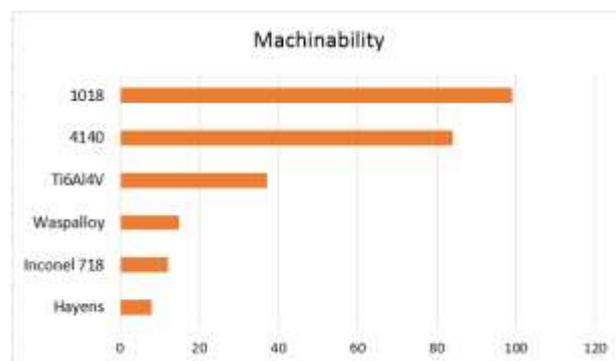


chart 1: Graph showing machinability of Ti-6Al-4V and some other materials with 1018 as a benchmark.

Temperature is one major concern like chatter stability and is the main limiting factor in process parameters selection, such as feed rate and cutting speed, in the machinability of some advanced materials like titanium and nickel-based alloys.

Stresses on the cutting tools, severe thermal stresses occur. The thermal stresses lead to increased probability of tool fatigue and failures due to fracture, wear and chipping. Furthermore, if the temperature rises beyond the crystal binding limits, the tool wear rapidly increases mainly because of accelerated loss of bindings between the crystals in the tool material [3].

For the past fifty years, metal cutting researchers have developed various modelling techniques like analytical techniques, slip-line solutions, empirical approaches along with finite element techniques. But nowadays, the FEA method has particularly become the mainstream tool for simulating various metal cutting processes [2,3].

FEM techniques are used for calculating the stress, strain, strain-rate and distributions of temperature in the sub-cutting zones. Thus, temperatures in the workpiece, tool and the generated chips as well as cutting forces, plastic deformation, chip formation and its breaking behavior can be determined faster than using costly time consuming experiments. Usual approaches for numerical modelling of metal cutting processes are Lagrangian and Eulerian methods, and going further a combination of both called an arbitrary Lagrangian–Eulerian formulation (denoted as ALE henceforth) [4,5]. Do note that all these methods, though work differently, are mathematically equivalent. The major difference is that, for Lagrangian formulation the discretised mesh is attached to the workpiece. The material model is elastic–plastic, only plastic, or visco-plastic. Whereas for Eulerian finite element models the workpiece material is assumed to flow through a meshed control volume creating cutting zone and its strain should be computed from the strain-rates by integrating along stream lines. Thus in the ALE formulation there is a need to relate the stationary (Eulerian) frame to the moving (Lagrangian) frame[6].

### Finite Element Analysis (FEA)

The finite element analysis was first developed in 1943 by R. Courant. It is a computer based method which is used for simulating or analyzing the nature of engineering structure and components under various conditions. It is an advanced analytical technique that is used in design to replace experimental testing. It was initially used in nuclear and aerospace industry where safety of structure is critical. Today, the growth in usage of the method is directly attributed to the rapid advance in computer technology in the recent years. As a result it is capable of solving not only structural analysis problem but also wide range of phenomenon such as fluid flow etc.

**Table 1:Parameters used in FEA**

Sr No	Parameter	Work piece	Tool
1	Poission's ratio	0.28	0.22
2	Young's Modulus	114 GPa	520 GPa
3	Thermal Conductivity	17 W/m/°C	48 W/m/°C
4	Density	4200 kg/m <sup>3</sup>	11200 kg/m <sup>3</sup>
5	Specific Heat	490 J/kg/°C	400 J/kg/°C

The system can be used to model the industrial turning process, without any assumptions that are associated with orthogonal cutting conditions. These modeling procedures enable the engineer to study the process response for any change in process conditions. Cutting forces, cutting temperatures, chip shape, tool wear and tool life computations can be performed using this system. The engineer can study the effect of process parameters like, cutting speed, feed rate and depth of cut on the process response. DEFORM3DTM supports a special purpose template that expedites the simulation model setup procedures and uses the same engineering language of process engineer. The material flow stress data should cover the strain rate, strain and temperature range for metal cutting process. For most materials used in metal cutting, the typical range for strain rate is 0 - 106/sec, the range for strain is 0 - 5 and the range for temperature is 20 - 12000 C. Special material characterizing techniques are required to address this range of cutting conditions. The insert geometry can be made available in STL form, generated from any CAD system.

By specifying the model specific data, user can generate complete data required for the analysis. This stage of analysis constitutes the initial transient analysis. After executing the simulation and sufficient chip has formed, user can compute the steady state response of the process which includes the prediction of steady state thermal response and chip geometry. From the viewpoint of insert thermal response this stage will significantly reduce the computing time that is normally associated with transient analysis. The results obtained from this stage form important input to the tool wear and tool life

computations. The machining template comes with a set of library files for the insert geometry. User can also use any other insert geometry and save it along with the system library for any subsequent use.

DEFORM-3D supports a special purpose template that expedites the simulation model setup procedures and uses the same engineering language of process engineer. For turning applications the rotating workpiece, insert and their relation to the analysis domain is very important. In Deform Simulation and Modeling involves three basic steps Preprocessing, Simulating, and Post Processing. In Preprocessing apart from creation of geometry of tool and workpiece the properties of cutting tool insert, workpiece material, and properties of coolant are given. In this step all the boundary conditions are imparted on the cutting tool and workpiece geometry. During this investigation 3D model of the cutting insert was drawn in NX-4 CAD module and then imported in deform. The meshing is carried out using a relative mesh size of 25000. The tool during modeling is considered as a rigid body. The basic model along with coating is considered as a rigid body. The axis designation while simulation is +Y is the cutting direction, - X is the feed direction and Z is the depth of cut direction. The work piece is considered as perfectly plastic and simplified straight models is considered for the analysis.

### DEFORM VERSION 10.2:

Following boundary conditions are used for modeling

- The internal surfaces of the insert, which are in contact with the shim seat and the holder, are assumed to be smooth and in perfect contact.
- For the exterior boundaries of the insert are exposed to the air (except at the tool–chip contact area) a heat transfer coefficient of  $h = 20 \text{ W/m}^2 \text{ }^\circ\text{C}$  is considered.
- Initially whole model is kept at ambient temperature of  $20 \text{ }^\circ\text{C}$ .

#### Investigation on Finite Element Modeling

Finite Element Modeling is carried out to see temperature variations during machining Ti-6Al-4V. Deform 3 D is used for finite element modeling. Following is the summary of Finite element modeling.

- Modeling with Deform-3D indicates a lowest temperature of  $99 \text{ }^\circ\text{C}$  while machining with Speed of 50 Feed of 0.12 And depth of cut of 0.8. In case of actual temperature measurement lowest temperature found is  $94 \text{ }^\circ\text{C}$  while machining with Speed of 40 Feed of 0.1 And depth of cut of 1.
- All the values obtained in FEM shows deviation from actual temperature measurement because FEM is done with transient conditions and temperature is measure as a steady state entity so it is obvious that there will be some variation the actual and predicted results.
- Deform is very accurate module to predict temperature in machining because it predicts temperature at various stages in machining by taking the cutting parameters only.

Deform Image Gallery:

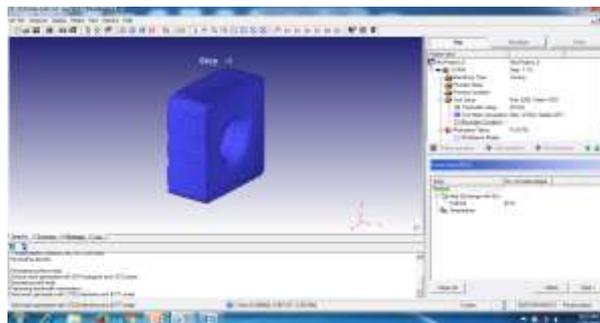


Figure 1: Tool insert modelling and specification

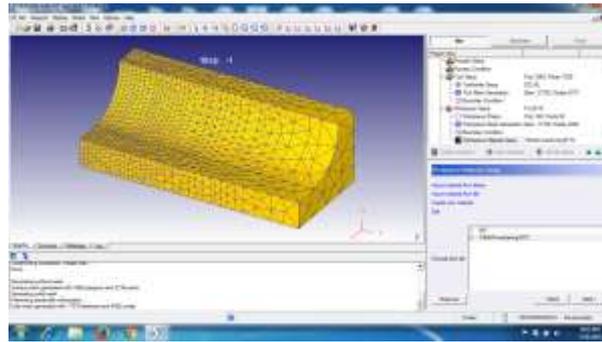


Figure 2: Workpiece modelling and specification

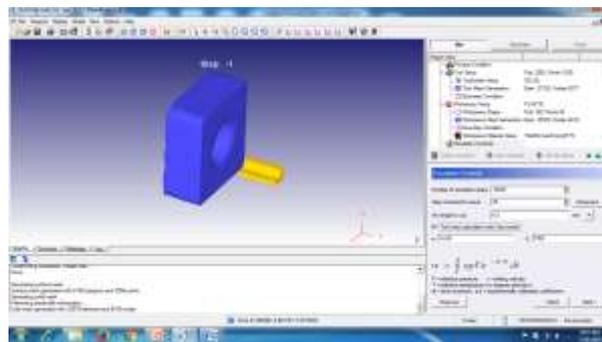


Figure 3: Work - tool interface

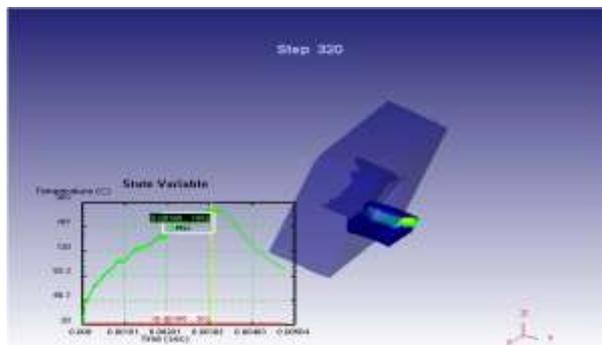


Figure 4: Temperature prediction

Table 2: Summary of Simulated Results:

	Actual	Simulation
Trial 1	111	138
Trial 2	94	105
Trial 3	109	125
Trial 4	138	143
Trial 5	140	152
Trial 6	108	99
Trial 7	122	140
Trial 8	118	135
Trial 9	151	150

**SIMULATION RESULTS:**

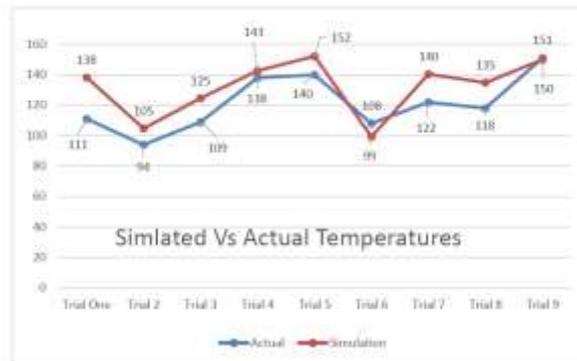


Chart 2: Simulated Vs Actual Temperatures

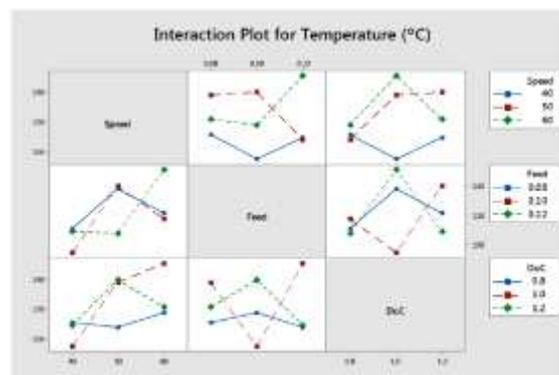


Chart 3: interaction plot for Temperature

**CONCLUSIONS:**

Finite element analysis using Deform is used to verify the findings of experiment. Some variation is found in few readings and it's corresponding analysis results but we can see the trend being followed in both. Deform clearly has an advantage over the other FEA tools because it only isolates cutting parameters directly affecting temperatures from rest of the non-influencing parameters. Variation of heat generation with cutting parameters is observed and it can be noted that with increase in either Speed, Feed and Depth of Cut or all together causes higher heat generation during the process.

The objectives of this research work defined in the beginning have been achieved successfully. With temperature measurement setup built using thermocouple and temperature analyzer we have found working method to measure temperature during such cutting operation. We also have discovered that Finite Element Analysis for prediction of tool temperature and heat flow during Turning of Ti-6Al-4V can be successfully performed with the help of Deform. Detailed comparison of experimental results and its corresponding analytical findings seems to be in agreement with each other.

**REFERENCES:**

[1] S.M. Athavale, J.S. Strenkowski, Finite element modeling of machining: from proof-of- concept to engineering applications, Mach. Sci. Technol. 2 (2) (1998) 317-342.

[1] F. Klocke, T. Beck, S. Hoppe, T. Krieg, et al., Examples of FEM application in manufacturing technology, J. Mater. Proc. Technol. 120 (2002) 450-457.

[2] W. Zhang, O.W. Dillon, I.S. Jawahir, A finite element analysis of 2- D machining with a grooved ool, Trans. NAMRI/SME 29 (2001) 327-334.

- [3] M.R. Movahhedy, M.S. Gadala, Y. Altintas, Simulation of chip formation in orthogonal metal cutting process: an ALE finite element approach, *Mach. Sci. Technol.* 4 (1) (2000) 15–42.
- [4] E. Usui, T. Shirakashi, *Mechanics of Machining—from Descriptive to Predictive Theory On the Art of Cutting Metals-75 Years Later*, vol. 7, ASME PED, New York, 1982. Pp.13–55.
- [5] K. Iwata, K. Osakada, Y. Teresaka, Process modeling of orthogonal cutting by a rigid-plastic finite element method, *J. Eng. Mat. Technol.* 106 (1984) 132–138.
- [6] C.H. Che-Harona, A. Jawaid, “The effect of machining on surface integrity of titanium alloy Ti-6% Al-4% V”, *Journal of Materials Processing Technology* 166 (2005) 188–192.
- [7] M. Cotterell, G. Byrne, “Dynamics of chip formation during orthogonal cutting of titanium alloy Ti-6Al-4V”, *CIRP Annals – Manufacturing Technology* 57 (2008) 93– 96.
- [8] S. Sun, M. Brandt, M.S. Dargusch, “Machining Ti-6Al-4V alloy with cryogenic compressed air cooling”, *International Journal of Machine Tools & Manufacture* 50 (2010) 933–942.
- [9] Suresh Palanisamy, Stuart D. McDonald, Matthew S. Dargusch, “Effects of coolant pressure on chip formation while turning Ti6Al4V alloy”, *International Journal of Machine Tools & Manufacture* 49 (2009) 739–743.
- [10] S. Sun, M.Brandt, M.S.Dargusch, “Characteristics of cutting forces and chip formation in machining of titanium alloys”, *International Journal of Machine Tools & Manufacture* 49 (2009) 561–568.
- [11] T.D. Marusich, M. Ortiz, Modelling and simulation of high-speed machining, *Int. J. Numer. Methods Eng.* 38 (1995) 3675–3694.
- [12] Y.-Ch Yen, A. Jain, T. Altan, A finite element analysis of orthogonal machining using different tool edge geometries, *J. Mater. Proc.Technol.* 146 (2004) 72–81.
- [13] E.G. Loewen, M.C. Shaw, On the analysis of cutting tool temperatures, *Trans. ASME* 76 (1954) 217–231.
- [14] G. Sutter, G. List, “Very high speed cutting of Ti-6Al-4V titanium alloy – change in morphology and mechanism of chip formation”, *International Journal of Machine Tools & Manufacture* 66 (2013) 37–43.
- [15] Ibrahim Deiab, Syed WaqarRazaa, Salman Pervaiza, “Analysis of Lubrication Strategies for Sustainable Machining during Turning of Titanium Ti-6Al-4V alloy”, *Procedia CIRP* 17 (2014) 766 – 771.