Prediction of Machining Induced Residual Stresses

MONANGI PRAMOD[1, a)], YARKAREDDY GOPI REDDY[1, b)]

PRAKASH MARIMUTHU K[1, c)]

[1]*Department of Mechanical Engineering, Amrita School of Engineering, Bengaluru, Amrita Vishwa Vidyapeetham, Amrita University, India.*

[a)]mpramod1996@gmail.com
[b)]yarkareddygopireddy@gmail.com
[c)]prakashkmuthu@gmail.com

Abstract. Whenever a component is machined, residual stresses are induced in it. These residual stresses induced in the component reduce its fatigue life, corrosion resistance and wear resistance. Thus it is important to predict and control the machining-induced residual stress. A lot of research is being carried out in this area in the past decade. This paper aims at prediction of residual stresses during machining of Ti-6Al-4V. A model was developed and under various combinations of cutting conditions such as, speed, feed and depth of cut, the behavior of residual stresses were simulated using Finite Element Model. The present work deals with the development of thermo-mechanical model to predict the machining induced residual stresses in Titanium alloy. The simulation results are compared with the published results. The results are in good agreement with the published results. Future work involves optimization or the cutting parameters that effect the machining induced residual stresses. The results obtained were validated with previous work.

INTRODUCTION

The titanium alloy(Ti-6Al-V4) have superior properties like, high strength, low density and excellent corrosion resistance, which give rise to a wide range of application in many industries such as Parts and prototypes for racing and aerospace industry (Used extensively within the Boeing 787 aircraft), Implants, prostheses etc. Previous work on finite element simulation such as evaluation of chip formation[1-3], analysis of ductile fracture[4, 5], forces induced[6], temperature distribution[7], influence of friction [8, 9] during machining process indicates that this simulation is a reliable, quick and time-effective method to analyze various machining environments without actual experimentation. There has been a lot of research in this field in the last decade. Our present work predicts the amount of residual stresses induced during the machining of Ti-6Al-V4 using finite element method by developing a 2D-Thermo-mechanical model. Prediction of residual stresses is crucial during machining as these stresses effect the material properties such as fatigue life [10-12], corrosion resistance [13] and wear resistance [14]. Also this prediction assists us to understand how the component behaves when it is subjected to any working environment. These residual stresses are of two types, tensile and compressive. Tensile residual stresses, if induced will reduce the life of the component. In case of fatigue failure [10], cracks usually originate on the surfaces and for a crack to be initiated, there should be presence of a tensile component. The compressive residual stress acts as a counterpart to tensile stress and prevents crack initiation and propagation. Also the prediction of machining induced residual stresses using experimentation involves costly equipment such as X-Ray diffraction [15]. So the Finite element modelling proves to be a handy process to predict the machining induced residual without performing any kind of experiments on the component after machining. Also we save lot of time money and labour using Finite Element Modelling.

FINITE ELEMENT MODEL

Finite element modelling helps researchers to understand any kind of process whether it is a flow analysis or a structural analysis. Generally for an analysis of a flow, Eulerian approach is used [16]. Whereas for an analysis of a structure, Lagrangian approach is used [17]. But for the problems which involve both flow and structural analysis, Arbitrary Lagrangian Eulerian (ALE) approach is used [18, 19].

BASIC SETTINGS OF MODEL

In our present work a finite element analysis software ABAQUS is used to develop a 2D- Thermo-mechanical model to study the residual stresses induced in Titanium alloy (Ti6Al4V) during orthogonal machining. The dimensions are given in Fig.1. The tool has a rake angle of 15^{o} and the clearance angle of 2^{o} respectively.

Figure 1. Model Dimensions (All dimensions are in mm).

MATERIAL MODEL AND PROPERTIES

The properties of tool and the work piece is homogeneous throughout. The tool material is Tungsten Carbide and the work piece material is Ti6Al4V. The properties of both materials are listed in Table1 and Table2 respectively. Both the work piece and the tool are assumed to be deformable elements with simple geometry for better results.

TABLE 1. Properties of Ti6Al4V [3].

Parameter	Value
Density	4430 Kg/m^3
Young's Modulus	113 GPa
Poisson's Ratio	0.342
Thermal Expansion Coefficient	9.1 x 10^{-6} ^{o}C^{-1}
Melting Temperature	1680 ^{o}C
Conductivity	7.0 W/(m-^{o}C)
Specific Heat	546 J/(Kg-^{o}C)

TABLE 2. Properties of tool [3].

Parameter	Value
Density	14.5 x 10^3 Kg/m^3
Young's Modulus	640 GPa
Poisson's Ratio	0.22
Conductivity	75.4 W/(m-^{o}C)
Specific Heat	220 J/(Kg-^{o}C)

The Johnson cook material model is widely used by researchers for those materials where the flow stresses are influenced by temperature. In this work the authors have used the Johnson cook material and damage model values given by Yao Xi[3]. The values are given in Table 3.

TABLE 3. Johnson cook material and damage values [3].

Parameter	Value
A	1098 MPa
B	1092 MPa
C	0.014
m	1.1
n	0.93
D1	-0.09
D2	0.25
D3	-0.5
D4	0.014
D5	3.87

Where "A" represent yield stress, "B" represent Strain Factor, "C" represent Strain Rate factor, "n" represent Strain Exponent, "m" represent temperature exponent, "D_1-D_5" represent Johnson cook damage parameters.

MESH GENERATION AND ELEMENT TYPE CHOICE

A plain strain, thermo coupled element is chosen in this model, as it gives reliable results. All elements are of quadrilateral type. The density of mesh is finer in the work piece than that of the tool. The size of the element is higher for the tool when compared with the work piece. The total number of elements after meshing were 10400 in work piece and 65 in tool. The model after meshing is shown in the Fig.2.

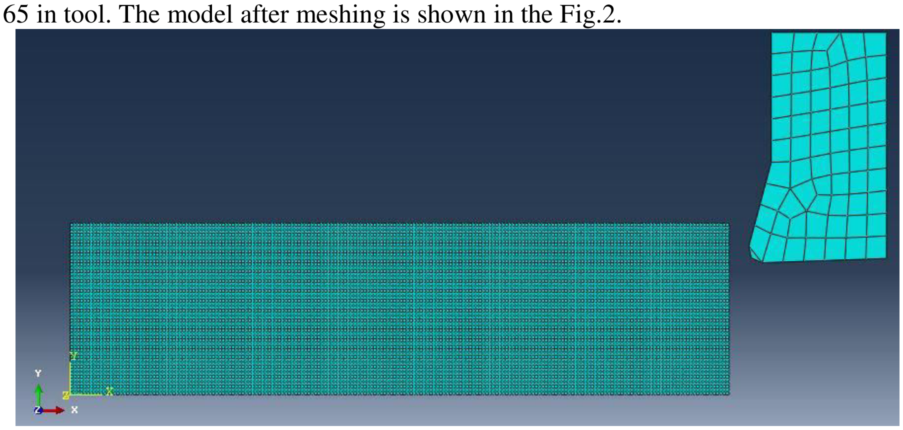

FIGURE 2. Meshing of Model.

CONTACT SETTINGS AND BOUNDARY CONDITIONS

ABAQUS has many contact methods, out of which Coupled surface-to-surface explicit contact method was used in this study. The tool act as the master surface and the work piece act as slave surface. Simple coulomb friction is assumed and friction coefficient of 0.2 is used. For the simulation purpose dry cutting condition is assumed.

The work piece's base is constrained in all directions. The tool is also constrained along Y and Z axis. The cutting speed is given the tool in the X direction.

EXPERIMENTAL VALIDATION OF MODEL

In order to validate the model, the cutting conditions used by F. Ducobu[20] were used. The chip morphology, temperature gradient and the cutting forces generated during the cutting process were studied and they are in good agreement with his work. The cutting conditions are as mentioned in the Table 4. The chip morphology and the temperature gradient values are shown in Fig.3 and the cutting force plot is shown in Fig.4.

TABLE 4. Cutting conditions used for validation of model [20].

Cutting Conditions	Value
Speed	300 mm/sec
Depth of cut	60 µm
Width of cut	1mm

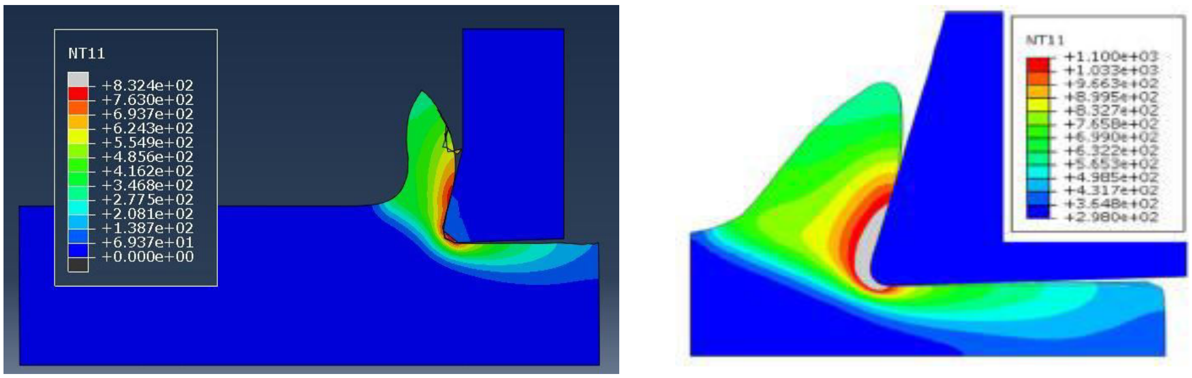

FIGURE 3. Temperature gradient of present work (a) and the published work (b).

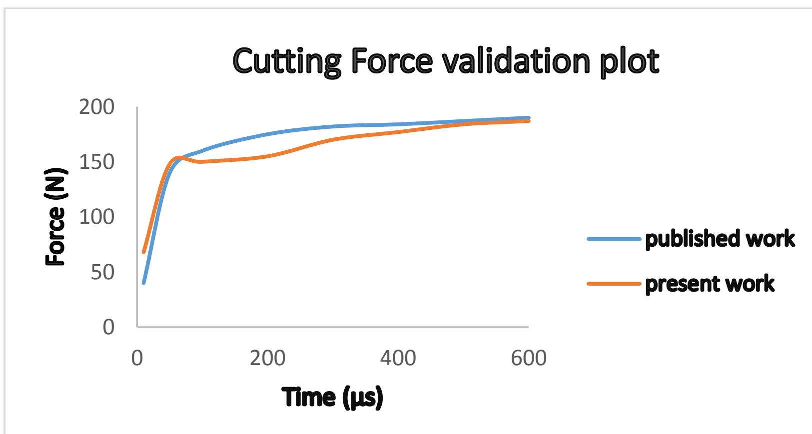

FIGURE 4. Force plot of present work and the published work.

RESULTS AND DISCUSSION

After validation of the model with the published work, various cutting conditions were used for determining residual stresses induced during orthogonal machining of the Ti6Al4V alloy. The cutting conditions were shown in Table 5.

TABLE 5. Cutting conditions for simulation.

Cutting Conditions	Value
Speed	100, 200, 300 mm/sec
Depth of cut	60 µm
Width of cut	1mm

Simulations were performed for combinations of above mentioned feed, speed and depth of cut. The corresponding force plot for different cutting speeds is shown in Fig.5. The Von Mises stresses obtained during the machining process are shown in the Fig.6.

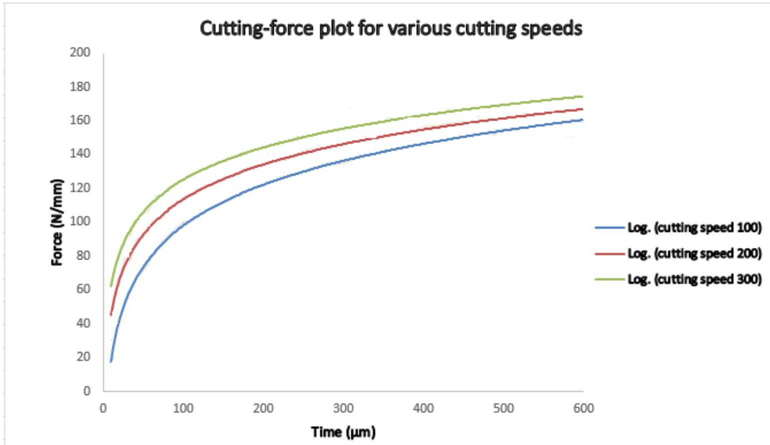

FIGURE 5. Force variation with different speeds.

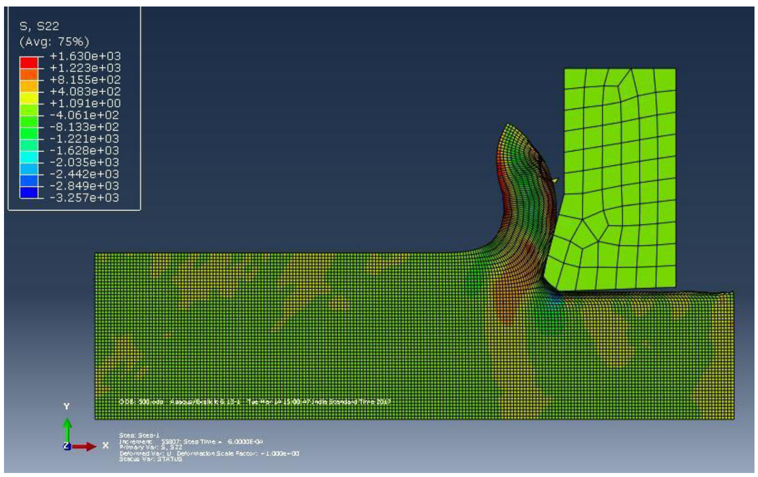

FIGURE 6. Von Mises stresses for the cutting speed of 500 mm/sec.

For different cutting conditions, the residual stresses were predicted. Compressive residual stresses were induced below the cutting surface of the work piece for a few microns and thereafter they becomes tensile in nature. The residual stress plotted for cutting speed 500 mm/sec, depth of cut 60µm and width of cut as 1mm respectively is shown in the Fig.7.

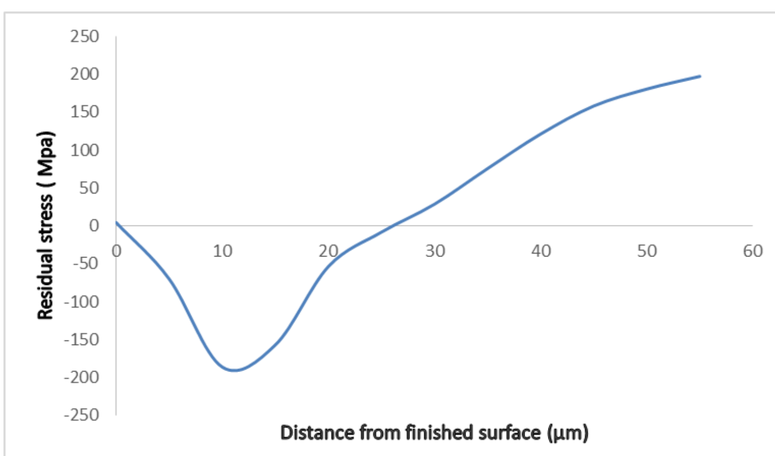

Figure 7. Von Mises stress distribution

CONCLUSION

Using a commercially available software, a thermo-mechanical model was developed. The obtained results and the published results were in good agreement. Irrespective of the cutting condition the machining process induced a compressive residual stresses just beneath the cut surface and there upon becoming tensile in nature. The developed model can predict the temperature distribution as well. Under different cutting conditions the maximum temperature that developed the work piece was ranging from 700 to 850 degree Celsius.

FUTURE WORK

The future work involves optimizing the cutting parameters that influence nature and magnitude of the residual stresses. Also the effect of sequential cuts on the machining induced residual stresses. Further research has to be done to determine the effect of the induced residual stresses on the functional performance of the components.

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