Coupled Temperature Displacement Model to Predict Residual Stresses in Milling Process

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Abstract. Materials when subjected to plastic deformations, stresses are induced in the material. The stresses that are induced in the material due to machining is very high due to extreme plastic deformation. The nature and magnitude of the stresses plays a vital role in the functional performance of the components. The stresses can be tensile or compressive. Sometimes the stress are beneficial sometimes it is not. The present work is to develop a 2D coupled temperature displacement analysis to predict the surface residual stresses that are induced due to milling operation. In this work the material considered is AISI 1045 steel and the tool that is used is HSS tool. The finite element model is used to predict the residual stresses and it is compared with the experimental results. The predict results are in agreement with the experimental results. The residual stresses where experimentally determined using X-Ray diffraction method. Finite element method helps us to remove costly experiments and the process is rather quick. Apart from the residual stresses, force, temperature, Von Mises stress can also be obtained from the developed model.

1. Introduction

Machining is one of the manufacturing processes which is widely used to realize the end product. It is one of the age old processes that have been used to manufacture new products. When machining is done on metals, after the machining process is complete, some stresses remain within the material even after the removal of the cutting processes. Such of the stresses are termed as residual stresses [1]. Researches have been trying to predict the induced residual stresses using different techniques [2-8]. Simulations have helped the researchers across the globe to predict various dependent outputs without the need for costly experiments [3, 9-12]

The nature of the residual stresses that are induced is very important along with the magnitude of the stresses. The stresses are either be tensile or compressive and it effect the functional performance of the components. Hardness, fatigue strength, corrosion resistance, are few performance that are effected by the retained stresses. Researchers have tried to predict the machining induced residual stresses in different materials like titanium, nickel, Inconel, steel etc., [13-16]. Also different

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techniques have been used to predict namely analytical, numerical and experimental. The authors of this work have attempted to develop a coupled thermos mechanical model to predict the machining induced residual stresses. One more aspect to be note is that there are very few works that are available that have done on sequential cuts in machining process and it has a high prospective in the future [5, 17, 18]. In the present work in order to predict the stresses using the Finite element model, it is assumed that the process is orthogonal, although the actual machining process is oblique for ease of computation and calculation it is assumed as orthogonal as done by many researchers in the past [19, 20]

2. Finite element model

As discussed earlier a 2D orthogonal coupled thermo-mechanical model is developed using Abaqus commercial software. The model is shown in Figure 1. Both the work piece and the tool are modelled as deformable. The meshed model is shown in Figure 2. The model is meshed with CPE4RT: A 4-node plane strain thermally coupled quadrilateral, bilinear displacement and temperature, reduced integration, hourglass control. The work piece is arrested for all Degree of freedom at the base. The tool can move in the x- axis and can rotate about the z axis. For the finite element model Johnson cook material and damage model is considered. The material for the work piece is AISI 1045 steel.

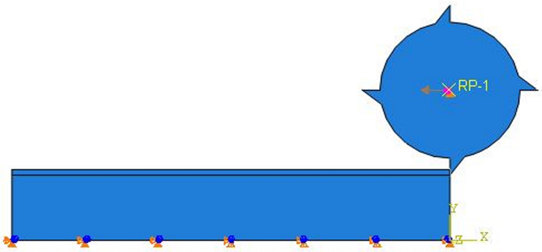

Figure 1. Finite element Model with Boundary conditions

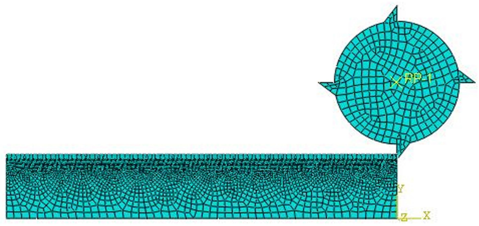

Figure 2. Meshed model

The material properties, that were used in the analysis is given in Table 1.

Table 1. Material Properties of AISI 1045 steel

Parameter	Value
Young's Modulus	210 GPa
Poisson's Ratio	0.3
Specific heat	432 J/kg/◦C
Thermal Conductivity	47.7 W/m◦C
Density	7800 kg/m^3
Friction Coefficient	0.3

The Johnson-Cook material values are given in Table 2.

Table 2. Johnson-Cook material properites

Parameter	Value
A	553.3 MPa
B	600.8 MPa
C	0.013
n	0.0234
m	1
D_1	0.06
D_2	3.31
D_3	-1.96
D_4	0.0018
D_5	0.058

3. Experimentation

The experiment was conducted on AISI 1045 steel. First the work-piece was reduced to 24 mm × 24 mm slab and 4 mm thickness. This was done to accommodate the specimen in X-ray diffraction machine. The specimens were heat treated so that the stresses that could have been induced due to machining operation to reduce the specimen to the required size. The temperature was 750◦C and the timing was 2 hours. The specimen was furnace cooled.

The specimen is shown in Figure 3. After the specimen was annealed the specimen was milled using a vertical milling machining using a 4 flute end mill cutter. The specimen was machined using the cutting conditions shown in Table 3.

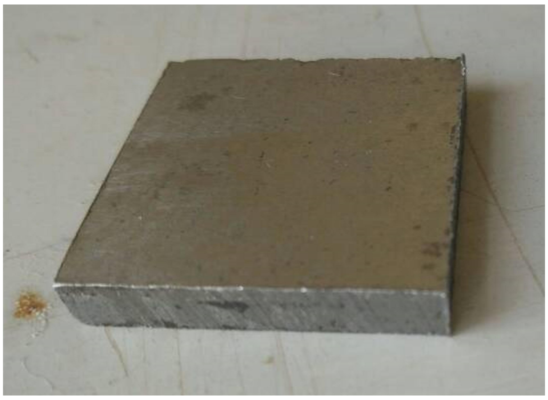

Figure 3. Specimen

Table 3. Cutting Conditions.

Cutting Speed	710 rpm
Feed	80 mm/min
Depth of Cut	0.2 mm

4. Results

The residual stresses were measured using X-diffraction machine. The surface residual stresses was measured at the centre of the specimen. For the cutting conditions that is shown in Table 3. Compressive residual stresses were induce and it was 222.3 MPa. From the finite element model the predicted residual stress is 199.23 MPa and compressive in nature.

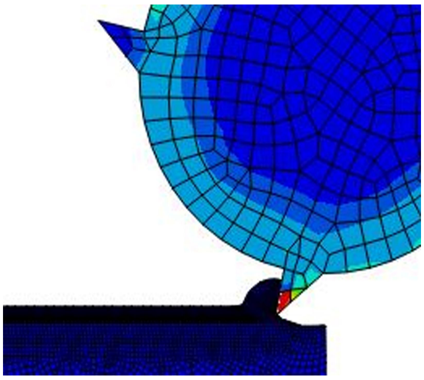

Figure 4. Chip formation.

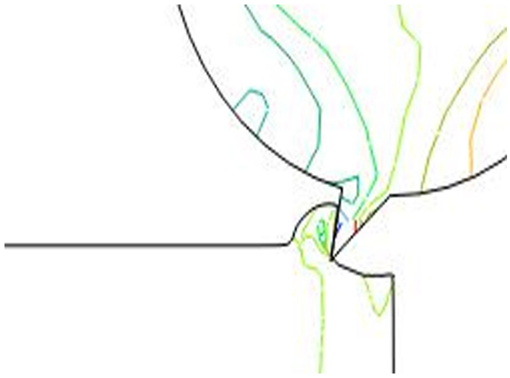

Figure 5. Residual stress plot

The Chip formation during the milling process is shown in Figure 4. The residual stress plot is shown in Figure 5. Apart from the residual stresses, force, Von Mises can also be predicted using the model that was developed by the authors. The force predicted is shown in Figure 6. The Von Mises stress plot is shown Figure 7.

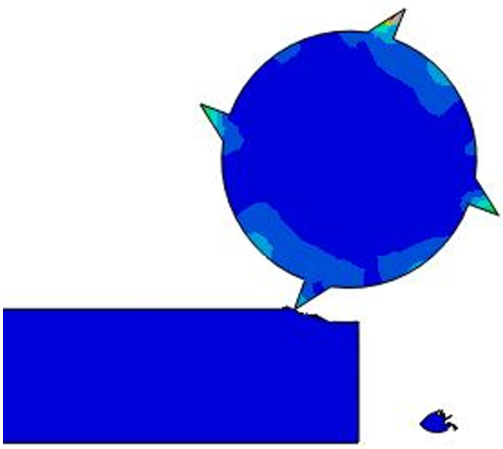

Figure 6. Von Mises Stress Plot

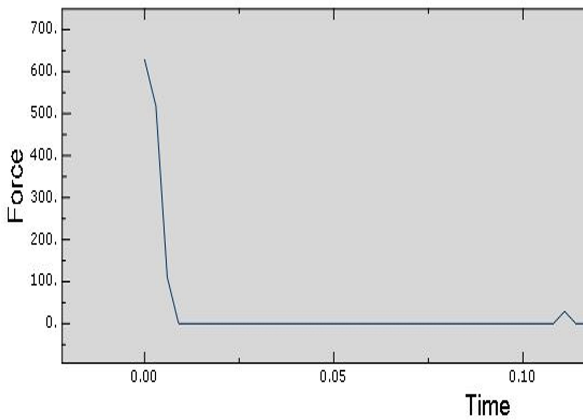

Figure 7. Force versus Time

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5. Conclusions

A 2D coupled displacement model to predict the residual stresses induce in milling operation was modelled. The error is less than 10% between the prediction and the actual experimental results. The future work involves developing an oblique cutting model. Developing a 3D model is remaining a challenge among the researchers due to the high computation time. Owing to the cost of measurement of the residual stresses the authors have done only few measurement, to get further insight into the process lot of experiments have to be conducted for different cutting conditions and the same has to done using the finite element model and the results need to be compare.

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