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Numerical Simulation of Sequential orthogonal cutting of Aluminium 6061 Alloy

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Abstract. Research in the area of machining has never reached a saturation point. Machining is a very complex process and the researchers have been trying to understand the machining process at various levels. The present work deals with the development of a finite element model to study the sequential orthogonal cutting process. The work is carried out on Al 6061 alloy. Thermo-mechanical model was developed using a commercially available Finite Element software. In the past very few works have been carried out to study the sequential cutting process. The force variation during the first and the second pass was studied herewith. Apart from the force variation the Von Mises stress distribution and the chip formation during the different passes have been studied. The developed model is capable of predicting the residual stresses, temperature variation, equivalent plastic strain distribution etc. It is observed that the forces that are generated during the second pass was higher than the forces that were generated during the first pass. The force variation was studied for different cutting speeds, keeping the width of cut and the feed constant.

1. Introduction

Aluminium alloys have recently emerged as capable materials for automobile industries and aerospace industries. Aluminium alloys are widely studied [1, 2] in particular because of their properties such as formability, corrosion resistance, medium strength, weldability, low cost and light weight etc. The material on which the present simulation is done is aluminium 6061 alloys. Aluminium 6061 alloys are used as a material in the manufacturing of various automobile parts like wheels and panels. Replacement of such aluminium alloys for steel can make it more economical and can even make them recyclable [3]. Every part manufactured using primary manufacturing processes such as casting, forming, sheet metal cutting etc. needs to be machined in order to achieve the required quality of the product. Machining is a manufacturing process which involves the removal of material from the work piece in order to obtain the required shape and size. When machining is done a lot of stresses are experienced by the work piece due to high deformation rate. These stress are due to the presence of cutting forces [4]. The examination of cutting forces is very much required for studying dynamics and mechanics of cutting process. It is required to perform force analysis on the work piece as it plays a major role in the prediction of surface quality. These cutting forces induce residual stresses in the specimen [5]. Since early seventies metal cutting is studied using numerical modelling with finite element method. Numerical models have help researchers to explore many under lying phenomenon be it, structural, flow or fluid structural interaction problems [6-10]. These numerical models can be used for getting details of stress and strain fields, induced residual stresses, shear zones and temperature fields in the

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case of machining analysis. As of today all the numerical models are based on modified Lagrangian and Eulerian formulas [11]. For the optimization of the working conditions and to obtain improved cutting tool design it is advised to use simulate cutting process. As per E. Ceretti the use of simulation helps in reducing the machining time as well as the cost of testing [12].

In this work a 2d model is used for simulating the sequential cutting process of machining an aluminum 6061 alloy specimen. From the literature survey it is understood that very few work has been carried out in this area [13, 14]. The work piece is machined using orthogonal machining technique and the whole process is simulated in Abaqus software.

2. Finite Element Modelling

In this present work a 2D Finite Element analysis was done. Aluminium 6061 alloy work piece was modelled as deformable body and tool made of tungsten carbide is also modelled as deformable body so that temperature interactions can be studied. A 2D modelling is done in order to represent orthogonal machining. The dimensions of the work piece taken are 5 mm*2mm and the tool dimensions are 1.5mm * 0.2mm. It has a zero rake angle and clearance angle of 6.72 degrees and a nose radius of 0.01mm. The tool is meshed uniformly all along but the work piece is fine meshed for the top layers which undergo machining. In order to capture sequential cutting the model is assembled as shown in Figure 1. There are two tools separated by the distance of length of work piece along X axis and feed distance in the Y axis. The meshing is fine at the top of the work piece in order to understand the chip formation properly.

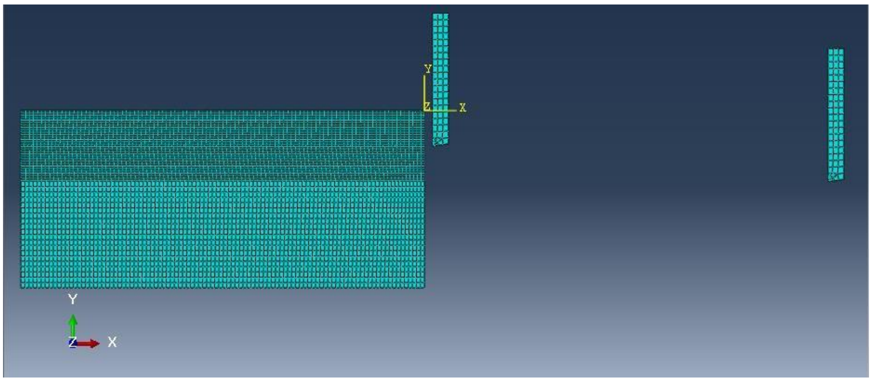

Figure 1. Meshed Finite Element model.

3. Material Properties

Material selection is an important criteria in the machining simulation. Lot of material models are available for performing the machining simulation, however Johnson-Cook material model and damage model have yield good results. The tables given below represent the material properties of tool and work piece. Johnson-Cook material model and Johnson-Cook Damage model constants shown in Table 1. were taken into consideration for the simulation [15-17]. The material properties of the work piece and the toll are given in Table 2. A, B, C, n, and m are Yield stress, Strain factor, strain factor strain exponent and temperature exponent respectively [18]. This model is used to take care of strain hardening, strain rate as it is a severe plastic deformation and the thermal softening. D1 to D5 are damage constants used in the model for the element to delete after it has reached maximum strain. D1 is initial fracture strain, D2 is Exponential factor, D3 is Triaxiality factor, D4 is strain rate factor and D5 is temperature factor.

Table 1. Johnson-Cook material constants.

Parameter	A	B	C	n	m	D1	D2	D3	D4	D5
Values	324 MPa	114 MPa	0.002	0.42	1.34	-0.77	1.45	-0.47	0	1.6

Table 2. Material Properties of AL 6061 alloy.

Parameter	Al 6061	Tool
Young's Modulus	68.9 GPa	210 GPa
Poisson's Ratio	0.33	0.22
Specific heat	896 J/kg/◦C	346 J/kg/◦C
Thermal Conductivity	167 W/m◦C	40.15 W/m◦C
Density	2700 kg/m3	1190 kg/m^3
Friction Coefficient	0.9	0.9

4. Cutting conditions

The machining is done using orthogonal machining process where the base of the work piece is constrained in all direction. The tool is constrained in Y and Z directions, the speed of the tool is given in along X direction and is varied for comparison of forces and stresses induced at different speeds. The work piece is made deformable to observe the formation of chip. Sequential orthogonal machining is done with a feed of 0.4mm/rev and the width of cut is considered to be 4.1mm. The cutting process is simulated for 0.04 seconds. The machining is done for two passes. The simulation was carried out for three different speeds, 1000 m/s, 700 m/s and 300 m/s. The cutting condition used for the simulation is shown in Table 4.

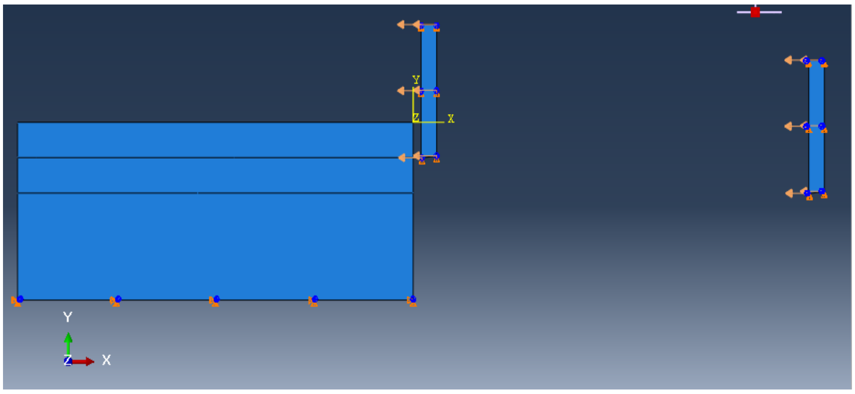

Figure 2. Model showing the different boundary and loading condition.

Table 3. Cutting conditions used for the simulations.

Cutting Condition	Value
Speed	300, 700 and 1000 m/s
Feed	0.4 mm/rev
Width of Cut	4.1 mm

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Results

The primary aim of the research work is to simulate the sequential cutting process and to understand the effect of the sequential cutting process on different parameters like chip formation, stress, forces induced, residual stresses.

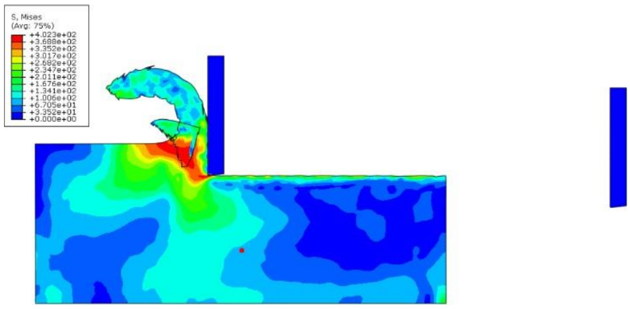

Figure 3. Von Mises stress distribution during the first pass at 300 m/s.

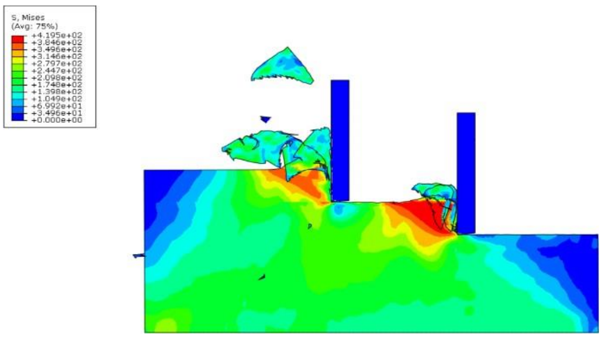

Figure 4. Von Mises stress distribution during the second pass at 300 m/s.

Figure 4. shows the Von Mises distribution during the second pass as well. It is observed that the chip formation is continuous chip during the first pass as seen in Figure 3. And the chips tend to break apart during the second pass which may be due to induced residual stresses and the increased hardness due to severe plastic deformation. The force variation for different cutting conditions during the first pass is shown in Figure 5.

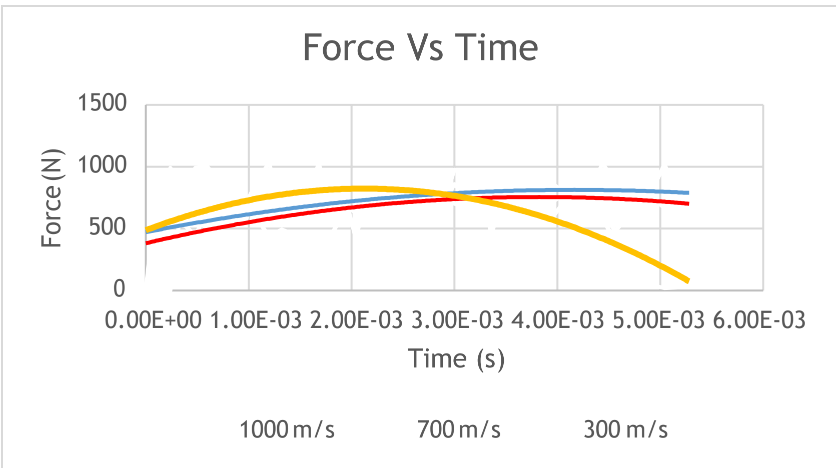

Figure 5. Force Variation with respect to time-first pass.

The Force variation during the second pass is shown in Figure 6. It is observed that the induced force is higher than the first pass during the work hardening that happens during the plastic deformation.

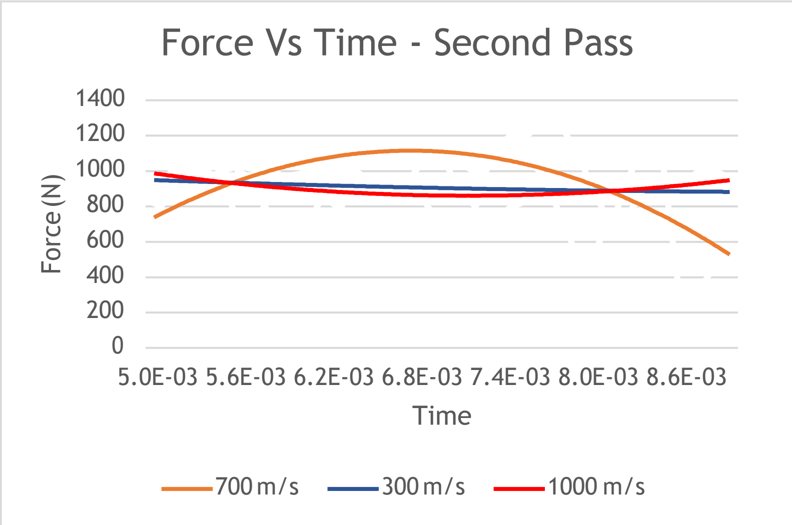

Figure 6. Force Variation with respect to time-second pass.

6. Conclusion

A 2D thermo-mechanical model was developed using commercially available FEM software. The force variation during the sequential passes during orthogonal cutting process was studied. It was observed as the cutting speed increases the forces increase then it drops. It was also found out the force generated during the second pass is higher when compared to the first pass which may be due to the hardening factor. Further the model can be used to study the residual stresses variation, temperature variation etc. Future work involves development of a model for different friction coefficients, developing a model to replicate the oblique cutting process. Also future work involves development of mathematical model and drawing a relationship between the machining parameters and the dependent output variables [19].

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