Thermal Analysis of Machining Al 7075 – T6 Using Carbide Tipped Tool

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Abstract — A practical explicit 3D FEM model is developed to analyze turning of Al 7075 – T6 using uncoated carbide tipped tool, so as to incorporate the thermal properties of work material during machining. An improved model has been proposed to characterize total heat generated corresponding to tool, chip and workpiece. FEM generally is used in predicting overall cutting performance, including chip flow and morphology, cutting forces, residual stresses and cutting temperature, often beyond capabilities of current methods of measurements. FEM model provides reasonable level of accuracy in evaluating the said process parameters. Modelling and analysis were done in ANSYS 16, employing transient state, where in temperature pertaining to each node is evaluated

Keywords— FEM, Cutting temperature, Temperature Distribution, Chip formationcomponent; formatting

I. INTRODUCTION

Aluminium is the world's most abundant metal, comprising 8% of earth's crust. In the hundred years since the first aluminium were produced, the worldwide demand of aluminium has grown to around 29 million tons per year. Alloys composed mostly of aluminium have been very important since the advent of high speed, greater capacity aircrafts and mega structures. Aluminium alloys with a wide variety of properties are mainly used in engineering structures due to their high strength to weight ratio. On the other hand pure aluminium metal is much too soft for such uses and it does not have high tensile strength needed for such applications. They offer a wide variety of interesting mechanical and thermal properties, moreover, they are easy to shape metal in machining, which is primarily a material removal process. Aluminium alloys as a class are considered family of materials offering the highest level of machinability. Selecting the right alloy for any given application should take into consideration of its tensile strength, density, ductility, formability, workability, weldability and corrosion resistance to name a few. Typically aluminium alloys have an elastic modulus of 70 GPa, which is around 33% of elastic modulus of most kinds of steel and steel alloys.

Machining includes the various processes where in a piece of raw material is cut into any desired shape and size by a controlled material removal process, which can be either additive manufacturing or subtractive manufacturing. Turning is an engineering machining process in which cutting tool describes the helical tool path by moving linearly while workpiece rotates. Turning can be either on the outside of the cylinder or on the inside to produce various complex geometries. The relative forces in an turning operations are important in the design of machine tools, where in it should be able to withstand these forces without causing significant deflection, vibrations or chatter. There are three principle forces during a turning operations mainly tangential force, field force and thrust force. The different speed and feed corresponding to turning operations are chosen based on cutter material, workpiece material, machine tool rigidity, spindle power and other factors

I.I INTRODUCTION TO ANSYS

ANSYS is a powerful multi-purpose analysis tool used to formulate solution for commercially available general purpose FEA program. ANSYS program is capable of problem simulation under a wide range engineering disciplines. However most problems focus on two basic disciplines:

a) Structural Analysis

This is used to find deformation stress and strain field as well as reaction forces in a solid body. Structural analysis includes static, Modal

b) Thermal Analysis

This analysis type addresses different types of thermal problems which includes primary heat transfer, phase change or even thermo-mechanical analysis. This is also used to calculate steady state or time dependent temperature field and heat flux in a solid body.

ANSYS solution for both these analysis disciplines provides nodal values of field variable, called as degree of freedom as presented in Table 1.

Table 1 – Degree of freedom for structural and thermal analysis discipline

Discipline	Quantity	DOF
Structural	Displacement, stress, strain, reaction forces	Displacement
Thermal	Temperature, flux	Temperature

ANSYS supports two types of thermal analysis:

a) Steady State Thermal Analysis

The steady state thermal analysis is used to calculate the effects of steady thermal loads over a system or component. A steady state analysis also can be the last step of a transient analysis, performed after all transient effects have diminished. We can use steady state analysis to determine temperatures, thermal gradient, heat flow rate and heat fluxes caused by thermal loads which do not vary over time. This includes convections, radiation, heat flux, heat flow rate and constant temperature boundaries.

b) *Transient Thermal Analysis*

A transient analysis basically follows the same procedures as a steady state analysis, main difference being applied loads, in a transient analysis are functions of time. Many heat transfer application, heat treatment problems, nozzle, engine blocks, pressure vessel involves transient analysis.

II. EXPERIMENTATION DETAILS

A. Workpiece

Aluminium is one of the most abundant elements in the earth’s crust and usually resides in the form of an oxide. Aluminium alloy 7075 is an alloy with zinc as the primary alloying element. It is strong, with strength comparable to many steels, has good fatigue strength, average machinability, but less resistance to corrosion than many other aluminium alloys. Its relatively high cost limits its use to those applications where cheaper alloys are not suitable. The mechanical properties of Al 7075-T6 are as shown in Table. 2. Properties of aluminium alloys can be enhanced to a greater extent by proper heat treatment. To identify the scope each alloy has on a particular application, thermal analysis of aluminium is being done frequently by researchers.

Table. 2 – Mechanical Properies of Al 7075 – T6

Property	Scale
Thermal conductivity	130 W/m-K
Yield strength	572 MPa
Specific heat	0.96 J/g°C
Young’s Modulus	71.7 GPa
Density	2.81 g/cc
Poisson’s Ratio	0.33

B. Finite element analysis procedure

Simulation of turning operation is a time dependent process and hence is usually determined by transient thermal analysis. Transient thermal analysis basically follows the same procedures as steady state thermal analysis, main difference being applied loads in a transient analysis are functions of time hence for specifying time dependent loads we either use function tool defining an equation or describing the curve and apply this function as the boundary condition. The second method is by dividing the load versus time curve into load steps.

In the first step effect of tool motion is completely confined to an equation, in the form of formula. This is a much easier process and exact solution can be obtained. The heat generated during a machining process is primarily due to plastic deformation energy, transforming itself in the form of heat. The heat generation rate, Q (W) is given by Sata and Takeuchi as;

$$Q = 1.68af^{0.15}V^{0.85}$$

where *a* is the depth of cut (mm), *f* is the feed rate (mm/rev), and *V* is the cutting speed (m/min).

C. Boundary Conditions

The transient thermal analysis was performed using an ANSYS commercial finite element code. The calculated heat flux applied to the tool-chip contact area on the rake face of the cutting insert was the basis of the thermal analysis. The boundary conditions applied on the finite element model can be seen in Fig. 1. The calculated heat flow on the tool-chip interface was 17 W. Other surfaces, except for the end of the tool holder, were set to be adiabatic and the end of the tool holder was set to the ambient temperature. The ambient temperatures considered were in the range of 20 °C to 30 °C. The adiabatic boundary condition of the rest of the exposed surface was based on the boundary conditions set by Tay *et al*.[14]

Fig. 1 - Boundary condition and temperature distribution

D. Meshing

ANSYS and ANSYS professional program comprises about 40 elements so as to help us carry out steady state analysis. These elements are used to find out temperature at each node. Here SOLID 70 is the element used. SOLID 70 have a 3 dimensional thermal conduction capability. This element has 8 nodes with single degree of freedom, temperature, at each node. This element is applicable to a 3D steady state or transient thermal analysis, compensating for mass transport heat flow from a constant velocity field. The meshing representation is shown below. This SOLID 70 mesh is divided into 27,100 eight noded brick elements and number of nodes corresponds to 29,478 as shown in Fig. 2

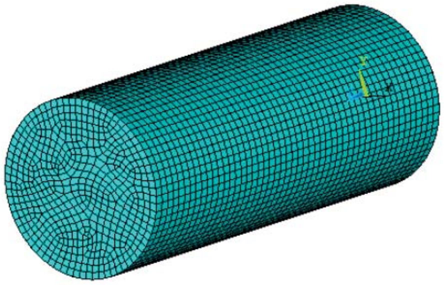

Fig. 2 – Meshing of Al 7075 – T6

III. SIMULATION RESULTS AND DISCUSSIONS

Based on the formula proposed by Sata and Takeuchi, the total heat generated during FEA simulation of turning Al 7075-T6 is obtained using ANSYS. For finding the right solution for a problem, right formulation must be chosen so as to describe finite element mesh associated with the workpiece material. The result at the start, middle and end of a run, at 0 degree, 90 degree, 180 degree and 270 degree are formulated to give a clear picture, as shown in Fig. 3, Fig. 4 and Fig. 5 respectively.

Here cutting speed was taken as 100m/min, depth of cut 1mm and feed rate as 0.05mm/rev. In this Lagrangian formulation was implied. In Lagrangain formulation finite element mesh is attached to the workpiece and deformed together. This is particularly useful for relatively low distortion and possibly large deformations and the state of material in each element is completely known. Lagrangain method tends to be faster, as no transport of material through the mesh need to be calculated. Lagrangian formulation is preferred due to more convenient modeling of chip evolution from the starting stage to a steady form. As told earlier transient analysis has been implied for the formulation of results.

From Fig. 3 to Fig. 5 we can see that as the point of contact is moving, location of heat generation also changes. At the start the material is closed to room temperature and hence the temperature at the start is very low. As the tool progresses along the workpiece the temperature also increases and the plot shows increasing high temperature at the end of machining processes. Plotting the graph between temperature and time we can see that as time increases, temperature also increases as shown below from Fig. 6 to Fig. 8.

Also we can see proportional increase in temperature with cutting speed. The Fig. 9 and Fig. 10 shows the effect of cutting speed on overall temperature. Also we can see that as cutting speed increases from 100°C to 150°, there is increase in cutting temperature also. The rise in temperature at the start, middle and end for increasing cutting speeds of 100m/min and 150m/min is as shown in Table. 3

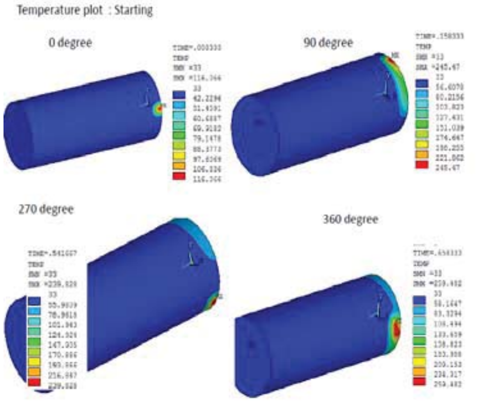

Fig. 3 – Temperature plot at the starting

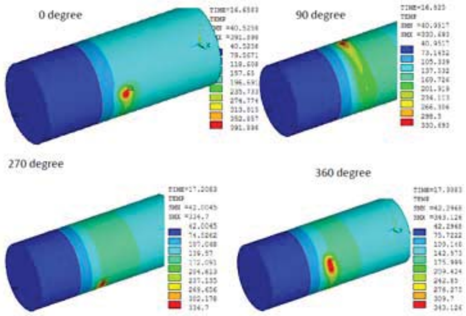

Fig. 4 – Temperature plot at the middle

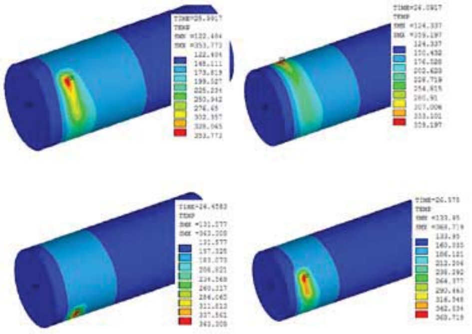

Fig. 5 – Temperature plot at the end

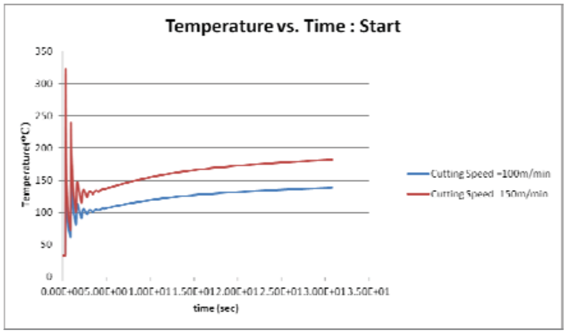

Fig. 6 - Temperature Time graph at the start of cycle

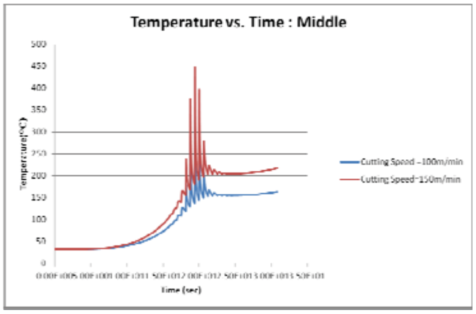

Fig.7 - Temperature Time graph at the middle of cycle

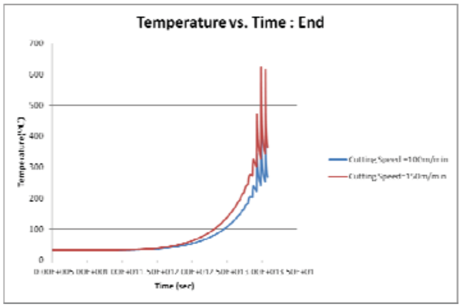

Fig. 8 - Temperature Time graph at the end of cycle

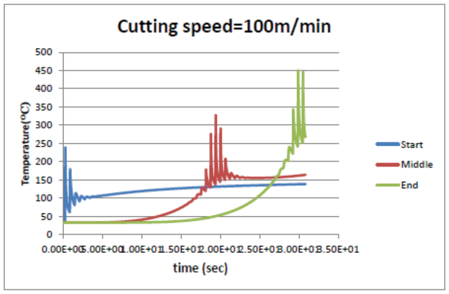

Fig. 9 – Effect of cutting speed on temperature for a cutting speed of 100m/min

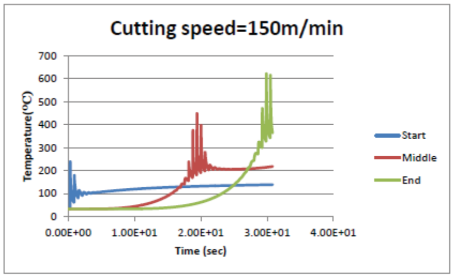

Fig. 10 – Effect of cutting speed on temperature for a cutting speed of 150m/min

Table. 3 – ffect of cutting speed on temperature

Cutting Speed (m/min)	Temperature(ºC)		
	Start	Middle	End
100	230	330	450
150	243	440	620

IV. CONCLUSIONS

a) A practical explicit 3D FEA model has been developed using ANSYS to simulate turning of Al 7075-T6 heat treated alloy. FEA incorporates thermal behavior of work material.

b) Here we employed a transient behavior for performing our analysis and found out that as the point of contact of workpiece is moving from start to the end location of heat generation also changes.

c) The process parameters employed where cutting speed, feed and depth of cut. From Table. 3 and Fig 9 to 10, we see that there is a proportional increase in temperature with increase in cutting speed i.e, as cutting speed increases, temperature also increases.

d) From Fig 3 to Fig 8, we can see that at the start of machining process, material is at room temperature and as the point of contact progresses along the workpiece, to the middle and towards the end, the heat generated also increases progressively. The heat generated during the start of machining process is around 116°C and the total heat generated at the end is close to 400°C.

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