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# **Finite Element Machining Simulation of AISI6150 Steel**

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**ABSTRACT:** In metal cutting process, chip formation is a phenomenon needed to investigate in detail to explore the machining characteristics of materials. This paper describes, the performance of the coated carbide tool is studied by varying the cutting speeds i.e. 140m/min, 200m/min and 300m/min with constant feed 0.11mm/rev and depth of cut 1mm. The commercial DEFORM 2D finite element software with special remeshing capabilities enabling the simulations has been used in this work. The fully coupled thermal-mechanical finite element analysis accurately simulates the formation of chip and predicts the cutting load and temperature distribution. The simulation results of cutting forces, cutting edge temperatures and chip formation are presented and discussed. Also, from the FEA results show clearly that the relationship between input variables with output responses.

**KEYWORDS:** Finite Element Analysis, Machining, Simulation, Cutting force, Temperature distribution.

## **I. INTRODUCTION**

Machining is a common process of manufacturing for producing parts of desired dimensions and shapes. In order to understand the mechanisms and mechanics of cutting process, much attention has been paid to develop simplified model. The new challenge is the implementation of these simplified models in a finite element environment in order to perform a machining simulation to identify chip formation, cutting forces and temperature distribution in tool and workpiece. In recent years, application of finite element technique in chip formation analysis develops rapidly because of its many advantages over empirical and analytical methods, the development of powerful computer and the availability of more commercial FE codes. Several finite element models have been developed by various researchers to predict various process variables.

## **II. LITERATURE REVIEW**

Halil bil et al [1] studied the effects of friction, chip formation model and material data in the simulation of metal cutting. The friction parameter affects the simulation results drastically, but tuning this parameter yields good agreement only for some variables the range. Then, plain damage models for chip formation are not appropriate for machining purposes. Although the remeshing model gives better results, it is based on the misconception of the crack generation in the material at the tool tip.

Liu and Guo [2] proposed that thermo-elastic plastic coupling Finite element method is to predict the effect of sequential cuts on the residual stress in the machined layer. But, cutting forces, chip formation and temperature at the machined layer are only slightly affected by the sequential cuts. Akbar et al [3] quantified that the variables are heat partition into the cutting tool on the tool-chip interface temperatures, Von Mises stresses and the tool-chip contact

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length from the FE Simulation AISI/SAE4140 steel. The results also show that heat partition can significantly modify the tool-chip contact area and hence affect the capability of FE model to adequately represent the process.

Ozlu et al [4] observed total contact length increases by the feed rate and decreases by the cutting speed. For AISI1050 steel and coated carbide tool, the total contact length decreases with the speed upto 30% where as this ratio is about 10% for CBN tools. Then, the apparent friction coefficient strongly depends on the relative lengths of the sticking and sliding zones, and the sliding friction coefficient. The apparent friction coefficient is always smaller than the sliding friction coefficient. Although this depends on the cutting speed, the difference between both the coefficients is around 20% in most applications.

According to Khaliq and Safaei [5] showed, when cutting speed increases, cutting forces remains almost the same at a constant chamfer width or angle and observed that with increase of chamfer width, the shear angle increases and the chip thickness decreases. But, chip thickness and shear angle are of most the same values for different chamfer angles. It is demonstrated that with increase in width of chamfer, the ratio of the force to the cutting force increases. For a constant width of chamfer, increasing the cutting velocity elevates the maximum temperature of the tool tip. The simulations show that when chamfer angle increases, the force ratio decreases. Davim and Maranhao [6] proposed that friction co-efficient is significantly lower in high speed machining when compared to traditional machining. For conventional speed machining, the plastic strain presented an error only 2.5% and 1.4% for the plastic strain rate. It is believed that finite element analysis can be considered a good method to predict both plastic strain and plastic strain rate.

Umbrello et al [7] developed and validated a hardness-based flow stress model for AISI H13 steel. Both critical damage and friction factor value were as a function of temperature. But complex metallurgical features like white layer formation in the chip and workpiece were not considered in the model. Huang and Liang [8] investigated, on the chip side; the effect of the primary shear zone is modeled as the uniform moving oblique band heat source and that of the secondary shear zone as the non-uniform moving band heat resource within the semi-infinite medium. For the tool side, the effects of both the secondary and the rubbing heat sources are modeled as non-uniform static rectangular heat sources within the semi-infinite medium. On the work piece side, the effect of the primary shear zone is modeled as the uniform moving oblique band heat source and that of the rubbing heat source as the non-uniform moving band heat source within the semi-infinite medium. The temperature distribution along the worn flank is calculated based on the material properties of the work piece and tool. It is found that the progression of flank wear does not change the average rake face temperature noticeably and both the average flank face temperature and average rake face temperature increase with the flank wear length and cutting speed, but decrease with feed rate. Mamalis et al [9] identified that the numerical results of the constructed finite element machining model indicate that the FE method may be more reliable for machining operations than the related analytical methods, since the effect of parameters such as large strain, strain-rate and temperature, on the workpiece material properties can be taken into account. However, the properties of the materials under such conditions are difficult to be obtained, which limits the accuracy of the results of any FE machining model.

## II. MATERIAL MODELING

Accurate modeling of the material behaviour is the key for FE –based machining modeling. Therefore, Modeling on the material is quite important to FE simulation. The material model must represent the actual changes of the material physical properties during machining simulation. Many different constitutive models exist to describe the material's behaviour in the plastic stage. The Johnson-Cook material model [11] is used to describe material behaviour in the plastic stage over large strains at high strain rates and at high temperatures. The flow stress model can be expressed as (1)

$$\bar{\sigma} = \left[ A + B(\varepsilon)^n \right] \left[ 1 + C \ln \left( \frac{\dot{\varepsilon}}{\dot{\varepsilon}_0} \right) \right] \left[ 1 - \left( \frac{T - T_0}{T_m - T_0} \right)^m \right] \quad (1)$$

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Where,  $\bar{\sigma}$  is the equivalent flow stress,  $\epsilon$  is the equivalent plastic strain,  $\dot{\epsilon}$  is the plastic strain rate,  $\dot{\epsilon}_0$  is the reference strain rate ( $1.0s^{-1}$ ),  $T$  is the temperature of the material,  $T_0$  is the room temperature and  $T_m$  is the melting temperature. The empirical constants are as follows:  $A$  is the initial yield stress,  $B$  is the hardening modulus,  $C$  is the strain rate sensitivity parameter,  $n$  is the work hardening exponent, and  $m$  is the thermal softening co-efficient. Table 1 reports the material constants obtained for non-hardened steel (30HRC) by the Hohne et al [10].

Table.1. Johnson-Cook law parameters for AISI6150 Steel

A (MPa)	B (MPa)	C	m	n	T <sub>m</sub> (°C)	T <sub>0</sub> (°C)
900	341	0.01	1.5	0.203	1520	20

### III. FINITE ELEMENT MODEL AND ASSUMPTIONS

In the FE machining simulation of AISI6150 steel, TiN+TiCN+Al<sub>2</sub>O<sub>3</sub>+TiN coated (CCMT 09T304 FG) insert without chip breaker produced by Taegu Tec was used. Inserts have 0° rake angle, 7° clearance angle, and 0.4mm nose radius. In this work, a DEFORM 2D software is used to simulate the orthogonal cutting process, which is based on the lagrangian equation.

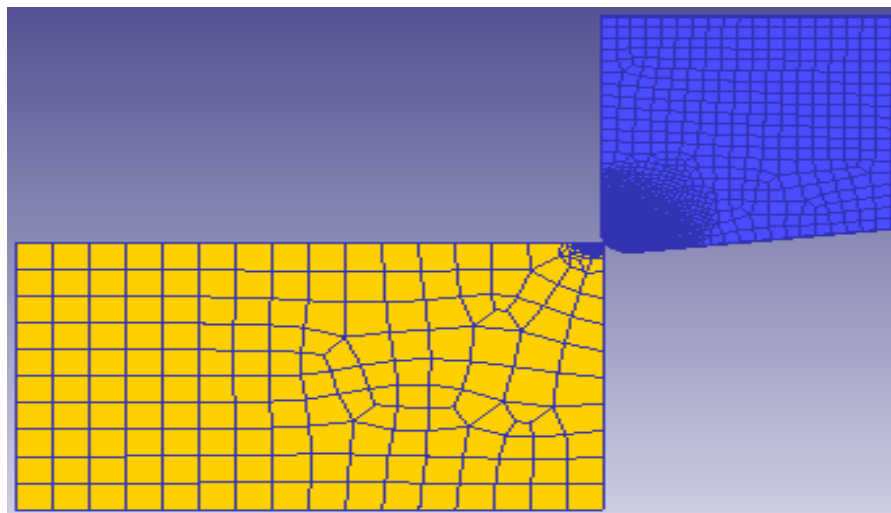


Fig.1. Finite element model of orthogonal cutting

The workpiece was assumed to be rigid-visco plastic with a rectangular shape. The tool was defined to be a rigid body which considers thermal transfer for modeling the cutting temperature field. The two-dimensional FE model with initial meshing of the cutting mechanism as shown in Fig.1. This model was generated under a plane strain assumption because the width of cut is larger than the undeformed chip thickness in this orthogonal cutting arrangement. The nodes on the bottom layer of the workpiece were fixed in the vertical direction and were defined with the cutting velocity in the horizontal direction. In numerical simulation, the tool penetrates through the workpiece model for a set of given Input values. In cutting simulations, the chip formation was performed as plastic flow and continuous remeshing technique was used. Initial temperature of workpiece and cutting tool is set at 28°C. Finite

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element simulation is carried out to reach at steady state, which allowed the thermal to flow into the work material during simulation of cutting process. Then the simulation is continued to reach the transient condition. The simulations are performed at three different cutting speeds i.e. 140m/min, 200m/min and 300m/min with constant feed 0.1mm/rev and depth of cut 1 mm.

### IV. FRICTION CONDITIONS

Coulomb model to provide a first approach to the friction value and using that value as a starting point, several iterations must be carried out until the results are satisfactory. Coulomb model is suitable as an initial point it is able to define if the friction co-efficient is smaller or bigger than standard friction co-efficient as considered as 0.5[12]. In this work, Coulomb-friction with  $m=0.4$  is used as a friction model [10] for all machining simulations.

### V. RESULTS AND DISCUSSION

#### 5.1 Effect of Cutting speed on Cutting forces and Tool Temperatures

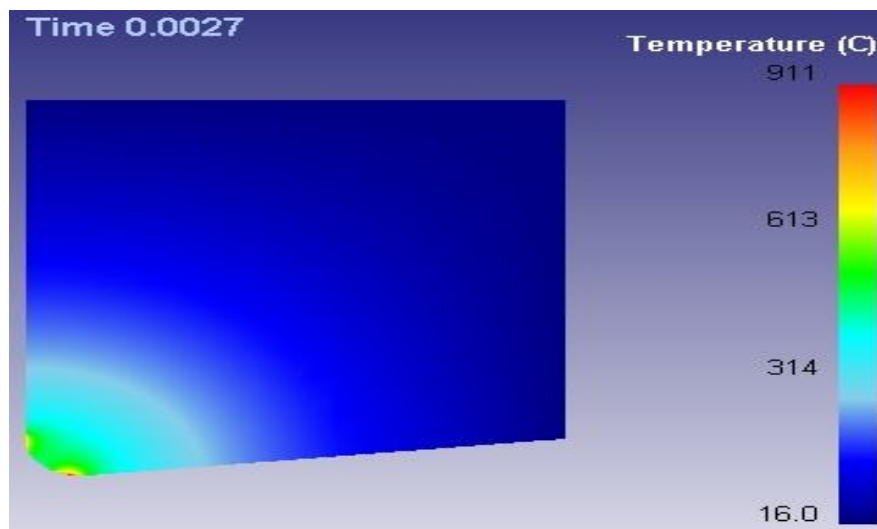


Fig. 2. Temperature distribution plot for cutting speed 140m/min

As seen in these following figures, the effect of clearance angle and nose radius on temperature is significant. Also, the magnitude and distribution of temperature are affected by the cutting speed. It can be observed in Figure 2, 4 and 6, the cutting speed increases 140m/min to 200m/min, maximum tool temperature at the interface zone also increases from 895°C to 906°C.

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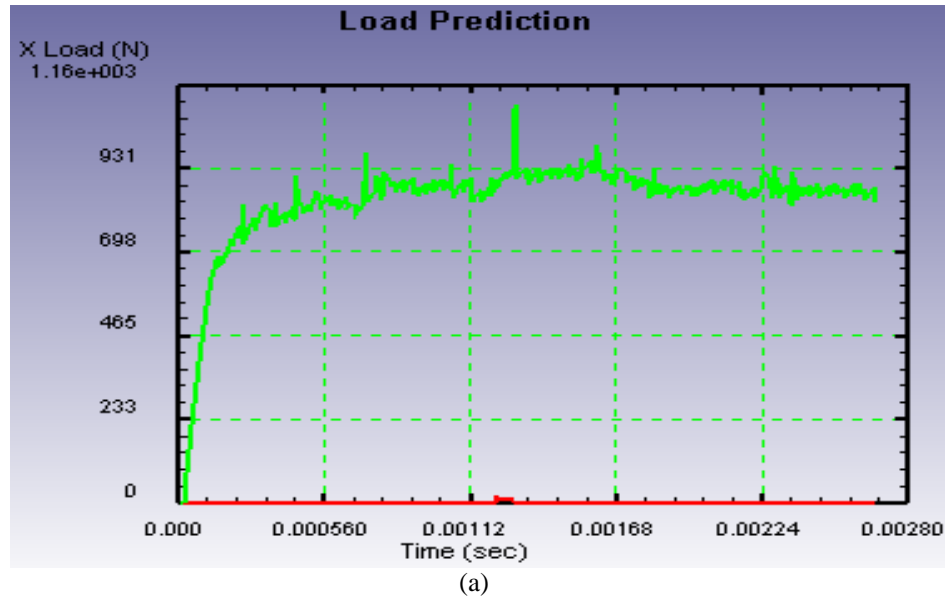


Fig. 3. Load prediction plot for cutting speed 140m/min

From Figure 3 and 5 depicted that the average cutting force reduced from 900N to 840N by the increasing of cutting speed from 140 to 200 m/min. Further increasing the cutting speed 200 to 300 m/min the temperature raised to 927°C and primary cutting force reduced nearly 800N were observed figure 4.

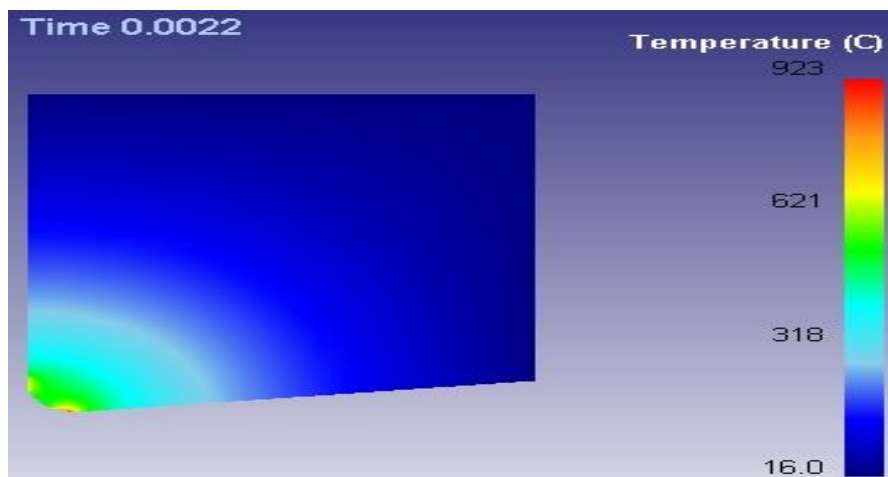


Fig. 4. Temp distribution plot for cutting speed 200m/min

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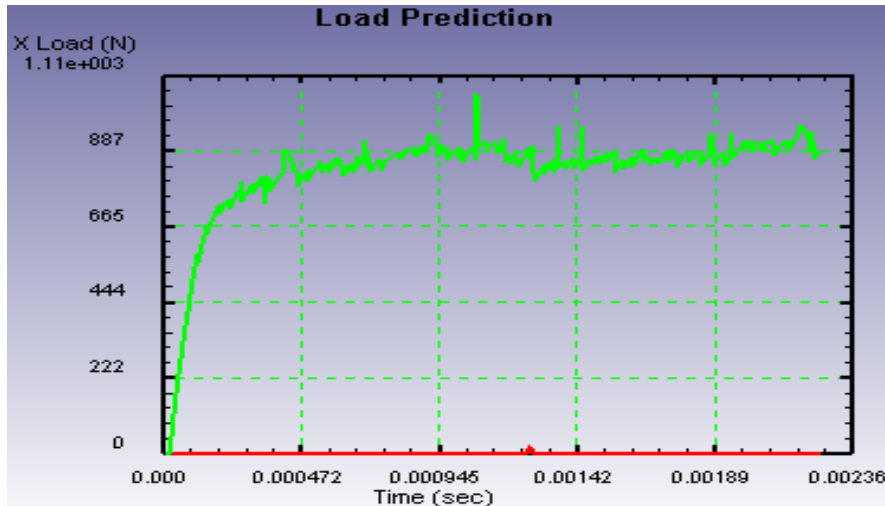


Fig. 5. Load prediction plot for cutting speed 200m/min

The reason behind is thermal conductivity of  $Al_2O_3$  decreases with increasing temperature. While, it increases with increasing temperature for WC, TiN and TiCN coated layers. Using 0.4 nose radius tool, an increase in tool-chip contact surface area and increase in heat energy, which comes out within certain unit of time. Increased chip-tool contact length results in increase the friction area on secondary deformation zone. As a result, temperature rise on the near the tool tip will be higher.

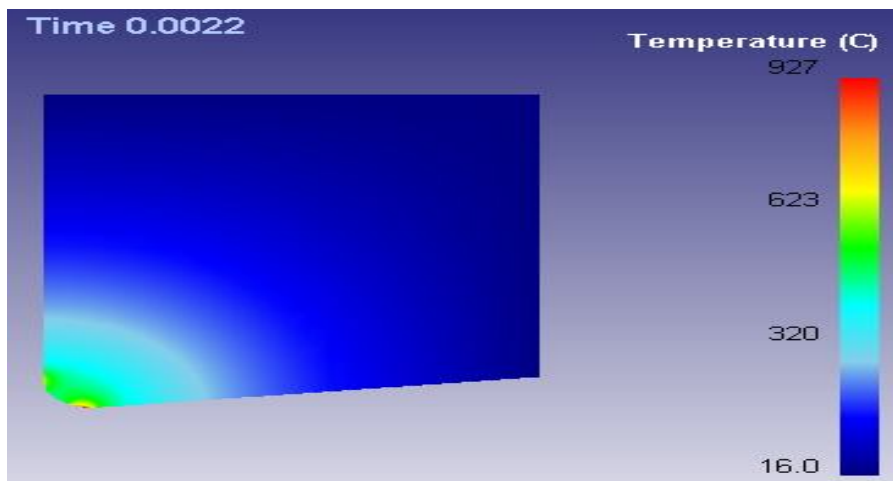


Fig. 6. Temp distribution plot for cutting speed 300m/min

With the increase in the cutting speed, the strain rate increases. An increase in the strain rate results in a high heat formation. Therefore, the cutting temperature increases in the tool-work piece zone. This possibly reduces the cutting force at the zone.

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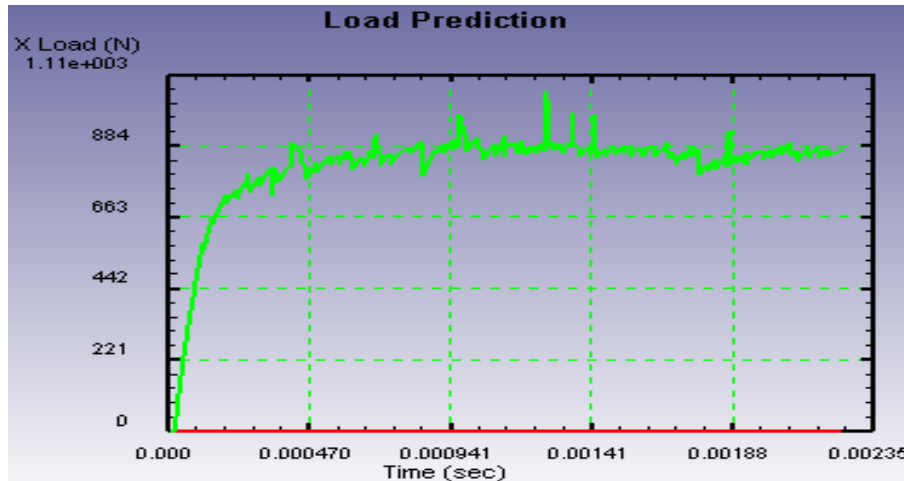


Fig. 7. Load prediction plot for cutting speed 300m/min

## VI. CONCLUSION

The finite element simulation was carried out model of orthogonal cutting using coated inserts, which reveals the effects of cutting speed and material data in the simulation. The following conclusions can be drawn from the analysis,

1. The Johnson–Cook’s constitutive equation with set of material constants was implemented in in simulation of machining model
2. The tool –workpiece interface temperature is increased with an increase in cutting speed was observed
3. The cutting force at the beginning of the cutting process is large and further decreases with subsequent incremental displacement were also observed.
4. The results from FE simulations show that the friction has a strong influence on cutting forces, thrust forces, chip geometry and cutting temperature.

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