

# Analysis of Orthogonal Metal Cutting under different Rake Angles using Finite Element Method

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**ABSTRACT:** This research study focuses on building 2-Dimensional finite element models to simulate the orthogonal machining process using DEFORM 2D tool. Finite element method is developed to investigate the effect of the tool rake angle and cutting variables on the chip, and the machined work piece during the cutting process. Cutting simulations were conducted under a variety of tool rake angles and cutting variables to explore the effect of tool rake angle on cutting force, temperature distribution, the equivalent stress distribution and strain. The tool material used in this work is AISI 4340 and work piece material is AISI 1020, aluminium alloy. The simulated results for different conditions are discussed.

**KEY WORDS:** Orthogonal cutting, rake angle, finite element method, DEFORM 2D.

## I. INTRODUCTION

In a typical orthogonal cutting operation, specifically turning, the work piece is rotated at a certain velocity called the cutting speed ( $V$ ), in one revolution of the work piece (a bar in this case), the tool advances in an axial distance  $f$  (the feed rate) to reduce the work piece radius by an amount  $d$  (the depth of cut) also known by to as the undeformed chip thickness and  $t_c$  is the chip thickness. The rake face is the face where the formed chip and tool come in contact. Rake angle ( $\alpha$ ) is an angle between the rake face and the chip formed. The clearance face is a surface which the tool passes over the machined surface. Clearance angle ( $c$ ) also known as the relief angle is an angle between newly machined surface and the clearance face. These variables determine the characteristics of the process and are shown in Fig 1. Experimental method of obtaining data involves high cost and wastages; there is strong need for development of other approaches. Analytical and numerical methods are used to obtain data of cutting process. In simulation approach models can be modelled in two dimensional or three dimensional models. In two dimensional, orthogonal models can be modelled and in three dimensional both orthogonal and oblique cutting models can be modelled. Finite element analysis can provide comprehensive and complementary approach to experimental, analytical approaches to predict and understand machining processes.

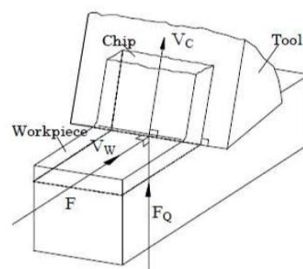


Fig 1: Orthogonal metal cutting

## II. RELATED WORK

Authors [1] and [2] have reported that till late 1990s, the majority of researchers generated their own FEM codes to use in their studies. Due to the long computational hours of simulations and high memory capacity needed, the use of FEM was limited and if used, 2D simulations were dominant. However, over the last 20 years, developments in technology (hardware and FE codes) dramatically increased, overcoming to an extent the limitations faced in modelling and computational difficulties. Commercially available software packages became more in use. The researchers [3–5] have reviewed the extensive literature elucidating the suitability of different finite element based software tools like Abaqus, Advantedge and Deform-2D/3D, etc. for predicting the machining characteristics like tool wear, cutting forces, chip morphology, residual stresses, etc. for a variety of metals. Many of the researchers [6–8] have attempted the simulation-based studies specifically on the turning process using different software tools. Whereas few researchers [9–11] have discussed the Deform-3D based simulation results for turning operation with experimental validation wherein the machining responses like tool wear, cutting forces, and chip morphology, etc. are predicted and analyzed using Deform-3D software for different materials. However, the accuracy of any software tool can only be ensured by providing accurate material properties in terms of material constants. In [12] authors have used ABACUS software for the estimation of cutting force in turning process. A 3D model for oblique cutting is used and modelled to analyse the turning of Inconel 718 using coated carbide inserts.

## III. METHODOLOGY

**Tool modelling and meshing:** The tool is considered to be a rigid body and modelled in the deform software as shown in the Fig 2 by selecting the primitive geometry and then it is meshed using relative mesh size equal to 700 as shown in Fig 3.

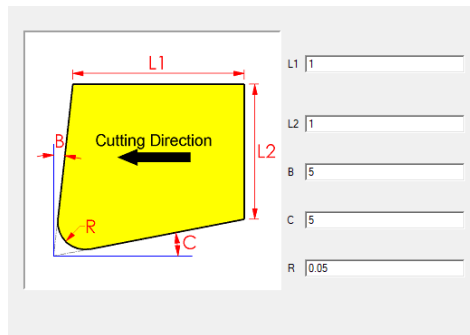


Fig 2: Tool modelling

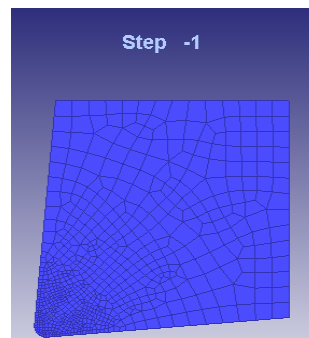


Fig 3: Tool meshing

**Work piece modelling and meshing:** The work piece is considered as a plastic body and modelled as shown in Fig 4 and meshed as shown in Fig 5 in the same way as that of the tool modelling and meshing.

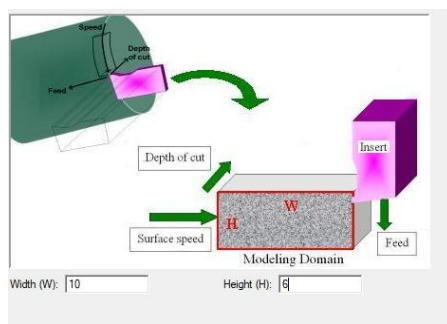


Fig 4: Work piece modelling

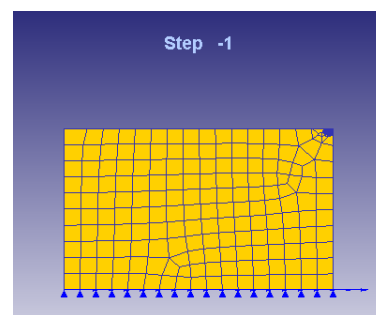


Fig 5: Work piece meshing

Table 1:  
Input parameters for simulation

Input parameters	
Environment temperature (°C)	20
Convection coefficient between tools and environment (N/s/mm/°C)	0.02
Friction factor	0.6
Heat transfer factor (N/s/mm/°C)	45
Tool type	Rigid
Tool temperature (°C)	20
Workpiece type	Plastic
Workpiece temperature (°C)	20
Width of workpiece (mm)	10
Height of workpiece (mm)	6
Rake angle (°)	5, 8, 11
Clearance angle (°)	5
Nose radius (mm)	0.1

**Positioning tool and workpiece:** The tool and workpiece are positioned as shown in the Fig 6

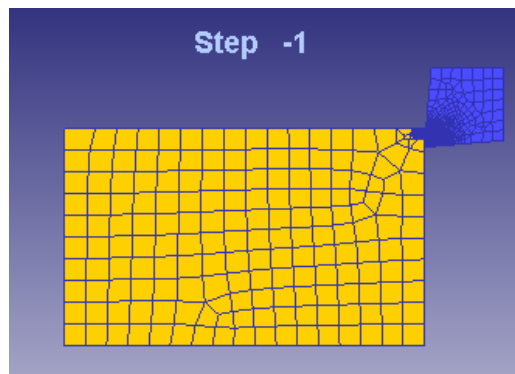


Fig 6: Positioning of tool and workpiece

#### IV. RESULTS AND DISCUSSION

A classical orthogonal cutting model is assumed to have plane-strain deformation conditions. A typical representation of the process model is shown in Figure 7. An important aspect of the cutting process, are the forces acting on the tool. The earliest and simplest model to understand the cutting process is Merchant’s model. The cutting forces vary with the cutting tool angles. The cutting force,  $F_c$ , is the component of the force acting on the rake face of the tool. This is usually the largest of the force components. The frictional force,  $F_f$ , is the force due to friction along the rake angle.  $F_t$ , is the thrust force, this force is in the direction of feed motion. Another component of the force is the normal force,  $F_n$ . This force is the smallest of the force components and tends to push the tool away from the work piece in a radial direction. Table 2 shows the of simulation results obtained from the turning of Aluminium alloy and Table 3 shows the simulation results obtained from the turning of AISI 1020.

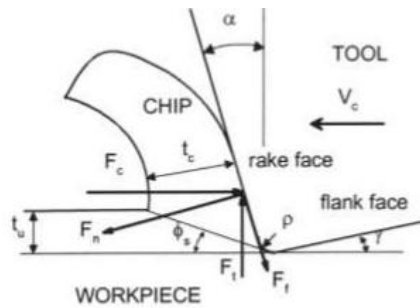


Fig 7: Forces generated during orthogonal cutting process

Table 2:  
Simulation results of forces obtained for turning Aluminium alloy

Cutting No	Cutting parameters			Simulation results	
	Speed (rpm)	Feed (mm/rev)	Rake angle (°)	F <sub>x</sub> (N)	F <sub>y</sub> (N)
1	160	0.5	5	88.23	149.17
2	160	0.5	8	83.13	132.8
3	160	0.5	11	79.03	123.88
4	360	0.5	5	80.58	129.93
5	360	0.5	8	75.37	121.6
6	360	0.5	11	72.95	112.3

Table 3: Simulation results of forces obtained for turning AISI 1020

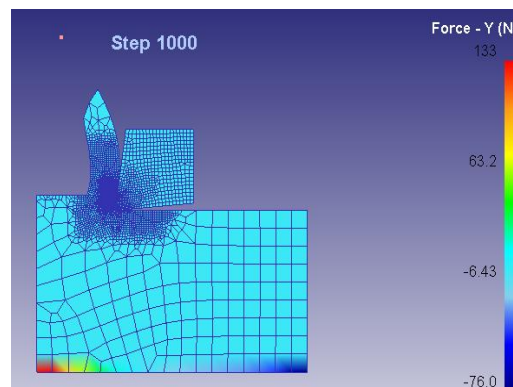
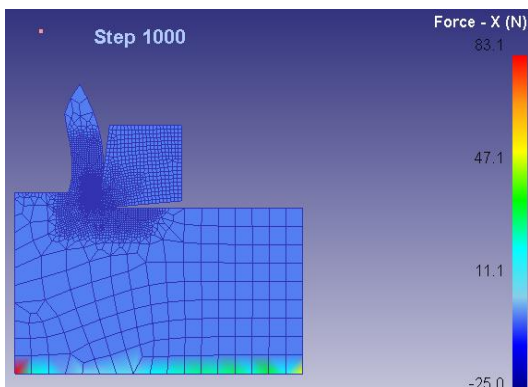
Cutting No	Cutting parameters			Simulation results	
	Speed (rpm)	Feed (mm/rev)	Rake angle (°)	F <sub>x</sub> (N)	F <sub>y</sub> (N)
1	160	0.5	5	188.42	308.39
2	160	0.5	8	178.64	282.66
3	160	0.5	11	164.96	262.26
4	360	0.5	5	196.41	304.65
5	360	0.5	8	181.45	285.38
6	360	0.5	11	168.45	262.41

Table 4:  
Simulation results of temperature, stress, strain for turning Aluminium alloy

Rake angle (°)	Cutting speed (rpm)	Temperature (° C)	Stress (Mpa)	Strain (mm/mm)
5	160	391	796	6.25
8	160	382	822	5.71
11	160	373	791	5.81
5	360	541	747	5.09
8	360	530	728	6.09
11	360	518	732	5.83

Table 5:  
Simulation results of temperature, stress, strain for turning AISI 1020

Rake angle (°)	Cutting speed (rpm)	Temperature (° C)	Stress (Mpa)	Strain (mm/mm)
5	160	553	1220	5.42
8	160	542	1230	6.47
11	160	535	1230	5.92
5	360	716	1230	6.30
8	360	700	1230	5.93
11	360	691	1230	6.41



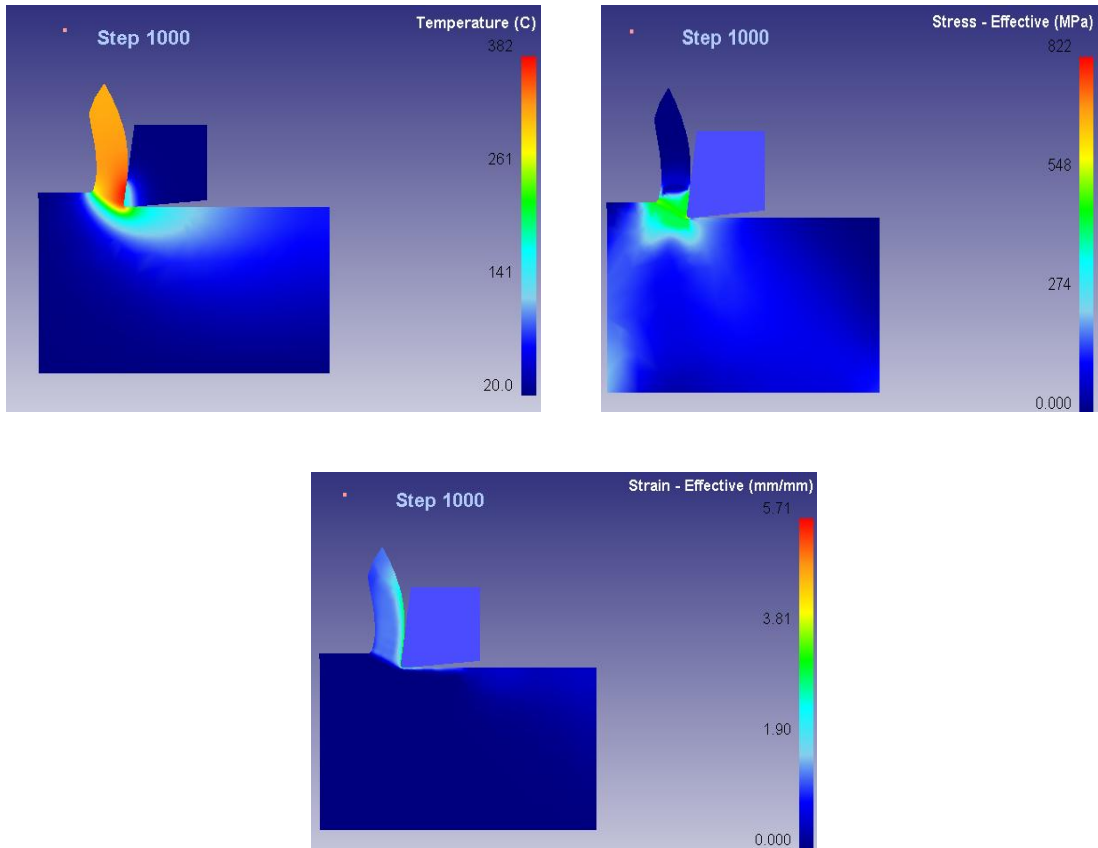
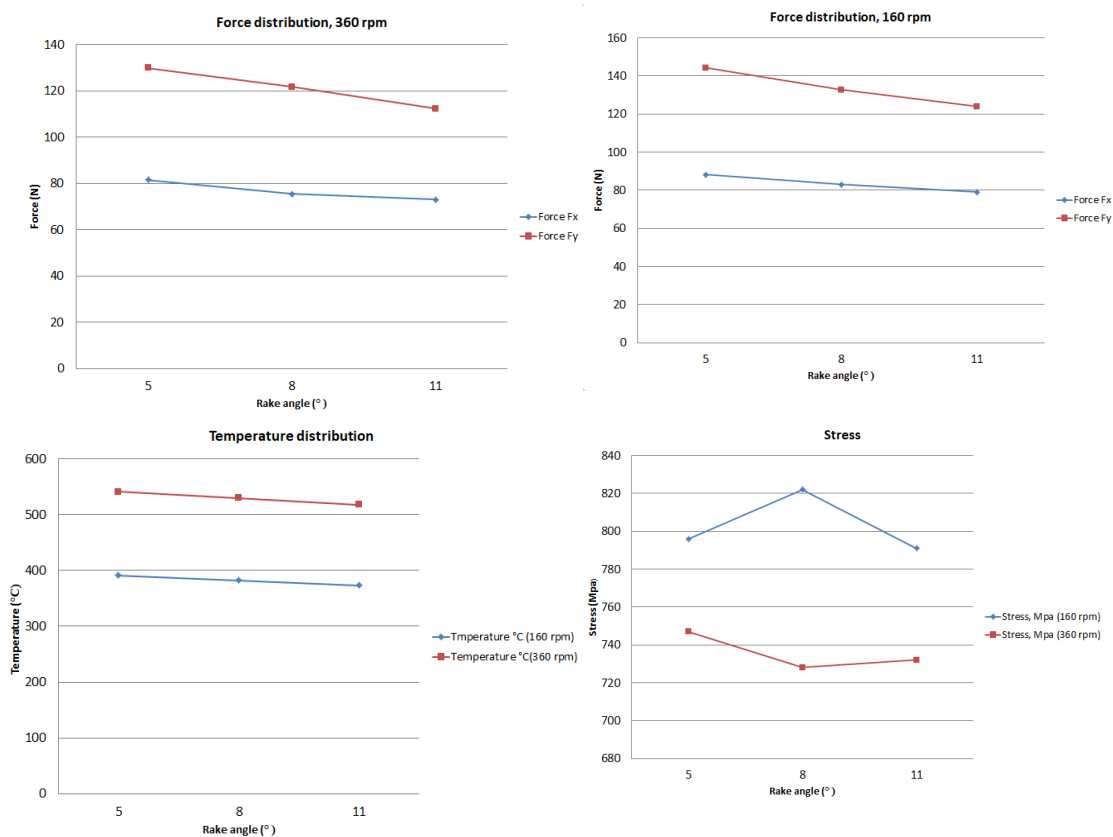


Fig 7: Simulation results of turning aluminium alloy at 160 rpm and 5° rake angle.



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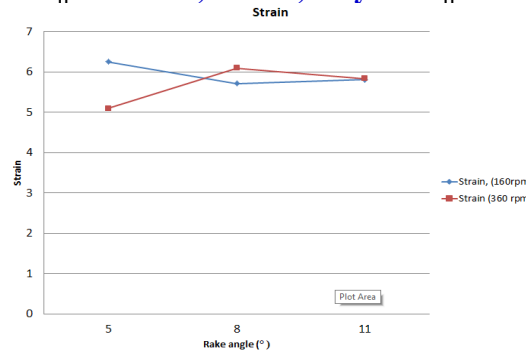


Fig 8: Graphical representation of the simulated results of turning Aluminium alloy

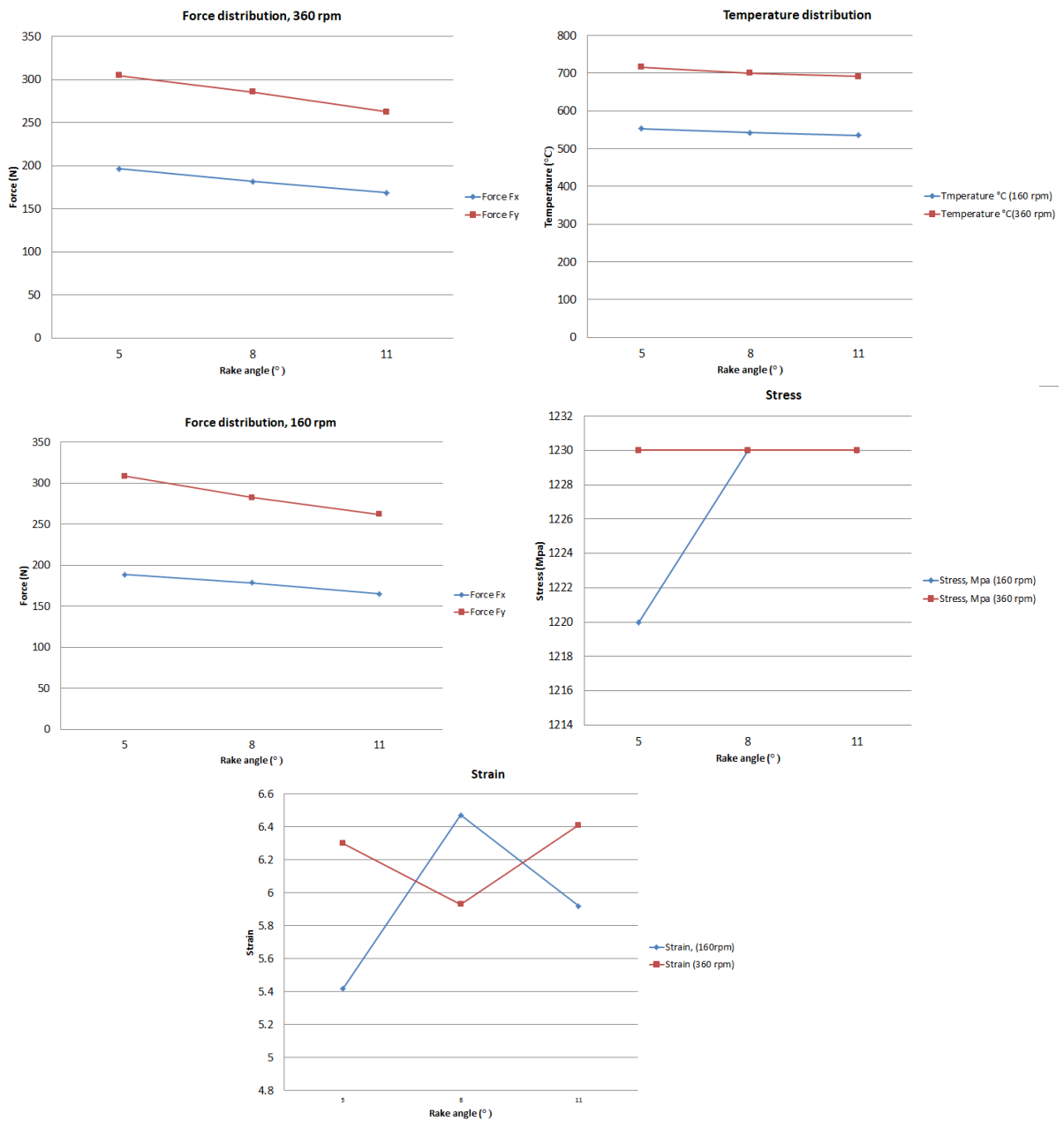


Fig 9: Graphical representation of the simulated results of turning AISI 1020

## V. CONCLUSION

Using FEM based simulation Deform 2D, cutting forces as well as temperature, stress and strain have been predicted for the turning of Aluminium alloy and AISI 1020 using AISI 4340 as cutting tool. From the obtained results following conclusions can be drawn.

- It was observed that feed force ( $F_y$ ) is greater than the tangential force ( $F_x$ ).
- Cutting forces generated is greater for turning Aluminium alloy than that of AISI 1020.
- The cutting forces decreases with increase in cutting speed.
- The cutting force decreases with increase in rake angle.
- Temperature increases with increase in cutting speed and decreases with increase in rake angle.
- Stress value obtained is greater for turning AISI 1020 than the Aluminium alloy.

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