

## 2D FE MODELLING OF MACHINING: A COMPARISON OF DIFFERENT APPROACHES WITH EXPERIMENTS

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### 1 INTRODUCTION

In recent years, finite element analysis has become the main tool for analyzing metal cutting. Although early models involved self-written codes, application of commercial FE packages is preferable for industrial utilization. Recently, some commercial FE codes offer the modelling of cutting. As these codes are based on different algorithms, it is not known if and by what degree results from each of them will differ. The aim of this study is to evaluate these different approaches to the modelling of machining. MSC.Marc, Deform2D and AdvantEdge have been used in the investigation. Experiments have been performed by cutting a tube from the end to verify the simulation results.

### 2 FINITE ELEMENT MODELS

The FE models consist of a rigid tool and a deformable workpiece, for which plane-strain condition was assumed. In MSC.Marc and Deform2D, left and bottom boundaries of the workpiece are totally fixed. AdvantEdge, however, is an automated program and the boundary conditions are hidden. Friction is modelled as constant shear in MSC.Marc and Deform2D, whereas, AdvantEdge uses the Coulomb friction model. The flow curves are represented by tabulated data, which depends on strain, strain rate and temperature<sup>1</sup>. In addition, MSC.Marc does not extrapolate and evaluates the flow stress at the limit of the available data range, whereas Deform2D extrapolates using the last two data points. Thirdwave AdvantEdge uses an analytical equation<sup>2</sup> for material characterization. In MSC.Marc and Thirdwave AdvantEdge, chip separation is achieved by continuous remeshing<sup>3</sup>. In Deform2D, on the other hand, element erase<sup>4</sup>, based on normalized Cockroft-Latham damage criterion, has been used for separation. For thermal solution, the heat is generated due to plastic work in the cutting zone and friction at the tool chip interface. At the same time, workpiece loses heat to the environment due to convection and to tool due to conduction.

### 3 COMPARISON OF RESULTS

Table 1 shows the experimental results of chip thickness and shear angle, where  $\gamma$  is the rake angle,  $f$  is the feed rate,  $t_c$  is the chip thickness,  $\phi$  is the shear angle, which is calculated from the measured chip thicknesses. In all experiments, cutting speed is 125 rev/min.

$\gamma$	$20^\circ$		$25^\circ$	
$f$ (mm/rev)	$t_c$ (mm)	$\phi$	$t_c$ (mm)	$\phi$
0.05	0.10	29.54°	0.12	24.62°
0.1	0.27	21.73°	0.21	28.24°

Table 1: Experimental results of chip geometry parameters.

$\gamma$	20		25		20		25		20		25	
$f$ (mm/rev)	0.05	0.1	0.05	0.1	0.05	0.1	0.05	0.1	0.05	0.1	0.05	0.1
$m=0.2$	0.08	0.16	0.07	0.15	31.62	30.77	34.83	33.63	37.65	37.20	40.60	40.07
$m=0.4$	0.09	0.18	0.08	0.18	28.01	30.97	32.39	29.01	32.66	32.45	36.22	34.32
$m=0.7$	0.09	0.22	0.11	0.22	28.45	25.61	27.73	27.39	32.45	26.83	28.38	27.68
	$t_c$ (mm)				$\phi$ (Strain Rate)				$\phi$ (Chip Thickness)			

Table 2: Chip geometry results obtained by MSC.Marc

$\gamma$	20		25		20		25		20		25	
$f$ (mm/rev)	0.05	0.1	0.05	0.1	0.05	0.1	0.05	0.1	0.05	0.1	0.05	0.1
$m=0.2$	0.07	0.12	-	0.12	32.74	38.74	-	33.42	44.45	48.27	-	51.25
$m=0.4$	0.08	0.13	0.07	0.12	29.60	37.41	29.93	31.36	39.06	43.28	44.65	49.38
$m=0.7$	0.09	0.14	0.08	0.13	33.69	33.69	26.57	29.28	34.68	42.99	37.59	46.26
	$t_c$ (mm)				$\phi$ (Strain Rate)				$\phi$ (Chip Thickness)			

Table 3: Chip geometry results obtained by Deform2D

$\gamma$	20		25		20		25		20		25	
$f$ (mm/rev)	0.05	0.1	0.05	0.1	0.05	0.1	0.05	0.1	0.05	0.1	0.05	0.1
$\mu=0.2$	0.09	0.18	0.09	0.18	27.73	31.04	32.21	32.86	32.92	32.02	34.72	33.93
$\mu=0.4$	0.103	0.211	0.10	0.20	27.39	26.39	31.18	29.22	28.59	27.97	30.71	30.24
$\mu=0.5$	0.11	0.23	0.10	0.21	27.78	26.15	26.50	30.25	26.82	25.89	29.53	28.35
	$t_c$ (mm)				$\phi$ (Strain Rate)				$\phi$ (Chip Thickness)			

Table 4: Chip geometry results obtained by Thirdwave AdvantEdge.

Table 2 shows the results from MSC.Marc. It can be concluded that for  $m=0.7$ , estimation of chip thickness is the best. Shear angle was found both by plotting the equivalent plastic strain-rate distribution and by calculating from the estimated chip thicknesses. By Deform2D (Table 3), chip thicknesses are estimated again better when the friction factor is 0.7. The shear

angles, calculated from chip thicknesses, are not in agreement with the experiments. In addition, results of Deform2D are not consistent in itself. Table 4 shows the results from Thirdwave AdvantEdge. The results of both chip thickness and shear angle are in very good agreement with the experiments when the friction coefficient is taken as 0.5.

In the view of above results, it can be concluded that the three commercial codes estimate the chip thickness and shear angle satisfactorily if an appropriate friction factor or coefficient is used.

Table 5 shows the effect of friction on cutting and thrust forces. Contrary to the chip geometry variables, cutting forces are estimated better when the friction parameter is small. AdvantEdge predicts higher cutting forces than the other two codes due to Coulomb friction law, which supplies regardless of the magnitude of interface pressure a frictional stress that is proportional to this pressure. However, the pressure is very high, yielding a frictional shear stress, which is even larger than the shear strength of the material. Hence, the supplied frictional stress is not realistic. This is also the reason that AdvantEdge is giving better (bigger) thrust force predictions.

		$\gamma=20^\circ$		$\gamma=25^\circ$	
		$f=0.05$	$f=0.1$	$f=0.05$	$f=0.1$
<b>Experiments</b>		62.4	131.5	58.8	127.9
<b>MSC.Marc</b>	$m=0.1$	64	126	58	125
	$m=0.2$	65	126	60	121
	$m=0.4$	74	142	65	139
	$m=0.7$	90	174	86	171
<b>Deform2D</b>	$m=0.1$	66	125	59	100
	$m=0.2$	63	110	-	100
	$m=0.4$	67	119	68	110
	$m=0.7$	76	136	72	125
<b>Advant-Edge</b>	$\mu=0.2$	110	200	100	185
	$\mu=0.4$	118	215	108	195
	$\mu=0.5$	130	220	120	215

(a)

		$\gamma=20^\circ$		$\gamma=25^\circ$	
		$f=0.05$	$f=0.1$	$f=0.05$	$f=0.1$
<b>Experiments</b>		55.2	65	49.7	57
<b>MSC.Marc</b>	$m=0.1$	-13	-24	-16	-39
	$m=0.2$	-10	-16	-14	-26
	$m=0.4$	-4	-5	-9	-5
	$m=0.7$	12	28	9	13
<b>Deform2D</b>	$m=0.1$	-23	-42	-25	-45
	$m=0.2$	-22	-31	-	-38
	$m=0.4$	-14	-24	-15	-32
	$m=0.7$	-6	-10	-8	-21
<b>Advant-Edge</b>	$\mu=0.2$	18	10	15	5
	$\mu=0.4$	26	30	20	20
	$\mu=0.5$	35	45	30	32

(b)

Table 5: Comparison of Cutting (a) and Thrust (b) Force Results.

In the results of MSC.Marc and Deform2D, for small friction factors the tool appears to be drawn into the workpiece (thrust force is negative). The reason is that, for small friction parameters, the vertical component of normal force exceeds the normal component of friction force; hence the tool is pushed into the workpiece.

#### 4. CONCLUSIONS

This study reveals the effects of friction, chip separation and material data in the simulation of orthogonal cutting. Friction parameter affects the simulation results drastically but tuning this parameter yield good agreement only for some variables in the range. A smaller friction parameter leads to good results for cutting force, whereas other variables (such as thrust force, shear angle) are computed more accurately with larger friction parameters. Therefore, the accuracy of a simulation must be assessed by examining all predictable process parameters. The plain Coulomb friction model is not appropriate for machining purposes since it supplies an unrealistic frictional stress.

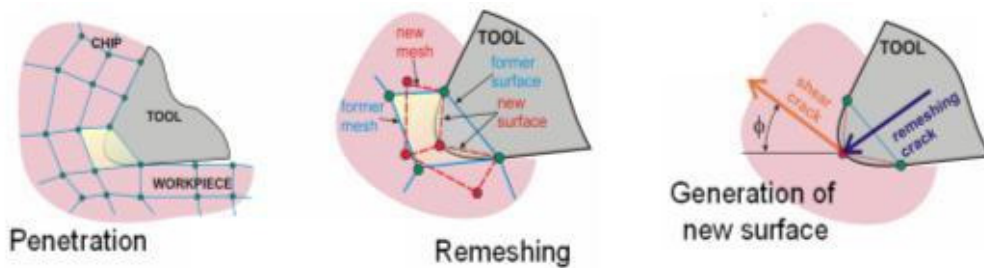


Figure 1: Crack generation during a remeshing step.

Although separation by remeshing gives better results, it is based on the misconception of crack generation in the material at the tool tip (Figure 1). After the penetration of tool into the material, a new mesh is defined with a new surface, which is bigger than the former surface with a constant volume. This is only possible by introducing a crack, which is independent from element size. In addition, the direction of this crack is not in the direction of shearing.

Despite the extrapolation of flow curves by completely different procedures, no significant effect has been observed on the results. This may be due to the simultaneous effect of hardening due to high strain rates and softening due to the high temperatures. It should also be noted that none of the well known shear angle relationships are material dependent; hence the real effect of material behaviour can only be seen in the parameters such as temperatures, forces.

#### 5. REFERENCES

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