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Analytical Investigation of Rake Contact, Cutting Forces and Temperature in Turning

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Abstract-* This project presents the application of analytical investigation of cutting tool geometries on the effective stress and temperature distribution in turning AISI 4340 steel. The tool geometries studied under various rake (α) angles of -5° 0, and 5°respectively. The effect of various machining parameters like cutting speed (100m/min to 300m/min) and feed rate (0.1mm/rev, 0.3mm/rev .6mm/rev and .8mm/rev) were also investigated. Nose radius (Rn) and depth of cut were kept constant at 0.75mm and 4mm respectively. Finite element methods were used to model the effect different material cutting tools and finite element analysis (FEA) to study the stress distribution. The results include stress and temperature distribution through the primary shear zone. Determination of the maximum temperature during machining process and its distribution along the rake surface is of much importance as it influences the tool life as well as the quality of machined part .The shear energy is created in the primary zone, where the main plastic deformation takes place, second at the chip tool interface zone where secondary plastic deformation takes place due to the friction between the heated chip and the tool takes place and the third zone where heat is generated at the work tool interface i.e., at the flanks where frictional rubbing takes place. Different rake angles i.e. from negative to positive angles are considered and modeled in PRO-E and analyzed in ansys (Coupled analysis- Structural and thermal). Numerous methods have been generated to approach the problem such as experimental, analytical and numerical analysis. In addition temperature measurement techniques used in metal cutting have been reviewed.

***Index Terms*— finite element method (fem), Pro-E, couple field analysis, AISI 4340 steel.**

I. INTRODUCTION

Turning process is a common machining process to produce cylindrical shape parts. In metal cutting operation, the position of the cutting tool is important based on which the cutting operation is classified as orthogonal cutting? Orthogonal cutting is also known as two dimensional metal cutting in which the cutting edge is normal to the work piece. In turning process the work piece material is rotated and the cutting tool will travel, removes a surface layer (chip) of the work piece material, producing three cutting forces components, i.e. the tangential force (Fy), which acts on the cutting speed direction, the feed force (Fx), which acts on the feed direction and the radial force (Fz), which acts on the direction normal to the cutting speed. In orthogonal cutting no force exists in direction perpendicular to relative motion between tool and work piece. It was observed that the cutting forces are directly depended on the cutting parameters i.e. cutting speed, feed rate, depth of cut, tool material, and geometry and work piece material type.

A. *CHIP FORMATION*

Depending up on the tool geometry, cutting conditions, and work material, a large variety of chip shapes and sizes are produced during different machining operations.

However there are three types of chips occur:

1. Discontinuous chips 2. Continuous chips 3. Continuous chip with built-up edge (BUE)

Fig.1: Principal components and movements of a typical lathe LZ350

SPEED(rpm)	FEED(mm/rev)	DEPTH OF CUT(mm)
45 – 2000	0.017 – 1.096	0.1 – 12

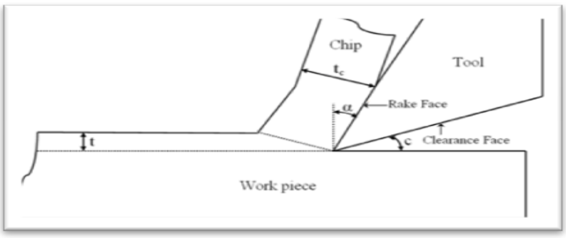

Fig.2: Variables in orthogonal cutting

II. INTRODUCTION TO COMPONENT

The basic carbides for production of common types of carbides for machining are tungsten carbide (WC) and titanium carbide (TiC), the bonding metal is cobalt (Co). As the other compounds the following are the most used: tantalum carbide (TaC), niobium carbide (NiC) and chromium carbide (Cr3C2). Uncoated carbides are divided into three groups: K-grade, P-grade and M-grade. According to the ISO standards, K-grade is a category that includes carbide cutting tools best suited for machining cast

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irons and nonferrous metals and alloys; M- grade is a category that includes carbide cutting tools best suited for machining ductile irons, harder steels, stainless steels, and high-temperature alloys; P-grade is a category that includes carbide cutting tools best suited for machining a variety of steels. Coated carbides are produced in the following way: the base made from common carbide (K-grade, M-grade, or P-grade) is coated with a material with high hardness and excellent abrasion resistance.

A. CUTTING TOOL GEOMENTRY

When the tool is engaged, cutting takes place mainly over the side cutting edge. The corner (or nose) and a small portion of the end cutting edge are also involved in the cutting. The rake face may be inclined with respect to the base. The angle of inclination measured in a plane perpendicular to the base and parallel to the length of the tool is called the back rack angle.

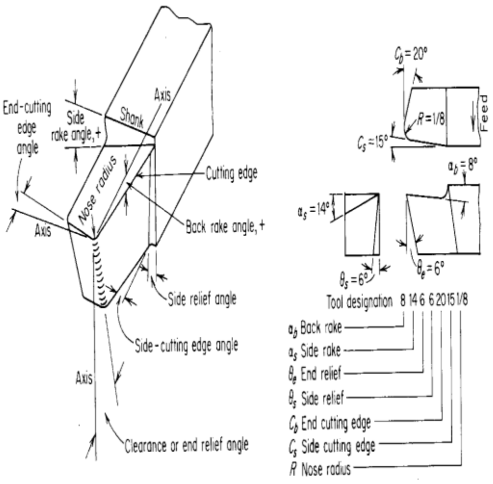

Fig 3. American System of Specifying Tool Angles

Tool signature (Designation)

Back rake angle (α_b): 8°
Side rake angle (α_s): 10°
End relief (θ_e): 6°
Side relief (θ_s): 6°
End cutting edge (γ_e): 12°
Side cutting edge (γ_s): 30°

CHEMICAL COMPOSITION OF CARBIDE P20 in (%)

Wc	TiC	Co
79	**15**	**6**

Thermal and mechanical properties of UN COATED CARBIDE – P(20)

Thermal conductivity (N/sec k)	0.0515
specific heat(j/kg/k)	1.72
density(kg/mm)	0.000008
Poisson’s ratio	0.3
elastic modulus(N/mm^2)	2.6e5

DIMENSIONS

Solid bar of AISI 4340 steel with 50 mm diameter, 152mm long and of 45 HRC is used as work piece.
The chemical composition of AISI 4340 steel in percentage by weight

C	Si	Mn	P	S	Cr	Ni	Mo	Fe
.382	.228	.609	.026	.022	.995	1.514	.226	95.998

III. INTRODUTION TO MODELING SOFTWARE

A. Geometric modeling

The **feature-based parametric modeling** technique enables the designer to incorporate the original **design intent** into the construction of the model. The word ***parametric*** means the geometric definitions of the design, such as dimensions, can be varied at any time in the design process. Parametric modeling is accomplished by identifying and creating the key features of the design with the aid of computer software. The design variables, described in the sketches and features, can be used to quickly modify/update the design.

In Pro/ENGINEER, the parametric part modeling process involves the following steps:

1. Set up Units and Basic Datum Geometry.
2. Determine the type of the base feature, the first solid feature, of the design.
Note: that *Extrude*, *Revolve*, or *Sweep* operations are the most common types of base features.
3. Create a rough two-dimensional sketch of the basic shape of the base feature of the design.
4. Apply/modify constraints and dimensions to the two-dimensional sketch.
5. Transform the two-dimensional parametric sketch into a 3D feature.
6. Add additional parametric features by identifying feature relations and complete the design.
7. Perform analyses/simulations, such as finite element analysis (FEA) or cutter path generation (CNC), on the computer model and refine the design as needed.
8. Document the design by creating the desired 2D/3D drawings

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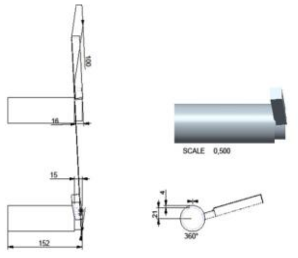

Fig.4: Assembly modeling

2. FEA SOFTWARE – ANSYS

ANSYS has evolved into multipurpose design analysis software program, recognized around the world for its many capabilities. Today the program is extremely powerful and easy to use. Each release hosts new and enhanced capabilities that make the program more flexible, more usable and faster. In this way ANSYS helps engineers meet the pressures and demands modern product development environment.

Analysis types available

1. Structural static analysis.
2. Structural dynamic analysis.
3. Structural buckling analysis.
   - Linear buckling
   - Non linear buckling
4. Structural non linearities
5. Static and dynamic kinematics analysis.
6. Thermal analysis.
7. Electromagnetic field analysis.
8. Electric field analysis
9. Fluid flow analysis
   - Computational fluid dynamics
   - Pipe flow
10. Coupled-field analysis
11. Piezoelectric analysis.

Importing PRO/E to Ansys

The Initial Graphics Exchange Specification (IGES) is a vendor neutral standard format used to exchange geometric models between various CAD and CAE systems. ANSYS's IGES import capability is among the most robust in the industry. Moreover, because the filter can import partial files, you can generally import at least some portion of your model. ANSYS provides the following two options for importing IGES files:

- DEFAULT-This option uses an enhanced geometry database and should, in almost all cases, be your choice. The option was designed to convert IGES files, if possible, without user intervention. The conversion includes automatic merging and the creation of volumes to prepare the models for meshing. If the DEFAULT option encounters problems translating the IGES file, ANSYS will alert you to this and activate a suite of enhanced topological and geometric tools designed specifically for interactive repair of imported models.
- ALTERNATE-This option uses the standard ANSYS geometry database, and is provided largely for backward compatibility with the previous RV52 import option. Occasionally, ANSYS will be unable to translate an IGES model using the DEFAULT option and you'll be instructed to try to ALTERNATE option. The ALTERNATE option has no capabilities for automatically creating volumes and models imported through this translator will require manual repair. However, the enhanced set of topological or geometric repair tools is not available for models imported through this translator; you must use the standard PREP7 geometry tools to repair your model.

CALCULATIONS

(AT V=100, F=.1, α= -5)

Calculating the shear angle, the cutting force component and resultant force on the tool using Merchant's Model for Orthogonal Cutting By the depth of feeds of cutting tool

Depth of feed f=.25mm

Rake angle of tool =**-5°**

Width of chip thickness **b=2mm**

Chip thickness ratio r_t=0.1

For tool steels yield stress K=472N/mm^2

UN cut chip thickness is calculated from

t=0.14

V=100, n=636

The shear angle $\emptyset$ is determined as:

Tan $\emptyset$ = [$r_t$cosα /1- r_t sinα]

=0.1cos(-5)/1-0.1sin(-5)

= $\tan^{-1}$ [0.65]

=33

Shear force along the shear plane

F_s =t.b.K/sin$\emptyset$N/mm^2

= 0.14*2*472/sin (33)

= 242

Result force

R= F_s/cos$\emptyset + \beta - \propto$

Here β is friction angle is calculated using lee & Shaffer's solution

$\beta = \quad 45 + \alpha - \emptyset$ =7

R=242/cos($\emptyset + \beta - \propto$)

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S.no	V(speed) m/min	Feed, F	Rake ∝	DOC	Force (N)	TEMPERATURE Work piece/Tool(c)	
1	**100**	**.1**	**-5**	**4**	**334**	**143**	**90**
2	100	.1	0	4	323	131	139
3	100	.1	5	4	316	122	187
4	150	.3	-5	4	874	138	201
5	**150**	**.3**	**0**	**4**	**795**	**115**	**449**
6	150	.3	5	4	740	106	467
7	200	.6	-5	4	1397	112	299
8	200	.6	0	4	1270	94	218
9	**200**	**.6**	**5**	**4**	**1248**	**91**	**820**
10	300	.8	-5	4	1977	82	749

=342N

Cutting force components

F_n=R [cos ($\beta - \alpha$)]N/mm^2

=334

Ft=71 (THRUST FORCE)

FRICTION FORCE

Ff=138

SHEAR-PLANE TEMPERATURE

Shear strian, γ_s= Tan(33)+cot(33) = 1.9

Chip Velocity Vf= 100*(SIN(33)/COS(33+5)) =69 m/min

SHEAR Velocity = 100*(SIN(90+5)/COS(33+5)=126 m/min

$$R = \frac{1}{1+1.328\sqrt{\dfrac{K'\gamma}{V_c t_u}}}$$

R= .58

The rate at which shear energy is expended along the shear plane is

S.no	V(m/min)	Feed Mm/rev	Rake α	Force Fc	Experimental Fc	Temp (c)	Experimntl (c)
1	100	.1	-5	334	330	308	512
2	150	.3	0	795	780	639	743
3	200	.6	5	1248	1214	986	1015

$$P_s = F_s V_s$$

The rate shear energy is expanded per unit area

Ts = ((1-.5)*334*126)/(3.8*.14*2*100) (from above formulae) = 197c

T_o is ambient temperature may be considered from 25-75 Celsius

TOOL-FACE TEMPERATURE

A=1.6 (from above formulae)

L=.35

l=.3

R'=.4

$$\Delta T_f = \frac{0.75 R' E_f (1/2)}{k\sqrt{L}}$$

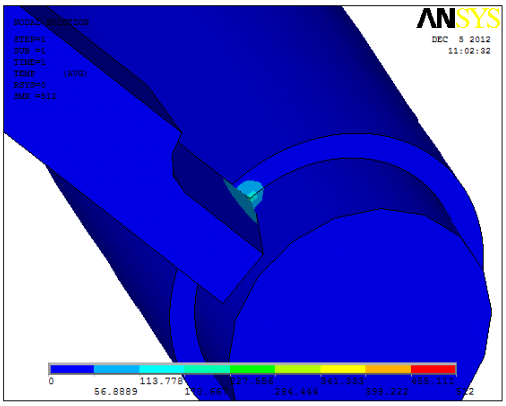
= 89

$T_c = \Delta T_s + \Delta T_f + T_{o}$ = 198+89+75= 362 C

IV. RESULTS

The result of the simulations conducted on the tool rake angles and feed of tool. Thus, the results represent the highest possible stress and temperature on tool. The results obtained for maximum deflection at different cutting parameters are The permissible deflection ranges from 0.025 mm for finish cuts to 0.9 mm for rough cuts. Considering as a cantilever

(AT V=100, F=.1, α= -5)



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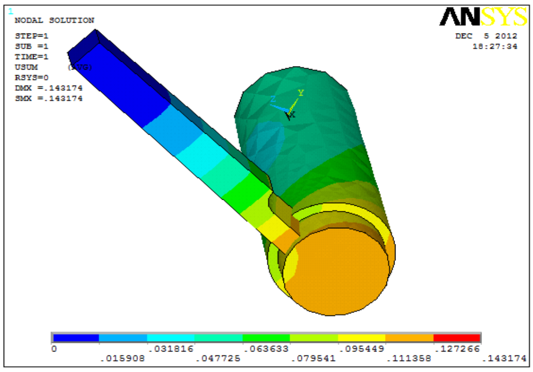
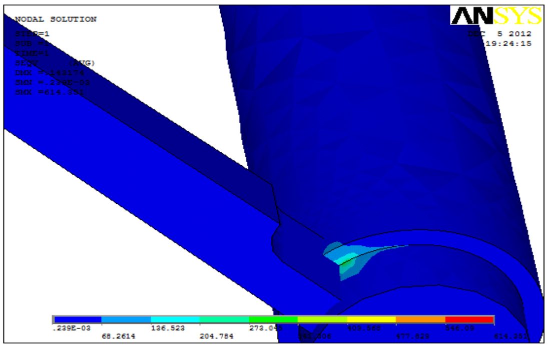
DEFORMED SHAPE

NODAL DISPLACEMENT



VON MISES



V. CONCLUSION

The cutting forces calculated theoretically based on available formulae and verified with Ansys software FEA Analysis. The stresses which are calculated at the tool-tip and rake faces are verified in Ansys. Based on theoretical and Ansys analysis the following recommendations are concluded. In this project a total of 10 experiments were carried on to find the effect of feed rate and rake angles on the cutting forces during orthogonal turning of AISI 4340 steel using P20 carbide cutting tool. From the results of this work the following conclusions can be drawn.

1. The cutting forces are increased in negative rake angle (-5) and decreased in positive rake angles i.e. 0 and 5

2. With increase in speed and feed the forces and temperatures are increased.

3. The stresses due to forces and thermal obtained for the given parameters (i.e. 100 to 200m/min)are1701,4050,6359 Mpa for forces and 1421,5475,5792Mpa for thermal are within the yield stress i.e. 8100Mpa

4. With FEM simulation it is possible to measure stresses on rake face at cutting tool and tool-work piece interface.

5. Comparison between analytical and experimental cutting forces and temperatures are good i.e.

10 to 15% variation for forces

20o 30% variation for temperature

6. At cutting speed 100, 150, 200 and 300m/min as per Taylor's principle the Tool Life is estimated to be 25, 11, 6.3 and 2.7 min

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