Research Paper Engineering

Simulation of Cutting Stresses and Temperatures on tool geometry at the onset of Turning operation by Finite Element Method

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ABSTRACT

Finite Element Method provide insight into the process of manufacturing design. Tool design is analysis is conducted through simulation before real object is made. The stresses and temperatures acting on tool geometry when contact with different material is evaluated. The stresses and temperatures acting on tool tip at the onset of machining is predicted

Keywords: Finite element method, tool geometry, stresses, temperatures.

I. Introduction

Machining is one of the most widely used production technique in industry for converting preformed blocks of metal into desired shapes with surface quality and dimensional accuracy. These shaping operations are done in forms of metal chips.

Metal cutting studies are as old as over 100 years. Early research in metal cutting started with Cocquilhat (1851), who was focused on the work required to remove a given volume of material in drilling. Tresca (1873) firstly attempted to explain how chips are formed. Ernest and Merchant (1941) first developed the simplest and most widely used model for cutting. Lee and Shaffer (1951), Kobayashi and Thomsen (1962) contributed to study of Ernest and Merchant. Oxley and Welsh (1963) introduced the first parallel-sided shear zone model of chip formation for a predictive machining theory. Most widely used text books are written by Armerago (1969), Boothroyd (1981), Shaw (1984) and Trent (2000). More general introductory knowledge can be found at text books written by Kalpakjian, et al. (2006), and DeGarmo, et al. (1997).

The experimental approach to study machining process is expensive and time consuming especially when a wide range of parameters included like tool geometry, materials, cutting conditions and so on. Because of these difficulties alternative approaches developed as mathematical simulations where numerical methods are used. Among these numerical methods, finite element method is proved to be useful and widely used.

Finite element method is basically defined as dividing a continuum system to small elements, describes element properties as matrices and assembles them to reach a system of equations whose solutions give the behavior of the total system.

Finite element method has a great use in modelling orthogonal (2D) and oblique (3D) metal cutting. Klamecki (1973) developed one of the first finite element models for metal cutting processes by using an updated Lagrangian elasto-plastic three dimensional model which was limited to the initial stages of chip formation. Usui and Shirakashi (1982) developed the first two dimensional FE orthogonal machining simulation by using a special method of computation called the iterative convergence method to obtain solutions for steady state cutting. Iwata, et al. (1984) developed a method of numerical modelling for plane strain orthogonal cutting in the steady state on the basis of the rigid-plastic material model where temperature effects were neglected. Strenkowski and Carroll (1985) developed a numerical model for orthogonal cutting without a preformed chip. Their model was based on a large deformation updated Lagrangian code. Komvopoulos and Erpenbeck (1991) introduced a chip separation criterion using the argument of distance tolerance criterion to investigate chip formation. Lin and Lin (1992) introduced a chip separation criterion using the argument of strain energy, and investigated the chip geometry, the residual stresses in the machined surface, the temperature distributions in the chip, the tool and cutting forces. Ceretti (1996) developed a cutting model by deleting elements having reached a critical value of accumulated damage. With the developments of hardware and commercial FE codes, modelling limitations and computational difficulties have been overcome to some extent, so many researchers focused on special topics of metal cutting. Bil, et al. (2004) compared three commercial FE codes used in 2D metal cutting simulations, Msc Marc, Thirdwave Advantedge and Deform 2D, by comparing experimental results with simulation results. Özel (2006) and Filice, et al. (2007) used Deform 2D to investigate the effects of different friction models on cutting results. Attanasio, et al. (2008) included an advanced approach to model heat transfer phenomena at the tool-chip interface in the numerical simulation to investigate tool wear by using Deform 3D. Davim and Maranhao (2009) used Msc Marc to investigate plastic strain and plastic strain rate effects during high speed machining (HSM).

In this study modelling and simulation of orthogonal metal cutting is performed by using finite element method.

II. METHODOLOGY

Tool modeling

In analysis, cutting tool is assumed to be a rigid body. Geometric variables of the tools are given in American system of specifying tool angles. The tool models are imported from pro-E to ANSYS in IGES format.

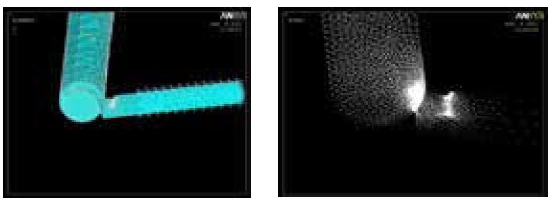
However, the specifying tool angle is not unique. In fact, different countries have developed different systems of tool nomenclature. British, American, German and ISO systems are the better known among them. In order to clearly understand the peculiar feature the tool is described in American system (ASA). 50x50x240 square (HBL). The dimensions of shank and tool length for cutting tools are generally used for single point cutting tools. As per Indian standards (IS): 1983 shank section for turning tools.

ANSYS Stands for Analysis System Product.

Dr. John Swanson founded ANSYS. Inc in 1970 with a vision to commercialize the concept of computer simulated engineering, establishing himself as one of the pioneers of Finite Element Analysis (FEA). It also supports a process-centric approach to design and manufacturing, allowing the users to avoid expensive and time-consuming "built and break" cycles. ANSYS analysis and simulation tools give customers ease-of-use, data compatibility, multi platform support and coupled field multi-physics capabilities.

ANSYS design optimization enables the engineers to reduce the number of costly prototypes, tailor rigidity and flexibility to meet objectives and find the proper balancing geometric modifications.

Competitive companies loom for ways to produce the highest quality product at the lowest cost. ANSYS (FEA) can help significantly by reducing the design and manufacturing costs and by giving engineers added confidence in the products they design. FEA is most effective when used at the conceptual design stage. It is also useful when used later in manufacturing process to verify the final design before prototyping.



In the finite element analysis the basic concept is to analyze the structure, which is an assemblage of discrete pieces called elements, which are connected, together at a finite number of points called Nodes. Loading boundary conditions are then applied to these elements and nodes. A network of these elements is known as Mesh. The figure 1 shows the boundary and loading condition of thermo mechanical model for a single point cutting tool. The tool tip of left to the shank is free to move and right was constrained in X, Y and Z directions.

Combination of materials and cutting tools

The two tool behaviors in this analysis is to study for the machining of materials Mild steel, AISI 1050 and Aluminum with Carbide P(20) and HSS (T100) tools have been considered.

Introduction

The modeling part of metal cutting simulation is very important step to achieve accurate results. In this, details of geometry modeling tool, work piece and cutting system are presented

Tool model 1:

Tool signature 1 - 9° 11° 6° 6° 12° 30° 2;
Tool signature 2 - 8 ° 10°6 °6 °12 °30 °2;
Tool signature 3 - 7 °8 ° 6 ° 6 °12 °20 °2.

Determining the rake angle from above designation using American system:

Theoretical numerical calculation based on American system Obliquity of tool: Tan$I$ = cos$\gamma_s$tanα_b - sin$\gamma_s$tanα_s = cos30 tan 9- sin30 tan11; I=2.28.

Veocityrake:tanα_v=tan$\alpha_s$cosγ_s+tan$\alpha_b$sinγ_s=tan11cos30+tan9 sin30 ; α_v=12.5

Normal rake angle α_n:Tan α_n=tan$I$cosα_v= tan12.5xcos1.92 α_n =13. 8°

Similar calculations for tool signature 2 , the corresponding angle is 12.8⁰ and for tool signature 3 is 9.8⁰ respectively.

Cutting forces developed for different materials:Mild steel, Aluminimum, AISI 1050 steel are as follows: Firstly the computing the forces on AISI 1050 material with cutting parameters: Depth of feed f=0.4 mm, Rake angle of tool =13. 8°,width of chip thickness b=2mm,chip thickness ratio r_t=0.4, Yield stress for AISI 1045 K=420N/mm² ,Uncut chip thickness calculated from t = fcos$\tan\alpha_s\cos\gamma_s+\tan\alpha_b\sin\gamma_s$ γ_s= 0.34.The shear angle □ is determined as: Tan□ = [r_t cosα /1- r_t sin α] = 0.4 cos13.8/1-0.4sin13.8=tan⁻¹(□) (=0.42) =23.23⁰ Shear force along the shear plane: F_s= t.b.K/sin□N/mm² = 0.34x2x420/sin (23.23) = 724.68NResult force R= F_s/cos(□+β- α) $\phi+\beta-\alpha$; β=45+α-□ = 34.3N R=724.68/cos(23.23+43.03-13.8)= 986.86N/mm² Cutting force components F_n=R [cos(β-α)]= 961.98N/mm² Figure 1.(left) Node generation and (right) boundary condition for tool-work contact For the given tool materials (Carbide and HSS) the cuttinging forces(N) and resultant forces(N) for AISI 1045 at rake angle 13.8⁰, for is 950.98 and 1024, 12.48⁰ is 953.88 and 1027.78, for 9.7⁰ 1034.66 and 1116.71 respectively. Similarly for Mild steel at above three different rake angles is 559.57 and 597.56, 559.04 and 611, and 569.04 and 611. Also forces (N) for Aluminimum 548.91 and 566.89, 479.01 and 488.2, 521 and 493.29.

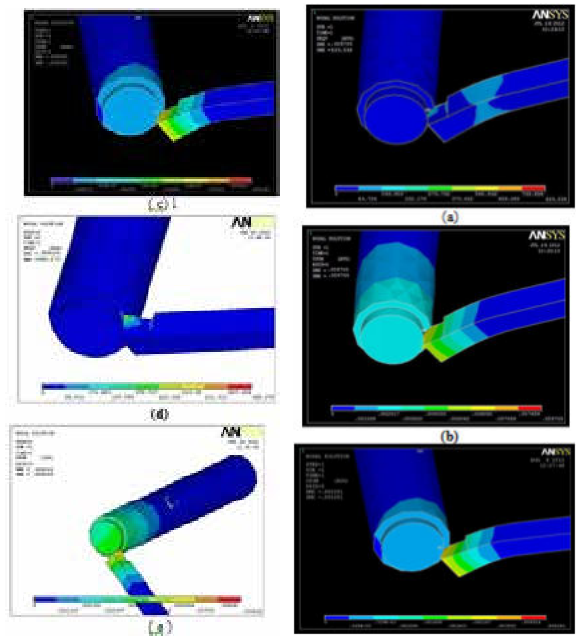
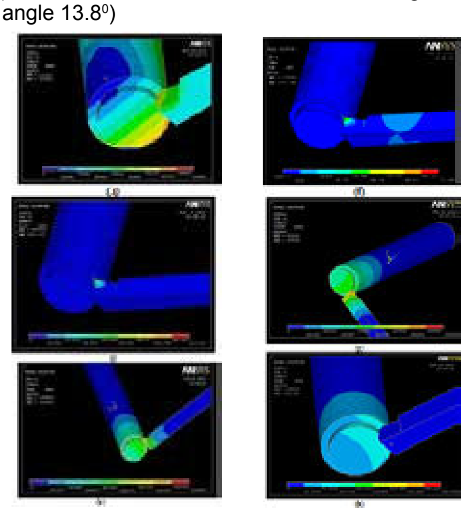


Fig 2. Shows Temperature - stress distribution for tool signature 1 for figures (a)-(b) for AISI 1050,(c)-(d) for mild steel (e)-(f) for Aluminium with carbide tool with Tool signature-1 (ie rake angle 13.8⁰)



Figures 3 (g)-(h),(i)-(j),(k)-(l) for AISI 1050,Mild steel and Aluminum indicate temperatures-stress with tool signature 1 for HSS tool with with Tool signature-1 (ie rake angle 13.8^0)

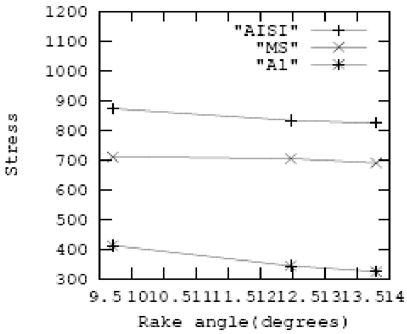


Figure 4. Stress on carbide tool,

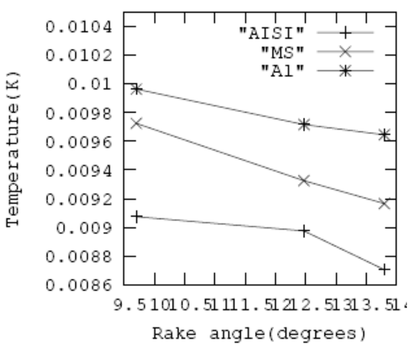


Figure 5: Temperature on Carbide tool.

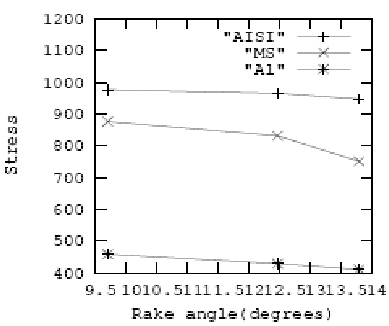


Figure 6. Stresses on HSS tool.

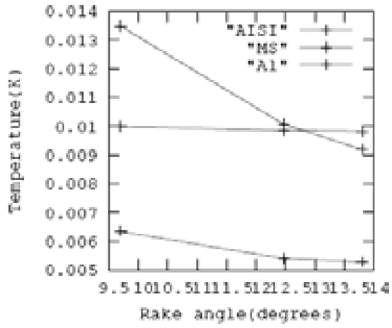


Figure 7 Temperature on HSS tool

Results and Discussions

The single point cutting tools are most universally used to remove metal from the blanks under controlled conditions. The efficiency of material removal from the blank is a function of relative hardness of work piece and tool materials, sharpness of the tool geometry, cutting forces applied etc.

The main aim of this work is developed model is able to predict stress distributions, cutting forces as well as temperature.

In this study, the behavior of materials on tool rake in metal cutting operations is analyzed using a thermo mechanical cutting process model Metal cutting is performed on three different material AISI 1045, Mild steel, aluminum with tool materials Carbide and HSS and able to predict stress distributions, cutting forces as well as temperature

The cutting tool is one of the most important elements in any machining process, for economic machining of components to prescribed sizes and shapes with desired accuracy and surface integrity. In the following part of the study, it is seen that rake angle of the tool has a strong influence on deformation, cutting temperature, contact length, steady state tool temperature and tool stress. Maximum stress on the tool tends to move to flank surface which may cause flank wear. It is also observed that the maximum stresses are more concentrated in the tool tip which may cause plastic deformation of tool edge such as cracking.

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