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Finite Element Analysis on Temperature Distribution of Turning Process

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ABSTRACT: *The aim of this study is to create a finite element analysis simulation model in order to obtain solutions of the cutting forces, specific cutting energy and adequate temperatures occurring at different points through the chip/tool contact region and the coating/substrate boundary for a range of cutting tool materials and defined cutting conditions. Interfacial temperature in machining plays a major role in tool wear and can also result in modifications to the properties of the work piece and tool materials. As there is a general move towards dry machining, for environmental reasons, it is increasingly important to understand how machining temperature are affected by the process variables involved (cutting speed, feed rate, tool geometry, etc.) and by other factors such as tool wear.*

Keywords: *turning process; FEA; data measurements*

I. INTRODUCTION

The turning process is used widely in industry and has countless applications. Traditionally, the process has been used to reduce the diameter of cylindrical work piece, or to change a work piece of non-circular cross-section. This is done by rotating the work piece about this of the machine's spindle and removing the work piece material with the cutting tool which is fed in the perpendicular direction. For the past fifty years metal cutting researchers have developed many modeling techniques including analytical techniques, slip-line solutions, empirical approaches and finite element techniques. In recent years, the finite element analysis has particularly become the main tool for simulating metal cutting processes. Finite element analysis are widely used for calculating the stress, strain, strain-rate and temperature distributions in the primary, secondary and tertiary sub-cutting zones. In consequence, temperatures in the tool, chip and workpiece, as well as cutting forces, plastic deformation (shear angles and chip thickness), chip formation and possibly its breaking can be determined faster than using costly and time consuming experiments. In this work, mechanically based models are developed that are able to predict the effect of various process variables on the performance measures of interests such as cutting forces, tool breakages, and surface accuracy.

1.1 The Turning Process

Turning is a very important machining process in which a single-point cutting tool removes material from the surface of a rotating cylindrical work piece. The cutting tool is feed linearly in a direction parallel to the axis of rotation. Turning is carried out on a lathe that provides the power to turn the work piece at a given rotational speed and to feed the cutting tool at a specified rate and depth of cut. Therefore, three cutting parameters, i.e. cutting speed, feed rate, and depth of cut, need to be determined in a turning operation [14].

Two basic models are in focus: orthogonal (two force) models, and oblique (three-force) models. Most machining processes are oblique but the orthogonal model studies are easier to simulate and they can be useful: adequate for understanding the basic mechanics of machining processes [13].

1.2 Finite Element Analysis of Turning Process

Finite element analysis is a most useful and accurate approach for the determination of field variables that is made possible by advancements in computational and processing power of computers and thus it is almost used for all the computer aided design methodologies in recent years. Applications range from deformation and stress analysis to field analysis of heat flux, fluid flow, magnetic flux, seepage and other flow problem. In this method of analysis, a complex region defining a continuum is discredited into simple geometric shapes called finite elements. The Present work is also based on the application of finite element for thermal analysis of single point cutting tool for turning operation. Once the model developed for determination of temperature field for single point cutting tool, it can also be implemented for other multipoint processes like drilling, milling or grinding also.

In this paper, a finite element code DEFORM-3D and ANSYS (13.0) was also applied to construct a coupled thermo-mechanical finite element model of plane-strain orthogonal metal cutting with continuous chip formation produced by plane-faced uncoated and differently coated carbide tools. The entire cutting process is simulated, i.e. from the initial to the steady state phase. The work piece material of choice, AISI 1040 carbon steel (mild steel), is modeled as thermo elastic-plastic, while the flow stress is considered to be a function of strain, strain-rate and temperature to represent better the real behavior in cutting. Friction between the tool and chip is of Coulomb type with the μ value of 0.5 [1].

1.2.1 Heat generation in machining

Heat generation while machining has significant influence on machining. It can increases tool wear and thereby reducing tool life [12]. It gives rise to thermal softening of cutting tool. It is commonly accepted that both the wear and failure mechanisms which develop in cutting tools are predominantly influenced by temperature and it also results in modification to the properties of work piece and tool material such as hardness. In order to predict the wear and failure characteristics of a tool, it is necessary to quantify the temperatures which develop during the cutting operation.

In machining operations, mechanical work is converted to heat through the plastic deformation involved in chip formation and through friction between the tool and work piece. Figure 1 shows three regions of heat generation in turning; which are, the shear zone, the chip-tool interface and the tool-work piece interface zone [12]:

The shear zone: The shear zone, where the main plastic deformation takes place due to shear energy. This heat raises the temperature of the chip. Part of this heat is carried away by the chip when it moves upward along the tool. Considering a continuous type chip, as the cutting speed increases for a given rate of feed, the chip thickness decreases and less shear energy is required for chip deformation so the chip is heated less from this deformation. About 80-85% of the heat generated in shear zone.

The chip-tool interface zone: The chip-tool interface zone, where secondary plastic deformation due to friction between the heated chip and tool takes place. This causes a further rise in the temperature of the chip. This chip-tool interface contributes 15-20% of heat generated.

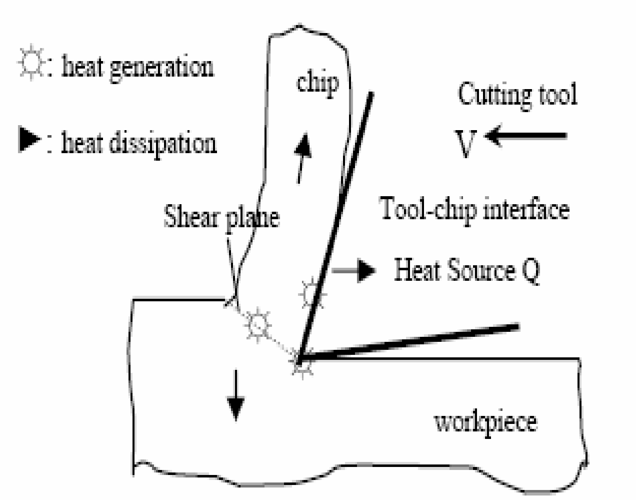

Fig 1: Zones of heat generation & dissipation during the metal cutting process.

The tool-work piece interface zone: The work-tool interface zone 3, at flanks where frictional rubbing occurs. This area contributes 1-3% of heat generated. As the portion of heat that flows into the tool cause very high temperature in vicinity of tool tip which in turn decrease the hardness of the tool material and in extreme case may even cause melting. The wear rate of tool therefore increases, resulting in a decrease in useful life of the tool. It is increasingly important to understand how Machining temperature is affected by the process variable involved which is cutting speed, feed rate, and tool geometry.

1.3. Data Measurement

1.3.1 Temperature Measurement

There are number of methods for measuring the chip tool interface temperature: Tool work thermocouple, Radiation pyrometers, embedded thermocouples, temperature sensitive paints and indirect calorimetric technique [4]. Of all these methods, the tool work thermocouple technique is the most widely used technique for the measurement of the average chip tool interface temperature. The other methods suffer from various disadvantages such as slow response, indirectness, and complications in measurement [4].

The cutting speeds used in experimentation made response times of the temperature measurement devices an important criterion. The temperature measurement devices also had to be robust and have a wide measurement range. K-type thermocouples were thus chosen as one of the temperature measurement devices. Thermocouples (contact temperature measurement device) are the most frequently used temperature transducers. A thermocouple is created when two dissimilar materials touch and the contact point produce a small open-circuit voltage as a function of temperature. Welded tip insulated K-type (chro-mel-alumel) thermocouples were used in these experiments. They have minimum continuous temperature of -200^0 C, a maximum continuous temperature of $+1100^0$ C [3].

The Pyrometers is technical advances have made it possible today to measure not only high temperatures but also temperatures far below freezing point from a distance and without making contact with the object to be measured.

Pyrometer Types:

- Spectral band pyrometers
- Total band pyrometers
- Ratio Pyrometers (2 color pyrometers)
- Disappearing filament optical pyrometer (portable)
- Infrared pyrometer
- Laser pyrometer

We use AME Optical Pyrometers, which work on very sophisticated mechanism. This thermal device detect temperature of an object by reckoning the emitted, reflected and transmitted energy by means of optical sensors & detectors and show temperature reading on display panel. The temperature Range is 300^0 to 1100º C.

II. LITERATURE REVIEW

A Review of literature describes to study of the Temperature distribution of turning process with the help of finite element analysis.

Typical approaches for numerical modeling of metal cutting processes are Lagrangian and Eulerian techniques, as well as a combination of both called an arbitrary Lagrangian–Eulerian formulation [2,10]. It should be noticed that all these methods are mathematically equivalent. The major feature of Lagrangian formulation used in this study is that the mesh is attached to the work piece.

Also, the finite element analysis were performed by Johnson-Cook's constitutive equation with three different sets of material constants (found by the application of several methods) is implemented in the FE model to study the behavior of Ti6Al4V alloy during the machining process in conventional and high speed regimes [8]. Demand for higher productivity and good quality for machining parts has encourage many researchers to study the effects of machining parameters using FEM simulation using either two or three dimensions version [9].

The effect of tool thermal property on cutting forces has not been addressed systemically and analytically. To model the effect of tool thermal property on cutting forces, this study modifies Oxley's predictive machining theory by analytically modeling the thermal behaviors of the primary and the secondary heat sources. Furthermore, to generalize the modeling approach, a modified Johnson–Cook equation is applied in the modified Oxley's approach to represent the work piece material property as a function of strain, strain rate, and temperature [11].

Several experiments have been conducted to determine the amount of heat generated and cutting temperature during machining. Analytical as well as Numerical methods were applied with an objective of calculating the peak and average temperature at shear zone where first, second and tertiary deformation takes place. The method involved analysis of heat conduction for both moving and stationary heat sources. The heat conduction effect too was analyzed where the unknown boundary values of heat flux were obtained from interior heat distribution [7].

D. O'Sullivan, M. Cotterell [3], presented the results the tool chip interface temperature measurement by the tool work thermocouple technique. Tool chip interface temperature is analyzed under a wide range of cutting condition during turning of aluminum alloys grade: 6082-T6 with tungsten carbide tools. The total work done by a cutting tool in removing metal can be determined from the force component on cutting tool. Approximately, all of this work or energy is converted into heat which is dissipated into the chip, tool and workpiece material. And experiment focus on the use of the infrared camera to monitor the process.

L. B. Abhang, M. Hameedullah [4], In this study, the temperature generated on the cutting tool and experimental methods for the measurement of temperatures are reviewed. Special attention has been paid to tool- work thermocouple method and an experimental setup fabricated to measure the temperature on the cutting tool and work piece junction during metal cutting is described. With this method, the average temperature at the tool-chip interface is measured. The output of the thermocouple is in the mill volt range and measured by a digital milli-voltmeter.

S.R. Carvalho, S.M.M. Lima e Silva, A.R. Machadoa, G. Guimaraes [15], The thermal model is obtained by a numerical solution of the transient three-dimensional heat diffusion equation that considers both the tool and the tool holder assembly. To determine the solution equation the finite volume method is used. Changing in the thermal properties with the temperature and heat losses by convection are also considered. Several cutting tests using cemented carbide tools were performed in order to check the model and to verify the influence of the cutting parameters on the temperature field.

Asmaa A. kawi [16], Finite element method is a successful technique to perform analysis to estimate cutting temperatures, a possibility of developing temperature forms adequately representing metal cutting temperature as a Polynomial models of third, fourth and fifth degree with time that give steady state temperature and for the four alloys steel used and different operation conditions. All alloys have a sever increasing temperature with increasing feed rate, while it looks less sharp with increasing cutting speed .Also the ratio of the number of nodes have maximum temperature for any operating conditions and any alloy used with respect to the total number of nodes is less than 1%.

Mofid Mahdi, Liangchi Zhang [17], This study considered the chip breaking and developed a 2D cutting force model with the finite element method. The variation of the cutting force was investigated carefully against both the cutting condition and the anisotropy of the material with the following development: (a) a constitutive model of a homogeneous anisotropic elastic material under plane deformation; (b) a failure model of the work material based on the Tsai Hill criterion; (c) a contact model of the mechanisms of the cutting process. A comparison with experimental measurements showed that the constitutive model leads to a reasonable prediction.

Adeel H. Suhail, N. Ismail, S. V. Wong and N.A. Abdul Jalil [6], the focus of present experimental study is to optimize the cutting parameters using two performance measures, workpiece surface temperature and surface roughness. Optimal cutting parameters for each performance measure were obtained employing Taguchi techniques. The orthogonal array, signal to noise ratio and analysis of variance were employed to study the performance characteristics in turning operation.

H.S. Qi, B. Mills [18], New flow zone model is developed during turning process, based on the concept of the cutting interface, which occurs where the shear strain rate of chip deformation reaches a maximum and not where the speed of the chip is zero. The model is a dynamic model and it explains the dynamic contact behavior between chip and the tool. The model enables changes and accumulation of changes in micro-machining to be related to tool wear and workpiece surface integrity. It will be able to produce information on changes in micro cutting conditions and the effect of change and the accumulation of such change on the tool wear and the surface integrity of the workpiece machined. The new flow zone model is used to interpret the tool wear processes occurring when machining three grades of austenitic stainless steel.

Tugrul Ozel, Taylan Altan [19], It shows a methodology to determine simultaneously (a) the flow stress at high deformation rates and temperatures that are encountered in the cutting zone, and (b) the friction at the chip–tool interface. This information is necessary to simulate high-speed machining using FEA based programs. A flow stress model based on process dependent parameters such as strain, strain-rate and temperature was used together with a friction model based on shear flow stress of the workpiece at the chip–tool interface. High-speed cutting experiments and process simulations were utilized to determine the unknown parameters in flow stress and friction models.

Xiaoping Yang, C. Richard Liu [20], Friction modeling in metal cutting has been recognized as one of the most important and challenging tasks facing researchers engaged in modeling of machining operations. To address this issue from the perspective of predicting machining induced residual stresses, a new stress-based polynomial model of friction behavior in machining is proposed. The feasibility of this methodology is demonstrated by performing finite element analyses. A sensitivity study is performed by comparing the cutting force and residual stress predicted based on this new model with those based on a model using an average coefficient of friction deduced from cutting forces and a model using an average coefficient of friction deduced from stresses.

Finite element Simulations has been successfully applied for modeling plain strain orthogonal metal cutting simulations based on Lagrangian techniques and thermo, mechanically coupled modeling software with adaptive remeshing. Large number of input parameters such as large deformation, high strain rate, temperature effects, tool – chip contact and friction models [7].

Taguchi can conveniently optimize the cutting parameters with several experimental runs well designed. Taguchi parameter design can optimize the performance characteristics through the settings of design parameters and reduce the sensitivity of the system performance to source of variation. On the other hand, it used to identify the most significant variables and interaction effects [6].

A series of experiments was conducted to obtain the surface temperature of the work piece by the aid of the infrared thermometer and surface roughness by the aid of stylus type tester. Taguchi method is being applied in to select the control factors levels (Cutting speed, Feed rate and depth of cut) that minimize the effect of noise factors on the response (surface roughness) and get the relationship between the signal factor (work piece surface temperature) and the response, to come up with the optimal surface roughness value using the rate of change for the response relative to the signal factor [6].

Following are the assumptions made to define how the problem is going to be solved as well as how and where to apply the boundary conditions:-

1. The cutting speed was kept not constant.
2. The width of cut taken was larger than the feed.
3. The cutting velocity vector was perpendicular to cutting edge.
4. Constant friction at tool-chip interaction and tool-work piece interaction.
5. The initial coolant temperature is selected as the room temperature.

Several attempts have been made to develop methods for accurately predicting the effects of machining operations over the past several decades. A common approach for assessing machining performance is tool wear/tool-life. Tool-wear/tool-life is one of the most significant and necessary parameters required for process planning and total machining economics. A review of numerous theoretical and experimental techniques for predictive assessment of tool-wear and tool-life reveals that eight different types of tool-wear/tool-life relationships are commonly being used for dry machining as shown in table,

Table 1: Tool life and Tool wear rate models

Empirical Tool Life Models	**Tool Wear Rate Models**
Taylor's basic equation: $VL^n = C_1$ **(n,C_1 = Constants)**	**Takeyama & Murata's wear model (considering abrasive wear and diffusive wear):** $\frac{dW}{dt} = G(v,f) + D\exp\left(\frac{-E}{RT}\right)$ **(G,D =constants)**
Taylor's extended equation: $L = \frac{C_2}{V^p f^q d^r}$ **(p,q,r,C_2 = constants)**	
Taylor's extended equation: $V = \frac{C_3}{L^m f^p d^q (BHN/200)^r}$ **(m,p,q,r,C_3 = constants)**	**Usui's wear model (considering adhesive wear):** $\frac{dW}{dt} = A\sigma_n V_s \exp\left(\frac{-B}{T}\right)$ **(A,B = Constants)**
Temperature-based equation(known as Hasting's tool life equation): $TL^B = A$ **(A,B =constants)**	

III. CONCLUSION

Based on the review, the following conclusions have been observed:

1. In consequence, the maximum interface temperature exists in the vicinity of the cutting edge i.e. in the first part of the tool-chip contact.
2. Increased cutting speeds (VC) resulted in decreased cutting tool forces and machined surface temperatures.
3. Tool wear resulted in increased cutting tool forces and machined surface temperature.
4. Force has been found to be an important variable in the generation of surface temperature.
5. Thus, it is possible to increase machine utilization and decrease production cost in an automated Manufacturing environment.
6. Increasing the rake angle in positive section caused the decrease of the cutting force. On the other hand, increasing the rake angle in negative section increases the cutting force.
7. The formation of built-up layers in metal cutting processes is very common with a variety of layers formed having different compositions and effectiveness in reducing cutting tool wear.

IV. FUTURE SCOPE

Turning Process is a important machining process in which a single-point cutting tool and cutting inserts removes material from the surface of a rotating cylindrical work piece, so by the finite element analysis on temperature distribution of turning process helps to determine problems were occur in tool and workpiece like plastic deformation, mechanical breakage, cutting edge blunting, brittle fracture and tool wear can reduce and by the considering optimized parameter we can find minimum surface roughness and high surface finish. Also we can increases tool life.

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