A Review on Force Modelling in Machining

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Abstract: **Metal cutting is a complex deformation process where heat is generated in a small cutting zone (Oxley 1989). In this process, material is removed in the form of chips to achieve the desired dimensional accuracy and surface finish. Various factors affect chip formation, such as tool geometry, work piece material properties, tool material properties and cutting conditions. It is a highly non - linear and coupled thermos mechanical process, where the mechanical work is converted into heat through the plastic deformation involved during chip formation and due to the frictional work between work and tool, chip, and work. This review discusses about that how to use Johnson and cook parameters apply to oxley's machining theory.**

Keywords:**chip formation, Oxley's machining theory, cutting tools.**

1.Introduction

Metal cutting is an important phenomenon in the manufacturing industry a variety of products.Metal cutting or machining is the process of producing a workpiece by removing unwanted material from a block of metal, in the form of chips. Metal cutting produces a desired shape, size, and finish on a rough block of workpiece material with the help of sharp tool. There are different types of machining process like turning, milling, drilling, boring, shaping, grinding etc. Machining is most frequently applied to the metals. Different part shape and special geometry features like screw threads, accurate round holes are possible in the machining process. There are two types of cutting process in machining.

1.1 Orthogonal and oblique cutting process

Orthogonal and oblique cutting are the two most fundamental machining types. The analysis of other more complicated machining processes such as milling, drilling etc. can be derived from the study of these two basic processes. The cutting tool in orthogonal cutting has a straight innovative, which is perpendicular to the cutting velocity direction. The forefront engages into the work piece with the depth of cut "t" with both ends extending out of the work piece. In oblique cutting, the straight innovative is inclined with an acute angle (inclination angle) from the direction normal to the cutting velocity.

In industry, most of cutting processes are performed under oblique cutting conditions. However, the simplicity and adequacy of the orthogonal metal cutting in describing the mechanics of machining make it favourable to researchers during the investigation of chip formation processes. Furthermore, the orthogonal cutting is experimentally advantageous and able to produce a reasonably good approximation of material responses to metal cutting operation under various conditions.

1.2 Forces in Orthogonal Cutting

The orthogonal cutting model is based on plane strain assumptions. The forces acting in an orthogonal cutting process. The geometric relations yield friction and normal forces on the rake face of the tool based on the measured cutting and thrust forces and the tool rake angle.

$F_N = Fc \cos \alpha - Ft \sin \alpha$ (1.1)

$F_f = Fc \sin \alpha + Ft \cos \alpha$ (1.2)

1.3 Model of the metal cutting process

The objective of metal-cutting studies is to establish a predictive theory that would enable the machining performance to be evaluated without the need for extensive cutting experiments. The metal cutting process has been analyzed by various methods over the years to enable better understanding of the complex deformation process and develop methods to predict the cutting forces, analyze chip formation and study the distribution of stress, strain, strain rate, temperature.

Different types of models were used in the literature in order to estimate these cutting coefficients which can be classified into four major categories:

- Empirical Models
- Analytical Models
- Mechanistic Models
- Finite element analysis Models

1.3.1 Empirical Models

The empirical models focus on deriving the cutting coefficients by using steady state cutting tests, dynamic cutting tests, and time-series methods. Kienzel developed an empirical model based on large number of experiments. The limitation of experiments is its empirical nature that requires change every time any of the cutting conditions or geometry or material is changed. Furthermore, experiments are costly.

1.3.2 Analytical Models

For analytical models, Merchant, Lee and Shaffer used a single shear plane theory. Whereas Oxley et al. Used the shear zone theory. Their approaches were to model the physical mechanisms that take place during the cutting process to predict the cutting forces. However, the main limitation of the analytical models is the high strain rates, high temperature gradients, and combined elastic and plastic deformations. Consequently, most of analytical models are unable to predict the cutting forces accurately.

1.3.3 Mechanistic Models

The main concept behind the mechanistic methods is that the cutting forces are proportional to the uncut chip area. The constant of proportionality is the cutting coefficients, which depends on the cutting conditions, cutting geometry, and material properties.

1.3.4 Finite Element Analysis Models

Using finite elements model to predict cutting forces and cutting coefficients has been widely used by researchers since early 70's. This type of modelling is very promising due to the great breakthroughs in software and hardware needed for such simulations. Three different types of finite element formulations are commonly used in FEM cutting models:

- Lagrangian formulation
- Eulerian formulation
- Arbitary-Lagrangian Eulerian (ALE) formulation

Each of them has its own advantages and limitation, and depending on the cutting process simulated and the expected results one of them is chosen depending on these advantages and limitations.

2. LITERATURE REVIEW

A literature review is a text written by someone to consider the critical points of current knowledge including substantive findings, as well as theoretical and methodological contribution to a topic. Literature reviews are secondary sources and as such, do not report any new or original experimental work. Also, a literature review can be interpreted as a review of an abstract accomplishment.

Y. Huang and s.y liang have worked on Cutting forces modeling considering the effect of tool thermal property—application to CBN hard turning[1] 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 workpiece material property as a function of strain, strain rate, and temperature. The model prediction is compared to the published experimental process data of hard turning AISI H13 steel (52 HRc) using either low CBN content or high CBN content tools. The conclusion of this paper is proposed model and FEM predict lower tangential and thrust forces and higher tool–chip interface temperature when using the lower CBN content tool.

D.I.lalwani , N.k.Mehta and P.k. Jain have worked Experimental investigations of cutting parameters influence on cutting forces and surface roughness in finish hardturning of MDN250 steel[2]. In This paper presents the findings of an experimental investigation of the effect of cutting speed, feed rate and depth of cut on the feed force, thrust force, cutting force and surface roughness in finish hard turning of MDN250 (50 HRC) steel using coated ceramic tool. The conclusion of this paper is Sequential approach in central composite design is beneficial as it saves number of experimentations required. This was observed in force analysis.

- Linear model is fitted for feed force, thrust force and cutting force whereas quadratic model is fitted for surface roughness.
- Cutting speed has no significant effect on cutting forces and surface roughness.
- Feed force model: the depth of cut is most significant factor with 89.05% contribution in the total variability of model whereas feed rate has a secondary contribution of 6.61% in the model.
- Thrust force model: the feed rate and depth of cut are significant factor with 46.71% and 49.59% contribution in the total variability of model, respectively.
- Cutting force model: the feed rate and depth of cut are the most significant factors affecting cutting force and account for 52.60% and 41.64% contribution in the total variability of model, respectively. The interaction between these two provides a secondary contribution of 3.85%.

• Surface roughness model: the feed rate provides primary contribution and influences most significantly on the sur face roughness. The interaction between feed rate and depth of cut, quadratic effect of feed rate and interaction effect of speed and depth of cut provide secondary contribution to the model.
• Good surface roughness can be achieved when cutting speed and depth of cut are set nearer to their high level of the experimental range (93m/min and 0.2mm) and feed rate is at low level of the experimental range (0.04mm/rev). This is borne by the fact that when cutting speed is increased from 55 to 93m/min at a depth of cut = 0.2mm and feed rate = 0.04mm/rev, the surface roughness decreases from 0.397 to 0.352m. which amounts to an 11.33% reduction of the surface roughness value and is attributed to the secondary effect of interaction between cutting speed and depth of cut.
• Contour plots can be used for selecting the cutting parameters for providing the given desired surface roughness.

D.I.lalwani , N.k.Mehta and P.k. Jain have worked on Extension of oxley's predictive machining theory for Johnson and cook flow stress model[3]. In This paper presents an extension of Oxley's predictive analytical model for forces, temperatures, and stresses at primary (shear zone) and secondary (tool-chip interface zone) deformation zone for Johnson and Cook flow stress model. The effect of strain in addition to strain-rate and temperature at tool–chip interface, which is ignored by many researchers, is considered in the present analysis. The extension is made in line with Oxley's predictive machining theory by introducing the term neq for Johnson and Cook material flow stress model. The conclusion of this paper is introduce the term neq = (dAB/dεAB) (εAB/AB) for n (strain hardening exponent of power law flow stress model used by Oxley). With neq term, the changed equations are in line with the Oxley's predictive theory. The effect of strain in addition to strain-rate and temperature on flow stress at the secondary deformation zone (tool–chip interface zone) is considered in the present analysis. Orthogonal cutting test data for two materials namely AISI 1045 and 0.38% carbon steel has been used for verifying the present work and agreed well with the experimental results. Further, this proposed model can be used for getting the constants of Johnson and Cook flow stress model using inverse approach.

Vahid Norouzifard n, Mohsen Hamedi are worked on Experimental determination of the tool–chip thermal contact conductance in machining process [4]. Tool–chip contact is still a challenging issue that affects the accuracy in numerical analysis of machining processes. The tool–chip contact phenomenon can be considered from two points of view: mechanical and thermal contacts. The conclusion of this paper is
– The tool and work piece mechanical and thermal properties, the tool rake surface roughness, the tool wear, the tool–chip interface temperature, and the normal pressure in the interface are the important parameters that affect the thermal contact conductance. TCC increases by the cutting velocity increase in the range investigated in this paper (30–150 m/min). As the cutting velocity increases the tool–chip interface temperature, thus TCC increases for all tested work piece materials. Thermal softening also can be mentioned as a reason of TCC increase, as cutting velocity increases. TCC decreases in the feed rates higher than 0.11 mm/rev. It seems that decreasing the average normal pressure in the interface, increasing the tool surface roughness because of tool wear, and increasing the heat conduction to the chip due to increasing chip thickness are reasons for TCC decrease.
– The average uncertainties of TCC estimation for the AISI 1045, AISI 304, and Titanium work piece materials are 49.6%, 21.62%, and 22.54% respectively. High uncertainties in the TCC measurements indicate that precise determination of TCC in practical condition is a difficult task.

B.Kristyanto, P. Mathew,* and J. A. Arsecularatne have worked on Development Of A Variable Flow Stress Machining Theory For Aluminium Alloys[5]. This paper describes the development of a variable flow stress predictive machining theory for aluminium alloys. This theory is based on the Oxley's machining theory which allows for the high strain-rate/high temperature flow stress and thermal properties of the work materials and has so far been applied and tested for plain carbon steels.The developed predictive theory for aluminium has been applied in predicting cutting forces, chip thicknesses, etc., for a wide range of cutting conditions (cutting speeds ranging from 100 to 1000 m/min) when machining two alloys: one with 97.64%Al and the other with 93.89%Al (a free machining aluminium alloy). The flow stress properties required in applying the predictive method were obtained from bar turning test results and by applying the machining theory in reverse.

Mahmoud Shatla, Christian Kerk, Taylan Altan have worked on Process modelling in machining. Part I: determination of flow stress data [6].In this study, two-dimensional orthogonal slot milling experiments in conjunction with an analytical-based computer code are used to determine flow stress data as a function of the high strains, strain rates and temperatures encountered in metal cutting. The workpiece materials selected for the present study are AISI P20 mold steel (DIN 1.2330, 35CrMo4) hardened to 30 HRC, AISI H13 tool steel (DIN 1.2344, X40CrMoV51) hardened to 46 HRC and Aluminium EN AW 2007 (DIN 1725 T1: AlCuMgPb, 3.1645) cold hardened to 100 HB. The conclusion of this paper is the automated technique for flow stress determination, developed in the present study, is easier and less expensive than other techniques such as the Hopkinson's bar method. Thus, it is more suitable to build a database of flow stresses for the different workpiece materials at different hardness values used in the metal cutting industry.

Yig it Karpat and Tugrul Özel1 are worked on Predictive Analytical and Thermal Modelling of Orthogonal Cutting Process—Part I: Predictions of Tool Forces, Stresses, and Temperature Distributions[7]. In this paper, a predictive thermal and analytical modelling approach for orthogonal cutting process is introduced to conveniently calculate forces, stress, and temperature distributions. The modelling approach is based on the work material constitutive model, which depends on strain, strain rate, and temperature. In thermal modelling, oblique moving band heat source theory is utilized and analytically combined with modified Oxley's parallel shear zone theory.The proposed methodology has been applied to two different materials, and promising results in close agreement with experimental results have been obtained. As a major contribution, the methodology proposed here

predicts detailed temperature distributions for machining of AISI 1045 steel, AL-6082-T6, and AL 6061-T6, aluminium alloys.

3. Conclusion

The modelling approach is based on the work material constitutive model, which depends on strain, strain rate, and temperature.Oxley's predictive machining theory is extended forJohnson-Cook flow stress model and it is used to find flow stress constants using orthogonal cutting tests data. Furthermore, in this area make an analytical model to predict cutting forces in orthogonal cutting.

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