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Evaluation of Cutting Force for Orthogonal Cutting Using Experimental Technique for AISI304

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Abstract*-Metal cutting is one of the most widely used manufacturing processes in an industry and there is great deal of studies to investigate the metal cutting process in both academic and industrial work. The objective of analyzing the metal cutting process is to tooling cost. Prediction of important process parameter using experimental investigation such as forces, stress distribution, temperature, etc. plays significant role for designing tool geometry and optimizing cutting conditions to improve productivity. We cannot find out the forces with analytical model exactly to experimentally measured cutting forces Here our aim of these researches is to choose the analytical model which will give best result for AISI304 material .By using 1) Ernst and merchant. 2) Lee and Schaffer and 3) Dautzenberg C.S model theoretically and comparing with each with experimental data. Experiments are carried out for different cutting condition. Also reason for this is found out and behavior of shear angle is studied for different cutting condition.*

Keyword*-Ernst and merchant; Lee and Schaffer and Doutzensberg C.S; Shear angle; thrust force;*

I. INTRODUCTION

Metal Machining is used as one of the most important processes in industry to obtain the final shapes of the products. A wide variety of machining operations are applied in industries that include material removal during cutting. Understanding the material constitutive behaviour in machining is becoming increasingly important for better understanding the parameters of machining such as, cutting force, plastic strain distribution and chip morphology. Machining processes involve high deformations, high strain rates, high local temperature, high transient phenomena and it has been known for a long time that a size effect exists in metal cutting, where the specific energy increases with decreasing in deformation size which have not been considered in conventional mechanics of materials [2]. The angle at which the chip will separate from the work material during metal cutting is called the shear angle and determines many fundamental aspects of the cutting mechanics such as the magnitude of the cutting force, the efficiency of the metal removal process and the surface roughness. A large shear angle is associated with continuous and thin chip formation, good surface finish and low cutting force. The value of the shear angle is measured either by measuring the deformed and unreformed chip thickness or by metallographic inspection of the machining zone of samples obtained by quick stop devices. There has been extensive research on close-form analytical modelling of the shear angle equation as specified by Ernest and Merchant [3-5].

II.PROBLEM DEFINITION

After referring to number of research paper, found that there are number of analytical models available to find out cutting forces in cutting process based on different theories and with lots of assumptions. Because of these assumptions it is difficult to find out the cutting forces with analytical model near to experimental cutting forces or experimentally measured cutting forces. We can use any one of these model to calculate cutting force. But, which one to choose is difficult task. Which Model will give us result to real value of cutting force is question. And which analytical model is good for which material is question. Case study for AISI304 is taken and experiments are carried out on it. Which are the factors responsible for deviation of force for AISI304 is analyzed and reason for best result is found. And behavior of shear angle for different condition of speed feed and depth of cut is studied.

III.METHODOLOGY

First of allMaterial for work piece is selected AISI304 because it is most widely used in industry, then after Tool design and fabrication is carried out. For experiment performance 6 degree rack and 5 degree clearance angle is selected. By using Minitab software Design of experiment for full factorial method is carried out and value of speed feed and depthof cut combination experiments are performed .Result of experiments and analytical calculation is graphically represented. Then by analyzing graph study of shear angle for different cutting condition we get. Also conclusion of the best model which can give near about value to experiment is done and reason behind it is found out.

VI. EXPERIMENTATION

To evaluate the cutting force models, orthogonal cutting experiments are carried out on an 802D CNC turning using cemented carbide TTM8 tool with 6° rake angle and 5° clearance angle on 30 mm diameter AISI304 shaft. The chemical composition of AISI304 is which was used in experiment is shown in table 1. The rake face of the tool is flat, no chip breakers are used. The turning lathe is provided with strain gauge type dynamometer Model: UIl15 to measure the cutting forces. The experiments are made without lubricant or cooling. Work piece material AISI304 is used in the experiment. This material is chosen because they are often found in engineering practices. Besides, with these alloy it is easy to produce straight and continues chips without a built up edge, which is one of the condition of sets by cutting force models. Though this material was in initially bar shaped, they are machined to tubular shape prior to experiments.

Fig 1 Experimental setup

The full width of the tubes is machined with the straight part of the tool. Now, by choosing cutting width at least ten times the undeformed thickness the cutting operation can be modeled to be two dimensional. The measurement data of the cutting experiment can be in table 1. Each experiment is performed at least three times and showed good reproducibility (in general the specific measurement of cutting force and chip thickness

C	Mn	Si	P	S
0.075	1.587	0.537	0.021	0.028

Table 1 Chemical Composition

To elaborate the models of Ernst-Merchant and Lee-Shaffer the shear flow stress $\boldsymbol{\tau_F}$ of the material has to be known, whereas the model of Dautzenberg C.S. uses the material equivalent stress$\bar{\boldsymbol{\sigma}}$. However, using the von Mises flow criteria for plan strain condition, the shear flow stress can be related to the equivalent stress as$\boldsymbol{\tau_F} = \bar{\boldsymbol{\sigma}}/\sqrt{\mathbf{3}}$. Since the model of Dautzenberg c.s. uses Ludwik relation$\bar{\boldsymbol{\sigma}} = \mathbf{C}\bar{\boldsymbol{\varepsilon}}\mathbf{n}$, the material behavior has to be determined in terms of specific stress C and τ_F tensile test is carried our[6].

.V. ANALYTICAL MODEL

Model 1: Ernst and Merchant

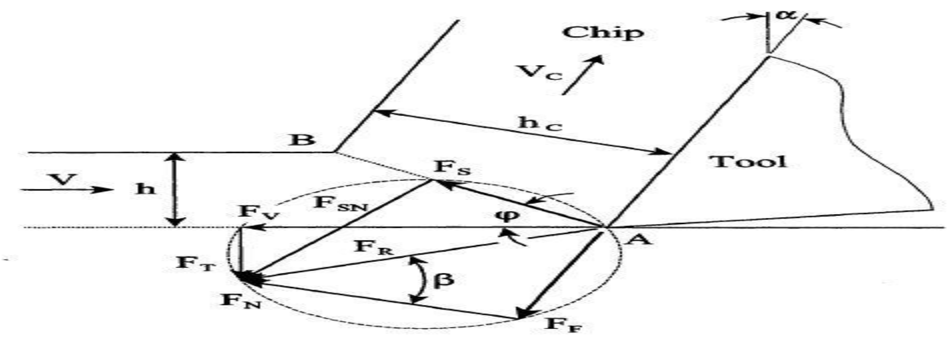

Fig 2 Geometry of merchant circle diagram

Ernst and merchant reasoned that the shear plan would take such position that the shear stress acting upon it would be maximum [7]. Assuming the shear stress to be uniformly distributed it holds:

$$\tau_F = \frac{F_s}{A_s} = \frac{F_r \cos(\phi + \beta - \alpha)}{A_s}$$

Where A_s is the area of the shear plane. The optimum was found by differentiating this expression with respect to ϕ and equating the resultant to zero. Under the assumption that $\boldsymbol{\tau_F}$ and β are independentofϕ, this leads to:

$$\phi = \frac{\pi}{4} - \beta + \alpha$$

This equation gives a simple relation between the shear angle ϕ and the friction angle β. Combining this equation with the force relationship of the plane representation in

$$F_v = \tau_F bh \frac{\cos(\beta - \alpha)}{\cos(\phi + \beta - \alpha) sin\phi} F_t = \tau_F bh \frac{\sin(\beta - \alpha)}{\cos(\phi + \beta - \alpha) sin\phi}$$

The cutting forces can be calculated if ϕ and τ_F are known. Using the geometrical relation of fig 2, the shear angle ϕcan be determined if the chip thickness is measured experimentally.

Model 2: Lee and Schaffer

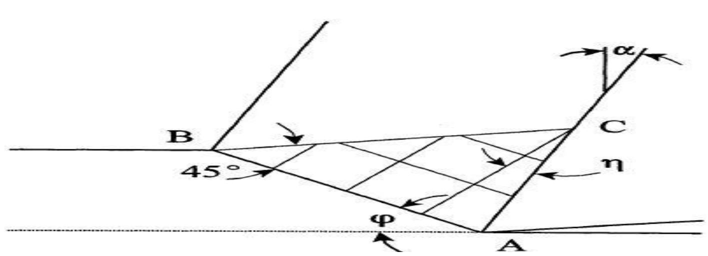

Fig 3 Lee and Shaffer's slip line field model

Lee and Shaffer applied the slip line theory to find the shear angle solution[8]. They treated the workpiece as a rigid plastic solid without strain hardening or thermal effect. As in the Ernst-Merchant model they assumed the shear plan AB to be a direction of maximum stress where all deformation takes place. However, Lee and Shaffer constructed a slip line field theory ABC in which material is in union state. The equation of Shear angle:

$$\phi = \frac{\pi}{4} - \beta + \alpha$$

Model 3 of Dautzenberg C.S. theories

Based on the upper bound theory Dautzenberg C.S. proposed a somewhat different approach to obtain the shear plan angle they divided the total energy consumption needed for the chip formation in two parts: energy needed for deformation in the shear zone and energy dissipation due to friction at the rack face. Using that the energy related to motion of feed is negligible to the energy related to the motion of cutting, the power of consumption can be approximated as $F_V V$. Thus they found:

$$\text{FvV} = \text{bhV} \int_0^{-\varepsilon AB} \bar{\sigma} d\bar{\varepsilon} + F_F V_C$$

In this equation σ is equivalent stress in the shear zone which was supported to follow Ludwick's equation $\bar{\sigma}$. The total equivalent strain in the shear zone and the chip speed Vc can easily be deducted from equation fig1.5

$$\bar{\varepsilon}_{AB} = \frac{\cos\alpha}{\sqrt{3} sin\phi \, \cos(\phi - \alpha)} \qquad \text{Vc} = \frac{sin\phi}{cos\phi}\text{V}$$

Now the power balance can be written as:

$$F_V V = bhV \frac{C}{n+1} \bar{\varepsilon}_{AB}^{n+1} + F_F V \frac{sin\alpha}{\cos(\phi - \alpha)} V \qquad 3.1$$

Finally, the optimum shear angle can be found by differentiating the right hand side of equation2.12 to ϕ and setting the resulting equation to zero. This leads to differential equation:

$$\frac{dF_F}{d\phi} sin\phi \cos(\phi - \alpha) + F_F cos\alpha - bh\bar{\varepsilon}_{AB}^{n} \frac{cos\alpha}{\sqrt{3} sin^2\alpha} [sin\phi \sin(\phi - \alpha) - cos\phi \cos(\phi - \alpha)] = 0$$

To solve this differential equation numerically a boundary condition for F_F must be known. Dautzenberg c.s argued that in case the tool friction is zero the chip thickness will remain the un-deformed chip thickness, so for the boundary condition it holds:

$$F_F \left(\phi = \frac{\pi}{4} + \frac{\alpha}{2}\right) = 0$$

Using this boundary condition eq.2.13 can be solved numerically to give F_F for a certain value of ϕ

VI. RESULTS

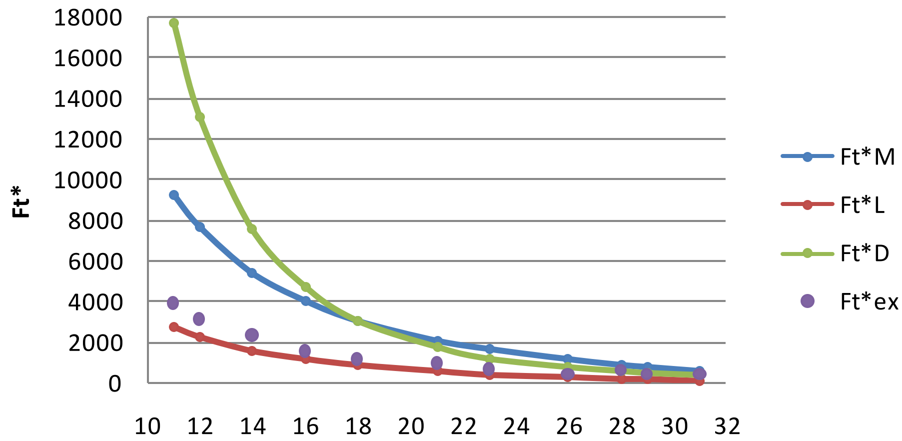

Fig 4 Shear angle ϕ Vs. thrust force Ft*

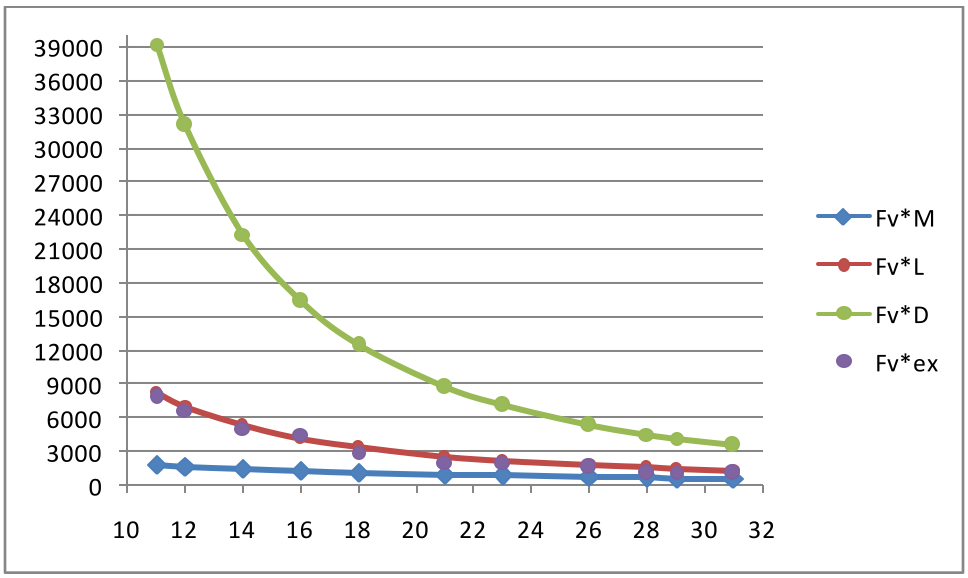

Fig 5 Shear angle ϕ Vs. thrust force Fv*

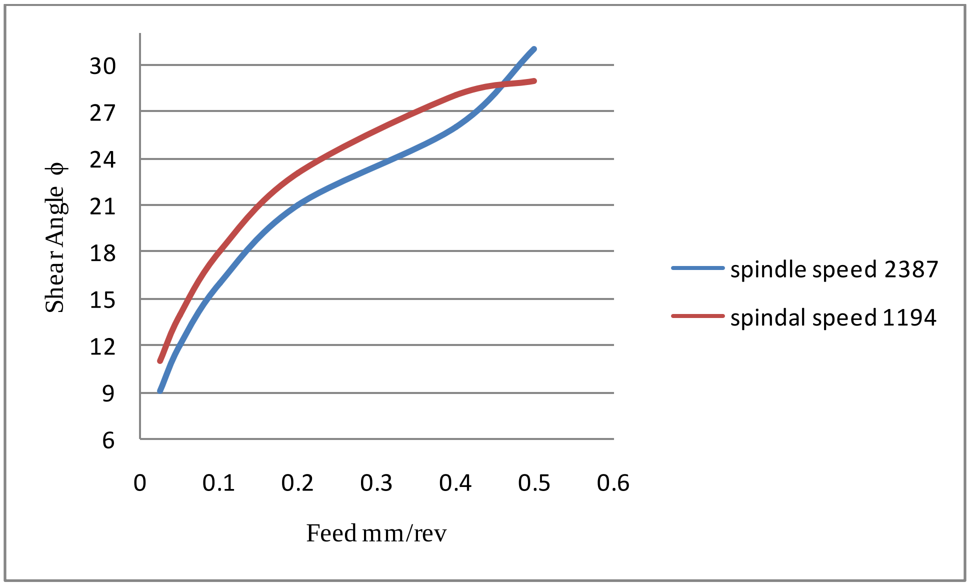

Fig 6 Feed Vs shear angle

VII. CONCLUSION

Each marker in above fig represents an average of three experiments carried out at identical cutting condition. Comparing the experiment to the model of Ernst and merchant, it is clear that both forces are overestimated considerably for the whole range of shear angles. Although the model of Dautzenberg c.s. is based on upper bound theory also, it gives much better results as the Ernst-Merchant model regarding the main cutting force (Fv). However, for low shear angle the thrust force is predicted far too high compared the measurement. In general, the best results are obtained with the slip-line field theory based model of Lee and Shaffer, that predicts especially the main cutting rather accuracy. As for the Dautzenberg c.s. model, however, the mismatch between theory and experiment becomes more evident for low shear angles where it shows the tendency to underestimate the thrust force. Given that the low shear angles are found for feed rate (0.025-.05), this underestimation can be expected. For, in case of low feed rates the cutting edge radius is of same order, or even bigger, than the undeformed chip thickness. As a result the ploughing forces that are not considered by the models will become a more dominant factor. The underestimation of the thrust force is therefore, in fact, a strong argument in favour of the lee and Schaffer model.

Fig 6 shows the graph of feed verses shear angle, when keeping the cutting speed constant and changing feed sequentially shear angle increases drastically. If the amount of spindle speed increases the value of shear angle decreases compare to low speed for same feed. At the more feed rate there mismatch accurse for shear angle and amount of shear angle is more for high speed for same feed rate

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