A Machining Program Employing a Slip Line Field Modelling Technique Over Other Constitutive Models

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ABSTRACT
Machining involves complex plastic material flow at the chip separation site which makes it difficult to predict forces and other machining outputs to higher accuracy. Modelling is a common technique which facilitates incorporation of analytical and experimentally derived equations to visualize the process and analyses the mechanism. It saves time and machining factors can be optimized without any trial and error method. In this paper, the significance of slip line field model over other constitutive laws in defining the complex regions in machining are thoroughly reviewed and a slip line field model is chosen which incorporates build up edge (BUE) of a larger size than the other previously defined slip line models for machining. The modified model also incorporate a region of shear zone instead of a shear line, takes into account the chip curl effect and conform to the velocity discontinuity and stress equilibrium. The slip line fields are generated using MATLAB and employing Dewhurst-Collin’s matrix technique.

KEYWORDS
Build-Up-Edge, Chip, Constitutive Models, Machining, Shear Zone, Slip Line Model, Tool-Chip Interface

1. INTRODUCTION
Nomenclature (with reference to Modified slip line model):

\( \nu \): Angular range of the slip line ‘GD’.
\( \psi \): Angular range of the slip line ‘BD’.
\( \theta \): Angular range of the slip line ‘AB’.
\( \eta \): Angular range of the slip line ‘CD’.
\( P_A \): Hydrostatic pressure at ‘A’.
\( P_{A1} \): Hydrostatic pressure at ‘A1’.
\( \tau \): frictional shear stress along the rake angle.
\( k \): Maximum shear flow stress.
\( \rho \): Velocity discontinuity along ‘ABC’.

DOI: 10.4018/IJMMME.2020040102

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ρ : Velocity discontinuity along CE.
a, a_t, a_v : Overstressing angles at ‘A’ and ‘A_t’.
σ : Initial base slip line (velocity discontinuity along ‘BD’)
ϕ : Angle turned by the slip line during curving.
ξ : X Mikhlin coordinates.
η : Y Mikhlin coordinates.
x, y : X and Y cartesian coordinates.
V : Cutting velocity.
γ : rake angle.
ω : Angular velocity of the chip.
V : Velocity of the chip at point ‘G’.
F_x : Forces in X direction along the Mikhlin X coordinates.
F_y : Forces in Y direction along the Mikhlin Y coordinates.
F : Cutting force in machining.
F_i : Thrust force in machining.

Machining is a metal cutting process where the cutting tool is brought in contact with the surface of a rotating work piece to remove material in the form of chips. Machining process can be considered as the most versatile and an important process in product development of a manufacturing industry.

Of the total cost of the product, the cost of machining has a share of about 15% (Merchant, 2003) which implies that by enhancing effectiveness and efficiency of the machining process, the factor cost of a product can be reduced for better quality to cost ratio. Machining process involves complex material flow behaviour at the chip separation site which can be attributed to the plastic deformation of the workpiece material during cutting. This phenomenon triggers unpredictable output results in the form of power and forces which needs to be modelled using analytical, numerical or empirical understanding of the process (Ding et al., 2010, Oxley, 1989, Adetoro and Wen, 2010). The first empirical understanding of the machining process was given by Taylor (Merchant, 2003) who analysed the previously experimented data and formulated a relation between the tool life and cutting velocity. Later a number of other factors such as the depth of cut and feed, were considered and incorporated in the formula. Though, empirical based models can provide an optimum level of all the machining factors for better effectiveness in the process, it lacks the basic understanding of physics behind the phenomenon. Analytical models such as merchant’s force model (Merchant, 1944) can explain the physics behind the mechanism but fails to predict the experimentally determined results and suffered from the variations in their output values. Numerical methods can take into account both empirical and analytical findings to converge the simulation results to actual experimental results using numerical computational tools such as Finite element method (FEM), Finite difference method (FDM) and Boundary element method (BEM). Analytical modelling of machining such as slip line field modelling can very well take into account a number of factors for the computational efficiency with complete understanding of the physics behind it as compared to other constitutive laws that employs Johnson-Cook model (numerically or analytically), Zerilli Armstrong model and Mechanical Threshold Stress (MTS) model (Ning et al., 2019; Pan et al., 2017; Mirzaie et al., 2016). The constitutive models and the slip line field model are compared for their robustness and simplicity, in defining three complex regions in machining involving complex material plastic deformation. These complex regions are:

1. Build up edge (BUE) and Build up layer (BUL) formation;
2. Shear zone plastic deformation region;
3. Tool rake-chip interface plastic deformation region.
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