17th International Research/Expert Conference
"Trends in the Development of Machinery and Associated Technology"
TMT 2013, Istanbul, Turkey, 10-11 September 2013

THE FRICTION MODELS INTEGRATION IN CALCULATION OF BULK METAL FORMING TECHNOLOGIES BY FINITE VOLUME METHOD

Hazim Bašić
Mechanical Engineering Faculty Sarajevo
Vilsonovo šetalište 9, 71000 Sarajevo,
Bosnia and Herzegovina

ABSTRACT
The usage of the finite volume method (FVM) for calculation of bulk metal forming working pressure is described in this paper. FVM is applied on two-dimensional orthogonal grids and colocated variable arrangement. The application of the FVM is done in case of solving the plastic flow during extrusion processes with different boundary conditions. The method of involving of the most frequently used friction models, Coulomb's friction and constant friction law into the FVM algorithm is presented. Obtained numerical results are in agreement with the theoretical considerations.
Keywords: Finite Volume Method, Extrusion, Coulomb's friction, Constant friction law.

1. INTRODUCTION
Due to the high pressures and temperatures, surface quality and lubrication properties, it is extremely important to perform the friction value and its influence on considered metal forming technology. Friction is one of the most important problem in metal forming processes. It is a complex and hardly understood and controlled phenomenon [2,5,6,8]. The most information on friction phenomena is obtained by studying the workpiece surface after metal forming. These studies render some insight into the mechanisms that govern friction but do not supply sufficient information to specify the constitutive relations that can be applied to model friction in a forming analysis.
Therefore, the different friction laws are developed in order to describe the friction influence on the plastic metal flow during metal forming processes [1,2,9]. In this paper the Coulomb's and the constant friction law are compared in the FVM algorithm for extrusion process simulation.

2. FRICTION MODELS
To model the friction, a variety of constitutive laws can be used to define the surface tractions that are exerted on a material when it is sliding along a surface. Usually, the tangential surface tractions τ_s is related to the size of the normal surface traction σ_{sn} and to the relative sliding velocity along the tooling $(\mathbf{v}-\mathbf{v}_{tool})$. As a point of departure a Norton-Hoff type law is considered which has the following form:

$$\tau_s = -m\sigma_{sn}^{\alpha}\left\|\mathbf{v}-\mathbf{v}_{tool}\right\|^{\beta-1}\left(\mathbf{v}-\mathbf{v}_{tool}\right) \qquad (1)$$

where *m* represents the friction coefficient, and *α* and *β* are additional constitutive parameters. Notice that for this law the dimension of *m* depends on the choice of *α* and *β*.
For metal forming processes the velocity of the tooling is given by:

$$\mathbf{v}_{tool} = \begin{cases} \mathbf{0} & \forall \mathbf{x} \in \Gamma_{die} \cup \Gamma_{container}, \\ \mathbf{v}_{ram} & \forall \mathbf{x} \in \Gamma_{ram} \end{cases} \qquad (2)$$

where Γ represents the corresponding surface area.
For the particular values of the parameters α and β, the following special friction laws are obtained:

— $\alpha = 0,\ \beta = 1$ - the Norton friction law,

— $\alpha = 0,\ \beta = 0$ - the constant friction law,

— $\alpha = 1,\ \beta = 0$ - the Coulomb's friction law.

In metal forming analysis all of these laws have been used to model friction. However, in some technologies, like extrusion practice, it has been observed that locally increasing the length of the bearings above a certain value, does not further improve the balance of the extrudate. This suggests that towards the exit of the bearing the frictional traction decreases and even vanishes for large bearing lengths. This trend cannot be captured by adopting the constant friction law.

Also, the Norton law is incapable of describing this behavior since it predicts that a particle that is sliding along the bearing will experience a frictional traction proportional to the sliding velocity. Since the velocity of a particle will not change significantly within the bearing, the Norton law suggests a nearly constant friction. Furthermore, there are indications that the sliding velocity has very little influence on the friction forces in metal-metal contact. Therefore, the comparison between the Coulomb's and constant friction law is done.

3. NUMERICAL SIMULATION OF FRICTION

In the simulation of extrusion processes, it is common to use a rigid-(visco)-plastic constitutive model to describe the material behavior and thus neglect the elastic properties of material. The reason for this is that the elastic deformations are small compared to the very large plastic deformations that occur during the process. For the frictional models comparison, the finite volume method, originally developed for the fluid flow and heat and mass transfer problems [3,4,7], is used in this paper. The tangential stress τ_b near to the cell faces with friction boundary conditions, Figure 1, is equal to product of viscosity and tangential velocity gradient in normal direction [3]:

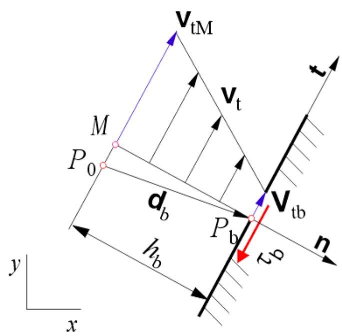


Figure 1. Velocity profile near the contact wall

$$\tau_b = \mu_b \left(\frac{\partial v_t}{\partial n} \right)_b = \begin{cases} m p_b & \text{- for Coulomb's friction law} \\ fk & \text{- for constant friction law} \end{cases} \qquad (3)$$

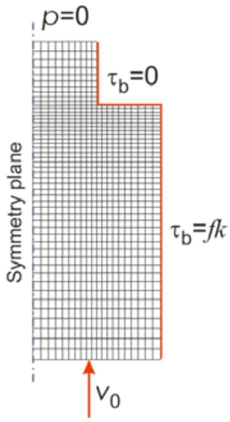
where m and f are the friction coefficient and friction factor respectively, p_b is the pressure at the boundary node and k is the share yield stress. The tangential velocity on cell faces is extracted from equation (3):

$$
\mathbf{v}_{tb} = \begin{cases} \mathbf{v}_{tM}\left(1 - m\dfrac{p_b}{\mu_b}h_b\dfrac{1}{|\mathbf{v}_{tM}|}\right) & \text{- for Coulomb's friction law} \\ \mathbf{v}_{tM}\left(1 - f\dfrac{k}{\mu_b}h_b\dfrac{1}{|\mathbf{v}_{tM}|}\right) & \text{- for constant friction law} \end{cases} \tag{4}
$$

where h_b is the normal distance between the calculation point M and boundary face, figure 1, and $\mathbf{v}_{tM}$ is obtained by linear interpolation from the values at points P_0 and P_k , where P_k are the neighbour control volumes. This boundary constrain is of Dirichlet (velocity prescribed) type.

4. THE NUMERICAL EXAMPLE

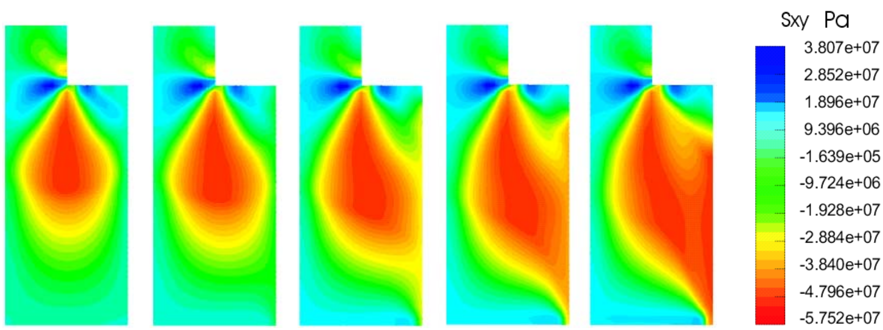
In this paper the constant friction and a Coulomb's friction models are analyzed in an example of plane strain forward extrusion through a flat faces die with the degree of deformation ε = 50%.



The prescribed workpiece yield stress is σ_Y=100 MPa, and a rigid-perfectly plastic model of material is used. The ram velocity is v_0=0,01 m/s. For the sake of simplicity, the friction boundary condition is prescribed only on the wall part of the die, Figure 2.
The discretisaton procedure by employing a finite volume method is in detail described by Demirdžić and Muzaferija [4]. The spatial domain is discretised into a finite number of contiguous arbitrarily shaped control volumes (CV) bounded by cell faces, with computational nodes placed in the centre of each CV.
The orthogonal numerical mesh consisting of 900 control volumes together with prescribed boundary conditions is given in Figure 2. Due to the problem symmetry, only the half of the solution domain is used for calculation.

Figure 2. The numerical mesh and boundary conditions

The obtained distributions of tangential stress component τ_{xy} for the constant friction law and different friction factors f are given in Figure 3.

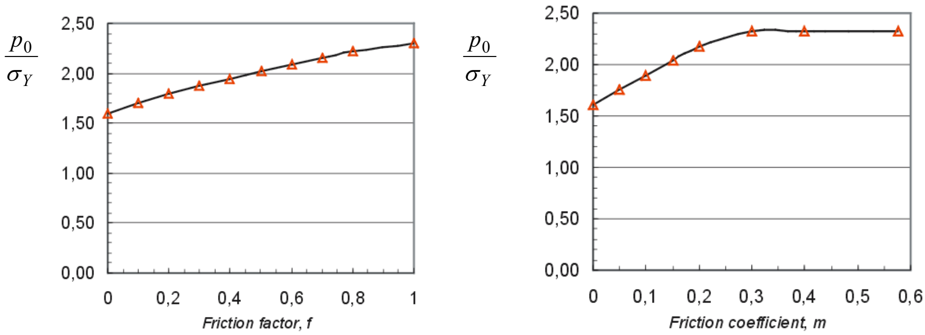


(a) $f = 0$ (b) $f = 0{,}2$ (c) $f = 0{,}5$ (d) $f = 0{,}7$ (e) $f = 1$

Figure 3. Distribution of the tangential stress τ_{xy} for the constant friction law

One can see that the tangential stress on the die wall is systematically increased with the increasing of the friction factor. The case $f = 0$, Figure 3(a) corresponds to the sliding interface, while the case $f = 1$ represents the sticking wall (tangential stress on the die wall is equal to the shear yield stress $\tau_{xy} = k = 57{,}7$ MPa), Figure 3(e).

The relation between the extrusion pressure and the friction factor/coefficient is given in Figure 4.



(a) (b)

Figure 4. The relation between the extrusion pressure and friction factor/coefficient.

One can see a uniform increasing of extrusion pressure in the case of constant friction law, Figure 4a. But, for the case of Coulomb's friction law the maximum extrusion pressure (corresponding to the sticking wall) is reached before, approximately for the friction coefficient $m = 0{,}3$. The further analyze shows that the value assigned to the Coulomb friction coefficient (or constant friction law) has a substantial influence on both the flow and the temperature fields of extrusion material.

5. CONCLUSION

The presented numerical method enable that in every point on the metal surface that is in contact with the tooling, the stress state and the velocity must satisfy the criteria that the frictional traction is opposed to the sliding velocity. Also the stick and slip are mutually exclusive. FVM enables obtaining the distribution of velocity components and pressure field throughout the solution domain, from which the other important variables e.g. strain-rate and stress tensor components can be easily calculated. The main advantages of the FVM are its simplicity and an efficient use of computer resources (steaming out of the iterative segregated solution procedure). The calculated results are in good correlation with theoretical considerations and experiments [3].

6. REFERENCES

[1]. Alexandrov, S., Mishuris, G., Miszuris, W., Sliwa, R.E.: On the dead-zone formation and limit analysis in axially symmetric extrusion, Int. J. of Mechanical Sciences, 43, pp. 367-379, 2001.

[2]. Altan, T., et al.: Simulation of metal forming processes – applications and future trends, Advanced Technology of Plasticity, 6th International Conference–ICTP 99, Nurenberg, Vol. I, pp. 23-27, 1999.

[3]. Bašić, H., Demirdžić, I., Muzaferija, S.: Finite volume method for simulation of extrusion processes, Int. J. for Numerical Methods in Engineering; 62, pp. 475–494, 2005

[4]. Demirdžić, I., Muzaferija, S.: Numerical Method for Coupled Fluid Flow, Heat Transfer and Stress Analysis Using Unstructured Moving Meshes with Cells of Arbitrary Topology, Comput. Methods Appl. Mech. Engrg., 125, pp. 235-255, 1995.

[5]. Gusel., L.: An investigation of local strain rate values during metal forming, 13th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology", TMT 2009, Hammamet, Tunisia, 16-21 October 2009

[6]. Janjić, M., Savićević, S., Vukčević, M., Šibalić, N.: Numerical simulation of bulk metal forming process, 15th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology" TMT 2011, Prague, Czech Republic, 12-18 September 2011.

[7]. Lou, S., Zhao, G., Wang, R., Wu, X.: Modeling of aluminum alloy profile extrusion process using finite volume method, J. of Materials Processing Technology, 206, 481-490, 2008.

[8]. Qin, Y., Balendra, R.: Optimisation of the lubrication for the extrusion of solid and tubular components by injection forging, J. of Materials Processing Technology, 135, pp. 219–227, 2003.

[9]. Yanga, H., Penga, Y., Ruana, X., Liub, M.: A finite element model for hydrodynamic lubrication of cold extrusion with frictional boundary condition, J. of Materials Processing Technology, 161, pp. 440–444, 2005.