Simulation of Kinetic Friction in L-Bending of Sheet Metals

Maziar Ramezani, Thomas Neitzert, Timotius Pasang

Abstract—This paper aims at experimental and numerical investigation of springback behavior of sheet metals during L-bending process with emphasis on Stribeck-type friction modeling. The coefficient of friction in Stribeck curve depends on sliding velocity and contact pressure. The springback behavior of mild steel and aluminum alloy 6022-T4 sheets was studied experimentally and using numerical simulations with ABAQUS software with two types of friction model: Coulomb friction and Stribeck friction. The influence of forming speed on springback behavior was studied experimentally and numerically. The results showed that Stribeck-type friction model has better results in predicting springback in sheet metal forming. The FE prediction error for mild steel and 6022-T4 AA is 23.8%, 25.5% respectively, using Coulomb friction model and 11%, 13% respectively, using Stribeck friction model. These results show that Stribeck model is suitable for simulation of sheet metal forming especially at higher forming speed.

Keywords—Friction, L-bending, Springback, Stribeck curves.

I. INTRODUCTION

THE most prominent feature of sheet metal forming process is an elastic recovery phenomenon during unloading which leads to springback [1]. The following statement best describes springback: "A purely elastically bent sheet will return to its original configuration upon removal of the bending moment. After partially plastic bending; permanent deformation and residual stress remain after unloading [2].

Evidently, bending causes the metal on the outside of the neutral axis to be under a state of tension, whereas the inside is subjected to compression. During the bending process, internal stresses are developed in the sheet and upon unloading; the internal stresses do not vanish. After bending, the extrados is subjected to residual tensile stress and the intrados is subjected to residual compressive stress. These residual stresses produce a net internal bending moment which causes springback [3]. The sheet continues to springback until the internal bending moment drops to zero.

Despite the broad application of sheet metal forming, the design of the tools and the selection of the sheet materials are still usually based on trial and error efforts, a very expensive and time consuming procedure. Reliable finite element models

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for describing the process would be of great value in reducing much of the tool tryout work [4]. For these finite element simulations, accurate models of the material behavior under deformation as well as the friction between tool and metal are needed. For metal forming simulations, a good friction model is very important, as shown by [3]–[5]. For most forming simulations the value of coefficient of friction is chosen as a constant, neglecting the fact that the parameters on which this value depends might change during the process. Coulomb friction model is a simple model frequently used in simulation. In this model, the ratio between friction force and normal force, defined as the coefficient of friction, considered to be constant, as used by [6], [7]. But, friction depends on a large number of parameters, e.g. the micro-geometry, the macro-geometry, the lubricant and the operational parameters: velocity, temperature and normal load. If one of the parameters changes; the coefficient of friction will also change [8].

In the present paper, the L-bending of mild steel and aluminum alloy 6022-T4 sheets is simulated with emphasis on Stribeck-type friction modelling. From the author's knowledge, there has been no previously published analysis of Stribeck-type frictional behavior in L-bending. The springback behavior of sheets was studied using numerical simulations by ABAQUS software with two types of friction model: Coulomb friction and Stribeck friction. The results have been compared with experimental results. The influence of forming speed on springback behavior of sheets is also studied experimentally and numerically.

II. STRIBECK FRICTION MODEL

When a metal forming process is observed, it is clear that the conditions in all the different contacts are very different. For most forming simulations the value of coefficient of friction is chosen as a constant, neglecting the fact that the parameters on which this value depends might change during the process. Often, several metal forming simulations with different values for the coefficient of friction have to be performed before the simulation provides acceptable results. It is clear that these simulations have no predicting power at all [4]. From this, it is obvious that a model which describes coefficient of friction as a function of local contact conditions is needed. The limiting strain of a material is not directly changed by friction, but friction changes the stress and strain distribution. The redistribution of stress and strain, can affect defects on metal forming, such as springback.

Stribeck is credited for carrying out the first systematic experiments unfolding a clear view of the characteristic curve

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of the coefficient of friction versus speed [9]. In recognition of his contribution, this curve is called "the Stribeck curve" [10]. The Stribeck curve has also been proven to be useful for identifying boundary, mixed, elasto-hydrodynamic and hydrodynamic lubrication regimes [11]. In bending process, contact regions operate in boundary lubrication regimes. Only very extraordinary conditions (such as high forming speed), make it possible for the contact functions to be in mixed lubrication regime.

In lubricated contact surface between punch and sheet, the total normal load F_T is shared by the hydrodynamic lifting force, F_H and the asperity interacting force, F_C.

$$F_T = F_H + F_C \qquad (1)$$

Similarly, the total friction force F_f is the sum of two components $F_{f,H}$ (the hydrodynamic friction force) and $F_{f,c}$ (the asperity interacting friction force). The hydrodynamic friction force $F_{f,H}$ is represented as

$$F_{f,H} = \tau_L (1 - e^{-\eta (u/h_c)/\tau_L}) . 2aB \qquad (2)$$

where B is the contact length; u is the relative velocity; τ_L is the limiting shear stress; h is the film thickness; and a is the half width of Hertzian contact. Assuming that the coefficient of friction f_{c_i} is constant for all asperities, we arrive at the following relationship for the friction force

$$F_{f,C} = \sum_{i=1}^{N} \iint_{A_{c_i}} f_{c_i} p_{c_i} dA_{c_i} = f_c \sum_{i=1}^{N} \iint_{A_{c_i}} p_{c_i} dA_{c_i} = f_c F_c \qquad (3)$$

where f_c is determined from experiments.

Hence, the coefficient of friction can be obtained from

$$f = \frac{F_f}{F_T} = \frac{F_{f,H} + f_c F_c}{F_T} \qquad (4)$$

A full description of the Stribeck theoretical model can be found in [12].

III. FINITE ELEMENT SIMULATION

The finite element method has been used to simulate springback in L-bending of sheet metals. To study the effect of friction model on springback prediction, the plane-strain bending process was simulated in the commercial FEM software ABAQUS/Standard. Springback is often an important part of a forming analysis because the springback analysis determines the shape of the final, unloaded part. ABAQUS provides the capability to import a deformed mesh and its associated material state from ABAQUS/Standard into

Abaqus/Explicit and vice versa. This capability is particularly useful in manufacturing problems; for example, the entire sheet metal forming process (which requires an initial preloading, forming, and subsequent springback) can be analyzed. In this case the initial preloading can be simulated with ABAQUS/Standard using a static procedure and the subsequent forming process can be simulated with ABAQUS/Explicit. Finally, the springback analysis can be performed with ABAQUS/Standard. Since springback involves no contact and usually includes only mild nonlinearities, ABAQUS/Standard can solve springback problems much faster than ABAQUS/Explicit can. Therefore, the preferred approach to springback analyses is to import the completed forming model from ABAQUS/Explicit into ABAQUS/Standard.

The rigid punch and die are modeled in ABAQUS/Standard as analytical rigid surfaces with the *SURFACE option in conjunction with the *RIGID BODY option. The top and bottom surfaces of the sheet are defined with the *SURFACE option. Two friction model: Coulomb friction and Stribeck friction, implemented to ABAQUS/Standard and the results have been compared with the experimental results.

Models for simulating sheet metal forming processes consist of different sub-models. Each of these sub-models takes a specific aspect of the total process into account. The main two sub-models for sheet metal bending are material model and friction model. The entire analysis is carried out in five steps. In the first step the blank holder is pushed onto the blank with a prescribed displacement to establish contact. In the second step the boundary condition is removed and replaced by the applied force of 100 kN on the blank holder. This force is kept constant during Steps 2 and 3. This technique of simulating the clamping process is used to avoid potential problems with rigid body modes of the blank holder, since there is no firm contact between the blank holder, the blank, and the die at the start of the process. The two-step procedure creates contact before the blank holder is allowed to move freely.

In the third step the punch is moved toward the blank by specifying a total displacement. This step models the actual bending process. During this step the DISCONTINUOUS analysis option is included since contact with friction tends to create a severely discontinuous nonlinearity and we wish to avoid premature cutbacks of the automatic time incrementation scheme.

The last two steps were used to simulate springback. In the fourth step all the nodes in the model are fixed in their current positions and the contact pairs are removed from the model. This is the most reliable method for releasing contact conditions. In the fifth, and final, step the regular set of boundary conditions is reinstated and the springback is allowed to take place.

Mild steel and aluminum alloy 6022-T4 were used for modeling. Simulations were carried out using Hill's plasticity model. The dimensions used in simulation of L-bending according to experimental work are shown in Fig. 1. The thickness of the sheet is 1 mm.

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The punch and die material is H13 tool steel. In this simulation two frictional models were used in the analysis: Coulomb friction model with a constant coefficient of sliding friction 0.13 and Stribeck friction model with initial coefficient of sliding friction of 0.13 for lubricated surface between mild steel sheet and punch and 0.14 between 6022-T4 AA sheet and punch. The value of coefficient of friction is based on historical data for similar cases [13]–[15]. The Stribeck curves used in this analysis are a function of velocity and contact pressure. These curves were implemented to model through contact property options.
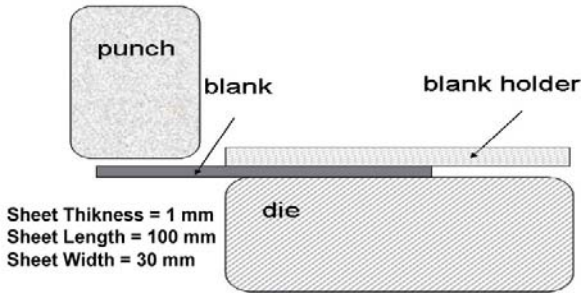
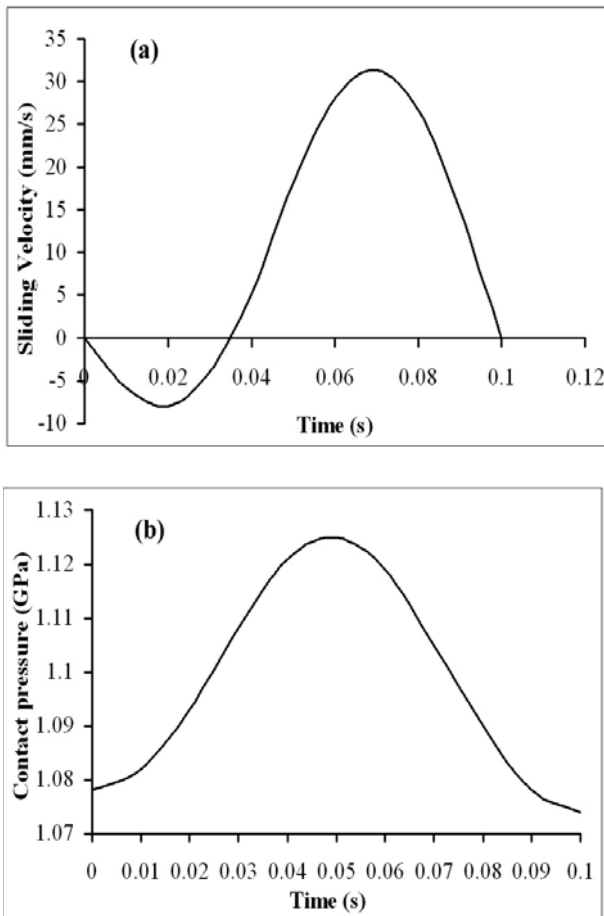Fig. 1 Dimensions used in L-bending

Fig. 2 Variation of (a) sliding velocity and (b) Hertzian contact pressure with time

IV. RESULTS AND DISCUSSIONS

As mentioned before, coefficient of friction changes during the process and has different values in different nodes and different time during the process. The change of sliding velocity and Hertzian contact pressure with time during plane strain bending process based on the Stibeck curve is illustrated in Fig. 2 for a sample point between punch and sheet for a period of 0.1s during the punching strive. The variation of coefficient of friction with time during plane strain bending process based on the Stibeck curve is shown in Fig. 3 for a sample point between punch and sheet for a period of 0.1s during the punching strive. As can be seen in Fig. 3, the change in coefficient of friction varies between initial value of 0.13 reducing to 0.11 at 0.07s and increases afterward which is significant and this affects the stress distribution in sheet which in turn affects the springback. As illustrated in Fig. 3, the coefficient of friction in different points between sheet and die changes significantly during process. So it is clear that using a constant coefficient of friction as uses by Coulomb model has no predicting power and may lead to poor results for precise sheet metal forming simulations.

The amount of springback for mild steel and 6022-T4 AA in L-bending was calculated numerically using finite element program ABAQUS/Standard. The relationship between springback and the ratio of the tensile strength to the elastic modulus for $u = 20mm/s$, using different friction models is given in Fig. 4. As can be seen from Fig. 4, as the ratio of the tensile strength increases, the springback increases. The FE prediction error for mild steel and 6022-T4 AA is 22.5% and 25% respectively, using Coulomb friction model; and 13% and 16% respectively, using Stribeck friction model. So, Stribeck-type friction model predict springback better than Coulomb model.

The amount of springback at different forming speeds was measured experimentally and compared with finite element results and illustrated in Fig. 5. According to Fig. 5, the prediction of springback is improved by using Stribeck frictional model. Especially at higher forming speeds, the FEM results are very close to the experimental results. For mild steel at $u = 25mm/s$, the FE springback prediction error using Coulomb model is 23.8%. Using Stribeck friction model, this error decreases to 11%. For 6022-T4 AA at $u = 25mm/s$, the FE prediction error using Coulomb model is 25.5%. Using Stribeck model, this error decreases to 13%. This is due to more changes in coefficient of friction at higher velocities, according to Stribeck curves.

The coefficient of friction contributes to the amount of springback. During bending, the metal is forced between the lower die section and the forming punch. If the clearance between these two sections is less than the metal thickness (as it usually is), intense friction is created. The amount of friction determines how much the bend will be stretched [16]. If the inside bend radius is large enough and the metal can be stretched over it, the amount of compression is reduced or eliminated. If compression is eliminated, both sides of the radius are in tension, thus reducing the amount of springback

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[17]. Although an increase in friction may reduce the amount of springback, intense friction may results in severe wear to the die sections. For this reason, lubricants should be used.
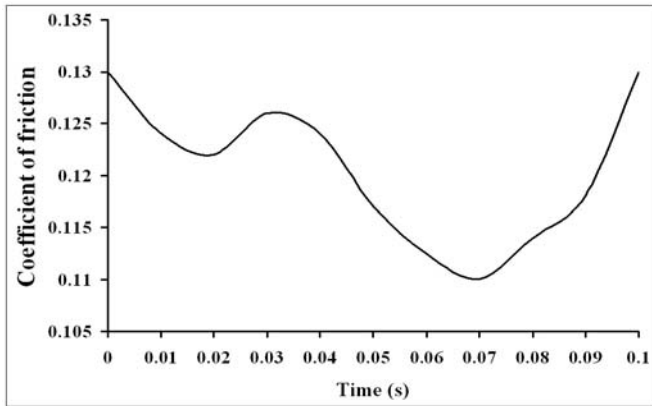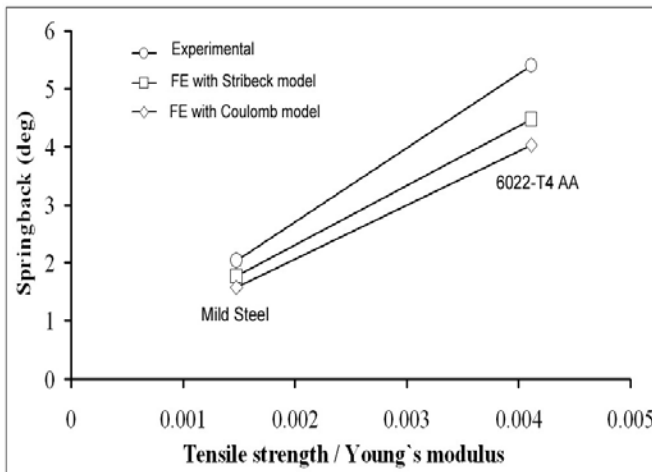
Fig. 3 Variation of coefficient of friction with time

Fig. 4 The relationship between springback and the ratio of tensile strength to elastic modulus for u=20mm/s
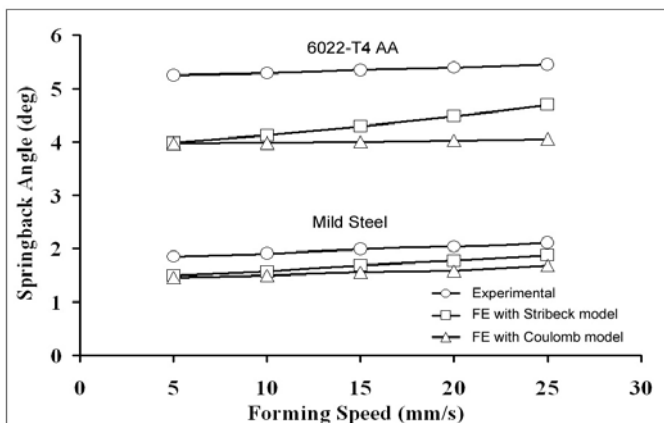

Fig. 5 Springback angle obtained from experimental and numerical analysis at different forming speeds

V. CONCLUSION

The prediction of springback in bending processes has been a challenging topic. For sheet metal forming processes, the frictional behavior depends on several parameters such as the contact pressure, sliding speed, sheet and tool material, surface roughness, lubricant and concurrent deformation. Because all of these variables influence friction, the question arises as to whether the Coulomb simple friction model is capable of describing the real frictional properties of sheet metal forming processes. In the present paper, the Stribeck friction model was used to investigate springback behavior of sheet metals under L-bending. The Stribeck curves can be calculated by varying the velocity while keeping the other operational conditions constant. The following conclusions were reached regarding the choice of stribeck friction model.

- Coefficient of friction changes during the process and has different values in different nodes and different time during the process. An accurate friction model which describes coefficient of friction as a function of local contact conditions is needed.

- Stribeck-type friction model has better results in predicting springback in sheet metal forming. The FE prediction error at $u = 20mm/s$ for mild steel and 6022-T4 AA is 22.5%, 25% respectively, using Coulomb friction model and 13%, 16% respectively, using Stribeck friction model. These results show that Stribeck model is suitable for simulation of sheet metal forming.

- Stribeck-type friction model has better results at higher forming speeds. For 6022-T4 AA at $u = 25mm/s$, the FE analysis shows 25.5% error using Coulomb model and 13% error using Stribeck model.

REFERENCES

[1] J.R. Cho, S.J. Moon, Y.H. Moon, S.S. Kang, "Finite element investigation on spring-back characteristics in sheet metal U-bending process", Journal of Materials Processing Technology 141 (2003) 109–116.
[2] Mullan HB (2004) Improved prediction of springback on final formed components. J. of Materials Processing Technology 153–154, pp. 464–471.
[3] Li KP, Carden WP, Wagoner RH (2002) Simulation of springback. Int. J. of Mechanical Sciences 44, pp. 103–122.
[4] M. Math, B. Grizelj, "Finite element approach in the plate bending process", J. of Materials Processing Technology 125–126 (2002) 778–784.
[5] Lee BH, Keum YT, Wagoner RH (2002) Modeling of the friction caused by lubrication and surface roughness in sheet metal forming. J. of Materials Processing Technology 130–131, pp. 60–63.
[6] Y.E. Ling, H.P. Lee, B.T. Cheok, "Finite element analysis of springback in L-bending of sheet metal", Journal of Materials Processing Technology 168 (2005) 296–302.
[7] F.K. Chen, S.F. Ko, "Deformation analysis of springback in L-bending of sheet metal", Journal of Achievements in Materials and Manufacturing Engineering, Volume 18 Issue 1-2 September–October 2006.
[8] Matuszak A (2000) Factors influencing friction in steel sheet forming. J. of Materials Processing Technology 106, pp. 250–253.
[9] Jacobson B (2003) The Stribeckmemoriallecture. Tribology Int. 36, pp. 781–789.
[10] Lu X, Khonsari MM, Gelinck ERM (2006) The Stribeck curve: experimental results and theoretical prediction. ASME J. of Tribology, Vol. 128, October 2006.

[11] Gelink ERM, Schipper DJ (2000) Calculation of Stribeck curves for line contacts. Tribology Int. 33, pp. 175-181.
[12] Ramezani M, Ripin ZM, Ahmad R (2009) Computer aided modelling of friction in rubber-pad forming process. Journal of Materials Processing Technology 209 (10) , pp. 4925-4934.
[13] W. Wang, R.H. Wagoner,X.J. Wang, "Measurement of Friction under Sheet Forming Conditions", Metallurgical and Materials Transactions A, Volume 27A, December 1996–3971.
[14] Wang Z, Nakamura T, Dohda K, Obika T (2003) FEM analysis of contact mechanism in press-forming of lubricant pre-coated steel sheet. J. of Materials Processing Technology 140, pp. 514–519.
[15] Hao S, Klamecki BE, Ramalingam S (1999) Friction measurement apparatus for sheet metal forming. Wear 224, pp. 1–7.
[16] Kuzman K (2001) Problems of accuracy control in cold forming. J. of Materials Processing Technology 113, pp. 10–15.
[17] Gusel L, Anzel I, Brezocnik M (2005) Effect of lubrication on the stress distribution in an extruded material. Int. J. of Advanced Manufacturing Technology, pp. 25: 288-291.