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# NUMERICAL VERIFICATION OF A NEW TEST SETUP FOR MEASUREMENT OF FRICTION COEFFICIENTS IN SHEET METAL FORMING APPLICATIONS

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## Abstract

Due to its involved physical and difficult to model phenomena, friction is preferably characterized under environmental conditions specific to the process being analyzed. For the analysis of deep drawing and stretch forming of sheet metals, there are approaches to measure friction coefficients where either the specific test equipment or an inverse engineering analysis is necessary. In this study we verify numerically a testing setup for the measurement of friction coefficients where an existing FLC testing facility is used. This facility consists of a Nakajima testing device and an optic strain measurement system. The novelty of the approach lies in the direct assessment of the friction coefficient.

**Keywords:** Sheet Metal Forming, Finite Element Analysis, Friction Coefficient

## 1. Introduction

Friction is one of the most important phenomena influential in stretch forming process, which is used to form contoured sheet parts under the application of tensile and bending forces. During this process, opposite sides of the blank material are gripped by jaws parallel to the rolling direction and the sheet is wrapped around the form die (Figure 1). Since the process does not have capability to produce deep contours, the general fields of application consist of relatively flat parts of large dimensions whereby convex forms and large radius of curvatures are needed [1]. The advantages of sheet metal stretching processes are that higher quality and stronger workpieces can be produced with reduced cost compared to other forming techniques. Stretch forming process is extensively used to manufacture aircraft's wing members, tail structures, skin parts, fuselage segments and engine components [2].By the effect of recent developments in manufacturing techniques, high demands on the metal components which are used in aerospace industry are increasing in order to fulfill the high aero-dynamical and strength requirements. These requirements bring the necessity of manufacturing complex shaped products. In the light of these facts, applications of pre-visualization of the sheet metal forming processes with finite element method become widespread and important.

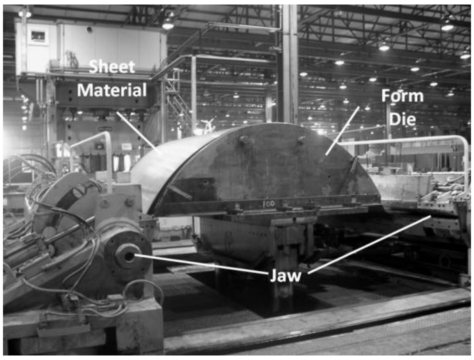


**Figure 1.**Stretch forming process

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As it is known, contact area between the blank-form die and blank-tool is quantitatively large in stretch forming operation. So that frictional forces acting between the interface of blank and tool material have great influence on obtaining the desired part. To achieve the desired contours in stretch forming, the surface of the metal is forced into contact with the die. This situation creates friction which decreases the amount of stretching that takes place. Conversely, excessive use of lubricant can cause over flow of the sheet material towards the negative contour of the die which results with wrinkling. Finite element analysis of the process which is performed to visualize possible defect before the real manufacturing requires well identified input variables (Figure 2). Since the friction coefficient is a significant input to those type of analyses, identification of accurate Coulomb friction coefficient, μ, values are prerequisites in order to accomplish successful numerical analyses.

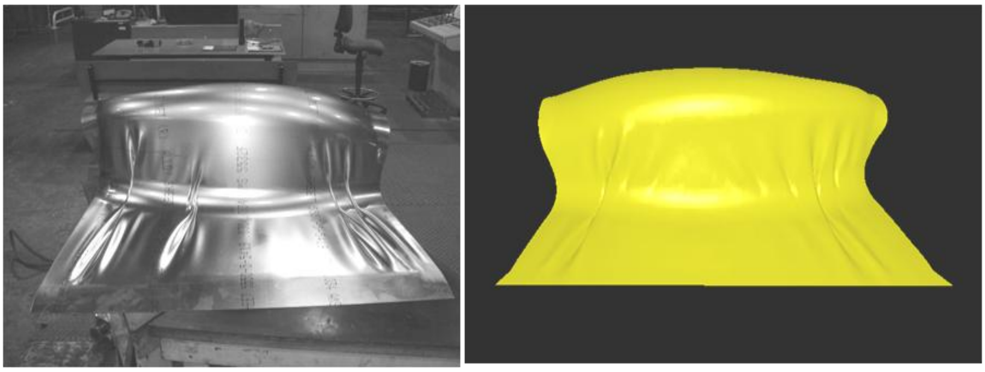

**Figure 2.**An illustration of wrinkle defect which is observed in both numerical analysis and actual process

Friction between contacting solid bodies is an extremely complicated physical phenomenon that encompasses elastic and plastic deformation of surface layers. Two friction models have commonly used to define friction condition in metal forming processes. These are Amonton-Coulomb (Equation 1) and shear friction model. Amonton-Coulomb model is the preferred friction model for cold and especially sheet metal forming processes.

$$F_f = \mu F_n \quad (1)$$

Where $F_f$ is the frictional force, $\mu$ is the friction coefficient and $F_n$ is the normal force. It is very easy to formulate Coulomb friction for forming simulations using the statement “nodal friction force is proportional to nodal normal force” [3-5].

In the literature, there are many studies performed to identify the influence of friction acting during sheet metal forming processes and these studies mostly require either the use of specific testing equipments or inverse engineering analyses.

Many inverse engineering applications are performed to obtain representative friction coefficients. Using numerical models of the process, results are obtained with different friction coefficients and these are then compared with the actual process in order to determine numerically corresponding coefficients of the friction [6-8].

On the other hand, in order to get rid of the burden of inverse engineering analysis, there are numerous fully experimental approaches[9],which are also used to identify the friction coefficients. As the common alternative of these, strip draw test is one of the most important tribotests which is used to find friction coefficient. A disadvantage that must be mentioned is that usually no stretch is present in strip-draw test[10], which is of course not realistic. Moreover, necessity of a special testing equipment for these tests is the other drawback.

Summing up, for the analysis of friction conditions especially for the stretch forming of sheet metals, either a specific test equipment or an inverse engineering analysis is necessary. In this study, we aim to show that a new approach conducted on an existing FLC testing facility maybe used to investigate the friction behaviour. The approach is verified using a numerical analysis. The simulation is the only environment where we set the friction coefficient and then evaluate the results, as if they are experimental results, in order to see whether the proposed evaluation approach can duplicate the input value of the friction coefficient.

## 2. Analytical Basis

During stretch forming process, sheet metal is curved on the forming die as shown in the Figure 3. Tensile forces are exerted by jaws, which produce normal contact pressure, *P*, at the forming tool contact interface.

The frictional shear stress is expressed with $\mu P$ where $\mu$ is the coefficient of friction. If an infinitesimal element, *ds*, is taken from a curved section, the length of the arc is expressed by the following equation;

$$ds = Rd\theta \tag{2}$$

As it is known, friction affects the flow of the sheet material. Therefore, equilibrium equation can be written for the Figure 4 which illustrates the free body diagram of a stretched sheet metal,

$$PRd\theta = T_1 \sin\frac{d\theta}{2} + (T_1 + dt)\sin\frac{d\theta}{2} \tag{3}$$

Usingthe assumption, $\sin\frac{d\theta}{2} \approx \frac{d\theta}{2}$ for small angles, Equation 3 becomes;

$$PRd\theta = T_1 \frac{d\theta}{2} + (T_1 + dt)\frac{d\theta}{2} \tag{4}$$

Ignoring higher order terms, the equation can be simplified as;

$$T_1 = PR \tag{5}$$

The equilibrium condition shown in the Figure 4, for forces along the normal direction of the sheet blank can be expressed by;

$$(T_1 + dT_1) - T_1 = \mu PRd\theta \tag{6}$$

Substituting Equation 5 into 6 gives;

$$\frac{dT_1}{T_1} = \mu d\theta \tag{7}$$

Integrating this equation between two point on the arc,

$$\int_{T_{1j}}^{T_{1k}} \frac{dT_1}{T_1} = \int_0^{\theta_{jk}} \mu d\theta \tag{8}$$

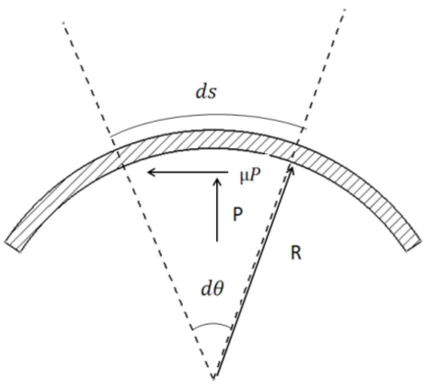


**Figure 3.** An illustration to large element of a stretched sheet

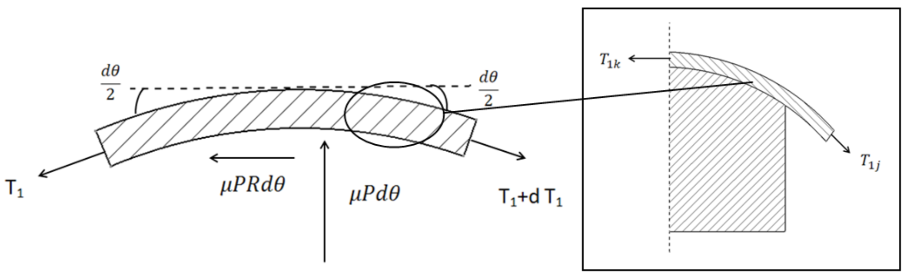


**Figure 4.** Corresponding free body diagram of a sheet segment

The well-known expression for the coefficient of friction acting in stretch forming operation can be found as;

$$\mu = \ln\left(\frac{T_{1k}}{T_{1j}}\right)/\theta_{jk} \tag{9}$$

## 3. Numerical Validation

FLC testing facility is used with a punch having a cylindrical top with 100 mm diameter (usually the FLC punch are spherical), Figure 5. The blank geometry is a standard tensile test geometry specified in ASTM E8-04 [11]. Numerical validation is performed to check the validity and reliability of the analytical approach. A commercial finite element code MSC-Marc is used for the analyses. During the analyses half symmetry is used and bilinear-Coulomb friction model is used. Simulations are repeated using different coefficients of friction which are; 0.05, 0.1, 0.25, 0.5 respectively.

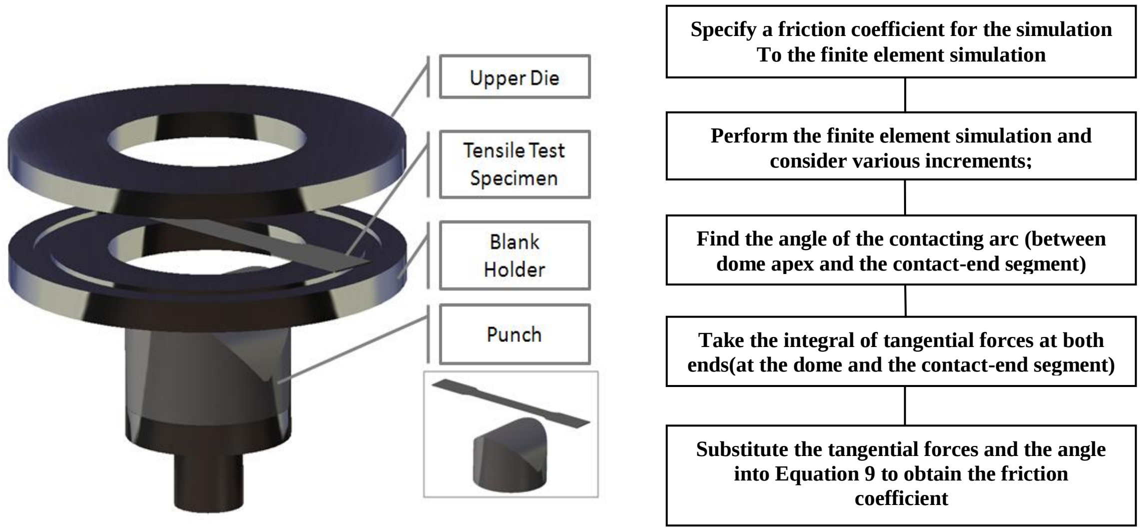


**Figure 5.** An illustration of FLC testing facility and the flow chart to describe the method to find the friction coefficient

S1 and S2 are the two sections taken from the dome apex and from the end of the contacting region of the strip, Figure 6. Tangential forces are calculated by taking force integral over these sections. Then, the angle between the two sections is calculated for each increment. Substituting these variables into Equation 9 gives coefficient of friction for the corresponding increment. As shown in Figure 7, for a range of increments the given friction coefficient could be re-computed using the simple formula (9). This agreement shows that, for a sheet material with a specified flow curve, the optic strain measurements, coupled with stress computations as developed in [12], could be used to evaluate the friction coefficient between the sheet metal and the punch material. The performance of any kind of lubrication could also be evaluated using this setup.

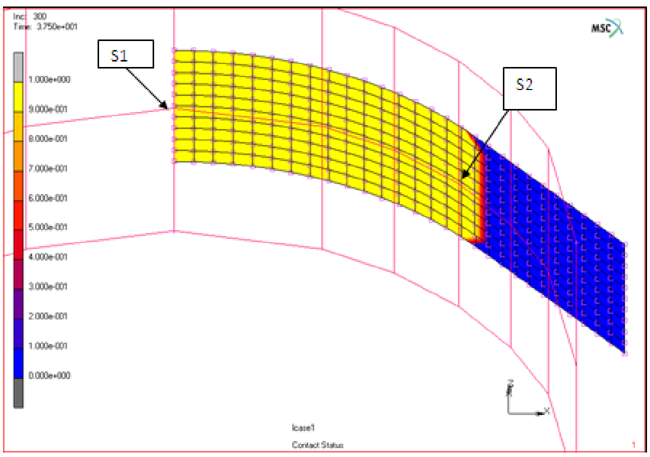


**Figure 6.** Finite element simulation and the illustration of segments S1 and S2

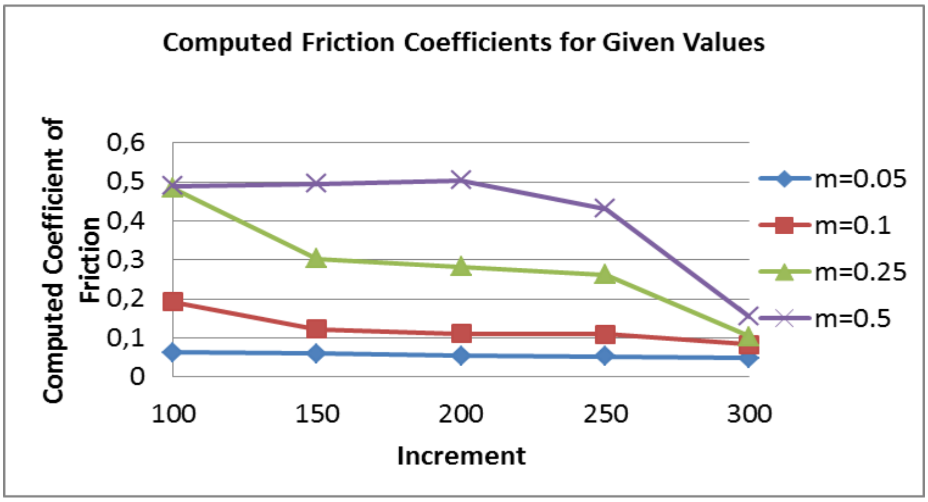


**Figure 7.** Computed coefficients of friction using finite element simulation to validate analytical model

## 4. Conclusion and Future works

In this communication, we present the early results of a study on determination of friction coefficients for stretch forming process using an analytical approach. Specifically, the validity of this approach is shown through numerical investigation of this setup. To cover a broad range for the validity assessment, this study is performed for various coefficients of friction. The results obtained from the proposed analytical model show good agreement with the friction coefficient input to the commercial finite element program.

Future works comprise of assessment of the proposed approach using an optical measurement system (GOM-Aramis) integrated on the FLC testing apparatus. With the mentioned optic measurement system, dome height, distribution of major-minor strains, geometry and displacements can be measured accurately.

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## References

1. Wick C., Benedict J., Veilleux R., Tool and manufacturing engineers handbook-Forming, SME, Fourth Edition.
2. Lange K., Handbook of Metal Forming, Society of Manufacturing Engineers (SME), First Edition, U.S.A., 1975.
3. M.S. Joun, H. G. Moon, I. S. Choi, M. C. Lee, B. Y. Jun., Effects of friction laws on metal forming processes Tribology International 42 (2009) 311–319.
4. Subramanion S., Evaluation of lubricants for stamping deep draw quality sheet metal in industrial environment. Thesis, Ohio State University, 2009.
5. Celik G., Experimental investigation of influence parameters on forming limit diagrams of aluminum alloy-AL 2024. Thesis, Atılım University, 2010.
6. Hatipoglu H., Polat N., Köksal A., A methodology to determine friction coefficient in Fluidcell forming process. Steel research Int 81 (2010) No:9 (640-642),2010.
7. B. H. Lee, Y.T.Keum, R. H. Wagoner, Modeling of the friction caused by lubrication and surface roughness in sheet metal forming. Journal of Material Processing Techonology, 130-131 (2002) 60-63.
8. R. Grueebler, P. Hora., Temperature dependent friction modeling for sheet metal forming. Int J Mater Form (2009) Vol. 2 Suppl 1:251-254.
9. Kim H., Altan T., Yan Q., Evaluation of stamping lubricants in forming advanced high strength steels using deep drawing and ironing tests., Journal of Materials Processing Technology 209 (2009) 4122–4133.
10. Wojtowicz W. J., Sliding friction test for metalworking lubricants. Lubrication Engineering, 11 (1955) 3, 174-177.

11. ASTM International Standards, Standards for Tensile Testing, ASTM E8-04, 2004.
12. Coruk E., Karadoğan C., Flow Curve Evaluation by Optic Strain Measurements and Force Balance at the Most Critical Section in the Neck Region of a Tensile Specimen, Steel Research International, pp. 714-719, Sept. 2011.