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Numerical Modelling of Drawbeads for Forming of Aluminium Alloys

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Abstract. The drawbeads in stamping tools are usually designed based on experience from the forming of steel. However, aluminium alloys display different forming behaviour to steels, which is not reflected in the drawbead design for tools used for stamping aluminium. This paper presents experimental results from different semi-circular drawbead geometries commonly encountered in automotive dies and compares them to those obtained from Stoughton's analytical drawbead model and the 2D plane strain drawbead model set up using LS-DYNA. The study was conducted on lubricated NG5754 strips. The results presented are in terms of drawbead restraining force versus strip displacement, as a function of drawbead depth. The FE drawbead model agrees well with the experiments whereas the analytical model overpredicted the drawbead forces.

1. Introduction

The significance of drawbeads in automotive sheet metal forming operations has been illustrated in [1]. The drawbead restraining force, hereafter referred to as restraining force, is the braking force experienced by the strip when it is drawn through the drawbeads. It is the sum of the bending and unbending forces and sliding friction forces. Drawbeads can locally control the sheet metal flow in drawing of complex non-axisymmetric automotive components and offer a distinct advantage of imparting a higher restraining force to the blank without a significant increase in the blank size and overall blankholder force. The tensile force exerted on the blank reduces the circumferential stresses which cause wrinkling [2] and helps in achieving stretch in the part to increase its impact strength. Even though aluminium alloys, because of light-weighting initiatives, have been of particular interest in the automotive industry, the drawbead design guidelines for automotive forming are based on forming of steels [3] and may not be appropriate for forming of aluminium alloys [4].

Trial and error experiments to determine the optimum drawbead geometry for a complex automotive part and for new sheet materials is an onerous task. Therefore, several analytical and FE drawbead models were developed to predict the restraining force and the blankholder force taking into account the effect of drawbead geometry, sheet material properties, and the process parameters. Tufecki et. al. [5] analysed drawbead force models and concluded that the Stoughton drawbead force model agreed well with the drawbead strip draw experiments performed in line with the experiments conducted by Nine [6] on AKDQ steel, rimmed steel, and 2036-T4 aluminium test strips. The Stoughton model [7] attempts to not only predict the restraining force and the blankholder force but also the calculation of the effective bending radius of the strip and hence, suits partial and full drawbead penetrations. The model uses constants which directly relate to mechanical parameters obtained from a tensile test and is a good formulation for understanding the significant factors in drawbead design.

It has been demonstrated that 2D plane strain models for drawbeads give an agreeable prediction of drawbead forces [8] if the width of the sheet is significantly larger than the thickness. Findings from an extensive review [1] also confirmed that 2D plane strain drawbead models are able to reflect the local deformation behaviour and allow the use of both linear and non-linear contact models to define dynamic friction conditions.

The aim and scope of this paper are to determine a suitable approach for predicting restraining forces required in drawbead design by comparing the Stoughton analytical restraining force model with a numerical 2D plane strain drawbead model and drawbead strip-draw experiments.

2. Research methodology

2.1 Experimental set-up

The experiments were performed on a new drawbead tool, based on Nine's design [6]. The layout can be seen in figure 1. Four drawbead depths 'd', were used; 3.9mm, 5.8mm, 8.7mm, and 11mm. The strips were drawn at 85mm/s and a blankholder force of 15kN was applied to ensure that the blankholder remain closed. Aluminium NG5754 strips, 500mm long, 50mm wide and 1.5mm thick were carefully deburred and lubricated with a synthetic forming lubricant having a viscosity of 244.5mm^2/s at 20°C, with a coat weight of 1.5±0.5gm/m^2. The strips were drawn in the rolling direction on both, roller drawbead and fixed drawbead set-ups. The roller drawbead set-up approximates frictionless conditions. Each experimental run was repeated twice to account for the measurement error.

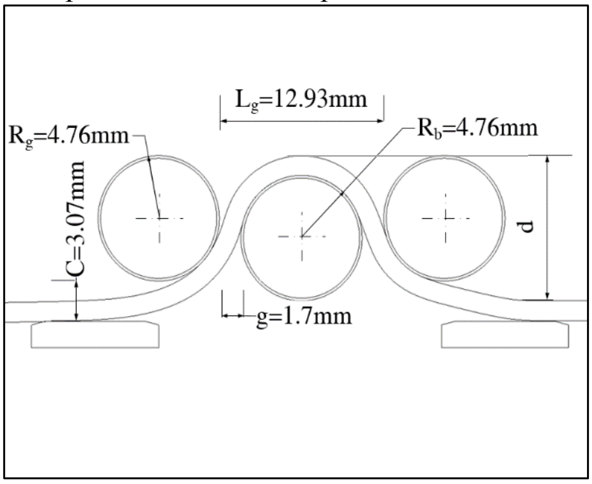

Figure 1: Drawbead geometry used in experiments and simulations

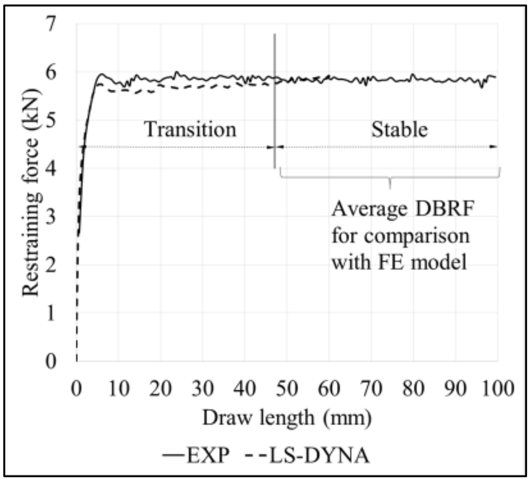

Figure 2: Restraining force as a function of draw length, NG5754, μ=0, depth=8.7mm

2.2 FE Model set-up

A drawbead model as shown in figure 1, closely representing the experimental set-up was built in LS-DYNA where the groove and the drawbead are modelled as rigid steel tools with a fine mesh and the strip had a 0.3mm square mesh with 5 elements through the thickness for better discretization. A 2D plane strain element type ELFORM 13 with 4 integration points was chosen. As the restraining force in the experiment stabilized after 50mm, figure 2, the draw length in the FE model was set to 60mm to reduce the computational time. The material flow curves used in the model were obtained from the uniaxial tensile test in the rolling direction. Voce hardening rule ($\sigma_0 = 117 + (319 - 117)(1 - e^{-12.4\epsilon})$, where σ_0 is the flow stress in MPa and ϵ is the effective plastic strain) was used to generate the flow stress curve used in LS-DYNA's MAT_24. The Coulomb friction model ($\tau = \mu p$, where τ is frictional shear stress, μ is the coefficient of friction and p is the contact pressure) was used to define friction in the FE model. For the Stoughton analytical drawbead model, a Hollomon hardening rule ($\sigma_0 = 459\ \epsilon^{0.28}\ MPa$) was used. Other material properties are given in table 1.

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Table 1: NG5754 material properties

Density (kg/m^3)	Young's modulus (MPa)	Poisson's ratio	Lankford coefficient
2700	70000	0.33	0.67

3. Results and discussion

Figure 2 shows the restraining force obtained from the drawbead strip-draw experiment and the FE model. Figures 3a and 3b compare the restraining forces obtained from the drawbead strip-draw test, the 2D plane strain FE model and the Stoughton model for μ of 0 and 0.15 respectively. It can be seen that apart from the lowest and highest drawbead depths, the results from LS-DYNA agrees reasonably well with the experiments. The FE model follows the linear relationship between the restraining force and the drawbead depth as established by the experiments. However, the Stoughton drawbead model overpredicted the restraining force for both, the friction and the frictionless case. The model also showed a slightly non-linear trend.

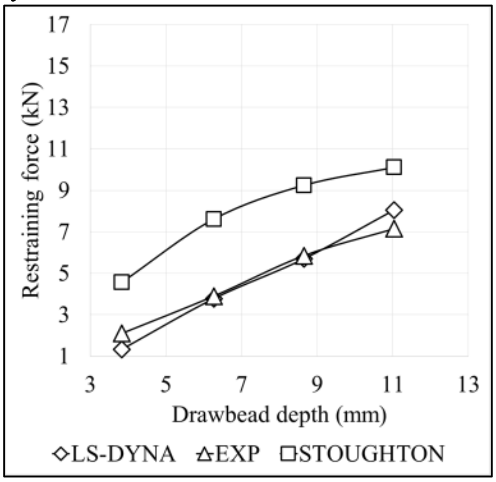

Figure 3a. Restraining force, μ=0

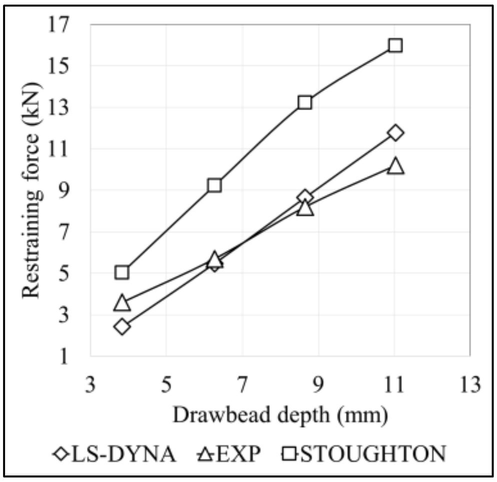

Figure 3b. Restraining force, μ=0.15

As illustrated in figures 4a and 4b, at the lowest drawbead depth of 3.9mm, there are only 3 strip nodes in contact and more than 24 nodes for the depth of 8.7mm. Therefore, the contact definition at the lowest depth is poor which may have led to smaller restraining forces simulated by LS-DYNA. At the highest depth, the FE model showed larger effective plastic strain in the strip, approximately 0.67, due to bending and unbending effect. This value is substantially higher than 0.19 which was observed at the point of instability in the uniaxial tensile test. It can be argued that LS-DYNA extrapolated the flow curve beyond effective plastic strain of 0.19 to obtain the effective stress at an effective plastic strain of 0.67 which resulted in the overprediction of the restraining force.

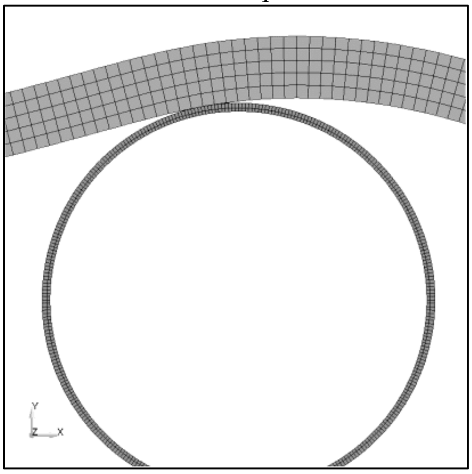

Figure 4a.Contact at d=3.9mm,μ=0.15

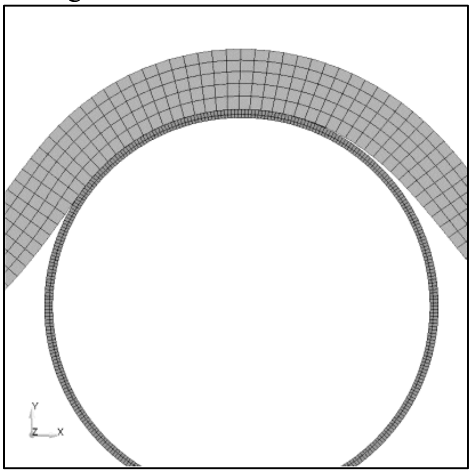

Figure 4b.Contact at d=8.7mm,μ=0.15

The coefficient of friction value was determined from the FE model by trying different values until satisfactory correlation with the results from the fixed drawbead strip-draw experiments was obtained. The coefficient of friction of 0.15 agreed well with experiments. While attempting to derive a coefficient of friction from the simulation, it was observed that no single value of the coefficient of friction gave good agreement with experimental results. This was in line with the Nine's formula [6] which gave lower coefficients of friction for increasing drawbead depth. Also, Ren [9] stated that a single coefficient of friction did not match the entire range of drawbead depths in the simulations and suggested a contact pressure based non-linear friction model which outputs lower coefficients of friction for higher drawbead depths. Both [6] and [9] contradict Coulomb's linear friction model and indicate that friction representation could be a significant source of variation in the simulated restraining forces. If this is true, then the restraining forces predicted by the FE model with μ=0, should agree with the results from roller drawbead strip-draw experiments. It can be seen from figure 3a that there is some difference between the simulated and experimental restraining forces for the frictionless case at lowest and highest depths. This difference increases in the presence of friction instead of helping in achieving a good correlation as illustrated in figure 3b. Hence, the Coulomb friction model can be appropriately applied in numerical modelling of sheet metal flow over drawbeads. However, a good contact definition must be ensured while simulating lower drawbead penetrations and applying a flow curve with larger effective plastic strains obtained from materials tests, for example, Watts-Ford test, may be beneficial.

4. Conclusion

In this paper, the Stoughton analytical drawbead model and an FE model of the drawbead strip-draw test were compared with the drawbead strip-draw experiments which were conducted on lubricated NG5754 aluminium strips. The Stoughton model significantly overpredicted the restraining forces whereas the numerical 2D plane strain drawbead model accurately predicted the restraining forces, especially for the drawbead depth ranging from 5.8mm to 8.7mm. For the both friction cases, μ=0 and μ=0.15, the FE model predicted a smaller restraining force at the lowest drawbead depth and overpredicted the restraining force at the highest drawbead depth. With proper contact definition for lower drawbead penetrations and an experimental flow curve with larger effective plastic strains, a 2D numerical plane strain model with Coulomb's friction law can reasonably predict the drawbead restraining forces.

5. References

[1] Xu S G, Bohn M L and Weinmann K J 1997 Drawbeads in Sheet Metal Stamping - A Review *SAE International*

[2] Zharkov V A 1995 *Theory and practice of deep drawing* (London: Mechanical Engineering Publications)

[3] Lange K 1986 *Handbook of Metal Forming* vol 4 (Springer-Verlag)

[4] Li R and Weinmann K J 1999 Formability in Non-Symmetric Aluminium Panel Drawing Using Active Drawbeads *CIRP Annals - Manufacturing Technology* **48** pp 209-12

[5] Tufekci S S, Wang C-T, Kinzel G L and Altan T 1994 Estimation and Control of Drawbead Forces in Sheet Metal Forming *SAE International*

[6] Nine H D 1978 *Mechanics of Sheet Metal Forming,* ed D Koistinen and N-M Wang: Springer US) pp 179-211

[7] Stoughton T B 1988 Model of drawbead forces in sheet metal forming In: *15th IDDRG,* (Dearbon, USA) p 205

[8] Carleer B D, Meinders T and Huetink H 1996 Equivalent drawbead model in finite element simulations In: *NUMISHEET '96, Third International Conference on Numerical Simulation of 3D Sheet Metal Forming Processes,* ed J K Lee, *et al.* (Dearborn, Michigan) pp 25-32

[9] Ren F, Chappuis L and Xia Z C 2009 Drawbead Restraining Force Modeling: Nonlinear Friction *SAE Int. J. Mater. Manuf.* **2** pp 530-6