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Influence of the pressure dependent coefficient of friction on deep drawing springback predictions

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ABSTRACT

The aim of this work is to show the influence of defining a pressure dependent friction coefficient on numerical springback predictions of a DX54D mild steel, a HSLA380 and a DP780 high strength steel. The pressure dependent friction model of each material was fitted to the experimental data obtained by Strip Drawing tests and then implemented in the numerical simulation of an industrial automotive part drawing process. The results showed important differences between defining a pressure dependent or a constant friction coefficient. Finally, the experimental part was produced to compare the real geometry with the predictions obtained with the different simulation strategies. An improvement of 20–25% in springback prediction was achieved when using the pressure dependent friction model.

1. Introduction

The automotive industry demands very short delivery periods. This leaves no margin for errors that could prolong the time that die suppliers have to fulfill the requirements of their clients. Accurate die designs reduce the need for subsequent redesigns, thereby decreasing time and manufacturing costs. Current design procedures are based on numerical simulations that predict the behavior of sheet metal parts with the aim of achieving more efficient manufacturing processes.

Furthermore, in the assembly lines of the automotive industry most of the joints between components are handled by automatic robotic arms. This requires geometric tolerances to be increasingly strict. For this reason, the springback phenomenon is of great importance. Springback is defined as the elastic recovery that the part suffers after being deformed to a determined shape. The accurate prediction of springback is one of the biggest issues in stamping and a lot of research has been done in this topic in recent years [1]. Previous works state that the use of kinematic hardening models [2], advanced anisotropy constitutive models [3] and Young modulus degradation models [4] significantly increases the accuracy of the numerical springback prediction. Apart from the material parameters, springback is mainly influenced by the meshing quality of the numerical simulation [5] and the coefficient of friction (COF) definition [6].

In a deep drawing operation, three main tools are involved: the punch, the die and the blankholder. In these dies two areas can be distinguished; the die cavity area, where the sheet is deformed to the required shape of the part, and the blankholder area, where the flow of the material is restricted. In this area, the drawbeads in combination with the friction forces determine the restriction forces that the material has to overcome to flow into the die cavity. By this way, the draw-in of the material is controlled and in consequence the strain and stress distribution of the sheet. So the COF is critical in the blankholder area as it is the zone where the maximum flow of the material occurs.

The COF is a significant parameter to take into account when trying to obtain accurate predictions in numerical simulation [7]. As it is explained in the previous paragraph, the COF influences the restriction level of the material flow through the tools and an inaccurate definition of the parameter generates wrong predictions such as splits, insufficient deformations and, moreover, unexpected springback phenomena. A lower COF induces lower stress-states and as a consequence higher elastic recovery [6]. Therefore, it is necessary to correctly define the COF in order to accurately predict the final geometry of the component through the numerical simulation.

Traditionally, the COF has been considered to remain constant during the drawing process of a component. However, some studies discussed the possibility of applying different constant COF for each surface that is in contact with the sheet [8]. More recent tribological studies have revealed that the COF is affected by several contact features. In this way some authors have developed variable COF models based on micro-scale contact behavior [9,10]

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or macro-scale [11,12] ones. In both cases there is a generalized agreement that one of the most important parameter affecting the COF is the contact pressure [13]. As the contact pressure is increased, the irregular topography of the contact surfaces are subjected to a flattening of each asperities, so the contact geometry changes resulting in a change of the COF [14]. This is an important effect to take into account since in drawing processes, the blankholding force remains constant but the contact pressure applied to the sheet increases as the flange area decreases while the material flows into the die cavity. Moreover, the thickness changes differently in each area of the sheet with the flow of the material causing a heterogeneous contact pressure distribution along the sheet. Therefore, the contact pressure varies continuously during the drawing.

Asgari et al. [15] studied the influence of the coefficient of friction on an industrial B-Pillar automotive part and concluded that it was not relevant for the springback prediction. Other researchers disagreed and demonstrated that the COF has a great importance on the prediction of the springback [16]. In terms of the robustness of springback predictions Souza et al. [17] determined that springback results are more sensitive to high friction values than to low ones. Lee et al. [18] have also recently studied the influence of implementing a variable COF on the springback prediction of a U-bending test. However, it has not been analyzed yet the effect of a variable COF on a real industrial component where the contact pressure is not homogeneous on the blankholding area.

In this work, the effect of a pressure dependent COF model in the springback prediction of an industrial component is analyzed. For that, the effect of three friction models, two models with constant friction values and one pressure dependent model were compared. In order to characterize the COF behavior on the blankholder area, Strip Drawing tests at different pressure values, ranging from 1 MPa to 16 MPa, were carried out and then a pressure dependent model was fitted to the experimental results. The effect of each friction model was numerically analyzed on a B-Pillar reinforcement component using three different steel grades: a DX54D mild steel (0.7 mm thickness), a HSLA380 (1.05 mm thickness) and a DP780 high strength steel (1.3 mm thickness). Finally, the numerical results were compared to the geometry of a manufactured B-Pillar reinforcement in order to determine the most promising model in terms of springback prediction accuracy.

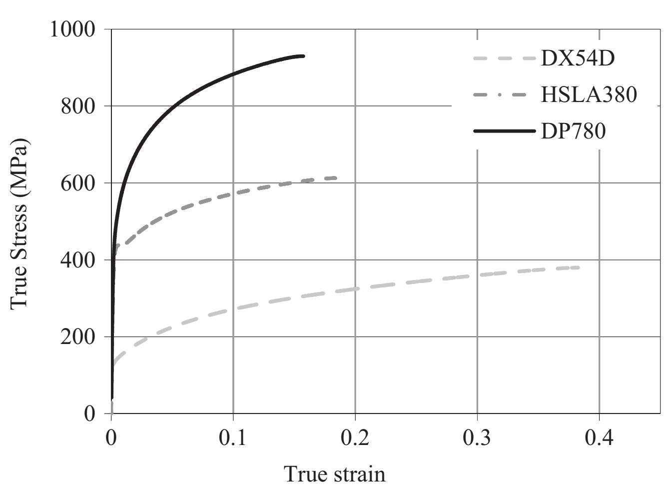

Fig. 1. Tensile test curves of the three materials studied in rolling direction.

2. Mechanical characterization

The materials studied in this work were characterized following the ASTM E8-04 standard tensile tests. The selected materials cover a wide range of strength from a mild steel of around 150 MPa of yield strength up to a high strength steel of about 500 MPa of yield strength (Fig. 1). These results were used for the material definition in the numerical simulation.

In Table 1 the summary of the most important parameters of the materials is shown. As it can be seen, the DX54D and DP780 are coated by hot dip galvannealed, while the HSLA380 is a non-coated sheet.

3. Friction characterization

The friction characterization was carried out using the Strip Drawing test [13]. The tests were conducted using a biaxial testing machine of 4 independent 25 t hydraulic cylinders. One of the cylinders made the clamping force while the other cylinder pulled the sheet tangentially to the surface of the blocks, as set out in Fig. 2.

The cadency of the deep drawing of the component was about 10 strokes per minute. Since the maximum draw-in was 36 mm the sliding velocity of the material was estimated to be around 10 mm/s. In order to reproduce the same conditions, the Strip Drawing tests were carried out in a constant velocity of 10 mm/s. The tests were performed at contact pressures ranging from 1 to 16 MPa and using pre-lubricated sheets by MULTIDRAW PL 61 SE (1.5 g/m^2) without any additional lubrication.

The pressure range was defined in concordance with the observed contact pressures at the blankholding area in the numerical simulations. Fig. 3 shows the contact pressure distribution along the sheet. As it can be seen, the major sheet area is under low contact pressures. However, due to the local thickening of the sheet on some blankholding areas, the contact pressure arises up to 16.7 MPa at a determined moment of the process.

The material and the surface roughness of the blocks used in the Strip Drawing tests were the same as the ones used in the die and the binder of the experimental drawing process. The blocks were manufactured using a GGG70 tempered grey iron and the surface roughness was about 0.4 μm achieved through industrial

Table 1
Strength of steels, uniform elongation, r-value, roughness, thickness and steel type.

Material	Rp0.2 (MPa) Yield Strength	Rm (MPa) Ultimate Tensile Strength	Ag (%) Uniform elongation	$r_0/r_{45}/r_{90}$	Roughness (Ra)	Thickness (mm)	Steel type and surface coating
DX54D	153	309	27.8	1.87/1.75/1.56	1.33	0.7	Mild Steel hot dip galvannealed
HSLA380	439	519	23.7	0.76/1.14/0.77	1.51	1.05	High Strength Low Alloy no coating
DP780	490	786	12.6	0.76/0.89/0.82	1.19	1.33	Dual Phase hot dip galvannealed