Enhancement of springback prediction of AHSS parts by advanced friction modelling

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Abstract. The complex springback behaviour of advanced high strength steel parts makes a robust manufacturing process challenging, mainly in terms of part dimensional accuracy. Therefore, an accurate springback prediction using sheet metal forming simulation is of great importance to realize reliable forming processes and to achieve the target geometry. An accurate springback prediction requires an exact computation of the elastic stresses from the plastic deformations, which can be influenced among others by the retention of the sheet metal and the frictional properties of the parts. However, the frictional behaviour in the forming process has been often simplified by using a constant friction coefficient in the simulation, which could lead to a significant deviation in the springback prediction. To address this limitation, TriboForm software provides an advanced friction model in which friction is a function of several process setting parameters, namely pressure, strain, temperature and velocity. In this contribution, the advanced friction models for DH800 and CP800 materials are generated. Compared to a constant friction coefficient of 0.15, it is found that the prediction of flange angle of deep drawn hat profiles, produced by several blank holder forces, can increase up to 70% and of the sheet’s draw-in up to 10%.

1. Introduction
Increased safety standards and the additional weight of electric drive concepts pose great challenges of today’s lightweight car body structures. For this reason, the development of new steels has concentrated on increasing strength in order to achieve weight savings by reducing sheet thickness. These requirements are often met by the so-called advanced high strength steels (AHSS). However, the application of AHSS is associated with further challenges, such as the control of the complex springback behavior, which makes a robust manufacturing process more difficult [1]. In this context, an accurate springback prediction using sheet metal forming simulation is of great importance to achieve dimensional accuracy of the parts. In order to improve the springback prediction, efforts have already been made to map the material behaviour of AHSS [2]. Especially the consideration of phenomena such as the Bauschinger effect and the reduction of the tangent modulus have shown a significant improvement of the springback prediction, which is related to an enhanced computation of the elastic
stresses from the plastic deformations [3]. Beside these aspects, the computation of the elastic stresses is influenced by the retention of the sheet metal and the tribological condition during forming process [4]. However, the tribological conditions in industrial forming simulation is often simplified by using a constant friction coefficient of 0.15 [5, 6]. This could lead to a significant deviation in the springback prediction [7]. To address this limitation, TriboForm software provides an advanced friction model in which friction is a function of several process setting parameters, namely pressure, strain, temperature and velocity. Previous studies have already shown an improvement in the predictions of sheet’s draw-in, failure and springback using the advanced friction model [7, 8]. In this study, first the tribological properties of two AHSS, namely DH800 and CP800 while lubricated with a drawing oil, are determined to consequently generate the advanced friction models of these tribology systems. Subsequently, these friction models are used as an input into the forming simulations to compare the experimental and simulation results for both the simplified and advanced friction models.

2. Materials and experimental procedure

2.1. Materials

A dual-phase steel and a complex phase steel with tensile strength of about 800 MPa are investigated: CR440Y780T-DH GI50/50-U (trivial name DH800) and CR570Y780T-CP GI50/50-U (CP800) according to VDA 239-100. The abbreviation DH denotes a dual-phase steel with higher ductility, which is attributed to the retained austenite in the microstructure. Both sheet metal surfaces are produced by rolls created by electro discharge texturing process (EDT) and are hot dip galvanized. The nominal sheet thickness of both sheets is 1.5 mm. The mechanical properties are determined using the uniaxial tensile test with three repetitions (n) for each material. The direction of loading corresponds to the rolling direction. Table 1 summarizes the main mechanical parameters obtained from the tensile test.

| Material | n | Yield stress [MPa] | Tensile stress [MPa] | Uniform elongation [%] | Tangent modulus [GPa] | Work hardening exponent n2-20\Ag | Anisotropy value r0\Ag |
|----------|---|------------------|---------------------|------------------------|-----------------------|-------------------------------|----------------------|
| DH800    | 3 | 466 ± 5          | 787 ± 4             | 16.7 ± 0.33            | 212 ± 1.65            | 0.208 ± 0.002                | 0.674 ± 0.05         |
| CP800    | 3 | 684 ± 7          | 844 ± 5             | 7.4 ± 0.16             | 203 ± 1.89            | 0.088 ± 0.002                | 0.805 ± 0.02         |

2.2. Modelling of tribological conditions

To generate the advanced friction models, first a series of calibration tests consist of friction tests and 3D surface measurements are performed on the lubricated strips of both sheet materials. These calibration tests are merely aimed to determine the intrinsic tribological properties of these two tribology systems namely the interfacial shear strength at the sheet – lubricant – die interface. Then, these properties are used as input for the TriboForm Solver to predict tribological conditions by physical-mathematical models under a wider range of lubrication amounts, roughnesses and process settings [9]. For this purpose, the strip drawing tests are performed by Tribometer 5000 series from Raziol Zibulla & Sohn GmbH. The lubricated sheet metal strips with the lubrication amount of 0.5g/m² is applied to characterize the chemical interaction between mating surfaces and the lubricant at the interface during calibration while minimizing the hydrodynamic effect of lubricant. The lubricant type is Multidraw ALS 40 from Zeller + Gimelin GmbH & Co. KG and the tool material is tool steel 1.2379. Physically determined friction coefficients from the tests for both materials are demonstrated in figure 1(a). Furthermore, the surface roughness and topography of both un-deformed and deformed sheet metal strips under different loading conditions, normal load versus sliding, are determined by using optical 3D surface measurements (figure 1(b) and (c)). In addition, 3D surface measurements are performed on the tool surfaces to determine the surface roughness and topography, which are also given in the figure 1(b). The testing results of both tribology systems show a clear pressure-dependent effect by a lower friction
The comparison between the two AHSS sheet metals shows consistently lower friction coefficients for the CP steel.

![Figure 1. Measured friction coefficient by strip drawing tests (a), surface roughness values of used sheet materials and tools (b) and measured surface of virgin DH800 (c)](image)

2.3. Experiments and parts

Firstly, the blanks for the hat profiles are cleaned and freed from lubricants in the as-delivered condition. This prevents any influence on the subsequent lubricant application. Blanks are lubed by an automatic lubrication device from Raziol Zibulla & Sohn GmbH. The lubrication amount of about 0.8 g/m² is applied on both sides of the blank. The tool set consisting of a die, a punch and two blank holders as well as the schematic forming process are shown in figure 2(a). The forming process represents a combination of stretching and bending of the material over the tool radii. During forming, the sheet is restrained at the bottom of the hat profile by the leading blank holder 1 and then at both sides of the sheet by blank hold 2 until the complete drawing depth of the hat profile is reached. While the force of blank holder 1 is kept constant with 660kN, the force of blank holder 2 is varied between 200kN and 800kN. The springback is evaluated by six flange angles as shown in figure 2(b). The flange angle includes the geometric deviations of the entire component and thus describes the global springback behavior. The reference geometry represents a hat profile with a horizontal flange and is used for counter measurement in optical measuring system by GOM Atos.

![Figure 2. Tool set and forming process schematically (a) Shape of the hat profile and demonstration of flange angles and draw-in (b)](image)

To determine the sheet’s draw-in, the mesh of the digitalized part by GOM is imported into the CAD system Siemens NX, in which the surface after springback is unrolled by means of a section curve onto
the tool geometry. Subsequently, the distance between the unrolled end of the flange and the edge of the initial blank corresponds to the sheet’s draw-in. Figure 3 demonstrates the formed hat profiles and the associated evaluation parameters. One conspicuous observation is that the flange angle and draw-in of the hat profiles of DH800 is almost not affected, although the retention of the sheet has been increased by the blank holder force.

Figure 3. Test components produced by varied blank holder force (a) as well as determined flange angle and draw-in (b)

3. Simulation conditions and results

3.1 Framework

The mechanical properties in the material maps are adapted using the results from the uniaxial tensile tests from the table 1. The isotropic kinematic hardening is taken into account using the AutoForm model, which is developed by approaches of Kubli et al. [3]. Based on the results from tension-compression tests, the model parameters for isotropic kinematic hardening is approximated and used in the simulation. Other models used in the material map are listed in table 2.

| Extrapolation Hardening Curve | DH800 | CP800 |
|-------------------------------|-------|-------|
| Yield Criterion               | Hill90| BBC2005|
| Kinematic Hardening           |       | AutoForm Model |
| Element Type                  |       | Elastic-plastic shell |

The resulting TriboForm friction models are imported into the AutoForm R8.0 in conjunction with the TriboForm FEM Plug-In for AutoForm. Hence, it is possible to compare simulations results between using a constant coefficient of friction (μ = 0.15) and an advanced friction model. Furthermore, to incorporate a realistic pressure distribution to accurately calculate the resulting friction as a function of normal stress, the pressure distribution of the blank holder force is computed by taking the position of the force-introducing pins into account.

3.2 Friction modelling

The TriboForm software allows for multi-scale modelling of a time and spatially varying friction coefficient under a wide range of process conditions. Section 1.2 described the procedure to generate the advanced friction model which includes the tribological conditions for the considered tribology systems. The resulting TriboForm friction models are a function of local contact pressure, straining of the sheet material, relative sliding velocity and interface temperature. Furthermore, the detailed
specification of tribology system including the sheet and tool surface roughness and lubrication amount (0.8g/m²) are defined. Figure 4 shows the resulting friction models for DH800 (Sa=1.25µm) and CP 800 (Sa=1.15µm) for the tool roughness of 0.83µm which shows strong pressure and strain dependency. Velocity and temperature dependencies are negligible due to the relatively low amount of lubrication.

Figure 4. The advanced friction models for DH800 (a) and CP800 (b) are shown as a function of velocity, pressure, and stain. Each plain represents one value of strain (0 to 0.2).

3.3 Springback prediction

Figure 5 shows the deviations of the predicted flange angle and sheet’s draw-in by the forming simulations with the constant coefficient of friction and advanced friction models compared to the optical measurements of the test components. For the smaller blank holder force of 200kN, the predictions of the flange angles for both models are comparable for the DH800, whereas for the CP800 the angle is slightly overestimated by the advanced model. A significant improvement of the springback prediction using the advanced friction modeling is evident, when the blank holder force is increased to 800kN with about 60% and 70% for DH800 and CP800, respectively. Worth to be mentioned is a consistent deviation level of the predictions by the advanced model compared to the simplified model, which significantly reduced the scatter between the predictions. A similar trend can be seen in the prediction of the sheet’s draw-in. As it can be seen in the figure 5(b), the enhancement by using TriboForm friction models is about 10% for the DH800, and about 6% for the CP800. Contrary to the flange angle, the prediction of draw-in is improved for both 200kN and 800kN. It is interesting to note that the prediction accuracy for the flange angle is reduced slightly for the CP800, while the prediction accuracy for its draw-in is increased simultaneously by making use of TriboForm. To clarify this, further investigation on the local springback at the sidewall and radii is needed. Furthermore, they must be related to the accuracy of the material mapping for the simulation.

Figure 5. Prediction of flange angle (a) and draw-in (b) by the simplified and advanced friction model for different blank holder forces
In the following, four parameters are selected to illustrate the influence of the friction models on the subsequent springback prediction. The contact and tool pressure are generated due to the blank holder forces and part radii. The friction shear stresses are caused by the relative movement between the sheet and tool surfaces when normal forces are acting. Depending on that, the magnitude of plastic strains is changed, which is considered here by the equivalent plastic strain. All evaluation values are visualized in figure 6(a) on a central section through the part before springback. The results are shown for one half of the component due to part symmetry. The intersection curves show differences between the simulations with simplified (dashed lines) and advanced (solid lines) friction models. Compared to the simulation with a constant friction coefficient of 0.15, the considered parameters change as follows when TriboForm is applied: While slightly smaller pressures are predicted at the part radii, higher pressures are predicted at the flanges due to the computation of an increased draw-in. In contrast, the component shows significantly lower friction shear stresses at the flanges and at the radii as well. The reason for this are the lower friction coefficients that result primarily due to high pressures applied here. Based on this, the sheet retention is greatly reduced, hence the applied plastic strain is reduced due to the yield stress or hardening stress not being reached. Remarkable is the disappearing plastic strain component in the flange of the hat profile for the DH800, whose yield point is consequently not reached due to reduced sheet metal retention.

For an accurate springback prediction, the stress state before unloading and the unloading behavior itself are decisive. The former is further influenced by the changing magnitude of the friction shear stresses and the strains implied by them. Furthermore, the unloading behavior is determined by the magnitude of the elastic strains, which increases as the tangent modulus decreases with progressing strain [11].

Figure 6. Intersection curves for the evaluated parameters contact and tool pressure, friction shear stress and plastic strain (a); friction shear stress and plastic strain colored for hat profiles of DH800 for the applied friction models (b)

Figure 7 shows the influence of friction modeling on the stress state before springback and the magnitude of elastic strains by the degradation of the tangent modulus. In figure 7(a), the stresses acting in the
direction of material flow across the sheet thickness from top to bottom side is listed at one shell element in the lower part of the component’s sidewall. Especially, at the top side of the blank, the compressive stresses take over a larger area across the sheet thickness causing the neutral fiber to be displaced towards the center of the sheet. Considering that the integral of the listed stresses corresponds to the acting bending moment, the magnitude of springback is significantly changed at the observed point. Based on this punctual analysis, a changed stress state before springback can be expected over the entire part wall and radii. Regarding the unloading behavior, figure 7(b) shows the decrease of the tangent modulus along the previous section. The degradation of the tangent modulus is linked to the equivalent plastic strain in the used kinematic hardening model [3]. Analogous to the reduced plastic strains because of lower friction shear stresses, a smaller decrease of the tangent modulus can be observed, which affects the magnitude of the reversible strains and springback respectively.

![Figure 7. In-plane stress across the sheet thickness from top to bottom side (a) and degradation of the tangent modulus (b) for applied friction models](image)

4 Discussion

The results from the strip drawing tests of DH800 and CP800 already show smaller friction coefficients for low contact pressures (≥ 5 MPa) than the constant friction coefficient of 0.15, which is mostly used in the simulation. While this generally overestimates frictional conditions, the discrepancy is even greater for CP800 with consistently smaller friction coefficients compared to DH800. For this reason, a greater improvement in prediction accuracy is obtained for this material with increasing blank holder force than for the DH800. It should be noted that the applied lubrication amount of 0.8g/m² is higher than the amount used in the strip drawing test. In principle, friction decreases as the applied lubrication amount increases. Therefore, it can be assumed that a further increase of the lubrication amount leads to greater deviations between the springback prediction with a constant friction coefficient of 0.15 and the investigated test components, while the use of TriboForm adjusts the friction coefficient as a function of the lubrication amount.

Furthermore, the changed friction conditions due to TriboForm lead to different levels of friction shear stresses, which in turn change the stress state before springback as well as the magnitude of elastic strains during unloading and the magnitude of the calculated springback respectively. It can be assumed that the improved description of the material behavior, for example by taking the Bauschinger effect and the decrease of the tangent modulus into account, shows an even greater improvement in accuracy when the frictional conditions in the forming process are described accurately.

Compared to real car body components, the analyzed hat profile has a much smaller flange area, which leads to large contact pressures for higher blank holder forces, resulting in the reduction of the friction coefficient. Larger flange or pressure area makes the contact pressure smaller, which can result in a coefficient of friction close to 0.15. However, depending on the forming method and tool geometry,
the use of higher-strength materials might require higher sheet retention for targeted plastic forming. In addition, the variety of possible textures can lead to different friction properties depending on the roll surface of the respective manufacturer, which is why the consideration of the surface and its development in the process is also necessary.

5 Summary

Advanced friction models are generated for the steels DH800 and CP800. These are used in the simulation, whereby the accuracy of the springback prediction is evaluated compared to a simplified friction model using a constant friction coefficient. The following statements can be summarized:

- The sheet type and its surface characteristics have an influence on the frictional behavior. For the DH800 and CP800, lower friction coefficients than 0.15 result even at low contact pressures.
- The changed friction conditions due to TriboForm lead to different levels of friction shear stresses, which change the stress state before springback and the magnitude of elastic strains during unloading.
- The prediction accuracy of the flange angle of deep drawn hat profiles can increase up to 70% and of the sheet’s draw-in up to 10% for an increased blank holder force of 800kN.

6 References

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