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Numerical simulation of U-Drawing test of Fortiform 1050 steel using different material models

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Abstract

Steel has been used in vehicles from the automotive industry's inception. Different steel grades are continually being developed in order to satisfy new fuel economy requirements. For example, advanced high strength steel grades (AHSS) are widely used due to their good strength/weight ratio. Because each steel grade has a different microstructure composition and hardness, they show different behaviors when they are subjected to different strain paths. Similarly, the friction behavior when using different contact pressures and sliding velocities is considerably altered.

Third generation steels present high yield strength together with high elongation capacity and strain hardening. Thus, it is logical to think that elastic modulus reduction and Bauschinger effect are important aspects when stamping these materials. Furthermore, high contact pressures arise when forming these steels and friction coefficient may significantly influence the numerical results.

Stamping forming processes are nowadays usually optimized by numerical tools such as Finite Element Models. In order to get reliable results, these numerical tools require proper material and contact models in order to correctly predict the real behavior and flow of the materials.

In the present paper, Fortiform 1050 material is deeply characterized using uniaxial and cyclic tension-compression tests. Friction coefficient is obtained using strip drawing tests. These results have been used to calibrate mixed kinematic-hardening material models as well as the friction. Finally, the geometrical accuracy of the different material models has been obtained by means of the comparison of the numerical predictions with experimental demonstrators obtained using a U-Drawing tester.

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Keywords: Third generation steels, friction, hardening, elastic-modulus, springback, U-Drawing test

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1. Introduction

During the last decades, many new grades of high-strength steel materials have been developed [1-4]. However, it is well known that the formability of steels decreases with increasing strength. This is also valid for the newly developed third generation high-strength steels as well [5]. The light weighting potential of these new commercial steels is said to be around 20% in comparison to already used Dual Phase steels. For example, the Dual Phase 780 steel has a yield strength of 480 MPa and an ultimate strength of 830 MPa. Having the same formability and comparable forming limit curve, the Fortiform 1050 steel, the material studied in this paper, has a yield strength of 760 MPa and an ultimate strength of 1100 MPa.

Besides the significant decrease in formability, the increased post-forming springback is one of the biggest technological problems when defining and developing new high strength sheet metal components. Current industrial problems when using these materials are premature cracks and excessive set-up times needed for springback compensation.

In order to achieve a good accuracy when numerically predicting the final geometry of the components two main aspects must be considered: the material model and the restraining forces due to the friction between the tool and the material. If these variables are not accurately defined the numerical predictions can be far away from the experimental results [6-7].

Concerning the material behavior, a good definition of the hardening behavior is very important when the material suffers alternative tensile and compression cycles [8]. This is the case of deep drawing processes when the material goes through the drawbeads and/or the die radius. Meanwhile mild steels present nearly an isotropic hardening behavior, high strength steels present a kinematic or mixed hardening behavior [9-10]. Consequently, a poor definition of the hardening behavior may result in very low accurate results of springback.

The coefficient of friction (COF) is a significant parameter to take into account when trying to obtain accurate predictions in numerical simulation [11-12]. COF influences the restriction level of the material flow through the die tools and an inaccurate definition of this parameter can induce undesirable splits, insufficient deformations and, moreover, unexpected springback phenomena. A lower COF induces lower stress-states and as a consequence higher elastic recovery [13]. Therefore, it is necessary to correctly define the COF in order to accurately predict the final geometry of the component through the numerical simulation.

Among the several works published for AHSS steels, no scientific paper has been found where the above mentioned aspects have been studied for a third generation steel. For this reason and because some new third generation steel grades are currently being launched to the market by several steel makers, the current work was carried out aiming to study the Fortiform 1050 third generation steel behavior under stamping conditions. Advanced material and tribological characterization have been performed and an U-Drawing operation is numerically and experimentally studied to analyze the effect the different numerical models have in the final springback predictions.

2. Material characterization

The studied material is an electrolytically galvanized third generation Fortiform 1050 steel, from Arcelor Mittal, having a thickness of 1.2 mm. Chemical composition and mechanical properties are shown in the next table.

Table 1. Chemical composition and mechanical properties of Fortiform 1050.

C	Mn	P	S	Si	Al	N	YS (MPa)	UTS (MPa)	A%
0.2069%	2.1755%	0.0107%	0.0005%	1.4521%	0.0366%	0.0051%	775	1235	10

2.1. Uniaxial and tension-compression cyclic tests

Besides the mechanical properties, the Lankford or anisotropy coefficients of the material have also been obtained following the ASTM E 517-00 standard and using GOM ARAMIS digital image correlation technique. The Lankford coefficients at different directions and the monotonic hardening curve are shown in Fig. 1.

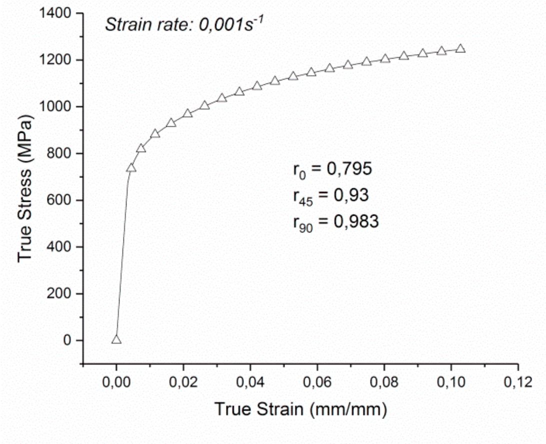
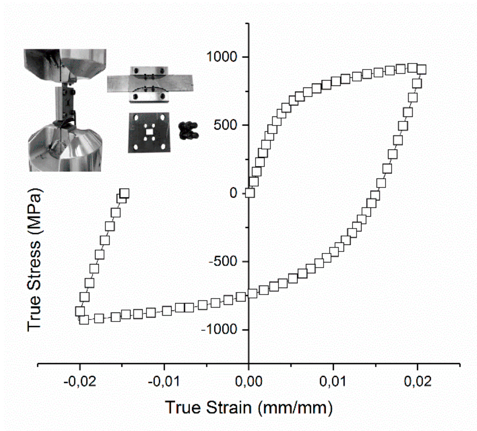


Fig. 1. Monotonic hardening curve and Lankford coefficients.



. Fig. 2. Tension-compression experimental results.

As explained in the introduction, the cyclic hardening of the material is very important to predict the springback and therefore the final geometry of the deep drawn components. Therefore, tensile-compression tests have been carried out in order to identify the kinematic behavior of the material. A servo hydraulic MTS 810 Material Test System has been used for the experiments. Force data has been acquired through an axial load cell and strain data has been measured with small strain gauges to obtain continuous measurement.

The material has been subjected to cyclic tension compression test for hardening characterization during the experimental test. A maximum strain of +2% in tension and -2% in compression has been achieved during the tests. Experimental results and the experimental test equipment used to avoid specimen buckling are shown in Fig 2.

3. Tribological characterization

3.1. Tool steel and sheet surface characteristics

1.2379 tool steel hardened at 60 HRc has been used for the strip drawing tests. Same machining protocol as followed by industrial toolmakers has been used for machining and polishing the tool inserts. Roughness in longitudinal direction of tool inserts is approximately Ra0.4.

The Fortiform 1050 steel specimens are electrolytically galvanized and EDT textured. The longitudinal and transversal surface roughness of the as received material are Ra1.2 and Ra1.24 respectively.

Mild oil conditions have been used to perform the strip drawing tests and the experimental U-drawing tests. The lubricant amount of the sheets is 1.5-2.0 g/m^2.

3.2. Strip drawing tests

Strip drawing tests have been performed to identify the friction coefficient to be used in the numerical simulations. The contact pressure has been set to 5 MPa and sliding velocity has been 10 mm/s during the tests. The strip drawing tooling and the exemplary curves obtained from the normal and tangential force sensors are shown in Fig.3 and Fig.4.

Resulting coefficient of friction for the above mentioned conditions is 0.126.

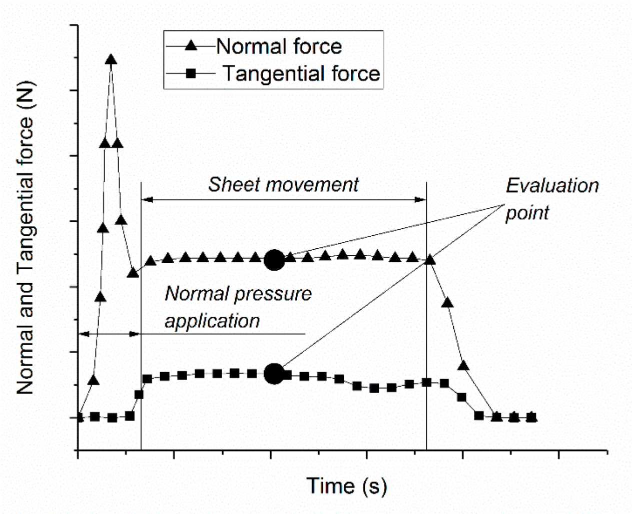


Fig. 3. Strip drawing test results.

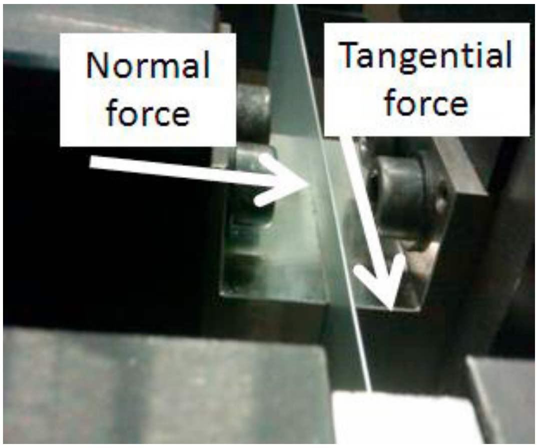


Fig. 4. Strip drawing tester at Mondragon University.

4. Experimental U-Drawing test conditions

Experimental U-drawing tests have been performed at Mondragon University aiming to identify the best numerical models to predict springback when using third generation high strength steels. The tooling is modular and die inserts, punch inserts and drawbead inserts can be exchanged to obtain different test variables. The characteristic dimensions of the configuration used for this study are summarized in Table 2 while the schematic view of the tooling is shown in Fig. 5.

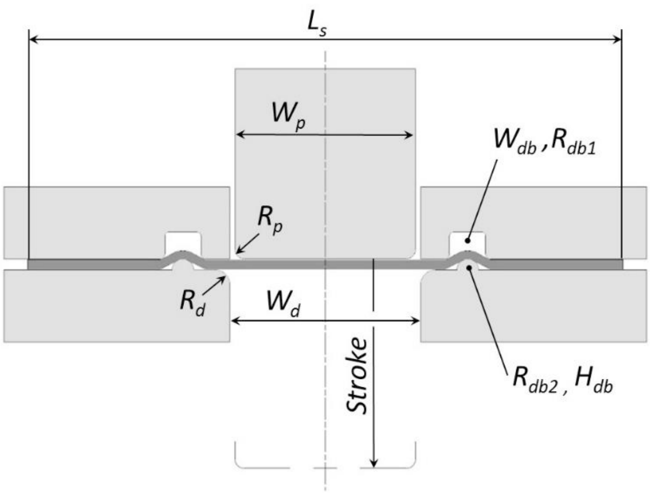


Fig. 5. Schematic drawing of the U-Drawing tester.

Table 2. Characteristic dimensions (mm) of Mondragon University's U-drawing tester.

Ls	Wp	Rp	Wd	Rd	Wdb	Rdb1	Rdb2	Hdb	Stroke
330	100	5	106	8	20	3	6	2	80

A hydraulic press has been used to perform the drawing experiments. The drawing speed has been set to 1 mm/s and 60 mm width specimens have been used for all the tests. In order to avoid the direct contact between the blankholder and the die, spacer shims have been used with a total gap of sheet thickness + 0.1 mm. Restraining force is obtained by the use of round shape drawbeads having a height of 2 mm and a radius of 6 mm.

5. Numerical simulation

5.1. Numerical models

Two different numerical models have been compared in the current study using the Autoform R6.2 software. All simulations were defined with a sheet thickness of 1.2 mm with elastic plastic shell elements, an initial element size of 10 mm with a maximum of 4 refinement levels and 11 layers through the thickness. For both models the elastic modulus has been set to 205 GPa and Hill48 yield criteria has been defined by means of the above mentioned Lankford coefficients. Friction coefficient of 0.126 and geometrical drawbeads have been used in both cases.

Regarding the hardening behavior of the material, the first model, named as conventional, has been defined using a combined Swift Hockett-Sherby hardening model. For this definition monotonic tensile test data has been used.

The second model, so-called as Kinematik, accounts for the mixed kinematic hardening only. Autoform's own model has been used for that and apparent elastic modulus change has been set to zero. Detailed coefficients of both models are summarized in Table 3.

Table 3. Autoform model inputs.

Model	Input parameters
Conventional	E=205 GPa / Hill 48 (r_0, r_{45}, r_{90}) / μ=0.126
	Isotropic hardening – Combined S-H ε_0=0.00312, m=0.14, C=1725, σ_i=766.8, σ_{sat}=1435, a=5.91, p=0.657, α=0.25
Kinematik	E=205 GPa / Hill 48 (r_0, r_{45}, r_{90}) / μ=0.126
	Isotropic hardening - Combined S-H
	Kinematic hardening – Autoform model K=0.012, ξ=0.8

5.2. Numerical and experimental results

Experimentally deep drawn specimens have been digitalized using a Mitutoyo 3d measurement machine. For geometrical accuracy comparison, GOM ATOS software and technique has been employed. The numerical and experimental results are shown in Fig. 6.

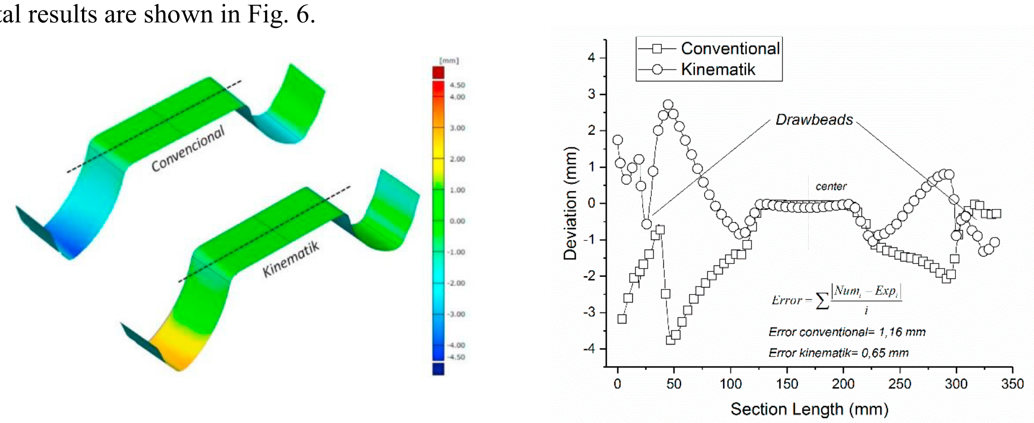


Fig. 6. Numerical and experimental results a) GOM ATOS measurement and b) section plot of geometrical deviations.

6. Conclusions and Outlook

Many authors have recently demonstrated the importance the hardening law, the apparent elastic modulus change and the friction coefficient have on springback predictions. However all these effects have not been previously evaluated for third generation high strength steels. In this article the importance of using a conventional or a mixed kinematic hardening model has been analyzed using the Fortiform 1050 third generation steel. For the selection of the best model the final springback prediction has been used.

The tribological study has shown the contact behavior of these steels is similar to the one observed when using high strength Dual Phase steels. The friction coefficient at medium contact pressures is 0.126.

Regarding the hardening model, the kinematic model gives more accurate springback predictions. As it can be observed in Fig. 6 the average error of the section points where the springback has been measured is 1.16 mm for the conventional model and 0.65 mm for the kinematic one.

The conventional model underestimates the springback values and all the control points are below the final experimental measurements. On the other hand the kinematic model overestimates the final springback and this is observed in the positive values of the deviations.

The authors are currently performing new tribological and loading-unloading material characterization tests in order to use a pressure and sliding velocity dependent friction coefficient and a non-constant elastic modulus. An eventual lower friction coefficient due to high contact pressure would cause less straining in the material, resulting in a less numerical springback prediction, making the kinematic model more reliable.

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