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EFFECT OF FRICTION COEFFICIENTS AND EXTRAPOLATION LAWS ON SPRINGBACK PREDICTION OF HSLA420 STEEL

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ABSTRACT

The high strength steels are widely used especially for the metal stamping. This process could have important differences with the desired geometry due to the springback phenomenon. The numerical simulation of the stamping and springback is widely adopted in automotive industry. The accurateness is highly dependent on numerical techniques as well as process parameters. Among the parameters that affect the precision, we can mention: the bending radius-thickness ratio, the friction coeffcients, the yield loci, the finite element formulation, the damage ... In this work, the effects of friction coefficients and the extrapolation laws on springback numerical prediction are investigated. The accuracy of this work is demonstrated through the industrial stamping process of an automotive part with High-Strength low-alloy steel HSLA420. The numerical results are obtained with the Pam-stamp 2G. It was shown that the extrapolations of the laws have the same order of influence as the friction coefficients

Keywords: Stamping, springback, laws extrapolation, HSLA420

1 INTRODUCTION

The metal stamping is widely used in manufacturing industry in general and in automotive industry particularly. Unfortunately, serious springback is unavoidable along the stamping process and can lead to important differences with the desired geometry. This phenomenon has been analysed by many investigators for the case of steel HSLA420. Aleksy et al. [1] has conducted an experimental study of springback and has focused his study on the comparison between HSLA and DP steel. Hao-Jie Jiang et al. [2] has proposed a method combining stretch and bending strain and isotropic hardening to study the springback for HSLA steel plate. Friction is a parameter that presents a great effect on the springback prediction.

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Many researchers shown that the coefficient of friction depend on load conditions (velocity, temperature, …) during the stamping process. Gruebler et al. [3] studied the dependence of temperature and velocity on friction modeling for a stainless-steel forming test. Santos et al. [4] investigated different friction coefficients based on the pressure region obtained with the deep drawing of the U-bending. A good accuracy is obtained between the measurements and their proposed numerical results. Hong-Liang Dai et al. [5] has proposed and investigation on the influence of damage to springback of U-shape HSLA steel plates. They have established relations between the springback angle and the friction coefficient. On our days, the numerical improvement of springback prediction is mainly relied on the mechanical behavior of materials and Finite Element Analysis (FEA) development. Navajyoti Panda et al. [6] have proposed a parametric study of process parameters affecting the springback for HSLA420 using finite element analysis and taguchi technique. They have advised the use of the parameters puch angle and die opening to obtain an optimum value of springback. Ben Elechi et al. [7] investigated the influence of friction and material model on the stamping of B-Pillar using a TRIP800 steel. The numerical results are compared with measurement and a classification of the studied parameters are presented. Meng et al. [8] studied the springback prediction of multiple bending utilizing different hardening laws. Their results exposed that YU model presents good prediction of springback within 5% of error for every bending.

The objective of this research work is to analyze the sensitivity of friction coefficients, extrapolation laws on the prediction of springback for an industrial part using the material HSLA420 steel. The numerical prediction results are obtained with industrial Pam-stamp 2G software [9].

2 STUDIED PARAMETERS

2.1 COEFFICIENTS OF FRICTION

The measurement of friction coefficient gives a value of 0.12 and is obtained with the flat-die test. This friction test is based on the compression of the pre-lubricated specimen between two flat tools and drawing of the sheet with horizontal force, more details can be found on the work of Emmens [10]. To evaluate the influence of this process factor on the prediction of springback, three values of friction coefficients are chosen; the measured friction coefficient μ = 0.12, a higher value of friction coefficient (+33%) μ = 0.16, and a lower value of friction (-33%) μ = 0.08.

2.1 EXTRAPOLATIONS OF LAWS

In this study the HSLA420 steel is used and the numerical results of stamping and springback are obtained with the software: Pam-stamp 2G. Three extrapolation laws « Hockett-Sherby, Swift, and SHS » are chosen to represent the sensitivity of the isotropic hardening law: The Swift law presents an exponential extrapolation, the Hochett-sherby presents a horizontal extrapolation and the SHS law presents a combined extrapolation. The isotropic-kinematic work hardening behavior is presented with a "mixed" law. The description of these laws is presented in Table I.

Table I - Material extrapolation laws for HSLA420

Flow stress model	Expression
Swift	$\sigma = K\left(\varepsilon_0 + \bar{\varepsilon}^p\right)^n$
Hockett-Sherby	$\sigma = \sigma_{sat} - (\sigma_{sat} - \sigma_0)\, exp\left(-n\ \bar{\varepsilon}^p\right)$
Swift-Hockett-Sherby	$\sigma = (1-\alpha)K\left(\varepsilon_0 + \bar{\varepsilon}^p\right) + \alpha\left\{\sigma_{sat} - (\sigma_{sat} - \sigma_0)\, exp\left(-n\ \bar{\varepsilon}^p\right)\right\}$
Mixed	$X = X_{sat}\left(1 - e^{(-C_x \bar{\varepsilon}^p)}\right)$ $R = R_0 + R_{sat}\left(1 - e^{(-C_r \bar{\varepsilon}^p)}\right)$

Where: ε_0 is a constant strain, $\bar{\varepsilon}^p$ is the effective plastic strain, $K,$ and n are material parameters of hardening law, σ_{sat} is the saturation yield stress, σ_0 is the initial yield stress, α is the weight factor , X is kinematic hardening, R isotropic hardening, X_{sat} represent the saturation value C_x C_r and are saturation rates, R_0 is the initial value of the yield stress, R_{sat} is the saturation value of R .

Figure 1 shows the uniaxial tensile curves of different material laws. These laws are implemented in the industrial code: Pam-stamp 2G.

3 RESULTS

The numerical outcome of the forming process is realized with two stages: stamping and springback. The simulation of stamping (Figure 2) is performed with explicit method and the springback is performed with implicit method. The tools were modeled with rigid elements (die, punch, and blank-holder), and the sheet metal was meshed using S4R (four quadratic shell elements) with reduced integration. The number of integration points in thickness is fixed to 5. The loading force applied on the blank-holder is 38 tones and the initial blank thickness is 1.2 mm. An adaptative meshing with 4 levels is used during the stamping to obtain accurate results.

3.1 INFLUENCE OF FRICTION FACTOR

Three frictions coefficients (0.12, 0.16, and 0.08) are used to investigate their influence on the springback prediction of the automotive part. HSLA420 steel with SHS extrapolation law was used in the software Pam-Stamp 2G. Figure 3 shows the displacements occurred after stamping and springback with the friction coefficient μ=0.12. Two phenomena occur after the relaxation of the residual stresses: the cambering in the middle of workpiece and the twisting at upper left (zone of the red color). The maximum iso-values of the displacement is presented with red color and is equal to +18.7 mm and the minimum is presented with dark blue color and is equal to -7.17 mm. Figure 4 shows the displacement results obtained after springback with the friction coefficient 0.08. The maximum displacement is 16.5 mm and is located at the top left of the workpiece. The minimum is -10.8 mm and is localized at bottom corner of the workpiece. It is noted that the friction coefficient 0.08 presents more variation on displacement compared to the friction coefficient 0.12. Figure 5 presents the results of displacements obtained with the maximum friction coefficient (0.16). The maximum and the minimum are localized at the same zone of the workpiece with respectively 14.6 mm and -8.41 mm. It is noted that the variation of displacement reached with friction 0.16 is lower to those obtained with the friction coefficients 0.08 and 0.12. Figure 6 shows a comparison between displacement results obtained with friction 0.16 and friction 0.08. To obtain this relative displacement results a specific post-processing was developed and coupled with Pam-stamp software. It is noted that the maximum relative displacement is $\Delta U_{\ max}$localized

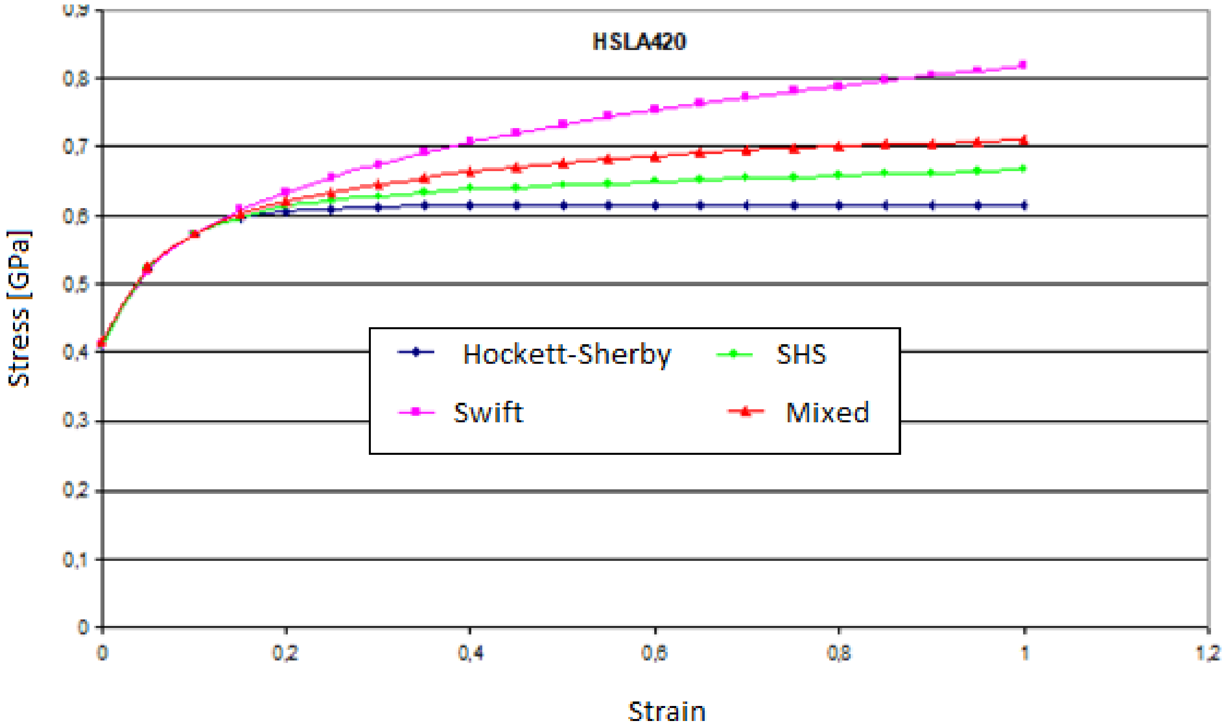

Figure 1 Extrapolation laws for HSLA420 steel.

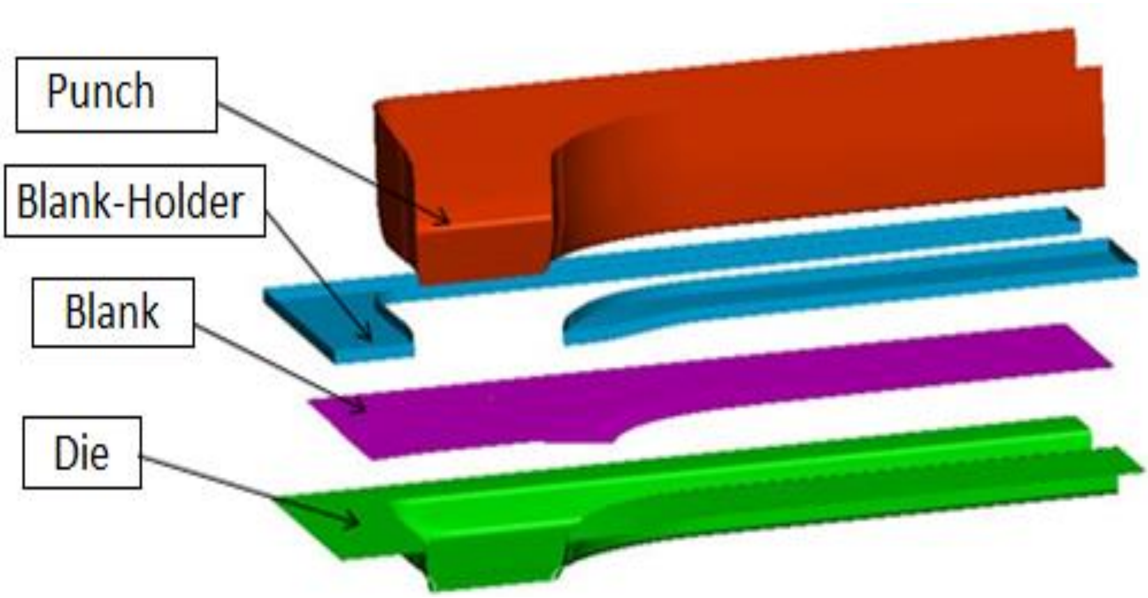

Figure 2. 3D view of the tools used for stamping.

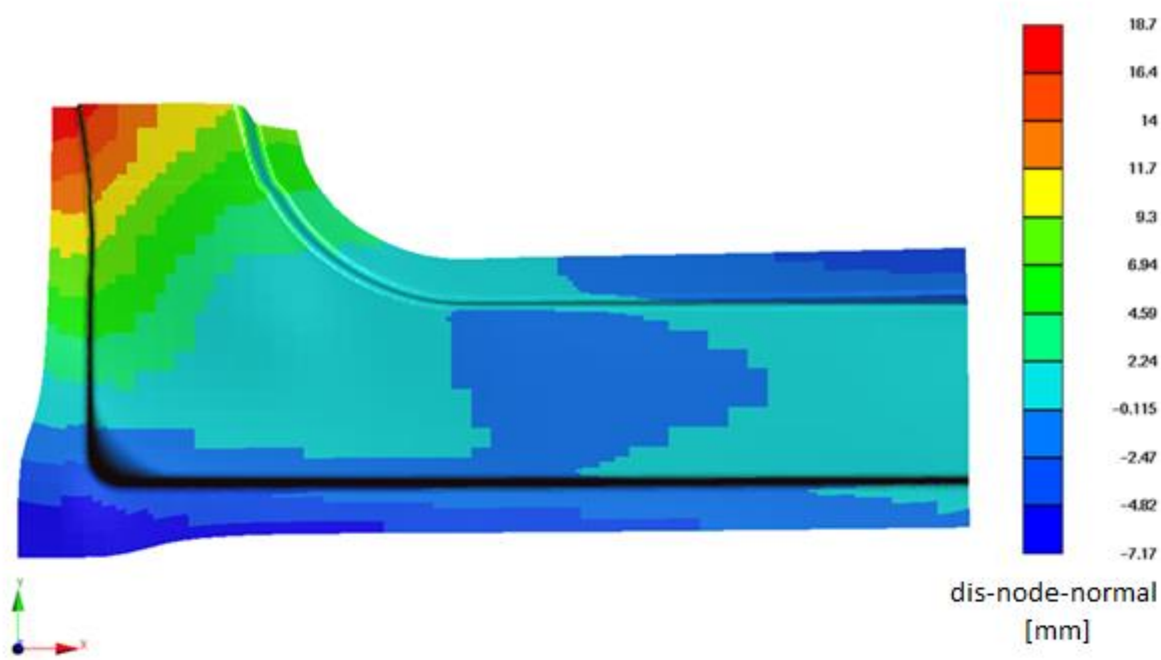

Figure 3 The displacements result after springback with extrapolation SHS law and friction coefficient 0.12

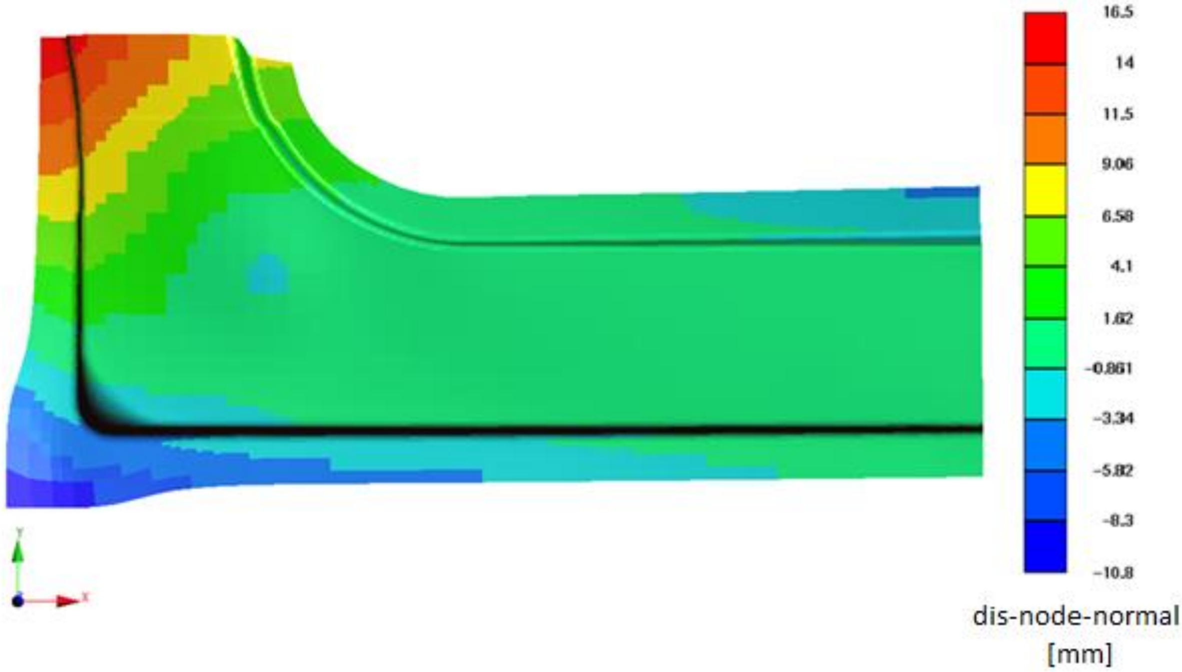

Figure 4 The displacements result after springback with extrapolation SHS law and friction coefficient 0.08

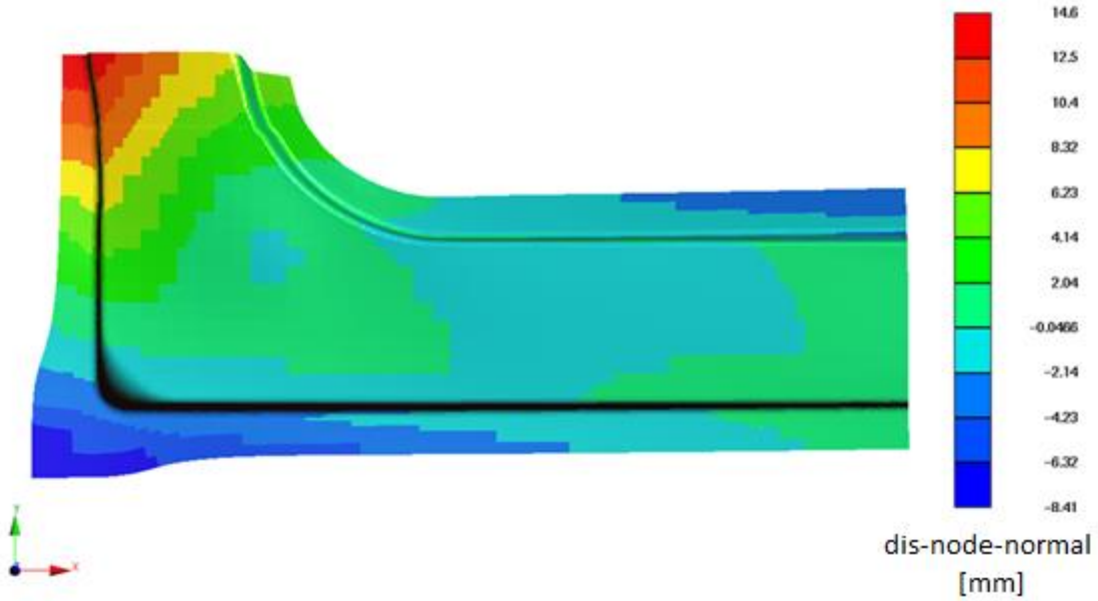

Figure. 5 The displacements result after springback with extrapolation SHS law and friction coefficient 0.16

at the corner of the workpiece and the minimum relative displacement is ΔU_{min} and is localized at top left of the workpiece. To quantify the influence of friction coefficient on the prediction of springback, the Relative Percentage Variation (RPV) is applied:

$$RPV = 100\frac{\text{variation between displacement results (Fig. 6)}}{\text{variation with reference displacement results (Fig. 4)}} \quad (1)$$

The calculation of the RPV for friction 0.16 and 0.08 is as following:

$$RPV = \frac{(2.56+2.01)}{(1.65+10.08)} \times 100 = 16.74\% \quad (2)$$

Table II resumes the relative percentages of variation obtained for three couple of coefficients of friction. It is noted that friction has a strong influence on springback and that the maximum RPV has been obtained with the couple of coefficients $\frac{0.12}{0.16}$. The maximum relative percentage variation is 20.98%.

Table II - Relative variation of friction coefficients (HSLA420 and SHS extrapolation law)

Couple of friction coefficients	Relative percentage variation
$(\mu = 0.12/0.16)$	20.98%
$(\mu = 0.12/0.08)$	20.25%
$(\mu = 0.16/0.08)$	16.74%

3.2 INFLUENCE OF EXTRAPOLATION LAWS

Three extrapolation laws have been employed to define isotropic hardening (Hockett-Sherby, SHS, Swift), and a mixed law to describe a combined work hardening. The HSLA420 steel is used, and the coefficient of friction is set to the medium value (0.12).

Figure 7 shows the displacement occurred after the removal of the tool for the Swift extrapolation law. It is shown that the maximum and minimum displacements with Swift extrapolation law present more variation compared to the previous results and are localized respectively at the same zones of the workpiece. A small cambering is observed at the middle and a twist at the top of the part.

Table III summarizes the RPV acquired with the different extrapolation laws. It is shown that the different tested hardening laws present an important influence on the prediction of springback. In fact, the minimum variation exceeds 16%. The results obtained prove that these extrapolation laws have an influence similar to the friction coefficients.

Table III - Percentage change in displacements for extrapolation laws

(HSLA420, coefficient of friction : $\mu = 0.12$)	
Couple of hardening	Percentage of displacements
(Swift /Hockett-Sherby)	16.99%
(Swift /SHS)	20.09%
(Swift/Mixed)	18.01%

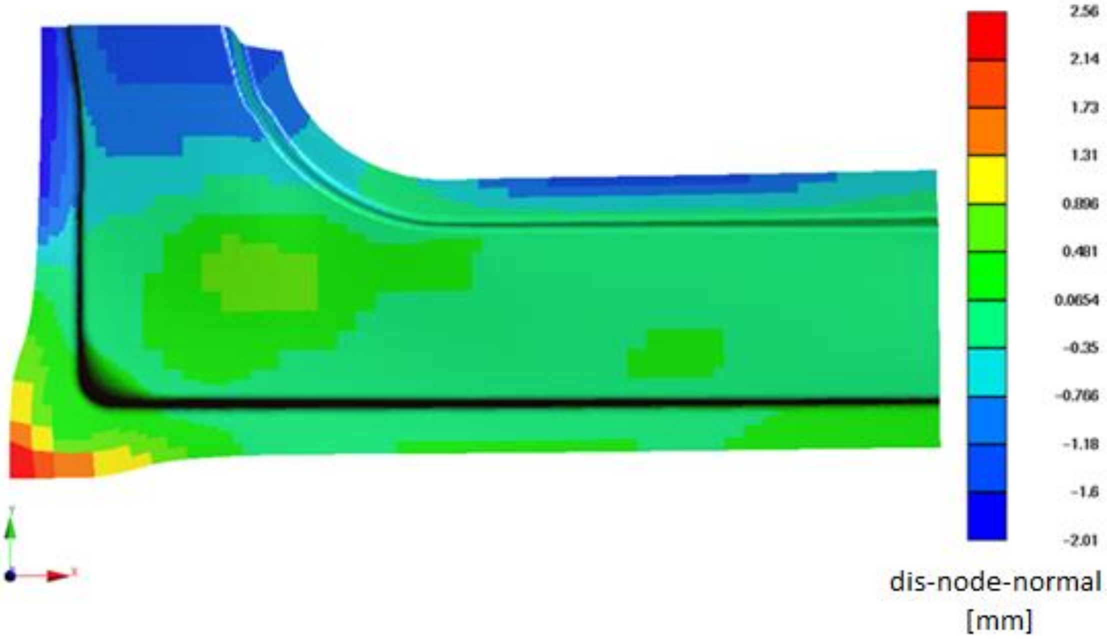

Figure 6 The relative displacements result with friction coefficient 0.16/0.08

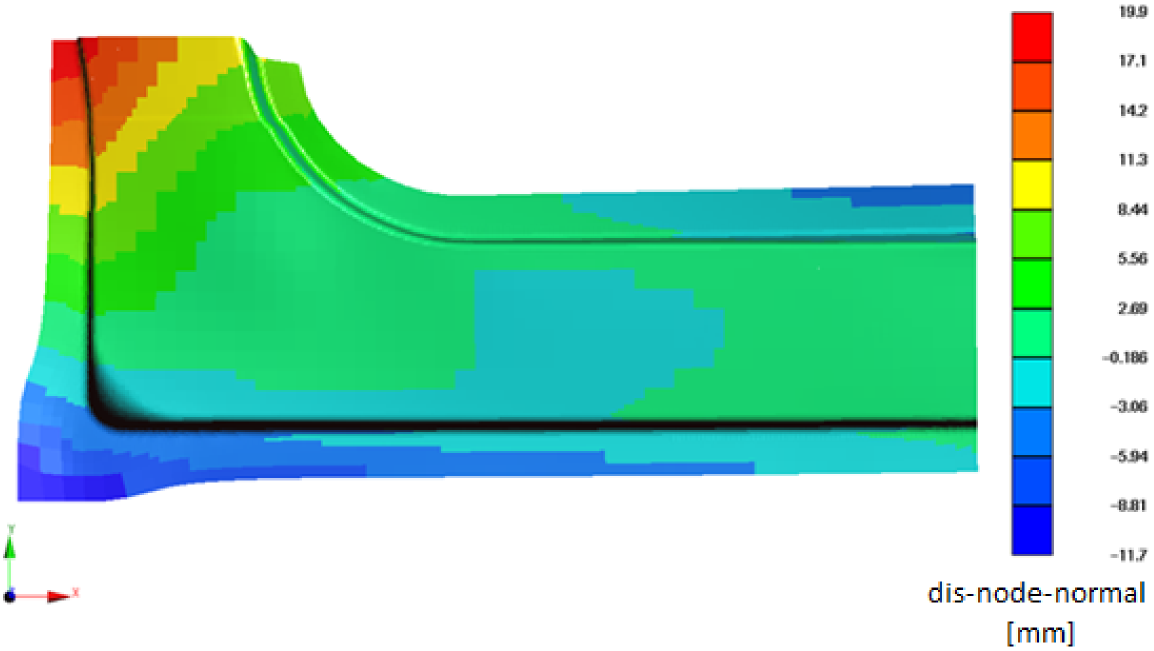

Figure 7 The displacements obtained with Swift extrapolation law

4 CONCLUSIONS

In stamping process of automotive parts, small number of researchers investigated the sensitivity of springback prediction of HSLA420 steel to friction coefficients and extrapolation laws. In this study, the industrial example of the stamping of an HSLA420 steel side sill closing was studied. Several extrapolation laws and friction coefficients are investigated to verify their impact on the prediction of springback. A specific criterion based on the displacement obtained after springback and called Relative percentage variation (RPV) is used to quantify the sensitivity of these parameters. The effects produced by these extrapolation models on springback were studied and compared to the influence of friction coefficients. The results obtained show that the extrapolations of the laws have the same order of influence as the friction coefficients. This trend will be analyzed for other steel grades such as DP600 and TRIP800.

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