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Comparison of experimental and simulation results of 2D-draw-bend springback

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Analysis and modelling

ABSTRACT

Purpose: This paper presents the results of experimental, analytical and numerical studies of draw-bend springback on the response of steel blank strips.
Design/methodology/approach: Springback, the elastically-driven change of shape of a part after forming, has been simulated with 2-D plane strain finite elements model (ABAQUS). Springback simulations compared with experimental test results under some test conditions and also sidewall curls were further discussed in this paper.
Findings: The results validate the finite element approach as a trustworthy tool for predicting the springback parameters for a given set of stamping conditions and material properties.
Research limitations/implications: This model is a simple and an efficient way to take apart the responsibilities of the steel maker for the selection of steel to be used and sheet stamping designer for the selection of the forming conditions to work in a safety zone in order to increase the reliability of the stamped structures.
Originality/value: Experimental and finite element analyses have been conducted on blank strips of Hadfield steel (high strength steel) and Mild steel with similar operational conditions.
Keywords: Computational mechanics; 2D-bending; Springback; Mild steel; Hadfield steel

1. Introduction

The phenomenon of springback in sheet forming operations can easily takes place during bending and unbending deformations of the sheet. This phenomenon appears when the sheet first makes contact with the tool surface at the stage of bending and then leaves the tool surface and partially or completely loses its curvature at the stage of unbending.

Accurate prediction of springback and sidewall curls is essential for the design of tools mainly used in sheet stamping operations. These deformation sets generate more complex stress-strain states in the sheet resulting in the formation of sidewall curl after the sheet is allowed to unload [1-8].

Mild steel (MS) and Hadfield steel (HFS) were used for this analysis, of which the yield stresses varied from 170 to 450 MPa. Springback, the elastically-driven change of shape of a part after forming, was simulated with 2-D plane strain finite elements model (ABAQUS) as many industrial sheet stamping operations are realized in plane strain conditions [2,4-8].

This paper aims essentially the correlation and comparison between experimental and simulation results of springback.

2. Experimental conditions

2.1. Materials

Hadfield steel and mild steel are used in this study. Useful data of materials and mechanical properties are given in Table 1.

2.2. Tools, lubrication and geometry

An apparatus of 2D-draw bending tools was specially designed according to the schematic drawing shown in Figure 1. The set up consists of a die, a punch and a blank holder. The upper and lower platens were separated from the blank holder by springs. The blank holder can move up and down freely on the four rods attached to the lower platen.

Table 1.
Materials properties

Material	Sheet thickness (mm)	Yield Strength (MPa)	Fracture Strength (MPa)	Strain until fracture	Strain hardening Exp(n)	Constitutive equation
Mild Steel	0.78	170	312	0.450	0.235	$\sigma = 565.32\left(0.007117+\varepsilon_p\right)^{0.2585}$
Hadfield Steel	1.20	420 ± 30	1350	0.50 ± 0.20	0.45-0.95	$\sigma = 1161.\exp\left(\frac{237}{T}\right)\dot{\varepsilon}^{0.01}\varepsilon^{0.257\exp\left(\frac{194}{T}\right)\dot{\varepsilon}\exp(0.01)}$

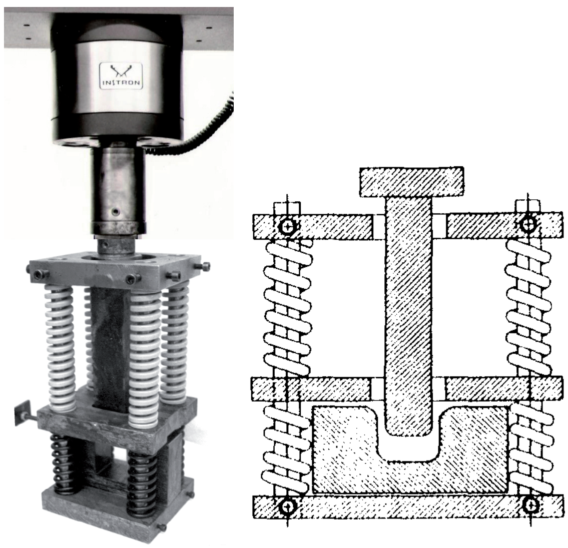

Fig. 1. Experimental stamping apparatus and schematic drawing detail of system

The lower springs hold the blank holder at a small distance from the die, so that the blank can be introduced easily.

The upper springs are used for the transmission of the blank holder force. The die and lower platen were fixed to the cross head after alignment with the punch which is attached to the load cell. After carefully placing the blank on the die, the upper platen is pressed against the blank holder, while monitoring the force.

Once the required blank holder force was reached, the upper platen was tightened to the rods. Care was exercised to keep the blank holder force as close to the specified value as possible.

Before each experiment both sides of the blank sheet surface were wiped with a paper towel dipped in the special lubricant and were then kept in a vertical position for 30 minutes for homogenization.

A standard U-shaped geometry was selected. Figure 2 gives the details of the geometry studied for the experimental and numerical analyses. This type of geometry was chosen for isotropic springback analyses. Typical measurement method of springback values was explained formerly [4].

All of experimental study was conducted on the INSTRON 8501 machine.

The punch speed was 1.66 mm/sec. The punch travel was selected at a specified distance of 70mm and throughout the experiments, the blank holder forces (BHF) were maintained at 2.45 kN and 19.6 kN at the test temperature of 20 + 2°C for each steel. The initial sizes of Hadfield and mild steel sheets are 1.2x35x350 mm and 0.78x35x350 mm respectively.

2D-draw bending tool was made from tool steel (D2) and hardened to 55 HRc. The average roughness values of the different tool parts were measured at 0.28 µm.

The average roughness values measured on the blank sheets was 1.04 µm for Mild steel and 1.15 µm for Hadfield steel. The clearance between the punch and the die was measured as 1.0 mm.

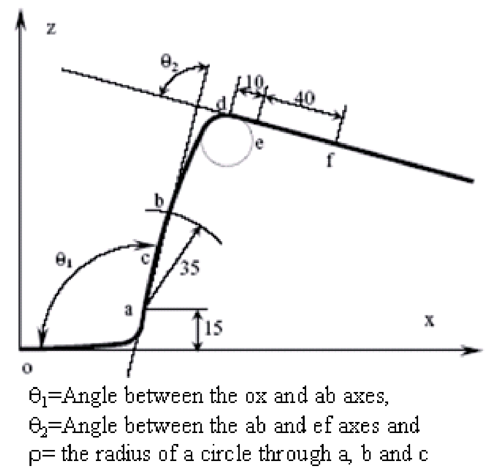

Fig. 2. Measurements parameters for the springback and side wall curl measured and used later in the finite elements model [4]

3. Results and discussion

3.1. Experimental results

Based on experimental study, springback results were evaluated and these results were used in order to validate the proposed finite element calculation.

After unloading of the hat sections, the sidewall curls (ρ, the radius of a circle through a, b and c) and springback values (θ_1 , angle between the ox and the [ab] segment and θ_2 , angle between the [ab] and [ef] segments) of the parts were determined.

Schematic description of measurement positions for springback and sidewall curls are given in the Figure 3.

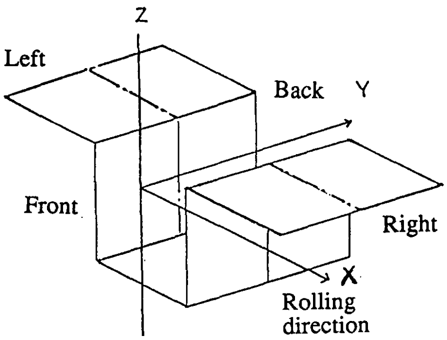

Fig. 3. Schematic description of measurement positions for springback and sidewall curls

The calculation of the springback and the sidewall curls were performed according to Figure 2.

The mean values of experimentally measured parameters taken on four measurements on each side of the blank sheets during the tests were evaluated for Hadfield and Mild steel respectively. They were prepared in the rolling direction. Only one test at the BHF of 19.6 kN has been carried out for two steel blank strips with an orientation of 90° with respect to the rolling direction.

The results obtained for both of steel blank strips in rolling direction were given in Table 2. There were no considerable differences in the results between two orientations of 0° and 90° from the rolling direction found for both of the steel blank strips.

This case can be explained for Hadfield steel because it is an isotropic material but for Mild steel, anisotropy does not contribute to springback in our experimental conditions.

This point will be clarified using finite element analysis in the next section. The detail discussion on the experimental and finite element results will be given in the full paper.

Table 2.
Experimentally measured parameters of springback

Material	BHF	θ_1 (°)	θ_2 (°)	ρ (mm)
MS	2.45	94	85	112
	19.6	100	85	120
HFS	2.45	115	75	103
	19.6	115	75	102

At the first approach, experimental results showed that there is no significant difference between springback values of Hadfield steel for two different blank holder forces. However, these values in mild steel indicate a very strong tendency to increase at higher blank holder forces.

It appears that, the blank holder force does not influence springback values for Hadfield steel. This case can be explained knowing that this steel work hardens very quickly as a function of plastic deformation level. In all experiments performed for two steels, sidewalls do not fail by tearing as blank holder force increases. In the same way, higher springback values of Hadfield steel than that of mild steel is due to yield property of Hadfield steel.

It is well known that this steel has higher yield strength and also as very high toughness properties. Therefore its yield strain is very high. As a result of unbending, springback values occur to be significantly related to the yield strain level. In other words, the higher the yield strength the greater the elastic return which results in higher springback values.

A picture taken from U shaped Hadfield strip at the BHF of 19.6 kN is shown in Figure 4a. 2D-draw bending specimens from Mild steel strips after removing from die are also given in Figures 4b and 4c.

a)

b) c)

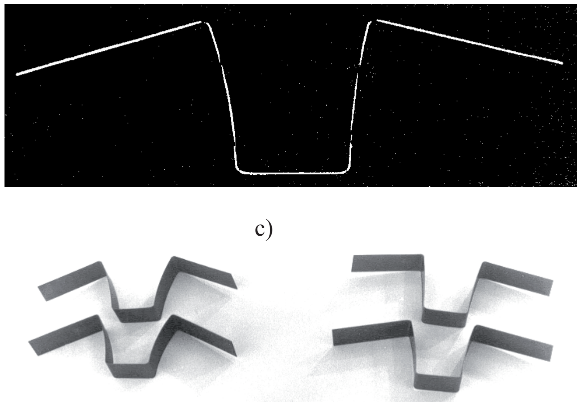

Fig. 4. 2D-draw bending specimens after springback for a Mild steel strip with a BHF of 19.6 kN (Fig. 4a) and for a Hadfield steel strip with a BHF of respectively 19.6 kN (Fig. 4b) and 2.45 kN (Fig. 4c)

Springback parameters obtained from experimental results were used to compare with those of final element analysis in order to better understand the phenomenon of springback in these materials that they will be detailed in the following section.

3.2. Finite elements analysis (FEA)

A 2D numerical analysis of the U-shaped bending process was carried out for comparison with experimental results. In order to truthfully validate materials parameters, both analyses were accomplished with similar operational conditions. This consisted of two constant blank holder forces of 2.45 and 19.6 kN for all the blank strips and a constant punch speed of 1.66 mm/sec, (a quasi static displacement was performed). In fact, the FEA was expected to be independent of rolling direction angle due to the yielding isotropy within the plane of the sheet. Some of the experimental and finite element results are given in Table 3 and it seems to show a good correlation. According to the dimensions of the blank in the out-of-plane direction, a two-dimensional plane strain model was used. The elastically - driven change of shape of metallic sheets have been simulated with ABAQUS code. Due to plane symmetry, only half of the process was modelled (Figure 5). The problem consists of the surface contact between steel blank strip and the tools such as the punch, die and blank holder that is a basic aspect of the stamping operations. The tools can be modelled as rigid surfaces because they are much stiffer than the blank. Figure 5 shows the basic arrangement of the components considered in FEM model. The blank strip is squeezed between the blank holder and the die trough a normal load applied on the blank holder while the die remains always unmoving. This force, in conjunction with the friction between the blank and blank holder and the blank and die, controls how the blank material is drawn into the die during the forming process. The contact between the punch and the blank was supposed to be frictionless whereas the contacts between respectively the blank and the die and the blank and the blank holder were supposed to have a coulomb friction law with a friction coefficient of 0.144.

Table 3.
Comparison of experimental and numerical results for a Mild steel bent with BHF of 19.6 kN

Angle	Experimental Mean values	Numerical results (°)	Comparison (%)
θ1 (°)	99	98.8	0.2020
θ2(°)	85	86.9	2.2353

The FEM took into account the forming process then the full unloading process, leading to a springback phenomenon. The forming process was controlled by the displacement of the punch. The unloading procedure consists in totally removing the punch, suppress the BHF and remove the blank holder and the die.

For the sake of the simplicity of the FEA, the following assumptions were considered:

- An elasto-plastic constitutive model was accepted with material isotropy and with a non-linear strain hardening condition.
- U-Shaped bending deformation was assumed to take place under the plane strain condition.

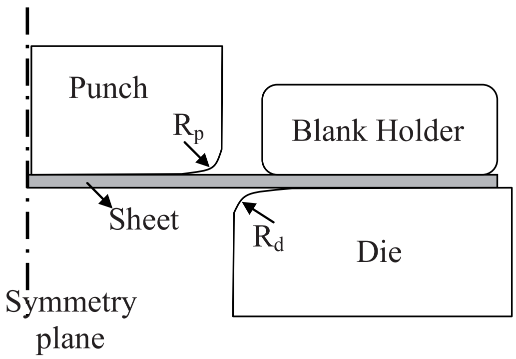

Fig. 5. Geometrical description of the simulation model

The tendencies form the experimental and FEA are in well agreement with tendency in the yield strength, it means that the higher the yield strength the greater the elastic springback values.

4. Conclusions

Experimental and finite element analyses have been conducted on blank strips of Hadfield steel (high strength steel) and Mild steel with similar operational conditions. The finite element results have been validated from experimental results. These results validate the FE approach as a trustworthy tool for predicting the springback parameters for a given set of stamping conditions and material properties.

This model is a simple and an efficient way to take apart the responsibilities of the steel maker for the selection of steel to be used and sheet stamping designer for the selection of the forming conditions to work in a safety zone in order to increase the reliability of the stamped structures.

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