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Springback prediction of high-strength steels in large radius air bending using finite element modeling approach

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Abstract

The springback analysis of different types of high-strength steels (Weldox 1100 and Weldox 1300) has been studied using finite element modeling. The two standard types of finite elements have been used: shell and solid elements. All calculations have been implemented in a commercial finite element software, Abaqus. The model for precise springback prediction has been implemented and the accuracy in function of the number of elements through the thickness - has been analyzed. The results of the finite element analysis have been validated experimentally by monitoring the bending process using a camera system that is aligned with the bend line. Deflections of the sheet during and after bending have been measured according to the images recorded by the camera.

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Keywords: Finite element analysis; Large radius bending; Air bending; High-strength steel; Springback

1. Introduction

Accurate production of designed parts is a main goal of the sheet metal industry, reducing the need for post-forming processing resulting in cost and time reduction. The problem of post-forming operations is more pronounced for thick sheets due to the weight of bent parts. Springback is the recovery of the elastic part of the deformation after removal of the external load that is applied during the bending operation; this phenomenon is a major source of inaccuracies in a bending process. Although, a number of studies have focused on springback

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calculation (Aerens, 2000; Burchitz, 2008; Eggertsen and Mattiasson, 2009), so far a universal solution has not been found (Wagoner et al., 2013). This indicates the complex nature of springback, depending on numerous material and process parameters.

The finite element modelling technique provides a relatively easy to implement approach with a wide range of ready-to-use commercial software. Although, an implemented finite element model may be slow, with appropriate mesh parameters reasonable simulation times are feasible. Despite prior research on springback calculation (Gomes et al., 2005; Firat et al., 2008) efforts on studying the behavior of thick sheets (more than 4 millimeters) of high-strength steels with large radius punches have been limited. Relevant input data along with a correct solution scheme provide a solid foundation for an accurate finite element solution. The material model and correct material properties are necessary factors to obtain a correct simulation. Additionally a finite element model for bending of sheet metal is sensitive for a wide range of parameters, e.g. friction coefficient.

The aim of the present work is to obtain material properties and build a correct material model for high-strength steels (Weldox 1100 and Weldox 1300) along with the calculation of a springback angle in non-conventional (or big radius) bending. The authors are committed to create a finite element model which provides results with an error of less than 5% on springback angle.

2. Experimental investigation

In order to obtain an appropriate simulation behavior of the sheet during and after the bending process, and to get appropriate values for the material properties for finite element simulation, an experimental approach was made consisting of tensile tests and bending tests on a press-brake, with a capacity of 50 tons. Monitoring of the bending process was performed by means of a camera, shown in Fig. 1a and b. The images were logged using LabVIEW. The camera is mounted in line with the bottom of the punch. The tooling dimensions are shown in Fig. 1.c where ΔY is the vertical movement of the punch. For reducing the telecentric effect, a distance of 1.5 meter from the camera setup to the tooling was selected.

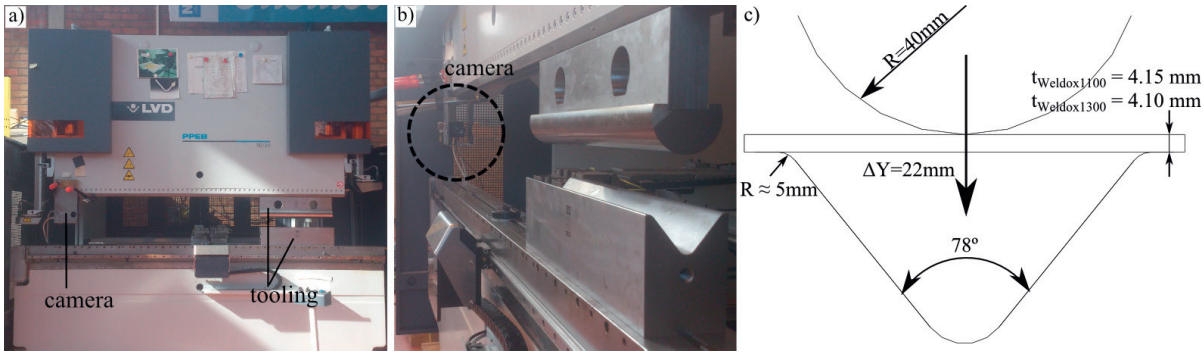

Fig. 1. Overview of the bending setup: a) and b) filming setup; c) scheme of tooling.

2.1. Tensile tests

In order to overcome the lack of information on the high-strength steel, tensile tests were performed on Weldox 1100 and Weldox 1300. A sketch of the tensile sample is depicted in Fig. 2a (because of the extreme hardness the use of hydraulic clamps is not advisable, and samples with pin clamping have been used). In order to check the materials for anisotropic behavior, the tensile tests were conducted in three different directions: along, transverse and at 45° relative to the rolling direction. Since the experiments show no significant differences in properties with respect to the rolling direction, the Von Mises' yield criteria have been chosen for the finite element simulations. According to the tensile test data the stress-strain curves for Weldox 1100 and Weldox 1300 have been constructed

(see Fig. 2b). The Weldox 1100 and Weldox 1300 material parameters for finite element calculations are presented in Table 1.

Table 1. Material properties of Weldox 1100 and Weldox1300.

Material	Thickness, mm	Elasticity modulus, GPa	Yield strength, MPa	Maximal stress (ε_{tr}=3.9%), MPa
Weldox 1100	4.15	175	1078.7	1531.2
Weldox 1300	4.10	175	1046.3	1614.1

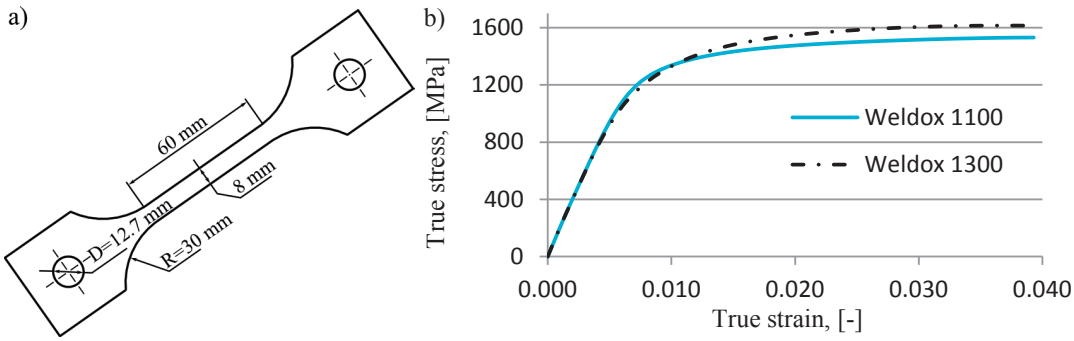

Fig. 2. (a) Sketch for tensile sample and b) stress-strain curves for Weldox 1100 and Weldox 1300.

2.2. Bending tests

The experimental bending tests and finite element simulation were performed on sheets of 200 by 150 mm with a bending angle of 91° (a 1° safety margin was used to ensure that air bending was the main process mechanism and forces wouldn't' exceed the limit of the tool set). The tests were executed both along and transverse the rolling direction; the observed values of springback in both directions were identical. This observation also supports the idea of isotropic behavior of Weldox steels. Fig. 3 contains an overview of the experimental investigation performed on Weldox 1100 and Weldox 1300.

3. Finite element investigation

The simulations of the bending process have been performed using commercial finite element software, in casu Abaqus. Input data for model construction has been implemented as macros written in Python. In the current work shell and solid formulations were used. The parameters for both formulations are the same, except for the specific requirements for each model, e.g. the specific difference in mesh construction.

The material properties have been implemented as a multi-linear stress-strain curve with isotropic hardening law. The overview of the computational mesh is presented in Fig. 4a and Fig. 5a. Seven elements along the sheet and 80 elements across were used, these mesh parameters allow for correct (within specified error) springback prediction and are necessary to achieve exact contact interaction between the tooling and the sheet. Further investigation involves only the influence on the results of the number of integration points over the thickness for the shell model and the number of elements for the solid model.

For both the solid and shell models the tooling has been modeled as analytical rigid surfaces. The contact interaction between the sheet and the tooling was modeled by surface to surface sliding contacts with following friction coefficients: for Weldox 1100 – 0.25; for Weldox 1300 – 0.30.

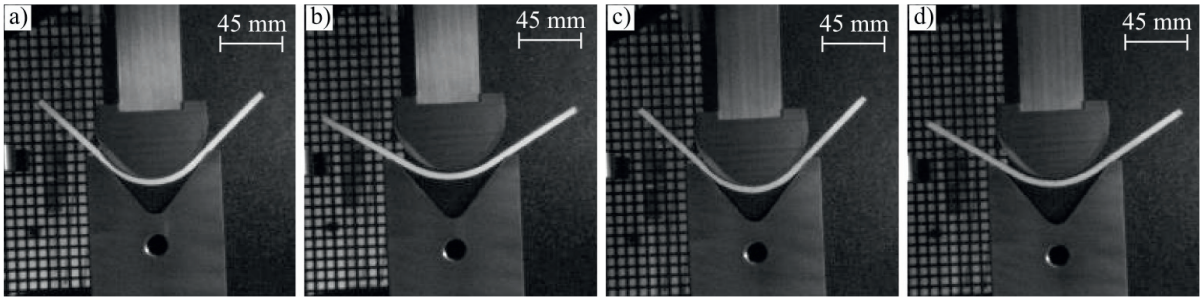

Fig. 3. Overview of experimental investigation: Weldox 1100 (a) before springback and (b) after springback; Weldox 1300 (c) before springback and (d) after springback.

For this particular task a symmetrical model could be implemented, but the next step in the research is to predict the behavior of thick high-strength steel sheets in the bumping (or step bending) process. A full model (without the use of possible symmetry) has been implemented for this reason. The boundary conditions in the model are as follows: a die part – anchorage; a punch part: vertical movement, anchorage in other directions; a sheet part: symmetrical boundary condition with respect to the center of the sheet.

For all models the solution has been implemented in two steps: an explicit bending step followed by an implicit springback step. Afterwards the results from an output database have been processed and the bend angle as well as the springback angle were determined.

The comparison of the experimental and finite element approaches are presented in Table 2. The error was calculated as the finite element result minus the experimental result, divided by the experimental result. The slightly bigger error for Weldox 1100 may be caused by the input error in the friction coefficient estimation.

Table 2. Comparison of finite element calculations and experimental results (bending angle of 91°).

Material	Model	Springback, °	Calculation time, min	Error, %
Weldox1100	Experiment	23.5	-	-
	Shell	24.6	2.5	4.7
	Solid	24.0	60.0	2.1
Weldox1300	Experiment	26.2	-	-
	Shell	25.8	2.5	1.5
	Solid	25.9	60.0	1.1

3.1. Shell model

An overview of the finite element mesh and the obtained results for the shell model are shown in Fig. 4. For the shell model S4R elements were used: a 4-node doubly curved thin or thick shell, reduced integration, hourglass control and finite membrane strains. An important factor for the springback calculation is the number of integration points through the thickness of an element (Wagoner and Li., 2007; Burchitz and Meinders, 2008). In the present work the authors performed a number of calculations to obtain the influence of the number of integration points on the accuracy of the solution. The results of these calculations are shown in Fig. 5. The solution quickly converges to the experimental result and from 7 integration points to 15 (interval characterized by errors less than 5%) the total difference in error is about 0.8%. However, the calculation time for the shell model is less than 3 minutes, and a calculation can be performed even with 31 integration points through the thickness without huge increase in calculation time. For each number of integration points the approximate calculation time has been measured and shown in Fig. 5b together with the calculated springback angle; the actual springback angle is given for reference.

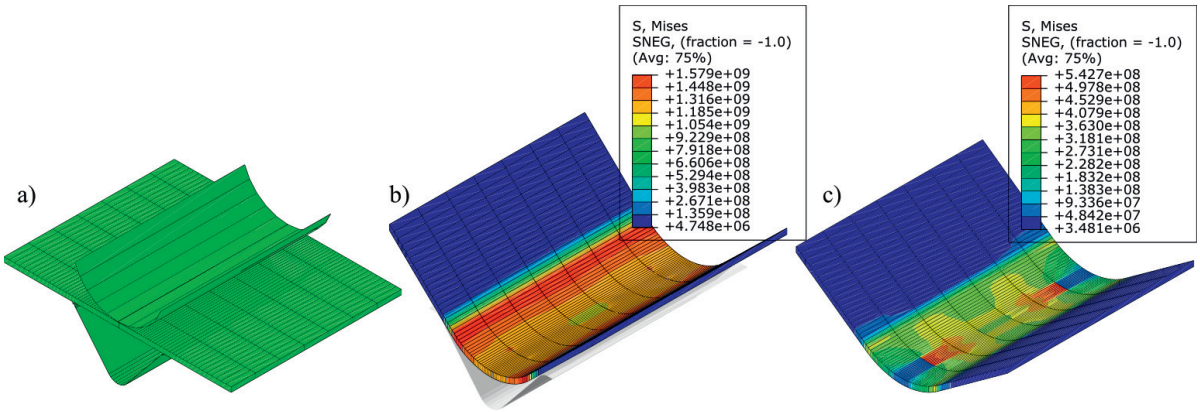

Fig. 4. (a) Overview of shell finite element model and (b) stresses for shell model before springback and (c) after for Weldox 1100.

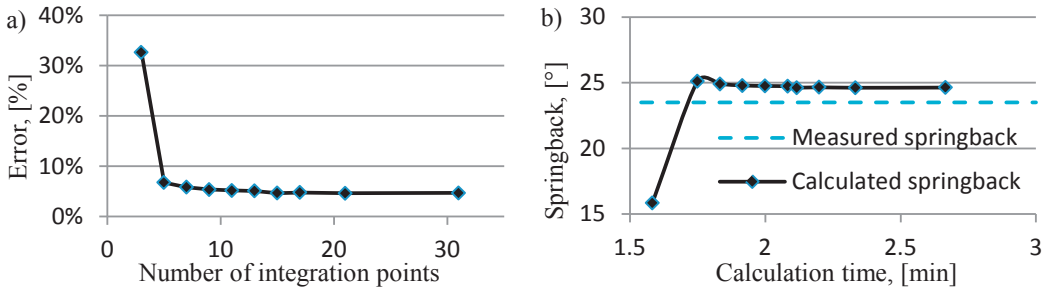

Fig. 5. Effect on shell model of (a) number of integration points over the thickness and (b) calculation time versus calculated springback.

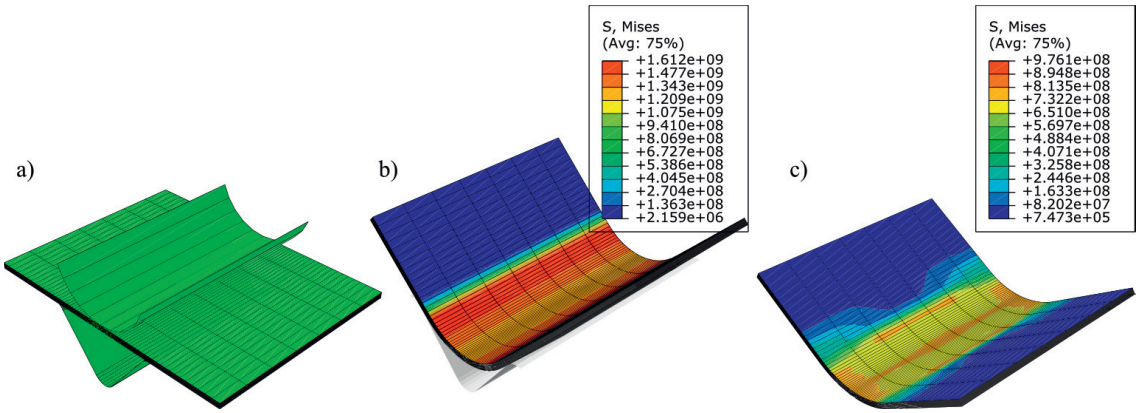

Fig. 6. (a) Overview of solid finite element model and (b) stresses for solid model before springback and (c) after for Weldox 1100.

3.2. Solid model

The overview of the finite element mesh and the obtained results for the solid model are shown in Fig. 6. For the solid model C3D8R solid elements were chosen: an 8-node linear brick, reduced integration, hourglass control. Increasing the number of elements over the thickness drastically increases the calculation time (see Fig. 7a), however the solution converges according to the measured value of the springback. For each number of elements over the thickness, the approximate calculation time has been measured and depicted in Fig. 7b, together with the calculated springback angle. The actual springback angle is given for reference.

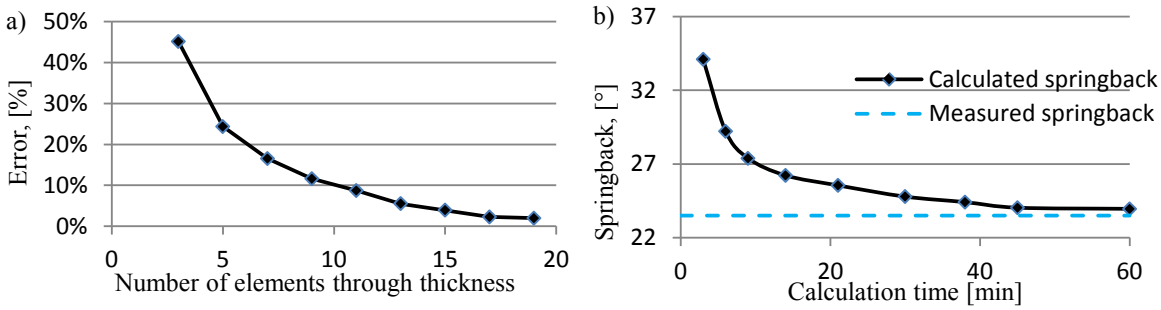

Fig. 7. Effect on the solid model of (a) number of integration points over thickness and (b) calculation time versus calculated springback.

4. Conclusion

The shell and solid models provide results with the required accuracy (see Table 2) for large radius bending of Weldox 1100 and Weldox 1300 steels. The information about the appropriate number of divisions over the sheet thickness will be used for a future analytical solution. The isotropic hardening model is suitable for Weldox 1100 and Weldox 1300 for the considered task, but for more advanced bending processes, e.g. with bumping, a more sophisticated hardening mechanism, including kinematic hardening, should be used.

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