

Springback prediction with FEM analysis of advanced high strength steel stamping process

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Abstract

In many manufacturing processes involving sheet metal fabrication, springback is a major concern that makes tool design a very complex task. New demands have led to an increase in the use of Advanced High Strength Steel (AHSS) as work material. An increase in strength decreases the formability of the material and increases the springback behaviour. The aim of the numerical simulation carried out in this paper is to verify the stamping process and the shape of the final component for studying springback of AHSS. Finally, a test case of a simple profile stamping process was analysed using the incremental approach of the AutoForm 4.04 Incremental software code for two different AHSS materials: Dual-Phase (DP 600) and Transformation-Induced Plasticity (TRIP 800).

Keywords: Springback, Advanced High Strength Steel, Stamping, Finite Element Methods

1. Introduction

As a forming expert in one of the leading car manufacturing companies, Schacher [1] summarized the current pressure on this industry as: "In the past we introduced 3 new models every 10 years, now we introduce 10 new models every 3 years". This drastic reduction of development periods as well as the trend to reduce weight of the cars in order to reduce the fuel consumption leads especially in the car manufacturing industry to a rebuilding of the conventional design and manufacturing procedures. Sheet metal forming as an important production process (see for instance [2]) is heavily experience based and involves trial-and-error loops. These loops are repeated the more, the less the experience on the part geometry and the material is. In innovative process design procedures, however, trial-and-error loops are reduced by means of modern numerical approximation analysis, which is known ironically also as virtual production. Obtaining

consistent and accurate part dimensions is crucial in today's competitive manufacturing industry. Inconsistencies in part dimensions slow new product launches, increase changeover times, create difficulties in downstream processes, require extra quality assurance efforts, and decrease customer satisfaction and loyalty for the final product. In the sheet metal forming process, a major factor preventing accurate final part dimensions is springback in the work material [3]. Springback is the geometric difference between the part in its fully loaded condition, i.e. conforming to the tooling geometry, and when the part is in its unloaded condition, i.e. free state. For a complicated 3-D part, undesirable twist is another form of springback. The uneven distribution of stress through the sheet thickness direction and across the stamping in the loaded condition relaxes during unloading, thus producing springback. Factors that affect the amount of springback include variations in both process and material parameters, such as friction

conditions, tooling geometry, material properties, sheet thickness, and die temperature [4]. Because controlling all these variables in the manufacturing process is nearly impossible, springback, in turn, cannot be readily controlled. Moreover, as springback is a highly nonlinear phenomenon, numerical simulations and correcting methods become highly complex.

1.1 Forming analysis with *AutoForm-Incremental*

Finite element methods (FEM) simulations based on incremental approaches [5] offer a full process model that simulates the metal sheet forming stages as accurately as possible in the logical order from blankholder to final flanging. Consequently, incremental simulations are computationally very intensive and time consuming in comparison with the corresponding one step analysis, and require tooling information to be manually inputted [6]. There are two types of incremental codes based on either ‘implicit’ or ‘explicit’ mathematical formulations. Implicit codes, such as the *AutoForm-Incremental* software code [7], typically complete the forming simulation in 1-4 hours, depending on part complexity, whereas the explicit counterparts tend to be 2-4 times slower.

In the automotive industry, FEM methods for metal forming analysis are often used, particularly explicit codes like LS-Dyna (LSTC) and Pamstamp (Easy) and implicit codes like *AutoForm-Incremental*. Explicit solvers can be used to simulate dynamic analysis and allow to evaluate large deformations (like in drawing processes), whereas implicit solvers are suitable to simulate static analysis (like the springback phenomenon). Thus, in metal forming process simulation of car body components, a final implicit static step may be used to obtain a static springback solution after the tool is removed from the die. In this way, the springback solution starts from the stress-strain state of the forming simulation without numerical dynamic oscillations [7].

In this paper, the springback phenomenon is analysed through the use of the *AutoForm 4.04 Incremental* software code by simulating a test case stamping process applied to advanced sheet metal materials of great interest for the automotive industry.

1.2 Materials

In this study two Advanced High Strength Steels (AHSS) with different hardening curves (see Fig. 1) are considered: Dual-Phase (DP 600) and Transformation-Induced Plasticity (TRIP 800).

DP steels consist of a ferritic matrix containing a hard martensitic second phase in the form of islands. These islands create a higher initial work hardening rate plus excellent elongation. This gives DP steels much higher ultimate tensile strengths than conventional steels of similar yield strength.

The microstructure of TRIP steels is retained austenite embedded in a primary matrix of ferrite. In addition to a minimum of 5% by volume of retained austenite, hard phases such as martensite and bainite are present in varying amounts. The retained austenite is progressively converted to martensite with increasing strain, thereby increasing the work hardening rate at higher strain levels [8].

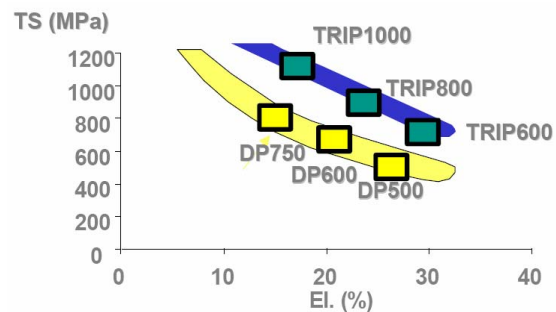


Fig. 1. Differences between Dual-Phase and Transformation-Induced Plasticity AHSS in a tensile strength (TS) vs. elongation (El) diagram.

2. Test case with *AutoForm 4.04 incremental code*

The test case realized in *AutoForm 4.04 Incremental* code is a simple profile stamping simulation with angle variations in the component vertical side walls using two different Advanced High Strength Steel (AHSS) materials. An incremental simulation was performed for a stamping process consisting of three stages: forming, trimming and springback. The most important criteria to evaluate the stamping process success are the following result variables: formability, thinning and springback (material displacement and angular displacement).

2.1 Input parameters

The stamping simulation was performed based on single action press.

This procedure is based in a single slide (ram) movement: the punch is stationary, the die moves down in its direction pressing the metal sheet against

the blankholder (binder), and then deforms the blank with the punch (Figure 4.6).

Cycle time is reduced by approximately 25% in comparison with the double action process.

In this case were applied two drawbeads (Db) to uniform the formability of the final part (see Fig. 2).

The most influent parameters on final results are described on table 1, Lubrication (Lube), Drawbeads (force factor [-] (FF), line force [N/mm](LF)) and Force applied between binder and die (Force).

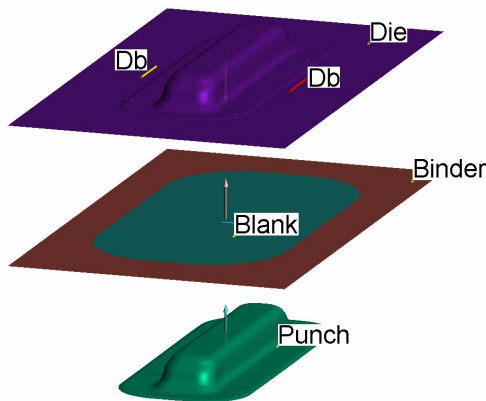


Fig. 2. Single action press tools

	Material	Blank Thickness	Lube	Drawbeads	Force
10°	DP600	0,8mm	0,15	FF - 0,450 LF - 388,2	1,80E+06
	TRIP800	0,8mm	0,15	FF - 0,530 LF - 457,2	1,90E+06
11°	DP600	0,8mm	0,15	FF - 0,450 LF - 388,2	1,60E+06
	TRIP800	0,8mm	0,15	FF - 0,530 LF - 457,2	1,90E+06
12°	DP600	0,8mm	0,15	FF - 0,350 LF - 301,9	1,80E+06
	TRIP800	0,8mm	0,15	FF - 0,620 LF - 519,3	1,80E+06

Table 1 – Input parameters

2.2 Analysis of results (colour display of result variables)

In the following, the analysis of the most important result variables will be discussed. These results can be displayed as coloured and shade images (see Fig. 3 for the results of the failure variable).

2.2.1. Formability

Formability is the ease with which a metal can be shaped through plastic deformation. Evaluation of the formability of a metal involves measurement of strength, ductility, and the amount of deformation required to cause fracture. The term workability is used interchangeably with formability; however, formability refers to the shaping of sheet metal, whereas workability refers to shaping materials by bulk forming.

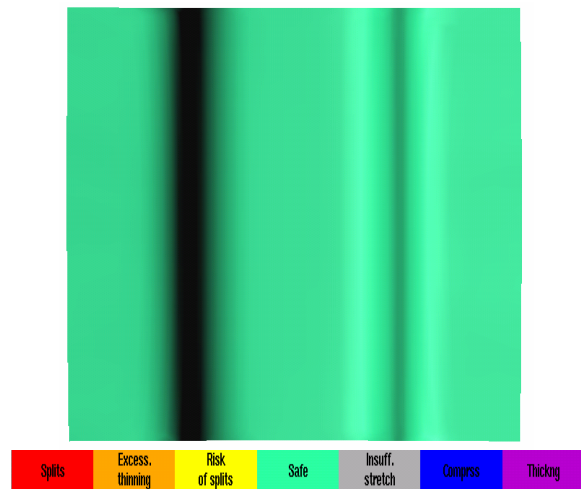


Fig. 4. Formability.

Figure 4 reports the results of the formability variable.

- Splits: Areas of cracks. These areas are above the FLC of the specified material (see Fig. 5).
- Excessive Thinning: in this area, thinning is greater than the acceptable value (default value for steel is 30%).
- Risk of splits: these areas may crack or split. By default, this area is between the FLC and 20% below the FLC.
- Safe: all areas that have no formability problems.
- Insufficient Stretch: Areas that have not enough strain (default 2%).
- Compression.
- Areas where wrinkles might appear: in these areas, the material has compressive stresses but no compressive strains.
- Thickening: Areas where wrinkles can be expected, depending on geometry curvature, thickness and tool contact; the material in these areas has compressive strains which means the material becomes thicker during the forming process (see Fig. 6).

2.2.2. Forming Limit Diagram (FLD)

The Forming Limit Diagram (FLD) provides a method for determining process limitations in sheet metal forming and is used to assess the stamping characteristics of sheet metal materials (see Fig. 5). Usually, the Forming Limit Diagram is used in method planning, tool manufacturing and in tool shops to optimize stamping tools and their geometries. The comparison of deformations on stamped metal sheets with the FLD leads to a security estimation of the stamping process.

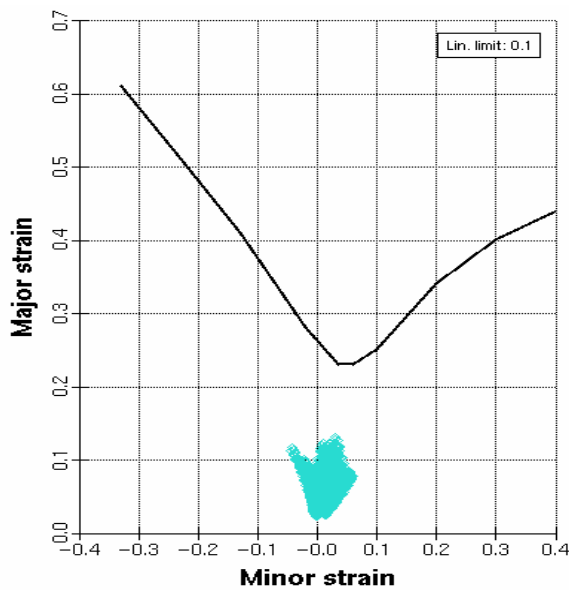


Fig. 5. Forming Limit Diagram (FLD) graphic.

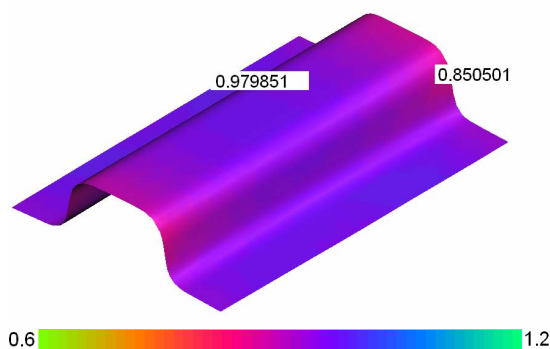


Fig. 6. Thickness.

2.2.3. Wrinkling criterion

Wrinkling is one of the major defects in stamping, especially for those parts on the outer skin panels where the final part appearance is critical. In addition, it can damage the dies and adversely affect part assembly and function. The prediction and prevention of wrinkling are, therefore, extremely important.

Naturally, wrinkling is a phenomenon of compressive instability under excessive in-plane compression. Plastic bifurcation analysis is one of the most widely used approaches to predict the onset of wrinkling.

Figure 7 reports the results for the wrinkling variable.

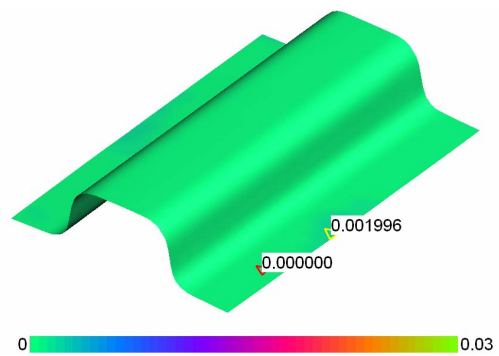


Fig. 7. Wrinkling criterion.

2.2.4 Plastic-strain ratio (revalue)

The plastic-strain is the ratio of the true width strain to the true thickness strain in a sheet tensile test. It is a formability parameter that relates to drawing; it is also known as the anisotropy factor. A high revalue indicates a material with good drawing properties.

Figure 8 reports the results of the plastic-strain variable.

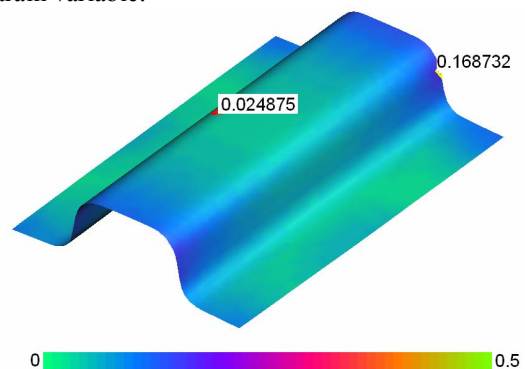


Fig. 8. Plastic-strain.

2.2.5. Springback graphic results

Figures 9-11 reports the springback variable results in graphical form.

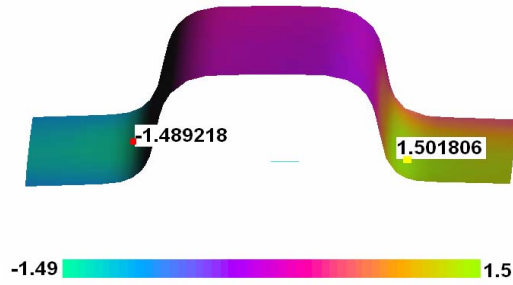


Fig. 9. Material displacement in X.

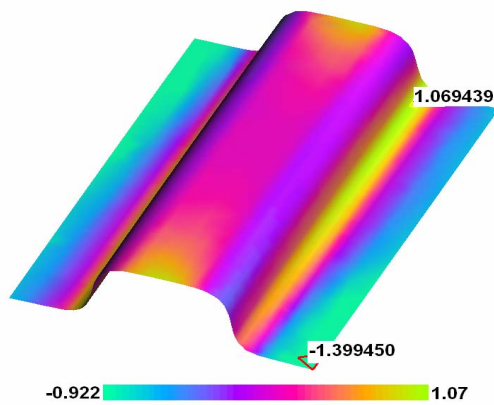


Fig. 10. Normal displacement.

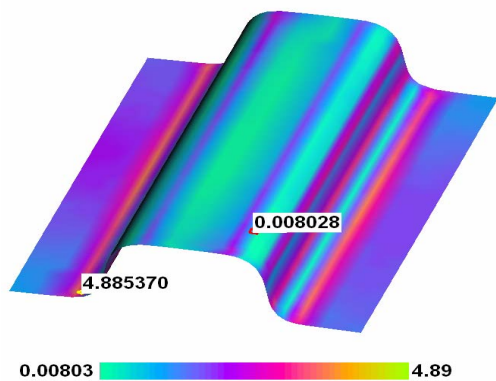


Fig. 11. Angular displacement.

2.2.5.1. Comparison between DP 600 and TRIP 800 of normal displacement in 10° profile

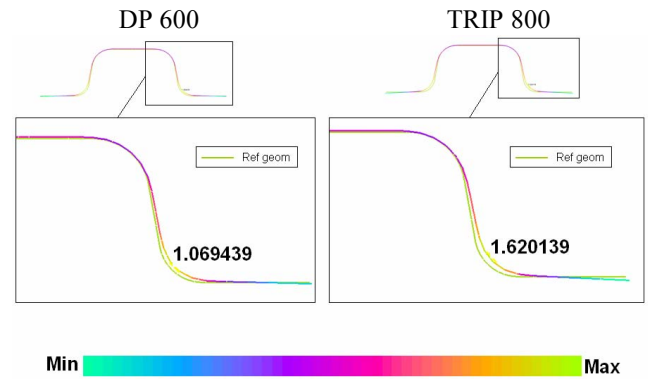


Fig. 12. Normal displacement for different AHSS.

Figure 12 reports the results of the normal displacement in 10° profile.

For the same material, the springback increases with the increasing of angular variation.

For the same angle profile, it can be concluded that material TRIP 800 has more displacement than material DP 600 (see Table 2).

	Displacement	DP 600	TRIP 800	Difference (%)
10°	X (mm)	0,96	1,50	56,3
	Y (mm)	0,20	0,23	15,0
	Z (mm)	0,95	0,97	2,1
	Normal (mm)	1,07	1,49	39,3
	Angular [°]	4,89	5,06	3,5
11°	X (mm)	1,04	1,63	56,7
	Y (mm)	0,22	0,26	18,2
	Z (mm)	1,20	1,06	-11,7
	Normal (mm)	1,20	1,69	40,8
	Angular [°]	5,02	5,31	5,8
12°	X (mm)	1,02	1,79	75,5
	Y (mm)	0,26	0,26	0,0
	Z (mm)	1,29	1,18	-8,5
	Normal (mm)	1,30	1,93	48,5
	Angular [°]	5,20	5,73	10,2

Table 2

Displacements for DP 600 and TRIP 800.

3. Conclusion

A FEM study was carried out on springback, a great obstacle in the application of Advanced High Strength Steel sheets for the stamping of automobile parts, with focus on the mechanism of its occurrence and the techniques to counter it.

With the introduction of the examples of analyzing springback using FEM, it was shown that the analysis enables to predict the influence of material strength.

It is considered possible to decrease springback problems in actual parts in the future by the application of techniques for improving shape fixability and by FEM analysis.

It has been shown that the AutoForm software code is a powerful tool for the stamping process; it can considerably increase the product quality (production of more complicated parts, know-how accumulation for new materials, optimization by variants), reducing the time and cost of production (early checking of producibility of workpieces, reduction of development times, cheaper products, reduction of die costs).

In [9], the recent developments of modern Advanced High Strength Steel sheets were reviewed, paying special attention to their physical metallurgy.

A series of highly formable new high strength steels have been developed using sophisticated physical metallurgy and have contributed to expanding the application of high strength steel sheets, especially for production of automobile bodies and parts.

Besides further developments of new types of high strength steels with better mechanical properties, the development of proper forming and welding technology is required to expand the use of high strength steel sheets.

Therefore, a key to extending the use of high strength steel sheets for automobile parts is the cooperation of the automotive industry and steelmakers in developing materials and forming and welding technologies simultaneously. A new concept 'early involvement and concurrent engineering' being carried

out through the joint efforts of the automotive industry and steel industry leads to expect a promising future.

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