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Understanding robustness of springback in high strength steels

T. de Souza [a,*], B.F. Rolfe [b]

[a] Institute for Frontier Materials, Geelong Technology Precinct, Deakin University, Waurn Ponds, Vic. 3216, Australia
[b] School of Engineering, Faculty of Science and Technology, Deakin University, Waurn Ponds, Vic. 3216, Australia

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ABSTRACT

The rapid uptake of high strength steels (HSS) to help reduce vehicle weight has caused some concerns for increased springback in many automotive stamping plants. The variation in springback, caused by subtle changes in the forming process and material conditions, is even more complex and has received little attention. This paper investigates the effect of typical control parameters, such as blank holder pressure, friction coefficient, punch radii and die radii, on the springback robustness when forming a semi-cylindrical channel from Dual Phase steel through finite element method. Results show that the springback response is heavily influenced by two factors; the process response window, governed by the process conditions, and the plastic modulus of the materials flow curve. In particular, the characteristics of the material's flow curve significantly influence the robustness of the system. This study highlights the reason for increased variability in high strength steels such as TRIP steels.

1. Introduction

Manufacturers continually strive to deliver high quality products, which meet their own stringent specifications and more importantly the needs of the consumer. The production of sheet metal products often includes a series of steps in the engineering process that allow the stamping engineer to tune the process to achieve the final part shape and component properties. The tool design stage often involves performing iterative finite element simulations to avoid, or compensate for shape defects like springback or wrinkling, and prevent the risk of excessive thinning or tearing. The stamping engineer cannot change the entire geometry of the part; however, they have the ability to adjust certain process control parameters. These include, blank holder pressure (BHP) or draw bead penetration; some tooling and blank geometries; and lubrication conditions. Often the experience and knowledge of the stamping engineer are drawn upon here to specify the values for these parameters. In the case for springback, the process is usually 'tuned' to ensure the magnitude of springback is satisfactory. However, the sensitivity of the process to small fluctuations in the many input variables of a sheet metal forming process is often not considered until either try-out or when full scale production has commenced [1]. If the process is highly sensitive in this state, with a high reject rate, changes to tooling or press setup can be extremely time consuming and expensive.

This paper investigates the effect of typical control parameters, such as blank holder pressure, friction coefficient, punch radii and die radii, on the springback robustness when forming a semi-cylindrical channel from Dual Phase (DP) steel through finite element method (FEM). While the relationship between these parameters and springback has been well researched [2–6], the effect on the variation of springback is only just starting to be considered by researchers [7–10].

Previous work by the authors [11] characterised the effect of material and process variation on springback robustness for a single process state. The development of an effective stress–effective strain response window presented a graphical representation of the processes robustness and characterised the effect of the noise parameters on springback variation. The effective stress–effective strain response window plots the effective stress vs. effective strain (equivalent von Mises strain) for a critical location in the formed part for each individual simulation performed, and shall here in be referred to as the response window. A large scatter in stress/strain response, and, subsequently a large response window corresponds to a highly sensitive process setup. The previous study [11] showed that material variation had a greater effect on increasing the size of the response window. Variation in processing conditions, such as BHP and friction coefficient, had a lesser effect. A link between the approximate size of the response window and the variation in springback was shown. However, this previous study [11] focussed on a single operating window and, as such the location of response window along the material's flow curve remained constant. This paper will extend this by investigating how the location of the stress–strain response window, governed by the chosen process operating

* Corresponding author. Tel.: +61 352271132.
E-mail address: timothy.desouza@deakin.edu.au (T. de Souza).

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Nomenclature

$\bar{\sigma}$	effective stress
$\bar{\varepsilon}$	effective strain
σ_y	yield stress
R_p	punch radius
R_d	die radius
c	die clearance
t	sheet thickness
w_0	initial sheet strip width
μ	friction coefficient
UTS	ultimate tensile strength
BHP	blank holder pressure
BHF	blank holder force
FEM	Finite Element Method
AHSS	advanced high strength steel
DP	dual phase
TRIP	transformation induced plasticity
IQR	interquartile range
SPC	statistical process control

window, will affect the shape stability of the Dual Phase semi-cylindrical channels. The changes in operating window are simulated by making changes to common control parameters used to 'fine tune' the stamping process, such as blank holder pressure, friction coefficient and tooling geometry. Additionally, this paper will discuss the effect of steel type on robustness, providing some insight into the lack of robustness in TRIP steels with regard to stamping.

2. Methodology

The tooling setup is shown in Fig. 1, where the clearance (c) is 2.1 mm (approximately equal to the sheet thickness+5%). The punch radius (R_p) and die radius (R_d) are control parameters and vary according to Table 1. The sheet thickness (t_0) and blank width (w_0) were noise parameters described by Table 3 and the draw depth of the channels was 40 mm.

The FEM simulation used in this study has been validated and described in previous work by the authors [12]. This previous study created an experimental data set where the noise sources: material property variation (σ_y, *UTS*), blank geometry variation (t_0, w_0) and process variation (*BHP*, μ), were quantitatively measured creating the probabilistic inputs for the stochastic simulation, as shown in Table 3. To quantify the potential variation in mechanical properties of the Dual Phase steel, 36 intrinsic tensile tests were performed according to AS 1391-2005 standards. The tensile specimens were blanked from the same coil, at different locations, hence only showing 'in coil' variation, which is suitable for this study. The blank geometry (t_0, w_0) was measured prior to forming a series of semi-cylindrical channels. One hundred experimental Dual Phase channels were formed using an Erichsen (Model 145) laboratory press. Blank holder pressure was monitored and precisely controlled to within 1% of the desired value (21 MPa) due to the resolution of the load cell and to minimise the effect of frictional variation, the sheet forming tests were conducted with no lubricant. This experimental method allowed us to quantitatively capture the noise parameters as accurately as possible. A simple method to accurately (within 0.1%) and precisely measure the springback, as measure by the flange angle from horizontal was devised [12]. The springback of each of the formed semi-cylindrical channels were measured to develop an experimental data set.

The experimental setup was replicated using AutoForm v4.1 and a stochastic noise analysis conducted using the Sigma module. The stochastic FEM was compared to the experimental data set to assess both the accuracy and precision of the springback prediction when susceptible to noise in the input parameters. Accuracy of the springback prediction had a slight negative bias of 0.28° (3%) of the experimentally measured flange angle and the precision (in terms of the Interquartile Range) also under predicted slightly by 0.21°. The small error in the prediction by the FEM provided confidence in the use of the tool for further investigation.

Table 1
The control parameters investigated and the associated levels at which the springback robustness is assessed.

Control parameter	Level 1 (low)	Level 2 (mid)	Level 3 (high)
BHP (MPa)	21	39	57
Punch radius (R_p) (mm)	15	20	25
Die radius (R_d) (mm)	3	5	7
μ	0.09	0.135	0.2

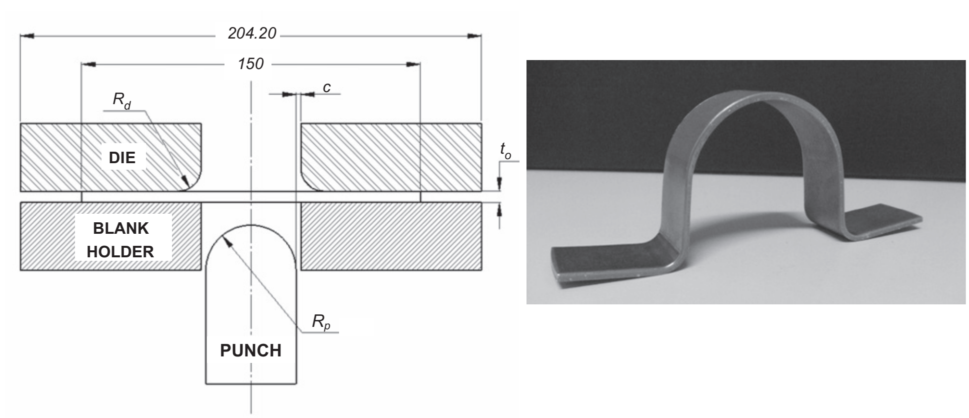

Fig. 1. Tooling geometry of the semi-cylindrical channels.