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Technical Paper

# Investigation of forming parameters on springback for ultra high strength steel considering Young's modulus variation in cold roll forming

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ABSTRACT

Ultra High-Strength steels (UHSS) is increasingly used in automotive industry to reduce weight and improve consumers' safety. However, prediction of springback in cold roll forming is one of the crucial problems to be solved for ensuring dimensional tolerances. The variation of Young's modulus is a significant challenge to accurate springback prediction. In this work, two mechanically-measured tests, such as uniaxial and loading unloading loading cycle test, were performed to determine the Young's modulus variation with the increase of plastic strain. One mathematical model that considers Young's modulus variation was proposed and applied in 3D Finite Element Analyses (FEA) to simulate the cold roll forming process. Roll forming tests of hat-shaped section and the relational springback analyses were implemented to compare with FEA simulation results. The calculated accuracy of springback used nonlinear elastic modulus considerably improved by 18% to Swift's material model. The springback prediction was significantly improved if the Young's modulus variation was taken into the FEA simulations. The developed model is applied for comparing the effects of different forming parameters on the product springback, showing that springback increases with increasing flange width, sidewall height, roll gap and the distance, decreases with increasing the strip thickness and the web width. The findings are hoped to help roll forming designers predict springback tendency before the roller design is applied in practical production.



## 1. Introduction

With the manufacture of lightweight structures entering into a rapid development period, advanced High Strength Steel (AHSS) and Ultra High Strength Steel (UHSS) of different species have increasingly used in new generation vehicle [1]. Particularly, Dual Phase (DP) steel is gaining popularity in automotive makers to reduce the overall weight and improve humanity safety [2]. The automotive industry has traditionally applied stamping technologies to manufacture vehicle component. Compared with the stamping, cold roll forming (CRF) is a manufacturing process that progressively deform the sheet material into the desired complex cross section with multiple pairs of contoured rolls at room temperature, which is an economical and efficient method for the production of constant-section parts with high measurement accuracy without changing the material thickness.

One major defect in AHSS and UHSS roll forming process is their high tendency to springback, which often results in undesired product shapes to hinder their wider application. The springback occurring in roll forming is due to undesirable longitudinal and transverse strains, especially the elastic strains that will be recover when the forming force moved from the rollers. The magnitude of springback depends on the amount of elastic deformation which AHSS and UHSS steels have more elastic deformation than do normal steels [3]. The accuracy of springback prediction in roll forming of AHSS and UHSS steels is becoming increasingly important, which is the reason many researchers work on springback prediction [4].

The prediction of springback in CRF of UHSS steel is becoming difficult in the uncertain material characteristic such as Young's modulus. Several authors have already investigated the forming material characteristic which effect on springback prediction. Lindgren [5] investigated that the longitudinal peak strain decreases,

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which it is given less residual stresses, when the yield strength is increased with higher yield strength. However, high strength steel has larger springback in using fever-forming steps. Since high-strength steel produce more elastic strains compared nominal steel, the amplitude of springback in high-yield materials forming can be higher than the low yield materials as in Ref. [6]. Park and Tran [7] have presented the FEA of aluminum automotive component in CRF, which have many different characteristic to steel, and concluded that the springback angle increase with increase in strain hardening, meanwhile decrease with increase in Young's modulus. Most of the investigations, used to predict springback in CRF process of UHSS, assume a constant elastic modulus during deformation. However, Young's modulus of UHSS is changeable during the cold roll forming process. Previous researchers have studied that the elastic unloading modulus of UHSS degrade with an increase of the plastic strain, as it is showing a significant departure from linearity [8–10]. Yang proposed one improved analytical model, which is described as hardening rule and Young's modulus variation with a piecewise function [11]. Their study showed that the Young's modulus has a significant influence on the springback predictions. The important phenomenon that Young's modulus (E) changes with plastic deformation can be found in most of UHSS metals. Nevertheless, to predict springback accurately, Young's modulus variation has not previously discussed in cold roll forming and will investigate in this work.

According to the tight dimension tolerances and the larger springback experienced in roll forming UHSS materials, which is a challenging task for designer. Finite Element Analysis (FEA), which is regarded as an essential tool in the early design and optimization stages, has been increasingly applied in roll forming industry. FEA simulation of springback is sensitive to various element type, element size, number of integration points, solver type, boundary conditions and definition of the tool model. One solid-shell 185 element proves to be efficient for accurately forecasting springback phenomenon. An arbitrary number of integration points through thickness direction within a single element layer can be used to simulate sheet material behavior [12]. Choosing the number of integration points is critical for accurate springback simulation [13]. However, previous literature that reported springback predictions in CRF seem to be ignored the number through-thickness integration.

Currently, it is common to investigate the effect of forming parameters on the springback prediction in CRF though a numerical and an experimental way for UHSS material. Han et al. [14] used the B-spline finite element method to simulation a hat shaped section and found that the inter-station distance, material thickness, the web width and flange width had significant effects the longitudinal edge strain. Zeng [15] introduced the response surface method to the roll forming process for optimization design of roll profiles. The majority of the analyses concentrated on angle increment, roll radius on springback angle and maximum edge membrane longitudinal strains. Paralikas [16,17] have investigated the effects of forming parameters on longitudinal and transversal strains. The increase in roll gap has a significant effect on springback in roll forming DP780 using numerical and experimental study, where the inter-distance have slightly effect on springback [18]. Abvabi studied the influence of residual stress about DP780 material on one roll forming process and conducted that the thickness reduction in roll forming decreases the maximum bow height while the springback angle increases [19]. However, more forming parameters that influence the springback defect, such as web width, flange width, sidewall high, material thickness, inter-station distance and bending radius of DP980 material, have not been experimentally investigated before.

Although theoretical investigation establishing a mathematical method for analyzing deformation in the contact region is proverbially applied. One method was provided for description the deformation length by minimizing the deformation energy and assuming the material to be rigid-plastic mode [20]. Panton [21] established a theoretical elaboration of the fundamental deformation type on the deformed surface to predict the strains in CRF. Liu [22] has set up a new mathematical model that is based on the geometric contact conditions between the sheet and the rolls to analyze the bend angle distribution and longitudinal strain development in roll forming a channel section. However, according to the previous studies, springback in roll forming were ignored the variable Young's modulus that influenced the accurate prediction it.

Prediction and compensation of springback can be applied by various methods. One inline closed-loop calibration system was introduced to compensate for springback in CRF of ultra-high strength steels [23], in which system is based on feedback signal where was taken from laser triangulations and two cameras. Abeyrathna [24] set up a simple in-line compensation system that based on the monitoring of roll load and torque for roll forming DP780 steel. It was major investigated the effect of the effect of yield strength and hardening exponent on bow. Additionally, there is another approach which is applied a straightener unit to eliminates springback defects in Ref. [25]. However, this require the re-adjusting tool changing to compensate the continuous occurrence of parameter variation in forming different shape products. So, it is vital to accurately predict the springback in CRF to compensate as it is one of the main challenges for UHSS roll forming.

In this work, two mechanically-measured tests, such as uniaxial and loading unloading loading cycle test, were performed to determine the Young's modulus variation with the increase of plastic strain. The improved material model with Young's modulus variation, which describes the material's property accurately, should not be ignored to predict springback in cold roll forming. Compared with the Swift's model, our investigation give clear evidence that improved model can be accurately predicted the springback. Further forming parameters that influence on springback defects in roll forming will investigated by mean of numerical simulations and experimental methods. This knowledge is of high value for automotive industry where springback is still a major topic in cold roll forming of UHSS material.

## 2. Material characterization and analytical model

### 2.1. Material characterization

#### 2.1.1. Dual-phase (DP) 980 steel

The DP980 material was selected in this study because its high strength and good ductility in CRF process [26]. The steel showed low yield strength, high work hardening rate and superior formability. The microstructure of analyzed material is illustrated in Fig. 1, which mainly contains ferrite matrix embedded with martensitic islands. Dual phase 980 steel contain 51.3% of the amount of martensite in the microstructure of the steel. The higher strengths of DP steel can be realized by increasing the volume fraction of hard martensitic. The average of ferrite grain size about DP980, measured through metallographic microscope, was 7.2 μm.The chemical composition of the DP980 steel produced by Baosteel is shown in Table 1.

**Table 1**
Chemical composition of UHSS (DP980 wt%).

| C | Mn | Si | p | S | Alt | V | Cr |
|---|---|---|---|---|---|---|---|
| 0.08 | 2.13 | 0.38 | <0.02 | <0.02 | 0.008 | 0.004 | 0.02 |