

Experimental Study of Edge Stretching Limits of DP980IBF Steel in Multistage Forming Process

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ABSTRACT

Automotive structural parts made out of Advanced High Strength Steel (AHSS) are often produced in a multistage forming process using progressive dies or transfer dies. During each forming stage the steel is subjected to work hardening, which affects the formability of the steel in the subsequent forming operation. Edge flanging and in-plane edge stretching operations are forming modes that are typically employed in the last stage of the multistage forming processes. In this study, the multistage forming process was simulated by pre-straining a DP980 steel in a biaxial strain path with various strain levels followed by edge flanging and in-plane edge stretching. The biaxial prestrains were obtained using the Marciniak stretch test and edge flanging and in-plane edge stretching were accomplished by the hole expansion test using a flat punch and a conical punch, respectively. The measurement of the edge strain limits at fracture for each tooling set up was performed using the Digital Image Correlation (DIC) technique. The results show that biaxial prestraining has no significant effect on edge flanging, however biaxial prestrain reduces formability in the in-plane edge stretching mode. This behavior is related to the relative uniformity of the strain distribution around the expanding hole.

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INTRODUCTION

In order to meet the new standards and requirements for the weight reduction and crash performance, an increasing number of automotive structural parts are designed and produced using advanced high strength steels (AHSS) and ultra-high strength steels (UHSS). The structural parts manufactured by cold stamping are often produced in a multistage forming process using progressive dies and transfer presses. During each of the forming operations, the steel is subjected to work hardening, which affects the formability of the steel in subsequent forming operations. In a multistage forming process, the conventional strain based forming limit diagram (FLD) may not be applicable due to strain path changes, and the stress based forming limit diagram (SFLD) [1-2] is often adopted. The effect of the deformation history produced during the multistage forming process on the forming limits was studied by Sklad et al. [3] where the key parameters of multistage forming processes affecting the forming limit were identified as the pre-strain magnitude, the deformation path, and the direction of deformation relative to the material orientation. Those studies were focused on the forming failure away from the edge, which was predictable by the FLD or SFLD. When the failure occurs at the edge, then the FLD or SFLD cannot be used to predict this kind of failure since the edge strains at failure are often below the conventional FLD or SFLD.

During forming of actual automotive components, the sheared edge can be stretched in-plane, named here as "in-plane edge stretching," or out of plane, named here as "edge flanging." As discussed above, multistage forming employs different forming modes and edge stretching can occur in the form of edge flanging and/or in-plane edge stretching, typically after the primary deformation or in the last stage of the multistage forming process. The history of the prior deformation in terms of the strain level and the strain path may be critical in determining the edge performance. The objective of this study is to understand the effect of the prior deformation on the edge stretching limit and performance for a dual phase steel (DP) with a minimum tensile strength of 980 MPa.

EXPERIMENTAL PROCEDURES, TEST RESULTS AND DISCUSSIONS

The material selected for this study is a 1.2-mm Dual-Ten 980IBF® (DP980IBF, dual phase steel with a minimum 980 MPa tensile strength with improved bending and flanging (IBF) performance). The effect of work hardening during the multistage forming process was simulated by radial stretching a 330 mm × 330 mm blank to levels of 2%, 3%, 5%, 6% and 7% balanced biaxial strain using a 203-mm-diameter Marciniak stretch test (flat bottom punch). The

prestrained flat area was then cut off using a CNC machine for subsequent edge stretching tests. A schematic for the sample preparation is shown in [Figure 1](#).

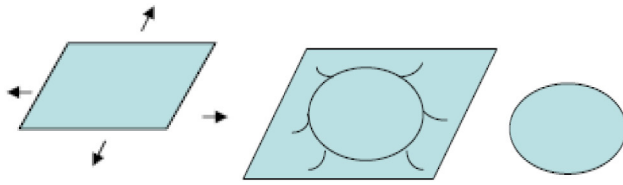


Figure 1. Schematic for pre-strain sample preparation

The effect of work hardening produced by the biaxial stretch was evaluated by tension testing extracted coupons from the center of the stretched Marciniak samples. The tensile testing was performed in the rolling direction of the material using sub-size specimens (ASTM E8) [Figure 2](#) shows the engineering stress-strain curves measured in the as received condition (0%) and after biaxial pre-strains of 2%, 3%, 5%, 6% and 7% and the material strengths at various prestrain levels.

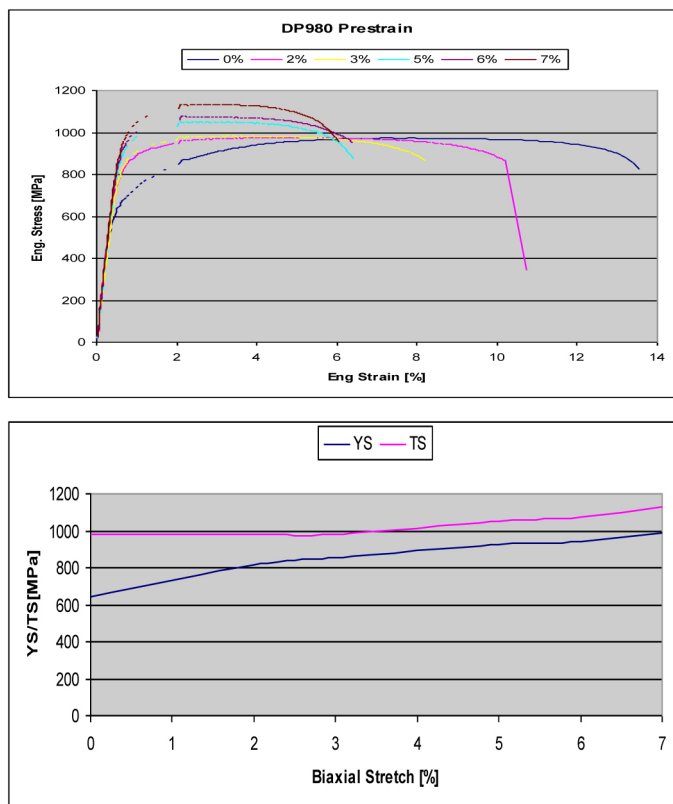


Figure 2. Engineering stress strain curves for the DP980 IBF measured from various biaxial prestrains and their corresponding material yield and tensile strengths

It is seen from [Figure 2](#) that, for the DP980 IBF steel, the yield strength increases significantly with biaxial stretching, while the tensile strength increases more gradually with the biaxial stretch. The explanation of this behavior is based on the strain partitioning phenomena that takes place between the soft phase and the hard phase of dual phase steels during plastic deformation [4],[5]. In this case [Figure 2](#) shows that the soft phase ferrite is continuously yielding, increasing the yield strength of the material, while the

martensite starts to deform after approximately 4% biaxial stretch, resulting in work hardening the martensite phase and consequently increasing the tensile strength of the DP980 IBF steel. This explanation is consistent with the findings communicated by Kang et al. [6] where they studied the strain partitioning in DP steel and measured the local strain of ferrite and martensite phase as a function of the average pre-strain level.

In order to simulate the edge flanging operation in a multistage forming process, a 10 mm or 40 mm diameter hole was punched in the center of the extracted coupons from the biaxial stretched specimens and then the hole was flanged to failure using a 60 degree conical punch. The punching clearance was 15 % and the flanging operation was performed with the burr up condition for all the specimens. The hole expansion ratios (HER) for both 10 mm and 40 mm holes were measured to assess the edge stretchability on the specimens with various prestrain levels. A schematic for this multistage forming process is shown in [Figure 3](#).

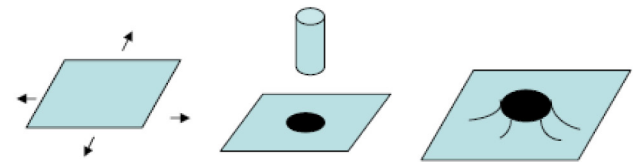


Figure 3. Schematic of the multistage forming process for biaxial stretching, hole punching and flanging

The HERs at various prestrain levels are shown in [Figure 4](#) for both 10 mm and 40 mm holes along with the total elongation (remaining ductility) measured from the prestrained samples.

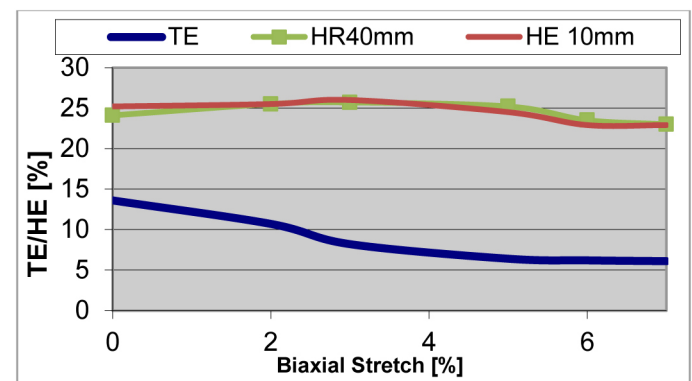


Figure 4. TE% and HER using a 60 degree conical punch for 10mm and 40mm punched holes in the as received condition and after biaxial stretch at 2%, 3%, 5%, 6% and 7%

It is noted from [Figure 4](#) that when a conical punch is used for the hole expansion test, the HER is generally independent of the level of the biaxial pre-strain, and the size of the initial hole has no effect on the HER, while the total elongation (TE) measured from the prestrained specimen is lower at the higher prestrain level. There is no correlation between the HER and the material ductility measured by the TE, which implies that in a multistage forming process, the forming operations prior to edge punching will not decrease the flangeability performance of the sheared edge. This finding is similar