Investigation of forming behavior prediction of different steel grade materials using numerical simulation

Sudhir Chakravarthy Katragadda[1], Shaik Salkin[2], Perumalla Janaki Ramulu[3#]

[1&2]Department of Mechanical Engineering, Holy Mary Institute of Technology, Hyderbad-501218

[3]Department of Mechanical Engineering, Vardhaman College of Engineering, Hyderbad-501218, Email: perumalla@vardhaman.org

Abstract

This study aims to investigate the forming behavior prediction of different steel grade materials using numerical simulation. The simulation has been done using limiting dome height test (LDH) for different automobile steel grade materials like HSLA, DP, TRIP, HSS, and DQ steel. In LDH test, the mechanical properties are strain hardening exponent (*n*), yield strength (σ) including the plastic strain ratio in three rolling directions (0º, 45º and 90º) are considered. The different strain paths are chosen from 25×200 to 200×200 i.e. from drawing to stretching side; in-total eight strain paths are considered for LDH test simulation. The Hollomon's law for flow stress and Hill's 1948 yield criterion are used for all the simulation by taking 1 mm mesh size for all strain paths. From the simulation results, the major strain and minor strain developed at necking zone in all the strain paths are noted using thickness based necking criterion. Forming limit curves are drawn using obtained major strain and minor strain. Thickness distribution compared for better investigation of the formability among five steel grades. Results showed that better formability steel showed better thickness distribution and vice versa.

Keywords: *Advanced high strength steels; limiting dome height; forming limit curve; thickness distribution*

1 Introduction

Now a day's steel is not only an important material in automotive components but also the strongest material. Steel is treated as the best material for automotive components due to its great flexibility to design, cost effectiveness and low emission during manufacturing. Steel material sheets have good forming behavior, so complex shapes can also be manufactured using different forming tests. From the past decades research is going on steels to reduce the weight of the automotive components, to increase the crash resistance, and to enhance the best formability. In this view a new steel material called as Advanced High Strength Steel (AHSS) which is also known as Ultra High Strength steels (UHSS) is introduced for more applications oriented. There are few important types in AHSS such as Drawing Quality (DQ), High-Strength steel (HSS), Transformation-Induced Plasticity steel (TRIP), Dual Phase steel (DP), High-Strength Low-Alloy steel (HSLA) and interstitial-free (IF) (Wilhelm (1993); Kuziak *et al.* (2008); Billur and Altan; Galan *et al.* (2012)).

There were many studies carried out on mechanical properties evaluation, the formability of steels to understand the forming behavior and forming process parameters effect during the deformation. For example, Panda *et al.* (2009) studied the formability of three different types of tailor-welded blanks (TWB) has been studied by limiting dome height tests in plane-strain deformation mode. In all the three TWB combinations, the effect of weld orientation, with respect to major principal strain on formability, has been studied. It has been found that in TWBs with difference in thickness and properties, the LDH is higher in transverse (weld line parallel to width) cases when compared to longitudinal (weld line parallel to length) cases. Panda *et al.* (2010) fabricated two different dissimilar material combinations high strength low alloy (HSLA) grade steels were laser welded with two different dual phase steels (DP980 and DP600) , and formability of these welded blanks was evaluated through different strain paths by conducting limiting dome height and uniaxial tensile tests. Five different weld locations and two different weld orientations were chosen to understand their influences on forming behavior. Strain distributions on the deformed welded samples were measured and fracture mode was observed to understand the influences of weld location, weld orientation, and strain path. Ramos et al (2010 a & b) investigated a comprehensive data set for DQ steel sheet and used to calibrate a modern texture-based simulation of formability behavior – quantitative descriptions of texture and multiaxial, principal-stress flow curves – and then verified the predictions from simulation – Lankford coefficients measured at various angles to the rolling direction and FLC curves. They explored the minimum data set required for accurate prediction of metal forming behavior. Li and Wierzbicki, (2010) studied the three-parameter Modified Mohr–Coulomb fracture model and the determination of the material parameters were briefly described. The formulation of the post-initiation behavior was proposed by defining both the explicit softening law and the incremental damage evolution law. As opposed to the existing attempts to simulate slant fracture with material weakening before crack formation, softening was assumed to occur only in the post-initiation range. Element deletion with a gradual loss of strength was used to simulate crack propagation after fracture initiation. The main emphasis was the numerical prediction of slant fracture which was almost always observed in thin sheets. Fracture of flat-grooved tensile specimens cut from advanced high strength steel (AHSS) sheets was simulated by 2D plane strain element and shell element models.

Kim *et al.* (2013) studied formability on two AHSS sheets, DP590 and TRIP590. Sheets were deformed by the limiting dome height (LDH) test. This test was predicted with finite element simulations using various constitutive models. Three yield functions, von Mises, Hill's 1948, and Yld2000-2d, were considered to examine the effect of the yield criterion on formability. The anisotropy parameters were determined from different experimental tests and their influences on LDH predictions were analyzed. Golovashchenko *et al.* (2013) reported the results of formability testing of dual phase steels in electro hydraulic forming (EHF) conditions and provided an explanation of the observed formability improvement based on analysis of the experimental results and through the use of a modeling technique developed as part of this work for simulating the EHF process. Comparison of the maximum strains resulting from EHF into a conical die and a v-shape die to the maximum strains resulting from quasistatic LDH testing (limiting dome height) indicated that substantially higher strains can be accomplished in the EHF process.

From above studies, the current work is focused on the forming behavior of five AHSS steels by simulating the LDH test for eight straight paths. The obtained major strain and minor strain values are plotted on x and y-axes and forming limit diagrams are constructed. Thickness distribution is also compared for three cases.

2 Methodology

2.1 Base materials and their mechanical properties

For the present work, five different steel grades materials were considered such as Drawing Quality (DQ), High-Strength steel (HSS), Transformation-Induced Plasticity steel (TRIP), Dual Phase steel (DP), High-Strength, Low-Alloy steel (HSLA). The mechanical properties of the all materials were shown in the Table 1. All the properties were taken from the available literature (Panda *et al.* (2009); Panda *et al.* (2010); Kim *et al.* (2013); Ganesh Narayanan and Narasimhan (2006)).

Table 1 Mechanical properties of different Advanced High Strength Steels materials

Steel Grade	Yield Strength (σ) (MPa)	n	K (MPa)	R_0	R_{45}	R_{90}
DP590	420	0.173	1043.6	0.91	0.85	1.12
HSS	278	0.21	469	0.98	0.66	1.22
TRIP590	437	0.23	1100	1.26	1.11	1.3
DQ	301.3	0.23	653.4	1.19	1.07	1.68
HSLA	421	0.13	760.9	1.02	1.23	1.16

2.2 Modeling of limit dome height test simulation

In a LDH test, the sheet is deformed by a hemispherical punch with diameter: 101.6mm inside a die opening of diameter 105.7mm. Simulations were performed for eight strain paths with sheet dimensions 25x200, 50x200, 75x200, 100x200, 125x200, 150x200, 175x200, 200x200 mm. The LDH setup used for simulation of all the steel grades sheets. The tools required for LDH test, punch, die, blank holder, draw bead, and blank generated in Solid Works, a CAD package, and meshed using Delta Mesh facility in PAM STAMP 2G. The base material comprised quadrilateral shell elements of Belytschko–Tsay formulation with five through-thickness integration points. Hollomon's strain hardening law and Hill's 1948 isotropic hardening yield criterion was used as the plasticity model. A uniform mesh size of 1mm was used throughout the simulations. The thickness gradient based necking criterion is sensitive to mesh size and it was found that for accurate prediction of limit strain 1–5mm mesh size is optimum. The friction coefficient μ was assumed to be 0.12 and is kept constant throughout the study. Blank holder force (80kN) was chosen such that the blank neither draws in nor tears near draw beads during forming prediction.

2.3 Thickness gradient - based on necking criterion (TGNC)

The displacement at failure can be obtained from the thickness gradient – based necking criterion. When the thickness gradient (ratio of thickness of nearest elements or circles) falls below 0.92 then the necking occurs in the sheet metal. Here the thickness ratio is equals or falls below 0.92 are considered as necked elements (Nandedkar, (2000)).

2.4 Forming limit diagram (FLD) construction

Major limit strain and minor limit strain were evaluated from the deformed sheets using TGNC during simulation for each steel grade sheets. According to the TGNC the ratios of the two meshing elements thickness is calculated and major strain and minor strain were considered where thickness ratio 0.92 or lesser has obtained. For constructing FLD, major strain values on y-axis and minor strain on x-axis. Forming limit curve was plotted by joining these limit strain co-ordinates. This procedure was followed for all the materials.

3 Results and Discussion

From simulations limit strains are obtained for eight different strain paths. FLC diagrams are constructed for different strain paths of five steel grades of AHSS. The FLC diagrams for the different grades are shown in the followed Figures.

3.1 FLD AHS steel

Figure 1 shows the FLD of the DP 590 steel. All the limit strains of eight strain paths are plotted. A free hand curve is drawn by joining the maximum limit strains. This curve is treated as forming limit curve for DP 590 steel. From the Fig. 1, Formability of DP 590 steel is decreased towards plane strain. The forming behavior of DP 590 steel from plane strain region to drawing and stretching zones is increased. The major limit strain in the drawing side is 0.584 for 25x200 mm strain path whereas minimum is 0.34 for 125x200 mm strain path. The similar behavior is seen in the other steel grade materials as shown in Fig. 2 to Fig. 5.

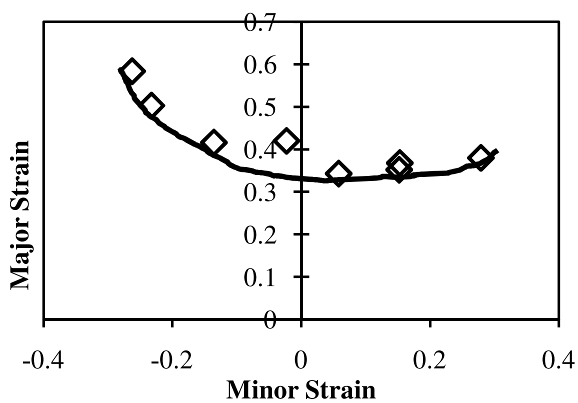

Figure1 FLC for DP 590 steel

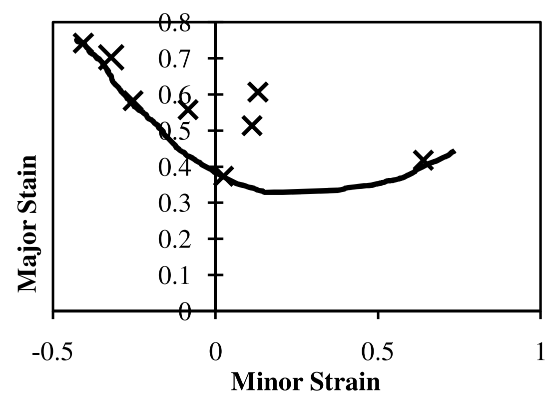

Figure 2 FLC for DQ steel

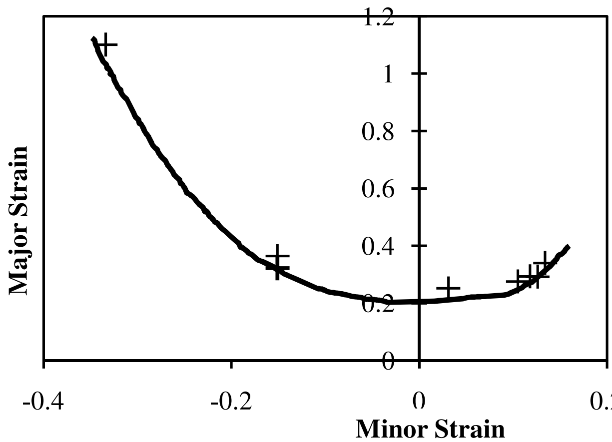

Figure 3 FLC for HSLA 590 steel

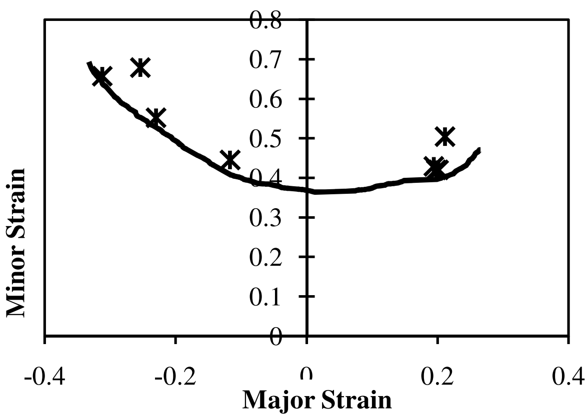

Figure 4 FLC for HSS steel

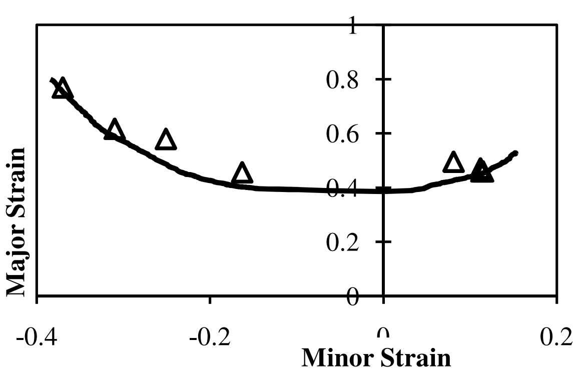

Figure 5 FLC for TRIP 590 steel

Figure 6 shows the master FLD in which all the FLC are compared. Among five steel grades HSLA steel sheet has lowest formability than other especially in the stretching side and it followed by DQ, TRIP 590, HSS and DP 590 steel. In the stretching side, HSS and DP 590 steels are almost a similar behavior. Likewise TRIP 590 and DQ also have similar behavior. Similarly, when forming behavior is seen in the drawing side DQ had high major strain value and TRIP 590 had less and followed DQ, HSLA and DP590 in between.

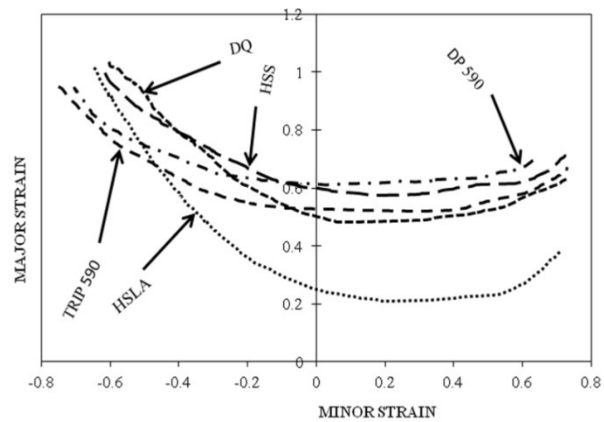

Figure 6 Combined FLC's for different steels

2.2 Thickness Distributions comparison

Forming behavior can be understood using thickness distribution also. By which, strain localization and strain distribution in the sheets can be seen. In the followed discussion, thickness distribution comparison is made for the strain paths of 25x200, 100x200 and 200x200 mm. Figure 7 shows the thickness distribution comparison of all the five grades with 25x200 mm strain path. Among all, thickness distribution is more uniform for HSLA and less for TRIP 590 steel. This is clearly shown in Fig.6 also where major strain is more for HSLA and less for TRIP 590 steel. Similar behavior is seen in the other two Fig. 8 and 9 also, in which thickness distribution is compared for in-plane (100x200 mm) and biaxial (200x200 mm) strain paths.

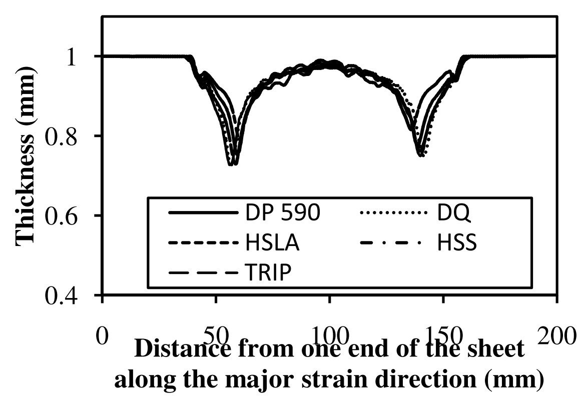

Figure 7 Thickness distribution comparisons of different steel grades with 25x200 mm strain path

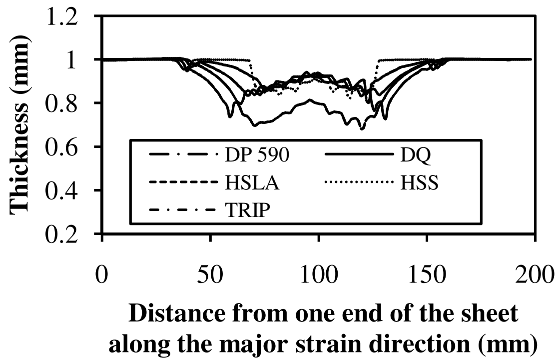

Figure 8 Thickness distribution comparisons of different steel grades with 100x200 mm strain path

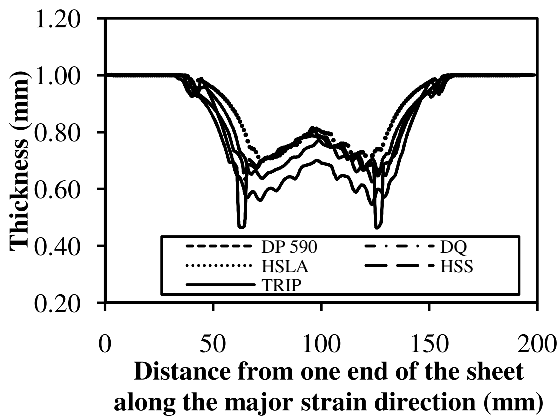

Figure 9 Thickness distribution comparisons of different steel grades with 200x200 mm strain path

4 Conclusions

From the present numerical simulation the following conclusions are drawn.

- From the forming limit diagrams, it is noticed that all the steel grades have better forming in the drawing zone.
- Among the all the steel grades, DP 590 has better formability and followed the HSS,DQ, TRIP and HSLA.
- Thickness distribution variation also observed according to FLC and more uniform thickness is seen for sheet which showed better formability.

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