Investigation of the micromechanical behavior of ferritic-martensitic steel under complex loading

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ABSTRACT

In this paper, the mechanical behavior of dual phase steel has been investigated in the macro and micro scales as experimentally and numerically. In order to study the influence of stress states on the mechanical behavior and fracture strain of DP600, four different specimens were tested under different stress states. Afterward, the obtained microstructure images by light microscope, were utilized to generate a 3D representative volume element based on the real microstructure. The microstructure images converted to a 3D RVE model by an image processing and finite element codes in Matlab and Abaqus commercial software, respectively. Then, the ability of the micro mechanical model to predict the macro mechanical behavior was evaluated under different stress states. The results demonstrate, the micro mechanical model is able to predict the macro mechanical flow curve under different stress states except shear. Finally, the influence of stress states on the stress to strain partitioning rate and the local plastic strain at fracture point were assessed. The results show stress-strain partitioning and local plastic strain are strongly dependent on stress state.

KEYWORDS

Dual phase steel, Micromechanical modeling, Stress state, Stress-strain partitioning, Plastic strain localization.

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1. Introduction

Dual-Phase (DP) steels are utilized in the automotive industry as one of the main types of steel. DP steel contain two different phases i.e., martensite and ferrite phases, which the mechanical behavior of these steels are dependent on the microstructural features of their phases [1]. Several researchers have evaluated the damage evolution in DP steels as experimentally [2-3]. They studied the influence of microstructural features (martensite phase volume fraction, grain size, chemical composition) on micro-mechanical behavior. Recently, the micromechanical simulations have adopted to assess the influence of microstructural parameters on the macro-mechanical behavior of dual-phase steels [4-5]. In this model, a representative volume elements (RVE) utilizes to evaluate the deformation patterns of phases during different loading conditions. Darabi et al. [4] proposed a 2D and 3D RVEs, based on real microstructure to predict the evolution of strain localization in phases. Several researchers have tried to predict the macro-flow curve by micro-mechanical model and a good agreement was observed between the obtained flow curves from the 3D RVE model and tensile experimental results [1, 4-5]. Few studies have been performed on micro-mechanical modeling under complex loadings and the ability of micromechanical model to predict the stress-strain curves under different stress states has not been evaluated. In this paper, the mechanical behavior of DP600 steels will be analyzed under different stress-states and the results will be compared with the experimental tests. Then, the fracture strain will be presented based stress states parameters. Finally, the effect of stress states parameters on stress-strain partitioning will be analyzed during loadings.

2. Experiment

In this study, four different specimens with different stress states were considered to evaluate the effect of stress states on stress-strain curve according to DIN EN ISO 6892. Figure 1 shows the specimens with different stress triaxiality and Lode angle parameters. All the specimens were tested using a universal testing machine (MTS Sintech 65/G) at the strain rate of 0.01 mm/s.

3. Micromechanical model

a 3D RVE was generated statistically in the out- of-plane direction. In this approach, the first layer of the model was generated by an image processing code on the basis of actual microstructure. Afterwards, random distributions of martensite phase were generated by an image processing code. Finally, a python code was adopted to convert the generated layers to a 3D micromechanical model. In this model, the volume fraction of martensite phase remains constant. For all specimens, the loading conditions were extracted from the deformation of the critical macro-mechanical element which is illustrated in Figure 2.

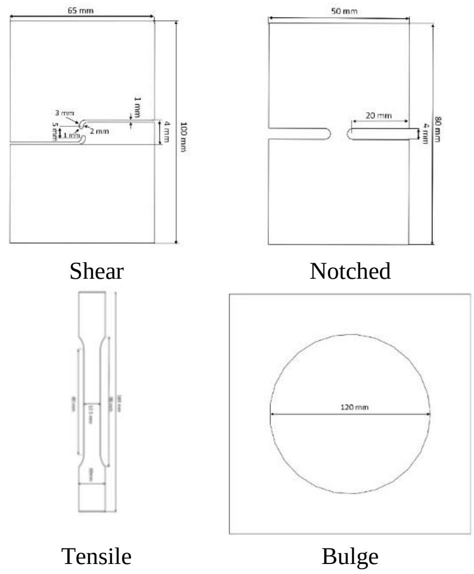

Figure 1. Geometries of specimens under different stress states.

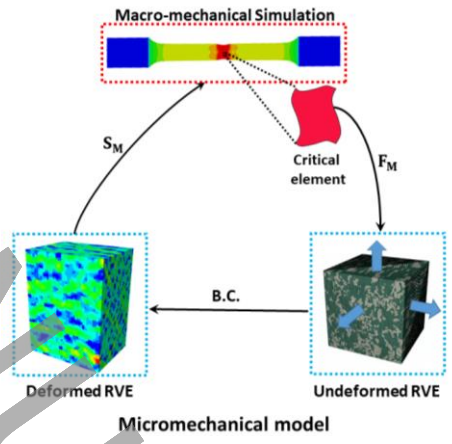

Figure 2. The scheme of the boundary conditions extraction from macro to microscale simulation.

4. Result and Discussion

The generated RVE was used to investigate the macro stress-strain curves of DP600 under complex loading and without the consideration of a damage model. Figure 3 shows a comparison pattern with micro-simulation, macro simulation and tensile experimental results, which shows the micromechanical model is able to predict the tensile test Therefore, this approach will be used for further investigation under different loading conditions. The results indicate that the 3D RVE have acceptable results for tensile, notched tensile and bulge boundary conditions. However, these models are found to not accurately predict experimental stress-strain curves under shear loading.

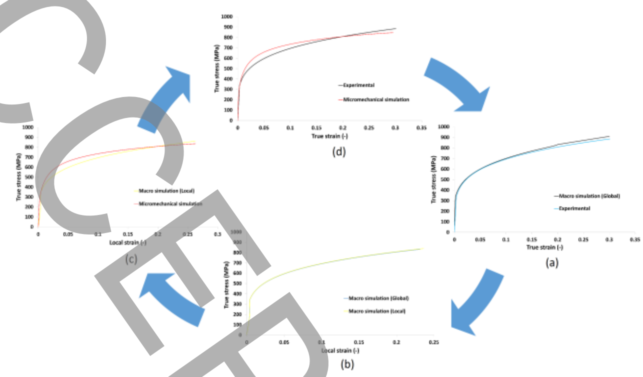

Figure 3. Comparing the experimental stress-strain curve with the micromechanical results.

The influence of triaxiality and lode angle parameters on Stress-strain partitioning coefficient are demonstrated in Figure 4 for at fracture point and strain=0.2. A same pattern was observed for both strain point. The results show, the stress-strain partitioning coefficient varies relative to stress states parameters as a quadratic function. The minimum value of stress-strain partitioning coefficient happens lode angle zero and as the lode angle increases or decreases the coefficient increases. Further, the maximum value of the coefficient occurs at triaxiality 0.33 and as the triaxiality increases or decreases the coefficient decreases.

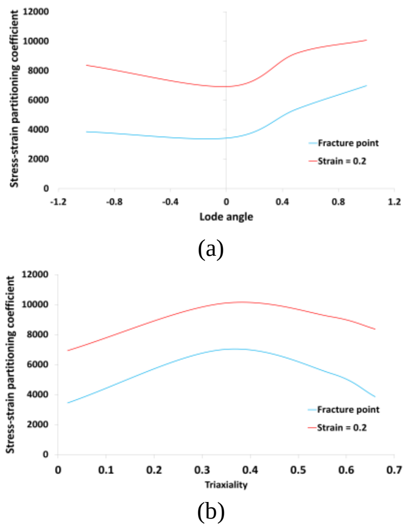

Figure 4. The changes of stress-strain partitioning coefficient to (a)Lode angle and (b) triaxiality

Figure 5 shows the local plastic strain surface at fracture point based on triaxiality and Lode angle. As reported already by Bai and Wierzbicki [6] which the local plastic strain has a parabolic behavior in the Lode angle parameter direction and exponential equation in the stress triaxiality direction.

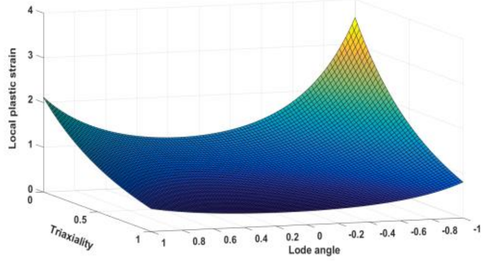

Figure 5: Local fracture strain surface based on triaxiality and Lode angle

5. Conclusion

According to the results, the main conclusions of this study are as follows:

- The 3D micromechanical model with random distribution is able to predict the macro flow curves under different stress states except shear loading.
- Local fracture strain is dependent on triaxiality and Lode angle parameters, and the fracture locus can be shown by as parabolic surface
- Stress-strain partitioning coefficient depends on stress states parameters, it means that the ferrite and martensite phases have different role under different stress states.

6. References

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