Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 51(3) (2019) 1-3
DOI:

Micromechanical Failure Analyses and Tensile Behavior of Dual Phase Steel Using Two and Three -Dimensional Representative Volume Elements

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ABSTRACT: In dual phase steels, hard martensite phases dispersed in the soft ferrite phase. This kind of steels has some features such as high strength and ductility that make them attractive especially in the automotive industries. In the past, researches analyzed the behavior of dual phase steels based on the micromechanical and macro-mechanical simulation using two-dimensional representative volume element. Meanwhile, the failure mechanism of dual phase steel under uniaxial tensile test using two-dimensional representative volume element is investigated. Analysis of three-dimensional representative volume element can be considered for more detailed investigation of failure mechanisms and modification of two-dimensional representative volume elements . In this paper, prediction of deformation pattern and damage mechanisms of dual phase steels and failure of specimens, with various ratio of thickness to width, using two and three-dimensional representative volume elements are performed in the microstructure scale using finite element method. Experiments have been carried out at three stages necking, after necking, and failure point were used for investigation of deformation pattern and failure mechanisms at the micro scale. Finally, by comparing the experimental and numerical results, the max value of hydrostatic stress is obtained as an indicator of failure in the dual phase steels.

Review History:

Received:
Revised:
Accepted:
Available Online:

Keywords:

Dual phase steel
Stress–strain curve
Representative volume element
Microstructure
Finite element method

1- Introduction

Dual Phase (DP) steels have been initially developed in the 1970s [1] and can be considered as composites that contain soft ferrite matrix with hard martensite reinforcement particles that the hard phase volume fraction is between 5 to 30% [2]. A large number of experiments and numerical analyses were already performed for dual phase steel, but most of them were based on Two-Dimensional (2D) stress-strain analyses. Although some researches have been performed on dual phase steel using Three-Dimensional (3D) modeling, there are still gaps in the physical arrangement of the phases and also their effects on mechanical behavior.

In this paper, the main aim is studying on the deformation pattern and failure mechanism of typical DP steel using 3D finite element modeling of the microstructure and investigation with 2D stress-strain analyses done by Hosseini-Toudeshky et al. [3]. The specimens are tested under uniaxial tensile load. Scanning Electron Microscope (SEM) and metallography images are used to obtain a deformation pattern and failure mechanism. The obtained deformation and failure patterns from experimental images and finite element analyses are finally discussed.

2- Experiments

In this study, DP600 dual phase steel produced by SSAB is tested using ASTM standard [E 466-82]. For 3D stress distribution analysis three specimens (Fig. 1) were produced. Tensile tests were performed using a 50 kN hydraulic testing machine and the obtained data were reported.

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Figure 3. Dimensionless tip deflection in terms of time.

The obtained stress-strain engineering curve from the uniaxial tensile test is shown in Fig. 2. Tensile tests were performed with a different acceptable load for microscopic studies.

There were three voids models in the 2D state of stress condition [3] but in the 3D state of stress, all of the voids are in the spherical form as shown in Fig. 3. The spherical shape of the voids could be an indication for similar effectiveness of all three normal stresses σ_x and σ_y and σ_z meaning that the voids have the same growth in all three directions and finally have a spherical form. Therefore, the formation of these voids in the 3D state of stress in DP steel can be considered as hydrostatic stress condition. Also, this phenomenon has been predicted using finite element analyses.

3- Deformation Pattern in the Microstructure

The obtained distributions of von Mises stress, shear stress and

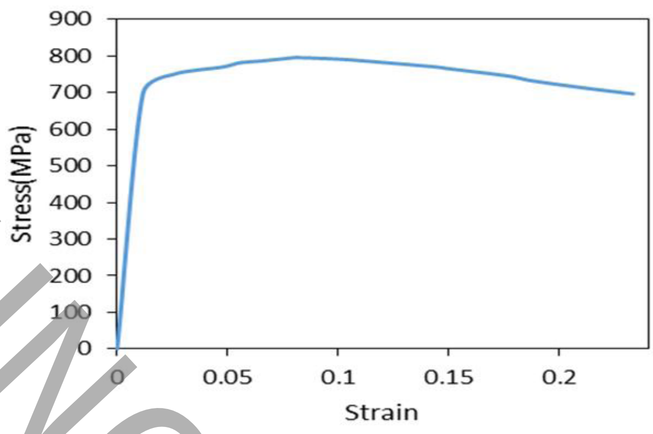


Figure 2. Engineering stress-strain behavior of DP-600 steel.

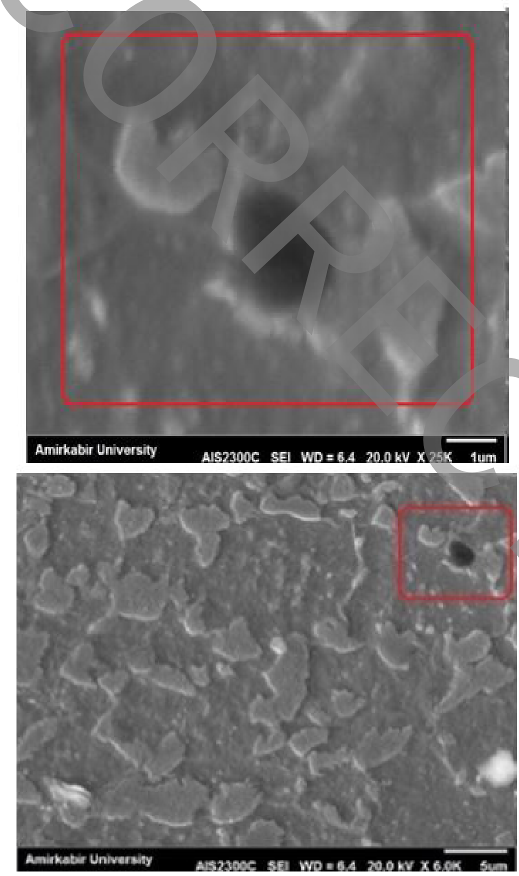


Figure 3. Pattern of void formation and deformation of martensite islands in 3D experimental specimens using SEM images.

hydrostatic stress at various loading stages are investigated using finite element method. These obtained hydrostatic stress distributions in Fig. 4 show that the voids are formed in the grain boundaries. As observed in the SEM images, these voids have also spherical form. So it can be represented that hydrostatic stress is the main factor of the formation of voids in the 3D stress distribution.

4- Failure Pattern: Predictions versus Experiments

The main cause of the formation and growth of voids and finally failure in the 2D state of stress is shear stress concentration

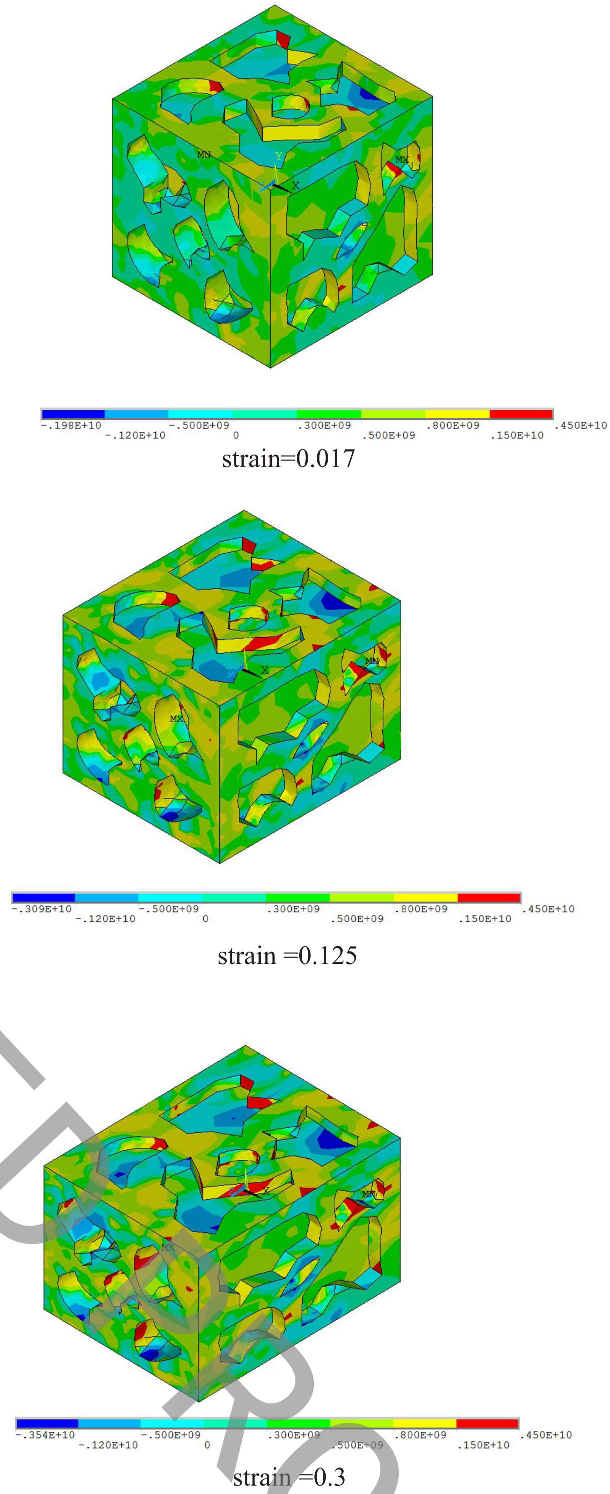
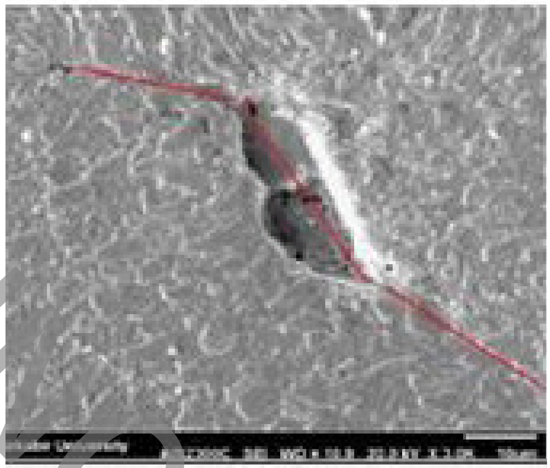
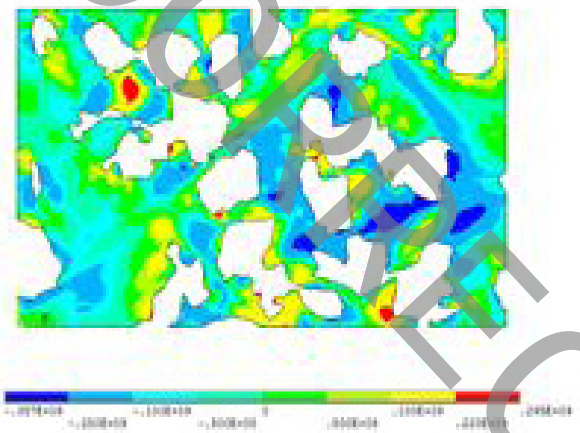


Figure 4. Deformation pattern at different loading values, hydrostatic stress distributions.

(Fig. 5 [3]). But for the 3D state of stress, as shown in Fig. 6 the voids grow as spherical so the stress is applied in all directions, are relatively equal and can be considered as hydrostatic pressure as mentioned in the previous sections. So it can be considered hydrostatic stress as the main cause of voids creation in the 3D specimens of DP steels and the hypothesis that was presented in the experimental section is proved (Fig. 6).



(a)

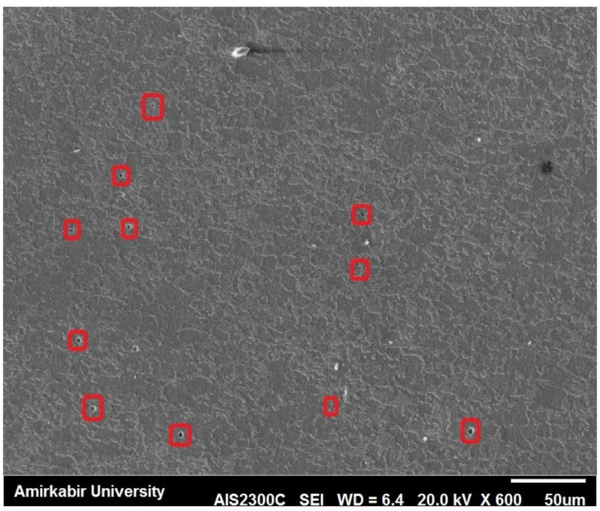


(b)

Figure 5. Voids formation in 2D RVE [3] :(a) SEM image, (b) FEM.

5- Conclusion

In this paper, mechanical behavior and failure pattern of dual phase steel for thick specimens are studied using 3D RVE model that was simulated based on the real microstructure



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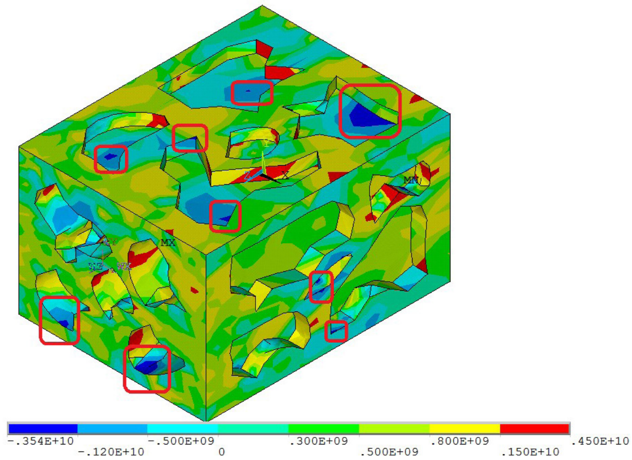

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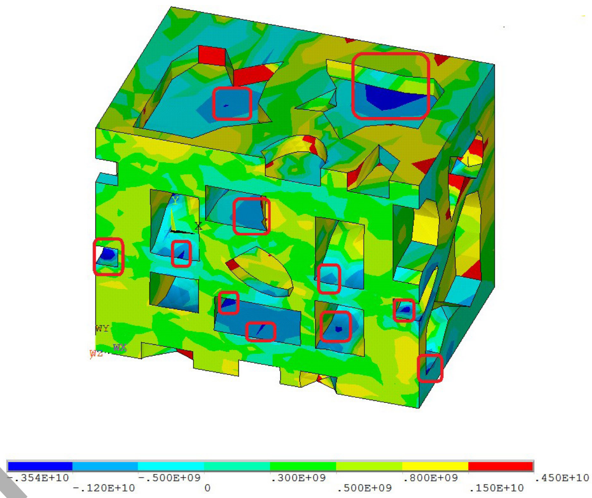

(c)

Figure 6. Voids formation :(a) SEM image, (b) parts of FEM model.

and analyzed using finite element method. The experiments were performed at three loading stages: necking area, localization, and failure. Metallographic and SEM images were used to access the failure mechanism at the micro scale. In metallographic images, it was observed that martensite particles stayed almost in their original form and their elongation were very small and the SEM images shown the voids located in the grain boundaries. These voids grown in spherical form and the hydrostatic pressure are known as the main source of void formation.

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