Investigation of the Effect of Boundary Condition on the Property of TRIP Steel by Finite Element Simulation

J.H. Li  H.P. Deng  S.Yu

Department of technology, Dongguan zhongfan new material technology Co., LTD, Dongguan, 523808, China
Email*: zhongfankeji88@163.com

Abstract. TRIP (Transformation induced plasticity) steel combined high strength and high plasticity perfectly, which depend on the micro structure of the material greatly. Residual austenite plays an important role on the micro material transformation and macro property. Different boundary condition makes different stress and strain field of the TRIP steel and induced different residual austenite transformation. Under different compression stress, the residual austenite transformation was different, to predict the micro transformation behavior, investigation of the macro stress character was necessary. Finite element simulation was carried out in this paper to investigate the stress filed of TRIP steel under different boundary condition to predict the micro residual austenite transformation and macro property development.

1. Introduction
TRIP (TRansformation Induced Plasticity) steels for its special mechanical properties with high-strength and high-plasticity developed rapidly in the past decades to satisfied the improvement of lightweight automobile requirements[1-3]. The excellent macro character of TRIP steel depends on the microstructure of TRIP steel, especially the retained austenite phase transformation with different stress state[4-5].

In fact, the macro mechanical properties of TRIP steel was determined by the stability of retained austenite, which was unstable under room temperature. Martensite was more stable than retained austenite, so the retained austenite was apt to transform into stable martensite with load, which provide the steel high strength and high plasticity characteristic[6-8]. For TRIP steel, phase transformation was the key point of its excellent mechanical properties, the microstructure development and macro micro stress distribution all depend on the phase transformation behavior of residual austenite. With different boundary condition, the stress and strain state was different for the retained austenite and induced different martensite transformation[9-11]. So to predict the property of TRIP steel, investigation of the stress state of the material was necessary.

Experiment was always carried out to investigate the stress and strain character of material under different deformation condition, but which was difficult in providing detail stress and strain distribution. Finite element simulation based on the variation principle, by simulate the large component with many small elements, which predict the stress and strain distribution exactly and widely used in the macro simulation. Continuum mechanics was the fundamental of finite element, which always regards the component as uniform and homogeneus. Calculation of the component by each integral point, which represents a part of the material and the stress responds to strain directly [12-15].
To enhance the investigation efficient, finite element simulation was carried out in this paper, the component with different compression boundary condition was discussed. With the different stress distribution, the portion of retained austenite transformation can be calculated.

2. Another section of your paper

For continuum thermodynamics, material behavior is related to energetic, entropic and dissipative processes. Energetic and entropic process are embodied in free energy density $\psi$ and free energy density $\psi'$ can be expressed as

$$\psi = \psi(F, \theta)$$

(1)

Where $F$ is deformation gradient and $\theta$ was temperature. The derivative of $\psi'$ was

$$\psi' = \psi'(F, \theta) = P : \dot{F} - \eta \dot{\theta} = \left(\frac{\partial \psi(F, \theta)}{\partial F}\right)_\theta : \dot{F} + \left(\frac{\partial \psi(F, \theta)}{\partial \theta}\right)_F : \dot{\theta}$$

Where

$$P = \left(\frac{\partial \psi(F, \theta)}{\partial F}\right)_\theta$$

(3)

was the first Piola-Kirchhoff stress and

$$\eta = \left(\frac{\partial \psi(F, \theta)}{\partial \theta}\right)_F$$

(4)

was entropy density. For isothermal process, free energy degenerate to strain energy. As a kind of metallic materials, TRIP steel is dissipative materials, so internal variables were needed to describe the plastic behavior. Free energy density $\psi'$ changed to

$$\psi' = \psi'(F, \theta, \xi_1, \ldots, \xi_2)$$

(5)

Where $\xi$ was internal variable and the derivative of $\psi'$ was

$$\psi' = P : F - \eta \dot{\theta} - D_{int}$$

$$= \left(\frac{\partial \psi(F, \theta, \xi_1, \ldots, \xi_2)}{\partial F}\right)_{\theta, \xi_2} : \dot{F} + \left(\frac{\partial \psi(F, \theta, \xi_1, \ldots, \xi_2)}{\partial \theta}\right)_{F, \xi_2} : \dot{\theta} + \sum_{i=1}^{2} \left(\frac{\partial \psi(F, \theta, \xi_1, \ldots, \xi_2)}{\partial \xi_i}\right)_{F, \theta} : \dot{\xi}_i$$

(6)

For anisotropic metals, the additive form of energy density $\psi'$ can also be expressed as

$$\psi'(\theta, F, F_p, \varepsilon) = \psi_R(\theta, F, F_p, \varepsilon) + \psi_H(\theta, F, F_p, \varepsilon)$$

(7)

Where $\varepsilon$ was internal variables relative and the key point was to determine the plastic deformation gradient, which was the central of deformation gradient multiplicative decomposition

$$F = F^p F^\varepsilon$$

(8)

and following flow rule,

$$\dot{F}_p = L_p F_p$$

(9)

strain calculation

$$E = \frac{1}{2} (F^{\varepsilon T} F^\varepsilon - I)$$

(10)

and stress calculation

$$T = C : \frac{1}{2} (F^{\varepsilon T} F^\varepsilon - I)$$

(11)

Trail stress and return-mapping algorithm was always adopted to calculate the macro material behavior with finite element. In macro continuum thermodynamics, stress was determined by strain.
directly, it is locally response of strain. Some time strain gradient was also considered in macro finite element simulation, but it is also dependent on internal variable, nonlocal response was not intrinsic.

3. Model of finite element
To discuss the effect of boundary condition on the TRIP steel stress responding, the following finite element model was set up. Rectangle TRIP steel with length 100mm, wide 20mm and radius of middle hole 5mm was shown as fig.1. The model was meshed with hexahedron element and TRIP steel material model from experiment was imported.

The component was applied two different load boundary condition, the first was compression on the X direction and the second was compression on X direction and also in Y direction together.

4. Results and discussion
Fig.2 was the simulation result of the first kind boundary condition. From the result we can see that the stress distribution of the TRIP steel component was non-uniform, the higher stress near the vertex of the middle hole. It is clear, because higher stress was near the vertex of the middle hole, retained austenite has not more space to transformed to martensite, so the strength near the vertex of the middle hole will keep stable than the other parts and make local stress uneven. The material property will also be uneven after deformation.

Fig.3 was the simulation result of the second kind boundary condition. From the picture we can see that the stress distribution of the TRIP steel component become even than the first kind of stress condition. The higher stress point was not on the vertex of the hole, but on the full boundary of the hole. It is clear that with compression in Y direction, the stress was adjust with the circle of the hole, the stress was no longer concentrate on the one point, but distribute evenly with the circle. Transformation of retained austenite to martensite need space, the second boundary condition provide even space for the microstructure transformation, so the macro property will be more even.
5. Conclusion
The macro property of TRIP steel depends on the microstructure greatly, especially the portion of retained austenite and its transformation. By finite element simulation, the stress distribution of TRIP steel component with hole was discussed and the following conclusion could be drawn.

(1) Finite element was practical in calculation of TRIP steel macro responding in exhibiting the stress distribution of the component and predict the property of the component.

(2) For component with hole in the middle, with compression in one direction, the stress distribution was uneven, with higher stress near the vertex of the middle of the circle, which will hinder the retained austenite transformation, and with the compression in two direction boundary condition, the stress distribution will even greatly and make the property average.

(3) By finite element simulation, the response of TRIP steel under different boundary condition can be provide and the property of the component can be predicted correctly.

Acknowledgments
Authors wishing to acknowledge assistance and encouragement from Dongguan Innovation and Entrepreneurship Leadership Program Funding.

References
[1] FU Yong-tao, LIU Jing, SHI Jie, CAO Wen-quan, DONG Han, Effects of Cold Rolling Reduction on Retained Austenite Fraction and Mechanical Properties of High-Si TRIP Steel, JOURNAL OF IRON AND STEEL RESEARCH, INTERNATIONAL. 2013, 20(5) : 50-56
[2] X. Sun, A. Soulami, K.S. Choi, O. Guzman, W. Chen, Effects of sample geometry and loading rate on tensile ductility of TRIP800 steel, Materials Science and Engineering A 541 (2012) 1-7
[3] S. Zhang, K.O. Findley, Quantitative assessment of the effects of microstructure on the stability of retained austenite in TRIP steels, Acta Materialia 61 (2013) 1895–1903
[4] W.J. Dan, W.G. Zhang, S.H. Li, Z.Q. Lin, Finite element simulation on strain-induced martensitic transformation effects in TRIP steel sheet forming, Computational Materials Science 39 (2007) 593–599
[5] J. Chiang, B. Lawrence, J.D. Boyd, A.K. Pilkey, Effect of microstructure on retained austenite stability and work hardening of TRIP steels, Materials Science and Engineering A 528 (2011) 4516–4521
[6] Q. Furnemont, F. Lani, T. Pardoen, F. Delannay, Multiscale mechanics of TRIP-assisted multiphase steels: I. Characterization and mechanical testing, P.J. Jacques, Acta Materialia 55 (2007) 3681–3693
[7] W.J. Dan, S.H. Li, W.G. Zhang, Z.Q. Lin, The effect of strain-induced martensitic transformation on mechanical properties of TRIP steel, Materials and Design 29 (2008) 604–612
[8] K.S. Choi, A. Soulami, W.N. Liu, X. Sun, M.A. Khaleel, Influence of various material design parameters on deformation behaviors of TRIP steels, Computational Materials Science 50 (2010) 720–730
[9] S. Zaeflerer, J. Ohlert, W. Bleck, A study of microstructure, transformation mechanisms and correlation between microstructure and mechanical properties of a low alloyed TRIP steel, Acta Materialia 52 (2004) 2765–2778
[10] Yu Hai Yan, Gao Yun Kai, Meng De Jian, Transformation behavior of retained austenite under different deformation modes for low alloyed TRIP-assisted steels, Materials Science and Engineering A 441 (2006) 331–335
[11] A. Nasser, A. Yadav, P. Pathak, T. Altan, Determination of the flow stress of five AHSS sheet materials (DP 600, DP 780, DP780-CR, DP 780-HY and TRIP 780) using the uniaxial tensile and the biaxial Viscous Pressure Bulge (VPB) tests, Journal of Materials Processing Technology 210 (2010) 429–436
[12] P. Haupt. On the mathematical modelling of material behavior in continuum mechanics[J]. Acta Mechanica, 1993, Vol. 100: 129-154
[13] Richard Becker. Developments and trends in continuum plasticity[J]. Journal of Computer-Aided Materials Design, 2002, 9(2): 145-163
[14] G. J. Li et al. 3D Finite Element Analysis of Industrial Metal Forming Processes. Proc. of 5th ICTP. 1996: 479-484
[15] Guoqun Zhao, Ed Wright and Raman V. Grandhi. Forging Preform Design with Shape Complexity Control in Simulating Backward Deformation. Int. J. Mach. Tools Manufact.. 1995, 35(9): 1225-1239