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Effect of microstructure features on the mechanical properties of spheroidized steel by crystal plasticity method.

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ABSTRACT: Finite element method based on crystal plasticity becomes a powerful tool in investigating mechanical properties of ferritic steel and dual phase steel. In this work, a three-dimensional, microstructure-based representative volume element method is employed for simulating the mechanical properties of the alloy steel 42CrMo4, a typical spheroidized ferrite–cementite steel. A computer program has been developed to generate automatic models considering microstructural features such as grain size, volume fraction, distribution of particles, ferrite texture and carbide bands in ferrite–cementite steel. The spheroidized cementite is generally without plastic deformation under the normal tensile test even at the fracture moment. Crystal plasticity constitutive law is employed to model the ferrite grains employing Huang's code in Abaqus software. Material hardening parameters are determined and calibrated by comparing simulated tensile tests with experimental stress-strain curves. To study the influence of microstructure features and the capability of this method to predict the material mechanical behavior, several 3D samples including different microstructural features are modeled. The results show that when the proportion of cementite in the steel increases, the strength of the steel increases accordingly. Although in this study a random texture is assigned to crystalline aggregates, the code is capable of working with any texture data. Also, effects of ferrite grain size and carbide band which leads to the microstructure inhomogeneity and stress concentration are studied..

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1- Introduction

Ferrite-cementite steel sheets have been widely used in cold forming processing such as drawing and blanking. For normal hot rolled steel sheets with ferrite and lamellar pearlite phases, the hard lamellar pearlite will cause cracking during cold forming. Therefore, long-time annealing treatments which produce spheroidized carbide/ferrite microstructures will usually use to improve formability and machinability in these sheets [1]. In these steels, dispersions of spherical carbide particles, particle size, spheroidization ratio, carbide band and other microstructural features can affect material's mechanical properties and forming quality.

In recent years, various studies and micromechanical modeling using crystal plasticity finite element methods have been conducted on various materials to simulate the tensile deformation of polycrystalline metals [2]. Thus, the macroscopic material properties can be predictable and measurable by consideration of microstructural features. Micro-mechanical modeling within the framework of crystal plasticity has been extensively employed in simulating the mechanical response of materials containing single phase [3]. Recently, micro mechanical studies on dual phase steels consists of a soft ferrite phase with dispersed hard martensitic phase have been done [4].

In the present work, the crystal plasticity finite element method has been employed to study the influence of microstructural features on mechanical behavior of the steels with ferrite and spheroidized cementite.

2- Methodology

Although, it is possible to analyze a macro scale model by Crystal Plasticity Finite Element Method (CPFEM) considering all grains, but it is not computationally cost-effective. Thus, it is preferred to utilize small size models in which the macro scale behavior can be assessed and all microstructural features can be considered. The flowchart of multiscale simulation process used to investigate the effects of microstructural features on the mechanical behavior of ferrite-cementite steel is shown in Fig. 1. A preprocessor code is developed to model this type of steel with its sophisticated microstructural features such as grain size, volume fraction, distribution of particles, texture and carbide bands. Also, different mechanical properties of each phase, loading and boundary conditions can be applied in this code. The output of the code is a *.inp file proper to be imported in Abaqus software and to run with the UMAT developed based on Huang's UMAT. Experimental stress-strain curves determined by Zhuang et al [5] have been

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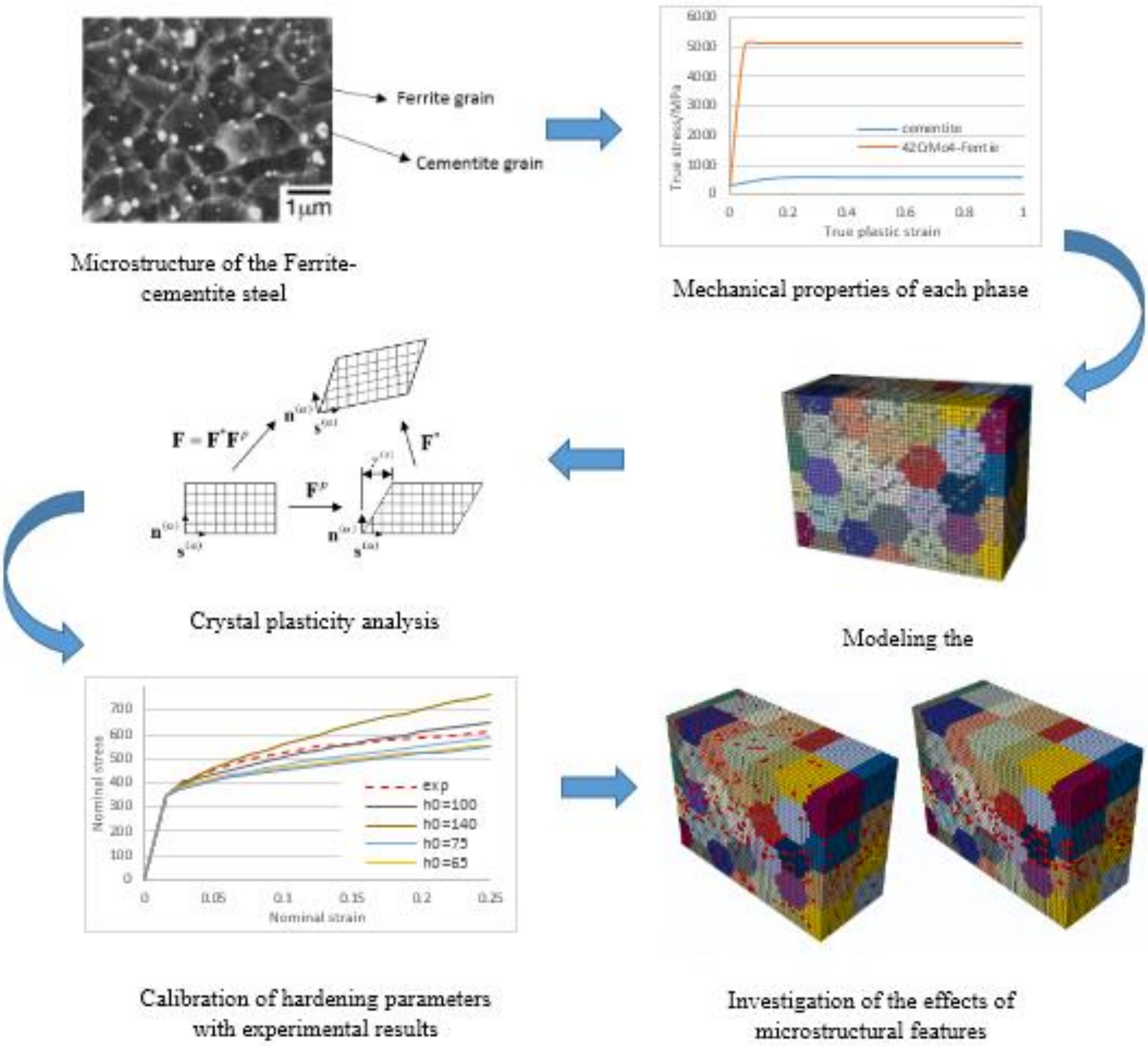

Fig. 1. Flowchart of multiscale simulation process

employed to calibrate crystal plasticity material parameters. They annealed steel sheets with the thickness of 6mm and produced ferrites with average grain size of 7μm and cementite particles with average grain size of 0.65 μm. The volume fraction of cementite particle is 10±0.5%.

The representative volume element size is extracted from the previous work done by Assempour et al [6]. Thus, the simulated Representative Volume Element (RVE) was considered by dimensions of 32μm ×24μm ×14μm. The experimental standard tensile test was conducted at a strain rate of 10^(-3) s^(-1). Both ferrite and cementite phase have the elastic modulus 210 GPa and Poisson's ratio of 0.3 [5]. Also, according to the experimental data, the yield strength of cementite could reach a value of 3000 MPa. The spheroidized cementite is generally without plastic deformation under normal tensile test even at the fracture moment [7]. In fact, CPFEM is the best model to simulate the plastic deformation of polycrystalline materials like ferrite as used in this study. This method has been expressed in detail by Asaro [8]. The Peirce et al hardening relation was used in Huang's UMAT [9] and the material hardening parameters are determined and calibrated by comparing simulated tensile tests with experimental stress-strain curves obtained in [5].

3- Results and Discussion

The 3D generated RVEs were simulated under tensile test and engineering stress-strain curves are extracted. By calibrating the hardening parameters, the influence of microstructure features and the capability of this method to predict the material behavior have been studied.

Effects of volume fraction of cementite

As shown in Fig. 2, by increasing the volume fraction of hard cementite phase, the ferrite-cementite steel indicates a higher hardening rate.

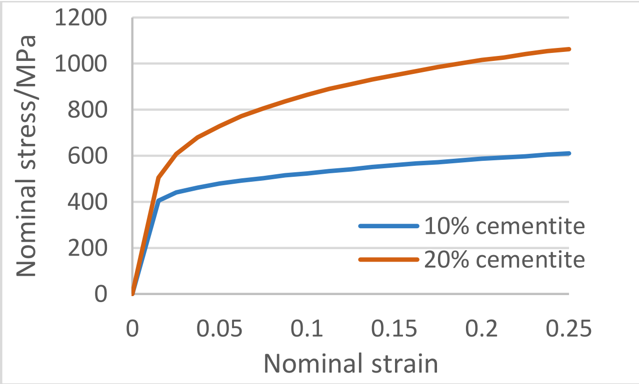

Fig. 2. Effects of volume fraction of cementite

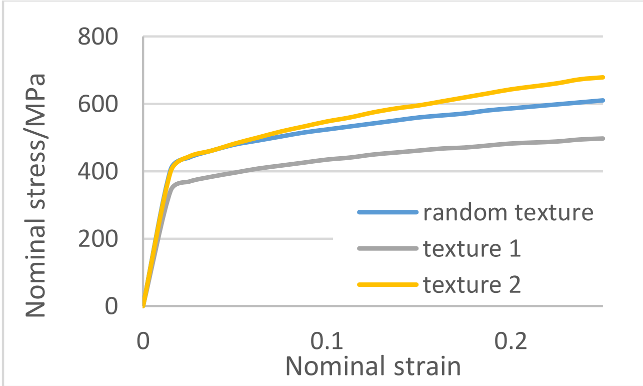

Fig. 3. Effects of ferrite texture

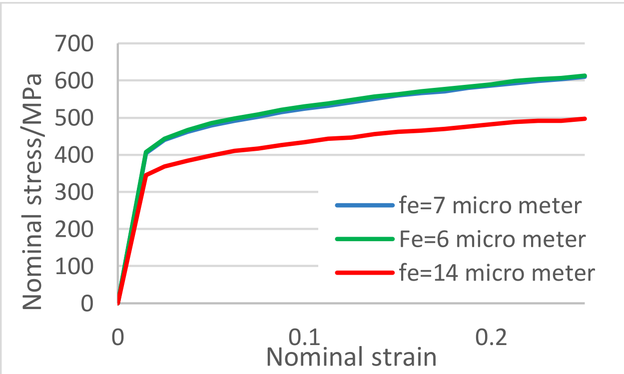

Fig. 4. Effects of ferrite grain size

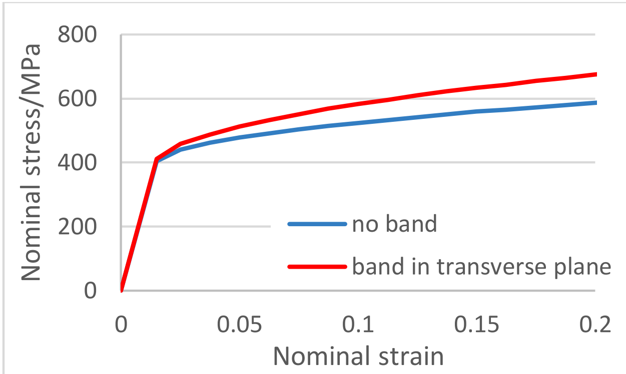

Fig. 5. Effects of microstructural carbide band

Effects of ferrite texture

Although in this study a random texture is assigned to crystalline aggregates, the code is capable of working with any texture data as shown in Fig. 3.

Effects of ferrite grain size

The simulation results in Fig. 4 show decreasing the ferrite grain size will cause an increase in the strength, yield stress and ultimate stress of ferrite- cementite steel.

Effects of microstructural carbide band

Carbide bands are usually observed in the transverse plane of sheet. As shown in Fig. 5, when more particles gather in carbide band, the microstructural inhomogeneity increase. Thus the local stress concentration in bands becomes more severe.

4- Conclusions

In the present study, a preprocessor code is developed to model ferrite-cementite steels with their sophisticated microstructural features as a 3D RVE and to apply different loading and boundary conditions. By calibrating the hardening parameters, the effects of microstructural features such as ferrite grain size and texture, cementite volume fraction and cementite bands were studied. It is shown that this method can be used to predict macro mechanical properties of this type of steel.

References

[1] G. Krauss, Steels: processing, structure, and performance, Asm International, 2015.

[2] L. Anand, S. Kalidindi, The process of shear band formation in plane strain compression of fcc metals: effects of crystallographic texture, Mechanics of Materials, 17(2-3) (1994) 223-243.

[3] X. You, T. Connolley, P. McHugh, H. Cuddy, C. Motz, A combined experimental and computational study of deformation in grains of biomedical grade 316LVM stainless steel, Acta materialia, 54(18) (2006) 4825-4840.

[4] J. Kadkhodapour, A. Butz, S. Ziaei-Rad, S. Schmauder, A micro mechanical study on failure initiation of dual phase steels under tension using single crystal plasticity model, International Journal of Plasticity, 27(7) (2011) 1103-1125.

[5] X. Zhuang, S. Ma, Z. Zhao, A microstructure-based macro-micro multi-scale fine-blanking simulation of ferrite-cementite steels, International Journal of

Mechanical Sciences, 128 (2017) 414-427.

[6] O. Amelirad, A. Assempour, Experimental and crystal plasticity evaluation of grain size effect on formability of austenitic stainless steel sheets, Journal of Manufacturing Processes, 47 (2019) 310-323.

[7] C. Zheng, L. Li, Y. Wang, W. Yang, Z. Sun, Micromechanical behavior of eutectoid steel quantified by an analytical model calibrated by in situ synchrotron-based X-ray diffraction, Materials Science and Engineering: A, 631 (2015) 181-188.

[8] R.J. Asaro, Crystal plasticity, (1983).

[9] D. Peirce, R.J. Asaro, A. Needleman, Material rate dependence and localized deformation in crystalline solids, Acta metallurgica, 31(12) (1983) 1951-1976.

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