Mechanics of Materials 106 (2017) 8–19

Contents lists available at ScienceDirect

Mechanics of Materials

journal homepage: www.elsevier.com/locate/mechmat

High cycle fatigue micromechanical behavior of dual phase steel: Damage initiation, propagation and final failure

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ARTICLE INFO

Article history:
Received 9 April 2016
Revised 7 January 2017
Available online 10 January 2017

Keywords:
Dual phase steel
High cycle fatigue
SEM
FEM
Micromechanics
RVE

ABSTRACT

Micromechanical analyses of various materials under high cycle fatigue (HCF) loading have been investigated previously. Experimental findings have shown that failure due to HCF occurred with different pattern comparing to the other loading conditions. The current work tries to carry out both experiments and simulations at micro scale. In this research, scanning electron microscopy (SEM) and metallography images of the specimens are taken to investigate the failure and deformation patterns in dual phase (DP) steel under high cycle fatigue loading. Failure mechanisms of DP steels are also predicted using a real representative volume element (RVE) and microstructural finite element (FE) modeling. The linear damage accumulation rule (Miner's damage rule) is used to determine the material degradation due to fatigue loading. The cyclic loading is implemented in the FE model of the microstructure by developing ANSYS parametric design language (APDL) code to obtain the damage, failure pattern and fatigue life of the RVE. It is also shown that the finite element modeling of the real RVE considering both plasticity and fatigue damage leads to acceptable compatibility between the obtained cracking patterns from SEM images (experiments) and finite element predictions.

1. Introduction

Nowadays automotive industries investigate application of dual phase (DP) steels in vehicle structures. This group of steels is very interesting for light weight constructions potential because of its advantages and effects in less fuel consumption, less manufacturing costs, less amount of pollution, low yield strength, high hardening ratio and absence of discontinuous yielding (Ramazani et al., 2013; Sodjit and Uthaisangsuk, 2012). As the automobile components experience load varying during service, this material requires to be evaluated in terms of tensile and fatigue properties. The fatigue properties of DP steels are an important consideration in the automotive industry. DP steel is a two-phase microstructure, in which the hard martensite grains are located in the soft ferrite matrix. DP steels have received considerable attentions due to their continuous yielding behavior, large work hardening rate and high ductility (Al-Abbasi and Nemes, 2003; Al-Abbasi and Nemes, 2003).

Experimental and numerical analyses were already performed to investigate the failure patterns and strength of dual phase steels under various loadings. Metallography and SEM images were prepared to study the ferrite matrix and martensite grains deformation and failure pattern under uniaxial tensile loading (Hosseini-Toudeshky et al., 2014; Kadkhodapour et al., 2014). Microstructural components of DP steels are under three distinct deformation processes in the mechanical response up to the failure point: interface debonding, brittle fracture and ductile damage in the soft phase. Authors of this paper used cohesive zone modeling (CZM) to predict the damage pattern and debonding of martensitic islands from the ferrite matrix (Hosseini-Toudeshky et al., 2015). It is believed by many authors that the brittleness of the martensite phase is likely to promote damage (Uthaisangsuk et al., 2011). Sun et al. (2009) demonstrated the ductile failure of dual phase steels in the form of plastic strain localization resulting from microstructure-level inhomogeneity between the martensite phase and the ferrite matrix. Choi et al. (2009) reported shear failure as dominant failure mode in DP steels using localization pattern.Vajragupta et al. (2012) used extended finite element method and ductile damage concept for martensite and ferrite, respectively.

Various experimental fatigue studies of DP steels are also available in the literature.Sperle (1985) showed strain hardening and

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http://dx.doi.org/10.1016/j.mechmat.2017.01.002

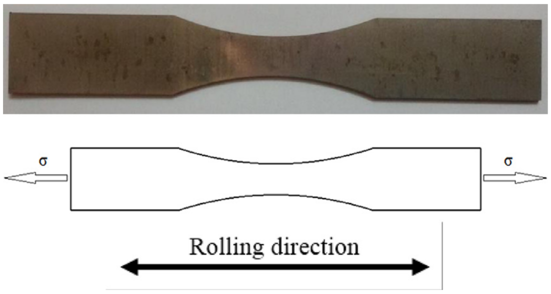

Fig. 1. Typical experimental specimen and loading.

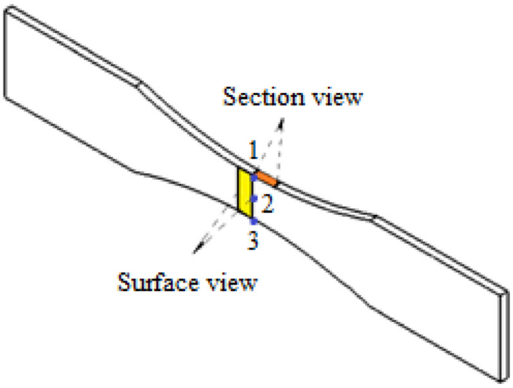

Fig. 3. Different imaging views and locations for metallographic and SEM images and experimental analysis.

bake hardening increase the fatigue strength. On the other hand, preliminary deformation and subsequent aging lead to an increase in the fatigue life and the fatigue limit of dual phase DP600 steel at 10^7 loading cycles (Terentev et al., 2014). Some of the investigations concentrated on the influence of martensite content volume fraction on the fatigue properties. Wännman and Melander (1991) reported the increase of cyclic stress with increase in the martensite content according to the results of strain-controlled fatigue tests.Sherman and Davies (1981) showed that the overall fatigue performance is improved up to 30% as the martensite content is increased but its effect is less than that for monotonic loading properties. The fatigue behavior of dual phase steel does not vary significantly beyond the 30% martensite content. Fatigue limit of DP steels with fibrous martensite morphology is greater than the fatigue limit of DP steels with network martensite with same martensite volume fraction (Molaei and Ekrami, 2009). The endurance limit for dual-phase steel was also investigated by Giri and Bhattacharjee (2012) and it was shown that Gerber equation would be an acceptable approximation for calculating the endurance limit for components without stress concentrator and the Goodman line is more appropriate for components with stress concentrators like hole.

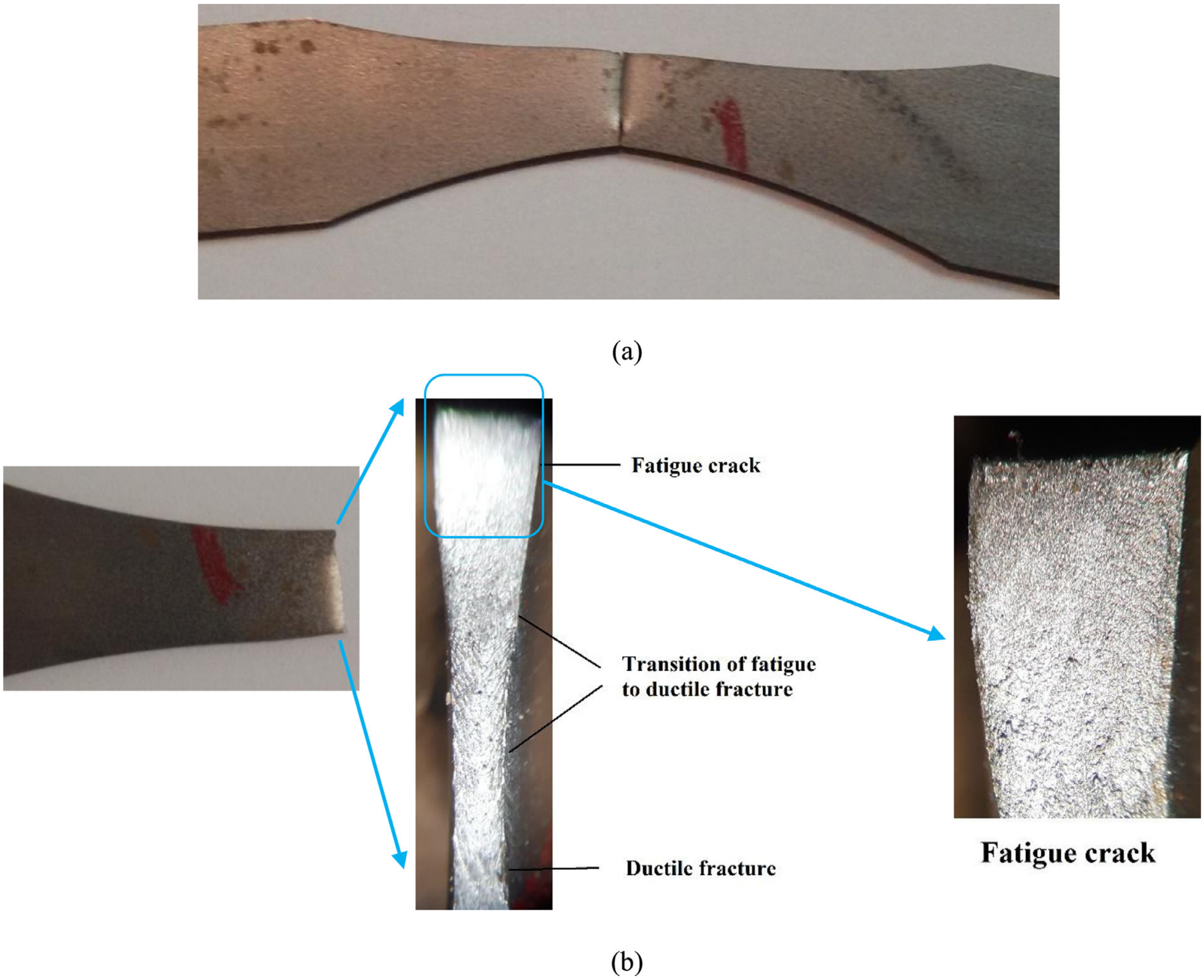

Fig. 2. Experimental specimens: (a) After loading (1170,000 cycle at stress range of 450 MPa), and (b) Fracture surface.