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Fatigue properties of ultra-fine grained dual phase ferrite/martensite low carbon steel

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Abstract

An examination has been made of the fatigue properties of ultra-fine grained two phase ferrite/martensite low carbon steel, produced by equal channel angular pressing (ECAP). The fatigue strength and fracture mechanism of the ECAP steel were compared with those of the as-received sample. The fatigue strength of the ECAP steel was twice as high as that of the as-received steel. The fatigue strength was linearly related to the tensile strength for both the ECAP and as-received steels although their slopes were different; the slope for the ECAP steel was greater. In addition, different fracture characteristics were observed; intergranular fractures were dominant in the ECAP steel whereas transgranular fractures occurred in the as-received steel. Such differences in fatigue strength and fracture characteristic are attributed to their material properties.

Keywords: Equal channel angular pressing; Dual phase steel; Ultra-fine grain; Fatigue properties; Fracture mechanism

1. Introduction

Grain refinement of carbon steels has recently been regarded as a method to improve strength and toughness simultaneously. More studies have been devoted to the refinement of ferrite grains using a thermo mechanically controlled process (TMCP). The minimum ferrite grain size achieved by TMCP for low carbon steels is believed to be limited to 5–20 μm [1]. As an alternative, an effective grain refinement method has also been proposed, using equal channel angular pressing (ECAP) [2]. In this process grain refinement is created by torsion under high pressure and wire drawing, which completely destroys cementite in the pearlite colonies and spreads it uniformly into the ferrite matrix [2]. Since fine grained steels exhibit high tensile strength and fairly large ductility [3,4], these materials are widely exploited as car parts and other structures. Although these materials are widely used, their material properties have not always been adequate for engineering alloys even when fine-grain steels have been successfully employed in engineering applications. This is because a decline in material properties can occur when the alloys are used over a long period of time. Even though component failure usually occurs through fatigue, there is very little consistency in the available data in the design of these fine grained steels [5–7]. The experimental approach to fatigue has involved the characterization of the cyclic number to failure in terms of a cyclic stress range, i.e., the "*S*–*N*" approach. Although several studies have been conducted to investigate the *S*–*N* relations of ECAP steels, previous work has been mainly focused on cyclic hardening/softening behaviors [3,4]. The aim of this study was, therefore, to investigate the fatigue behavior of a recently developed ultra-fine grained ferrite/martensite ECAP steel (UFG F/M DP) [8,9], via the *S*–*N* approach. In addition, the fundamental aspects of fatigue crack growth and the fracture mechanisms of the ECAP steel were examined.

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2. Materials and experimental procedure

2.1. Material preparation

The material selected for this investigation is an ultrafine grained ferrite/martensite two phase (UFG F/M DP) low carbon steel produced by an ECAP process [8,9]. The chemical composition of the carbon steel is (in wt%): 0.15 C, 0.25 Si, 1.1 Mn, <0.035S, <0.03P and Fe as the balance. The ECAP process was performed using a die having a two-channel camber, made of hardened carbon steel, illustrated schematically in Fig. 1. The angle between the channels (Φ) and the angle of external curvature (Ψ) were designed to be 90° and 20°, respectively. The ECAP was carried out using four passes with Route C, i.e. sample rotation by 180° after each pressing, as shown in Fig. 1. In this case, there occurs an effective strain of about 1.05 per pass, as estimated by the following equation [10]:

$$\varepsilon = \frac{1}{\sqrt{3}}\left[2\cot\left(\frac{\Phi}{2}+\frac{\Psi}{2}\right) + \Psi\operatorname{cosec}\left(\frac{\Phi}{2}+\frac{\Psi}{2}\right)\right] \quad (1)$$

After the ECAP process, the sample was heated to 730 °C for 10 min followed by water quenching. Fig. 2 presents the microstructure of the low carbon steel before and after the four passes process, as observed by scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The microstructure of the sample before the ECAP

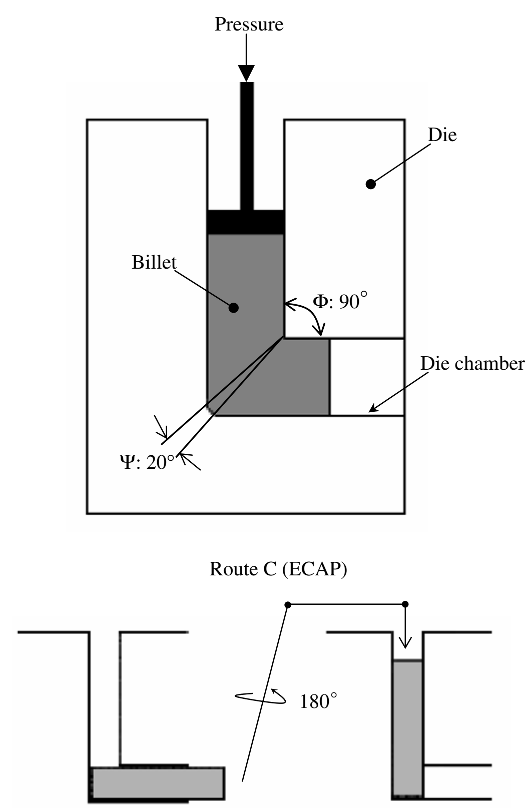

Fig. 1. Schematic illustration of the equal channel angular pressing process (Route C).

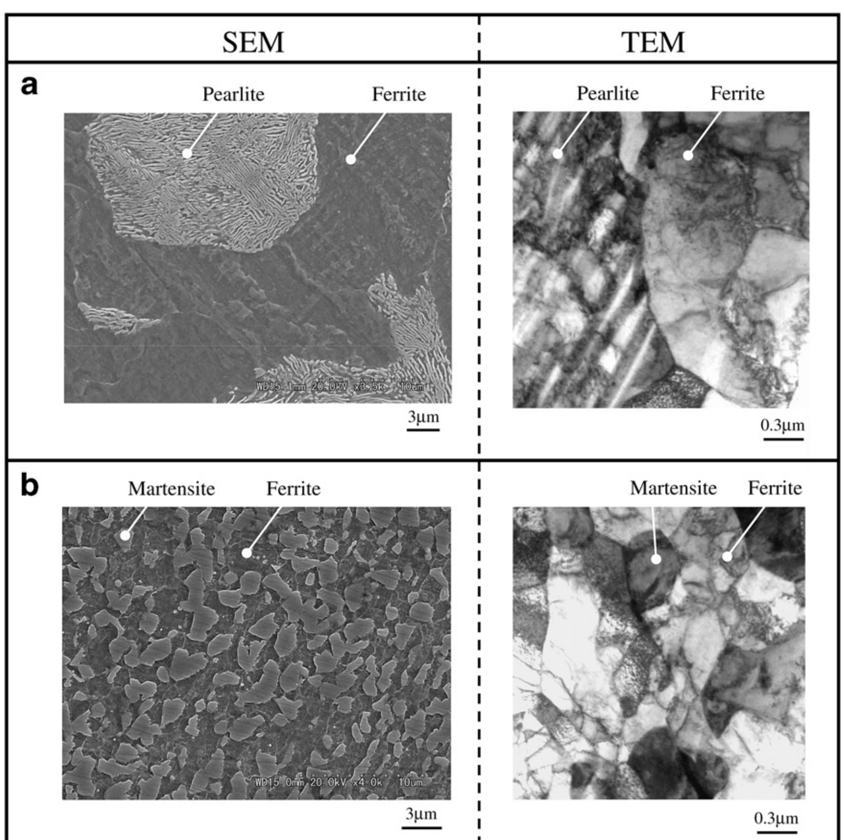

Fig. 2. Micrographs showing the microstructure of low carbon steel before and after the ECAP process: (a) as-received steel; (b) ECAP steel.