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On the effect of austenite stability on high cycle fatigue of TRIP 700 steel

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ABSTRACT

The high cycle fatigue behavior and the role of austenite stability on fatigue performance of low-alloy TRIP steel 700 have been experimentally investigated. The material was subjected to heat treatment in order to produce microstructures with different initial retained austenite volume fraction and austenite stability. High cycle fatigue tests were carried out to determine the S–N fatigue curve while austenite stability was measured by implementing a special technique for determination of M_s^σ temperature. The effect of austenite stability on fatigue behavior was assessed by measurements of volume fraction austenite before and after fatigue testing. The fatigue results indicated that austenite stability influences fatigue performance of TRIP steel in the high cycle regime, especially at high cyclic stresses.

1. Introduction

Low-alloy TRIP steels are increasingly used in automotive industry due to their high specific properties combined with ductility and formability as a result of the TRIP effect [1–4]. At the same time they are weldable, which in combination with their formability allows for the production of complex geometries and profiles. To meet the automotive design requirements for efficiency and safety, the fatigue behavior of TRIP steels is an important issue that has received limited attention.

The fatigue behavior in homogeneous austenitic steels exhibiting TRIP effects is generally controlled by the hardening caused by the martensitic transformation. This may be desirable under stress-control loading, because the strain amplitude is reduced, it could however be undesirable under strain-control because the stress amplitude increases. It has been verified that the transformation can reduce the fatigue life under strain-control conditions (low-cycle fatigue) in low strength [5] as well as high-strength austenitic steels [6]. However, under conditions of high-cycle fatigue, the transformation increases fatigue life [7] and fatigue endurance limits approaching the yield strength have been documented [8]. Studies in AISI 304 austenitic steel have shown that an improvement in fatigue life is feasible only if the transformation is triggered after fatigue crack initiation, in the opposite case the fatigue life will be reduced [9].

In contrast to homogeneous austenitic steels, the fatigue behavior of steels containing dispersed austenite has received only limited attention. Multiphase low-alloy TRIP steels contain retained austenite dispersions together with ferrite, bainite or martensite. Recent studies have shown that the transformation of retained austenite delays fatigue crack growth due to crack closure effects [10]. In a comparative study undertaken by the AISI, it was shown that amongst the multiphase high-strength steels, such as HSLA steels, Dual-Phase steels and Bake-Hardening steels, the low-alloy TRIP steels exhibited the highest fatigue resistance [11]. An improvement in fatigue behavior has been also observed by other researchers under tensile [12,13] and under bending fatigue loading conditions [14]. Recent electron microscopy studies have shown that transformation of retained austenite to martensite is triggered ahead of the fatigue crack tip, leading to a delay in fatigue crack growth [15]. Fatigue improvements in the high cycle fatigue regime have also been linked to the initial state of austenite volume fraction [16].

A clearer understanding of the TRIP effect on fatigue performance is feasible by examining the role of austenite stability on transformation under cyclic loads. It requires establishing a link between austenite stability with monitoring of martensitic transformation evolution during fatigue. This correlation could allow for a more sophisticated design of alloy compositions and processing for enhancement of fatigue resistance in this class of steels.

In the present study the effect of retained austenite stability on high cycle fatigue performance of TRIP steel 700 has been experimentally investigated. Heat treatment was implemented in order to vary the initial retained austenite volume fraction and stability. Subsequently, high cycle fatigue tests were carried out to obtain the S–N fatigue curves. Austenite stability was measured by means of special tests for determination of M_s^σ temperature. From the performed fatigue tests the effect of austenite stability on fatigue

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behavior was assessed. Martensitic transformation evolution which takes place under local cyclic deformation was evaluated and its effect on fatigue performance was analyzed.

2. Experimental procedures

2.1. Material

TRIP steel 700 in sheet form with a thickness of 0.8 mm was used for the experiments. The chemical composition of the material was in (%) weight 0.2C–1.33Al–1.8Mn–0.04Si–0.016P. The material composition is characterized as a Al-containing low-alloy TRIP steel.

2.2. Heat treatment

Following cold rolling the material was subjected to the heat treatment process in order to produce a microstructure with dispersed austenite content at room temperature. Two annealing schedules were carried out to obtain material with different initial austenite volume fraction and stability. Heat treatment (A) included intercritical annealing by holding at 890 °C for 60 s, to obtain a ferrite–austenite structure, cooling at 50 K/s to 400 °C and holding for 420 s to enable the isothermal transformation of austenite to bainite. Heat treatment (B) included intercritical annealing by holding at 890 °C for 60 s, cooling at 50 K/s to 460 °C and holding for 120 s. Important for austenite stability is the carbon partitioning from bainite to austenite [17,18]. The heat treatment schedules are shown in Fig. 1. The expected microstructure in both steels A and B, is a mixture of ferrite, bainite and retained austenite.

2.3. Metallography

Standard metallographic techniques of grinding and polishing were applied. Etching was performed with LePera reagent (1 part of 1 ml sodium metabisulfite in 100 ml distilled water and 1 part of 4 ml picric acid in ethanol). Austenite volume fraction was measured using the saturation magnetization technique [19].

2.4. Mechanical testing

2.4.1. Tensile tests

Tensile tests were carried out on 0.8-mm thick specimens to obtain the mechanical properties of (A) and (B) materials. The tensile specimens were produced according to DIN EN 10002-1 [20] with a geometry shown in Fig. 2.

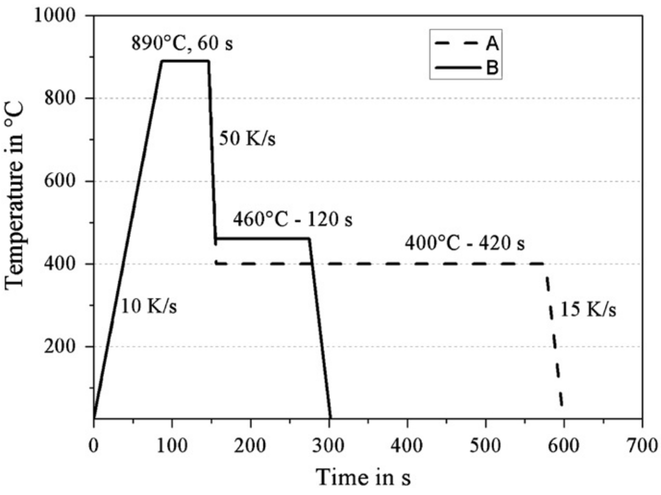

Fig. 1. Heat treatments (A) and (B).

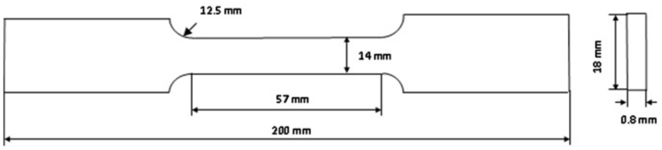

Fig. 2. Tensile specimen geometry.

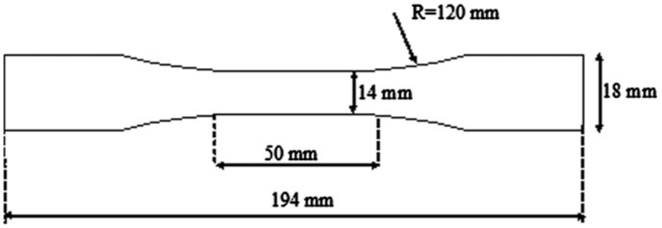

Fig. 3. Fatigue specimen geometry.

2.4.2. Fatigue tests

In order to evaluate the impact of austenite stability on fatigue performance, fatigue tests were carried out on TRIP 700 material with (A) and (B) treatments. Constant amplitude fatigue tests were performed at a stress ratio $R=\sigma_{\min}/\sigma_{\max}=0.1$, with a frequency of 20 Hz. Specimens of 0.8 mm thickness were machined according to ISO 1099:2006 [21] standard. The specimen geometry used is shown in Fig. 3. In total 11 specimens were tested (5 for A material and 6 for B material) to obtain the S–N fatigue curve. Experimental scatter was accounted for by subjecting a number of specimens from each material to the same $\sigma_{\max}$ level.

2.4.3. Measurement of M_s^σ temperature

Stability of retained austenite was determined by measurement of the M_s^σ—temperature using the Single Specimen–Temperature Variable–Tensile Test (SS–TV–TT) technique, which was introduced in [22]. The SS–TV–TT method includes application of a small prestrain on the specimen at a high temperature (e.g 25–30 °C) followed by unloading. Subsequently, the temperature is lowered by 10 °C and loading of the specimen is performed up to yielding. This procedure is continuously repeated with progressive lowering of temperature and loading up to yielding. As the testing temperature is decreased, the stability of the retained austenite decreases and at some temperature yielding is controlled by transformation rather than slip. At the stress where transformation occurs, a local unloading (stress relaxation) in the form of yield point is observed. The transition from smooth yielding to discontinuous yielding marks the M_s^σ temperature. The criterion where the selection of the first "sharp" yield drop is observed is based on the ratio $\Delta\sigma/\Delta\varepsilon$, i.e the stress drop over the strain range where the stress drop takes place and is calculated by using the tensile machine raw load–displacement data. The method is presented in [22].

Above the M_s^σ yielding is controlled by slip while below the M_s^σ yielding is controlled by transformation. The accuracy of the method increases with the amount of retained austenite in the microstructure.

3. Results and discussion

3.1. Microstructure

In the micrographs of Fig. 4 the ultrafine microstructure of TRIP 700 with austenite contents after (A) and (B) treatments is shown. The microstructure consists of ferrite (light gray) F, Bainite (dark) B and retained austenite (white particles) RA. The average austenite