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Effect of martensite morphology on low cycle fatigue behaviour of dual phase steels: Experimental and microstructural investigation

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ABSTRACT

The low cycle fatigue (LCF) behaviour of a dual phase (DP) steel with different martensite morphologies has been investigated in the present work. DP steels with coarse martensite morphologies show inferior LCF life in comparison with fine martensite morphologies for all martensite volume fractions examined. It is suggested that this is be due to the development of larger local plastic strain concentrations in the ferrite with a coarser microstructure, compared to the finer microstructural morphology. Fatigue cracks were observed to initiate inside ferrite grains, and to preferentially propagate through the softer ferrite phase. The average sub-cell size was finer in samples with higher martensite volume fractions, but the sub-cell size was almost unaffected by the martensite morphology.

1. Introduction

Low weight car bodies are one of the primary requirements in the automotive industry in order to reduce fuel consumption and emissions. Automobile body weight reduction is possible in two ways: increased utilisation of low density materials such as Al alloys, or the use of high strength formable steels which enable a reduction in the sheet thickness. Advanced high strength steels (AHSS) are a preferred choice, mainly due to the significantly cheaper cost of this material compared to the light alloys [1]. AHSS meet the two main design requirements of the automotive industry: high strength and good formability. Dual phase (DP) steels are the most extensively used AHSS due to their high strength and ductility combination. Other added advantages of DP steels include improved service performances in crashworthiness and fatigue durability [2,3], make them the current designers choice in automotive applications.

Dual phase (DP) steels consist of hard martensite islands embedded in a soft matrix of ferrite. Such a two phase microstructure is created by intercritical annealing or by controlled cooling after hot rolling. By controlling the intercritical annealing temperature DP steels with different martensite volume fractions can be created. It is well documented in literature that depending upon the martensite volume fraction and morphology, the tensile properties of DP steels can be significantly different, even for the same chemical composition [4–6]. Higher volume fractions of martensite increase the flow stress of the steel, and this is typically accompanied by a decrease in the ductility. Strain partitioning between the soft ferrite and hard martensite phases is reported in literature [5–8], with experimental and physically-based microstructural simulation [8] showing clear strain partitioning between phases. As a consequence of strain partitioning between phases the softer ferrite phase carries a larger amount of the imposed strain, and that this can lead to significant strain localisation. It may be the case too that strain partitioning occurs during low cycle fatigue, and the microstructural evolution during load cycling is therefore an area of great interest for DP steels for structural applications.

The fatigue performance of the materials used for automotive body structures are necessary for design and material selection consideration due to the cyclic loads/strains that are experienced during normal use. The nominal stress level are maintained below the yield stress of the material during the vehicle design, however small plastic deformation can be observed in the presence of stress riser. The bulk material can deform in cyclic elastic manner however, micro cyclic plasticity may be observed in the stress concentrated area. Fatigue cracks are more likely to initiate form those stress concentrated regions where the material may deform in micro cyclic plasticity manner. This makes it important to

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understand the effects of low-cycle fatigue (LCF) on the performance of automotive materials.

There have been a substantial number of studies examining the monotonic deformation behaviour of DP steels, however, comparatively few studying the low cycle fatigue (LCF) behaviour of this material [5–7,9]. Authors previous work [10] reported that the LCF life for a given plastic strain amplitude is significantly reduced by an increase in the martensite volume fraction. It was reported that cyclic hardening occurs during the initial few cycles followed by relatively low cyclic softening [10]. Mediratta et al. [5] also reported cyclic hardening in the initial few cycles, followed by an almost stable response. Zhongguang et al. [11] reported that DP steel with a martensite volume fraction of 50% shows cyclic softening behaviour at high strain amplitudes while cyclic hardening behaviour for lower strain amplitudes. Despite slight differences in the specific behaviour, all published literature on LCF behaviour of DP steel unanimously concluded that the martensite volume fraction has a significant effect on LCF life and cyclic hardening–softening behaviour. The effect of martensite morphology on LCF behaviour of DP steel, however, is less investigated. Mediratta et al. [6] reported that martensite morphology had a significant effect on LCF behaviour of DP steel with a 21% martensite volume fraction. They reported that DP steel with fine uniform dispersion of martensite in a fine grained ferrite matrix shows the best LCF life, while DP steel with coarse martensitic particles encapsulated in a ferrite matrix shows inferior LCF life. This current study will therefore investigate the LCF performance of DP steels with different martensite morphology at a wide range of martensite volume fractions. This investigation will be helpful in understanding the effect of LCF on one of the key elements of a DP steel microstructure, which allows better prediction capabilities of fatigue life and in the design of novel multiphase steel microstructures that show better fatigue performance.

2. Experimental methodology

A 2 mm thick DP steel sheet with a nominal chemical composition (in wt%) of: C 0.093, Mn 1.93, Si 0.88, P 0.014, Cr 0.022, Al 0.034 and balance Fe was considered for the present investigation. DP steel with two different martensite morphologies at various martensite volume fractions were generated by a three step intercritical annealing process. For heat treatment purpose, 75 mm × 150 mm (Rolling × Transverse direction) rectangular sheets were selected. The schematic diagram of heat treatment process is shown in Fig. 1. In the first step, samples were heated to either 920 °C for 5 min or 1200 °C for 60 min in a muffle furnace with a flowing argon atmosphere. The times and temperatures were chosen in order to develop extensive grain growth in the latter case, but minimal in the former. The extensive grain growth at 1200 °C ultimately results in a coarse martensite morphology. In the second step, samples were removed from the furnace and immediately placed into a second muffle furnace for intercritical annealing at either 585 °C, 610 °C or 726 °C for 5 min. In the final third step, the samples were removed from the furnace and quenched immediately into water.

The LCF and tensile test procedures are exactly the same as used by author previous publication [10]. Sample width of 2 mm and 7.9 mm parallel length, as used by Hilditch et al. [12] were selected for present investigation. A schematic diagram of the specimen is shown in Fig. 2. According to ASTM E606-92 [13], fully reversed ($R=-1$) total strain amplitude control LCF tests were performed on a 25 kN servo-hydraulic load frame. Strain was measured by 5 mm gauge length clip-on extensometer. LCF and tensile tests were conducted at a constant strain rate of 0.02 s^{-1}. LCF was performed at total strain amplitudes in the range from 0.005 to 0.010 and test frequencies were altered accordingly to maintain constant strain rate. At the touching points of extensometer edges and sample, epoxy was placed under the extensometer edges to prevent slippage or crack initiation.

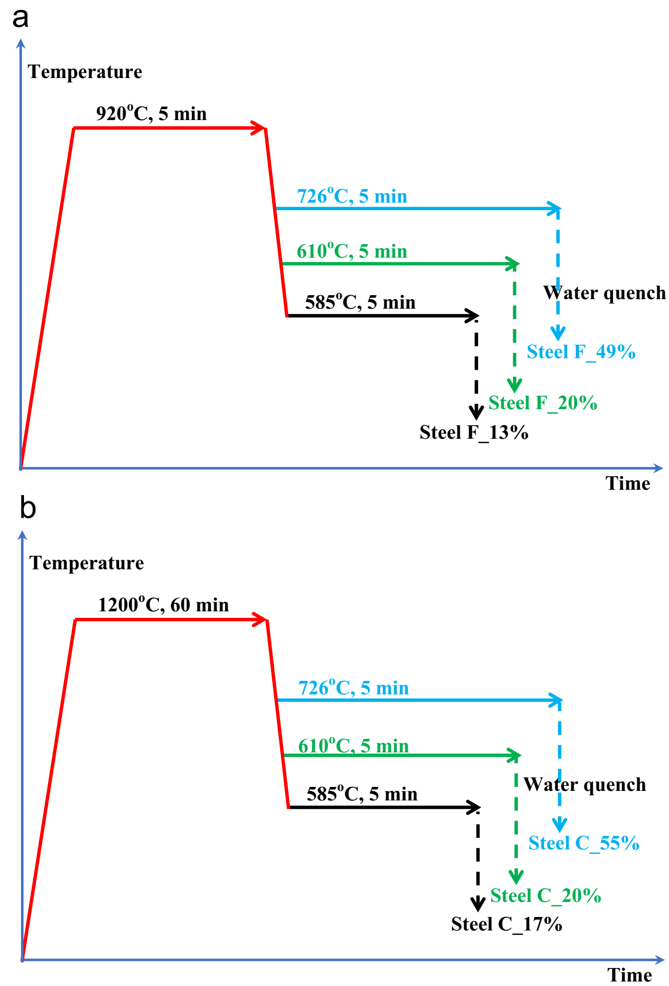

Fig. 1. Schematic heat treatment diagrams of DP steel.

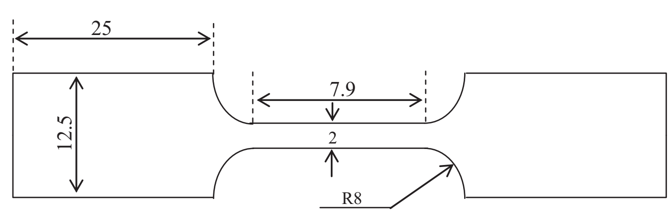

Fig. 2. Schematic of fatigue specimen geometry (dimensions are in millimetres).

SEM samples were prepared by mounting and polishing using standard metallographic techniques, followed by ~10 min polishing with OPS to examine the microstructural evolution during LCF. A Supra VP operated in high current mode using a Zeiss angular selective backscattered detector (ASB) was used to carry out electron microscopy imaging. A small working distance of ~5.5 mm and an accelerating voltage of 20 kV were used during electron microscopy. For optical microstructure, samples were polished and etched with 4% nital. Grain size was determined by Image J analysis software utilizing the linear intercept method. The volume fractions were determined using the point counting method. At least five fields of view were used to determine the grain size and phase fraction.