Fractography analysis on tensile and high cycle fatigue performance of FP 800 steel

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Abstract

In current research, high cycle fatigue performance and failure mechanism of ferrite-pearlite 800 steel was examined by using HCF test, contributed tensile tests, HCF test, SEM and TEM analysis. Its microstructure, consisting of ferrite and pearlite phases, makes it an attractive material for structural applications in automobile parts. Tensile test, it was found that the strength and ductility in the transverse direction were greater than the RD and DN. HCF tests for ferrite-pearlite 800 steel (FP 800 steel) in the transverse direction were conducted to determine the strain hardening exponent, endurance limit, and yield ratio. SEM analysis is used to observe the ductile fracture behaviour of tensile specimens. During low-stress amplitudes, fatigue cracks are mainly formed in precrack regions on the surface, and crack propagation takes mainly transgranular forms. In high-stress amplitudes, fatigue cracks form inside the surface along the shear plane, with most crack propagation occurring intergranularly.

Keywords: Ferrite-Pearlite 800 Steel, HCF, SEM, Tensile Properties

1. Introduction

The high strength steel are increasingly used in commercial wheels, exposed panels, structural parts chassis, and reinforcement etc. All these components, particularly the wheels, are subjected to repeated tensile, compression, and service loads during their lifetime. Therefore, developing steel grades for wheel applications requires a comprehensive understanding of their tensile and fatigue properties [1]. The service load experienced by different automobile components are usually below endurance limit of base materials which represents HCF conditions [2]. However, the wheel manufacturing process introduces several holes, weldments, etc. which creates conditions of localised plastic deformation within these wheels.

The further development of high strength steel is accomplished through the use of lower carbon and different components, which result from more advanced steel-making practices. Elements such as titanium and aluminium protects the alloying elements such as boron from oxidation [3]. Titanium also takes care of nitrogen present in the steel and reduces the problems caused by nitrogen. In addition, elements like titanium and molybdenum forms fine carbide precipitates which helps in improving the mechanical properties of the steel [4]. Vanadium and niobium help in grain refinement [5]. Silicon is seen to enhance austenite stability and inhibit the decomposition of austenite during partitioning. Furthermore, it is also observed that martensite formation is accompanied by transformation strain in austenite, affecting austenite's lattice parameter, which may give an unreliable carbon content estimation in austenite. [6]. For many years, all the investigators are interested to search in the field of fatigue crack initiation and growth of the high strength sheet metal of surface. All investigators have been working on the fracture surface generated by during the different forming methods. McGrath et al. has been found that temperatures, load, and strain rates can influence fracture during the forming of sheet metal [7].

Fatigue strength and rigidity is a basic requirement for automobile parts. Parts of the clutch, chassis and suspension parts must satisfy durability-related specifications, including those relating to fatigue characteristics, corrosion resistance, and other qualities. The fatigue resistance of components inside the car's floor is a significant determinant of a car's durability. A main requirement for automobile parts is ductility, tensile strength, hardness and fatigue strength. Often, the material performance is characterized by an S-N curve, which plots the magnitude of the cyclic stress (S) versus the logarithmic scale of cycles to failure (N) in which the number of cycles to failure is larger than 10^4 [8]. Sun et al. [9], have reported that the fracture surface observed for different grades of dual phase steels with tensile strengths between 600-980 MPa shows decreasing amount of microvoids near the fracture surface, thus increasing the strength level. A scanning microscope was utilized by Li et al. to locate the AL-6061 samples under various stress states using angles like 0, 90, and 45 degrees, which formed dimple-dominant, shear, and mixed fracture patterns with this angle [10] properties of different materials. Limited studies have been done to understand the role of precipitates under various service load conditions.

2. Experiment Technique

Ferrite-pearlite 800 steel was obtained as hot rolled sheets (approx. dimensions 1100mm x 350mm x 5mm) with the following chemical compositions: 0.062C, 0.023Si, 1.65Mn, 0.21Mo, 0.017P, 0.045Al, and 0.094Ti etc. The fraction indicates that the elements are present in wt. %.

2.1 Phase Analysis

A 3% Nital solution was used to etch the samples and observe the micrographs and fectrographs under an optical upright and stereo microscope, SEM at different magnifications (Model: FEI Nova NanoSEM 450, USA).

2.2 Microhardness

The hardness of the specimens was tested using an EMCO Vickers hardness tester (Model: EMCO DuraScan 20GS, Austria), and the hardness of the indentation was measured at a distance greater than 1.5 times the diagonal size of the indentation, following the ASTM E384 standard.

2.3 Tensile Property

The specimen had a gauge length of 60mm with same thickness of 5mm. The tensile testing was performed at strain rate of 0.001/s for all different grade steels and performed on INSTRON 5982 with a cross head speed of 5mm/min.

2.4 High Cycle Fatigue Test

HCF tests were performed on rectangular specimens of FP 800 steel with gauge lengths of 55 mm and 39.6 mm and same thicknesses of 5 mm. The specimens were prepared according to the ASTM E606 standard as shown in Fig.1. In the INSTRON 8850 MACHINE, all HCF tests were conducted using a stress ratio of R=-1 [10]. The strain amplitude was determined using an INSTRON strain extensometer with a strain range of 0.025. For all testing, a cyclic frequency of 10 HZ was used.

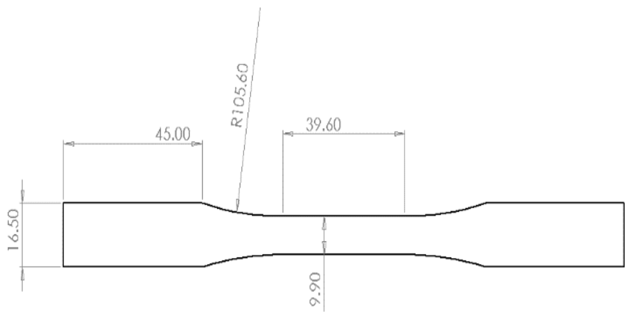

Fig.1 Schematic diagram of High cycle fatigue specimen

3. Results and Discussion

3.1 Phase analysis

Phase analysis was carried out both by optical microscopy (Fig. 2) and scanning electron microscopy (Fig. 3). The optical microstructure of FP 800 steel in the cross section is shown in Fig. 2 (a-b). Its unique microstructure, consisting of ferrite grains in the shape of polygonal with a second phase of pearlite, is described by the phase field in the equilibrium diagram [11]. It was also noted that the volume fraction of the ferrite phase was 85% by using image j, as shown in Fig. 3. SEM analysis under the higher magnification confirmed the present of cube shaped TiN inclusions in this microstructure.

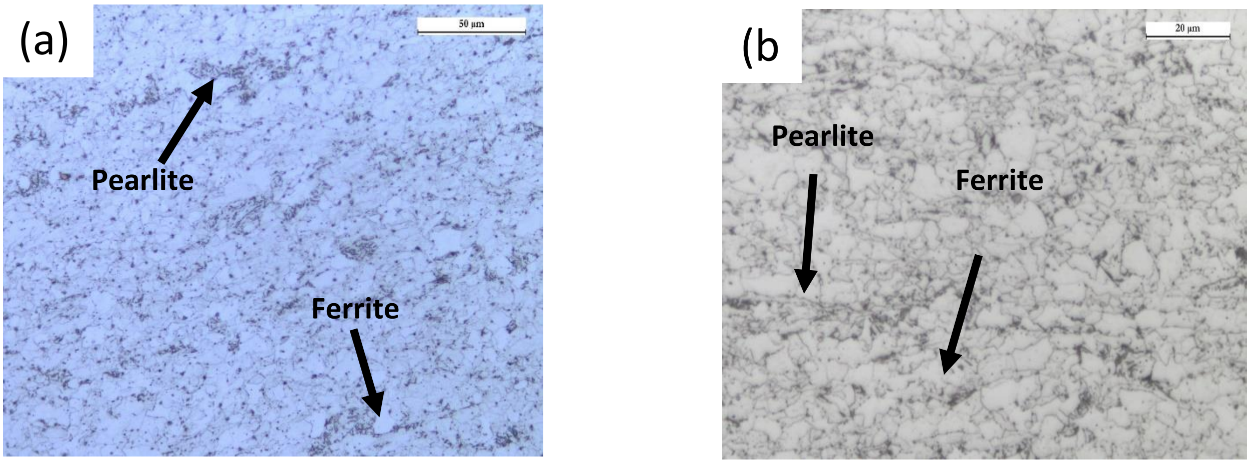

Fig.2 Optical micrographs of as received sample at different magnification

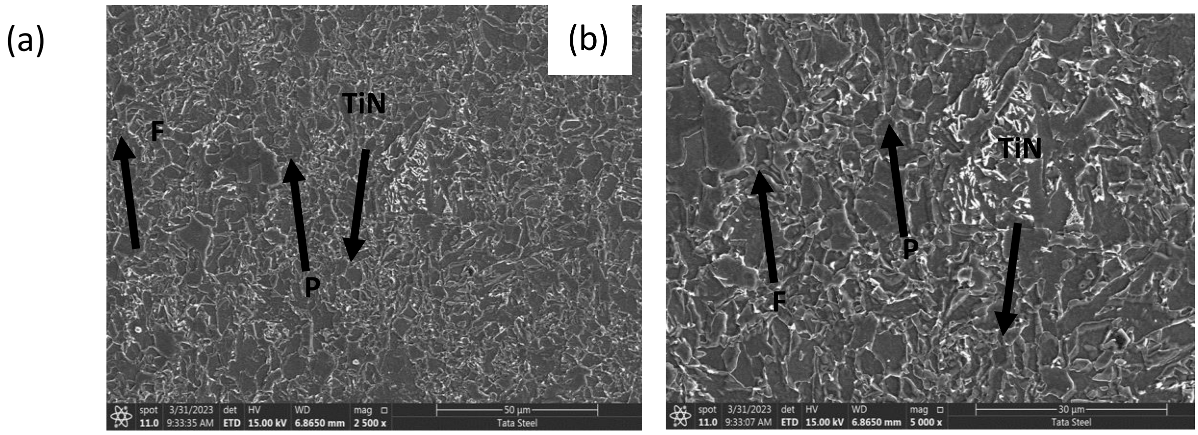

Fig.3 SEM images of as received sample at different magnification

3.2 Microhardness Testing

The hardness of the selected steel was measured in the transverse direction at a 10 kg load. At least five indentation was done on the specimens at different places to check the repeatability of the tests. The average value of hardness for FP 800 steel is 302±6.

3.3 Tensile Test

The selected steel was examined by following ASTM E08 standard in transverse directions [12]. The result of the test is shown in the Table 1, which describes that the property changes in yield strength (YS), UTS, and total elongation (TE) along this direction are effects due to anisotropy behaviour because this grade of steel has a degree of anisotropy due to changes in grain structure and type of grain boundaries along this direction [13].

Table 1 show tensile properties at different directions

Property	RD	TD	DN
YS (MPa)	747 ± 11	765 ± 7	739 ± 10
UTS (MPa)	810 ± 10	827 ± 7	807 ± 5
TE (%)	21 ± 2	20 ± 1	22 ± 3

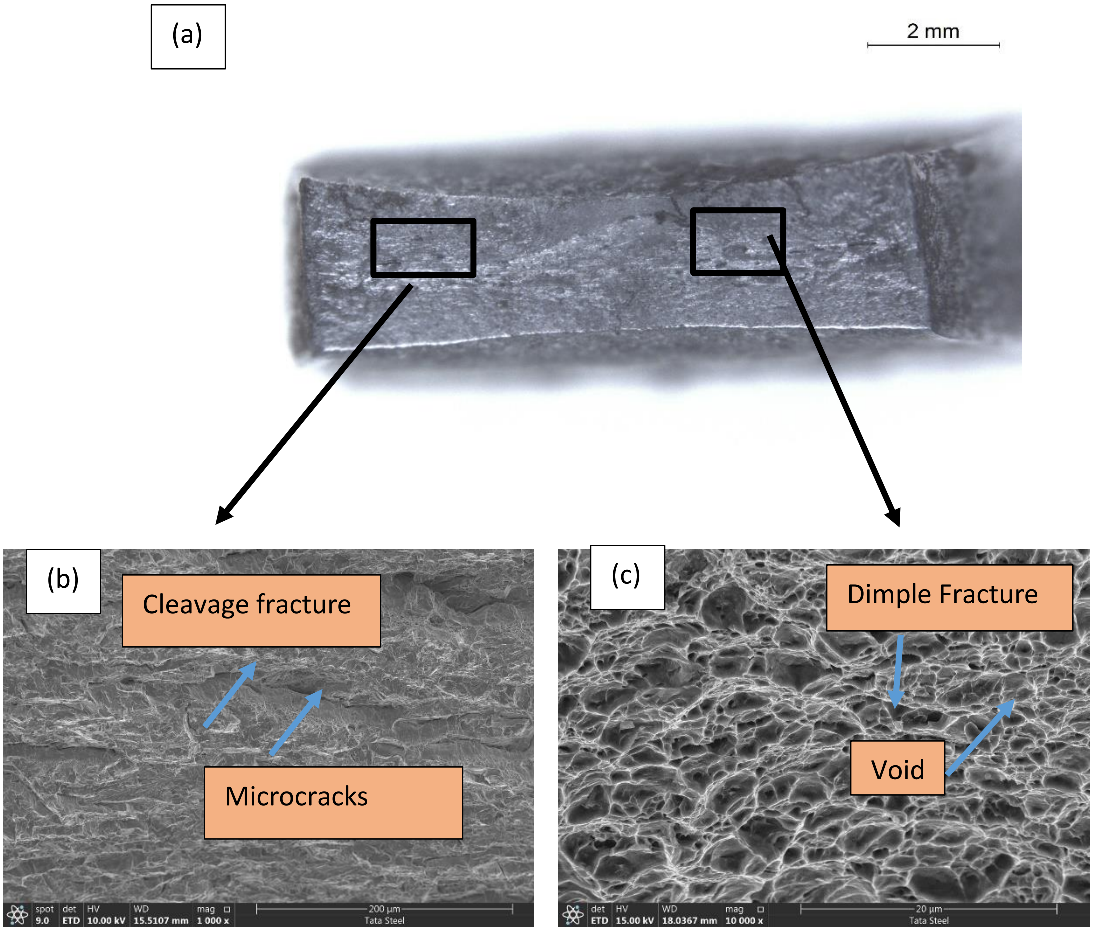

Fig 4. SEM Image tensile tested specimens at different magnifications

The tensile fracture surface of FP 800 steel was examined under stereo and scanning electron microscope as shown in Fig. 4 (a) and (b-c). The Tensile fracture surface of ferrite-pearlite steel (Fig.4 (b-c)) shows the presence of well-developed the transgranular dimples with voids and cleavage fracture indicating the ductile fracture behaviour under the uniaxial tensile test. The ductile fracture behaviour occurs through a void-controlled mechanism at specific stress states. They include void nucleation, void growth and coalescence, and microscopic failure [14].

3.3 High cycle fatigue test

As shown in Table2, FP 800 steel has high strain hardening exponent values between 0.17 to 0.19 and a TS/YS ratio of 1.57. This steels is expected to exhibit cyclic hardening. As shown in graph it is indicates the tendency of stress life curve of cyclic hardening. For the metals, the strain hardening exponents and yield ratio is greater than 0.15 and 1.4 respectively which are shown to undergo cyclic hardening.

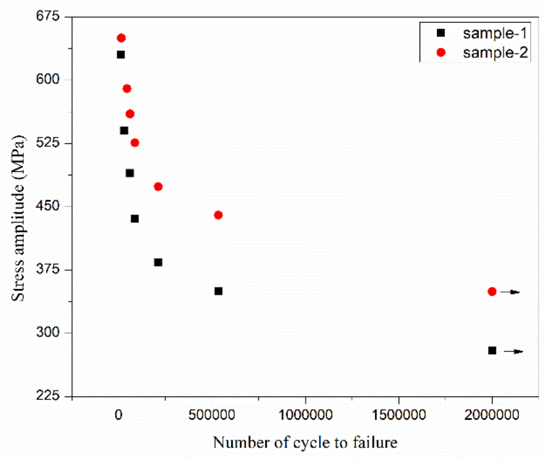

Fig.5 Stress life curve. Data point with arrow indicate no failure

Table 2 show fatigue properties of FP 800 steel

Specimen	Endurance limit	EL/YS	EL/TS	Yield ratio	Monotonic value
FP 800 steel	362	0.51	0.46	0.89	0.17

The failed sample after HCF testing at high stress amplitudes were analysed under SEM to understand the damage mechanisms. The fracture surface of the broken specimen for FP 800 steel was shown in Fig. 6 at low stress amplitude of 50% of YS. Figure 6 illustrates the three stages of fatigue failure: crack initiation, crack propagation, and final fracture. [15]. In Fig 6 (b), the crack initiation occurs from the surface in a precrack region. In Fig 6 (b), striations and microcracks are caused by crack propagation along a particular cleavage plane. The formation of striations and microcracks can be attributed to the repeated cyclic loading. Figure 6 (c) shows a typical transgranular dimple with void-like features in the final fracture zone. The fracture surface of the broken specimen for FP 800 steel was shown in Figure 7 at high stress amplitude of 90% of YS. In Fig 7 (a), the crack initiation occurs inside the specimens in a precrack region. In Fig 7 (b), striations and microcracks are caused by crack propagation along a particular shear plane. Figure 7 (c) shows a typical intergranular dimple with more void-like features in the final fracture zone. As shown in Fig. 8(a), TEM characterization shows fatigue cracks form inside the surface during the high stress amplitude and the presence of pearlite phase as dark field image in Fig. 8 (b).

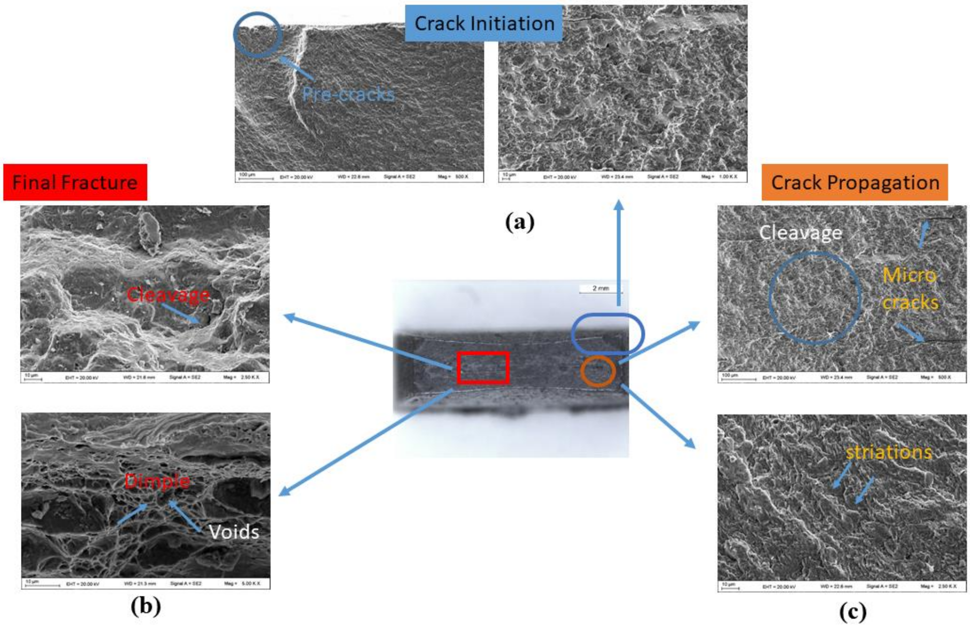

Fig.6 SEM micrographs, fracture surface after HCF testing at 50% load

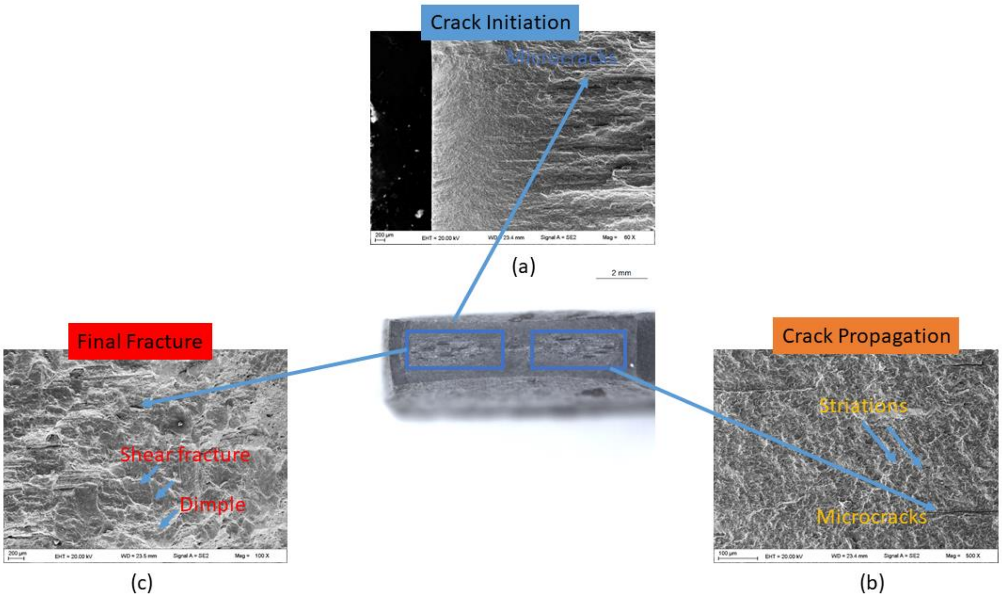

Fig.7 SEM micrographs, fracture surface after HCF testing at 90 % load

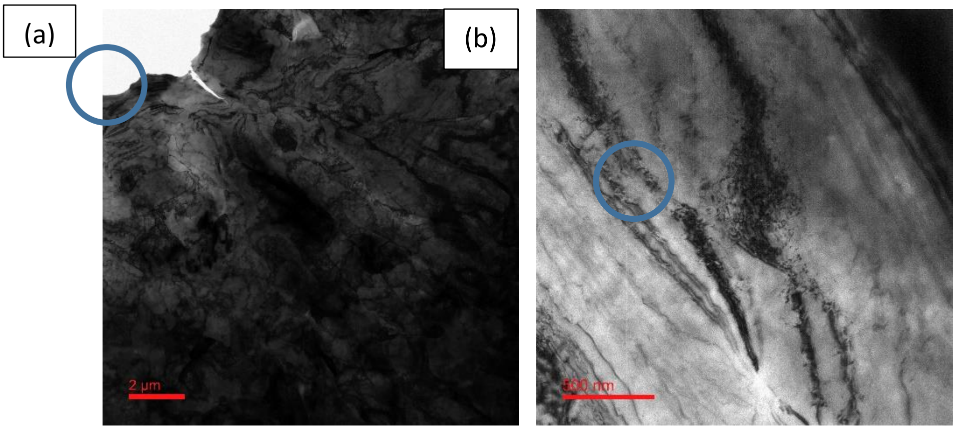

Fig.8 TEM micrographs, fracture surface after HCF testing (a) fracture zone at high stress amplitude (b) pearlite phase presence; dark field image (in a circle)

4. Conclusions

The fractography of ferrite-pearlite 800 steel during the tensile and fatigue performance has been studied, keeping in view their potentials applications in automobile wheels. There is a unique microstructure containing both ferrite and pearlite phases, and also cube shaped TiN inclusions. In transverse directions, the strength and ductility were greater than rolling and diagonal directions. On the tensile fracture surface of the specimen, the dimples with voids and cleavage fracture indicate transgranular ductile fracture. Three separate regions can be distinguished on the fracture surface: the precrack zone, the propagation zone, and the fast fracture zone, which are characterized by dimples, cleavage fractures, microcracks, and striations, resulting in transgranular ductile fractures at low stress amplitude, in high stress amplitude, fatigue cracks form inside the surface along the shear plane, with crack propagation mainly being intergranularly. As a result of HCF performance, cyclic softening occurs in FP 800 steel at high stress states, which may contribute to a longer fatigue life of wheels in service.

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