Chapter 1

Introduction

1.1 General Background

The global energy crisis as well as the need to comply with the international environmental regulations regarding greenhouse gas emissions, resource reduction and recyclability have thrown open perpetual challenges to the materials technologists to evaluate newer materials with improved combinations of high strength, ductility and toughness. This has led to the emergence of a series of steels with composite microstructures, in which dual-phase (DP) steels represent a distinguished class (Davies and Magee, 1978; Speich, 1981). The conventional DP steels for automobile applications usually exhibit microstructures consisting of about 80 percent ferrite and 20 percent martensite with small amounts of retained austenite and/or bainite, depending on their chemistry and processing.

In conventional forms DP steels exhibit highly desirable tensile behaviour like continuous yielding, high initial strain hardening and superior combination of strength and ductility properties when compared with high strength low alloy steels (HSLA). Such optimized combination of mechanical properties is the basic reason for their applications in energy efficient transportation system like automobile industry. These steels are produced either by intercritical annealing or controlled rolling (Mesplont, 1999; Llewellyn and Hills, 1996). Imposition of slow cooling rate during controlled rolling process is favourable for the bainite transformation (Bhadeshia, 2001). Thus a newer class of DP steels containing ferrite and bainite appear suitable for industrial processes. However, the entire range of the composite microstructure of soft ferrite and hard bainte in DP steels has not been well studied, particularly for the ones containing higher amount of bainite (>40%).

The specific potentials of ferrite-bainite dual-phase steels (FBDP) have been sparingly exploited for technological benefits. These newer varieties of dual-phase steels can very well compete with conventional ferrite-martensite dual-phase steels (FMDP) because of their superior ductility and formability characteristics.

Furthermore, an intriguing question arises. Why has there not been sufficient emphasis directed to exploit their potential for structural applications in components of thicker sections?

Considerable research efforts have been directed so far towards understanding the tensile behaviour of dual-phase steels with respect to their microstructures (Matsuoka and Yamamori, 1975; Sudo and Iwai, 1983; Kim and Thomas, 1981; Llewellyn and Hills, 1996; Kim, 1987), but efforts to understand their fatigue properties are limited. Some fatigue studies on the ferrite-martensite dual-phase microstructures have been carried out by earlier researchers with attempts to correlate this property with the volume fraction of martensite and its morphology (Bag, 2001; Sarwar, 2006; Colla, 2009). However, fatigue studies on FBDP steels are almost non-existent.

An appreciation of the importance of fatigue crack initiation and its growth and variables that influence fatigue crack propagation is being developed for more than a century. Micro-crack nucleation in structural materials is considered to be the first stage in fatigue damage. By now it is well established that a large percentage of (high cycle) fatigue life of smooth specimens is spent in the domain of crack nucleation and small crack growth especially in the emerging 'clean' structural materials with very low inclusion content. The second stage in fatigue damage is short crack growth (SCG). The earlier studies related to short crack growth is primarily directed to understand their mechanics and mechanisms followed by subsequent attempts to model the growth of these cracks (Suresh and Ritchie, 1984; Miller and Rios, 1986; Ritchie and Lankford, 1986; Ravichandran, 1999; Ravichandran and Li, 2000). It is well documented in several investigations that short crack exhibits several 'arrests' during their growth; these 'arrests' are often referred as short crack fatigue threshold (SCFTH) (Lankford, 1985; Liendstedt, 1998; Hussain, 1994; Ravichandran and Li, 2000; Narasaiah and Ray, 2005, 2006; Ray, 2004). The limited numbers of investigations on SCFTH are possibly due to difficulties associated with their determination. Attempts are therefore directed in this study to determine these parameters in a relatively simple manner by employing an alternative test procedure.

The design of structural material against fatigue damage requires the knowledge of the nature of variation of crack growth rate (d*a*/dN) with alternating stress intensity factor range (ΔK) and the magnitude of fatigue threshold (ΔK_{th}). The assessment of these engineering parameters is conventionally carried out following the ASTM standard E 647 (2008). The determination of ΔK_{th} usually requires engagement of servo-hydraulic or electro-magnetic resonance type machines for a considerable period of time. As a result, studies on fatigue behaviour at crack growth rates < 10^{-6} mm/cycle is limited compared with that at d*a*/dN > 10^{-6} mm/cycle. However, fatigue study at crack growth rates <10^{-6} mm/cycle is important to explore the mechanics and mechanisms of crack growth behaviour in structural materials designed for safe-life applications. Narasaiah *et al.*., (2006) have reported an alternative simple method for rapid determination of ΔK_{th}. One of the major aims of this investigation is to study the crack growth behaviour at low d*a*/dN values, and thereby to estimate ΔK_{th} of ferrite-bainite dual-phase steels using an alternative test sample.

The search for a possible quantitative relation between the lengths of crack paths and their associated microstructure has not been made so far in FBDP steels. Studies of this nature can bring forth information about the weak links in a microstructure through which a crack prefers to pass through or the affinity of a crack to travel through any specific phase or interface in a microstructure (Ray, 2004). This aspect has been examined for both short and long crack growth in ferrite-bainite steels.

The present investigation is directed to highlight the above issues. This investigation primarily aims to encompass a series of studies on microstructural characterization, determination of conventional mechanical properties, assessment of structure-properties correlations, examination of short crack growth behaviour and determination of long crack threshold of FBDP steels. Three low carbon Nb-microalloyed steels having carbon content (by weight) of 0.05%, 0.08% and 0.16% were selected for this study. These steels were suitably heat treated to give a range of microstructures.

1.2 Objectives of the present work

The major objectives of this investigation and some details of the work to fulfill these are enumerated below.

1. To characterize the microstructure and to evaluate the conventional tensile properties of the selected steels. The characterization of microstructure of the investigated steels incorporates (a) determination of the amount and distribution of the various phases in the microstructure (b) estimation of the cleanliness of the steels (c) measurement of ferrite grain size (d) determination of hardness and (e) evaluation of tensile properties.
2. To examine structure-property correlation in all the three steels. This consists of (a) study on the relationship between hardness and volume fraction of different phases, (b) examination of the effect of bainite content on tensile properties and (c) understanding the tensile fracture surfaces.
3. To determine long crack fatigue threshold using rotating bending machine and to evaluate fatigue threshold values of low carbon ferrite-bainite steels investigated in this work. This aspect incorporates (a) estimation of the fatigue threshold of these steels and (b) assessment of the effect of microstructure on the threshold value and crack path.

4. To characterize short crack growth behaviour in low carbon FBDP steels. This includes (a) determination of short crack growth characteristics and their threshold values in the three selected steels having different bainite content, and (b) examination of the influence of the microstructure on crack path.

1.3 Lay out of the Work

Chapter 1 presents a general background of the emergence of low carbon ferrite-bainite dual-phase steels as candidate material for automotive and structural applications as well as the challenges and motivation to pursue the present work. Major objectives and an overview of the scope of the present work is also presented in this chapter. Chapter 2 provides a critical review of the existing literature in the field of dual-phase steels and its fatigue behaviour. The information available in the published literature raises numerous questions and provides the directions for further research. The present study has been inspired by the achievements of the previous investigations, and has addressed the issue of structure-property correlation of low carbon FBDP steels and its fatigue behaviour, an area which needs exhaustive investigation. Chapter 3 contains information on the selection and characterization of steels and a detailed description of the experimental procedures. The methods used for

(i) the preparation of the ferrite-bainite and ferrite-martensite dual-phase steels having different volume fraction of bainite/martensite, (ii) specimen preparation and procedures associated with microstructural characterization, and (iii) hardness measurement have been discussed. This chapter also gives a detailed description of the results of the microstructural characterization of ferrite-bainite and ferrite-martensite dual-phase steels. Microstructure obtained by adopted heat treatment cycle has been discussed with emphasis on the formation of different amount of harder second phase/constituents. Chapter 4 deals with the measurement of the tensile properties of the investigated FBDP and FMDP steels and their correlation with the amount of bainite and martensite in the investigated steels. The variation of tensile properties with volume fraction of the constituent phases has been examined. Chapter 5 deals with the design of fatigue specimen and its testing for long crack fatigue behaviour of the investigated ferrite-bainite steels. The results of the experiments carried out to study the fatigue crack growth behaviour as well as long crack fatigue threshold at room temperature have been discussed in detail. The variation of the fatigue crack growth behaviour with volume fraction of bainite has been examined with emphasis on the determination of fatigue threshold. Chapter 6 presents the design of fatigue specimen and its testing for short crack growth behaviour of the investigated steels with respect to the volume fraction of bainite. The short crack fatigue threshold has been determined from the variation of crack growth rate with stress intensity factor. The effect of the volume fraction of the bainite on the short crack fatigue threshold has been analyzed. Chapter 7 presents the summary and the major conclusions drawn from the present work. A critical examination of the results leads to several questions and provides ideas and directions for further investigation.