Microstructural Aspects of Bainite-MA Type Dual-Phase Steel for the Strain-Based Design in Terms of Deformation and Fracture

ABSTRACT

Linepipe with the dual-phase steel of bainite and dispersed MA (martensite-austenite constituent) phases has been applied for many pipelines in the seismic and permafrost regions which require higher deformability of the linepipes. Bainite-MA dual-phase microstructure exhibits excellent deformability and high strength up to Grade X100. Finely dispersed MA phases in the bainitic matrix also show strong resistance to microscopic crack initiation and propagation, resulting in good toughness of the base metal. This paper introduces metallurgical features of the bainite-MA type dual-phase steel with exploring microscopic deformation and fracture behaviors.

KEY WORDS: Dual-phase microstructure, martensite-austenite constituent (MA), FEM, unit-cell model, EBSD analysis, void nucleation and growth, crack propagation

INTRODUCTION

Based on the strain-based concept of the linepipe products used in seismic and permafrost regions, materials with higher deformability, which means low Y/T, high n-value or high uniform elongation, are desirable. Dual-phase microstructure consisting of hard and soft phases is essential to obtain higher deformability. Ferrite-bainite type dual phase linepipe steel was first developed for the application of the gas pipeline installed in seismic area (Endo, 2000). Optimization of the microstructure of ferrite-bainite steels has been conducted to enhance strain hardenability based on the microscopic deformation mechanisms (Ishikawa, 2005; Ishikawa, 2013). Recently, dual-phase steels consist of bainite and dispersed MA phases (martensite-austenite constituent) have been developed by applying the on-line heat treatment process in the plate manufacturing process (Shinmiya, 2007; Ishikawa, 2008) and applied to the pipelines installed in the seismic and permafrost regions (Muraoka, 2010). The MA phase is formed by applying the on-line heat treatment process, since carbon enrichment into the untransformed austenite is enhanced by the heat treatment after the accelerated cooling. Harder second phase gives higher strain hardening since strain localization in the soft phase is enhanced by the harder second phase (Huper, 2000). Therefore, the use of MA phase is the most efficient way to improve the strain hardenability. Enough higher deformability can be achieved with small volume fraction of MA phases which doesn’t affect other material properties. MA phase is often observed in the heat affected zone of high strength steel welds, which is considered to reduce toughness (Ishikawa, 2006). However, it was demonstrated that finely dispersed MA phases dose not affect toughness of the base material since the bainitic matrix is refined by the TMCP (thermo-mechanical controlled processing) in the plate rolling process which consists of controlled rolling and following accelerated cooling (Shinmiya, 2007). Although many testing results of the bainite-MA type linepipes have shown excellent deformability and toughness, mechanisms governing the material properties of the bainite-MA steel have not been fully clarified.

Material design of the dual-phase microstructure is commonly used in the automotive industry, too. So-called the “DP steel”, dual-phase steel which consists of ferrite and martensite is used for the body parts in which higher elongation and strain hardenability are needed. In this case, the heat treatment above the Ac3 temperature, where both ferrite and austenite exist, is applied to enrich carbon into the austenite phase which will turn into martensite by rapid cooling after the heat treatment. The heat treatment at the ferrite-austenite temperature is also used for producing the structural steel plates for building use in which low Y/T ratio is required. Usually, quenching after the heat treatment at the ferrite-austenite two-phase region is applied, then the plates are tempered. Resulting microstructure is usually ferrite-bainite or ferrite-bainite-martensite. There are not so stringent toughness requirements on those steels for automotive and buildings uses, usually. But, comparison of the metallurgical and mechanical properties of the dual-phase steels produced by on-line heat treatment and conventional heat treatment at ferrite-austenite temperature clarify the difference of metallurgical and mechanical properties and governing mechanisms of the improved deformability and toughness.

In order to optimize the microstructure and further improve the mechanical properties, such as deformability and toughness, it is quite important to understand the governing mechanisms of the metallurgical and mechanical behavior of the dual-phase steels. In this study, the metallurgical characteristics of the bainite-MA steels were first investigated using TEM and EBSD. FE analyses were conducted in order to reveal micromechanisms of the deformation and fracture behavior of the dual-phase steel.