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Influence of hot working parameters on microstructure evolution, tensile behavior and strain aging potential of bainitic pipeline steel

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ABSTRACT

The microstructure evolution, tensile properties and aging behavior were studied in a low-carbon pipeline steel by performing a number of physical simulations in a thermo-mechanical simulator. The austenite status, before entering the finishing stage, was varied by varying parameters in the austenitization and the roughing stages. The finishing parameters and the subsequent cooling strategy were kept fixed throughout all applied simulations. It was found that starting the finish rolling stage with pancaked austenite is more effective in motivating the formation of acicular ferrite and refining martensite/austenite phase than refining the prior austenite grains. The former effect resulted in improving both of ultimate tensile strength and proof stress without significant ductility decrease. Increasing the deformation during roughing stage resulted in stimulating the transformation kinetics during subsequent processing and consequently decreasing the untransformed austenite that forms the martensite/austenite microconstituent. Furthermore, increasing the austenitization temperature is found to enhance both of strength and ductility when starting the finishing stage with pancaked austenite. On the other hand, attaining aging effect in the studied steel was only possible after creating new dislocations by pre-straining. An increase up to 63 MPa in the yield strength is recorded due to aging after 2% pre-straining.

1. Introduction

In order to respond to the requirements for pipeline steels to exhibit a good combination of high strength and good low temperature impact toughness balanced with adequate weldability, new generations of low carbon micro-alloyed steels have been developed [1,2]. This development is based on new alloying concepts along with the progress of thermo-mechanical rolling practices. In these steels, carbon is not the major source of strength; its concentration is reduced below 0.09 wt.%. The reasons for low C content are the well-known facts that high C concentrations cause poor weldability and inferior weld toughness [3]. The strength loss due to a low C content is compensated by an alloy design philosophy based on the advanced use of cost effective micro-alloying elements, such as Nb, Ti and B in conjunction with moderate levels of other alloying elements, such as Mn, Si, Cr, Mo and Cu [4]. The use of aforementioned combinations of micro-alloying and alloying elements in conjunction, thermo-mechanical controlled processing leads to the development of API X80, X100 and X120 qualities, exhibiting a yield strength from 550 MPa up to 825 MPa [2]. These alloying and micro-alloying elements and thermo-mechanical processing (TMP) contribute to the increase in strength via microstructural refinement, precipitation hardening and solid solution strengthening as well as strengthening through microstructural modification [4,5]..

The microstructure development of these steels is strongly influenced by the parameters of TMP. This microstructure is often complex, consisting of mixtures of different morphologies, and therefore, wide combinations of mechanical properties can be achieved controlling them. In this respect, it is known that the refinement of microstructure is enhanced by a fine-grained austenite before transformation, and especially by a microstructure of strengthened austenite with elongated grains, high dislocation density and ledges in the grain boundaries that increase the density of nucleation sites and promote high nucleation rates for the phase transformation processes [6,7].

Much research is conducted to study the effects of finish rolling parameters and cooling strategy on the microstructure development and mechanical properties of pipeline steels [8–13]. However, the effect of rough rolling parameters is scanty in the literature. Shin et al. [11], Gomez et al. [7] and Xiao et al. [13] varied the austenitization and the start rolling temperatures. Simultaneously they varied the finish rolling parameters and cooling strategies. Up to date, the effect of the roughing parameters has not been systematically and exclusively reported. During the current work, an investigation on bainitic pipe line steel is carried out to study the effect of parameters in the austenitization and roughing stages on the microstructure and mechanical properties. The tests of this investigation are combined with quench-interrupted tests to study the evolution of austenite microstructure entering the finishing stage. The subsequent finishing and cooling stages are kept unchanged.

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Table 1
Chemical composition of the studied material (wt.%).

C	Si	Mn	Cr	Mo	Ti	Nb	S	P	N
0.055	0.3	1.84	0.18	0.259	0.0256	0.101	0.0008	0.014	0.006

A thermo-mechanical simulator equipped with a dilatometry system which integrates both, the thermo-mechanical processing and control and monitor of microstructure evolution, is used for this purpose.

On the other hand, many studies are performed to evaluate the changes in mechanical behavior of pipeline steels which occurs as a consequence of subjecting them to working conditions like corroding and low temperature environments [11,12,14,15]. Other studies dealt with the mechanical properties in the heat affected zone (HAZ) of the pipes [16,17]. The static strain aging of pipeline steels is, so far, not covered in the literature. Static strain aging takes place in two stages, namely straining and aging. Straining usually takes place in pipeline steels during the cold forming processes applied to form pipes out of the thermo-mechanically processed strips. Subsequent use of this strained material in high environmental temperature results in diffusion of C and N atoms to the dislocations created during cold deformation. In general, strain aging increases the strength to some extent but results in a loss of some ductility. Strain aging is also accompanied by a decrease in fracture toughness, which is usually reflected by an increase in the brittle transition temperature (BTT) [18]. Generally, any component that is subjected to plastic straining during its manufacturing will be subjected to strain aging during its subsequent use at room temperature. In the automotive industry, steel producers supply strain aged steel grades to the automotive manufacturers with a shelf life of minimum 3 months [19]. Several studies show the dependence of aging behavior, called also bake hardening effect, of multiphase steels on the aging time and temperature [20,21]. One of the scopes of the current study is to shade light on the strain aging behavior of pipeline steels. Standard values for prestraining of 0% and 2% and for aging of 170 °C for 20 min are adopted during the current study to prove the potential of strain aging of the studied steel.

2. Experimental procedure

2.1. Material and specimens preparation

The current study was carried out on samples machined out of an industrially rolled transfer bar with a thickness of 52 mm and the chemical composition as given in Table 1. This composition corresponds to an API X80-grade.

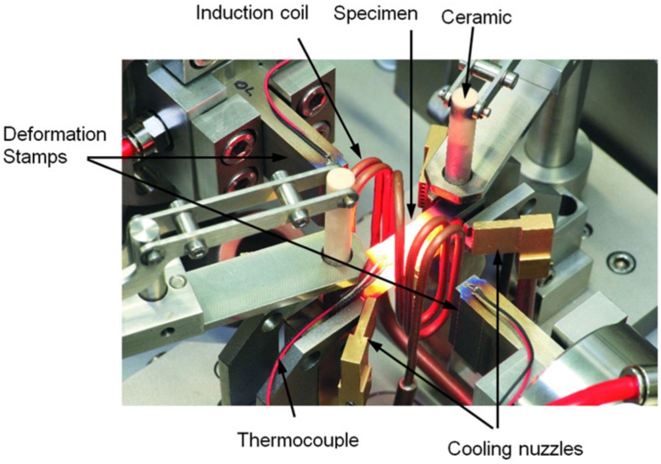

Fig. 2. The experimental setup for the flat-compression mode at TTS820.

The reason for the low C level is the enhancement of weldability. The hardenability loss due to the low carbon content is compensated through the addition of Mn, Mo and Cr. Mo and Mn cause the beginning of transformation to be retarded, because the polygonal ferrite (PF) start curve on the continuous cooling transformation (CCT) diagram is shifted to longer times [22]. The formation region of the intermediate transformation products such as granular bainite (GB) and acicular ferrite (AF) is expected to be obtained at slower cooling rate [23]. Meanwhile, it is accepted that when PF appeared in the acicular ferrite microstructure, the final mechanical properties of this steel are decreased [13,24]. Microalloying with Nb and Ti is to enhance the strength through refining the structure and providing a nanostructure second phase, which is the precipitates [5]. Furthermore, the high solubility temperature of the TiN results in remaining of an undissolved quantity of TiN particles during the austenitization stage. These particles limit the coarsening of the austenite grains by the strong pinning effect [7]. Thus Ti addition helps to control the austenite grain growth at high temperatures; nevertheless, Ti exerts a moderate effect on recrystallization inhibition [25].

Flat compression samples for the thermo-mechanical simulation were machined out of the transfer bar. The dimensions of the flat compression samples are shown in Fig. 1. The thickness of the specimens in the testing-zone is 6.4 mm. The specimens have 42 mm shoulders for

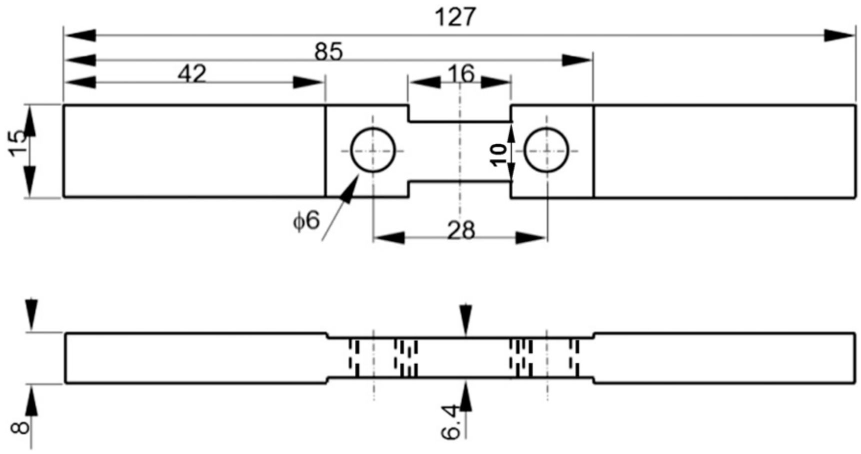

Fig. 1. Used flat compression sample. Dimensions in mm.