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A simulation study of pearlite-to-austenite transformation kinetics in rapidly heated hot-rolled low carbon steel

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ABSTRACT

The main aim of the present research was to obtain an optimized microstructure with adequate mechanical properties in a low carbon steel. The effect of microstructure on kinetics of austenite transformation was simulated. A 3.2 mm hot rolled steel was subjected to continuous annealing to obtain properties of Dual Phase 590 grade. Kinetics of austenite transformation was studied with respect to the condition of just pearlite dissolution to form austenite under rapid heating. Annealing parameters were based on process conditions of dual phase steel production in a continuous annealing line. DICTRA was used to simulate heating rates of the order 10–500 °C/s with peak temperatures in the range 750–850 °C to predict isothermal annealing time required for complete dissolution of pearlite into austenite under different temperature-heating rate conditions. Simulation results showed dependency of temperature and heating rate on austenite transformation time. Interestingly, no significant effect of heating rate on complete pearlite dissolution into austenite was evident. Results were validated with limited experimentation on Gleeble. Microstructure analysis validated the simulation results to be accurate. The observations have pertinent inputs while designing industrial continuous annealing line parameters where rapid heating rates are generally encountered (10–20 °C/s).

1. Introduction

Dual phase (DP) steels have proved a great potential in automobile sector for better fuel economy and passenger safety because of their superior specific strength [1–5]. DP steels consist of polygonal ferrite and martensite/bainite phases [6,7]. Ferrite phase is responsible for ductility whereas martensite/bainite phase is responsible for strength [8–10]. A good combination of strength and ductility can be obtained by achieving proper distribution of both the phases. The strength of DP steel depends upon the martensite volume fraction (MVF), the carbon content in martensite which determines its hardness, and the distribution of martensite phase in the microstructure [11–15]. Therefore, carbon dissolution in austenite during annealing is a critical parameter. The carbon content in austenite is maximum if austenite formation occurs just simultaneously with pearlite dissolution [16–18]. Austenite formation in the inter-critical region has been extensively studied [19–21]. Austenite growth in the given steel can be controlled by controlling the carbon diffusion in ferrite [22]. Austenite formation takes place in three basic steps: dissolution of pearlite into austenite (Step-I), growth of austenite into pro-eutectoid ferrite (Step-II), homogenization of the austenite formed (Step-III) [23]. The austenite formed during Step-I has maximum carbon concentration. With Step-II and Step-III, the volume fraction of austenite increases but carbon concentration in austenite decreases [16]. Austenite formed in Step-I has maximum carbon concentration, and further, the time required for formation of such austenite is minimum [17]. Thus, the holding time required for just pearlite dissolution into austenite assumes a critical importance for determining martensite fraction and hardness. From an industrial viewpoint, rapid heating rates are required for dual phase steel processing by continuous annealing line for meeting the objective of high production rates, reduced processing time, and increased annealing cycle efficiency. To fulfil these objectives, it is necessary that the important annealing parameters viz. heating rates, annealing temperatures, isothermal holding time periods, etc. be simulated [2,24]. In the present work, simulations were conducted on DICTRA software (Diffusion Controlled TRAnsformations software; DICTRA: version 27; developed by Thermo-Calc Software AB, Stockholm, Sweden) to determine the isothermal annealing time for complete pearlite dissolution into austenite at given annealing temperature-heating rate combinations. For DICTRA simulations, the local equilibrium model predicts the fraction of austenite/ferrite most accurately [25], and therefore, the local equilibrium model was used in

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Table 1
Chemical composition of the *as*-received hot rolled steel.

Element	C	Mn	Si	S	P	Al	N	Fe
% wt.	0.074	1.83	0.43	0.002	0.012	0.026	0.0032	Balance

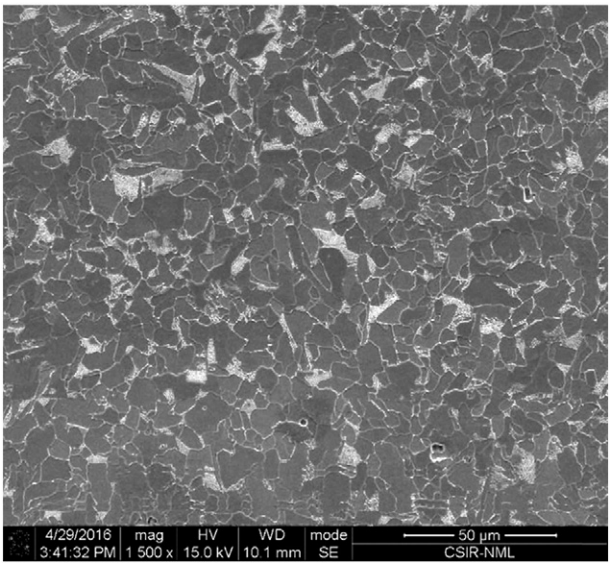

Fig. 1. Microstructure of the as-received hot rolled steel showing typical hot rolled structure consisting of ferrite and pearlite.

the current investigations. In the local equilibrium model, the interface is assumed to migrate under full local equilibrium conditions with both partitioning of carbon and alloying elements [25,26]. The present work is an attempt to simulate the rapid heating rates during continuous annealing and to investigate their impact on pearlite dissolution into austenite. DICTRA simulations were validated through experimental Gleeble simulations.

2. Experimental

2.1. Characterization of the as-received material

Experiments were performed on an industrially hot rolled steel sheet having chemical composition as shown in Table 1.

Specimens were subjected to standard metallographic procedure and were etched using nital (for normal etching; 2% nital solution) and picral reagent (for color etching; pre-etched in 0.4 g picric acid in 10 ml ethanol for 60 s and finally etched in solution of 1 g sodium metabisulphate in 10 ml distilled water) for optical microscopy. Picral being a color etchant showed martensite as dark brown and ferrite as white. A Leica microscope (DM2500 M) of Lieca Microsystems, Germany was used. For SEM microscopy, a scanning electron microscope set-up (Nova Nano SEM 430; Field Emission Inc., Hillsboro, USA) was used. Phase fractions in the microstructure and grain size distribution were determined using 'analySIS FIVE' software (analySIS Five 5.05.07; developed by Olympus Soft Imaging Solutions, Notting Hill, Australia). Finally, tensile tests were performed as per ASTM standard E–8 M at room temperature. Tests were conducted using flat dog-bone shaped specimens of 25 mm gauge length, strain rate of 1×10^{-3} s^{-}1 on an Instron 8862 system with 100 kN capacity.

The microstructure of the starting material typically comprised of ferrite and pearlite as shown in Fig. 1. By using the linear intercept method, the average grain size was determined as 9.13 µm. The volume fraction of pearlite was calculated as 18.82% using 'analySIS FIVE' software.

3. Predictions of phase fraction using Thermo-Calc

The inter-critical annealing temperature range for the given steel chemistry was determined using Thermo-Calc (Thermo-Calc 3.0; Thermo-Calc Software AB, Stockholm, Sweden). The predicted phase diagram is shown in Fig. 2. Lower (Ac_1) and upper (Ac_3) critical temperatures were predicted as 676 °C and 839 °C respectively as shown in Fig. 2(a). Fig. 2(b), shows the predicted phase fraction or increase in the volume fraction of austenite with increase in inter-critical (lower (Ac_1) and upper (Ac_3)) annealing temperatures under equilibrium conditions.

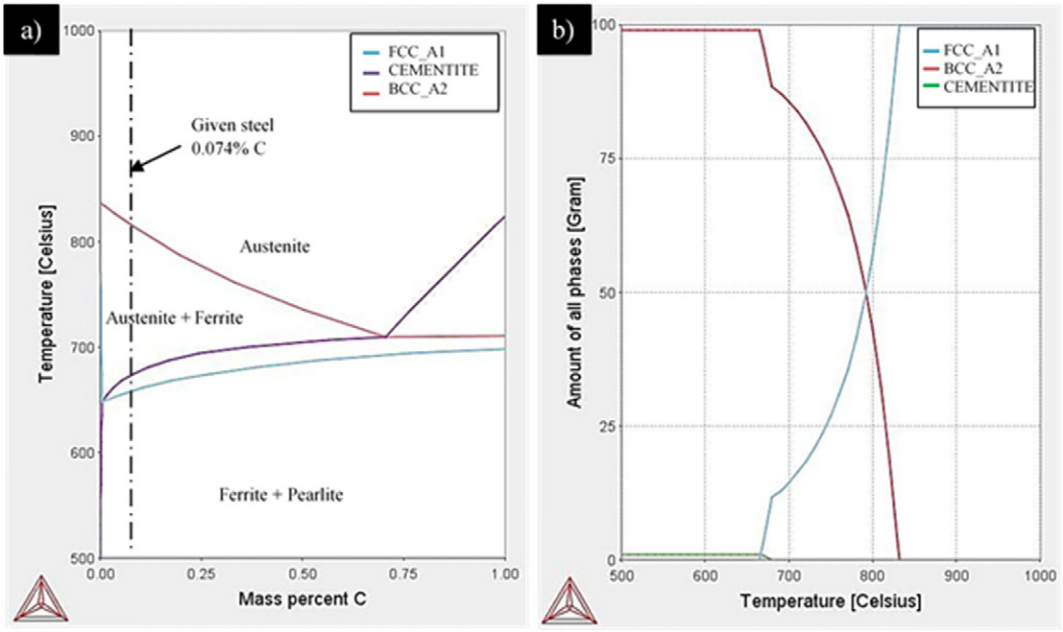

Fig. 2. Result window of Thermo-Calc for (a) phase diagram (b) change in volume fraction of various phases within inter-critical annealing temperature range under equilibrium conditions.