Institute for Materials Science and Welding (IWS)
Graz University of Technology, Austria

Ductility Investigations of a Low Alloyed Steel

D. Djuric[1], F. Stiefler[1], S. Zamberger[2], C. Sommitsch[1]

1. Institute for Materials Science and Welding, Graz University of Technology, Kopernikusgasse 24, 8010 Graz, Austria
2. voestalpine Stahl Donawitz GmbH & Co KG, Kerpelystraße 199, 8700 Leoben, Austria

INTRODUCTION

In the temperature range between 700 and 1100°C, low alloyed steels show brittle fracture and are susceptible to cracks during deformation processes after continuous casting. In these steels, alloying elements form precipitates preferentially at grain boundaries, where they lead to strain concentrations, hence void nucleation and crack formation. During cooling, ferrite first forms as a thin film surrounding austenite grain boundaries. This ferrite film is softer compared to the austenite grain, therefore, promoting grain boundary sliding and crack formation.

In order to investigate this phenomenon, boron-titanium alloyed steel is tested with a newly developed in-situ remelting, solidifying and hot tensile testing method to determine the second ductility trough in the cast structure on-cooling. A thermo-mechanical testing machine with induction heating is used for these experimental investigations. Results of in-situ tests are compared with tests performed with commonly used on-heating methods. Additionally, materials characterization such as electron microscopy is used to verify the microstructure and fracture surface.

Low Alloyed Boron Containing Steels

Table 1: Chemical composition of the investigated steel [weight%]

C	Si	Mn	Al	V	Ti	B	N_2
0.11	0.18	0.96	.054	.005	.038	.0046	0.004

Boron is added to unalloyed steels to increase hardness and to enhance through-hardenability. This has the advantage that small amounts of boron (approximately 50 ppm) can replace large amounts of expensive alloying elements. To obtain the same hardness the carbon content can also be reduced significantly, which leads to a better weldability. To keep the boron effect high it is important that the Boron atoms are dissolved. For this reason stronger nitride formers like titanium are added to protect boron against nitriding. Investigations show that a small amount of boron retard the formation of pro-eutectoid ferrite films, increase grain boundary cohesion and improve the hot ductility [1,2]. These tests are performed with on-heating methods and austenitising. In-situ on-cooling experiments after remelting and solidification with such steels were not performed so far.

Experimental Procedure

Heat Treatment

To show the differences between on-heating and on-cooling tests these two methods were compared with each other (Figure 1). The on-cooling testing method is more realistic to properly simulate the continuous casting process as well as crack formation in the laboratory.

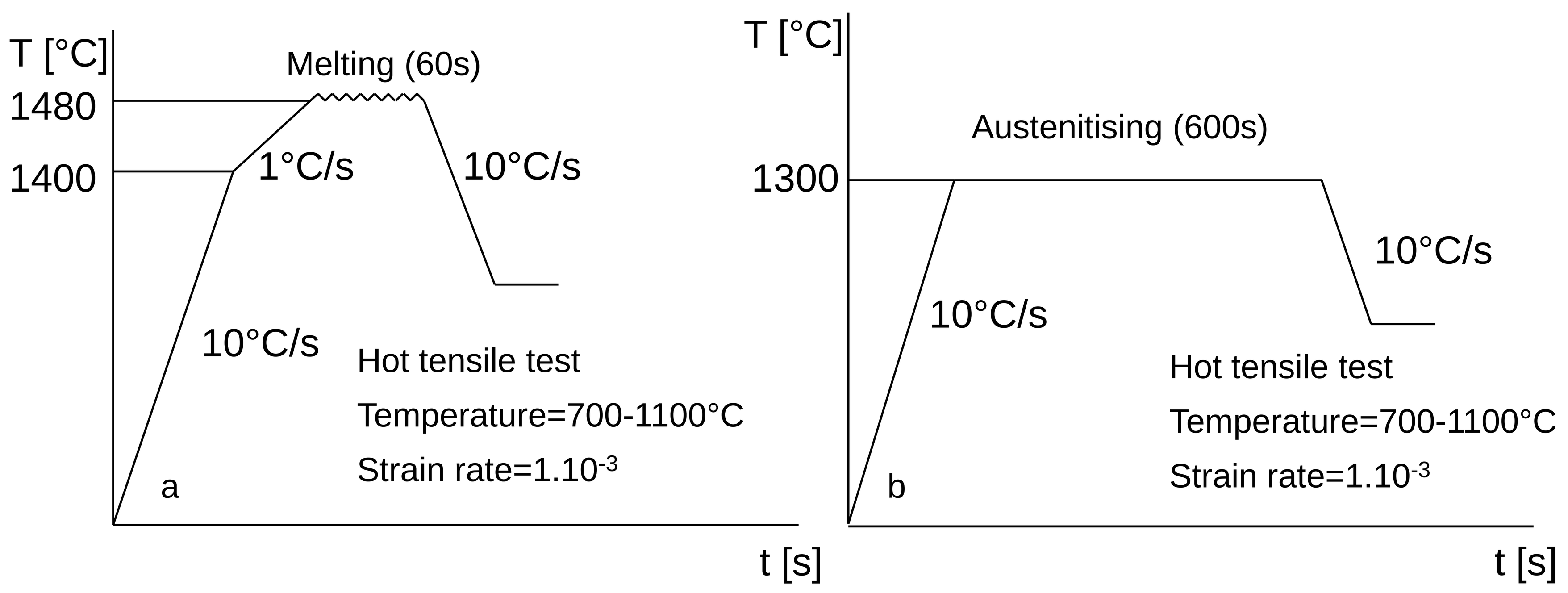

Figure 1: Hot tensile tests: a) on-cooling with remelting and solidification and b) on-heating with austenitising

Thermo-Mechanical Testing Machine

A thermo-mechanical testing machine with induction heating and a vacuum chamber is used for these tests (Figure 2). The in-situ melting tests were performed without any melting pool covers. At high temperatures a thin solid skin forms, which contains the melting pool inside the specimen. Samples have a diameter of max. 20mm and a length of 240mm. The tests were performed in vacuum and the temperature was measured with Pt-PtRh thermocouples as well as pyrometers.

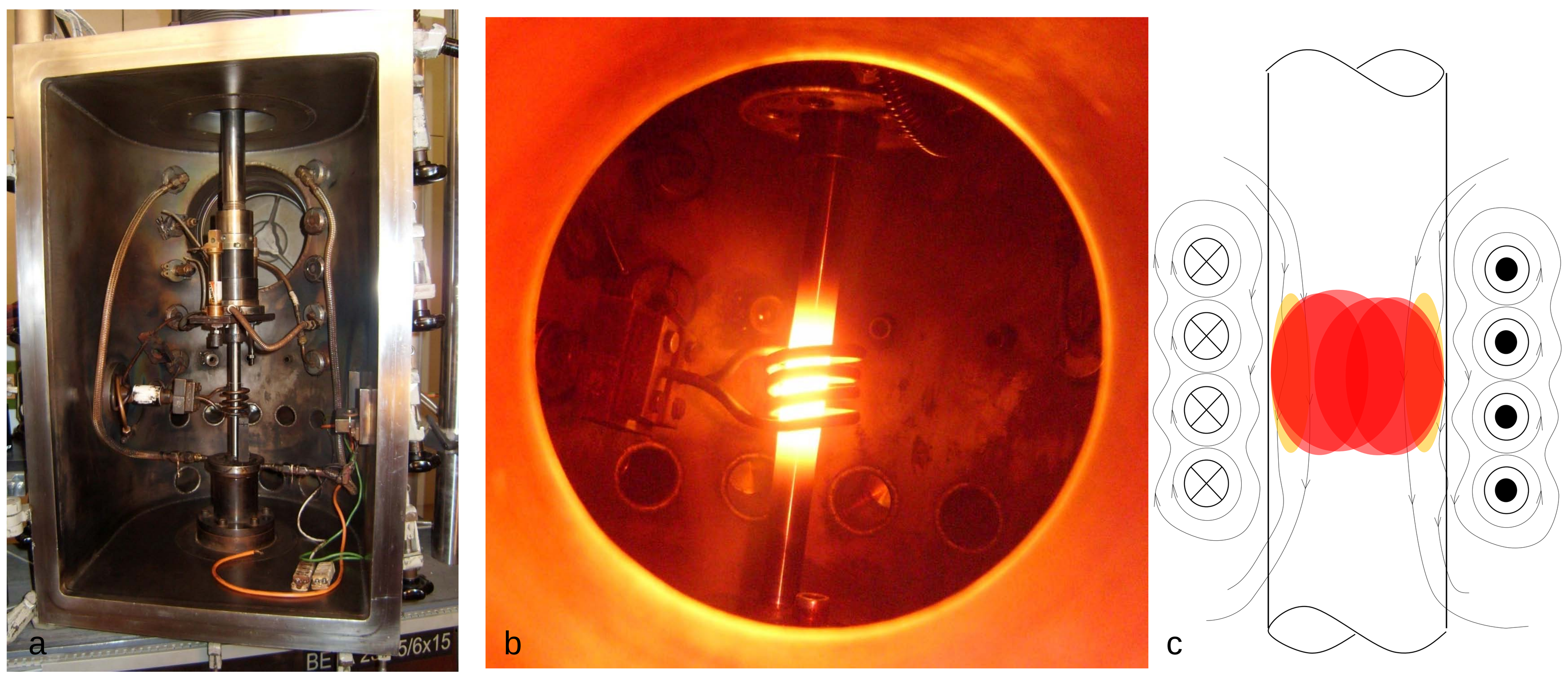

Figure 2: Thermo-mechanical testing machine: a) specimen chamber, b) melting without cover and c) schematic sketch

Results

Mechanical Properties

Figure 3 depicts that the heat treatment history has a significant influence on the hot ductility: melted specimens show a poorer ductility than reheated ones. To simulate the continuous casting process close to reality it is hence important to test the material in-situ after remelting and solidification.

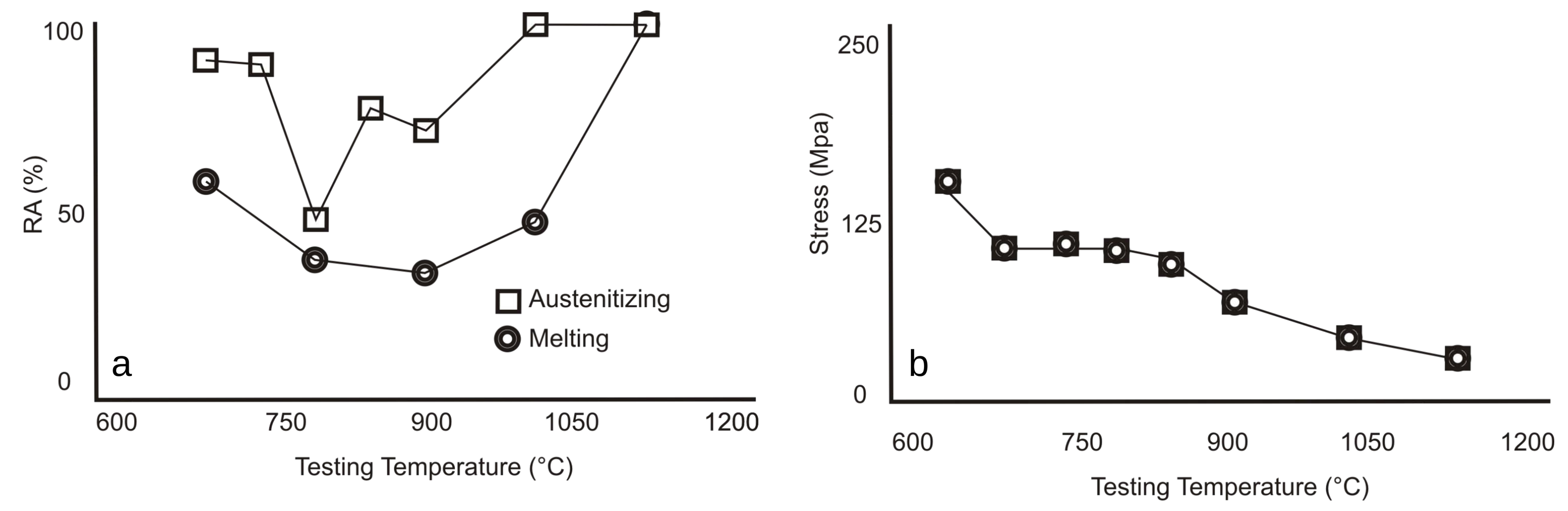

Figure 3: High temperature properties: a) hot ductility and b) strength vs. temperature from austenitised and melted specimens

Light Microscopy

On-heating tests show crack formation at the oxidized surface, see Figure 4, which results from the residual oxygen in the vacuum chamber and the austenitising time of 600s. This coat is the preferred place for crack formation.

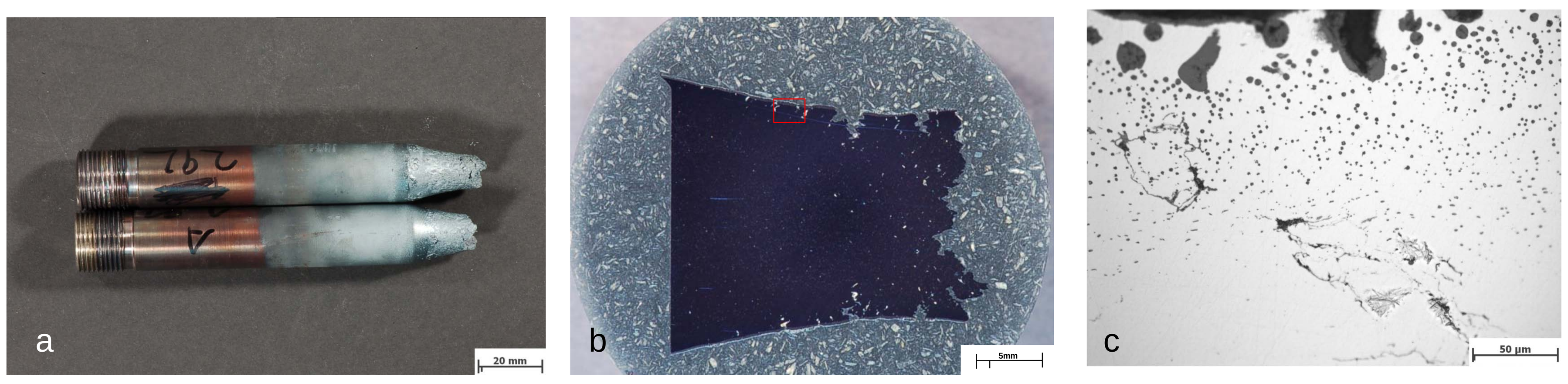

Figure 4: Tensile test at 800°C and crack formation: a) austenitised specimens, b) crack formation at the oxidized surface and c) surface detail of b)

On-cooling in-situ tests can be performed faster than the on heating tests because of lacking austenitisation, thus the oxidation layer is much thinner. Cracks form mostly inside the specimen due to the low grain boundary cohesion (Figure 5).

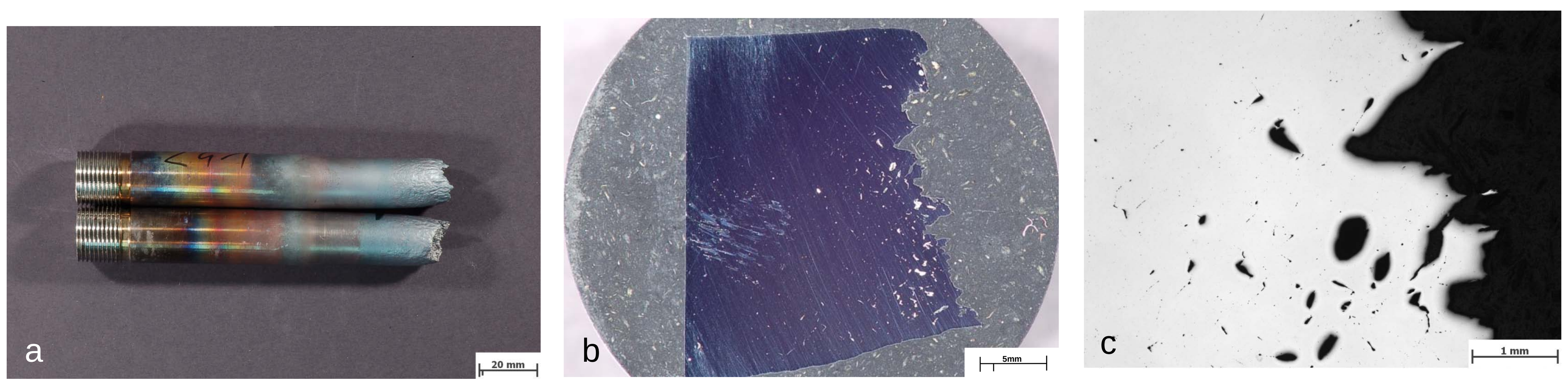

Figure 5: Tensile test at 900°C and crack formation: a) melted and solidified specimens, b) crack formation inside the specimen and c) crack surface detail

Scanning Electron Microscopy

Figure 6a shows a brittle fracture of an austenitised specimen, tested at 800°C at its ductility minimum. The melted and solidified sample in Figure 6b is tested at 900°C at its ductility minimum and exhibit larger grains and ductile regions at grain boundaries and triple points.

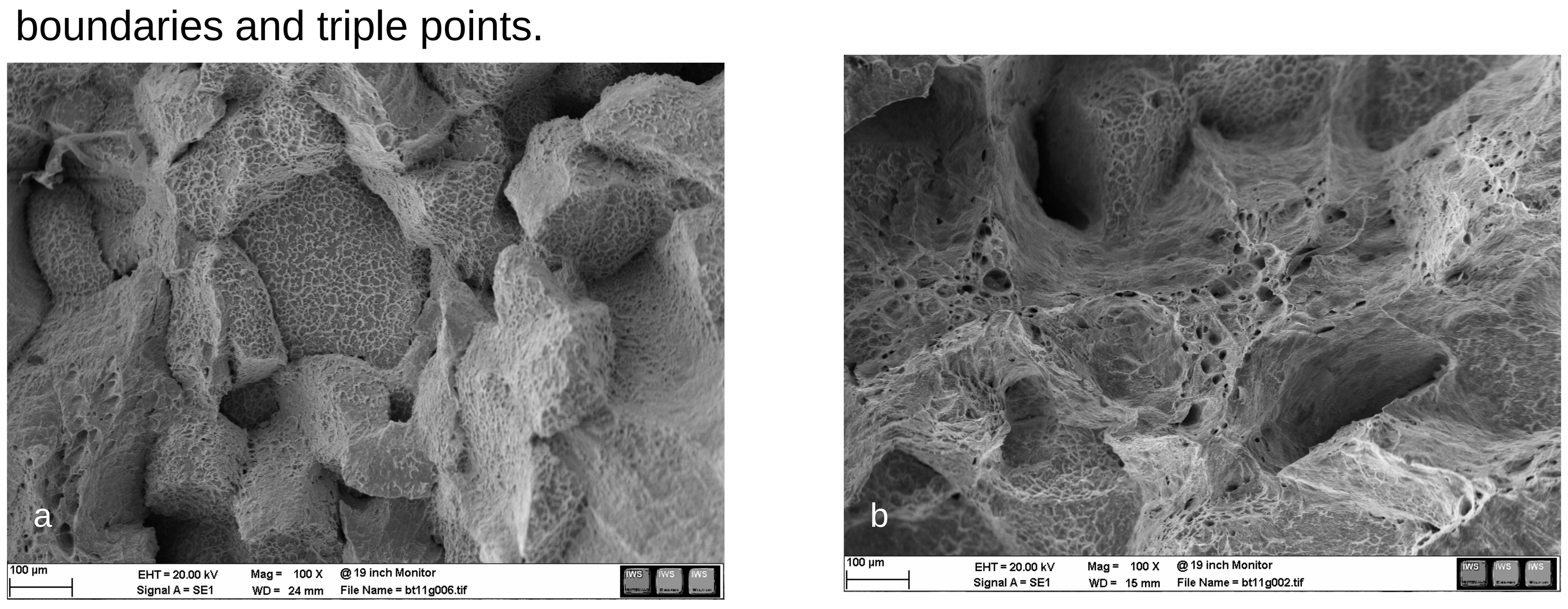

Figure 6: Fracture surfaces of a) austenitised and b) melted and solidified samples

CONCLUSION

On-cooling hot tensile tests after melting and solidification show different results in comparison to on-heating tests after austenitisation: the second ductility minimum decreases after remelting the specimens. Using the proposed method both qualitative assessment and understanding of crack formation is more meaningful in comparing different heat treatments in the laboratory. All heat treatment parameters have a strong effect on the microstructure and further to the material properties.

[1] S.-H. Song, A.-M. Guo, D.-D. Shen, Z.-X. Yuan, J. Liu, T.-D. Xu, Effect of boron on the hot ductility of 2.25Cr1Mo steel, Materials and Engineering A360 (2003) 96-100
[2] K.-C. Chao, D.-J. Mun, Y.-M Koo, J.-S. Lee, Effect of niobium and titanium addition on the hot ductility of boron containing steel, Materials Science and Engineering A 528 (2011) 3556-3561