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Investigation of the hot ductility of a high-strength boron steel

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ABSTRACT

In this study, the high-temperature ductility behaviour of an Al–Si-coated 22MnB5 sheet was investigated. The mechanical properties of Al–Si-coated 22MnB5 boron steel were examined via hot tensile tests performed at temperatures ranging from 400 to 900 °C at a strain rate of 0.083 s^{-1}. The deformation and fracture mechanisms under hot tensile testing were considered in relation to the testing data and to the fracture-surface observations performed via SEM. The hot ductility of the tested boron steel was observed as a function of increasing temperature and the Al–Si-coated 22MnB5 boron steel exhibited a ductility loss at 700 °C.

1. Introduction

In recent years, energy efficiency and environmental concerns have become the most important issues for the automotive industry. The most effective approach to addressing these concerns is weight reduction, which has led to the rapid development and adoption of advanced high-strength steels (AHSSs). AHSSs generally include martensites, bainites, ferrites and/or retained austenites obtained via phase transformation, including dual-phase steel, TRIP steel, complex-phase steel and boron steel. These materials are superior in both strength and ductility compared with conventional steels and thus facilitate energy absorption during impact and can help to ensure passenger safety while reducing vehicle weight [1,2]. They allow thinner and higher-strength parts to be used for the same function in comparison with conventional steels.

The most commonly used advanced high-strength steel is Al–Si-coated 22MnB5, which is the most preferable for hot stamping applications. Al–Si-coated 22MnB5 has a ferritic–pearlitic microstructure with a tensile strength of approximately 600 MPa and a fracture strain of approximately 15% in the delivery state [3]. The Al–Si coating has excellent oxidation resistance at elevated temperatures [4].

Hot stamping is a method in which the microstructure of a steel material is changed into martensite, and the tensile strength is significantly increased by approximately 1500 MPa in a single step, especially after rapid cooling [3,5,6]. This process and the resulting material are used for A and B pillars, bumper beams, side rails, door beams, etc. [6,7]. The optimum hot-formability parameters are obtained via hot-ductility tests. The hot ductility is influenced by several parameters, such as temperature, deformation rate and boron content. The addition of boron to plain carbon steel improves the hot ductility because solute boron atoms that segregate to grain boundaries can occupy vacancies and thus prevent the formation and propagation of microcracking at grain boundaries [8–11].

A small number of studies has been conducted regarding the hot ductility and fracture behaviour of boron steels [9,10,12–14]. The effect of boron on the hot ductility of 2.25Cr1Mo steel has been investigated by Song et al. [9]. Lopez-Chipres et al. [10] have investigated the influence of boron on the hot ductility of boron microalloyed steels. The results demonstrated that increasing the boron content improved the hot ductility of the materials. Mejía et al. [13] have studied the hot-ductility behaviour of a low-carbon advanced high-strength NiCrVCu steel with the addition of boron.

In the present investigation, an Al–Si-coated 22MnB5 boron-steel sheet was subjected to hot tensile tests at various temperatures to obtain a better understanding of the ductility and plasticity exhibited during hot-deformation processing and to characterise the fracture surfaces to determine the fracture mechanisms associated with the hot-ductility process.

2. Experimental procedures

The material used for this study was Al–Si-coated 22MnB5, which is manufactured by ArcelorMittal with a sheet thickness of

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1.7 mm. Its chemical composition (wt%) and mechanical properties are listed in Tables 1 and 2, respectively. The microstructure of the as-delivered Al–Si-coated 22MnB5 steel is presented in Fig. 1. It can be clearly seen in Fig. 1 that the material had a ferritic–pearlitic microstructure in the as-delivered condition.

In this work, to characterise the mechanical properties of Al–Si-coated 22MnB5 as a function of temperature, hot tensile tests were performed on a UTEST 25-ton universal tensile testing machine equipped with cross-field induction heating coils at six different temperatures (400, 500, 600, 700, 800 and 900 °C) and at a constant strain rate (0.083 s^{-1}). Hot tensile specimens with a thickness of 1.7 mm and a gauge length of 300 mm (Fig. 2) were first heated to the target temperature and then stretched at the selected constant temperature and strain rate. The hot ductility was quantified in terms of the per cent reduction in area (RA) at the fracture. The result of each hot tensile test is the average of the results of five specimens for each heat-treatment parameter.

Table 1
Chemical composition of the investigated Al–Si-coated 22MnB5 steel (mass%).

Material	C	Si	Mn	P	S	Cr	Ti	B	Ni
Al–Si-coated 22MnB5	0.19	0.649	1.13	0.0096	0.0021	0.192	0.0327	0.003	0.0189

Table 2
Mechanical properties of the investigated Al–Si-coated 22MnB5.

Material	Tensile strength (MPa)	Yield strength (MPa)	Young's modulus (GPa)	Vicker's hardness (HV_{10})
Al–Si-coated 22MnB5	543	418	222	130

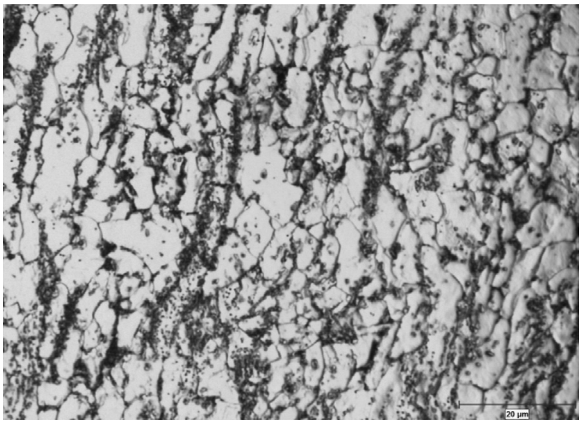

Fig. 1. Optical micrograph of as-received Al–Si-coated 22MnB5 (the dark areas are pearlite, and the light ones are ferrite).

The microstructures and fracture surfaces were examined using an optical microscope (Nikon MA100) and a scanning electron microscope (SEM, CARL ZEISS EVO 40, UK), respectively.

3. Results

3.1. Flow curves

The strength of a material at elevated temperatures is of primary concern in hot-deformation processing. Strength measurements are

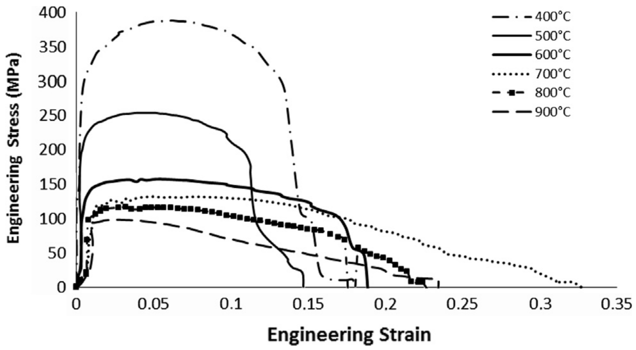

Fig. 3. The typical engineering stress–strain curves of Al–Si-coated 22MnB5 steel with deformation temperatures of 400–900 °C.

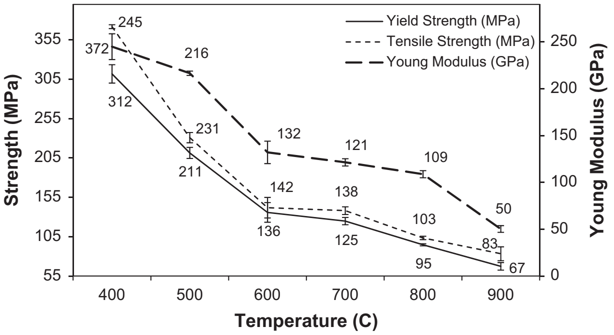

Fig. 4. Tensile yield stress and Young's modulus of Al–Si-coated 22MnB5 steel as a function of temperature.

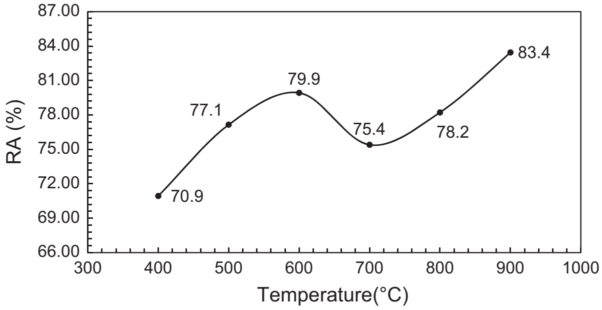

Fig. 5. Hot ductility (RA, or reduction in area) curve for Al–Si-coated 22MnB5 steel.

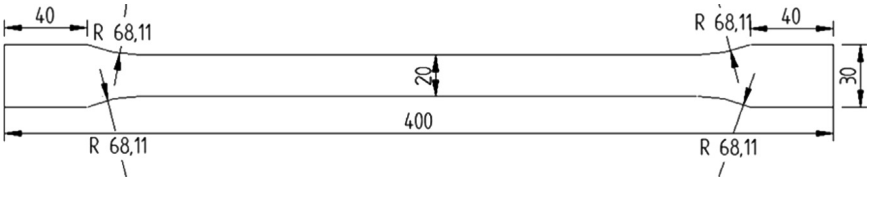

Fig. 2. The hot-tensile test specimen dimensions in mm.