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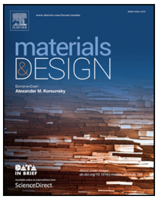

Microstructures and mechanical properties of dual phase steel produced by laboratory simulated strip casting

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ABSTRACT

Conventional dual phase (DP) steel (0.08C–0.81Si–1.47Mn–0.03Al wt.%) was manufactured using simulated strip casting schedule in laboratory. The average grain size of prior austenite was 117 ± 44 μm. The continuous cooling transformation diagram was obtained. The microstructures having polygonal ferrite in the range of 40–90%, martensite with small amount of bainite and Widmanstätten ferrite were observed, leading to an ultimate tensile strength in the range of 461–623 MPa and a corresponding total elongation in the range of 0.31–0.10. All samples exhibited three strain hardening stages. The predominant fracture mode of the studied steel was ductile, with the presence of some isolated cleavage facets, the number of which increased with an increase in martensite fraction. Compared to those of hot rolled DP steels, yield strength and ultimate tensile strength are lower due to large ferrite grain size, coarse martensite area and Widmanstätten ferrite.

1. Introduction

Dual phase (DP) steels are widely used in automotive industry due to a good combination of continuous yielding behaviour, high strength, high strain hardening rate, low yield stress-to-tensile strength ratio and good formability [1–3]. DP steels have high tensile strength in the range of 500–1200 MPa and total elongation in the range of 12–34%, which depend on fractions of ferrite, martensite and bainite [1,4]. Traditional microstructures of DP steels consist of polygonal ferrite and martensite. To satisfy custom requirements, ferrite–bainite–martensite and ferrite–bainite steels were produced in order to modify mechanical properties: bainite instead of martensite were shown to improve formability with a little decrease of strength [5–7]. The effect of martensite fraction, distribution and martensite region size, and the effect of ferrite fraction and grain size on mechanical behaviour of DP steels have been intensively studied. With increasing the martensite fraction, the yield strength and ultimate tensile strength increase while uniform and total elongations decrease [8,9]. The distribution of martensite also affects the mechanical behaviour [10–12]. Martensite regions existing as isolated areas within ferrite matrix result in a better combination of strength and ductility than martensite regions forming a chain-like network structure surrounding ferrite [10]. Refinement of ferrite or/and martensite regions simultaneously enhances strength and ductility [13–16]. Ultrafine-grained DP steels with the average ferrite grain size of ~1.2 μm exhibit a high ultimate tensile strength up to 1000 MPa [13].

In industry, the DP steels are successfully produced using hot rolling and cold rolling & annealing [1]. As alternative, the strip casting could be suggested as a more economic and environmentally friendly way for DP steels production. This technology is already used for carbon steels, silicon steels and stainless steels in industry [17,18]. It allows obtaining several millimetres thick strips directly from molten metals [17,18]. Due to this and elimination of many subsequent hot rolling stages required by conventional continuous casting and thin slab casting, the strip casting process has many advantages, such as energy saving and emission reduction, lower capital and operating costs, a smaller and more flexible operating regime, a higher tolerance to a high residual scrap and easy adjustment for different steel grades [17–20].

In this study, the feasibility of producing DP steel using strip casting was investigated in the laboratory. Heat treatment schedules were designed to obtain microstructures with 40%–90% ferrite. Mechanical properties were tested and compared to hot rolled DP steels. The correlation between microstructure and mechanical properties was analysed.

2. Materials and experimental techniques

The chemical composition of studied DP steel is shown in Table 1. Square specimens of 36 × 36 mm^2 and 1.2 mm thickness and cylindrical specimens of 20 mm diameter and 6 mm length were produced via dip

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Table 1
The chemical composition of the DP steel (wt.%).

C	Si	Mn	Al	Cu	Cr	P	S	B
0.0768	0.805	1.47	0.0346	0.0126	0.233	0.0055	<0.00050	0.00091

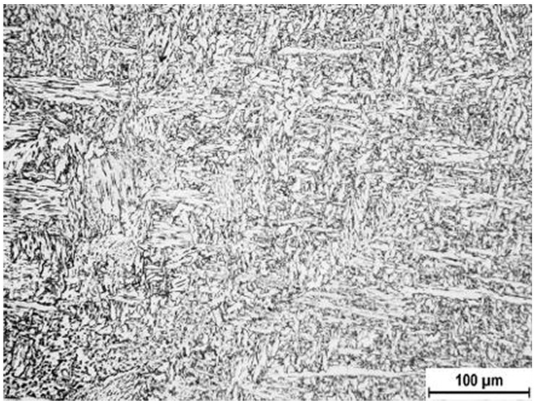

Fig. 1. The microstructure of DP steel after dip casting.

tester at Deakin University in order to simulate rapid cooling during solidification in strip casting process [21]. The dip tester is used to immerse a copper substrate into molten steel for a short and controlled period of time to simulate a rapid solidification. As-cast microstructure consisted predominantly of martensite and some bainite as shown in Fig. 1.

Heat treatments were carried out using a Theta Dilatronic III Quenching and Deformation dilatometer. It was operated under a vacuum of ~6.7×10^{-2} Pa which prevented oxidation and decarburization of the samples. The temperature was measured using an S-type (Pt/Pt–10%Rh) thermocouple spot-welded to the surface centre of a cylindrical and flat samples (Fig. 2).

To simulate the prior austenite grain size (PAGS) observed in cast samples, the flat samples (Fig. 2b) were heated at a rate of 30 Ks^{-1} to 1250 or 1300 °C, held for 120 or 180 s, and then helium quenched to room temperature at a rate of around 140 Ks^{-1}.

To obtain the continuous cooling transformation (CCT) diagram, cylindrical samples (Fig. 2a) were heated at a rate of 30 Ks^{-1} to 1300 °C, held for 180 s to simulate the grain size and distribution of prior austenite in strip casting, and then cooled to room temperate at cooling rates of 0.1, 1, 3, 10, 40 and 90 Ks^{-1}.

The schedule to simulate strip casting process is illustrated in Fig. 3a. The samples were heated at a rate of 30 Ks^{-1} to the austenitisation temperature $T_A = 1300$ °C, held for time $t_A = 180$ s, cooled to the austenite-to-ferrite transformation region at a rate of 90 Ks^{-1} or cooled to 1000 °C at a rate of 30 Ks^{-1} and then cooled at a rate of 10 Ks^{-1} (hereafter referred as 30–10 Ks^{-1} schedule) to ferrite formation temperature T_F, held for t_F time to achieve the desired ferrite fraction, and then quenched to the room temperature at 140 Ks^{-1} using helium.

Following the heat treatments, the specimens were cross-cut in the centre perpendicular to the long axis. The centre area of the cross section was used for observation. To reveal the prior austenite grain boundaries, the specimens were etched for 15–20 s at 65 °C temperature in the solution of saturated picric acid in ethanol plus few drops of benzene sulfonate. Equivalent grain diameter was utilised to describe the distribution of prior austenite grain sizes. Approximately 150–250 grains were measured for each condition. Etching with 2 vol.% nital was used to reveal ferrite and martensite. Microstructures and fracture surfaces were studied using a Leica DMR research optical microscope (OM), a JEOL JSM-7001F field emission gun-scanning electron microscope (FEG-SEM) operating at 15 kV of accelerating voltage and fitted with an 80 mm^2 X-Max energy dispersive X-ray spectroscopy (EDS) detector, and a JEOL 2011 transmission electron microscope (TEM) operating at 200 kV. Thin foils for TEM were prepared using twin jet electropolishing method with an electrolyte containing 10% of

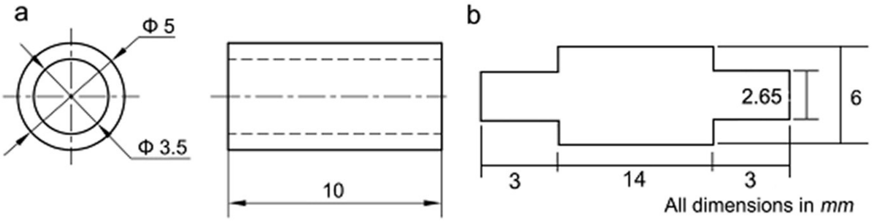

Fig. 2. (a) Cylindrical samples used for the determination of continuous cooling transformation diagrams, and (b) flat samples used for prior austenite grain size measurement and simulation of strip casting.

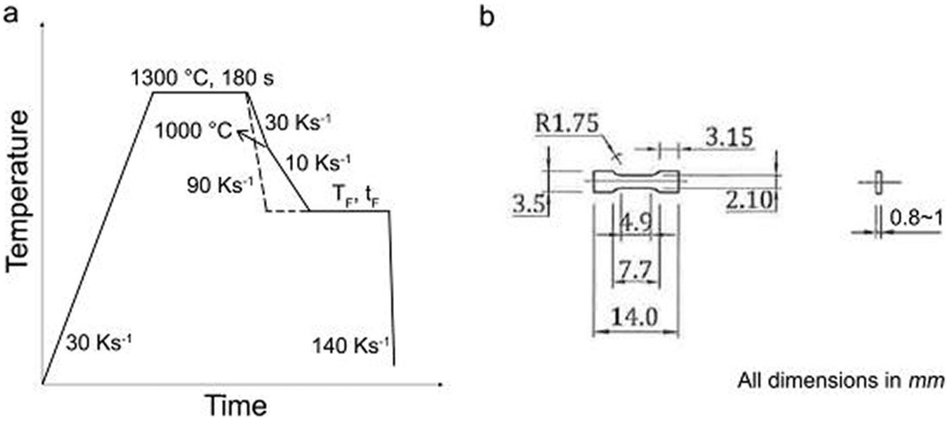

Fig. 3. Schematic diagrams of (a) heat treatments to simulate strip casting and (b) tensile test sample.