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Beneficial influence of an intercritically rolled recovered ferritic matrix on the mechanical properties of TRIP-assisted multiphase steels

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ABSTRACT

The present study deals with the microstructure and mechanical properties of intercritically rolled TRIP-assisted multiphase steels. It is shown that the occurrence of the TRIP effect in a recovered ferritic matrix brings about an improved strength–ductility balance with respect to a fully recrystallised ferrite matrix. On the other hand, the intercritical deformation does not influence the austenite transformation rate during straining at room temperature. The improvement of the mechanical properties results from the interactions between the transformation strain and the recovered ferrite.

1. Introduction

TRIP-assisted multiphase steels constitute now a well established class of high strength steels [1]. They consist of carbide-free bainite and retained austenite embedded in a ferritic matrix. The formation of such a microstructure requires different steps during the processing route [2]. The first one consists of the formation of a mixture of intercritical ferrite and austenite, while during the second one austenite partially transforms to bainite. During this bainite transformation, carbon diffuses from the supersaturated ferrite platelets into the surrounding austenite [3]. As carbide precipitation is hindered by the relatively large silicon (or aluminium) content (1–2 wt%) of this type of alloy, the austenite is enriched with carbon throughout bainitic holding and can finally be retained after quenching to room temperature [4].

Numerous studies scrutinised the role of several processing parameters or the effect of the microstructure on the mechanical properties. Much attention was devoted to the understanding of the formation of this kind of microstructure and of the resulting mechanical properties in the case of cold rolled and intercritically annealed steels [5–10]. On the other hand, several studies considered the processing of TRIP-aided multiphase steels by thermomechanical processing. However, most of these studies dealt with deformation stages above the no-recrystallisation temperature (T_{nr}) of austenite or considered the role of micro-alloying elements [11–17]. Hardly anything has been reported in the case of intercritical rolling of low carbon TRIP-aided steels [18]. In the case of ferritic steels, if the warm rolling practice was developed since it leads to an effective compromise between cost savings (due to lower reheating temperature) and mechanical performances [19], it is well known that the recovered ferrite that is induced presents a higher strength but completely depleted strain hardening capabilities [20]. It is also worth noting that some specific results were recently reported in the case of the δ-TRIP steels that present a ferrite–austenite microstructure at all temperature due to their specific chemical composition [21], or in the case of medium-Mn steels [22].

The aim of this study is to demonstrate the beneficial influence of an intercritical rolling stage on the mechanical properties of low alloy TRIP-assisted multiphase steels. Contrarily to the well known detrimental influence of a non-recrystallised ferrite state on its work hardening capabilities, the activation during straining of the martensitic transformation of retained austenite grains embedded in a recovered ferrite matrix brings about improved levels of strength and ductility. This paper thus deals with (i) the effect of hot deformation in the intercritical temperature range on the microstructure development and (ii) the relationship between the hot rolling parameters and the resulting mechanical properties.

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Table 1
Chemical composition of the investigated steel.

Element	C	Si	Mn	P	S	Al
wt%	0.15	1.52	1.49	0.015	0.009	0.032

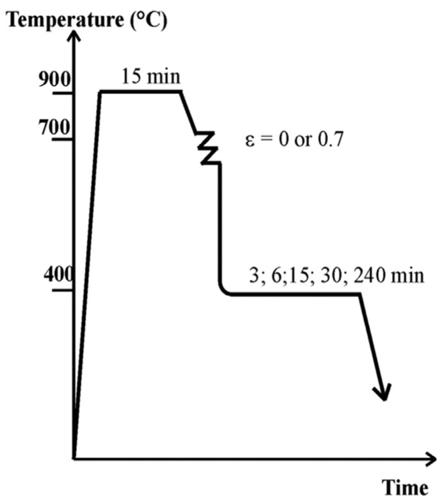

Fig. 1. Schematic representation of the thermomechanical processing route.

2. Experimental procedure

The composition of the investigated steel is given in Table 1. Its composition is typical of high silicon TRIP-assisted multiphase steels, i.e. a low-carbon steel with a significant amount of silicon (that enables the austenite to be retained at room temperature by incomplete bainite transformation), and some manganese (that provides hardenability). No micro-alloying elements were added. The steel was provided as two 150 kg ingots from which 100 mm thick plates were first hot-rolled down to 20 mm. These 20 mm thick plates were used as the raw material. The no-recrystallisation temperature (T_{nr}) as well as the Ar_3 temperature were estimated by hot torsion owing to the evolution of the mean flow stress during continuous cooling conditions similar to the thermomechanical process described below. Temperatures of 920 °C and 770 °C were found for T_{nr} and Ar_3, respectively.

The thermomechanical process (TMP) was simulated considering two steps. The first step (roughing) aimed at homogenising the microstructure and reducing the grain size owing to the austenite recrystallisation. After reheating at 1250 °C for 45 min, two deformation passes starting at 900 °C were applied for a total deformation of 1. The specimens were then quenched in boiling water (which provides a constant cooling rate of ~50 °C s^{-1}) down to 650 °C, held at this temperature for 1 h and finally furnace cooled as a normalising treatment. The second stage, which is depicted in Fig. 1, aimed at generating the multiphase microstructures. The specimens were reheated at 900 °C for 15 min. They were allowed to air cool down to 700 °C where they were deformed to a true strain of 0.7. This deformation temperature lies in the austenite/ferrite domain. For the sake of comparison, some specimens were not deformed at 700 °C. The different specimens were then quenched in a salt bath at 400 °C for the bainite transformation stage. Bainitic holding times of 3, 6, 15, 30 min and 4 h were investigated. The specimens were finally water quenched to room temperature. Amongst these different bainitic holding times, 30 min revealed to bring about the best strength–ductility balance while 4 h of holding leads to the complete decomposition of austenite into bainitic ferrite and carbides

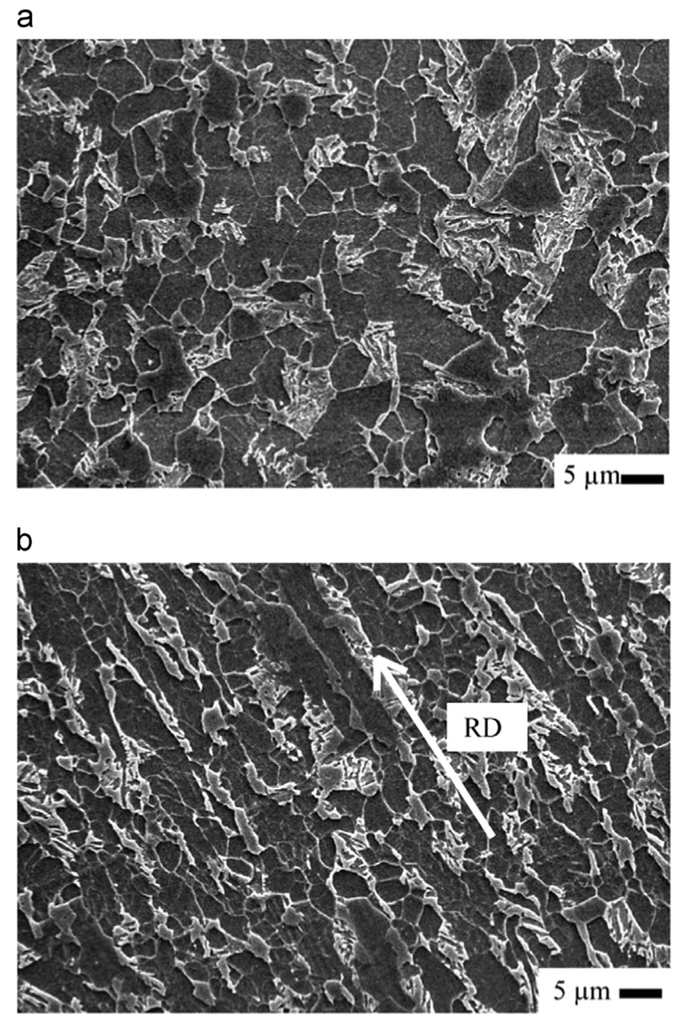

Fig. 2. SEM micrograph of the microstructure of (a) the specimen not deformed at 700 °C and (b) the specimen deformed to ε=0.7 at 700 °C. Both specimens were then held for 30 min at 400 °C.

[2,23]. In what follows, the different specimens will be denoted MPXXYY (MP for ‘multiphase’), where XX will correspond to the intercritical deformation and YY to the bainitic holding time.

The mechanical properties were measured in uniaxial tension with the tensile axis oriented in the rolling direction on samples machined following the European standard EN10002-1. The initial gauge length and width were 50 and 12.5 mm, respectively. The cross-head speed was 2 mm min^{-1}. Measured loads and elongations (with an extensometer) were converted to true stresses and true strains. Five samples were measured for each condition. Standard deviations for stress and strain are of the order of 10 MPa and 0.02, respectively. Strain hardening was described using the incremental strain hardening exponent (n_{incr}) defined as

$$n_{incr} = \frac{d\ln\sigma}{d\ln\varepsilon} \quad (1)$$

Microstructures were studied by SEM after conventional Nital etching. A prior 2 h annealing at 200 °C allowed the martensite and austenite to be distinguished [24]. Some specimens were also characterised by EBSD [25]. They were first ground and subsequently polished with diamond paste down to 1 µm. The last step consisted of a 1 h polishing stage with a 0.05 µm colloidal silica solution. Different areas were scanned with adequate step sizes in order to distinguish the features of the finely grained microstructures.