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Effects of lanthanum on hot deformation behaviour of Mn-Cr-Mo bainitic rail steel

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Abstract: Effects of lanthanum (La) as micro-alloying element on the hot deformation behaviour of the high strength Mn-Cr-Mo bainitic rail steel were investigated under a range of deformation conditions. The results indicate that La increases the flow stress by 10–30 MPa through strengthening nanoscale strain induced precipitation (SIP) θ-$(Fe, La)_3C$ during hot deformation. The hot deformation activation energy increases by 10-40 KJ/mol due to the "Zener effect" of SIP and the dynamic recrystallization (DRX) is retarded due to the competitive behaviour between SIP and DRX. Bainite plates in the DRX domain can be refined by adding La, resulting in the improvement of hot workability. The DRX domain with peak power dissipation efficiency of 52% is determined to be the optimal processing region for Mn-Cr-Mo-La bainitic rail steel.
Keywords: rare earth; hot deformation; strain induced precipitation; dynamic recrystallization; dissipation map; microstructure

1. Introduction

With the development of ultra-low carbon, ultra-pure steel smelting and micro-alloying technologies, RE (rare earth) technology in steel has achieved breakthrough, promoting the extensive application of steels containing RE. Besides the purification and metamorphism effect, the micro-alloying effects of RE in clean steel are becoming increasingly noticeable and stable.[1,2] At present, RE effects on hot deformation behaviours of some materials, including permanent magnetic materials, nonferrous metals, interstitial free steel steel and stainless steel have been widely investigated. These previous results showed that RE additions inhibited recrystallization behaviour, improved recrystallization temperature and refined the grain size.[3-6] Moreover, the study of Wang et al.[7] showed that RE significantly improved the hot ductility of austenitic heat-resistant steel by the purifying effect of RE at the grain boundary. Similarly, Luo et al.[8] confirmed the same effect of a small amount of RE in high-speed steel. But no study has been reported on micro-alloying effects of RE during hot deformation in controlled rolling bainitic rail steels, which are of great necessities to the optimization of the hot processing performance. Usually alloying additions such as manganese, chromium and molybdenum are employed in bainitic rail steel to improve steel hardenability for achieving the desired ultra-high strength, but the toughness decreased with increasing the strength. However, grain refinement could both improve the strength and toughness by adding RE because RE can greatly reinforce the hardenability of Mn, Cr and Mo elements, beneficial to the formation of a finer structure at lower temperature.[9]

Theoretically RE can improve the toughness in bainitic rail steel,[9] but whether it could be used as micro-alloyed elements in bainitic rail steel is also decided by the effects of RE in hot rolling. The purpose of this work is to investigate the effects of RE on the processing performance and inherent flow characteristics of bainitic rail steel during hot deformation, and to discuss the relationship between the flow behaviour and microstructural evolution. Furthermore, the constitutive equation of bainitic rail steel containing RE was established, and the hot processing performance was determined for the development of RE micro-alloyed bainitic rail steels.

2 Experimental

The two bainitic rail steels were smelted in a vacuum induction furnace and refined in LF furnace after adding alloying elements of manganese, chromium and molybdenum for refining. When preparing the Mn-Cr-Mo-La bainitic steel, a certain content of RE (La dominating) was added into the smelting steel in the VD furnace for vacuum degassing, fully deoxidizing and desulfurizing. Then the two smelted steels with and without La were both cast into the 20 kg ingots. The chemical compositions of the two test steels are listed in Table 1. Next, the 20 kg cast ingots were forged into 70 mm × 70 mm × 800 mm stocks and then homogenized annealing by heating up to 1180 °C and holding for 1 h.

The specimens for hot compression tests were cut from the forged stocks with a size of Φ8 mm × 12 mm. The hot compression tests were performed by using a Gleeble-1500D thermal-mechanical simulator under the protection of

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