Effect of Heating and Cooling Rates on the Microstructure of a Double Soaked Medium-manganese Al-alloyed Steel

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Received September 1, 2022; accepted September 26, 2022; published online October 21, 2022

Abstract: This contribution addresses the effect of heating and cooling rates on the microstructure of a double soaked medium-Mn 0.16C-5Mn-1.6Al-0.2Si steel with an increased Al addition. The obtained results show that the differences in applied heating and cooling rates have a small effect on the microstructure of the investigated steel. Some differences in the dilatometer response during final cooling to room temperature were noted. Moreover, some changes in the fraction of retained austenite at particular heating/cooling variants were identified using the XRD method. Scanning electron microscopy (SEM), electron backscatter diffraction (EBSD), and dilatometry were applied to investigate microstructural changes, which occurred during second annealing step in the intercritical temperature range.

Keywords: Medium-Mn steel, Double-step intercritical annealing, Heat treatment, Retained austenite, Dilatometry

1. Introduction

Medium-Mn steels belonging to the third generation of Advanced High Strength Steels (AHSS) are among the most perspective lightweight materials for body-in-white automotive sheet parts. These steels containing between 3 and 12wt.% of Mn show a beneficial combination of high strength at sufficient ductility. Typically, medium-Mn steels are manufactured through a single-step intercritical annealing, resulting in a duplex-type microstructure consisting of austenite and ferrite [1]. Despite many beneficial properties, such a multiphase microstructure has some dis-
advantages related to the high difference in the hardness of neighboring phases resulting in their poor stretch-flangeability and limited hole expansion ratio (HER). Limiting these problems is possible due to the use of novel double-step intercritical annealing allowing for the replacement of a significant part of soft ferrite by low-C martensite. Temperature and time of intercritical annealing are the key parameters that affect the fraction and mechanical stability of retained austenite. However, heating and cooling rates also have an impact on the microstructure evolution [2]. Therefore, the present study concerns the influence of heating and cooling rates during the second intercritical annealing step carried out at 850°C on the microstructure of 0.16C-5Mn-1.6Al-0.2Si steel.

2. Experimental

The hot-rolled 4.5mm sheet steel of the type 0.16C-5Mn-1.6Al-0.2Si was investigated. Detailed information on the hot rolling conditions can be found in [3]. The initial microstructure, before heat treatment, was fully martensitic. All samples were first heated to the intercritical region at 680°C for 30 min and then cooled to room temperature. After that a short secondary intercritical annealing (IA) step was performed at a higher temperature (850°C) for 30 s followed by cooling to room temperature. Different heating and cooling rates were applied. The heat treatment was carried out by means of dilatometry using a high-resolution BAHR dilatometer DIL805A/D, according to the time-temperature schedule, as shown in Table 1.

The microstructural changes of the studied steel were examined by scanning electron microscopy (SEM, FEI Quanta FEG 450 and Zeiss Supra 25), electron back-scattered diffraction (EBSD, FEI Quanta FEG 450), and X-ray diffraction (XRD, Empyrean PANalytical). Specimens for microstructural observations were prepared using standard metallographic procedures. The fraction of retained austenite determined using the XRD method was estimated from the average of three measurements using the Rietveld method.

3. Results and Discussion

Phase transformations during the second intercritical annealing step were monitored using dilatometry based on changes in a relative length (RCL) as a function of temperature. Dilatometric curves obtained during final cooling to the room temperature showed that the thermal stability of retained austenite (RA) in specimens annealed at 850°C is similar, regardless of applied heating and cooling rates (Fig. 1). A slightly higher fraction of martensite was formed in a specimen heated and cooled at the highest rates 80°C/s and 60°C/s, respectively. The Ms temperature was the highest in this case: 260°C. The lowest thermal stability of RA is related to the low diffusion rate of Mn during short heating time. A higher heating rate may result in local manganese and carbon heterogeneities due to the short time for homogenization of the austenite [2]. A higher heating rate results in a shorter time for enriching the austenite in carbon and manganese. Therefore RA characterized by reduced thermal stability can be present in the microstructure. Moreover, the application of a higher cooling rate favors martensitic transformation.

The goal of the second intercritical annealing step at a higher temperature is to replace some or all of the ferrite with austenite during heating and holding. Next, some fraction of new-formed austenite transforms into martensite during final cooling, thus replacing the ferrite+austenite microstructure with a microstructure containing both martensite and austenite [4]. The microstructure of investigated steel after the first step of intercritical annealing at 680°C (30 min) is composed of large fraction of ferrite, austenite, and some fraction of tempered martensite (Fig. 2a). The microstructure after the second step of intercritical annealing contains martensite, fine-dispersed RA, and a small fraction of ferrite. The microstructures of specimens after the second step of IA at 850°C are shown in Fig. 2b,c.

The differences in the applied heating and cooling rates have no effect on the size and morphology of RA. The differences in the heating rate were not sufficient to cause the grain refinement effect [2]. Some differences in the fraction of RA in specimens after the second IA were noted using the XRD method (Table 2). The amount of RA was smaller for specimens processed by using heating and cooling rates of 80°C/s and 60°C/s, respectively. The obtained results are in good agreement with the dilatometric data.

### Table 1

| Specimen type | Heating rate, °C/s | IA temperature, °C | Cooling rate, °C/s |
|--------------|------------------|------------------|------------------|
| 850_80_60    | 80               | 850              | 60               |
| 850_80_10    | 80               | 850              | 10               |
| 850_3_60     | 3                | 850              | 60               |

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4. Conclusions

The heating and cooling rates have a relatively small effect on the microstructure of double-soaked medium-manganese Al-alloyed steel. The slightly lower thermal stability of RA was noted for specimens processed by using the highest heating and cooling rates of 80 °C/s and 60 °C/s, respectively. It was due to the short time for enriching the austenite in C and Mn. The application of higher heating and cooling rates together with the second IA temperature of 850 °C allows for replacing a large fraction of initial soft ferrite by low-carbon martensite.
TABLE 2
Fraction of retained austenite (XRD) in investigated steel processed by using different heating and cooling rates

| Specimen type | Fraction of RA, % vol |
|---------------|-----------------------|
| Initial state (after first IA) | 19.4 |
| 850_80_60 | 3.1 |
| 850_80_10 | 4.2 |
| 850_3_60 | 5.1 |

Acknowledgements. The publication was supported under the Initiative of Excellence-Research University program implemented at the Silesian University of Technology in 2020, grant no. 10/010/SDU/10-21-01.

Funding. Open access funding provided by Silesian University of Technology.

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