Effect of Thermomechanical Processing in the Intercritical Region on Hardenability of Austenite of a Dual-Phase Steel

M. Sarwar, E. Ahmad, and R. Priestner

(Submitted 19 January 2000; in revised form 9 July 2001)

Steels slabs containing different percentages of C, Mn, and Cr were intercritically heat treated and rolled at 780 and 790 °C; they were then quenched to produce dual-phase microstructure in order to study the martensitic hardenability of austenite present in them. It was found that rolling of the two-phase \((\alpha + \gamma)\) microstructure elongated austenite particles and also reduced the martensitic hardenability of austenite particles, probably because the rolling increased the \(\alpha/\gamma\) interfacial area, thus promoting the formation of ferrite during cooling. The martensite particles obtained in the rolled material were also elongated or “fibered” in the rolling direction. It was observed that the thermomechanical processing of a two-phase \((\alpha + \gamma)\) mixture has the detrimental effect of increasing the quenching power needed to yield a specific amount of martensite.

In this paper, the thermomechanical processing treatments and intercritical heat treatments were designed to study their affect on the martensitic hardenability of austenite.

1. Introduction

The characteristic microstructure of dual-phase steel consists of 20 to 25% Martensite Island in a soft and ductile matrix of ferrite. Dual-phase steels have unique mechanical properties, which include low proof strength and high tensile strength relative to conventional low-carbon formable steel. They also exhibit high work-hardening rates in the early stage of plastic deformation and good ductility during forming relative to their strength in the formed condition. The latter quality puts dual-phase steel high on the list of materials that are being considered by the automobile industry to reduce the weight of vehicles for improved economy. The conventional method for the production of dual-phase steels is annealing on carbon steel within the intercritical temperature range for a few minutes, followed by cooling at a rate fast enough to transform the austenite to martensite. The annealing temperatures control the amount of austenite present during intercritical annealing, which also controls the carbon content and the hardenability of the austenite.

Lawson and Matlock (1) expressed the constituents of steel after cooling from intercritical annealing temperature in the form of “Microstructure map”. Austenite→martensitic hardenability diagram derived by Priestner and Ajmal (2) from microstructure map in which percentage of the austenite is plotted versus cooling rate, which specifically the martensitic hardenability of austenite. This concept has also been used in the present study to describe the effect of thermomechanical process on hardenability of austenite.

In this paper, the thermomechanical processing treatments and intercritical heat treatments were designed to study their affect on the martensitic hardenability of austenite.

2. Experimental Work

2.1 Material

The composition of the steel (weight percent) employed in the present study is listed in the following table.

<table>
<thead>
<tr>
<th>Type</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.16</td>
<td>0.24</td>
<td>1.03</td>
<td>0.01</td>
<td>0.09</td>
<td>0.14</td>
<td>0.04</td>
<td>0.15</td>
<td>0.20</td>
</tr>
<tr>
<td>B</td>
<td>0.088</td>
<td>0.26</td>
<td>1.2</td>
<td>0.01</td>
<td>0.09</td>
<td>0.78</td>
<td>0.04</td>
<td>0.15</td>
<td>0.20</td>
</tr>
</tbody>
</table>

The material was supplied in the form of hot-rolled slabs, and plates. Metallographic investigation of the as-received microstructure showed that it consisted of unband ferrite and pearlite and traces of martensite or retained austenite in both steels. In order to study the effect of intercritical annealing temperature on the volume fraction of austenite, specimens approximately 10 mm square and 2 mm thick were heat treated in the range of 725 to 830 °C (with approximately 15 °C intervals) in an argon atmosphere for 20 min and then quenched in ice brine. The austenite volume fraction was measured by the point counting technique.

2.2 Specimen Preparation

For rolling experiments, a set of specimens (both for steels A and B) with initial thickness of 10 mm and area of 60 × 30 mm were machined, so that, after rolling to 50% reduction, all the specimens would exit from the rolls at a common thickness of 5 mm. In addition, another set of specimens with 5 mm initial thickness and 50 × 50 mm area were heat treated, but were not rolled. The purpose of the common thickness of 5
mm for rolled and not rolled specimens was to ensure that the cooling rate would be the same in both.

### 2.3 Intercritical Heat Treatment at Selected Temperatures

For the purpose of studying the effect of warm rolling at the intercritical annealing temperature (ICAT) on the martensitic hardenability of austenite, the experiments were divided into two groups.

For group 1, the specimens of steels A and B with initial thickness of 5 mm and area of $50 \times 50$ mm were heat treated for 20 min at 780 and 790 °C, respectively. These temperatures were selected to obtain a planned austenite volume fraction of 55% based on the results of the experiments described in Fig. 1. At the end of the heat treatment, the specimen was removed from the furnace and plunged into one of the following cooling media:

- a quench tank containing ice brine (10% NaCl, at $-7$ °C),
- a quench tank containing cold water,
- a quench tank containing hot water,
- a quench tank containing boiling water,
- a quench tank containing oil (fensol 68) at room temperature,
- hot air blast,
- still air, and
- a box containing vermiculite.

In group 2, the thermomechanical treatment was carried out in order to study the effect of controlled rolling on the martensitic hardenability of the austenite.

Specimens of steels A and B with initial thickness of 10 mm were intercritically annealed at 780 and 790 °C, respectively, in a muffle furnace situated close to and facing the entry to the rolls. After the required soaking time, the door of the furnace was opened and the specimen was pulled by its handling rod from the furnace and put directly into the rolls. Immediately after exit from the rolls, it was cooled in one of the media listed above.

The volume fractions of the constituents present after cooling were determined by quantitative optical metallography.

### 3. Results and Discussion

#### 3.1 Effect of Intercritical Annealing Temperature on Volume Fraction of Austenite

Figure 1 shows the variation of austenite content with intercritical annealing temperature for both steels A and B. It can be seen that the volume fraction of austenite increased with the increase in the intercritical annealing temperature for both steels A and B. However, the volume fraction of austenite at any temperature for steel B was less than that for steel A because of the smaller amount of carbon content and higher content of Cr in steel B. Cr is a ferrite stabilizing agent that raises the $A_e$ temperature.

#### 3.2 Microstructure Map Developed at Zero Reduction

The dual-phase structures developed after intercritical annealing of steels A and B at 780 and 790 °C, followed by brine quenching, are shown in Fig. 2 and 3, respectively. At slower cooling rates, new ferrite formed before the remaining