EFFECT OF THERMOMECHANICAL PROCESSING ON A MORPHOLOGY OF RETAINED AUSTENITE IN AHSS CONTAINING 5%Mn

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Abstract
Two 5Mn-1.5Al steels with and without Nb microaddition, that can be classified as AHSS, were developed in the present study. The paper presents the results of their hot deformation resistance and microstructures obtained as a result of the thermomechanical processing after applying the isothermal holding temperature in a bainitic range from 350 to 450°C. The effects of the isothermal holding temperature and Nb microaddition on microstructure and hardness were discussed. It was found that the hot workability of AHSS containing 5% Mn is very challenging due to high values of flow stresses required. However, the thermomechanical processing enables to obtain fine-grained bainitic-martensitic microstructures with a fraction of retained austenite above 10%. The effect of Nb manifests by higher flow stresses required and better grain refinement of all the microstructural constituents compared to Nb-free steel.

Keywords: thermomechanical processing, hot compression, flow curves, AHSS, TRIP steel, retained austenite, Mn alloying, Nb microaddition

1. INTRODUCTION
Advanced high strength steels (AHSS) with multiphase microstructures satisfy different demands of the automotive industry. DP (Dual Phase), TRIP (TRansformation Induced Plasticity) and CP (Complex Phase) are characterized by a wide range of mechanical properties as well as technological plasticity [1-3]. A further need to obtain steel sheets with a higher strength-ductility balance (UTS·TEl ~ 30000 MPa·%) led to the development of high-manganese austenitic steels offering also very good mechanical characteristics during crash events [4-6]. In spite of excellent mechanical properties of high-Mn steels their application will be probably limited only for most challenging auto-body elements with a complex shape or in energy-absorbing zones. The reasons are different technological problems related to relatively poor casting, hot-working above 1150°C, corrosion resistance, Mn segregation and especially the high cost due to Mn (between 20 and 30 wt.%), Al and Si alloying concept.

Other concepts of further simultaneous increase in the strength and ductility of AHSS sheets aim to obtain a strength-ductility regime between multiphase steels and high-Mn austenitic alloys at cost only slightly higher compared to conventional DP/TRIP/CP steels [7]. New microstructure concepts consist in increasing a volume fraction of hard constituents and retained austenite. It is related to replacing polygonal ferrite by acicular or bainitic ferrite, non-carbide bainite, martensite and stabilization of austenitic phase in different ways, i.e., chemically or mechanically [7-10]. One of the chemical composition strategies to obtain a bainitic matrix containing a high volume fraction of metastable retained austenite is Mn alloying. Manganese is a main austenite stabilizer and its content varies from 3 to 12 wt.% in recently studied Mn-Al-Si alloys [7-9]. New chemistry designs require also improved manufacturing technologies and sheet metal forming concepts. The example is the quenching and partitioning process where the mixture of martensite and carbon-enriched austenite is obtained under conditions of the partitioning of C from supersaturated martensite [7, 11]. The thermomechanical processing, microalloying with Nb, Ti, V and reverse martensite transformation are another ideas to obtain complex microstructures with a high fraction of retained austenite of optimal stability for strain-induced martensitic transformation during drawing, stretching, bending, etc.
In previous works [12-14] the \( \alpha - \varepsilon \) curves and softening kinetics of austenite under conditions of hot-compression for 3Mn-1.5Al and 5Mn-Al steels were investigated. It was found that flow stress and critical strains required for dynamic recrystallization are higher compared to conventional TRIP steels. It is interesting that the softening kinetics of 5Mn-1.5Al steels is faster compared to 3Mn-1.5Al steels. Elaboration of the thermomechanical rolling requires also the knowledge of hot-working behavior of steels during multi-step deformation. These processes can be effectively modeled by physical simulation methods reflecting complex industrial temperature-time-strain cycles using small samples in metallurgical process simulators [1, 6]. The thermomechanical processing of AHSS still represents a new challenge due to a lack of data on the hot deformation resistance of alloys with increased Mn and Al contents. The final multiphase microstructure is highly dependent on the evolution of austenite during hot-working and cooling conditions, especially the temperature and time of isothermal holding of steel in a bainitic transformation range.

2. EXPERIMENTAL PROCEDURE

The paper addresses the thermomechanical processing of new-developed high-Mn high-Al TRIP steels with and without Nb microaddition. Special attention was paid to the effect of Nb on the hot-working behavior and multiphase microstructure formed at various cooling conditions of the thermomechanical treatment. The chemical composition of the investigated steels is given in Table 1. The chemical composition strategy was designed to obtain super high-strength bainite-based multiphase microstructures with retained austenite.

<table>
<thead>
<tr>
<th>Steel designation</th>
<th>C</th>
<th>Mn</th>
<th>Al</th>
<th>Si</th>
<th>Mo</th>
<th>Nb</th>
<th>S</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>5Mn-1.5Al</td>
<td>0.16</td>
<td>4.7</td>
<td>1.6</td>
<td>0.20</td>
<td>0.20</td>
<td>-</td>
<td>0.004</td>
<td>0.008</td>
</tr>
<tr>
<td>5Mn-1.5Al-Nb</td>
<td>0.17</td>
<td>5.0</td>
<td>1.5</td>
<td>0.21</td>
<td>0.20</td>
<td>0.03</td>
<td>0.005</td>
<td>0.008</td>
</tr>
</tbody>
</table>

The steels were produced by vacuum induction melting in the Balzers VSG-50 furnace. Liquid metal was cast in the Ar atmosphere into a cast iron mould. Ingots with a mass of about 25kg were forged at temperature range from 1200 to 900°C to a thickness of 22 mm. Then, cylindrical samples \( \varnothing 10 \times 12 \)mm for hot compression tests were prepared.

![Fig. 1. Schematic drawing of the thermomechanical processing](image-url)
Parameters of the thermomechanical processing are shown in Fig. 1. The experiments were carried out using the DSI Gleeble 3800 thermomechanical simulator. The specimens were inserted in a vacuum chamber, where they were resistance-heated to a temperature of 1200°C. After austenitizing for 30s the specimens were cooled to a temperature of first deformation. The thermomechanical processing consisted of four deformation steps (1150, 1050, 950, 850°C) and controlled cooling according to Fig. 1. The logarithmic strain value was equal to 0.25 at the strain rate of 10s\(^{-1}\) for each deformation step. Cooling times between successive deformation steps amounted to 12.5, 10 and 10s, respectively. The essential step of the thermomechanical treatment consisted in applying a various isothermal holding temperature of specimens in the bainite transformation range (\(T_B = 450, 400\) or 350°C). The holding time (\(t_B\)) was equal to 300s. Finally, the specimens were cooled with a rate of 0.5°C/s to room temperature.

Vickers hardness of thermomechanically processed samples was measured with 100N load. Microstructure observations of specimens etched in 10% aqueous solution of sodium metabisulfite at room temperature were carried out by the use of LEICA MEF4A optical microscope.

3. RESULTS AND DISCUSSION

New-developed steels show high hardenability even for air cooling conditions due to the high Mn content. Their microstructure consists of bainite and martensite lath packets containing interlath retained austenite. The thickness of the bainitic-martensitic laths in 5Mn-1.5Al-Nb steel (Fig. 2b) is smaller comparing to Nb-free steel (Fig. 2a). In both steels there are some regions of slightly different chemical composition than a bainite-martensite matrix. As the example, Fig. 2a shows a chaotic mixture of large bainitic ferrite laths located between B-M regions with a classical lath morphology. These bands contain probably a higher Mn content stabilizing an austenitic phase and hence lower \(M_s\) temperature. However, their martensite start is higher than room temperature what leads to martensitic transformation in a final stage of air-cooling from the hot-forging temperature. The final bainitic laths contain intra-lath martensite or martensite-austenite particles instead of cementite (Fig. 2a). The obtained microstructures are similar to degenerate lower bainite, i.e., a product of incomplete transformation of austenite. A more detailed analysis of the problem was carried out in [3, 13] using SEM and EDX. A number of the places with a different chemical composition in the Nb-microalloyed steel is much reduced and the bainitic-martensitic morphology is similar (Fig. 2b). A common feature of both steels is the presence of retained austenite in outer zones of the regions transformed into martensite.

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a) 5Mn-1.5Al  

b) 5Mn-1.5Al-Nb

**Fig. 2.** Lath-type bainitic-martensitic microstructures of the investigated steels in the initial state (after hot forging) containing retained austenite; a) 5Mn-1.5Al steel, b) 5Mn-1.5Al-Nb steel
Fig. 3. Influence of Nb microaddition on stress-strain curves obtained as a result of multi-step deformation

A result of the four-step compression at the temperature range between 1150 and 850°C are the stress-strain curves in Fig. 3. The values of flow stress increase significantly with decreasing deformation temperature. According to the results of softening kinetics [13] a fraction of recrystallized austenite between the last two compression steps should be lower than 35%. It is an additional reason of the growth of flow stresses up to 250-275 MPa at a final stage of hot-working. The flow stress values and a shape of curves are very similar to those obtained for 3Mn-1.5Al steels, hence the effect of Mn in a range from 3 to 5% is not essential. It appears on the basis of the curves that dynamic recovery is the process controlling work-hardening for the whole range of applied hot-working temperature. The flow stresses of Nb-microalloyed steel are initially slightly higher compared to Nb-free steel probably because of a solute drag effect of dissolved niobium. The difference increases with lowering the deformation temperature and reaches up to 30 MPa at 850°C (Fig. 3). It is probably related to the initiation of precipitation process of Nb(C,N) [12-14].

Table 2.
Hardness (HV10) of steels in the initial state and after the thermomechanical processing

<table>
<thead>
<tr>
<th>Steel grade</th>
<th>As cast state</th>
<th>After hot forging</th>
<th>Isothermal holding temperature, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>350</td>
</tr>
<tr>
<td>5Mn-1.5Al</td>
<td>398±31</td>
<td>461±33</td>
<td>489±27</td>
</tr>
<tr>
<td>5Mn-1.5Al-Nb</td>
<td>472±34</td>
<td>501±25</td>
<td>560±29</td>
</tr>
</tbody>
</table>

Thermomechanical processing does not change the phase composition of investigated steels compared to the initial state (Fig. 2) but results in a significant refinement of all the microstructural constituents (Fig. 4). A matrix of both steels consists of bainitic-martensitic laths containing interlath retained austenite. There is not apparent difference in the morphology of bainitic-martensitic regions (by the use of optical microscopy) dependent on the isothermal holding temperature of specimens in a bainite transformation range. However, the difference manifests by hardness results given in Table 2. The hardness decreases with increasing the holding temperature from 350 to 450°C. Nb-microalloyed steel is characterized by significantly higher hardness compared to Nb-free steel because of the complex effects of higher grain refinement, precipitation of Nb(C,N) and higher hardenability due to Nb dissolved in austenite.
Fig. 4. Bainitic-martensitic-austenitic microstructures after the thermomechanical processing with a various isothermal holding temperature of steels in a bainitic transformation range

A preliminary estimated fraction of retained austenite using X-ray is equal from 10 to 14%. However, a more detailed analysis is in progress. There is not a distinct effect of the holding temperature between 350 and 450°C on the fraction and morphology of γ phase. In both steels interlath retained austenite can be mainly observed (Fig. 4). Despite a high microstructure refinement some blocky grains transformed into martensite forming martensite-austenite aggregates with γ phase as a halo around martensite regions (Fig. 4f).
4. CONCLUSIONS

The thermomechanical processing of AHSS with increased Mn content is very challenging due to high flow stresses required, especially for the Nb-microalloyed steel. However, it is a very useful method to obtain fine-grained bainitic-martensitic microstructures containing interlath retained austenite. The steels containing 5% Mn are characterized by high hardenability which leads to the strong tendency to martensitic transformation of large blocky grains of γ phase. Isothermal holding of steel in a range from 350 to 450°C allows to obtain above 10 vol.% of retained austenite. The presence of a higher fraction of γ phase in 5Mn-1.5Al steels requires a further grain refinement what is a mechanical factor stabilizing retained austenite.

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LITERATURE


