MICROSTRUCTURE AND PROPERTIES OF REVERSION TREATED LOW-NI HIGH-MN AUSTENITIC STAINLESS STEELS

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Microstructure and properties of reversion treated low-Ni high-Mn austenitic stainless steels

Wetter auditorium (IT 115)
12:00
PRESENTATION OVERVIEW

• Introduction
• Experimental procedure
• Main results
• Summary
• Acknowledgements
AUSTENITIC STAINLESS STEELS

• Austenitic stainless steels have very good ductility and formability but their yield strength is quite low.

• There are various methods to improve the strength, e.g. solid solute strengthening, work hardening and grain refinement.

• Many austenitic steel grades are metastable at room temperature, during cold working formation of strain-induced martensite occurs readily increasing their strength.

• In a subsequent proper heat treatment martensite reverts back to austenite.

• As a result of this grain size refinement, excellent combinations of yield strength and elongation have been achieved to Types 304L, 316L, 301 and 301LN.
OBJECTIVES

• To study the details of the transformation of martensite and its reversion in order to characterize various microstructures achieved via reversion annealing.

• To achieve deep understanding on the relationships between processing and properties of austenitic Cr-Mn stainless steel.

• To reveal how the grain size distribution of the mixed reverted ultrafine-grained austenite and the coarse cold-worked austenite affects strain-induced martensite formation, strength and ductility during tensile testing.

• To establish the potential of microalloying to widen the processing window for the reversion heat treatment of the steel concerned.
**MATERIALS AND EQUIPMENT**

<table>
<thead>
<tr>
<th>Steel</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Ni</th>
<th>Cu</th>
<th>N</th>
<th>Nb</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>204Cu</td>
<td>0.079</td>
<td>0.40</td>
<td>9.00</td>
<td>15.2</td>
<td>1.1</td>
<td>1.68</td>
<td>0.115</td>
<td>0.05</td>
<td>bal.</td>
</tr>
<tr>
<td>0.05Nb</td>
<td>0.070</td>
<td>0.30</td>
<td>9.13</td>
<td>15.2</td>
<td>1.1</td>
<td>1.70</td>
<td>0.165</td>
<td>0.05</td>
<td>bal.</td>
</tr>
<tr>
<td>0.11Nb</td>
<td>0.072</td>
<td>0.28</td>
<td>9.18</td>
<td>15.2</td>
<td>1.1</td>
<td>1.74</td>
<td>0.130</td>
<td>0.11</td>
<td>bal.</td>
</tr>
<tr>
<td>0.28Nb</td>
<td>0.083</td>
<td>0.28</td>
<td>9.19</td>
<td>15.1</td>
<td>1.1</td>
<td>1.74</td>
<td>0.160</td>
<td>0.28</td>
<td>bal.</td>
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<td>0.45Nb</td>
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<td>8.90</td>
<td>15.2</td>
<td>1.1</td>
<td>1.70</td>
<td>0.160</td>
<td>0.45</td>
<td>bal.</td>
</tr>
</tbody>
</table>

Other studied austenitic stainless steels: 201, 201LN, 301, 301LN, test heat 1391L, test heat 1392L

Equipment:
Feritescope, XRD, LOM, SEM-EBSD, TEM, tensile testing, micro- and macro hardness
COLD DEFORMED STAGE

OM (a,c-e) and TEM (b) images after a,b) 5%, c) 12%, d) 20% and e) 60% cold rolling reduction (coded as CR) for the 0Nb steel.
DILATOMETRIC STUDY

a) Relative change in width ($\Delta W/W_0$) and b) its first derivate ($d(\Delta W/W_0)/dT$) as a function of heating temperature with the heating rates of 5 - 150 °C/s for the 0Nb steel.
The $\alpha'$-martensite fractions of the 0 - 0.45Nb steels after heating at 200 °C/s to 700 °C and holding for various durations.
MICROSTRUCTURE AFTER REVERSION TREATMENT

Inverse pole figure (a,d) and LOM (b,c,e,f) images after cold rolling and annealing at 700 °C for 0Nb (a-c), 0.11Nb (d,e) and 0.45Nb (f) for a,d) 10 s, b) 100 s and e,d,f) 1000 s.
MICROSTRUCTURE AND GRAIN SIZE

a) Image quality map and b) grain size distribution (taken from the coloured areas) of the 0Nb steel after annealing at 800 °C for 1000 s.
AUSTENITE GRAIN GROWTH

Inverse pole figure images for the 0Nb (a,d), 0.11Nb (b,e) and 0.45Nb (c,f) steels after annealing at a-c) 900 °C for 10 s and d-f) 1100 °C for 1000 s
Estimated driving ($F_d = 2y/D$) and pinning ($F_p = 3f^{(2/3)}y/(\pi r)$) forces for the 0.05, 0.11Nb, 0.28Nb and 0.45Nb steels after annealing at 1100 °C for a) 1 s and b) 1000 s.
α’-MARTENSITE CONTENTS

α’-martensite contents in different structures as a function of tensile strain for the 0Nb steel
DEFORMATION FEATURES FOR COARSE GRAINS

Formation of $\alpha'$-martensite at the intersection of shear bands.

Large amount of stacking faults.

$\gamma$ is shown in gray, $\varepsilon$-martensite in yellow, $\alpha'$-martensite in red.
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- **a)** 0.45Nb 700°C-100s
- **b)** 0.11Nb 800°C-1s
- **c)** 0.45Nb 1000°C-10s

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**Uniform elongation (%)**

- 800°C-10s
- 45Nb 0.11Nb
- 700°C-10s
- 0.11Nb, 0Nb

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**Yield strength [MPa]**

- 301 Rev. + RA [9]
- 301LN Rev. + RA; SR 0.003 s⁻¹ [9,10]
- 301LN Rex.; SR 0.003 s⁻¹ [9,10]
- 301LN Rex. [9,117]
- 301LN Rex.; SR 0.003 s⁻¹ [4]
- 301LN Rex.; SR 0.003 s⁻¹ [4]
- 304L Rex.; SR 5 mm/min [11]
- 304L Rex.; SR 1 mm/min [79]
- 201 Rev. + RA; SR 0.0005 s⁻¹ [118]
- 201 Rex.; SR 0.0005 s⁻¹ [118]
- 201L Rex.; SR 5 mm/min [113]
- Fe-17.5Cr-11.5Mn-0.25N
  - Rex.; SR 0.001 s⁻¹ [114]
- 0Nb 5-12% Temper-rolled;
  - SR 0.00075 s⁻¹ to 2% strain,
  - after which 0.005 s⁻¹ [88,119]
SUMMARY

• Various microstructures are achievable via reversion annealing.

• Reversion significantly refines the grain size. The structure consisting of reverted grains and partially recrystallized austenite possesses significantly enhanced strength with high uniform elongation. Nb alloying further increases the yield strength without reducing the uniform elongation.

• The nucleation sites of $\alpha'$-martensite vary with grain size. In ultrafine grains, it nucleates on the grain boundaries and mechanical twins. In coarser grains, $\alpha'$-martensite nucleates straight from austenite or via e-martensite at grain boundaries, shear bands and their intersections. In retained austenite, some deformation remains from the cold rolling so that further straining promotes martensite formation.

• 0.11 wt.% Nb alloying is sufficient to retard the grain coarsening at least up to 1000 s at 1000 °C, but annealing at the higher temperature of 1100 °C requires 0.28 wt.%. This grain growth behavior can be explained by the driving force predicted by Zener’s model and the pinning force predicted by the flexible boundary model.
Acknowledgements

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