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Room Temperature Plastic Flow Localization in a Mn-Alloyed Austenitic Steel

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Automotive Structural Steels (I)

desired properties of automotive steel structures:

- **Lower weight**
  - Lower fuel consumption
  - Lower pollution emission (Euro 4 – 5 …)
  - Increase useful load (commercial vehicle)
  - Lower cost

- **Increased safety**
  - Better crash energy absorption

- **Dent resistance** of automotive body components
Automotive Structural Steels (II)

- Current high-strength automotive steels:
  - HSLA (High Strength Low Alloy steel)
  - Dual Phase
  - TRIP (TRansformation Induced Plasticity)

- Recently proposed:
  - TWIP (TWinning Induced Plasticity)

  - High strength
  - High ductility
  - High energy absorption

Examined here: medium-C TWIP steel (CTWIP)
Automotive Structural Steels (III)

typical tensile curves

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Deep drawing

Localized deformation bands
Aesthetic defect

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Examined CTWIP steel

<table>
<thead>
<tr>
<th>steel</th>
<th>C</th>
<th>Mn</th>
<th>Ni</th>
<th>Si</th>
<th>Cr</th>
<th>P</th>
<th>S</th>
<th>V</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTWIP</td>
<td>0.48</td>
<td>23.5</td>
<td>0.05</td>
<td>0.16</td>
<td>0.13</td>
<td>0.025</td>
<td>&lt;0.001</td>
<td>0.22</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

*C*: increases YS and UTS  \n*Mn*: stabilizes austenite, decreases SFE (→ twinning)

average grain size = 2.5 µm
<table>
<thead>
<tr>
<th>Cross-head speed</th>
<th>Strain rate (mean)</th>
<th>Yield strength</th>
<th>Tensile strength</th>
<th>Uniform elongation</th>
<th>Strain hardening exponent</th>
<th>$\varepsilon_{PL}^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm/s</td>
<td>s$^{-1}$</td>
<td>MPa</td>
<td>MPa</td>
<td>%</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>0.06</td>
<td>0.0004</td>
<td>555</td>
<td>1180</td>
<td>65</td>
<td>0.35</td>
<td>0.2</td>
</tr>
<tr>
<td>0.5</td>
<td>0.004</td>
<td>540</td>
<td>1125</td>
<td>70</td>
<td>0.37</td>
<td>0.33</td>
</tr>
<tr>
<td>5</td>
<td>0.04</td>
<td>552</td>
<td>1100</td>
<td>72</td>
<td>0.37</td>
<td>0.52</td>
</tr>
<tr>
<td>40</td>
<td>0.4</td>
<td>557</td>
<td>1065</td>
<td>56</td>
<td>0.34</td>
<td>Not observed</td>
</tr>
</tbody>
</table>

$\varepsilon_{PL}$: strain at onset of Plastic Localization (PL)
Tensile Stress-Strain curves

Strain calculated from the cross-head displacement

Average strain rate (s^{-1})
- 0.0004
- 0.004
- 0.04
- 0.4

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Type I Plastic Localizations

Transit of a type I band through the gage length

Strain calculated from the gage displacement

polished spec.

TYPE I BAND

0.04 s\(^{-1}\)

850
900
950
1000
1050
1100
1150
1200
0.15 0.20 0.25 0.30 0.35 0.40 0.45

\(s\) [MPa]

\(\varepsilon\)
Type II Plastic Localizations

Crossed type II stationary bands

Strain calculated from the gage displacement

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Macroscopic Fracture Mode

0.0004 s$^{-1}$

0.004 s$^{-1}$

0.04 s$^{-1}$

0.4 s$^{-1}$
SEM analyses

Fracture surface (microvoids)

Plastic deformation relief on the previously polished specimen surface

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X-Ray Diffraction

aust. (111)

aust. (200)

aust. (220)

aust. (311)

aust. (222)

before tensile test

after tensile test

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Discussion - Portevin-Le Chatelier (PLC) Effect

- Plastic instabilities due to inhomogeneous plastic deformation
- occurring in limited strain-rate and temperature ranges
- due to a negative strain rate sensitivity
- in turn possibly due to Dynamic Strain Aging (DSA)

Known band types:
- **A**: propagate continuously along the tensile axis
- **B**: oscillatory / intermittent propagation
- **C**: appear suddenly and do not propagate
Conclusions

- The CTWIP steel exhibit a favorable combination of strength and ductility.
- It also exhibit PLC effect at R.T. for strain rates less than 0.4 s\(^{-1}\).
- Both type A and C (I and II herein) bands were observed.
- This may arise from interactions between solute C atoms and mobile dislocations, yielding a negative strain rate sensitivity.