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

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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*

![Diagram showing tensile curves for TRIP, CTWIP, and FeP05](image)
Deep drawing

Localized deformation bands

Aesthetic defect
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  
**Mn**: stabilizes austenite, decreases SFE (→ twinning)

Average grain size = 2.5 µm

Fe-Mn-C, 600°C
# Tensile test results

<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>ε_{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>

ε_{PL}^* : strain at onset of Plastic Localization (PL)

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Tensile Stress-Strain curves

Strain calculated from the cross-head displacement

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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

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Type II Plastic Localizations

Strain calculated from the gage displacement

crossed type II stationary bands

Strain rate (s⁻¹)

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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