Forming of TRIP and TWIP High-manganese Steels
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Outline

• Motivation

• Material Characterization
  – Processing of compression tests
  – Results of compression tests

• Material Production

• Conclusion
Motivation

Field of research: Hot and cold forming of ternary Fe-Mn-C HMS

Goals: Production of hot and cold rolled HMS sheets in laboratory scale and numerical simulation of the forming process

Needed: Flow curves in dependence of strain, strain rate, temperature and chemical composition

→ → → Investigation of the Influence of
  • Carbon content
  • Manganese content
  • Strain rate
  • Temperature

Method: Characterization of ternary Fe-Mn-C steels by compression tests
• Motivation

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Material within the SFB 761

- 8 compositions of Fe-Mn-C steels are planned
- Cast in a vacuum induction facility at Institute of Ferrous Metallurgy, RWTH Aachen
- Batches weighting approx. 70-100 kg
- Here 3 compositions are investigated:
  - I: Mn22C0.3 “TRIP”
  - II: Mn22C0.6 “TWIP”
  - III: Mn28C0.3 “TWIP”

OES analysis of tested materials (cast state)
OES performed at Institute of metallurgy and metal recycling, RWTH Aachen

<table>
<thead>
<tr>
<th>Composition</th>
<th>Fe</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Al</th>
<th>Cu</th>
<th>Co</th>
<th>Nb</th>
<th>V</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mn22C0.3, I (V16)</td>
<td>Bal.</td>
<td>0.34</td>
<td>22.65</td>
<td>0.14</td>
<td>0.01</td>
<td>0.00</td>
<td>0.30</td>
<td>0.01</td>
<td>0.05</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
<td></td>
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<tr>
<td>Mn22C0.6, II (V15)</td>
<td>Bal.</td>
<td>0.57</td>
<td>23.21</td>
<td>0.17</td>
<td>0.01</td>
<td>0.00</td>
<td>0.31</td>
<td>0.02</td>
<td>0.04</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Mn28C0.3 III (V19)</td>
<td>Bal.</td>
<td>0.28</td>
<td>28.12</td>
<td>0.10</td>
<td>0.01</td>
<td>0.00</td>
<td>0.02</td>
<td>0.04</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.020</td>
<td>0.02</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Diagram of steel compositions within SFB 761
SFE calculated by Saeed-Akbari, Institute of Ferrous Metallurgy, RWTH Aachen

Material characterization – processing of compression tests

Input: Cast blocks (140*140 mm² cross section)

Forging of cast blocks in 4 steps to 20 mm height
(initial temperature 1150°)

Annealing (1150°C for 5 hours)

Cutting into cylindrical Rastegaev samples
(height: 15 mm, diameter: 10 mm)

Processing: Isothermal compression tests
- Rastegaev cylinders with lubrication
- Temperatures (RT and 300 to 1200°C)
- Constant strain rates (0.1, 1 and 10 1/s)
- Computer controlled 1200-kN servohydraulic testing system, SERVOTEST LTD

Calculation of stress ($k_f$) and strain

Hot and Cold Forming
Assumptions and calculation

- Upsetting test in enclosed oven is adiabatic
- Totally in the specimen brought energy density corresponds to the surface below the flow curve
- Results in rise of temperature:
  \[ \Delta T_{total} = \frac{\int \sigma \, d\varphi}{\rho \cdot C_p} \cdot D \]
- Temperature dependent \( \rho \) and \( C_p^* \), \( D=0.9 \)
  \[ \Delta T_{HT} = \frac{2 \cdot \alpha}{\rho \cdot C_p \cdot h} \cdot (T_{t-1} - T_{die}) \cdot \Delta t \]
- \( \alpha \) T-dependent (\( \alpha \) by inverse modelling)
- Calculation of temperature of flow state
  \[ \Delta T = \Delta T_{total} - \Delta T_{HT} \]
- Flow curve (T-compensated) calculation by regression and interpolation

Examples for T-compensation of Fe-Mn22-C0.6

*\( \rho \) and \( C_p \) from TCFE4
Carbon content leads to different strain hardening behaviour.

Increasing manganese content reduces maximum strength.

With increasing strain rate flow stress slope is reduced.

Reference material: AISI 304, (1.4301, X5CrNi18-10), isothermal compression tests on cold drawn steel material.
Material characterization – results of compression tests at 300°C

Reference material: AISI 304, (1.4301, X5CrNi18-10), isothermal compression tests on cold drawn steel material

Increasing carbon content leads to higher maximum strength
Increasing manganese content reduces maximum strength
No influence of strain rate
Maximum flow stress 2 times of AISI304
Material characterization – results of compression tests at 500°C

Increasing carbon content leads to higher maximum strength.
Increasing manganese content reduces maximum strength.
With increasing strain rate flow stress slope is increased.

Reference material: AISI 304, (1.4301, X5CrNi18-10), isothermal compression tests on cold drawn steel material.
Material characterization – results of compression tests at 700°C

Carbon content shows small influence, increasing manganese content increases flow stresses. With increasing strain rate flow stress slope is reduced. Maximum flow stresses are in the same order of AISI304.
Material characterization – results of compression tests at 900°C

Carbon content shows small influence, increasing manganese content increases flow stresses.
Flow stresses of AISI are in the same order as those of HMS.

Reference material: AISI 304, (1.4301, X5CrNi18-10), isothermal compression tests on cold drawn steel material
Material characterization – results of compression tests at 1100°C

Carbon and manganese content show small influence
Flow stresses of AISI are higher than those of HMS

Reference material: AISI 304, (1.4301, X5CrNi18-10), isothermal compression tests on cold drawn steel material

Hot and Cold Forming
Material characterization – results of compression tests at 1200°C

Carbon and manganese content show small influence
Flow stresses of AISI are higher than those of HMS
Flow stress of HMS 4 to 6 times smaller than at 700°C

Reference material: AISI 304, (1.4301, X5CrNi18-10), isothermal compression tests on cold drawn steel material
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Material Production

Process Chain of Material Production

- Vacuum melting B1 (IEHK)
- Forging and annealing B2 (IBF)
- Hot and cold rolling B2 (IBF)

Casting: 140*140 mm² cross section and up to 100 kg weight

FG: 3 passes (1150°C) to 55 mm height, AN: 1150°C 5 hours

HR: 12 passes (1150°C) to <3 mm height
CR: up to 80% reduction

Problems encountered

- Inhomogeneities in the Mn (8%) and C (0.3%) content in the micro scale (cast state)
  Solution: Process chain developed, reducing segregations to Mn: 2% and C: 0.05%*

- Strong oxidation during heating and annealing caused enrolled scale
  Solution in the laboratory process chain: high pressure water jet

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Conclusions: Results

Material Characterization of Fe-Mn22-C0.3, Fe-Mn22-C0.6 and Fe-Mn28-C0.3 HMS:

- At smaller temperatures (RT to 600°C):
  - Higher carbon content (0.6 to 0.3) leads to higher stresses
  - Higher manganese (28 to 22) content reduces maximum flow stresses
- At middle temperatures (700 to 900°C):
  - Flow behaviour is comparable to steel AISI 304 (1.4301)
  - Higher manganese content increases maximum flow stresses
  - Influence of carbon content becomes smaller, but increases flow stress
- At higher temperatures (1000 to 1200°C):
  - Carbon content has negligible influence on flow curves
  - Higher manganese content has small but increasing influence on flow stresses
  - Flow stresses are lower than those of steel AISI 304

Material Production:

**Homogenization:** Forging (1150°C), annealing (1150°C / 5 h) and hot rolling (1150°C) reduces micro segregations: Mn: 8 to 2.2%, C: 0.3 to 0.05%

**Process chain** applied for 8 Fe-Mn-C HMS, CR up to 80% without cracking
Acknowledgement

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Thank You for Your attention