Mechanical Properties of Ferritic Stainless Steels at Elevated Temperature
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**Ferritic Stainless Steels**

- Low-cost, price stable, corrosion resistant steels
- Immune for stress corrosion cracking
- Widely used for household appliances, kitchenware, architecture (facades) and automotive exhaust systems
- Structural applications in the construction industry scarce
The Family Tree of Ferritic Grades

- **EN 1.4016**
  - ASTM 430
- **EN 1.4003**
  - ASTM S40977
- **EN 1.4512**
  - AISI 430Ti
- **EN 1.4510**
  - AISI 430Ti
- **EN 1.4511**
  - ASTM 430
- **EN 1.4512**
  - ASTM 409
- **EN 1.4513**
  - ASTM 434
- **EN 1.4511**
  - ASTM 434
- **EN 1.4521**
  - ASTM 444
- **EN 1.4592**
  - AISI 447

Corrosion resistance: ~11% Cr / ~16% Cr / ~17% / ~18% Cr / ~17% / ~20% Cr / ~30% Cr

Design guidance in the Eurocode
Fire Safety Design of Stainless Steel

• Past work on stainless steel focused on austenitic and duplex grades

• Only the low alloyed structural steel 1.4003 currently included in EN 1993-1-2

• Behaviour of medium and high chromium grades at fire temperature largely unknown
Purpose of the Present Work

- Derive the strength retention factors for ferritic stainless steel grades 1.4016, 1.4509, 1.4521 and 1.4621 in the temperature range between +20°C and +1000°C
- Medium and high chromium grades with corrosion properties comparable to standard austenitic grades
- Using material from at least two producers; cold-rolled material in annealed condition (2B)
Experimental Test Programme

• Steady state tests
  • 1.4003, 1.4016, 1.4509, 1.4521 and 1.4621
  • Between 20°C and 1000°C
  • 1.4003 included as a reference material

• Transient state tests on two grades 1.4509 and 1.4521
  • 16 load levels between 10% and 90% of yield stress
  • Heating rate of 10°C/min
## Materials

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<th>Grade</th>
<th>Supplier</th>
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KFF = Ferrite Factor

**Stabilized grades. Precipitates formed by Ti and Nb improve creep properties and increase strength at elevated temperature**
### Materials

<table>
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<tr>
<th>Grade</th>
<th>Identifier</th>
<th>Thickness (mm)</th>
<th>Rp0,01 (N/mm²)</th>
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Considerable overstrength compared to minimum values in the material standard.
Test Equipment

- **Zwick 250 kN tensile testing machine**
- **Environmental chamber for temperatures up to 550°C**
- **High temperature furnace**
Side-entry Extensometer with Ceramic Sensor Arms & Specimen
Steady State Results for 1.4016

- Strength remains constant $200^\circ C \leq T \leq 500^\circ C$ due to dynamic strain aging.
- Steady state creep deformation at $T \geq 600^\circ C$. Associated with a rapid decrease of strength.
Steady State Results for 1.4509

- Dynamic strain aging almost negligible
- Steady state creep at $T \geq 750^\circ C$. Associated with a rapid decrease of strength
Reduction of Strength

Unstabilized Steel
1.4016

Stabilized Steel
1.4509

Steady State Creep

Steady State Creep
Reduction Factors for 0.2% Proof Stress

Unstabilized Grades
Reduction Factor for Ultimate Strength

Unstabilized Grades

Temperature [°C]

$k_{u,\theta}$
Degradation of Elastic Modulus

Present work

Values published by steel producers

Steady State Creep
Transient Test Results

![Graph showing strain vs. temperature for different percentages.](image-url)
Degradation of Strength

Yield strength diving at 800°C
Steady state vs. Transient

0.2% Proof Stress

Ultimate Tensile Strength
Proposal: All Unstabilized Grades
Proposal: All Stabilized Grades
Proposal: k2%, θ for All Grades

Stabilized

Unstabilized
Summary

• Mechanical properties of various ferritic stainless steels investigated at temperatures up to 1000°C.

• The studied steels could be divided in two groups based on their behaviour at elevated temperature.

  I. Unstabilized Grades  
  1.4003, 1.4016

  II. Stabilized Grades  
  1.4509, 1.4521, 1.4621

• Strength reduction factors were derived for both groups
• Stabilized grades perform better under fire conditions
Thank You!

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