Mechanical Properties of Ferritic Stainless Steels at Elevated Temperature

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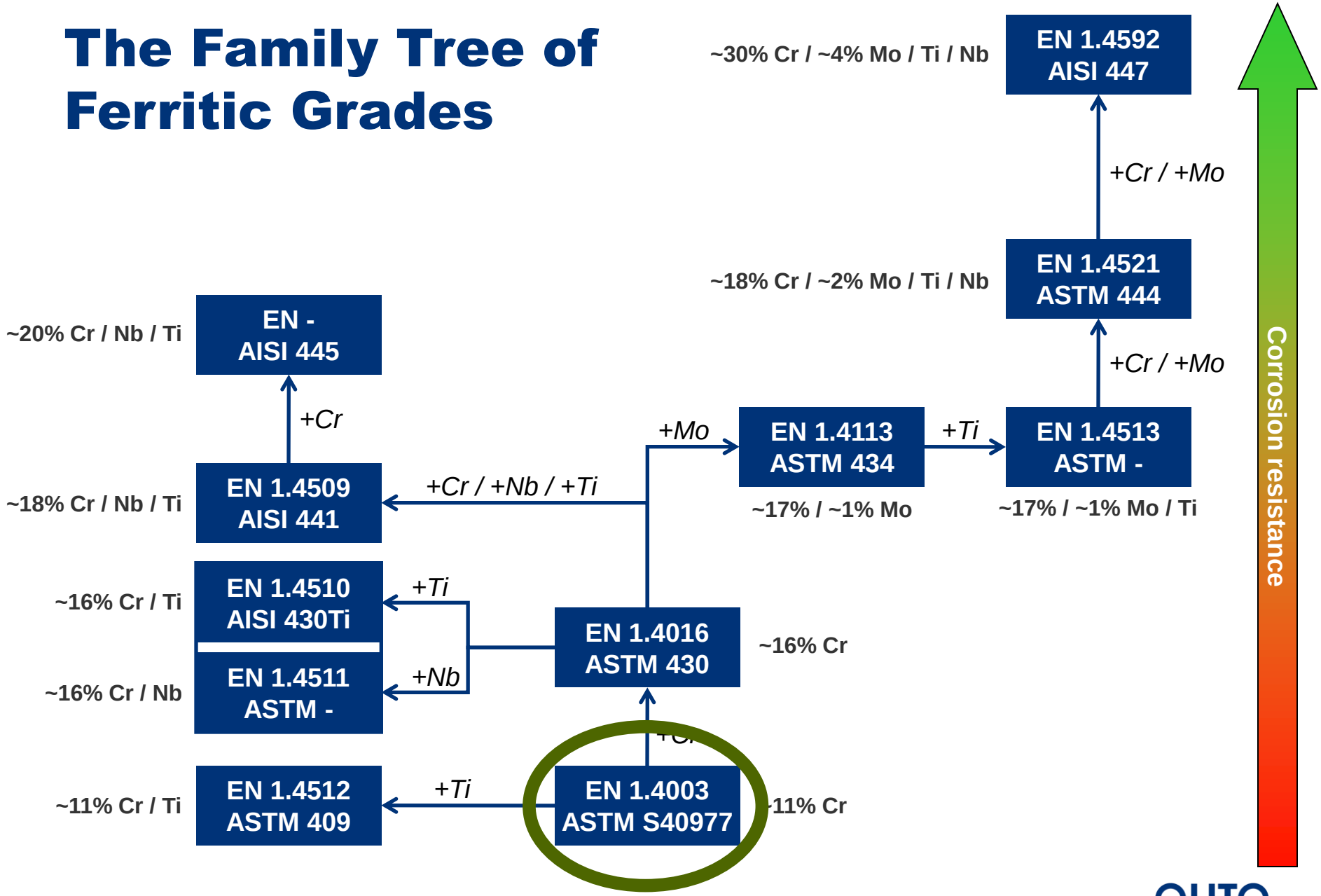
Contents

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



Design guidance in the Eurocode

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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)

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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

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Materials

Grade	Supplier	Type	Identifier	C	Si	Mn	Cr	Ni	Mo	Ti	Nb	Cu	Al	N	KFF
1.4003	B	2B	4003-1	0.015	0.26	1.45	11.4	0.4	0.0	0.00	0.01	0.1	0.00	0.013	7.4
1.4016	A	2B	4016-1	0.023	0.36	0.46	16.3	0.2	0.0	0.01	0.01	0.1	0.01	0.028	14.8
1.4016	B	2B	4016-2	0.046	0.30	0.48	16.1	0.2	0.2	0.00	0.02	0.1	0.00	0.027	14.1
1.4509	A	2B	4509-1	0.017	0.55	0.45	17.8	0.2	0.0	0.14	0.49	0.0	0.05	0.018	19.3
1.4509	B	2B	4509-2	0.020	0.55	0.48	17.9	0.3	0.0	0.12	0.40	0.1	0.01	0.030	18.4
1.4521	A	2B	4521-1	0.011	0.48	0.44	17.7	0.3	2.0	0.17	0.43	0.1	0.00	0.016	26.6
1.4521	B	2B	4521-2	0.015	0.52	0.49	18.0	0.1	2.0	0.13	0.40	0.2	0.01	0.019	27.3
1.4521	B	2B	4521-3	0.012	0.48	0.49	17.9	0.2	2.0	0.13	0.39	0.2	0.01	0.023	27.0
1.4621	C	2R	4621-1	0.014	0.21	0.23	20.6	0.2	0.0	0.01	0.45	0.4	0.00	0.014	19.7

KFF = Ferrite Factor

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

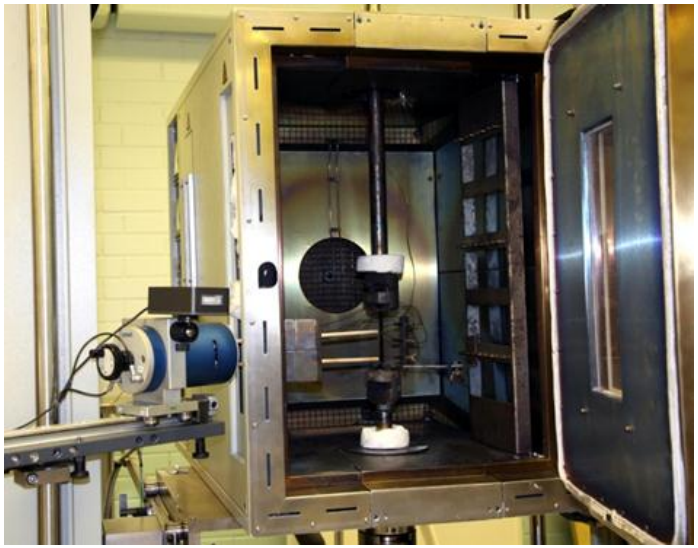
Materials

Grade	Identifier	Thickness (mm)	Rp0,01 (N/mm²)	Rp0,1 N/mm²	Rp0,2 N/mm²	Rp1,0 N/mm²	Rt2,0 N/mm²	Rm N/mm²	Ag %	A80 %	A5 %
1.4003	4003-1	2.0	234	318	330	357	380	493	16.2	31.3	50.7
1.4016	4016-1	2.0	237	299	311	338	358	478	16.8	26.0	38.0
1.4016	4016-2	2.0	237	305	315	333	349	458	17.4	33.3	53.3
1.4509	4509-1	2.0	250	321	331	353	369	479	17.6	29.0	43.0
1.4509	4509-2	2.0	287	358	367	384	398	488	15.9	33.0	54.3
1.4521	4521-1	2.0	291	367	375	396	416	542	16.2	29.3	44.7
1.4521	4521-2	2.0	309	382	394	419	438	564	15.6	27.7	43.7
1.4521	4521-3	2.0	337	379	391	411	410	532	17.3	28.4	41.9
1.4621	4521-1	1.5	279	351	359	373	406	469	15.9	32.0	56.0

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

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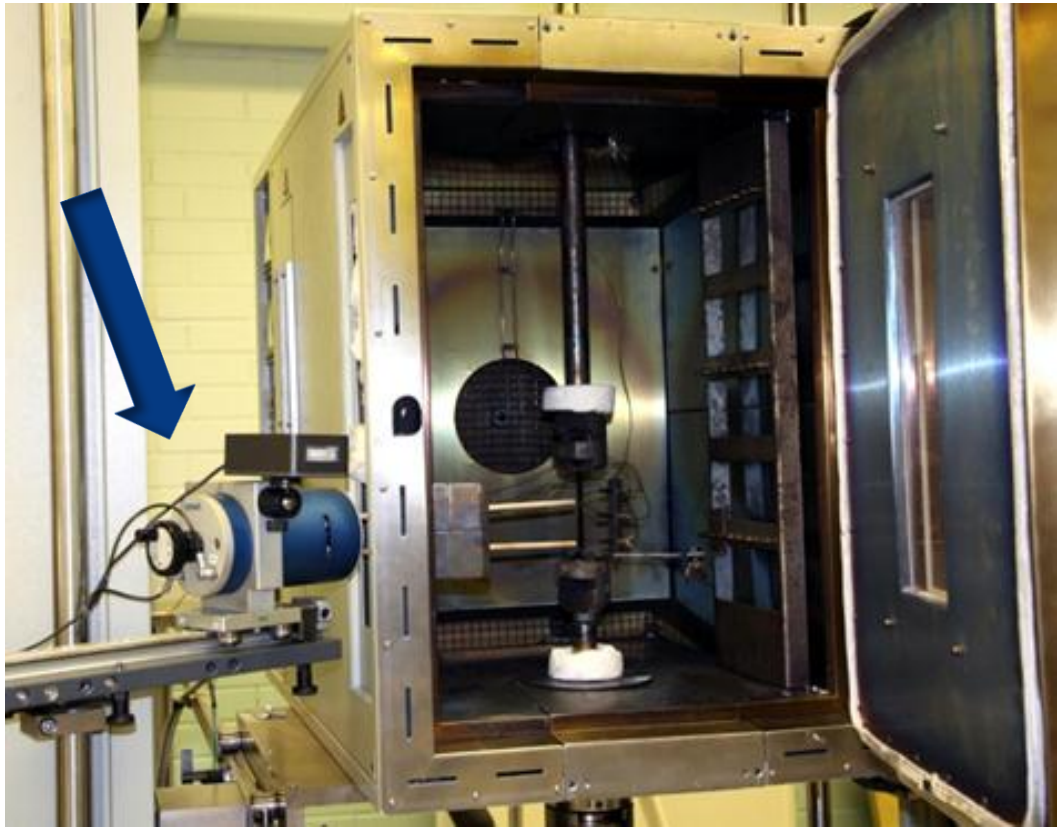
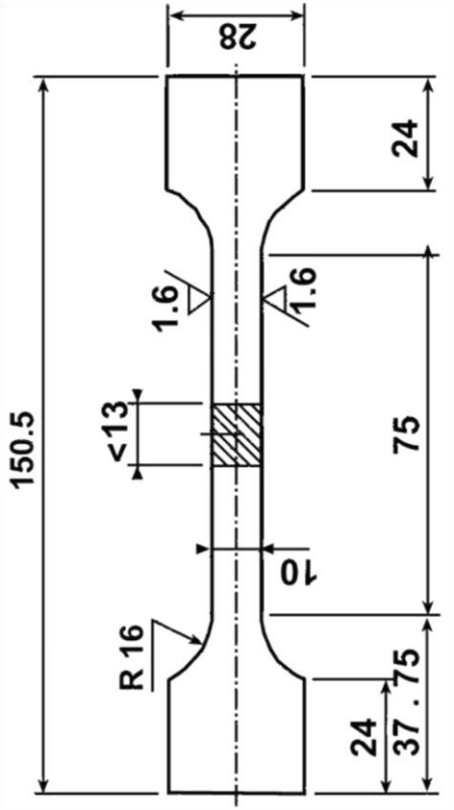
Side-entry Extensometer with Ceramic Sensor Arms & Specimen





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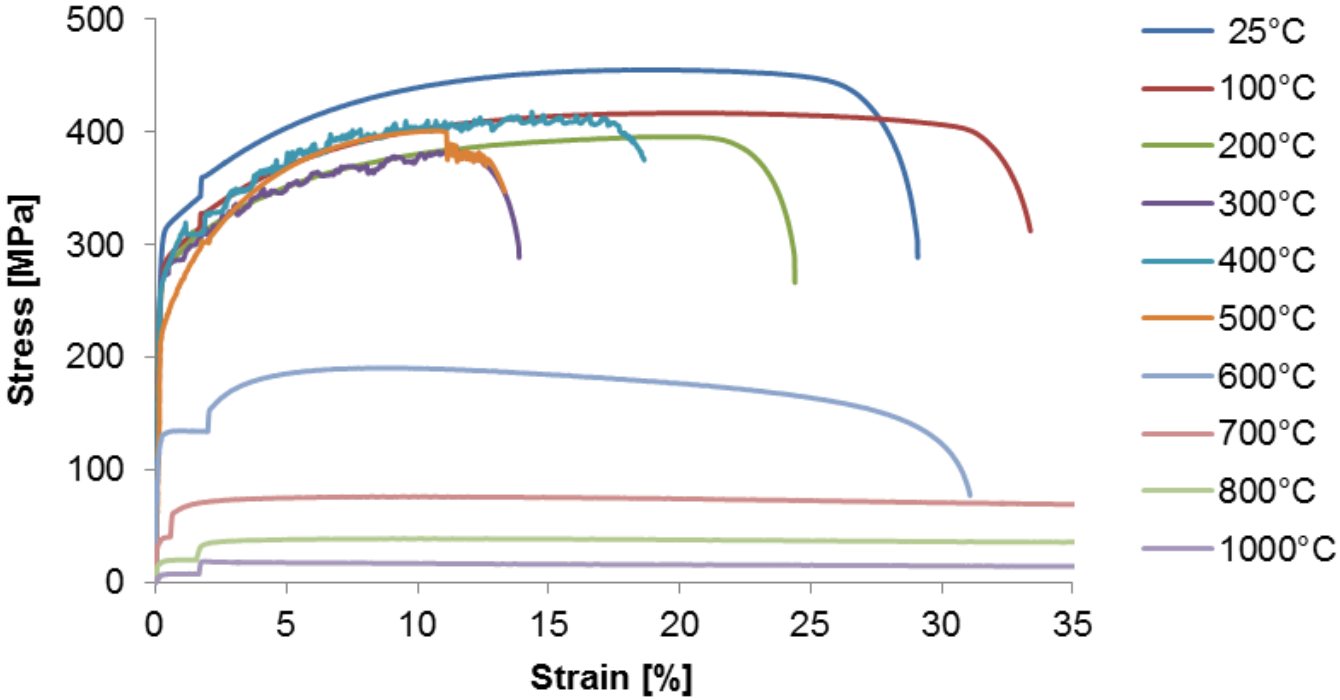
Steady State Results for 1.4016



- Strength remains constant 200°C ≤ T ≤ 500°C due to dynamic strain aging
- Steady state creep deformation at T ≥ 600°C. Associated with a rapid decrease of strength

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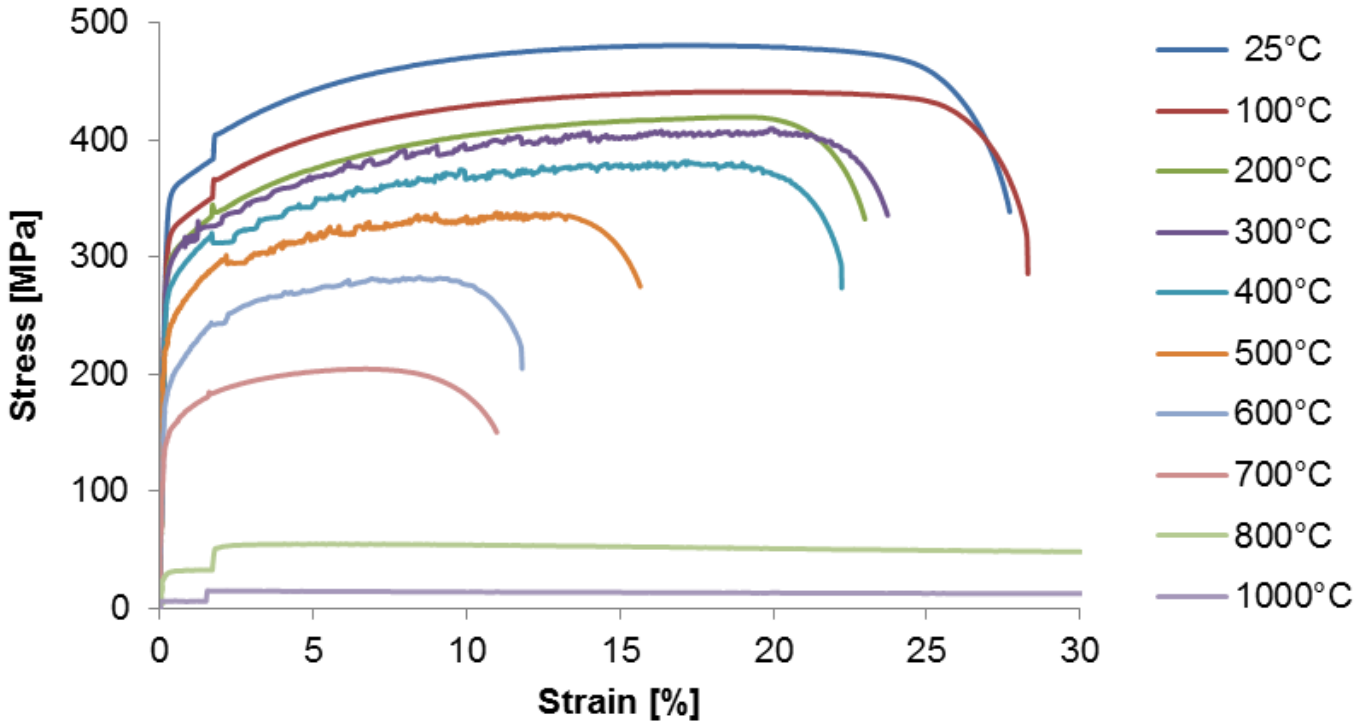
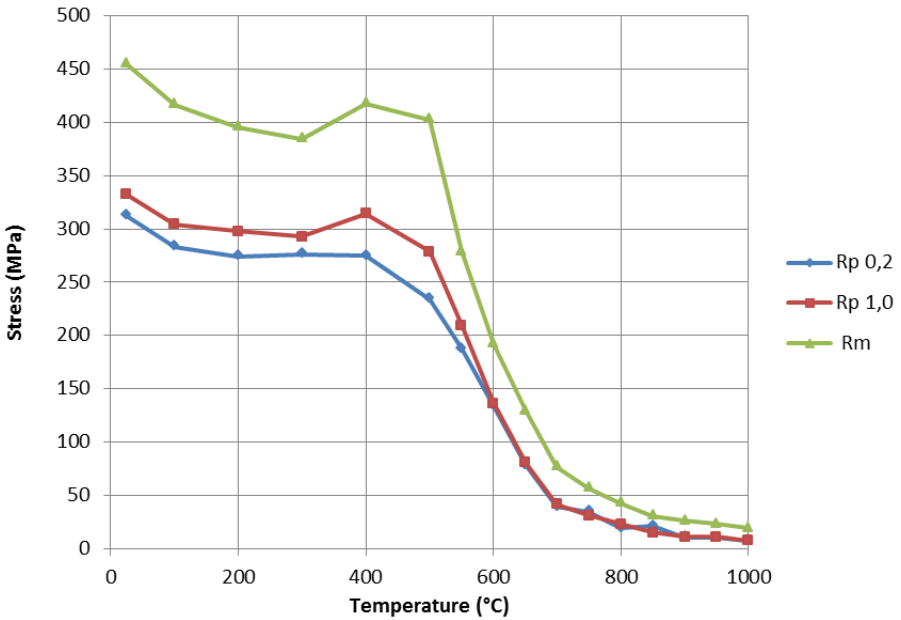
Steady State Results for 1.4509



- Dynamic strain aging almost negligible
- Steady state creep at T ≥ 750°C.
  Associated with a rapid decrease of strength

Reduction of Strength

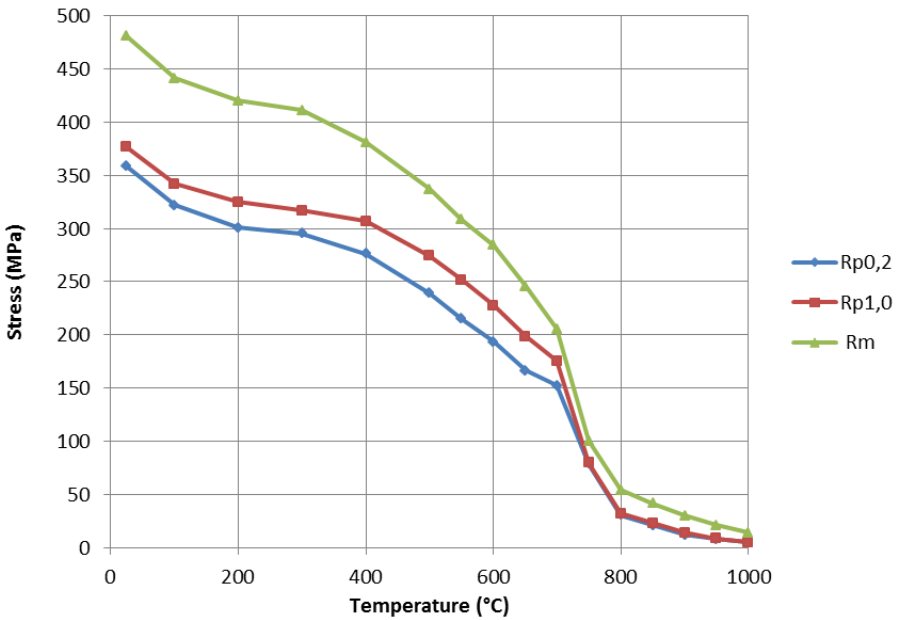
Unstabilized Steel 1.4016



DSA

Steady State Creep

Stabilized Steel 1.4509



Steady State Creep

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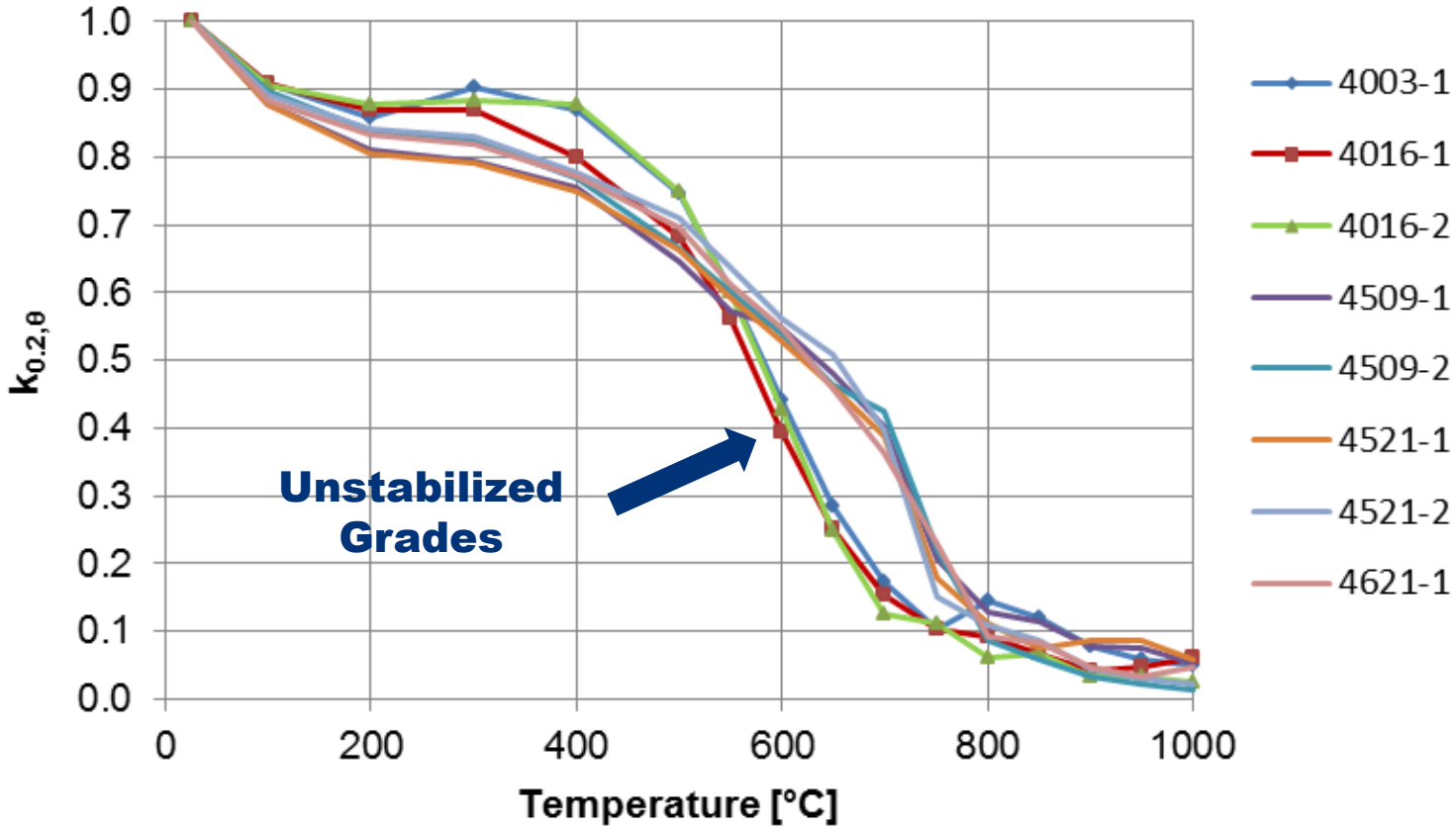
Reduction Factors for 0.2% Proof Stress



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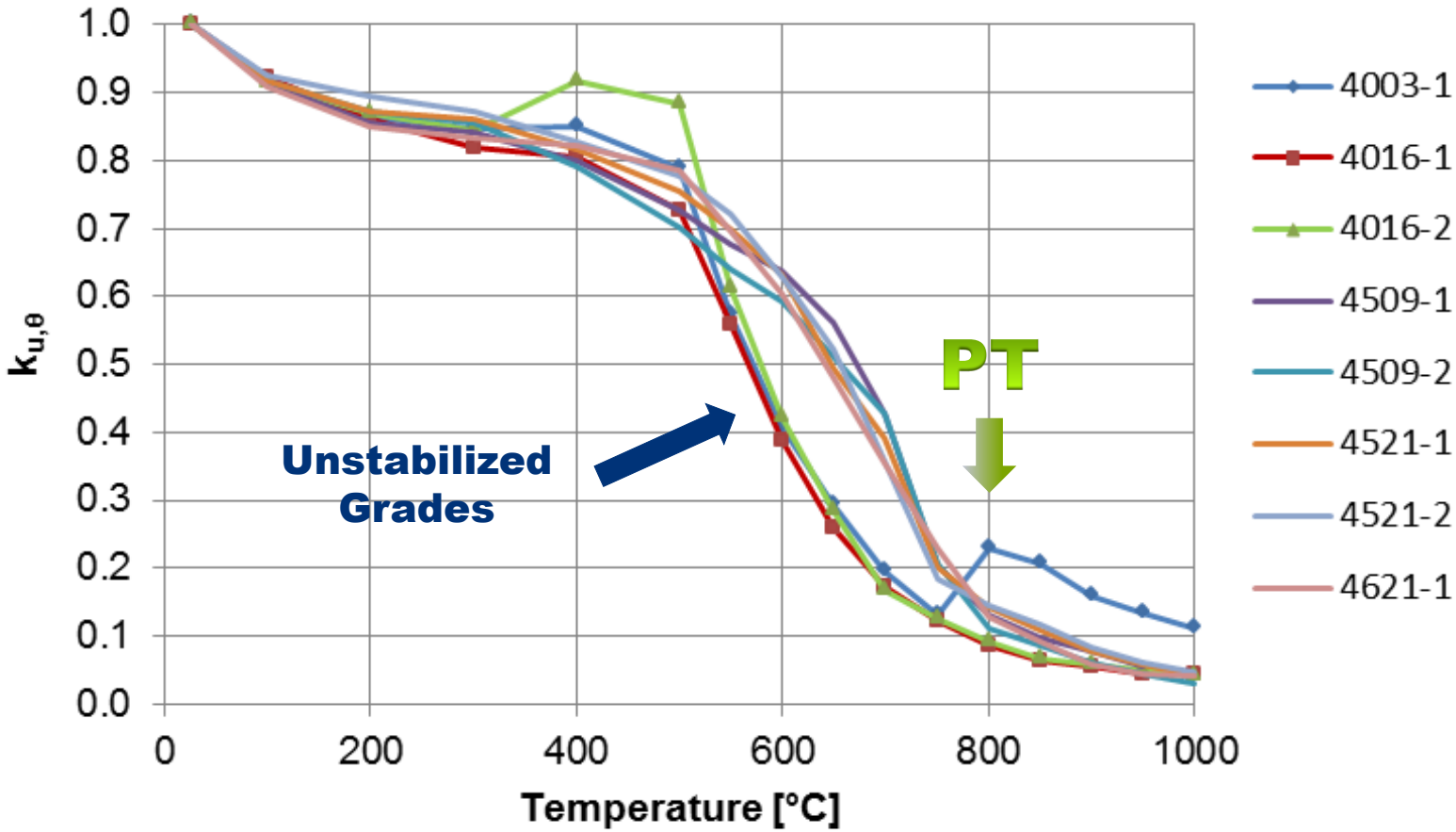
Reduction Factor for Ultimate Strength



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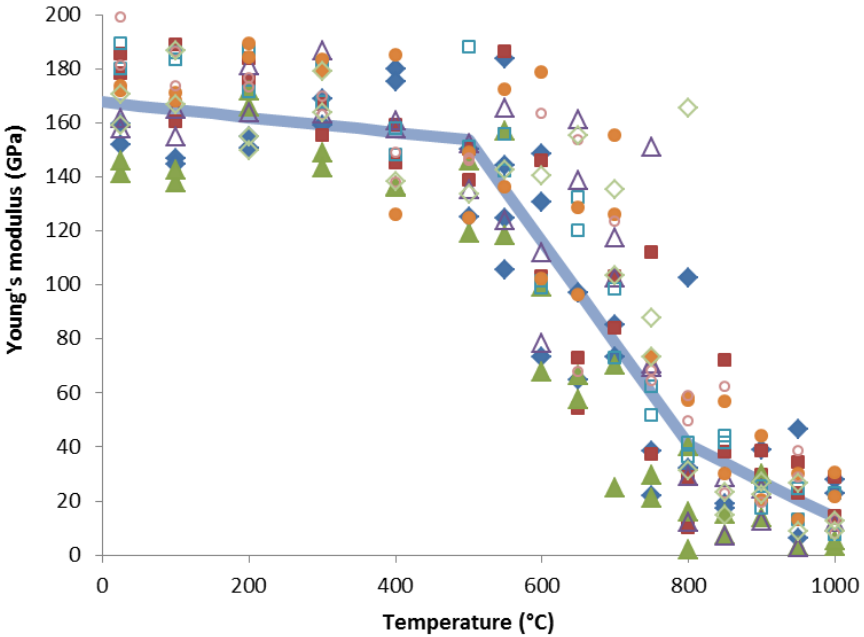
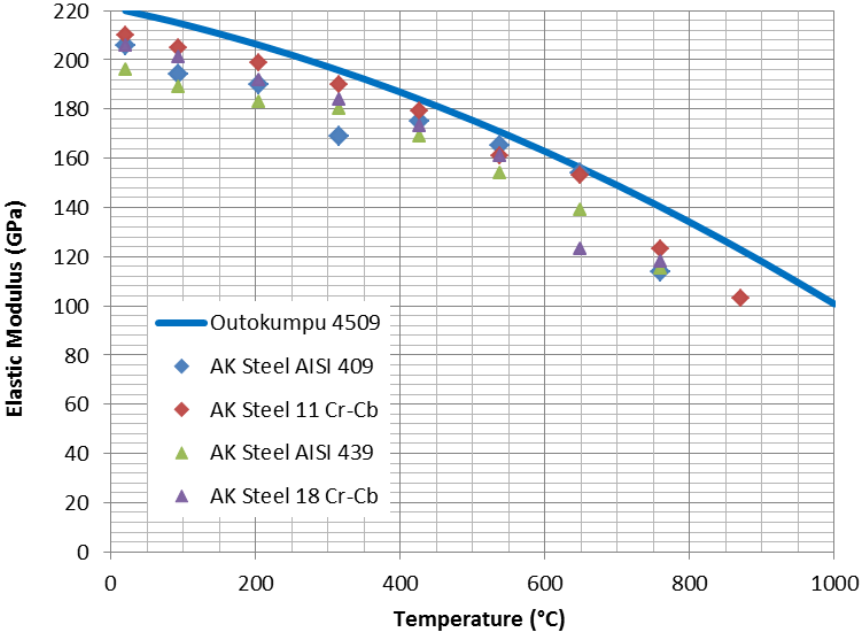
Degradation of Elastic Modulus

Present work



Steady State Creep

Values published by steel producers



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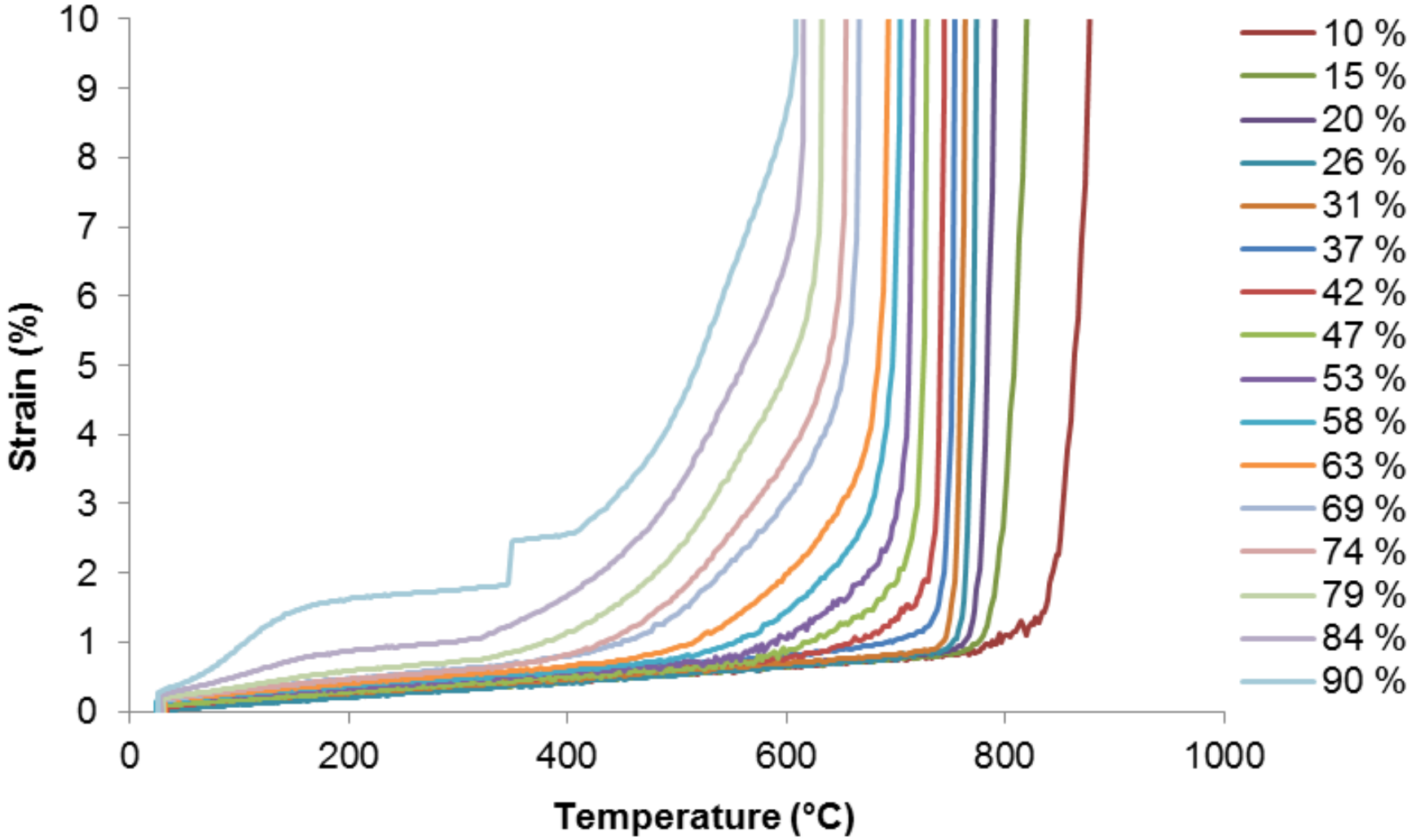
Transient Test Results



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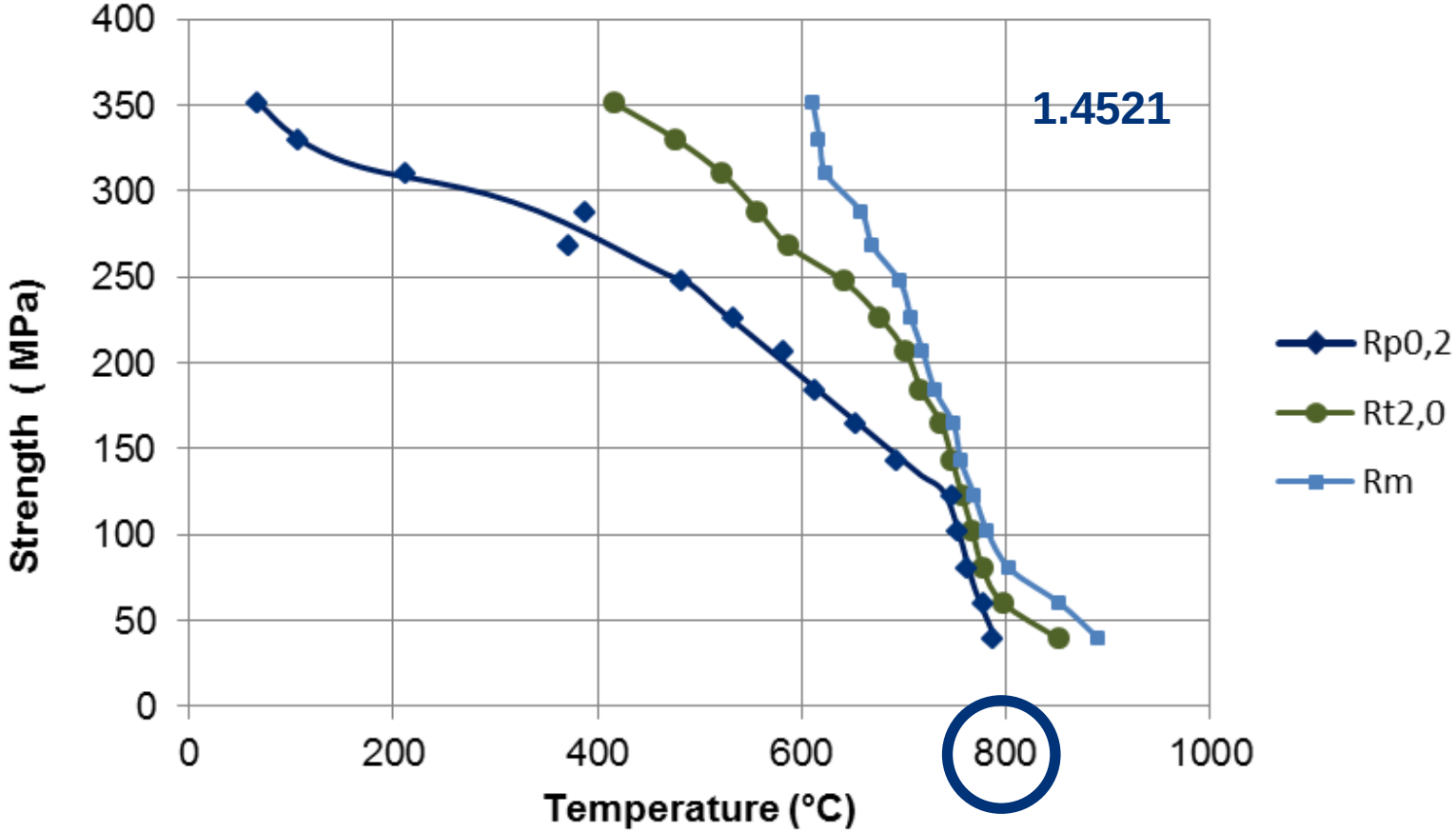
Degradation of Strength



Yield strength diving at 800°C

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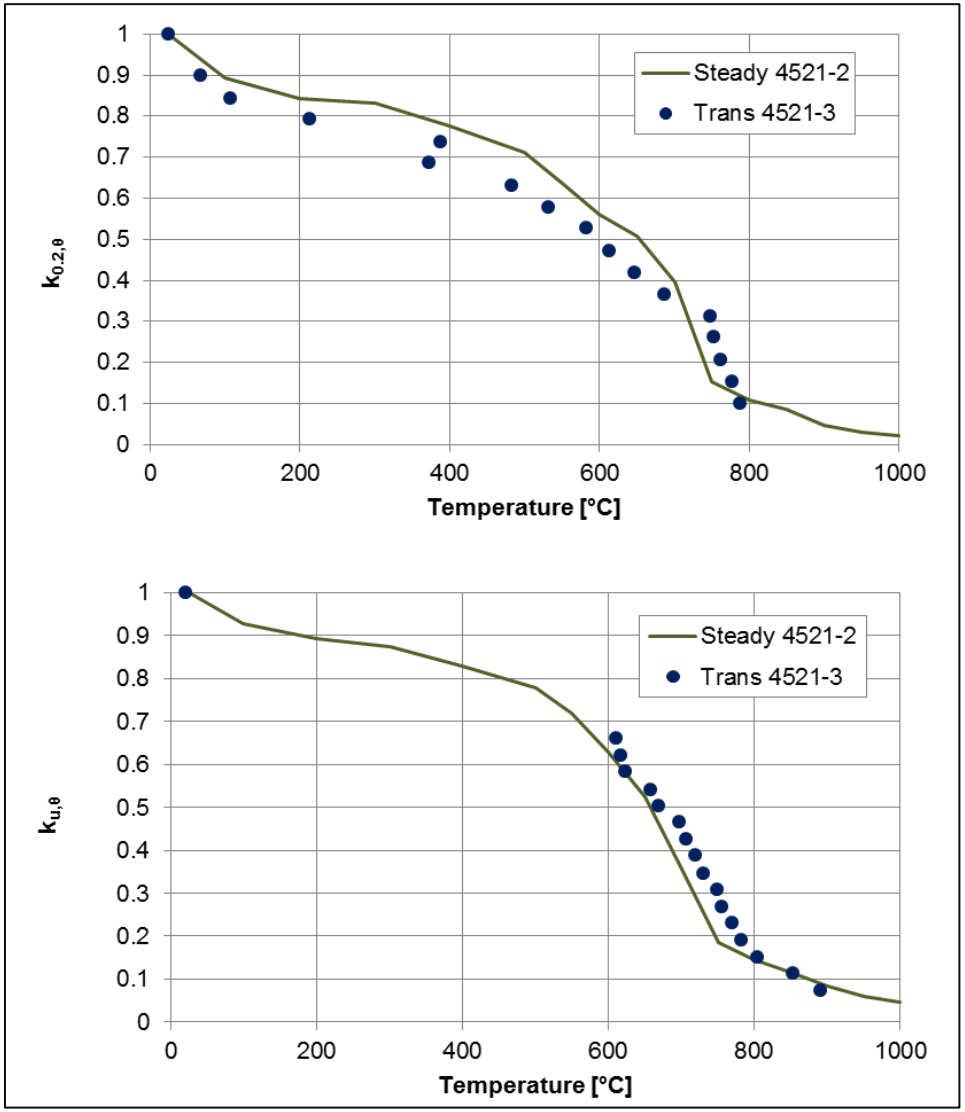
Steady state vs. Transient



0.2% Proof Stress

Ultimate Tensile Strength

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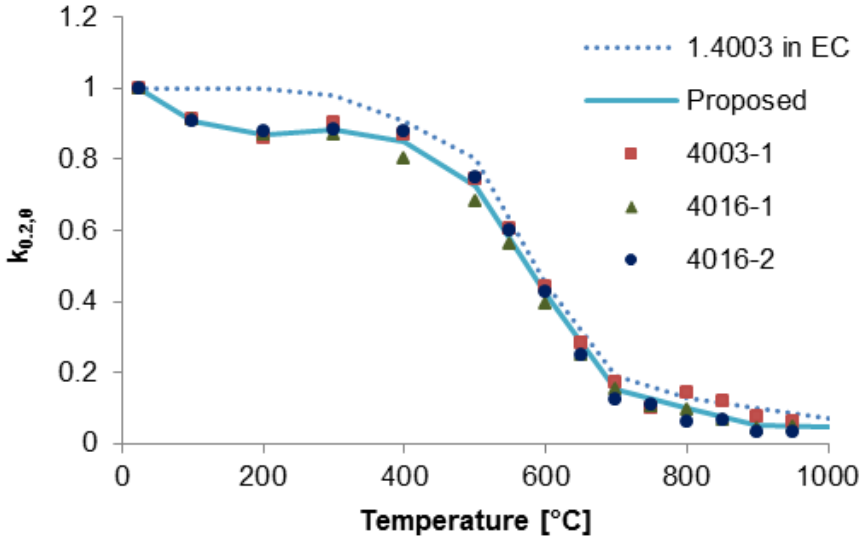
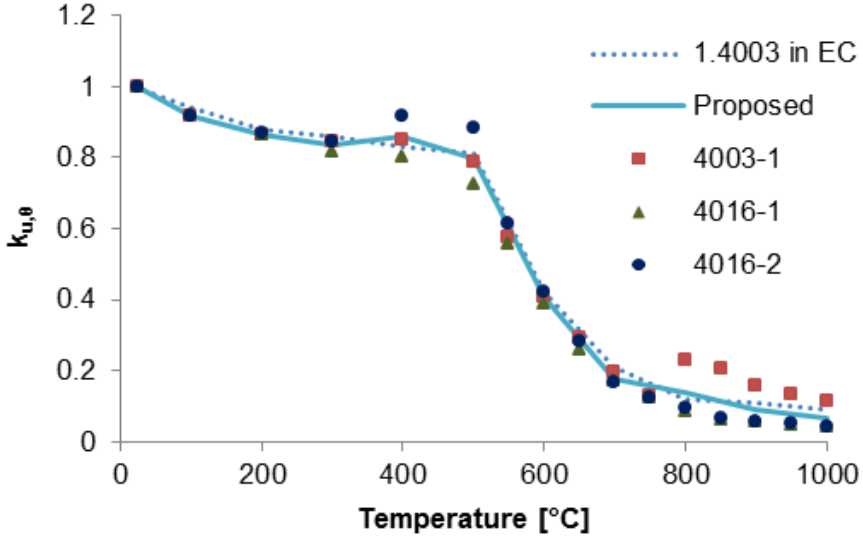
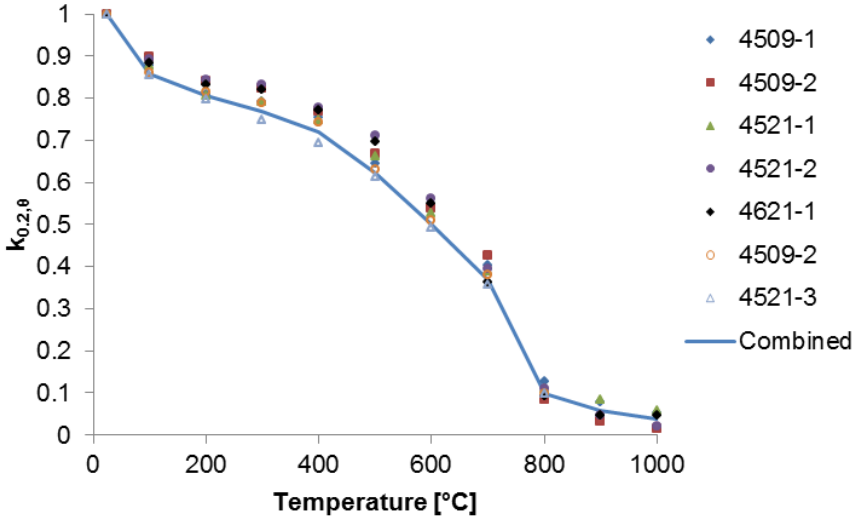
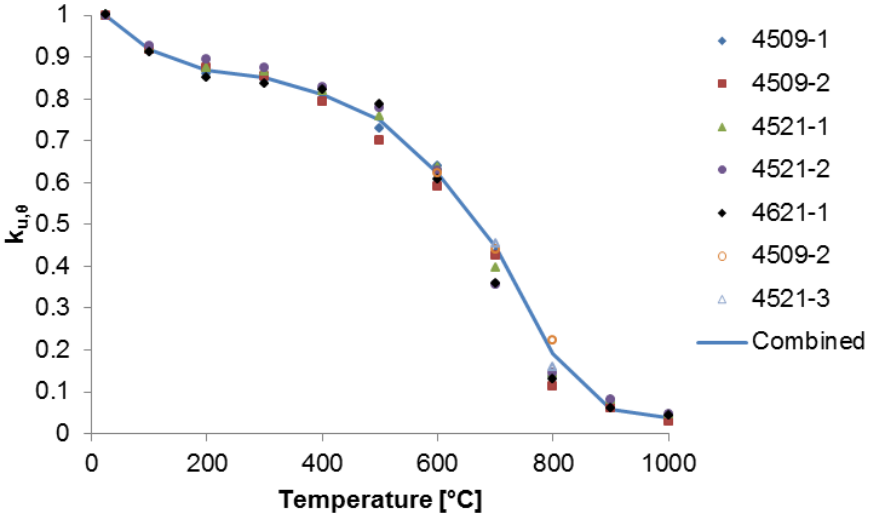
Proposal: All Unstabilized Grades





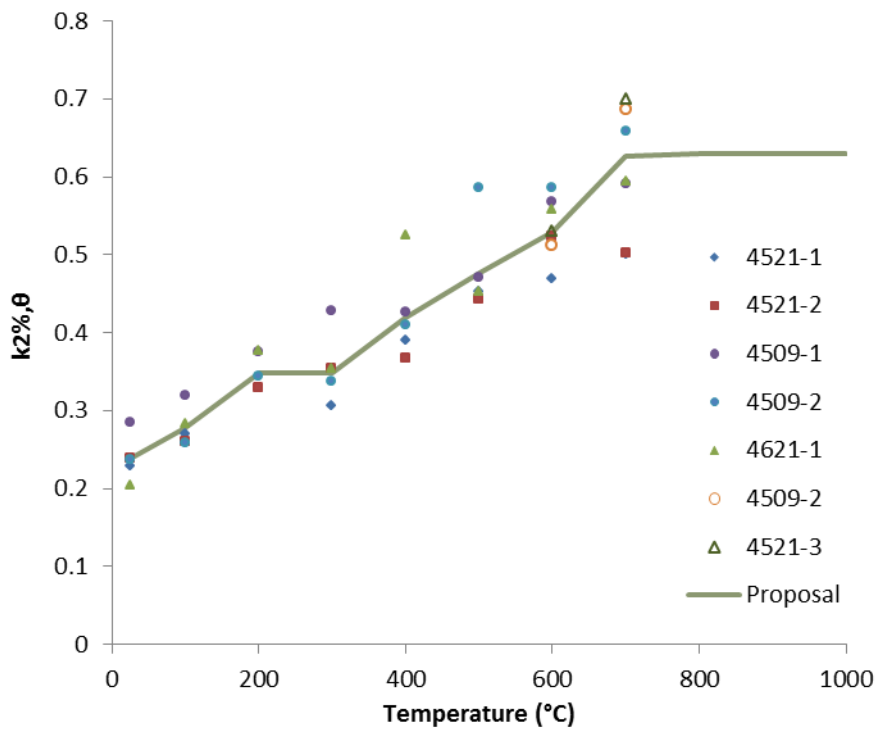
Proposal: All Stabilized Grades



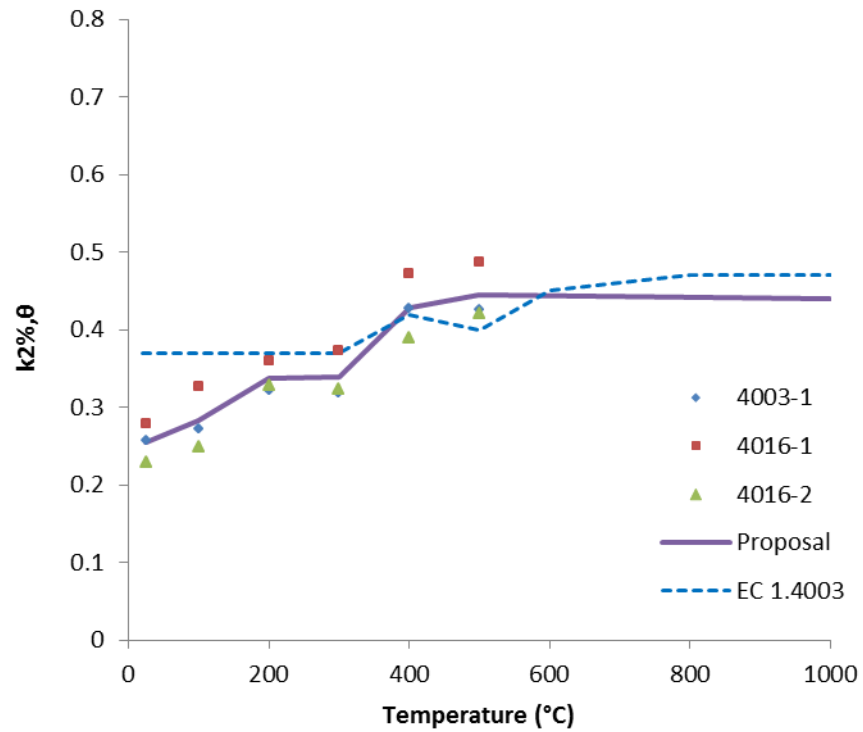


Proposal: k2%,θ for All Grades

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

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Thank You!

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