Hot forming and characterization of forming behavior of three Fe-Mn-C high-manganese steels

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Outline

- Motivation
- Material Characterization
  - Processing of compression tests
  - Results of compression tests
- Material Production

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

Comparison of the forming behavior to industrially applied austenitic steel

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 three ternary Fe-Mn-C steels and reference austenitic chromium nickel steel 1.4301 / AISI 304 by compression tests

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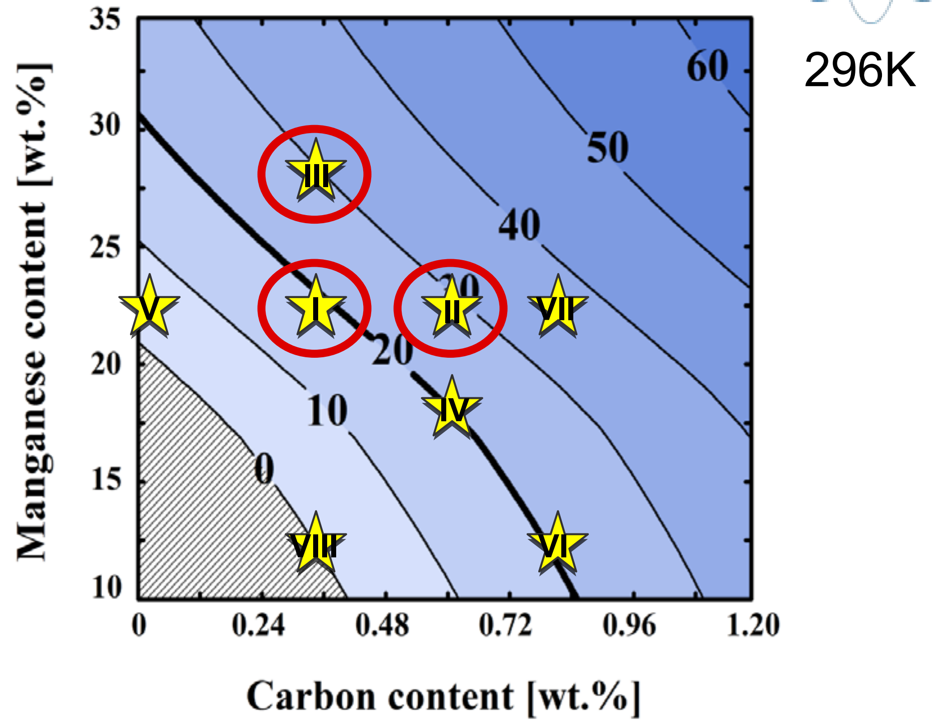
Material characterization – material description

Material within the SFB 761

- 8 compositions of Fe-Mn-C steels are planed
- 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

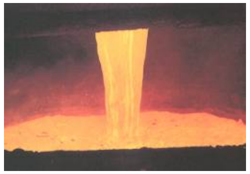
Diagram of steel compositions within SFB 761

SFE calculated by Saeed-Akbari, Institute of Ferrous Metallurgy, RWTH Aachen[1]

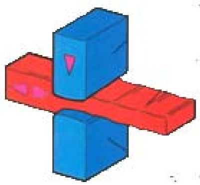
name / cont. wt. %	Fe	C	Mn	Si	P	S	Cr	Ni	Mo	Al	Cu	Co	Nb	V	N
Mn22C0.3, I (V16)	Bal.	**0.34**	**22.65**	0.14	0.01	0.00	0.30	0.01	0.05	0.01	0.01	0.01	0.02	0.01	0.01
Mn22C0.6, II (V15)	Bal.	**0.57**	**23.21**	0.17	0.01	0.00	0.31	0.02	0.04	0.01	0.01	0.01	0.01	0.01	0.01
Mn28C0.3 III (V19)	Bal.	**0.28**	**28.12**	0.10	0.01	0.00	0.02	0.04	0.02	0.01	0.01	0.01	0.02	0.02	0.02

1) Saeed-Akbari, A.; Imlau, J.; Prahl, U. and Bleck, W., Derivation and Variation in Composition-Dependent Stacking Fault Energy Maps Based on Subregular Solution Model in High-Manganese Steels, Metallurgical Materials Transactions A, Vol. 40A, Dec. 2009, pp. 3076-3090

Material characterization – processing of compression tests



Casting

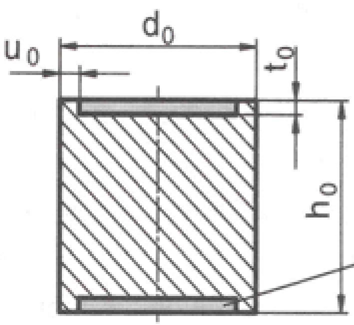


Forging

Annealing

Sample preparation

Rastegaev-geometry



Lubrication:

Up to 300°C: Teflon

Up to 700°C: Graphite

700 - 800°C: Boron-nitride

800 - 1.300°C: Glass

before test after test

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

Forging of cast blocks in 4 steps to 20 mm height (initial temperature 1150°) and annealing (1150°C / 5h)

Processing: Isothermal compression tests

- Rastegaev cylinders (15 mm height, 10 mm diameter, lubrication slots)
- 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 (kf) and strain
(temperature compensation (300 to 1200°C))

B. Wietbrock, W. Xiong, M. Bambach, W. Xiong, G. Hirt: Steel research international, 82 (2011) No. 2, pp. 127-136.
W. Xiong, B. Wietbrock, A. Saeed-Akbari, M. Bambach, G. Hirt: Steel research international, 82 (2011) No. 1, pp. 63-69

Material characterization – temperature compensation

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 ρ and C_p*, $D=0.9$

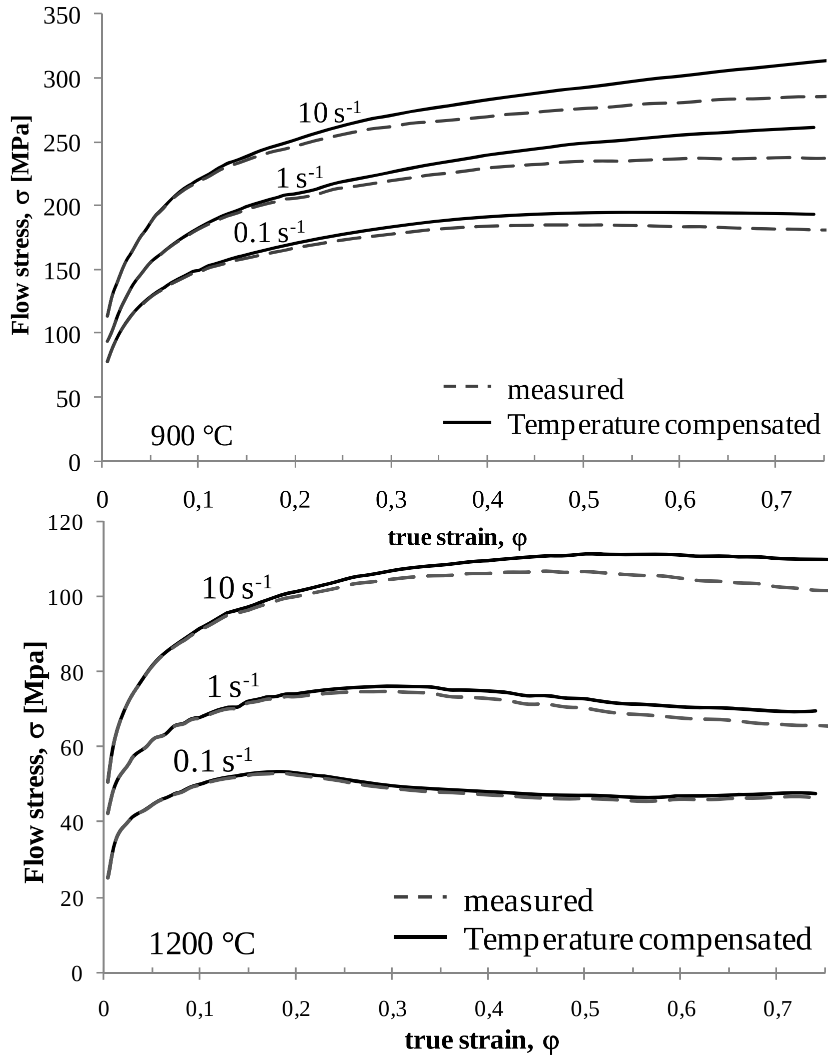
$$\Delta T_{HT} = \frac{2 \cdot \alpha}{\rho \cdot C_p \cdot h} \cdot \left(T_{t-1} - T_{die}\right) \cdot \Delta t$$

- α T-dependent (α 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

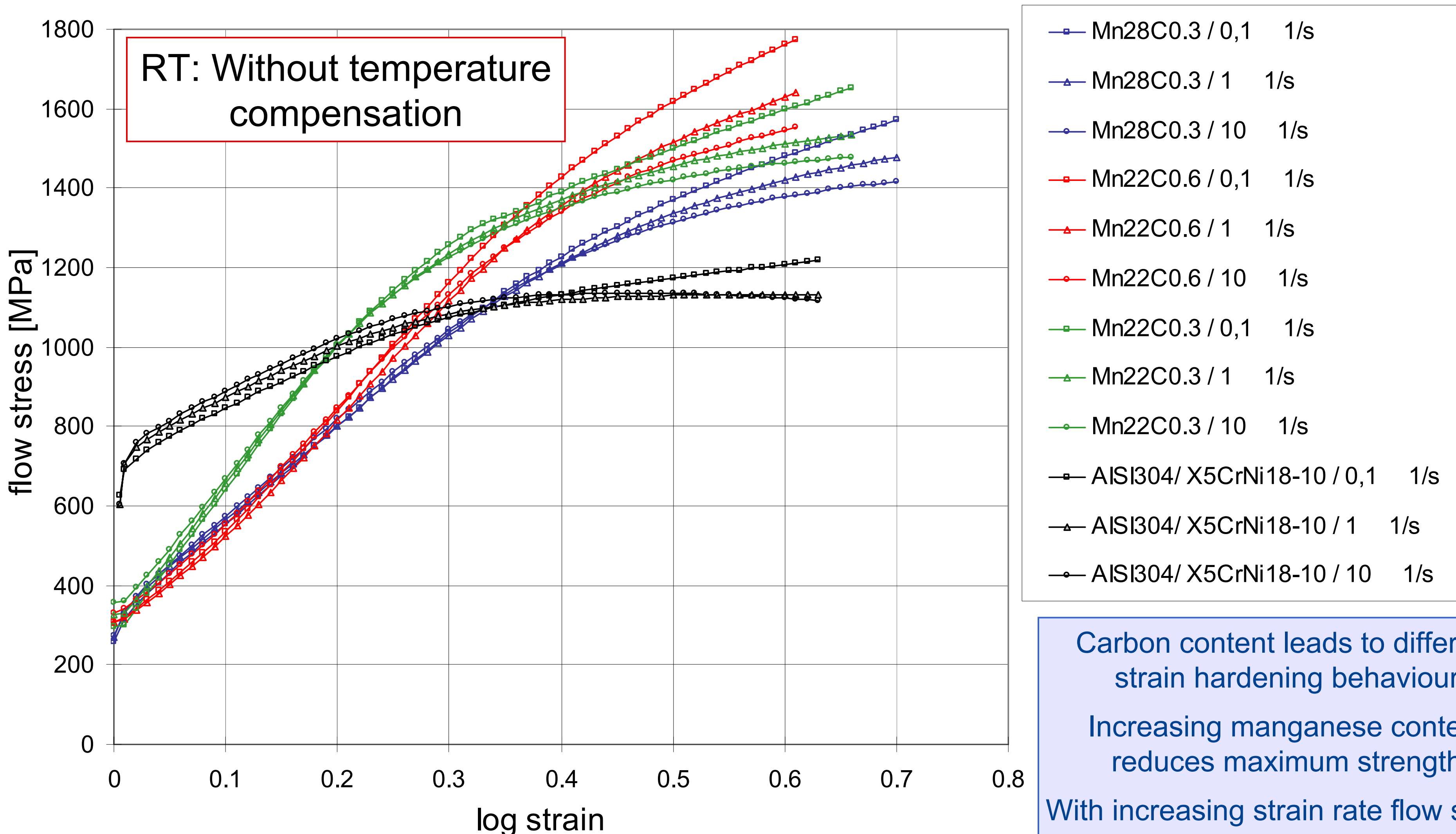
*ρ and C_p from TCFE4



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

B. Wietbrock, W. Xiong, M. Bambach, W. Xiong, G. Hirt: Steel research international, 82 (2011) No. 2, pp. 127-136.
W. Xiong, B. Wietbrock, A. Saeed-Akbari, M. Bambach, G. Hirt: Steel research international, 82 (2011) No. 1, pp. 63-69

Material characterization – results of compression tests at RT



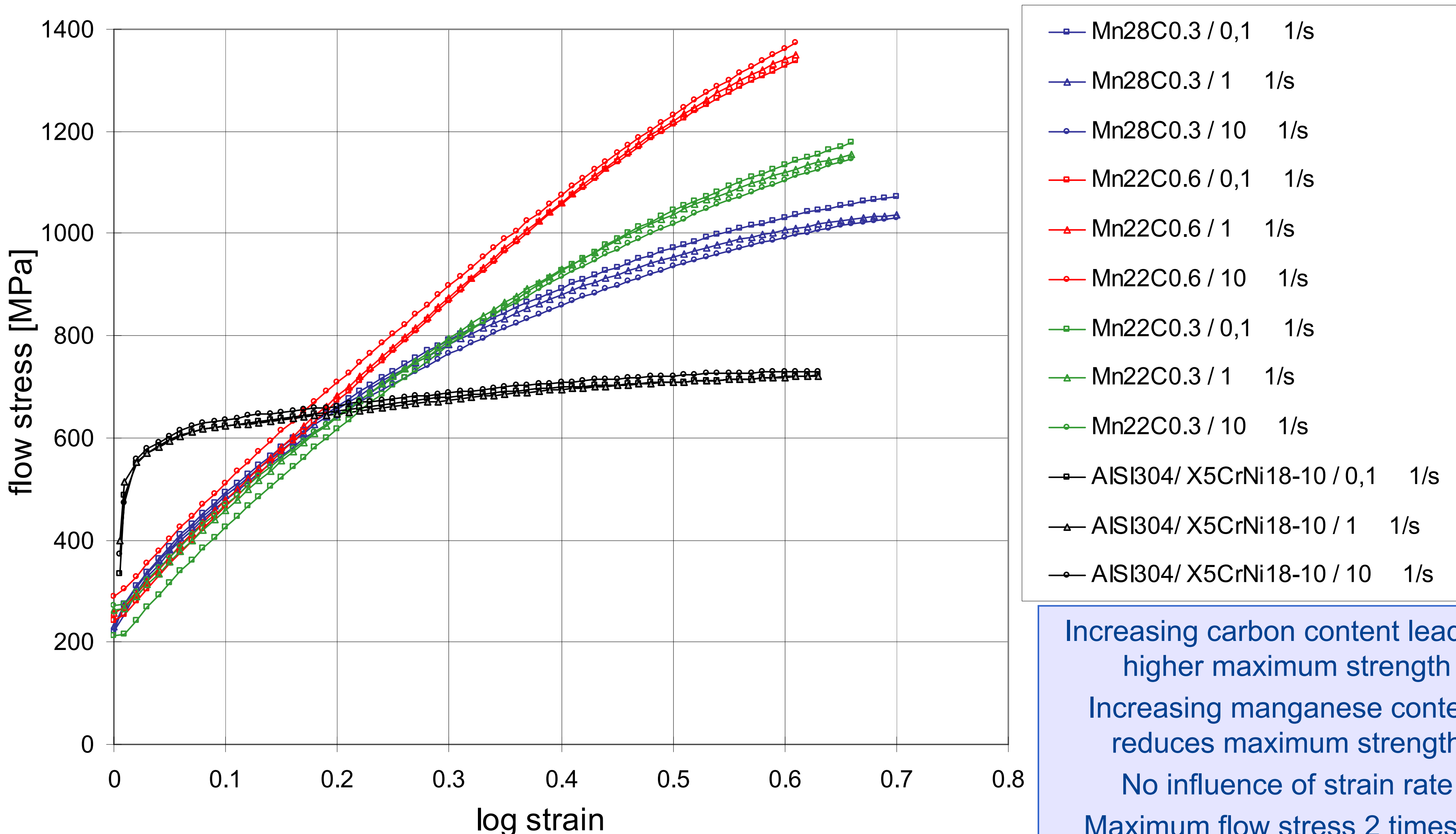
Carbon content leads to different strain hardening behaviour

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



Increasing carbon content leads to higher maximum strength

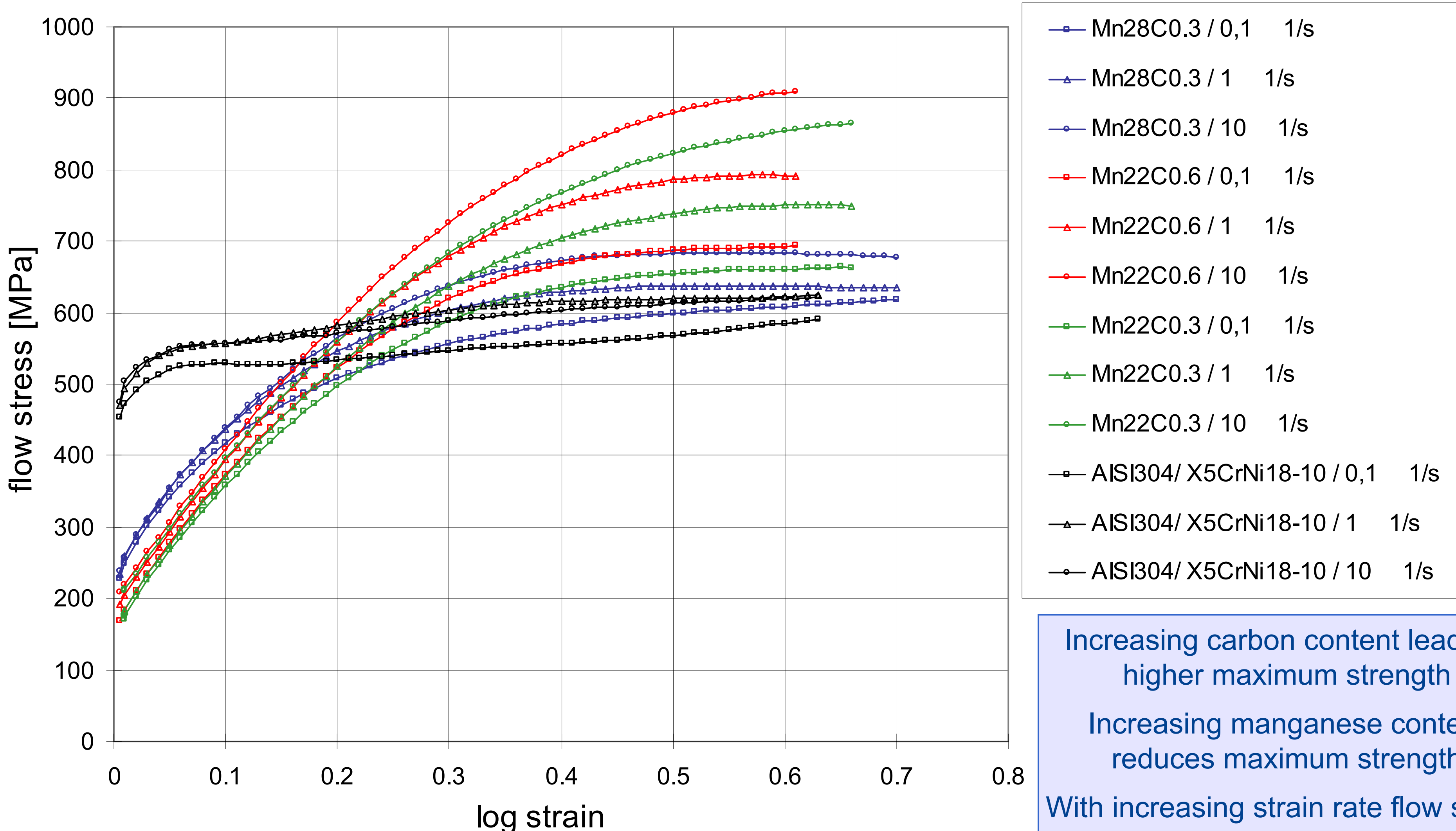
Increasing manganese content reduces maximum strength

No influence of strain rate

Maximum flow stress 2 times of AISI304

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

Material characterization – results of compression tests at 500°C



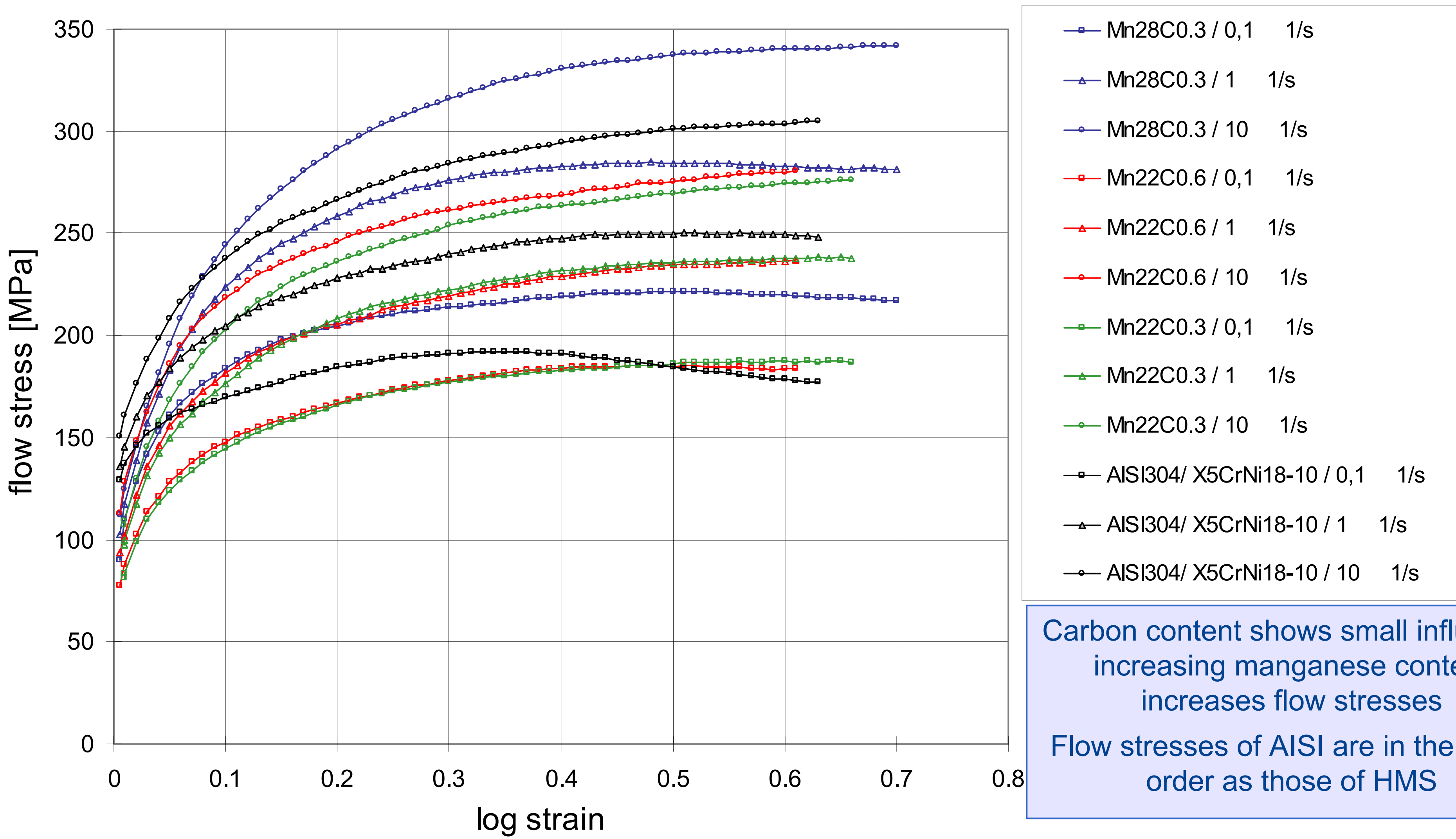
Increasing carbon content leads to higher maximum strength

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 900°C

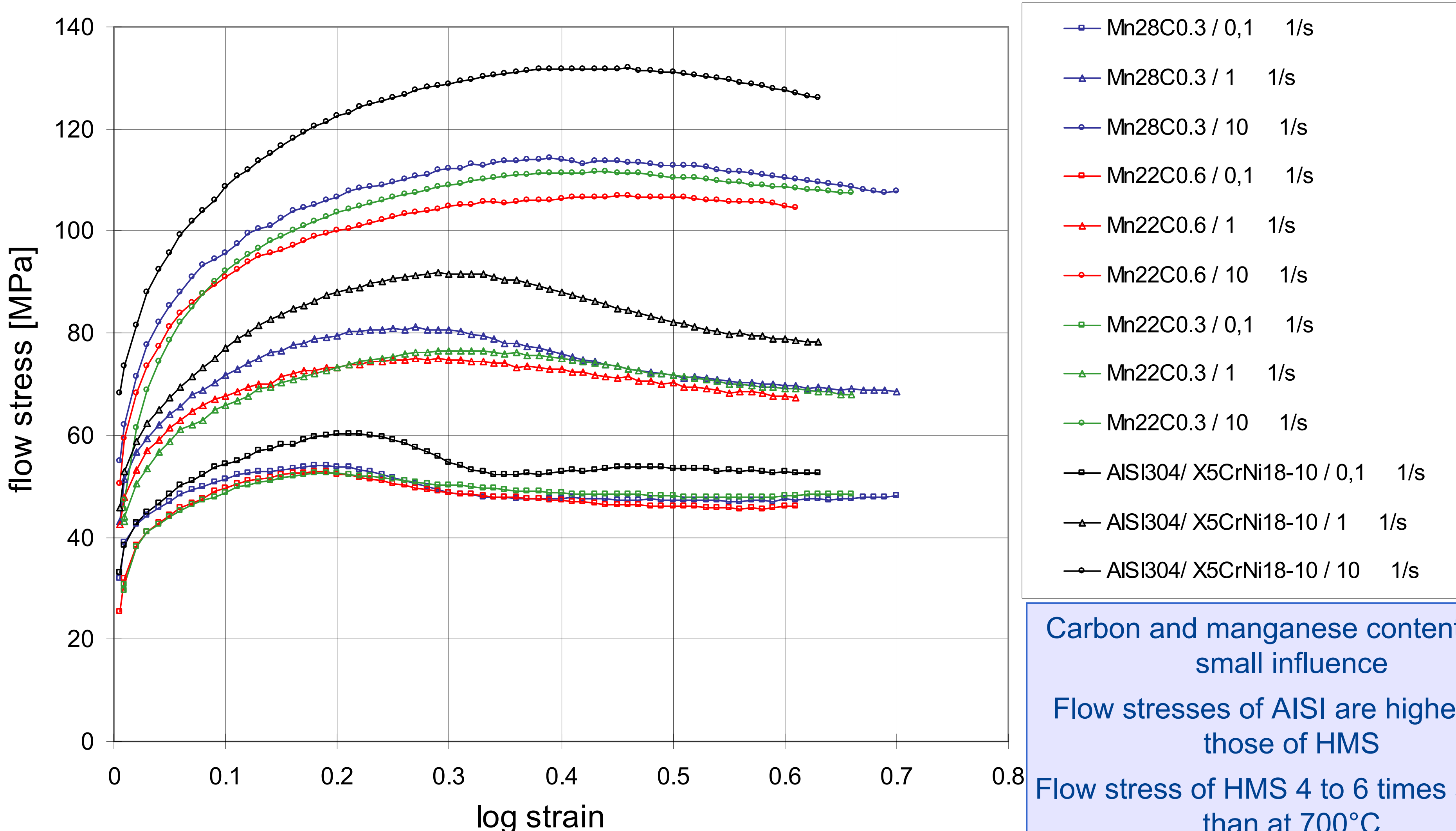


Carbon content shows small influence, increasing manganese content increases flow stresses

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 1200°C



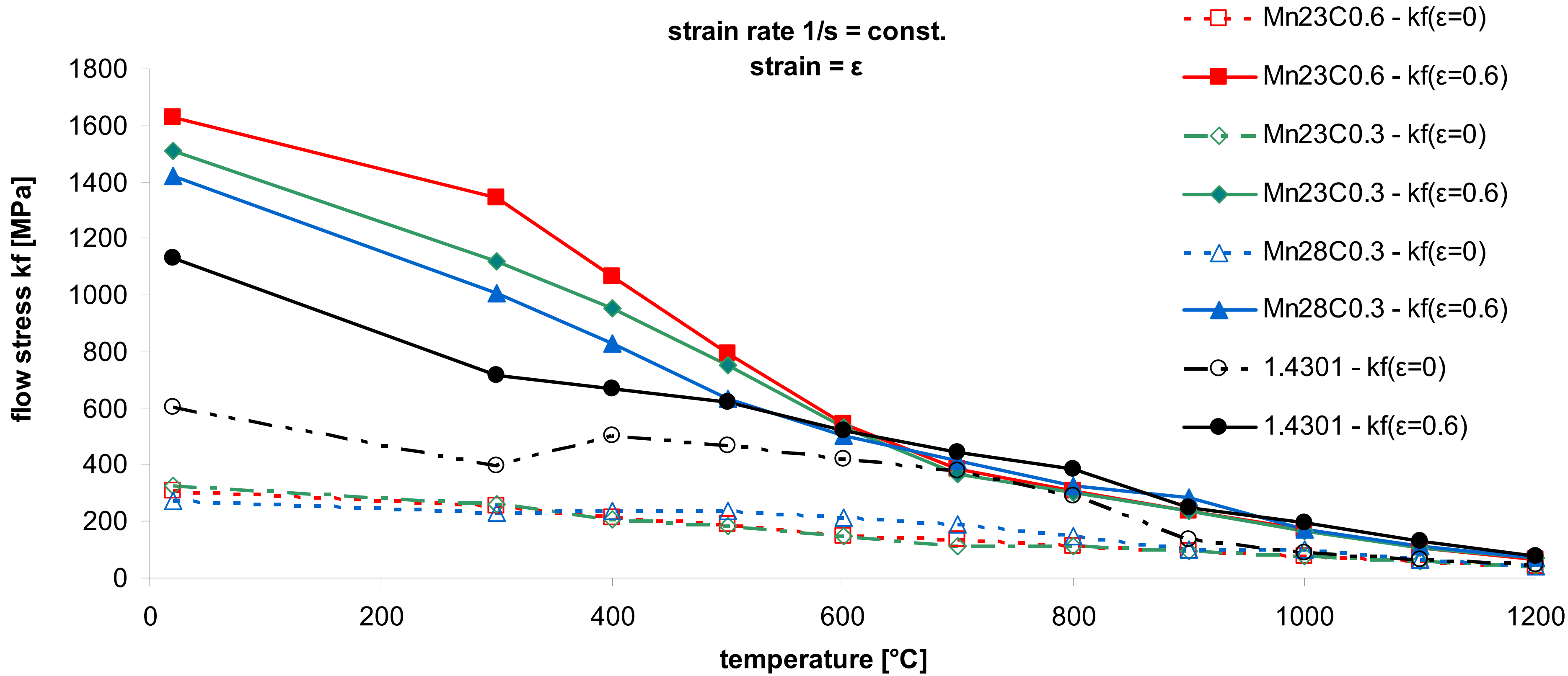
Carbon and manganese content show small influence

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

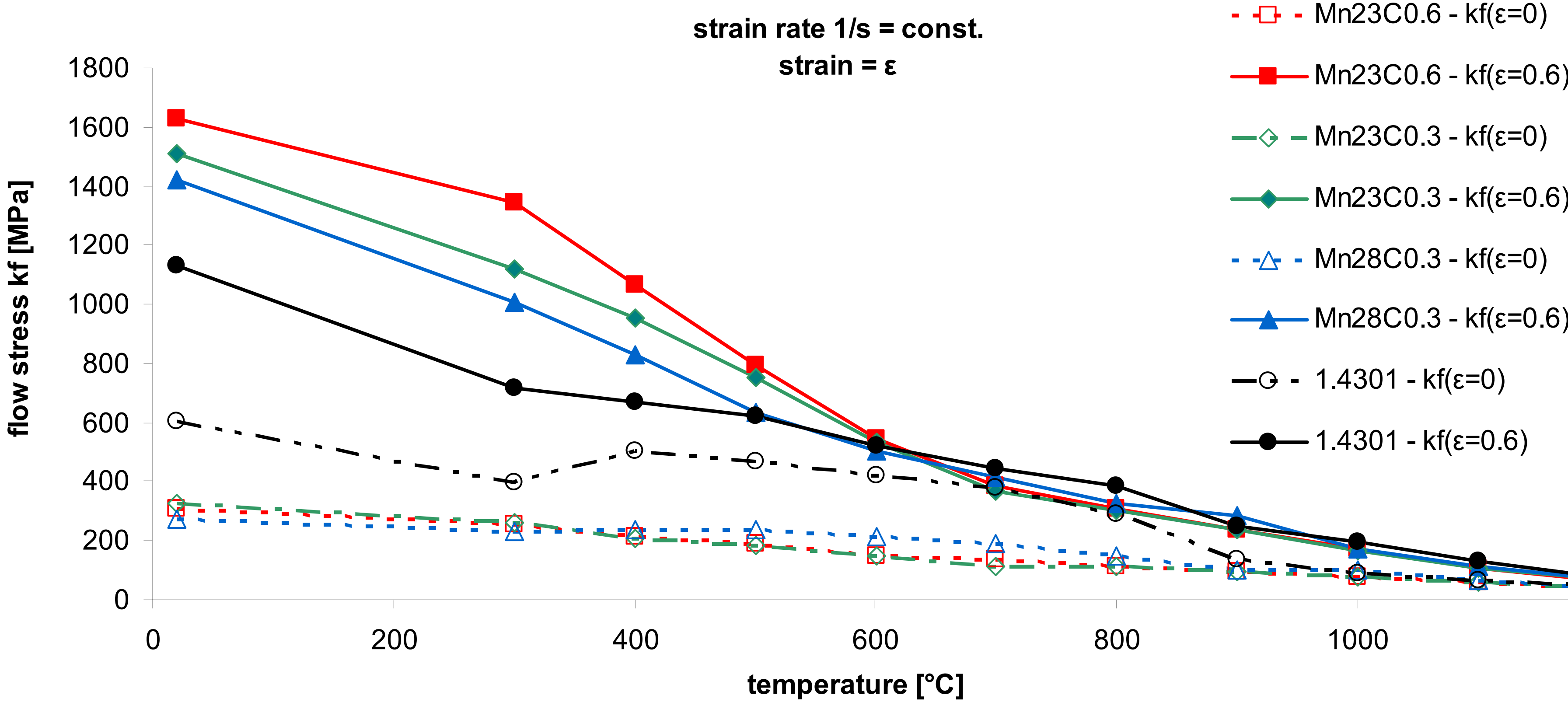
Material characterization – summery of compression tests I



At smaller temperatures (RT to 600°C):

- Higher carbon content (0.6 to 0.3 wt.%) leads to higher stresses
- Higher manganese (28 to 22 wt.%) content reduces maximum flow stresses
- Incipient yielding of all HMnS is lower than of 1.4301 / AISI 304 while strengthening is higher

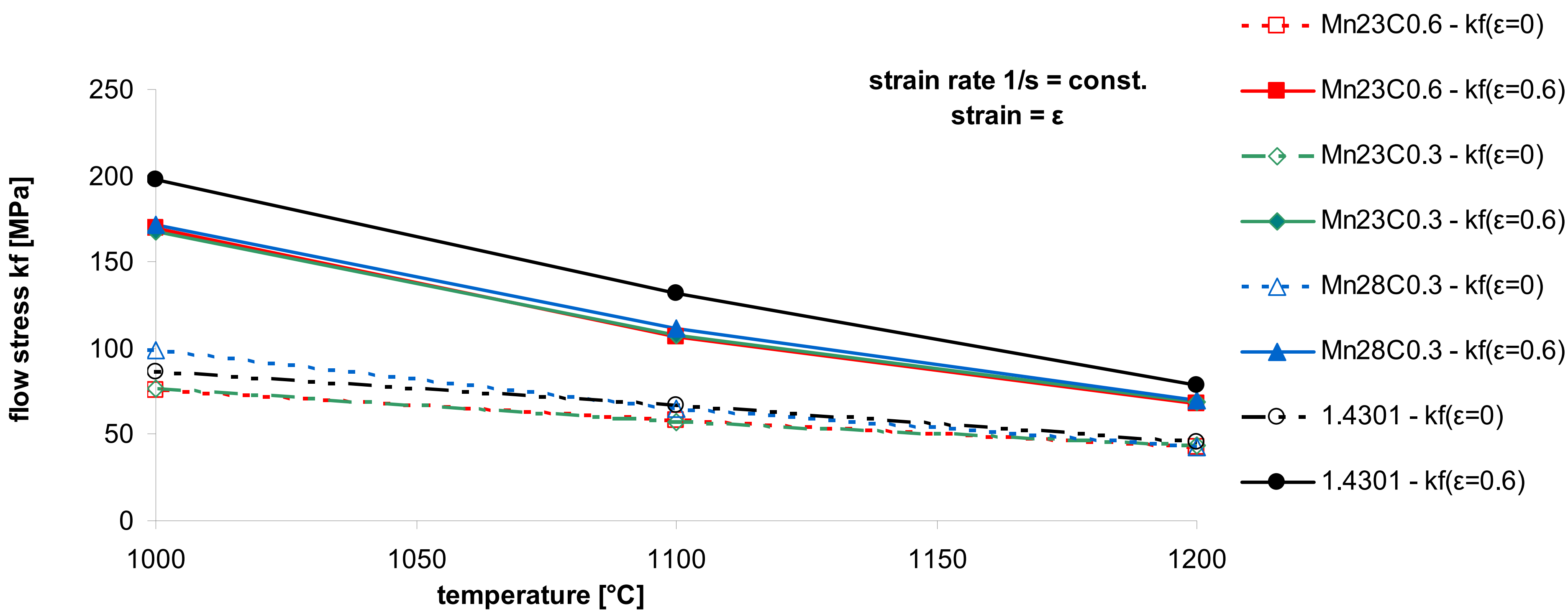
Material characterization – summery of compression tests II



At middle temperatures (700 to 900°C):

- Maximum flow stresses are comparable to steel 1.4301 / AISI 304
- Higher manganese content increases maximum flow stresses and incipient yielding
- Influence of carbon content becomes smaller, but increases the maximum flow stress

Material characterization – summery of compression tests III



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 1.4301 / AISI 304

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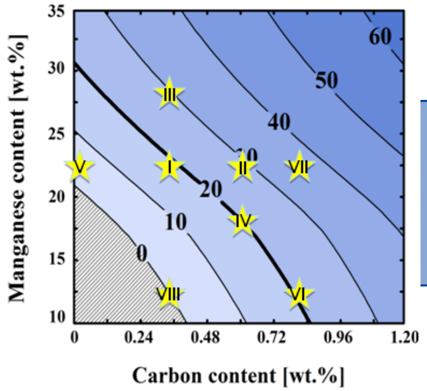
Process Chain of Material Production



Vacuum melting (IEHK)

Forging and annealing (IBF)

Hot and cold rolling (IBF)

Design of 8 different Fe-Mn-C compositions based on SFE (IEHK)[1]	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** of 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%[2]

- **Strong oxidation** during heating and annealing caused enrolled scale

Solution in the laboratory process chain: high pressure water jet

- Small possible **cold reduction rates** of only 15-20 % of TRIP compositions

1) Saeed-Akbari, A.; Imlau, J.; Prahl, U. and Bleck, W., Derivation and Variation in Composition-Dependent Stacking Fault Energy Maps Based on Subregular Solution Model in High-Manganese Steels, Metallurgical Materials Transactions A, Vol. 40A, Dec. 2009, pp. 3076-3090
2) Wietbrock, B.; Bambach, M.; Seuren, S.; Hirt, G.:, Homogenization strategy and material characterization of high-manganese TRIP and TWIP steels, Materials Science Forum (2010) Vols. 638-642, pp. 3134-3139

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Thank You for Your attention