28° SENAFOR – 12ª International Forging Conference

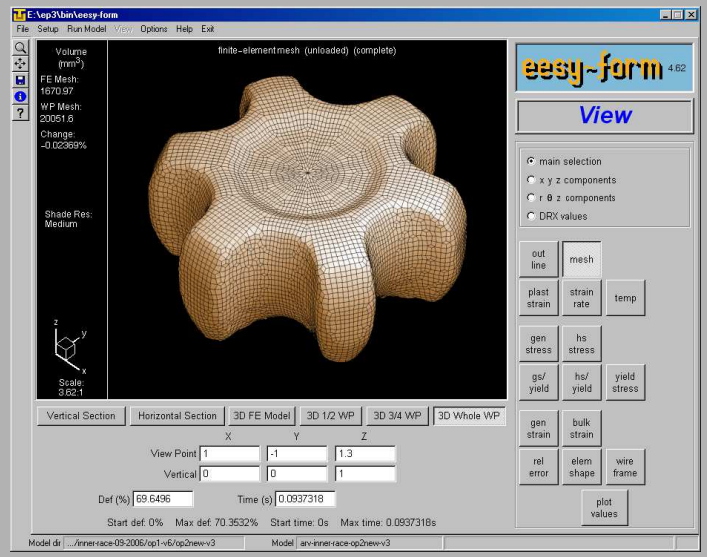
Porto Alegre, RS, Brazil, 9.-10. October 2008

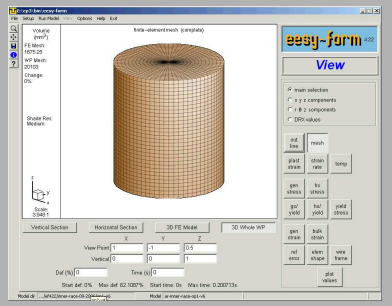
Importance of the yield stress –strain curves for the properties of a forged part

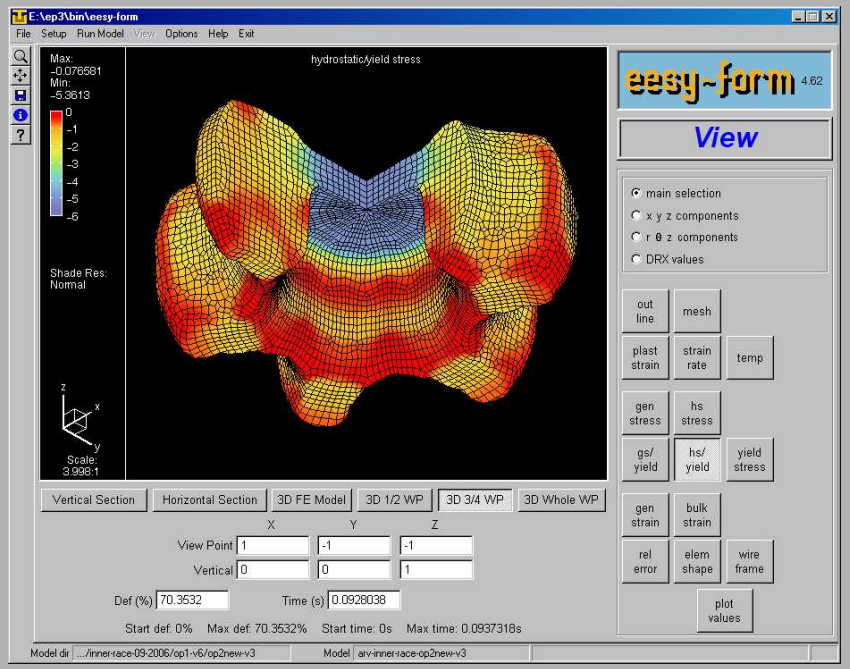
Report from a project by the GCFG and the IMU on „how to make yield stress – strain curves properly“

G. H. Arfmann, M. Twickler*)

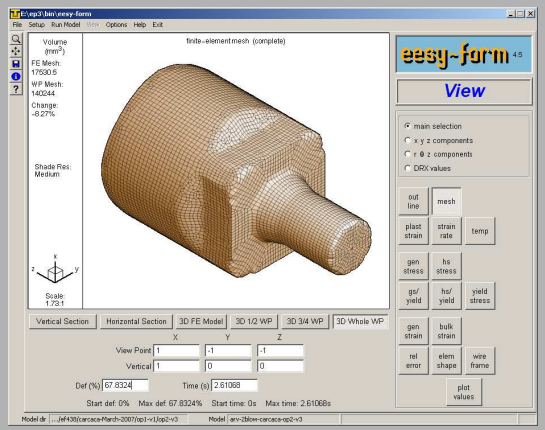
*)G. H. Arfmann and M. Twickler are joint managing director of CPM GmbH, Germany

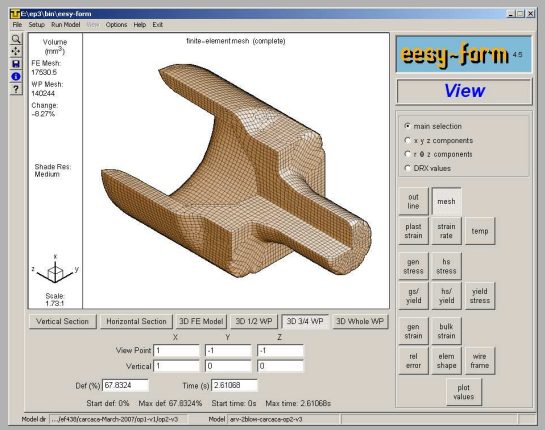


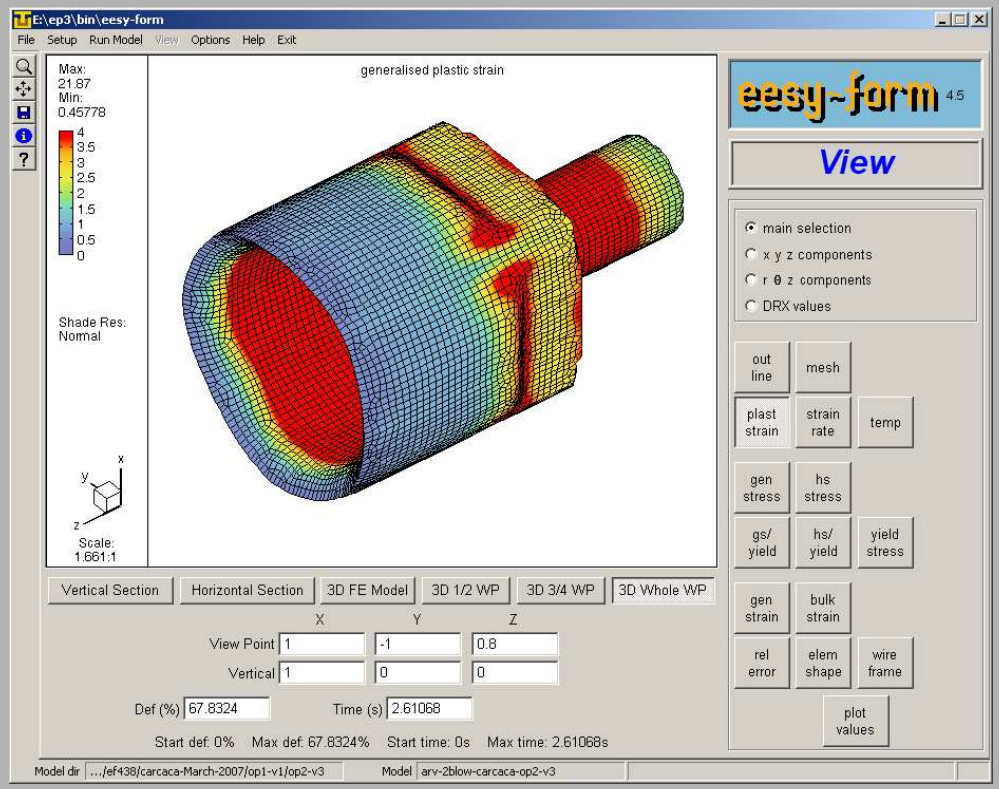




- Industrial simulation







- Industrial simulation

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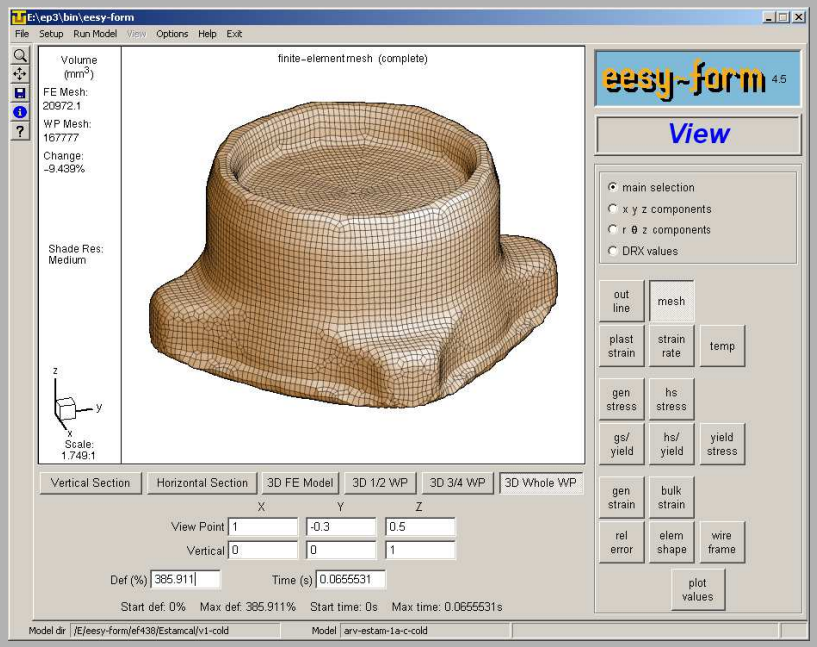
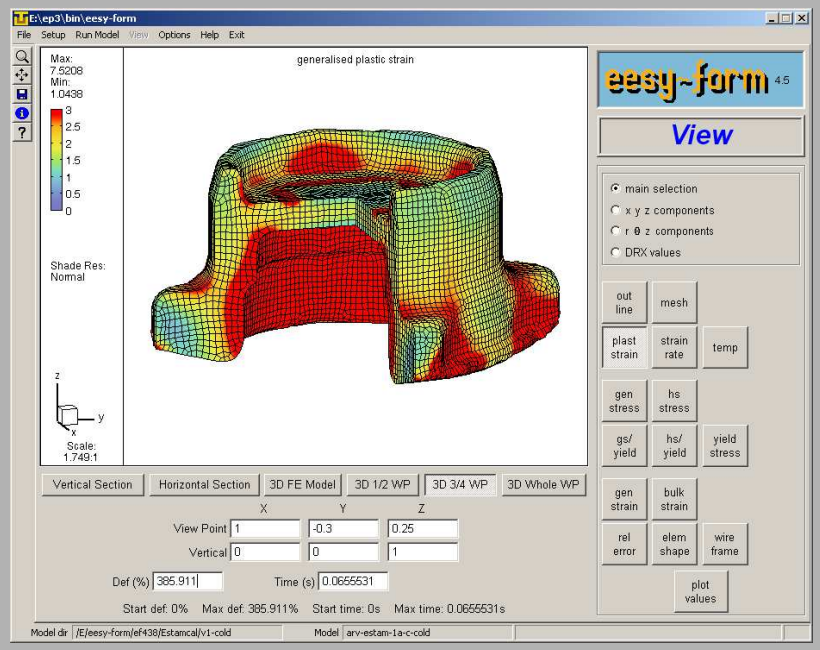
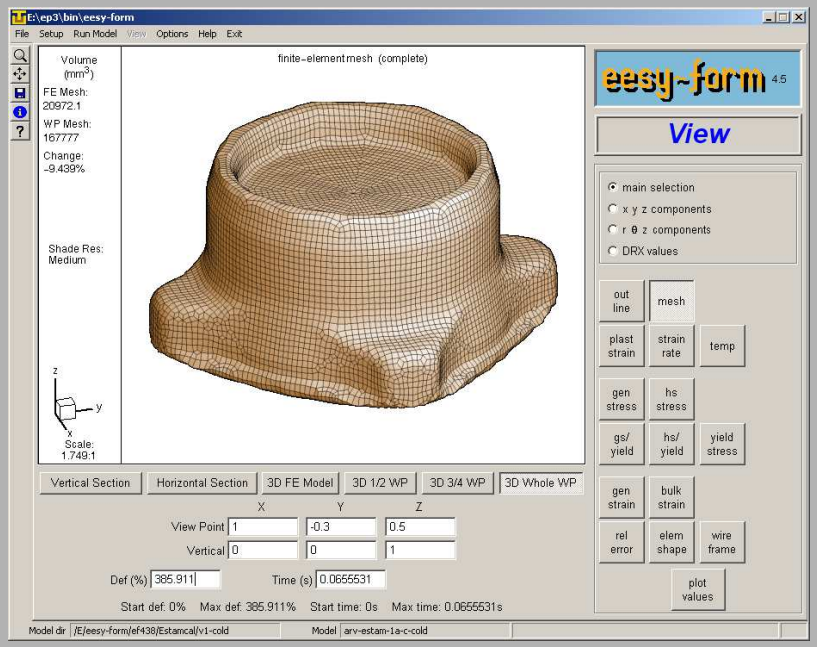
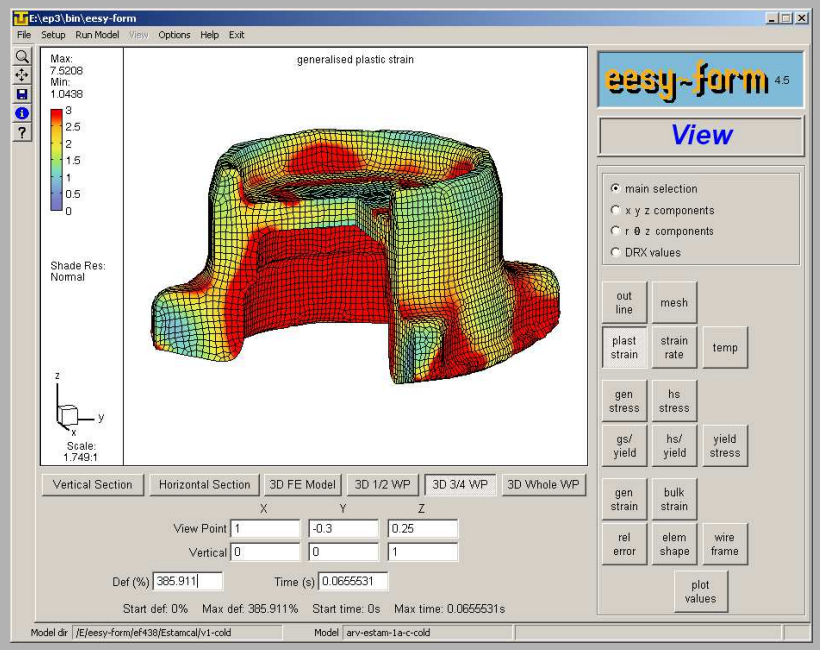




- Industrial simulation





Situation leading to the project

Metal forming simulation in forging showing

- geometry and material flow
- stresses and tooling loads
- microstructure

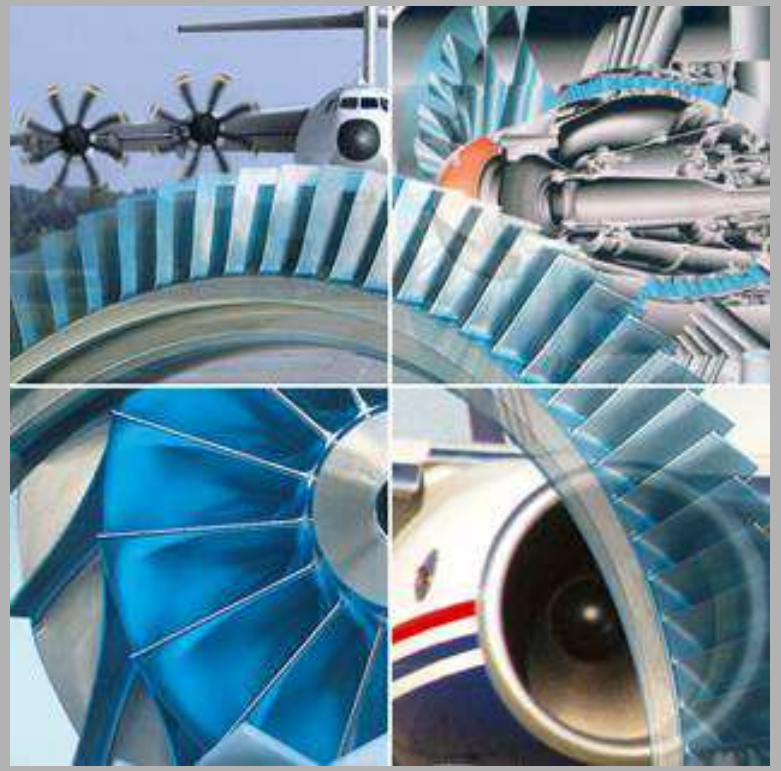
⇒ Requirements to the quality of material data (yield stress-strain, etc.)

- completeness of data
- reliable measurement method
- precise and reproducible measurement

⇒ necessity to formulate a guideline to describe

- the measurement method
- the necessary equipment
- the measurement technique
- the documentation
- etc.

=> Find a guide line (best practice) “how” to measure yield stress - strain



LEISTRITZ Turbinenkomponenten Remscheid GmbH

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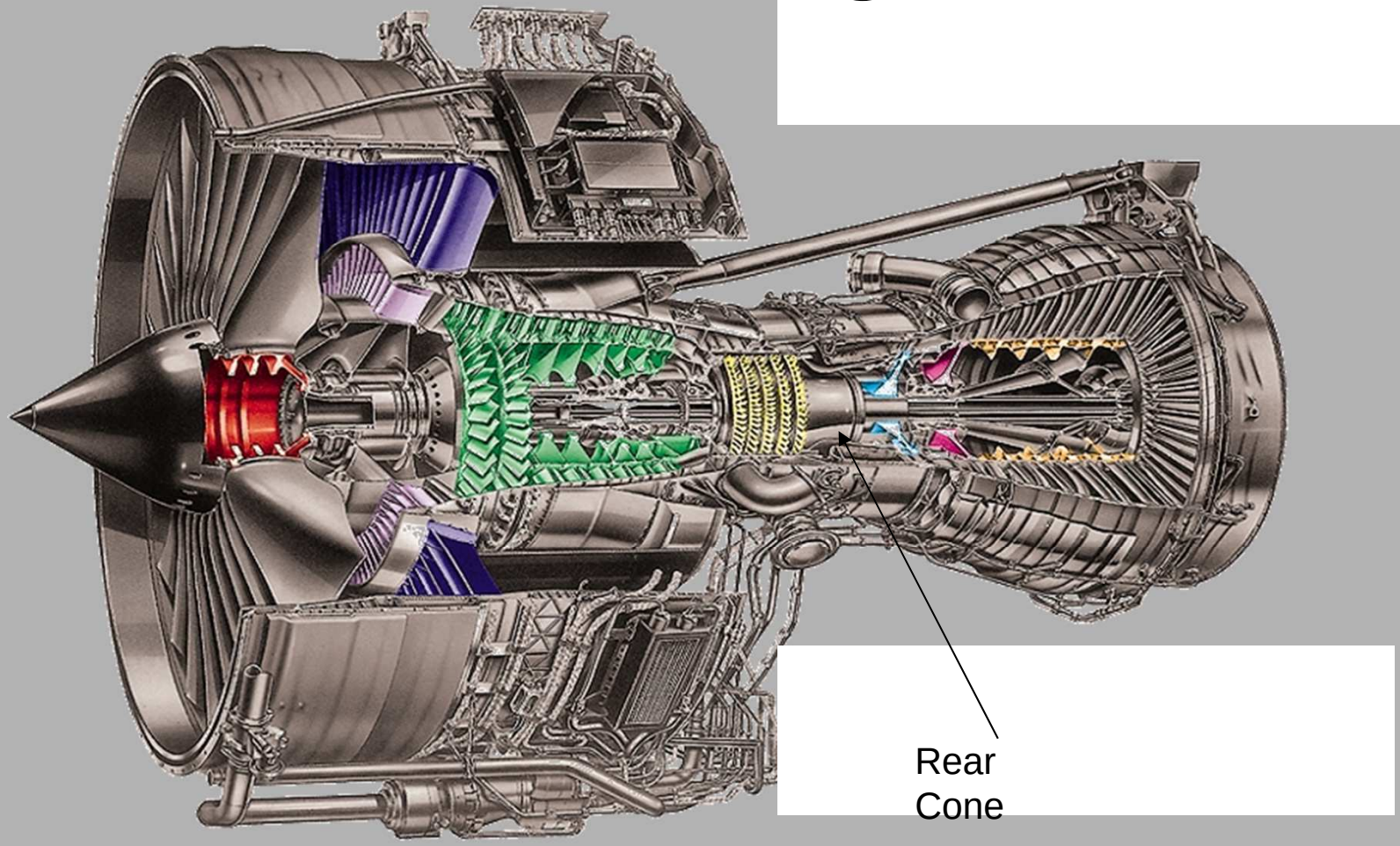
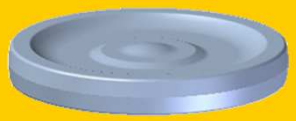
Schnitt durch ein Flugtriebwerk



Fertigungsfolge für Turbinenscheiben



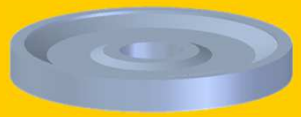
Schmieden

Anlage

- Hydraulische Presse 50 MN
- Gegenschlag-hammer 630kJ

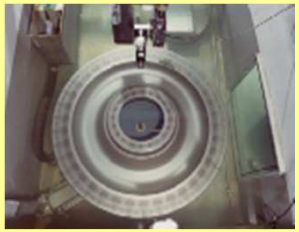
Wärme-behandlung

- Automatische Wbh-Anlage mit Öl-Abschreck-becken
- Drehherdöfen



Drehen auf Ultraschall-Prüfkontur

- universal CNC Drehmaschinen



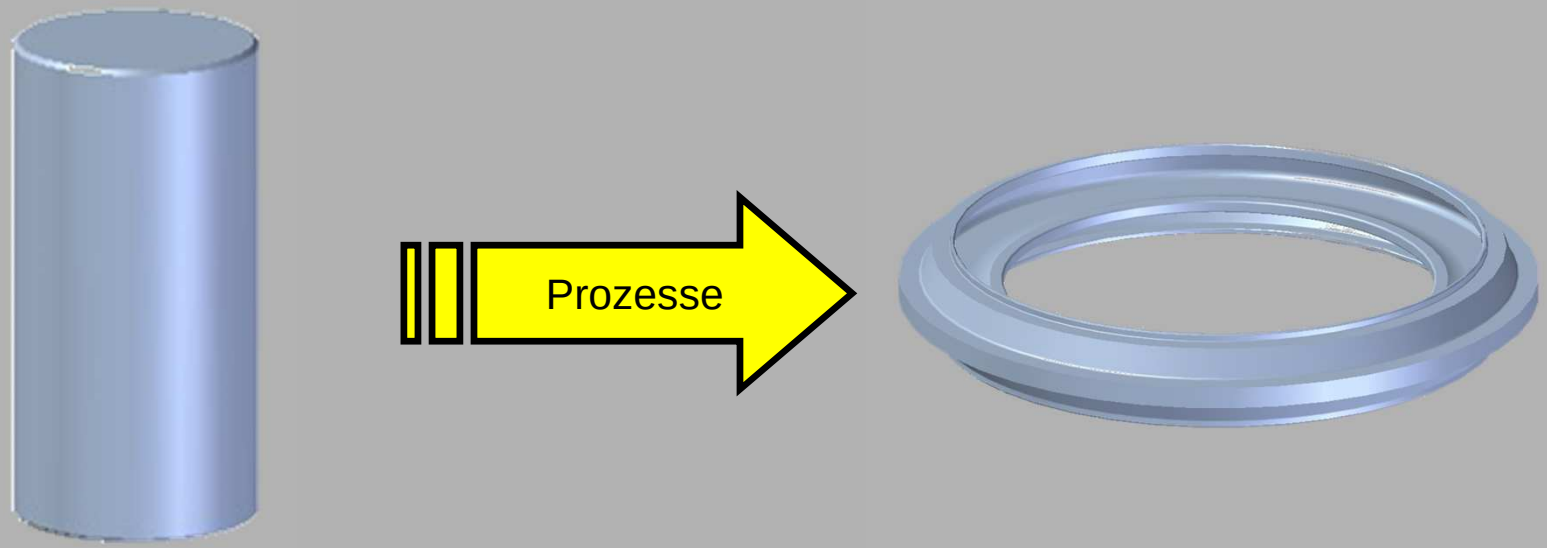
Ultraschall-prüfung

- Krautkrämer USP 1200
- Krautkrämer UPR-7

Rißprüfung

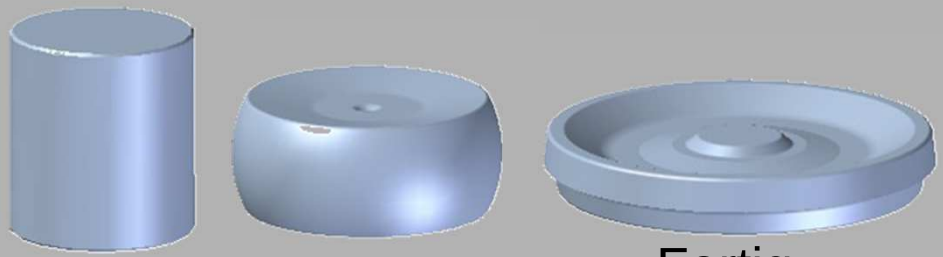
- Farbeindring-stoffprüfung

Fertigung von der Stange zur Scheibe



Scheiben-Fertigungsprozess iso-iso (2mal Isotherm-Presse)

Prozess

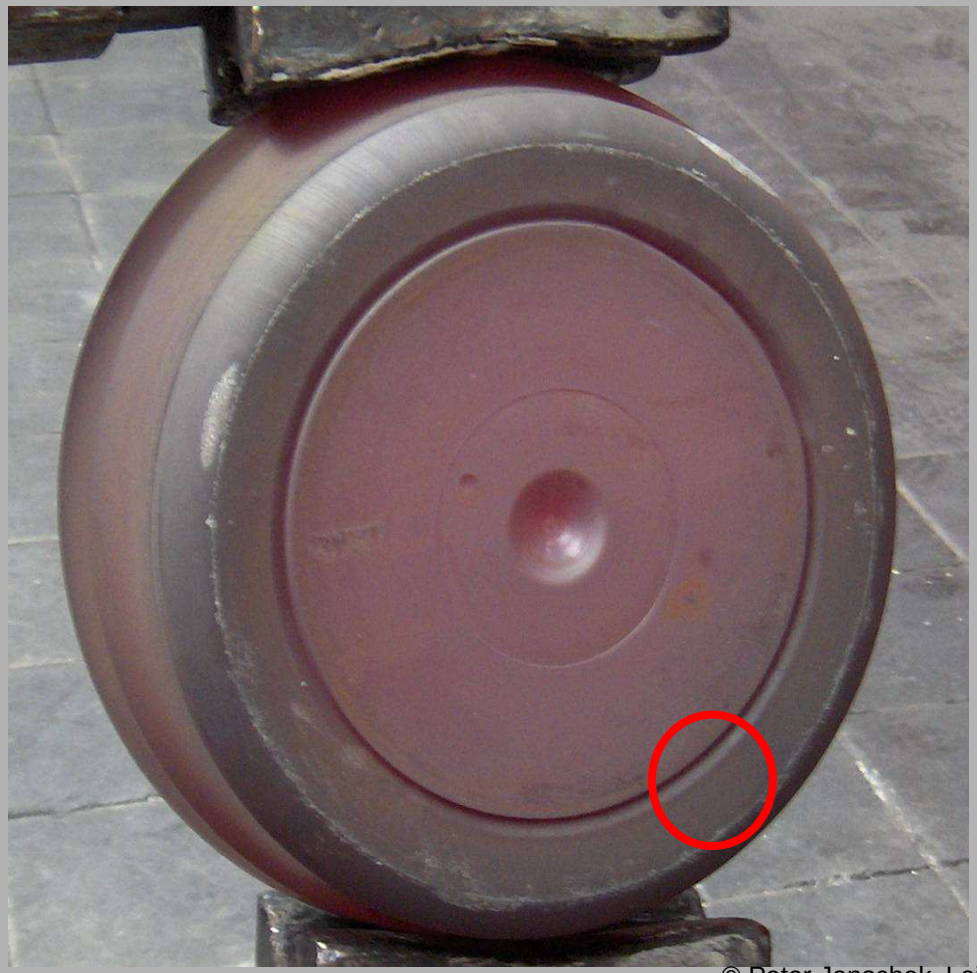


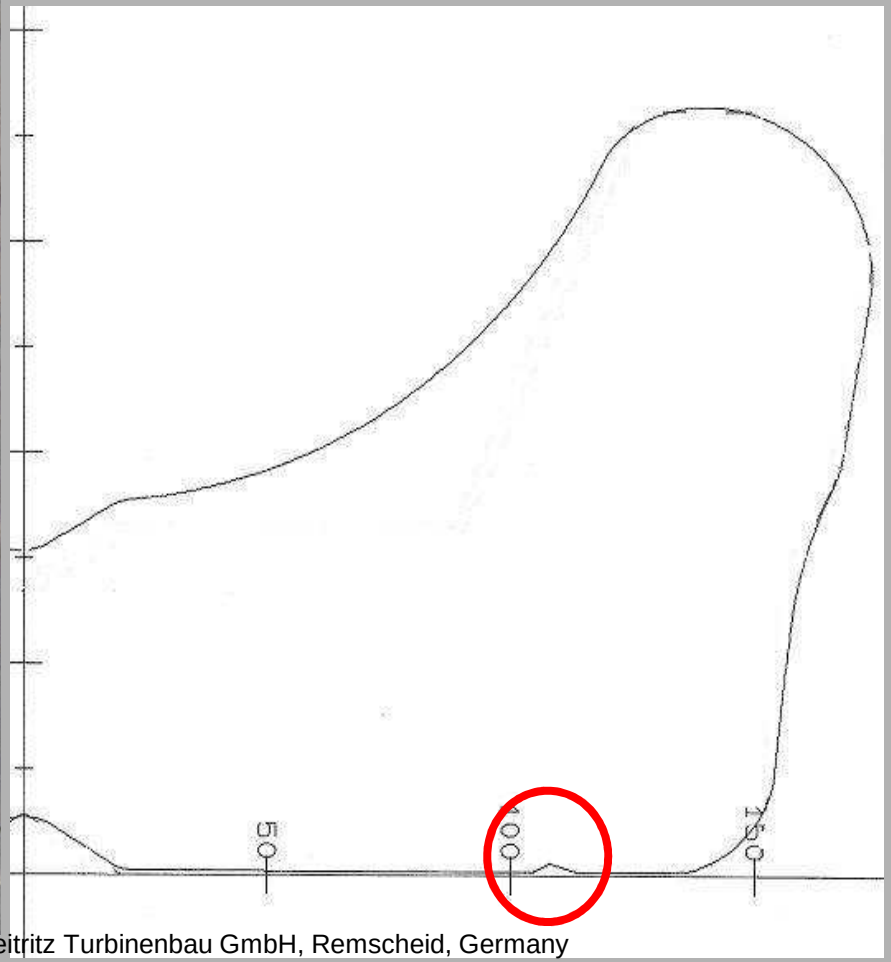
Billet Pancake Fertig-schmieden

Produkte

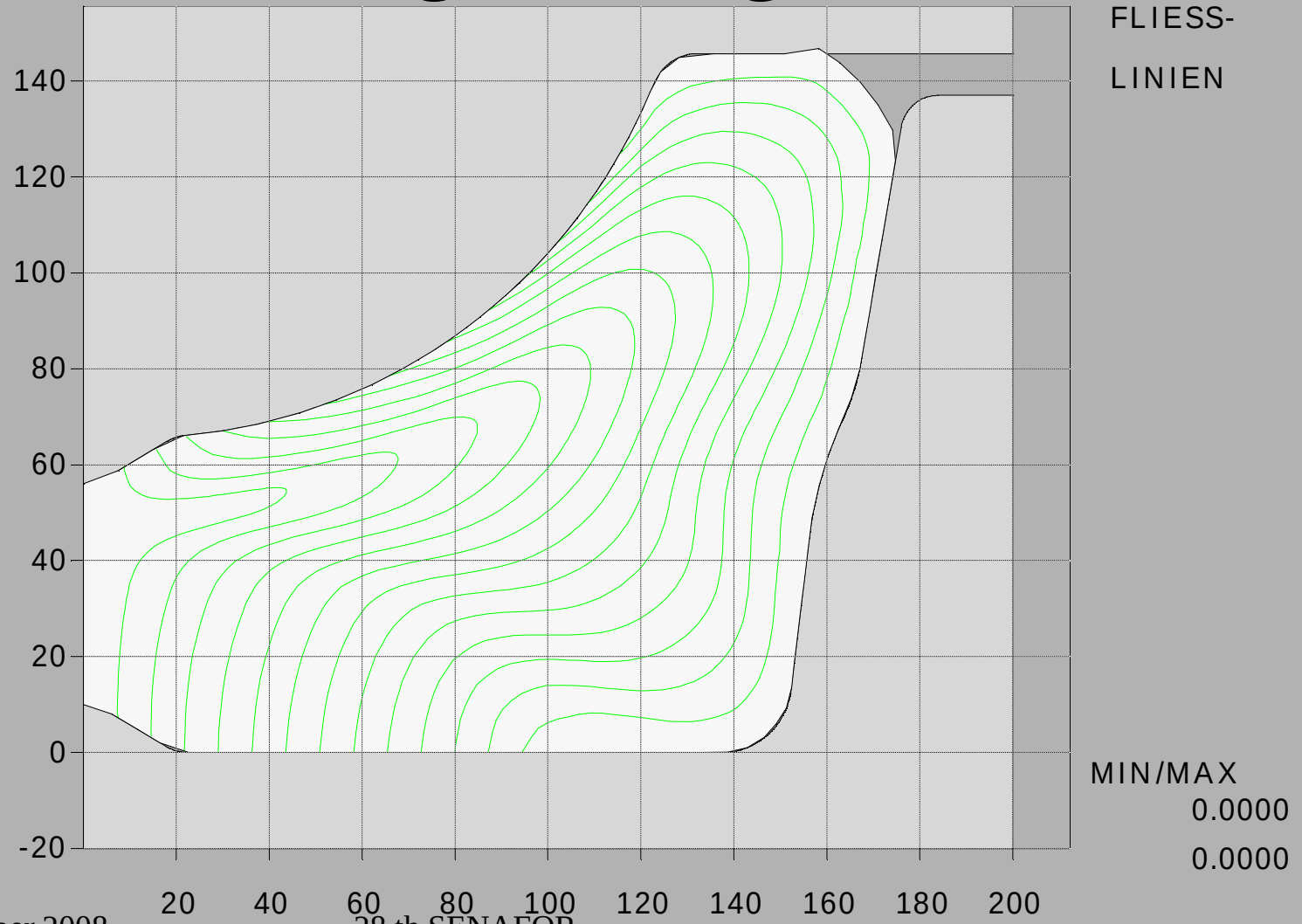
- BR 710/715 HPC Stages 4-6
- BR 710 HPT Stages 1+2
- EJ 200 Cover plate + HPT

Scheibe nach dem Vorschmieden – Ringkerbe auf der Unterseite

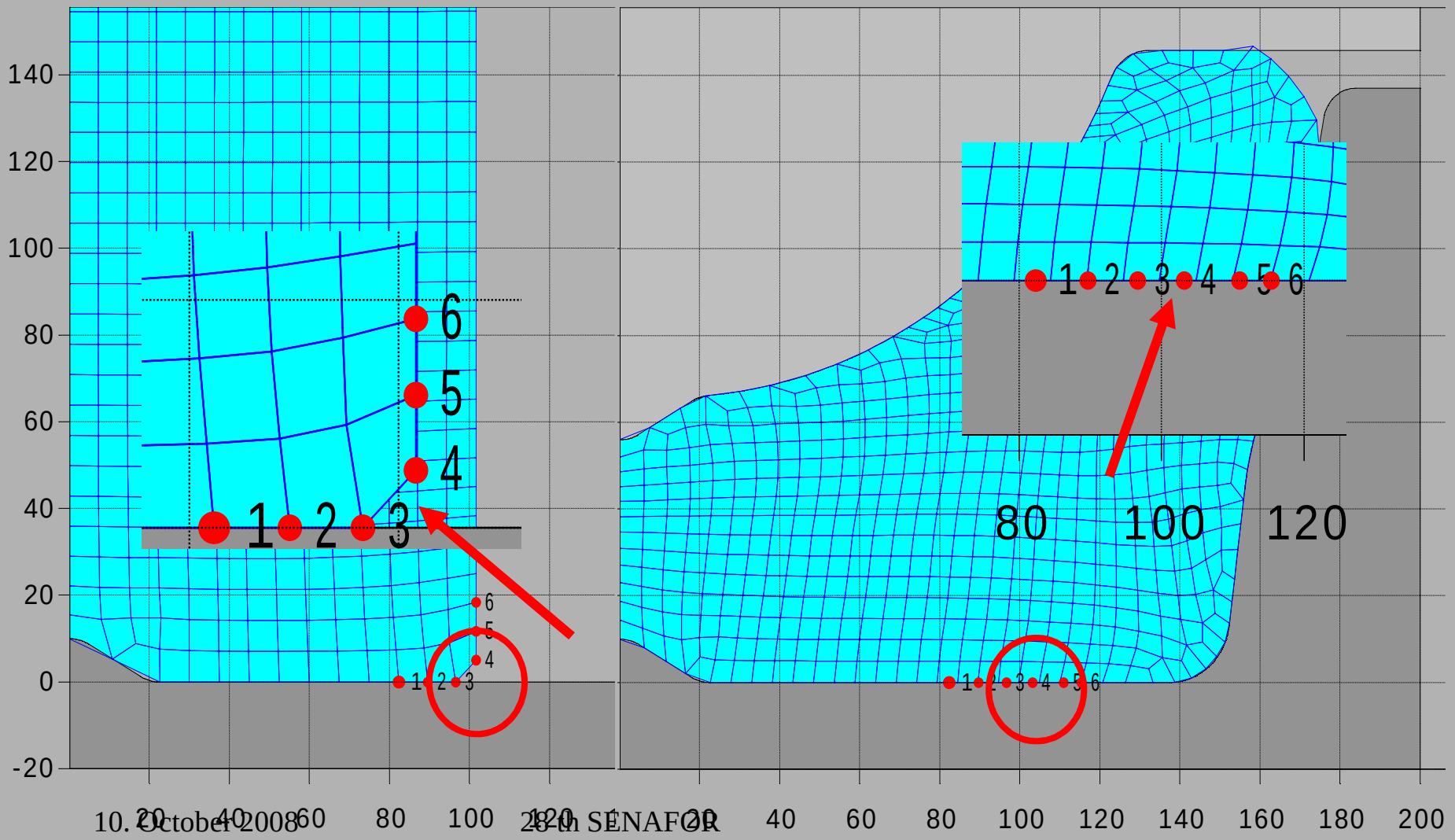




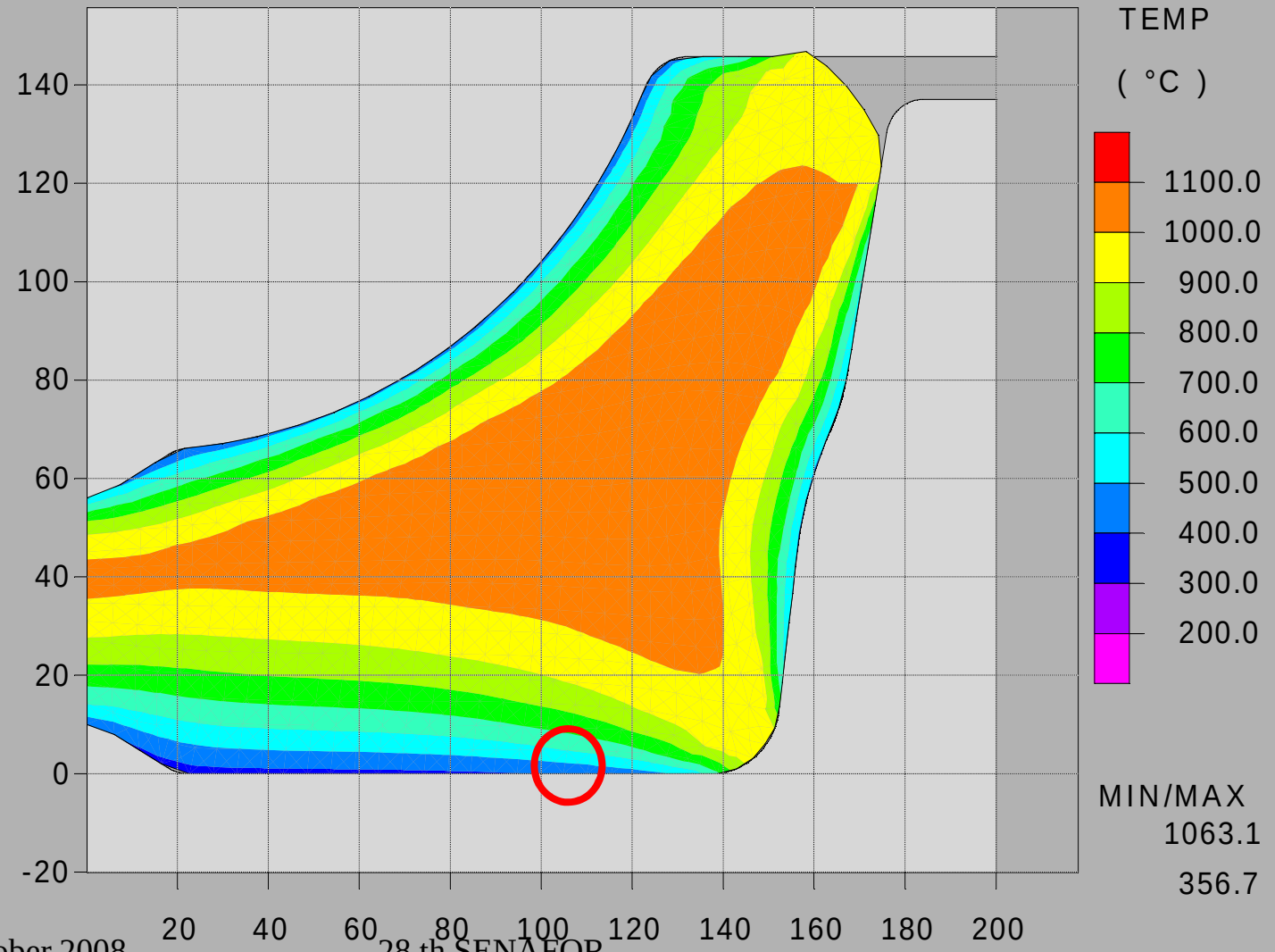
Fliesslinien zeigen keine Unregelmässigkeit



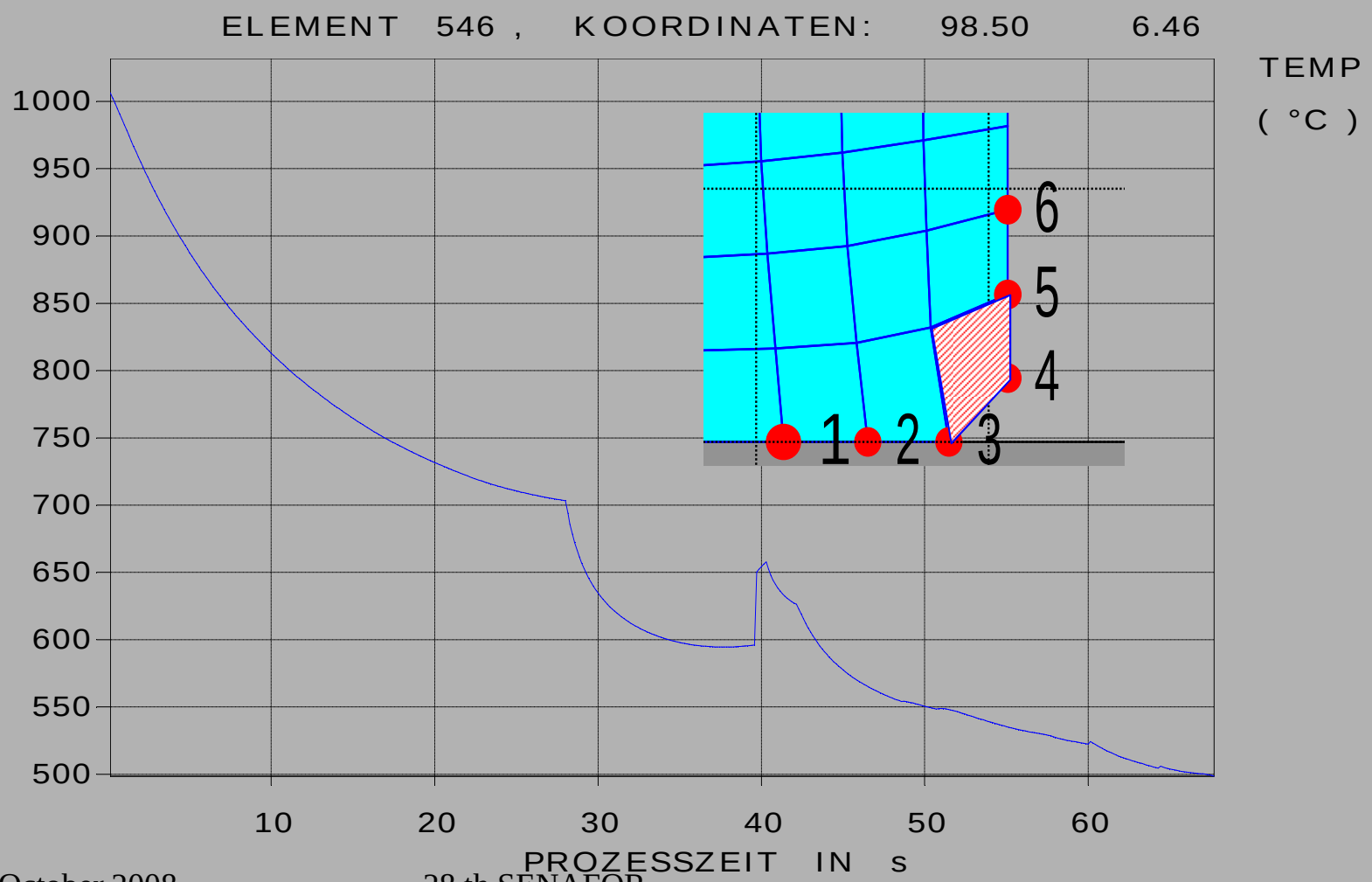
Woher kommt die Kerbe?



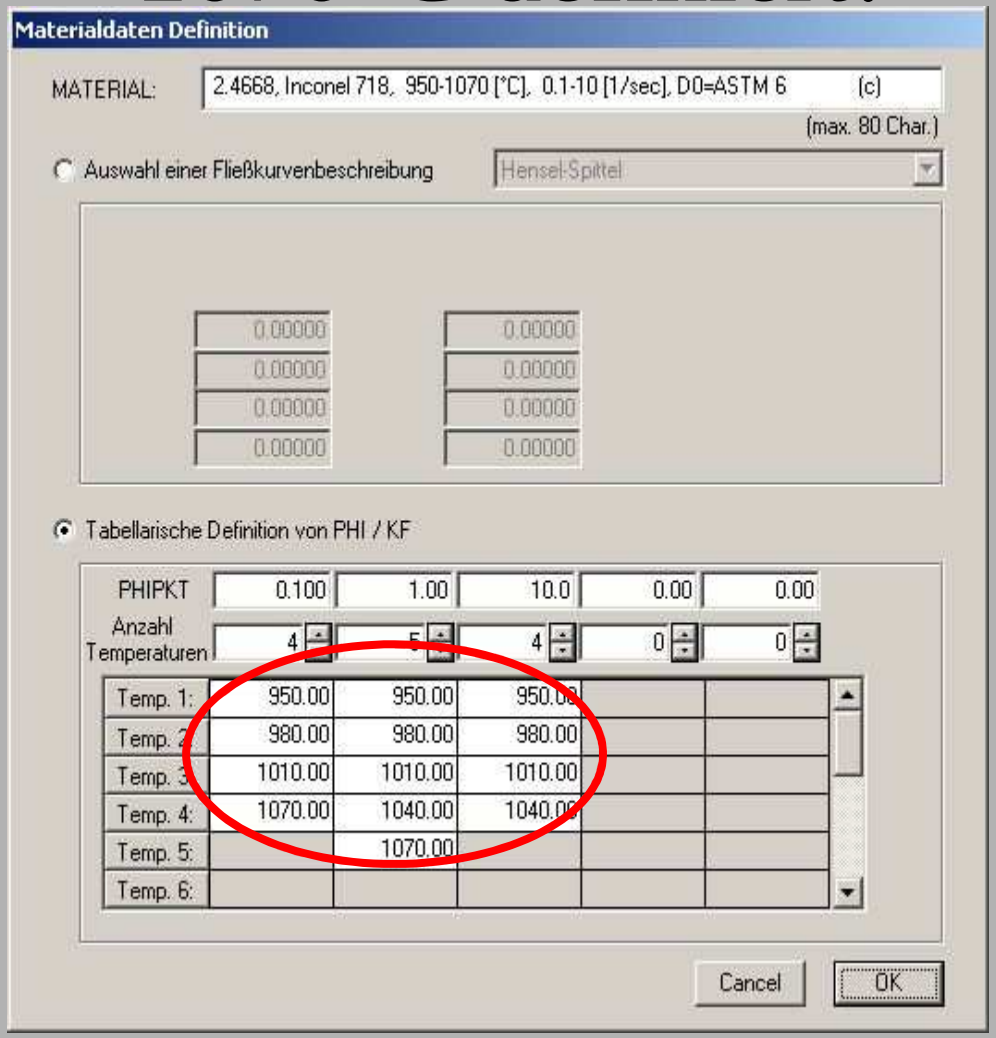
Temperaturverteilung beim Vorschmieden



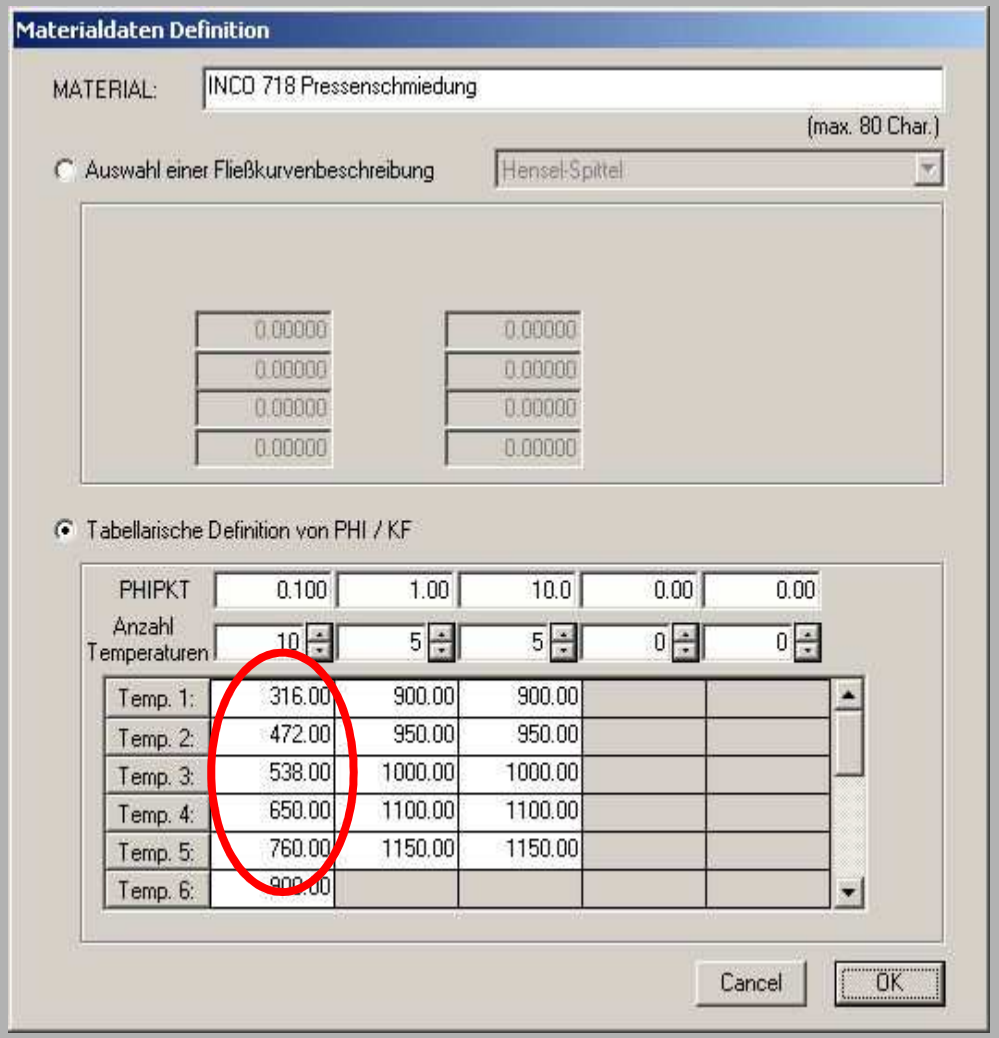
Temperaturverlauf des Eckelements



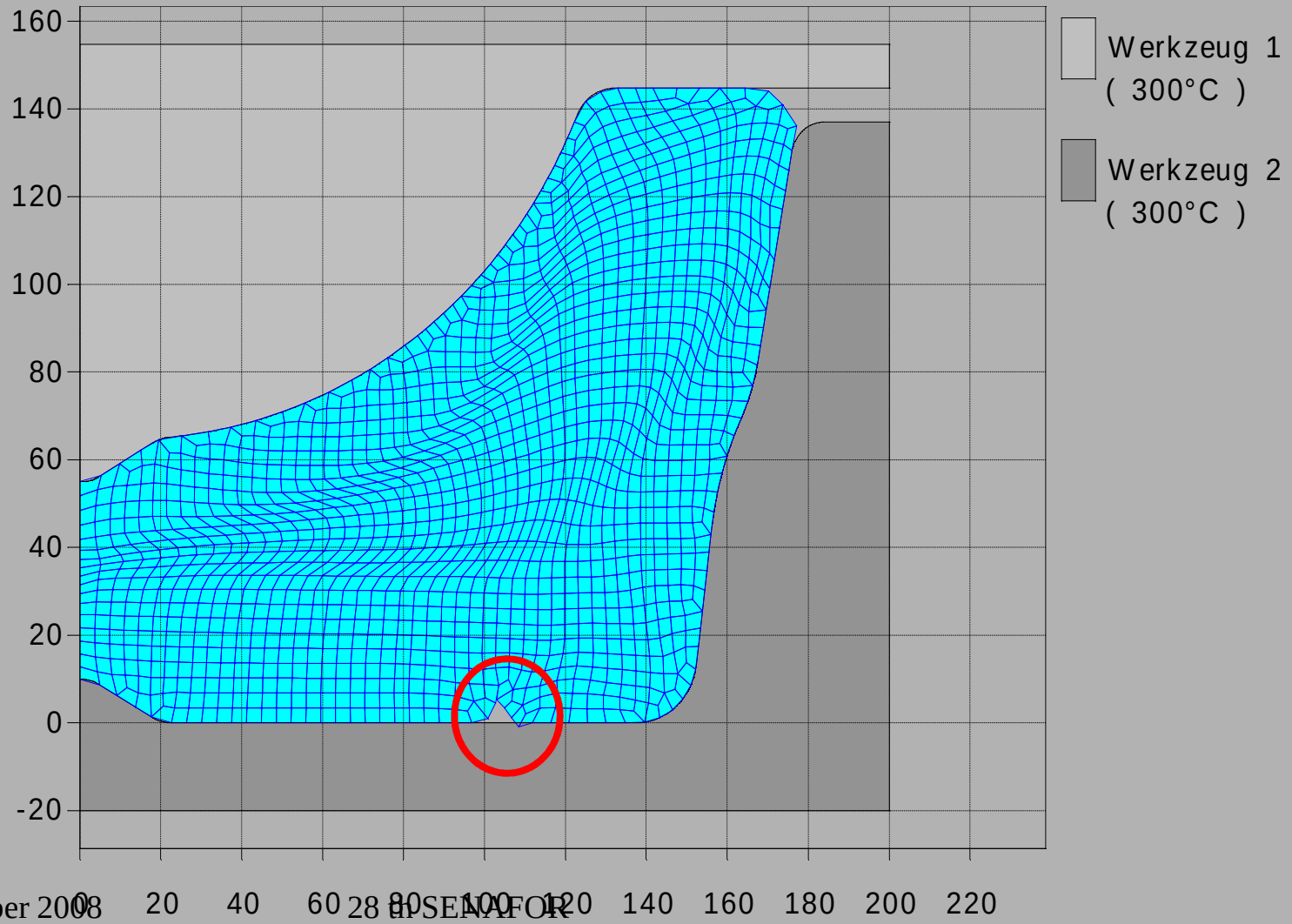
Fliesskurve ist nur zwischen 950 und 1070°C definiert!



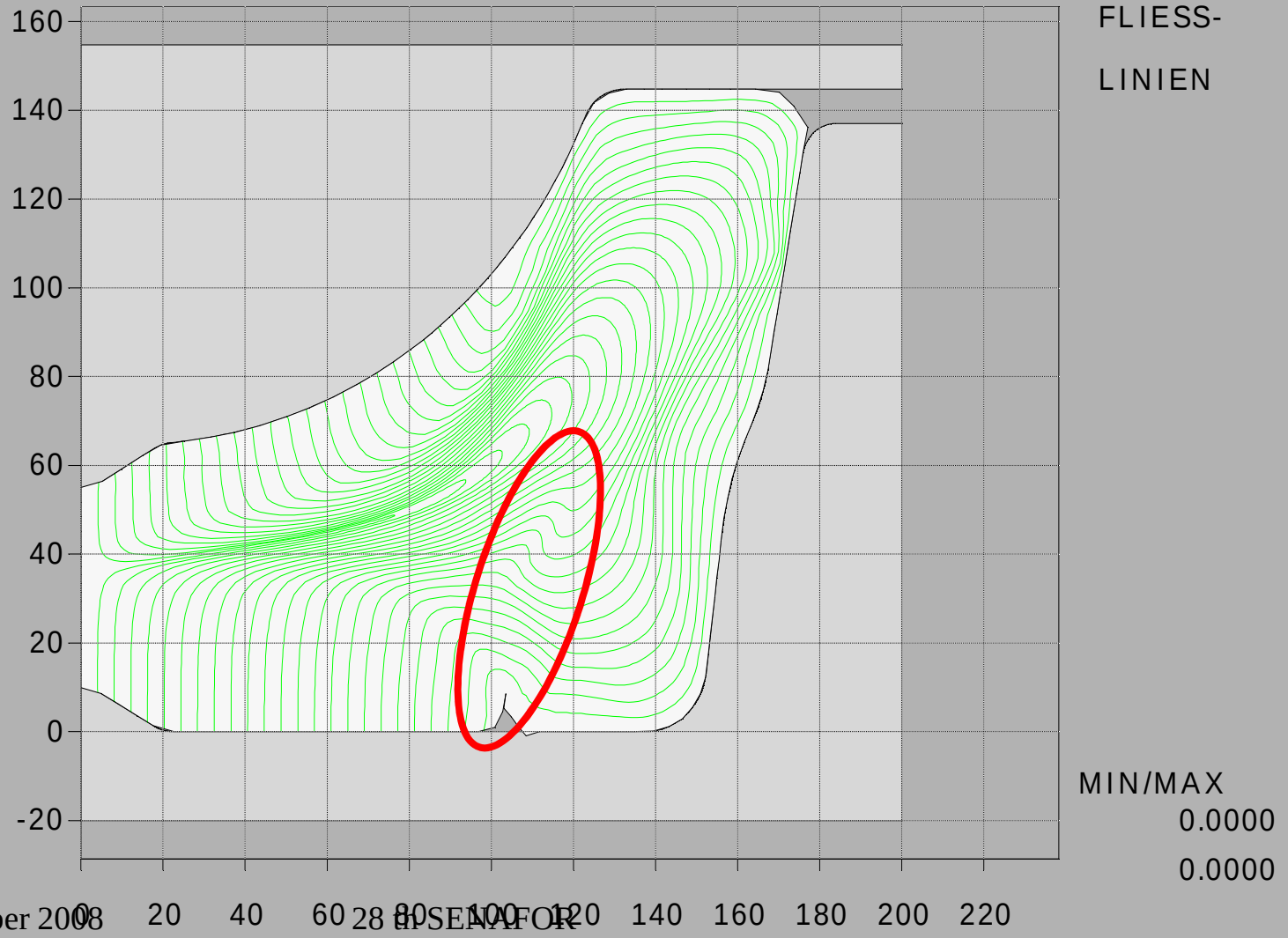
Erweiterung des Temperaturbereichs



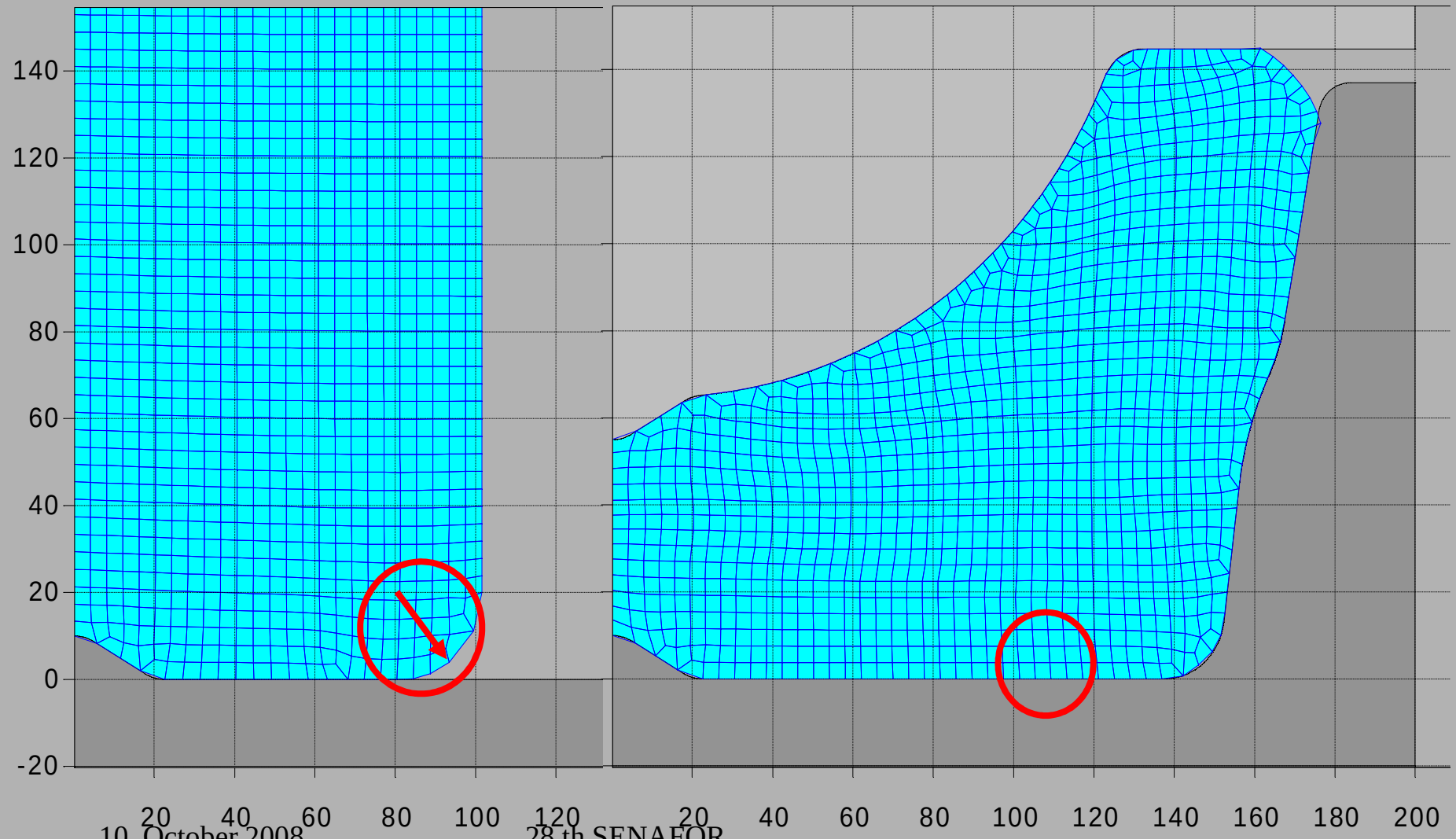
Mit gültigen Fliesskurven wird das Verhalten richtig abgebildet



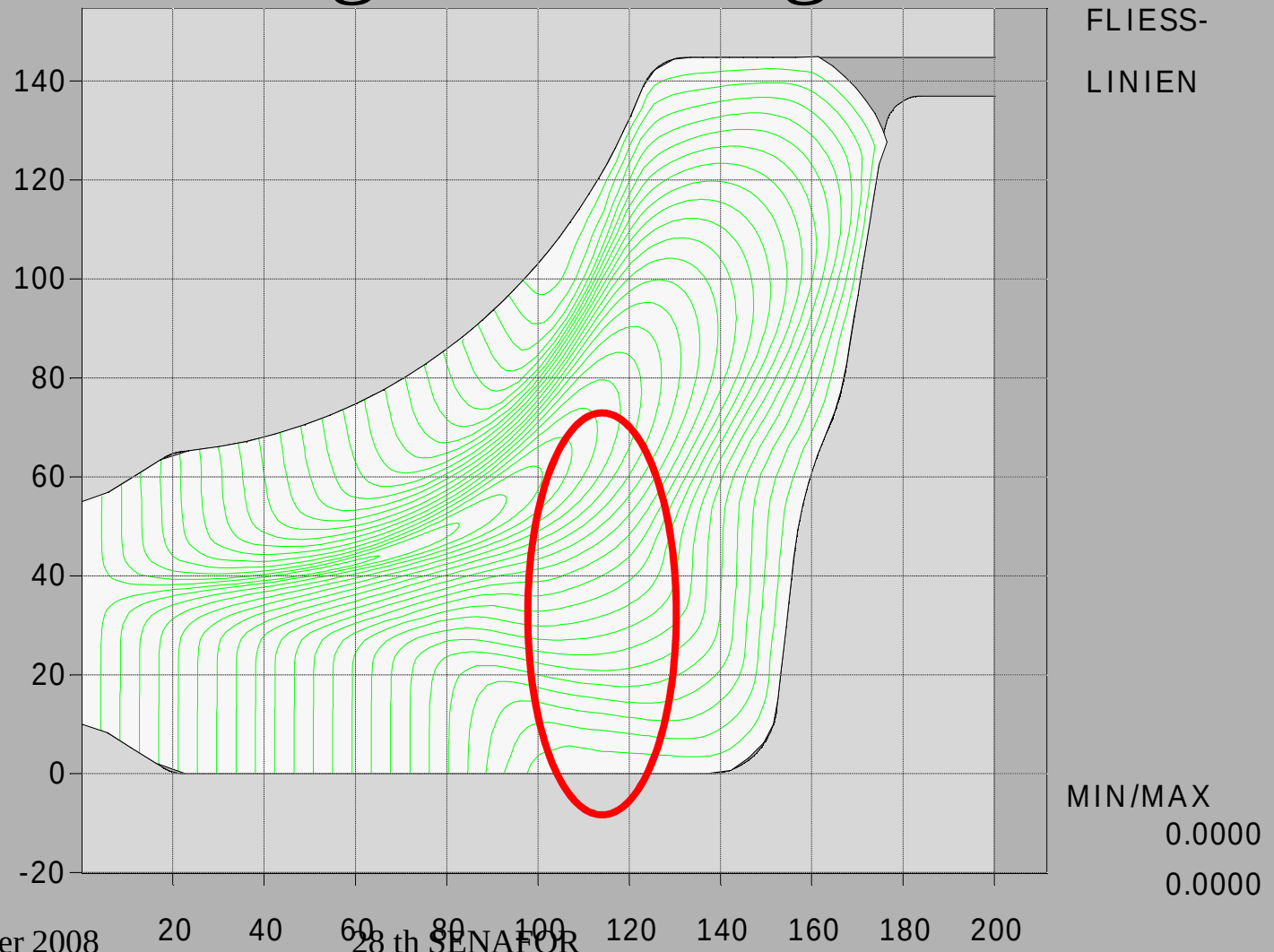
Die Fliesslinien zeigen eine Störung im Stofffluss



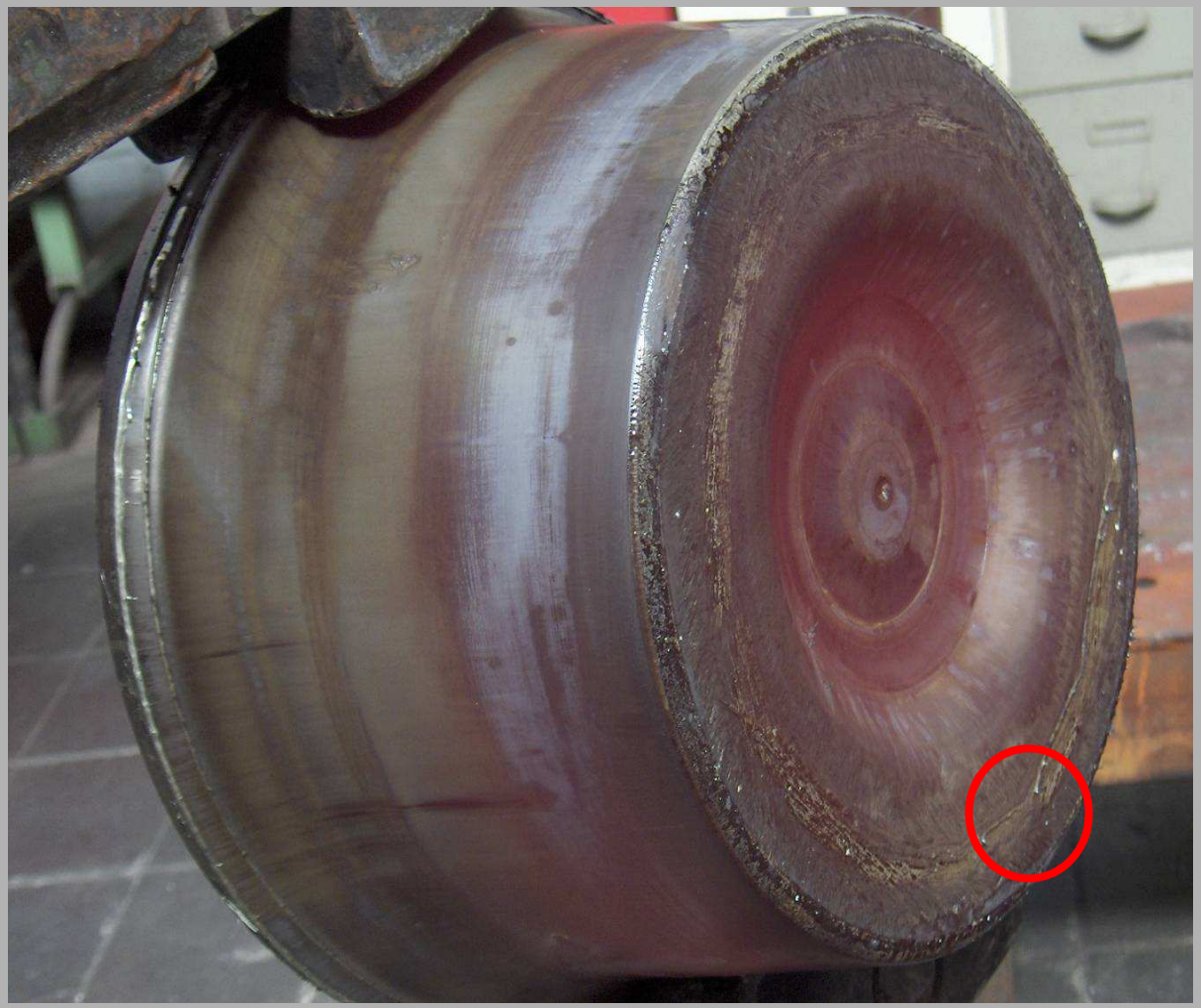
Änderung des Eckenradius auf R = 20 mm – Simulation ohne Fehler



Auch die Fliesslinien laufen jetzt gleichmässig



Das Schmiedeteil zeigt sich nach der Radienänderung fehlerfrei



Fazit:

- korrekte Simulationsergebnisse setzen (u.a.) gültige Fliesskurven voraus
- Gültig bedeutet für die Benutzung von Tabellen:
  Fliesskurven müssen im gesamten Temperatur-, Geschwindigkeits- und Umformgradfeld, das während der Simulation berechnet wird, Stützwerte aus Messungen besitzen

Project schedule (part 1)

Pre - Phase: October 2005

Project Start: December 2005 / January 2006

Contact with potential participants: January 2006

Final agreement about participation between the partners: till March 2006

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Participating research institutes and their activity in the project

IAM Duisburg	Cold	Hot
Anonymous 1 (cancelled)		
IEHK Aachen		Hot
IFU Stuttgart	Cold	Hot
IFUM Hannover	Cold	Hot
Anonymous 2 (later stopped)	Cold	Hot
IMFT Freiberg	Cold	Hot
LFT Erlangen	Cold	Hot
Anonymous 3 (later stopped)	Cold	Hot
Anonymous 4 (cancelled)		

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Participating Industry

CDP Bharat	Specimens provided (hot)
Hatebur	
Hirschvogel	Specimens provided (cold and hot)
Leistriz	
IMU	
Tekfor	
Daimler Chrysler	
Gerlach	

Project schedule (part 2)

Specification of specimen shapes by the institutes: till Mai 2006

Agreement with two ind. Partners to make the specimens: till Mai 2006

Specimen drawings sent to the industrial partners: 02. 06. 2006

Specimens for the cold tests sent to the institutes: 09. 10. 2006

First results of Yield stress – strain curves (cold): 13.03.2007

First project meeting: 14.03.2007

Project schedule (part 3)

Specimens for the hot tests sent to the institutes: 16. 03. 2007

Further results of Yield stress – strain curves (cold): : till 17.12.2007

Results of Yield stress – strain curves (reference test - cold): till 17.12.2007

Further results (cold) related to ‘specimen shape‘ and ‘corrections‘: till 17.12.2007

First results of Yield stress – strain curves (hot): till 17.12.2007

Second project meeting: 18.12.2007

Project schedule (part 4)

Corrected results for the reference test (cold): till 05.05.2008

Results for the reference test (hot): till 05.05.2008

Third project meeting: 05.05.2008

Corrected results for the reference test (hot): July 2008

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Werkstoffauswahl (Industriebefragung)

Werkstoff-Nr.	Werkstoff-bezeichnung	Werkstoffnorm	Firmen Kalt	Firmen Warm	Firmen Halbwarm
EN AW-5754	EN AW-Al Mg3	DIN EN 573-3 : 2003-10	EJOT		
EN AW-6060	EN AW-Al MgSi	DIN EN 573-3 : 2003-10	EJOT		
EN AW-7075	EN AW-Al Zn5,5MgCu	DIN EN 573-3 : 2003-10	EJOT		
	AlSi1Mg			CDP Bharat (400…520)	
	AlSi1MgCu			CDP Bharat (400…520)	
	AlMgSiCu			Hirschvogel	
1.0214	QST 36-3 / 10 C 10	DIN 1654 / EN 10263-2	TEXTRON		
1.0205	Rst 36-2		TEXTRON		
1.0234	QSt 38-3 / C 15 C	DIN 1654 / EN 10263	TEXTRON		
1.0303	QSt 32-3		TEXTRON		
1.0503	C45	DIN EN 10250-2 (12/1999), DIN EN 10277-2 (10/1999)	Presta 20,100,200,250,300,350,400,450,500 °C		Presta
1.0535	C55	DIN EN 10250-2 (12/1999)	Presta 20,100,200,250,300,350,400,450,500 °C		Presta
1.1132	Cq 15	DIN 1654 / EN 10263	TEXTRON		
1.1152	Cq 22		TEXTRON		
1.1192	Cq45	DIN EN 10263-4 (02/2002)	Presta		Presta
1.1199	49MnVS 3			Fridingen	
1.1213	Cf53		GKN, Daimler	GKN, Daimler	GKN, Daimler
1.1303	38MnSV6			Fridingen	
	38MnVS5			Gerlach, Daimler	
	38MnSi6			CDP Bharat (650...950)	CDP Bharat (650...950)
1.1352	30MnVS6			Fridingen, Daimler	
1.1519	17CrNi6			Fridingen	Fridingen
1.4016	X 6 Cr17		TEXTRON		
1.4301	X 5 CrNi 1810		TEXTRON		
	X 5 CrNi Cu 189		TEXTRON		
1.4305	X8CrNiS 18-9			Fridingen	Fridingen
1.4541	X 6 CrNiTi 1810		TEXTRON		
1.5213	27MnSV6			Fridingen	
1.5508	22 B2 / 23 B2	DIN 1654 / EN 10263	TEXTRON		
1.5508	25 CrB2		TEXTRON		
1.5508 (Sondergüte)	18 B3 / 23 B2	DIN 1654 / EN 10263	TEXTRON		
1.5511	35 B2	DIN 1654 / EN 10263	TEXTRON		

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Werkstoffauswahl (Industriebefragung)

Werkstoff-Nr.	Werkstoff-bezeichnung	Werkstoffnorm	Firmen Kalt	Firmen Warm	Firmen Halbwarm
1.5535	23MnB4	DIN EN 10263-4	EJOT, Textron		EJOT
1.6580	30CrNiMo8			Fridingen	Fridingen
1.6587	17CrNiMo6			Fridingen	Fridingen
1.7015	15Cr3		Daimler		
1.7018	9 SMnPb28			Fridingen	Fridingen
1.7034	37 Cr4		TEXTRON		
1.7076	32 CrB4	DIN 1654 / EN 10263-4	TEXTRON		
1.7131	16 MnCr 5		TEXTRON, Daimler, Hirschvogel	CDP Bharat (650...950)	CDP Bharat (650...950)
1.7147	20MnCR5	DIN EN 10084 : 1998-06	GKN, Hirschvogel	Fridingen, GKN	Fridingen, GKN
1.7149	20MnCrS5	DIN EN 10263-3 (02/2002), DIN EN 10277-4 (10/1999)	Presta 20,100,200,250,300,350,400,450,500 °C		Presta
1.7168	20 MnCrB5		TEXTRON		
1.7182	27MnCrB5 2			Fridingen	Fridingen
1.7220	34CrMo4	DIN EN 10263-4	EJOT, Textron, Daimler, Hirschvogel		EJOT
1.7225	42 CrMo 4		TEXTRON	Gerlach	
	42CrMoV4			CDP Bharat (650...950)	CDP Bharat (650...950)
1.7321	20MnCr4		Daimler	Fridingen	Fridingen
1.7323	20MoCrS4	DIN EN 10084 (06/1998), DIN EN 10263-3 (02/2002)	Presta 20,100,200,250,300,350,400,450,500 °C		Presta
1.7325	25MoCr 4			Fridingen	Fridingen
1.7326	25MoCrS4		Presta 20,100,200,250,300,350,400,450,500 °C		Presta
1.7333	22CrMoS3 5			Fridingen	Fridingen
1.7335	15CrMo5			Fridingen	Fridingen
1.7709	21 CrMoV57	DIN 1654 / EN 10263	TEXTRON		
1.8519	31 CrMoV9			Fridingen	Fridingen
	100Cr6			CDP Bharat (650...950)	CDP Bharat (650...950)
	70MnVS4			Daimler	
	C70S6			Daimler	
	23MnCrMo5		Daimler		
	21NiCrMoS6		Hirschvogel		
	SAE1050				Hirschvogel
2.4668	Inco718			Leistriz	
3.7164	Titan64	TiAl6V4		Leistriz	
	Ti6246			Leistriz	
	Ti6242			Leistriz	
	Ti834			Leistriz	
	Ti829			Leistriz	
	Ti811			Leistriz	
	Ti679			Leistriz	
	Aluminium2618	UNSA92618		Leistriz	

Materials and testing parameters

Cold

Material:		**16 Mn Cr S 5**
Temperatures:		**20°C, 100°C, 200°C**
Strain rates	**:**	**0,1/sec, 1,0/sec, 10,0/sec**

Hot

Material:		**38 Mn Si V S 5**
Temperatures:		**800°C, 950°C, 1100°C**
Strain rates	**:**	**0,1/sec, 1,0/sec, 10,0/sec**

Available results for the yield stress- strain curves (cold), phase 1

	20°C			100°C			200°C		
	0.1	1	10	0.1	1	10	0.1	1	10
MPIE									
IAM									
LFT									
IMFT									
IFUM									
IFU									

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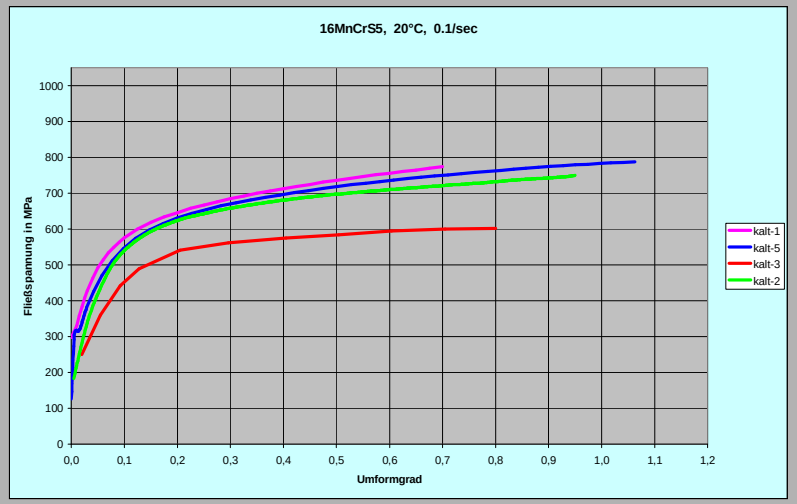
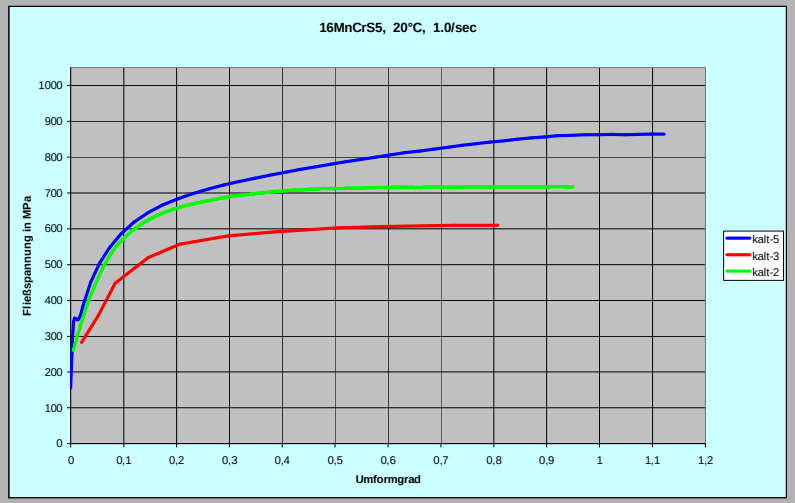
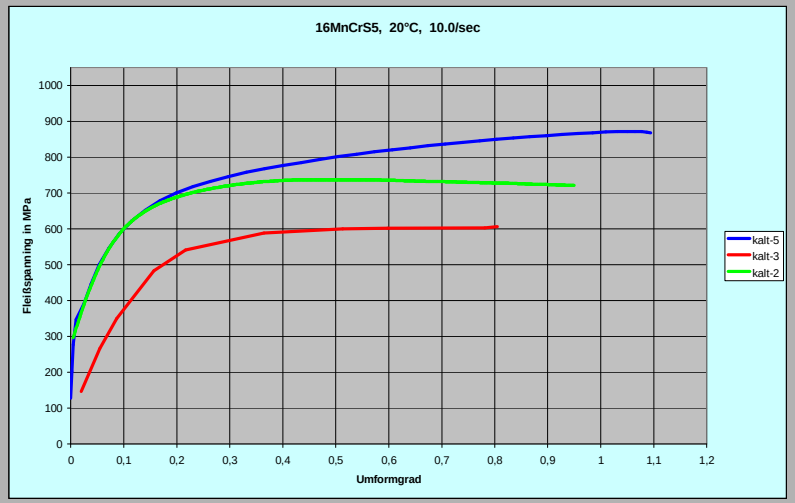
Available results for the yield stress- strain curves (cold), phase 1

here: T = 20°C







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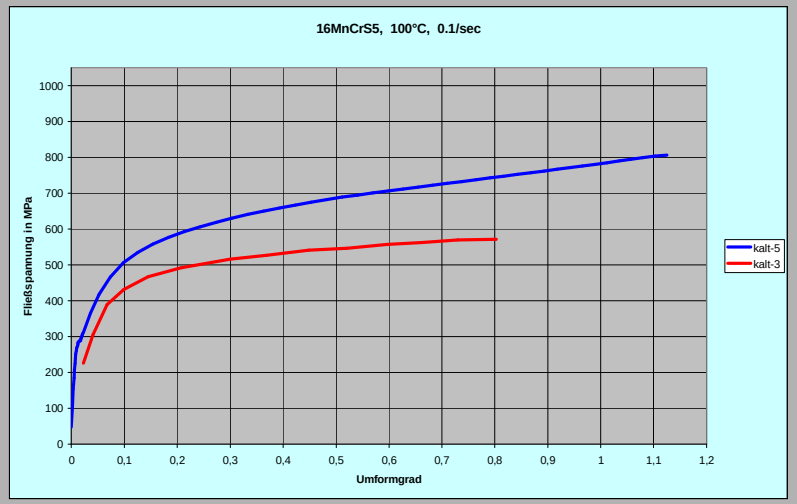
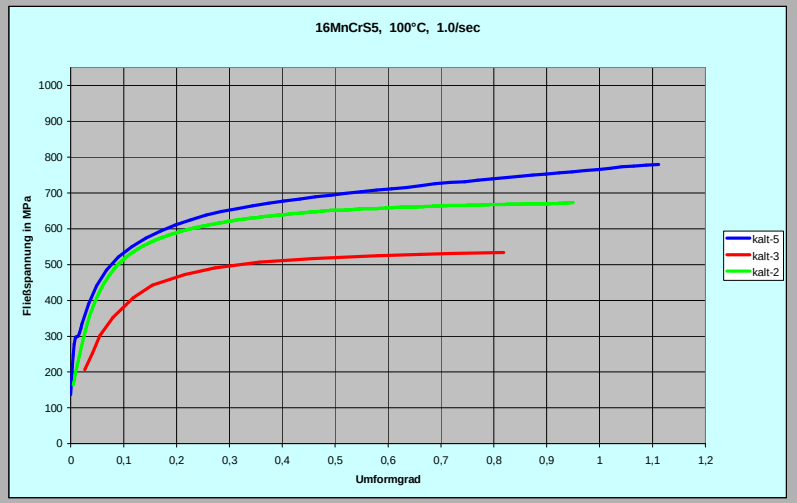
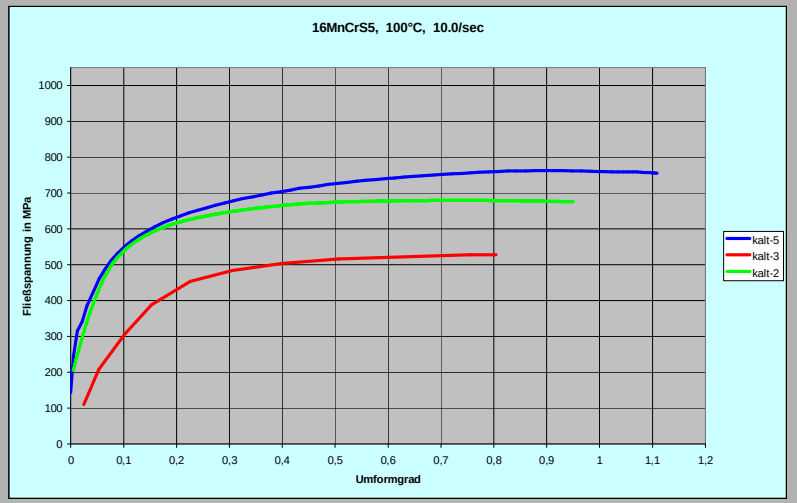
Available results for the yield stress- strain curves (cold), phase 1

here: T = 100°C







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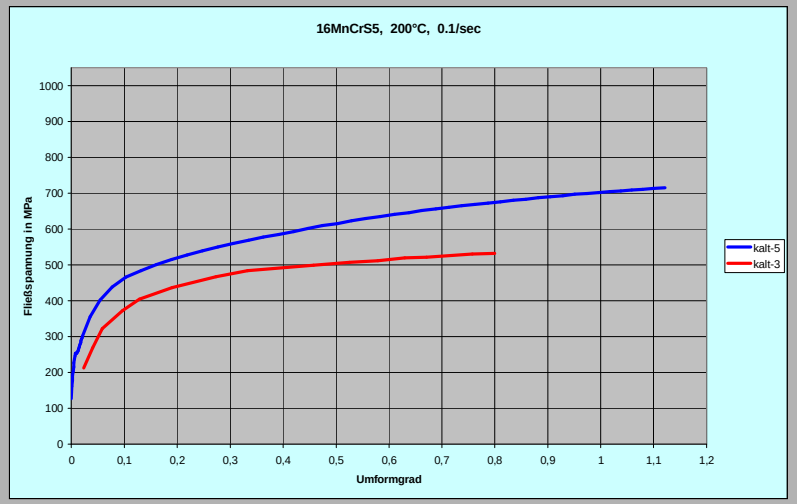
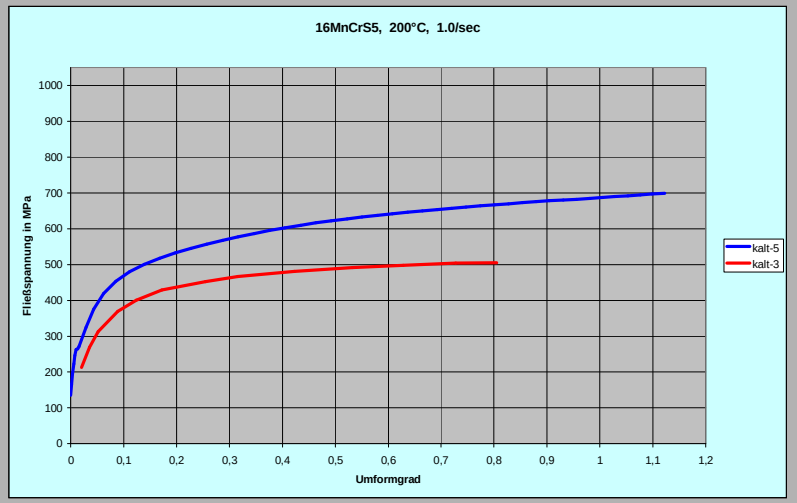
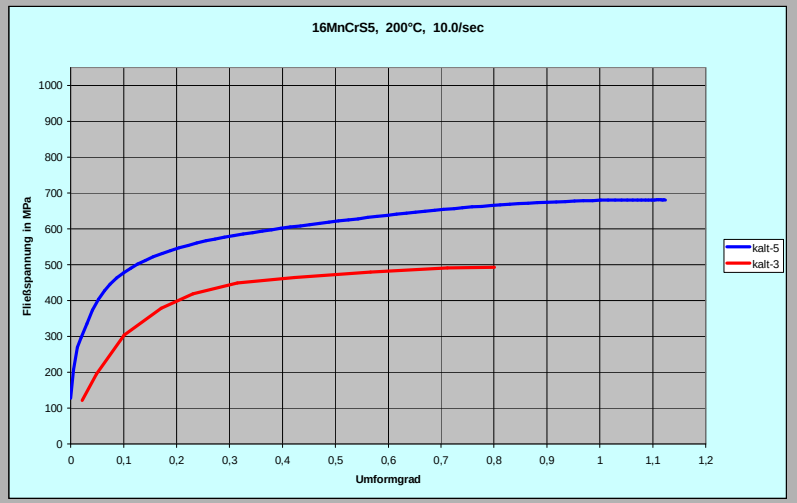
Available results for the yield stress- strain curves (cold), phase 1

here: T = 200°C







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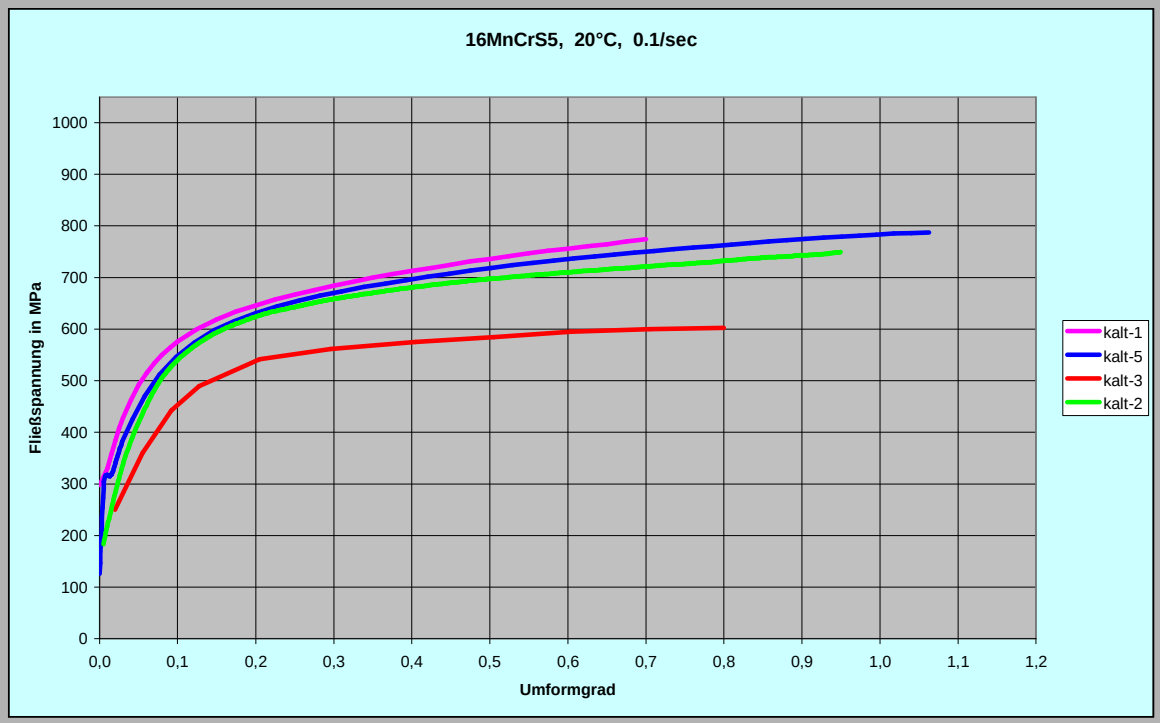
Remarkable deviation: results of kalt-3 are about 15-20% lower than all other results



Assumption: systematic failure in the measurement and/or data processing => re-check !

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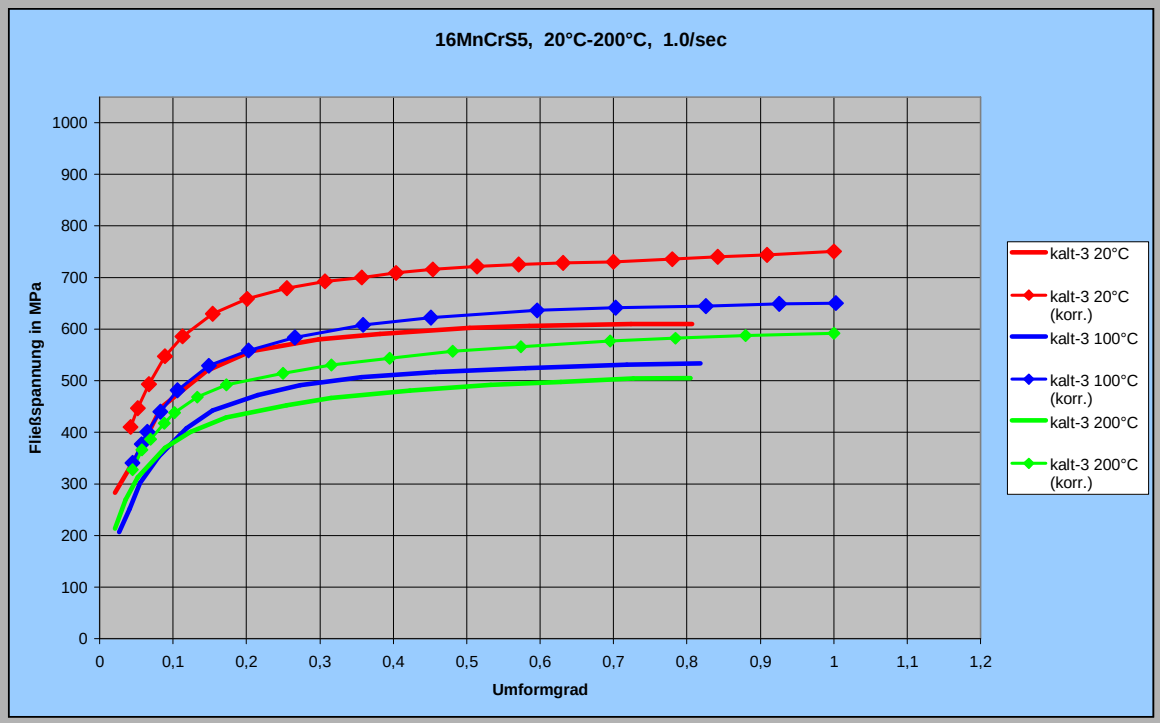
Results of the re-check: failure in the calibration of a sensor



Result: elevated level of stress at all temperatures

Available results for the yield stress- strain curves (cold), phase 2

	20°C			100°C			200°C		
	0.1	1	10	0.1	1	10	0.1	1	10
MPIE	■	■	■	■	■	■	■	■	■
IAM	■	■							
LFT	■								
IMFT	■	■	■	■	■	■	■	■	■
IFUM	■	■	■		■	■			
IFU		■	■		■	■		■	■

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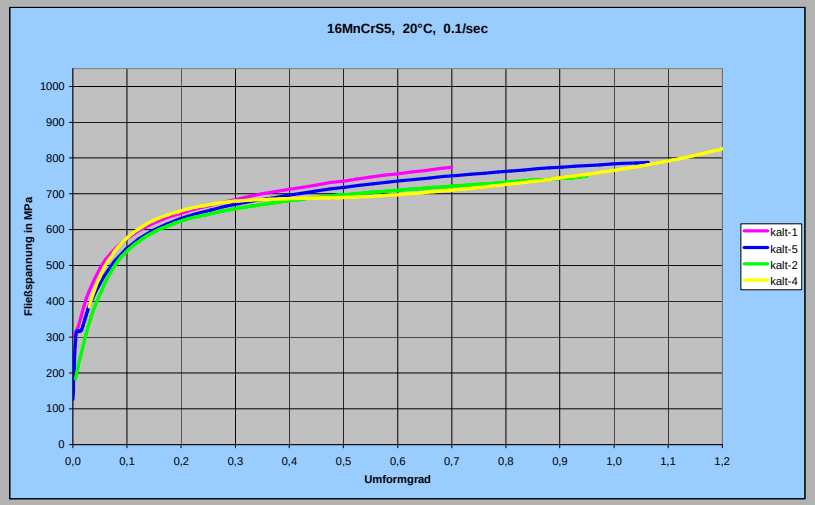
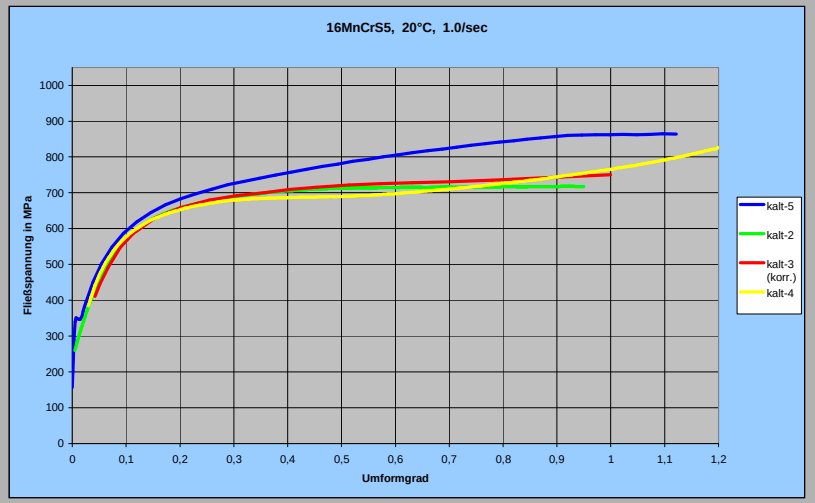
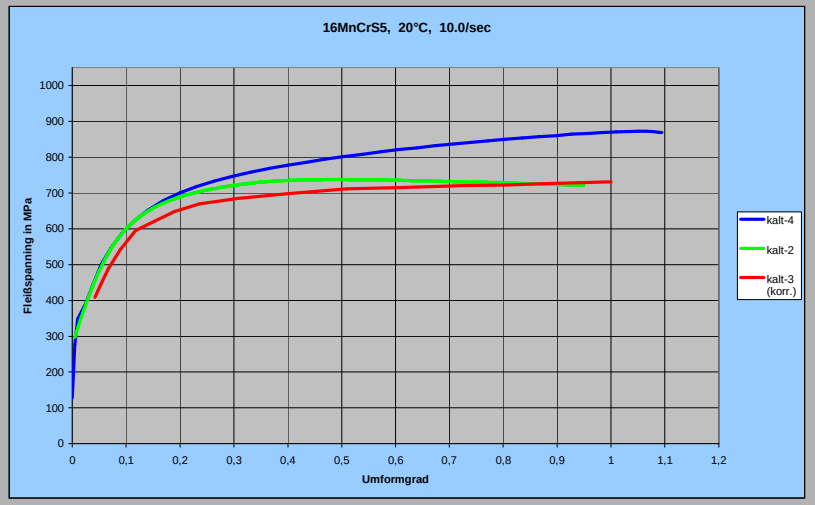
Available results for the yield stress- strain curves (cold), phase 2

here: T = 20°C







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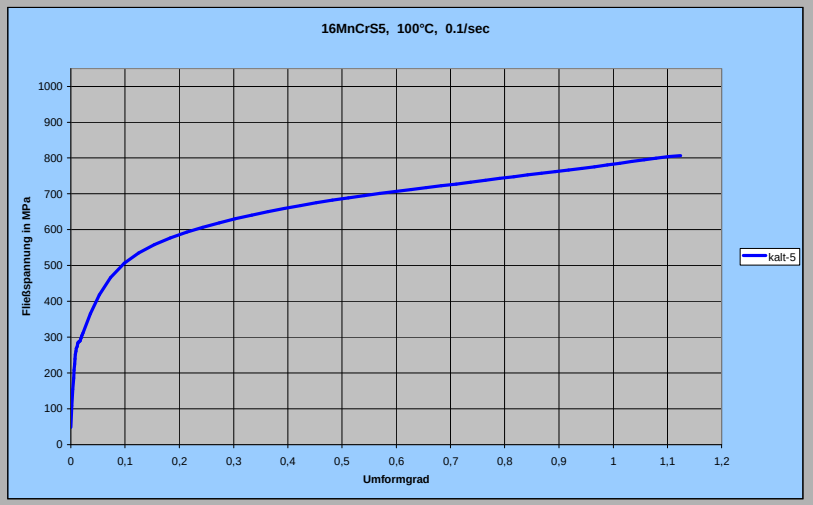
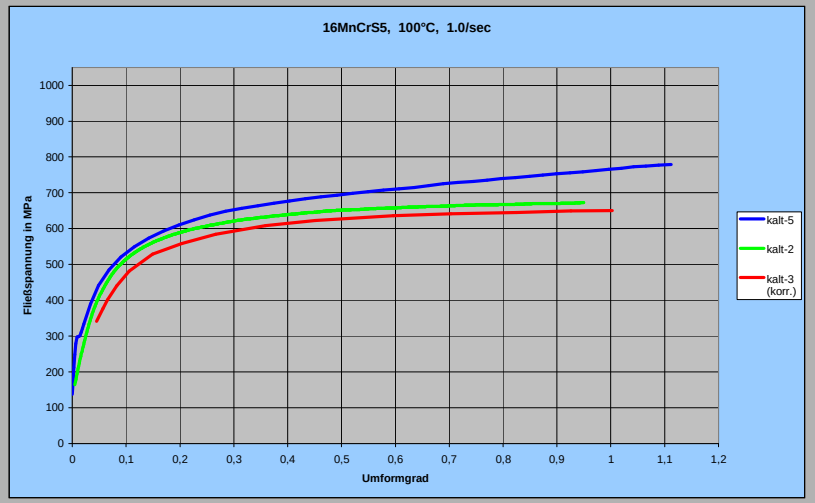
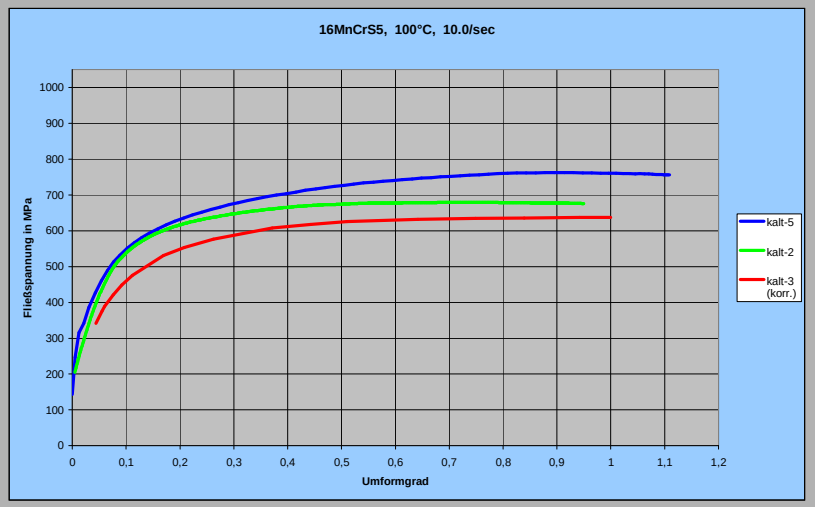
Available results for the yield stress- strain curves (cold), phase 2

here: T = 100°C







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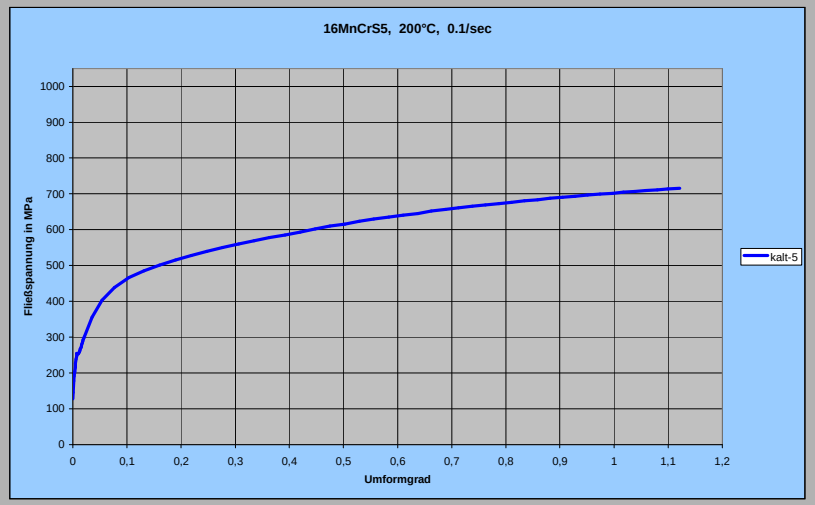
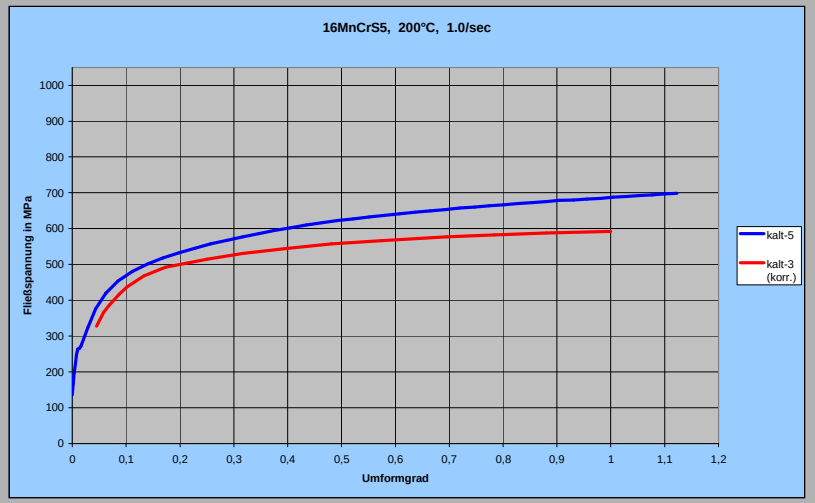
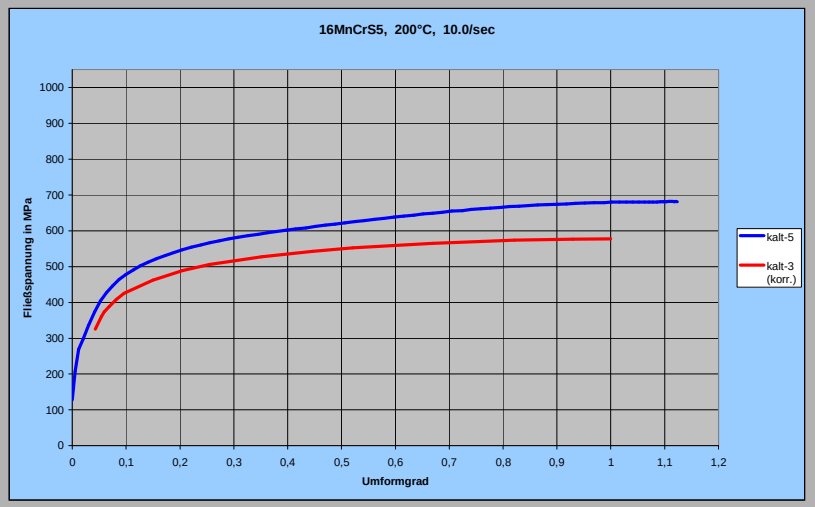
Available results for the yield stress- strain curves (cold), phase 2

here: T = 200°C







Points to be investigated about their influence on the measurements:

- specimen dimension / specimen quality
- specimen shape
- lubrication
- extended methods of data correction

⇒standard test with same specimen geometry, same specimen dimensions and same lubrication

Specimen shape: Cylinder
Lubrication: Teflon
Parameter: Temperature: 20°C, Strain rate: 1.0/sec

=> Further investigations related to specimen shape and correction methods (performed by kalt-5)

Available results for the reference test (cold)

Temperature	20°C
Strain rate	1 1/s
MPIE	
IAM	
LFT	
IMFT	
IFUM	
IFU	

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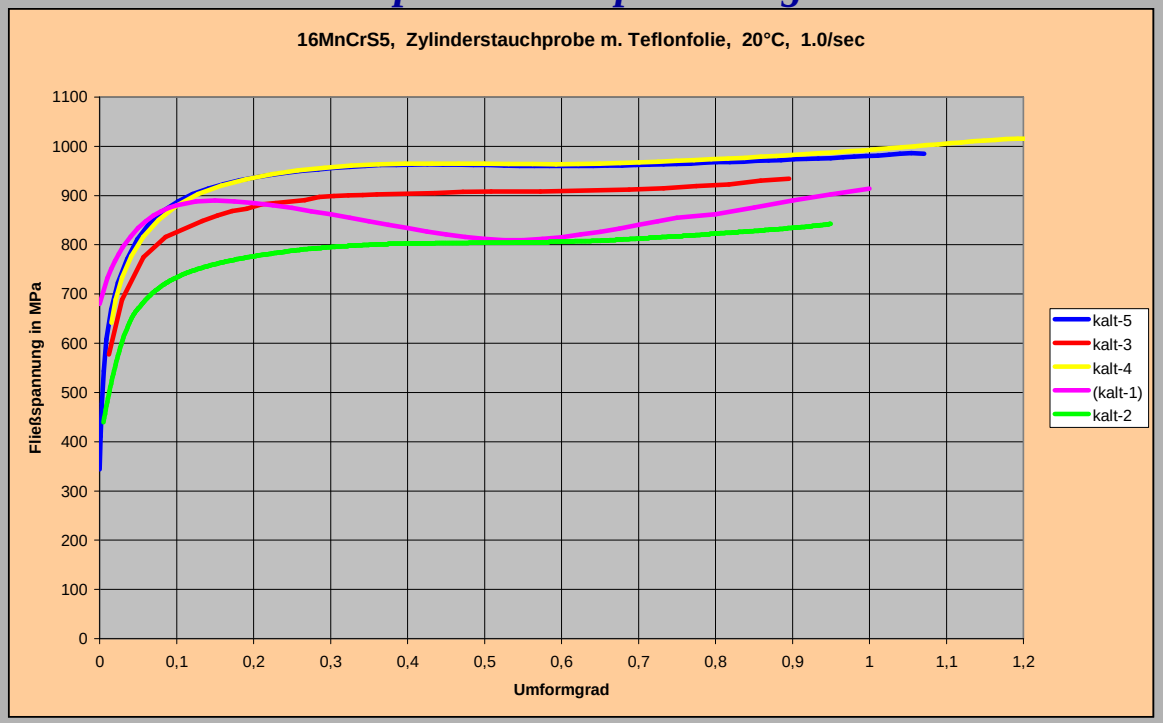
Available results for the reference test (cold)

Rem.: for some technical reason kalt-1 could not provide a precise data processing



Remarkable: too low results of kalt-2, Assumption:
Failure in the measurement or in the data processing
=> to be checked !

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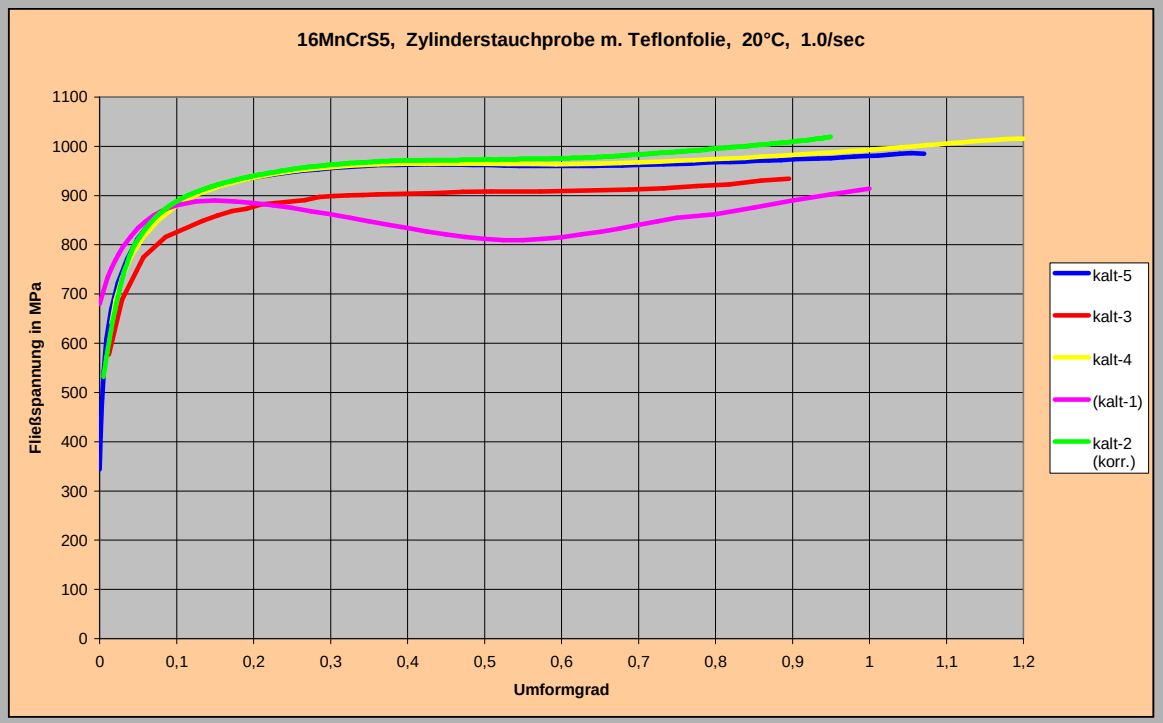
Available results for the reference test (cold) after correction of kalt-2



Result of the check: failure in the data processing software, specimen dimension was not considered correctly.

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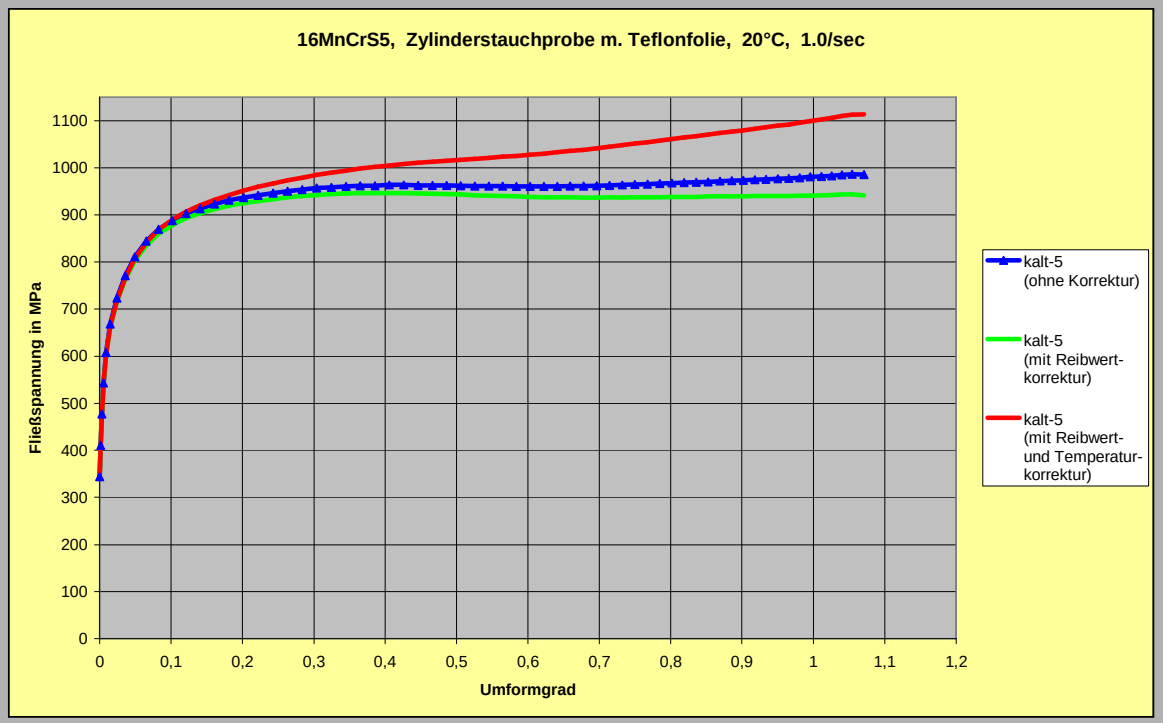
Results related to the correction of temperature and friction (kalt-5)



hier: Zylinderstauchprobe

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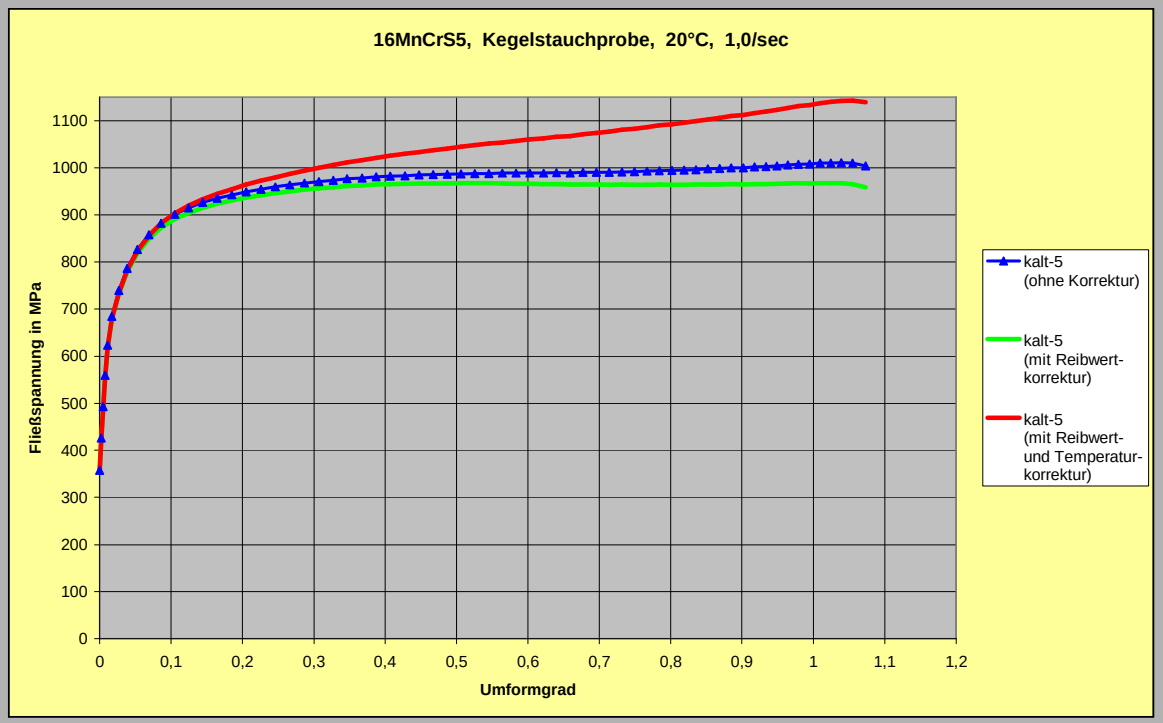
Results related to the correction of temperature and friction (kalt-5)



here: conical specimen

Available results for the yield stress – strain curves (warm)

	800°C			950°C			1100°C		
	0.1	1	10	0.1	1	10	0.1	1	10
MPIE	■	■	■	■	■	■	■	■	■
IAM									
LFT	■	■		■	■				
IMFT	■	■	■	■	■	■	■	■	■
IFUM	■	■	■	■	■	■	■	■	■
IEHK	■	■	■	■	■	■	■	■	■

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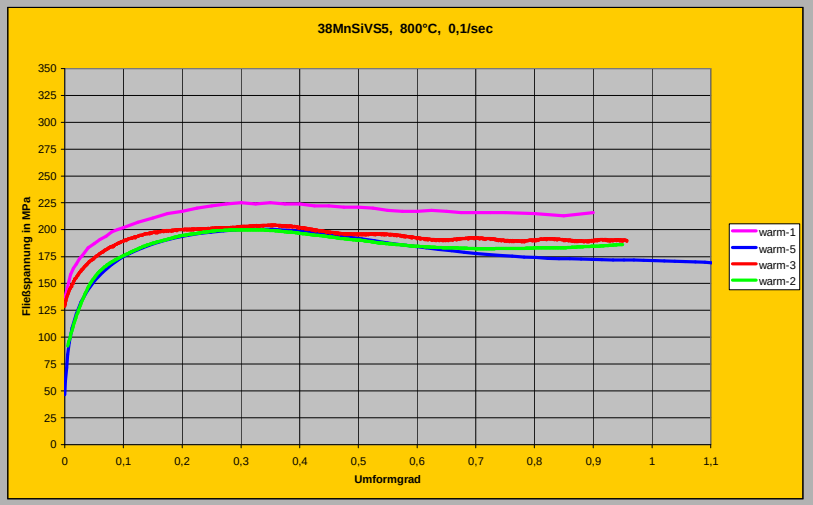
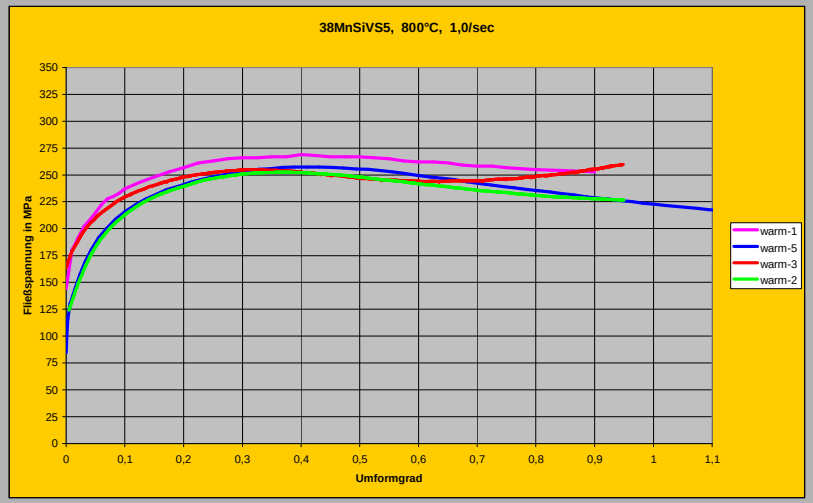
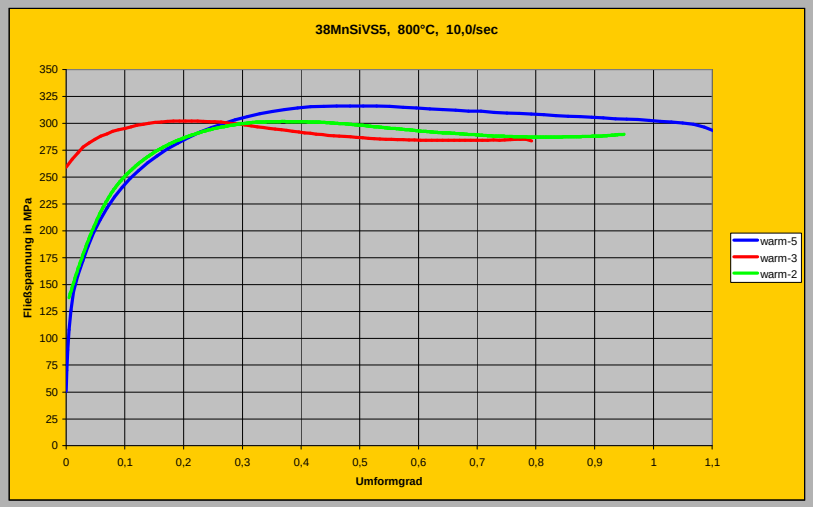
Available results for the yield stress – strain curves (warm)

here: T = 800°C







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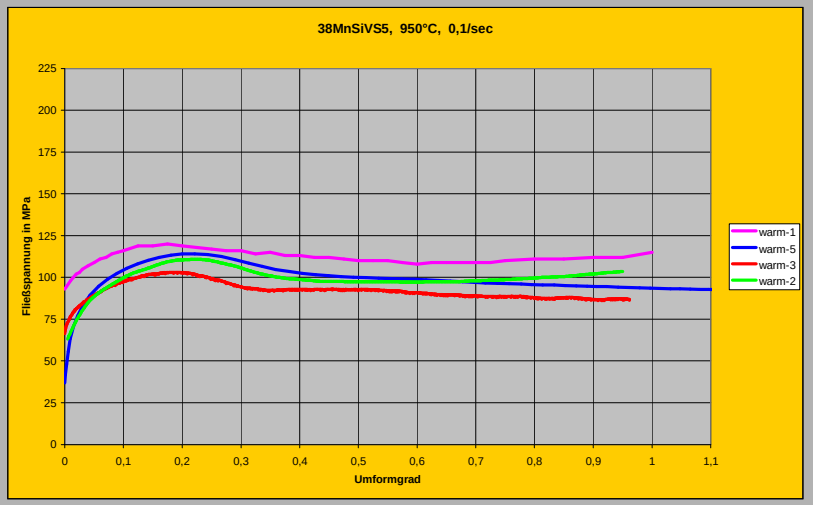
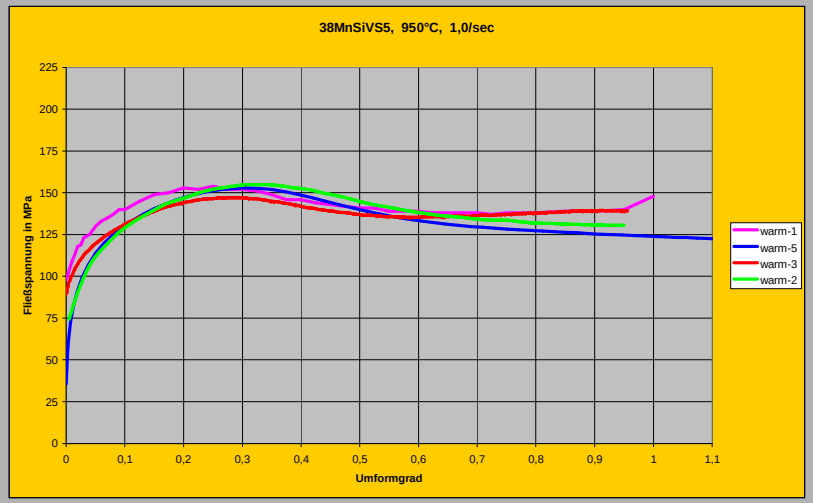
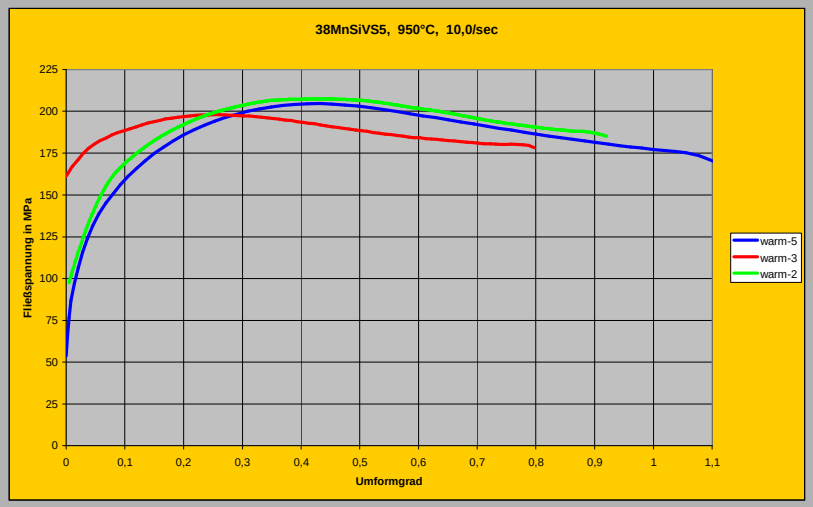
Available results for the yield stress – strain curves (warm)

here: T = 950°C







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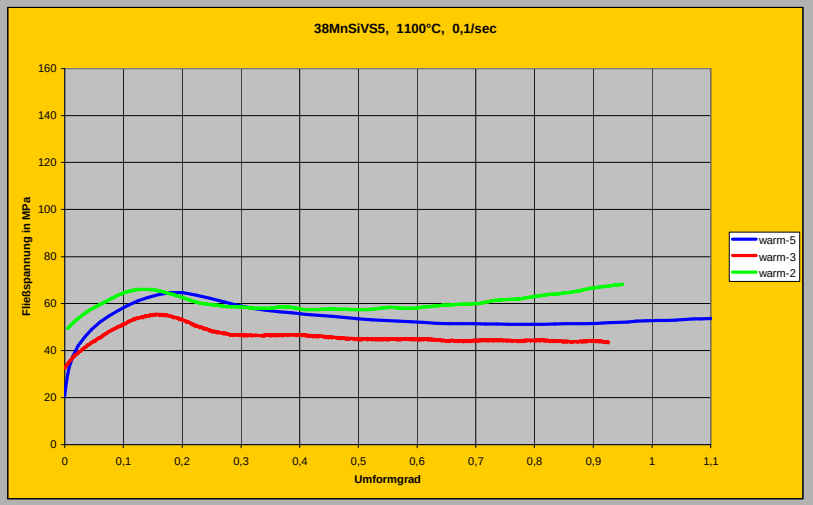
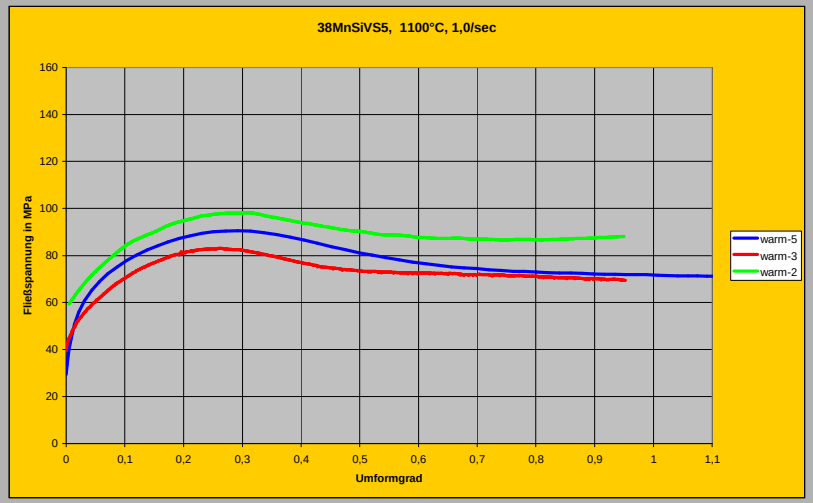
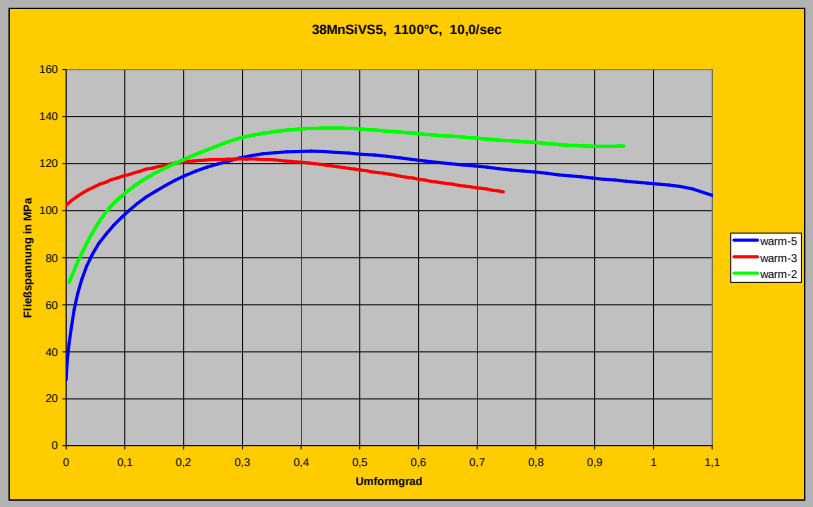
Available results for the yield stress – strain curves (warm)

here: T = 1100°C







Points to be investigated about their influence on the measurements:

- specimen dimensions
- specimen shape
- lubrication
- determination of the yield point
- heating procedure

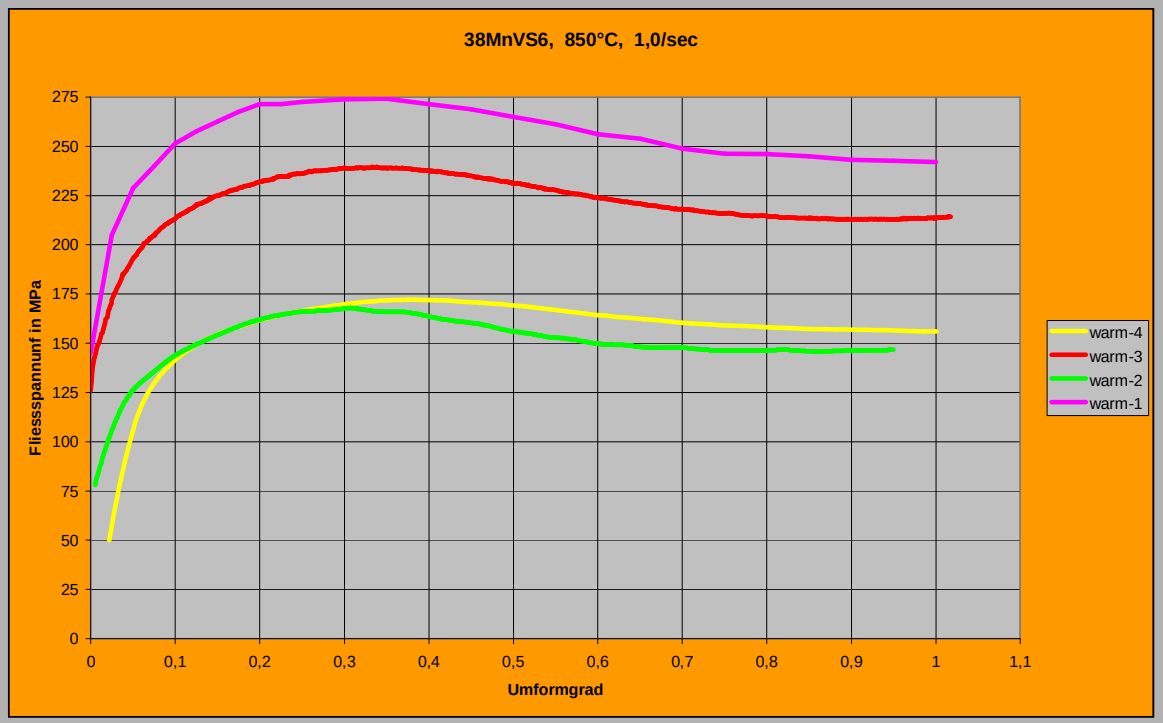
⇒standard test with same specimen geometry, same specimen dimensions and same lubrication

specimen form: cylinder
lubrication: Lubrodal BN
Parameter: temperature: 850°C, strain rate: 1.0/sec

Results of the reference test (hot)

Temperature	850°C
Strain rate	1 1/s
IAM	
LFT	
IMFT	
IFUM	
IEHK	

Reference test (original)



remarkable: too low results of warm-2 and warm-4,
questionable results of warm-1 => to be checked again !

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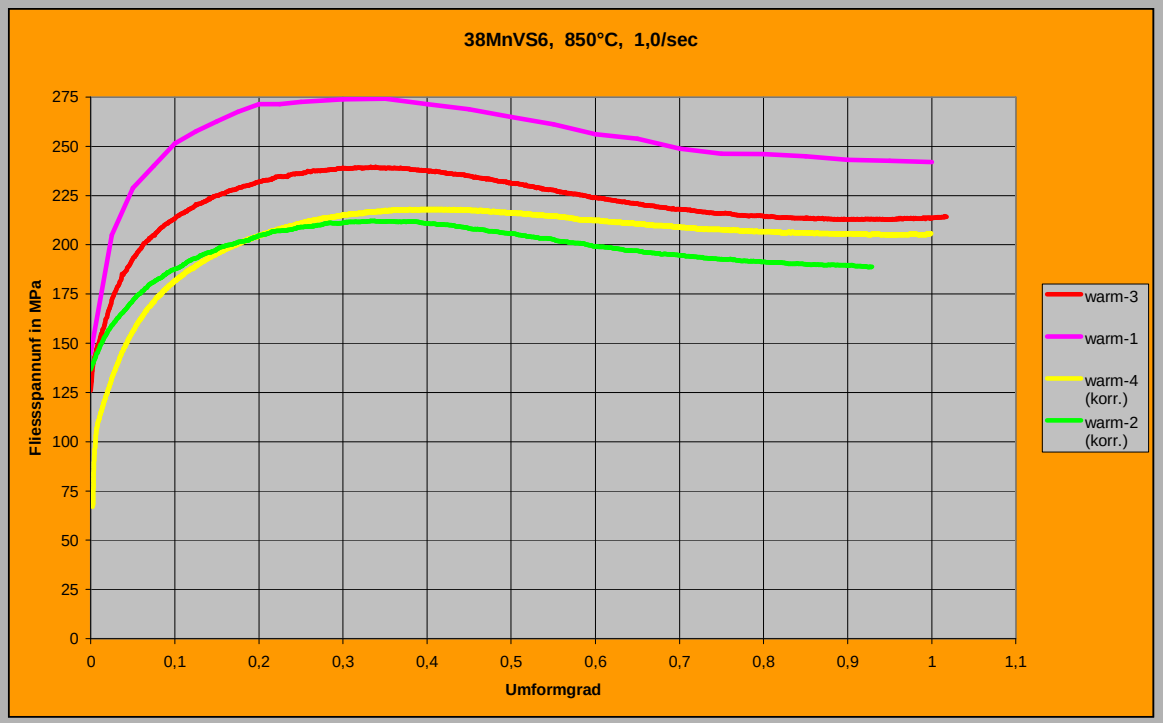
Reference test after corrections of warm-2 and warm-4



Results of the check: incorrect data processing (warm-2), wrong strain rate (warm-4), insufficient and inhomogeneous heating (warm-1).

Result of the project
„Richtlinie zur Fließkurvenaufnahme“
by CPM together with the participating institutions

The guideline formulates requirements like:

- form of specimen
- least number of specimens to be tested
- tooling
- lubrication
- setup of the testing machines
- measurement techniques
- data processing
- documentation