IMPaCT

EPSRC Centre for Doctoral Training in Innovative Metal Processing (IMPaCT)

Determination of No-Creep and Negligible Creep Temperatures using Accelerated Testing Methods

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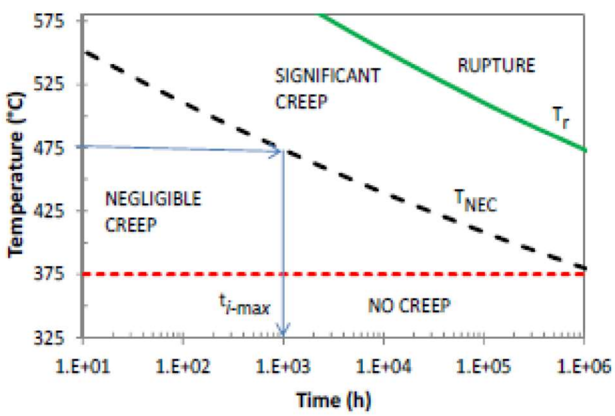
Recap

Principle of defining 'no-creep' and 'negligible creep' temperatures - EN13445-3



(10^6 hours later revised to 2.10^5 hours in committee).

T_{NEC} negligible creep curve is defined as the temperature that causes 0.2% creep strain in a specified time

T_{NC} no-creep temperature (permissible creep deformation 0.2% at 200khr)

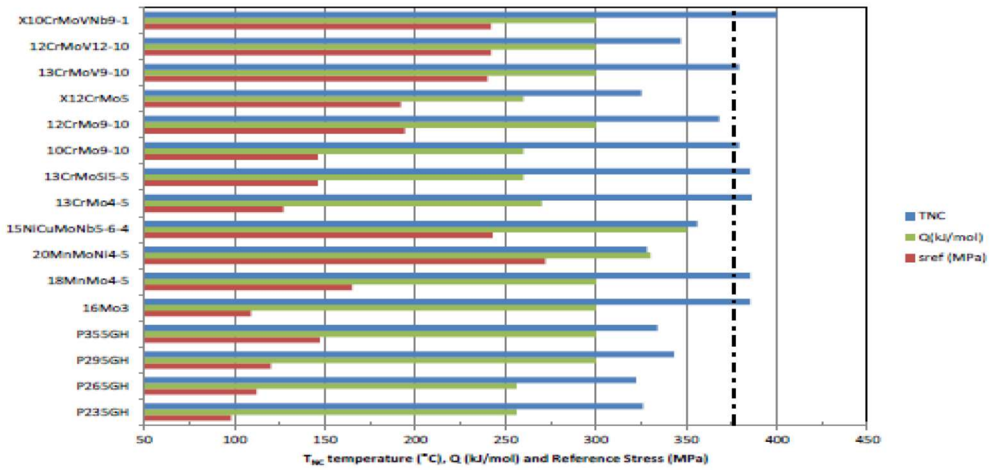
This 'no creep' temperature is traditionally 375°C (ferritic/martensitic) and 425°C (austenitic) steels (pressure vessels and pipework)

Reference stress (F/M), $s_{ref} = 2/3.Rp_{0.2\ min/T}$.

(Holmström 2016)

Material ‘no-creep’ temperature Ferritic/Martensitic

Holmström (2017) establishes no creep temperature (TNC) calculated from EN standard strength values using a time factor (RTF) to estimate time to 0.2% strain from rupture data



Several materials appear to have a ‘no-creep’ temperature below the ‘classical’ 375°C (ferritic/martensitic) limit

Reference Stress, s_{ref} ,

BS EN 13445-3:2014+A2:2016
EN 13445-3:2014+A2:2016 (E)
Issue 3 (2016-07)

6 Maximum allowed values of the nominal design stress for pressure parts

Table 6-1 — Maximum allowed values of the nominal design stress for pressure parts other than bolts

Steel designation	Normal operating load cases[a b]	Testing and exceptional load cases[b c]
Steels other than austenitic, as per 6.2 $A < 30\,\%$[d]	$f_d = \min\left(\frac{R_{p0,2/T}}{1{,}5}; \frac{R_{m/20}}{2{,}4}\right)$	$f_{test} = \left(\frac{R_{p0,2/T_{test}}}{1{,}05}\right)$
Steels other than austenitic, as per 6.3. Alternative route $A < 30\,\%$[d]	$f_d = \min\left(\frac{R_{p0,2/T}}{1{,}5}; \frac{R_{m/20}}{1{,}875}\right)$	$f_{test} = \left(\frac{R_{p0,2/T_{test}}}{1{,}05}\right)$
Austenitic steels as per 6.4 $30\,\% \le A < 35\,\%$[d]	$f_d = \left(\frac{R_{p1,0/T}}{1{,}5}\right)$	$f_{test} = \left(\frac{R_{p1,0/T_{test}}}{1{,}05}\right)$
Austenitic steels as per 6.5 $A \ge 35\,\%$[d]	$f_d = \max\left[\left(\frac{R_{p1,0/T}}{1{,}5}\right); \min\left(\frac{R_{p1,0/T}}{1{,}2}; \frac{R_{m/T}}{3}\right)\right]$	$f_{test} = \max\left[\left(\frac{R_{p1,0/T\,test}}{1{,}05}\right); \left(\frac{R_{m/T\,test}}{2}\right)\right]$
Cast steels as per 6.6	$f_d = \min\left(\frac{R_{p0,2/T}}{1{,}9}; \frac{R_{m/20}}{3}\right)$	$f_{test} = \left(\frac{R_{p0,2/T_{test}}}{1{,}33}\right)$

Ferritic /Martensitic

Austenitics

a For testing group 4 the nominal design stress shall be multiplied by 0,9.
b Yield strength R_{eH} may be used in lieu of $R_{p0,2}$ if the latter is not available from the material standard.
c See 5.3.2 and 6.1.2.
d For definition of rupture elongation, see EN 13445-2:2014, Clause 4.

BS EN 10028-2:2017
EN 10028-2:2017 (E)

Table 4 — Minimum values for the 0,2 % proof strength at elevated temperatures [a]

Steel grade		Nominal thickness [b] t	Minimum 0,2 % proof strength $R_{p0,2}$ MPa at a temperature in °C of									
Steel name	Steel number	mm	50	100	150	200	250	300	350	400	450	500
P235GH	1.0345	≤ 16	227	214	198	182	167	153	142	133	–	–
		16 < t ≤ 40	218	205	190	174	160	147	136	128	–	–
		40 < t ≤ 60	208	196	181	167	153	140	130	122	–	–
		60 < t ≤ 100	193	182	169	155	142	130	121	114	–	–
		100 < t ≤ 150	179	168	156	143	131	121	112	105	–	–
		150 < t ≤ 250	164	155	143	132	121	111	103	97	–	–
P265GH	1.0425	≤ 16	256	241	223	205	188	173	160	150	–	–
		16 < t ≤ 40	247	232	215	197	181	166	154	[illegible]	–	–
		40 < t ≤ 60	237	223	206	190	174	160	148	[illegible]	–	–
		60 < t ≤ 100	208	196	181	167	153	140	130	[illegible]	–	–
		100 < t ≤ 150	193	182	169	155	142	130	121	[illegible]	–	–
		150 < t ≤ 250	179	168	156	143	131	121	112	[illegible]	–	–
		≤ 16	285	268	249	228	209	192	178	[illegible]	–	–

Min $R_{p0.2,375}$ for the sample size (<=16mm) = 155MPa

s_{ref} = 2/3 x 155 =103MPa

Data Extrapolation motivation

- The blanket generalisation for ferritic/martensitic (375°C) and austenitic materials (425°C) appears too simplistic.
- There is little experimental evidence in the open literature for materials at the relatively low temperature range 350-450°C to validate either the curve (T_{NEC}) or the 'no creep' (T_{NC}) temperature.
- Many of the time-temperature parametric (TTP) models used in creep design do not extrapolate to 375°C – The P355 MH4 Model does.

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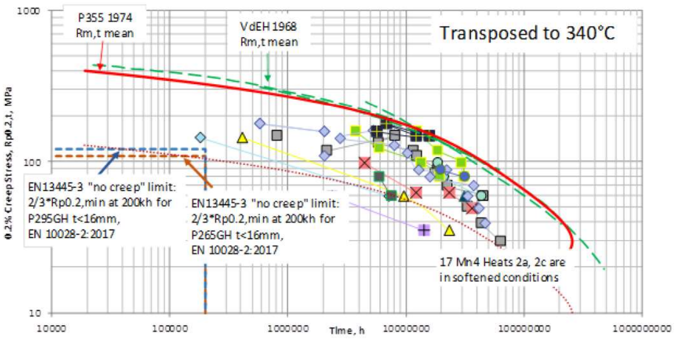
Results from Extrapolating VDEh Data

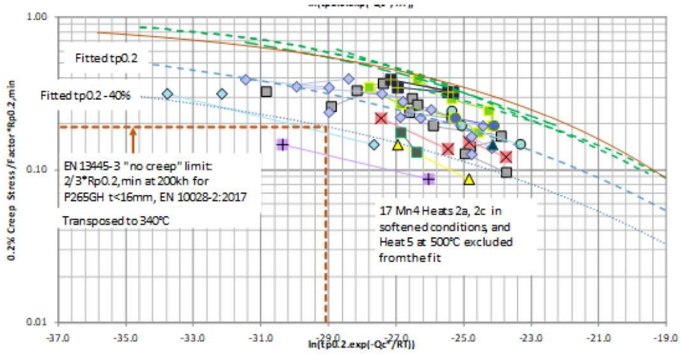
- In general the lower ferritic grades are seen to be creeping below 375°C.
- Higher alloyed steels are seen to have “no creep” temperatures well above current limits allowing opportunities for cost savings in both design and creep monitoring if they were raised.
- Broad agreement with Holmström (2017).

Data Extrapolation (VDEh 1969)- P265GH

MH4 Model



Wilshire model



Both models indicate C-Mn P265GH steel has a 'no creep' temperature (T_{NC}) 340°C

Accelerated creep testing motivation

To determine the ‘no-creep’ and ‘negligible creep’ temperatures of representative heats of three different materials with varying creep properties.

P265GH – a general low grade C-Mn steel used for pressure vessels and piping used up to 400°C

Grade 91 steel

An austenitic 316L(N) (425°C)

Experimental Work

Establish the tensile properties at elevated temperature – material specific reference stress

Use isostress test matrix with high sensitivity creep tests 25°C intervals

Temp °C	375	400	425	450	475
Stress1	x	x	x	x	x
Stress2	x	x	x	x	x

Confirm linear temperature relation over range and extrapolate data

This is the first time this methodology has been used to establish the ‘no creep’ temperature

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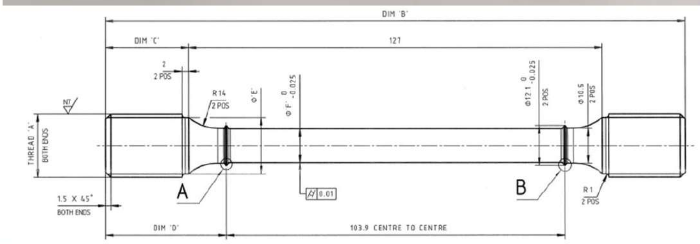
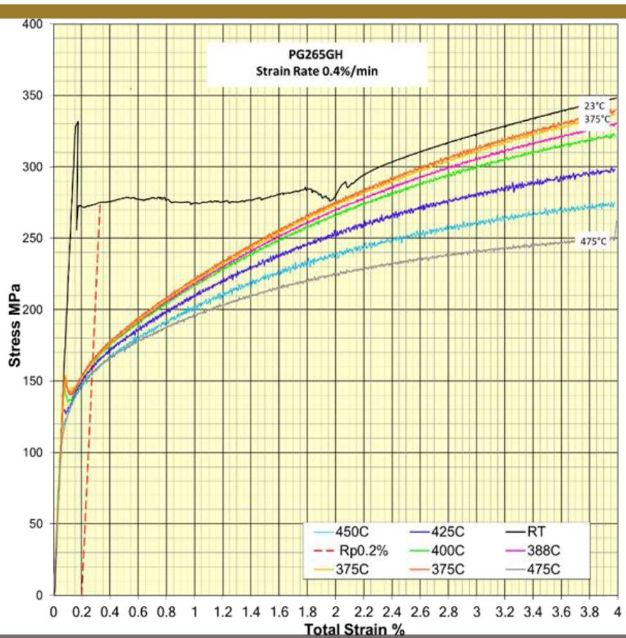
Test Samples



Elevated Temperature Tensile Testing EN6892-2 30mm gauge length 6mm dia.

High Sensitivity Creep Test 170mm overall length 100mm reference length 9mm dia.

P265GH Elevated Temperature Properties



Yield point phenomenon evident

Continues up to 425°C

Lower yield point 140MPa @ 375°C

Rp0.2,T over a very limited range from 375-475°C (155-165MPa)

Curves rise steeply up to 4% strain

Material specific reference stress

BS EN 13445-3:2014+A2:2016
EN 13445-3:2014+A2:2016 (E)
Issue 3 (2016-07)

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a For testing group 4 the nominal design stress shall be multiplied by 0,9.
b Yield strength R_{eH} may be used in lieu of $R_{p0,2}$ if the latter is not available from the material standard.
c See 5.3.2 and 6.1.2.
d For definition of rupture elongation, see EN 13445-2:2014, Clause 4.

Test ID	Strain Rate #1, %/min	Strain Rate #2, %/min	Test Temp, °C	RT Mod. GPa	ET Mod. GPa	Rp0.01, MPa	Rp0.02, MPa	Rp0.05, MPa	Rp0.1, MPa	Rp0.2, MPa	Rp0.5, MPa	Rp0.5, MPa	Rp1.0, MPa	Rp2.0, MPa	Rm, MPa	A5, %	Z, %
W7379	0.4	8	23	212	0	330	322	273	272	275	277	276	290	448	446	31.6	76.4
W7375	0.4	8	375	228	203	151	147	143	148	165	194	229	282	419	419	42.6	88.6
W7376	0.4	8	375	195	178	149	143	145	148	166	193	228	281	415	415	39.8	88.7
W7377	0.4	8	388	209	197	146	147	141	148	[illegible]	191	225	276	407	407	42.7	88.1
W7378	0.4	8	400	227	208	145	140	137	147	163	191	223	272	398	398	37.8	87.9
W7380	0.4	8	425	216	205	130	129	131	144	160	185	214	258	370	370	45.4	91.0
W7381	0.4	8	450	184	187	120	123	132	143	157	180	205	243	343	343	46.5	90.2
W7382	0.4	8	475	218	188	114	121	133	144	156	177	199	227	316	316	40.3	91.0

Notes
1. Specimen design J055C026/2 used throughout, 30mm gl x 6mm diam.

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Reference Stress

$$\frac{Rp0.2{,}375}{1.5} = \frac{165.2}{1.5} = \quad \mathbf{110.1MPa}$$

The material is at the lower bound for P265GH
(EN10028 min $Rp_{0.2,375}$ = 155MPa

Isostress testing matrix

Stress 1 = 110.1MPa, Stress 2 = 88.1MPa (0.8x Stress1)

11 creep tests

Temp °C	350	375	400	425	450	475
110.1 MPa	x	x	x	x	x	x
88.1 MPa		x	x	x	x	x

T48 test creep frames, 1 of 6 different type used

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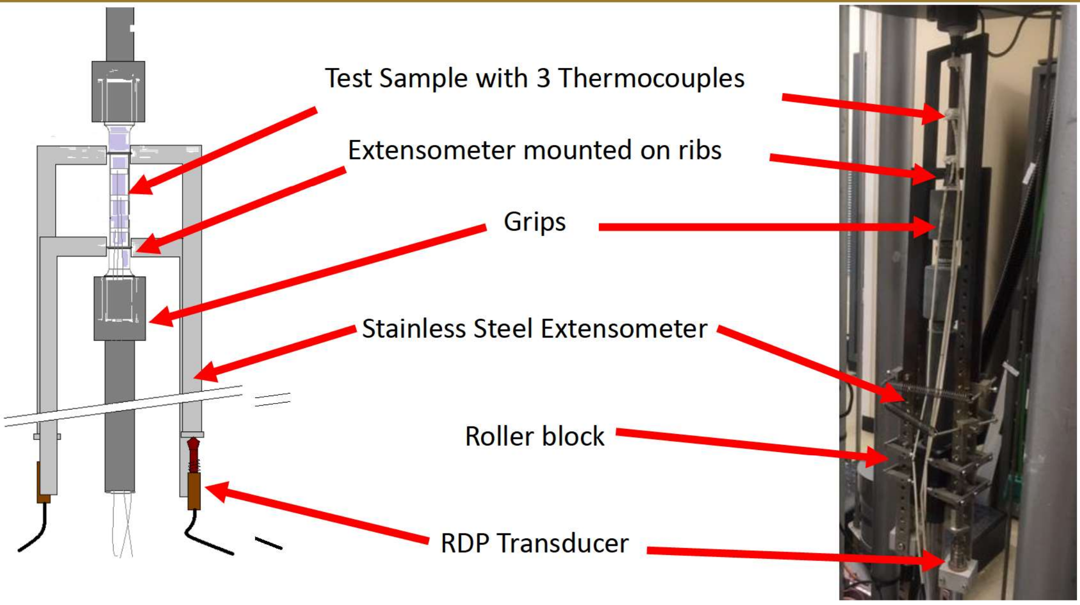
High sensitivity creep testing-constant load



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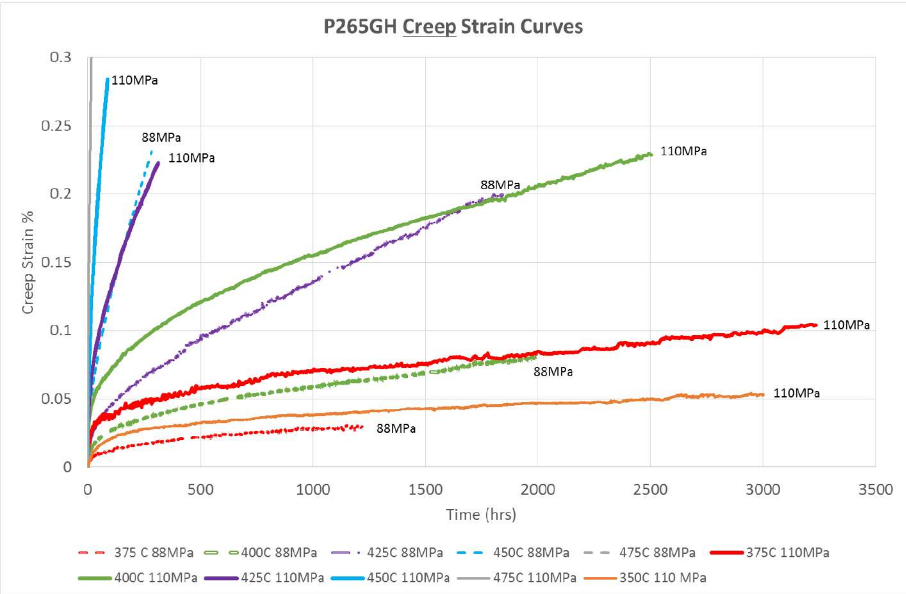
Uniaxial Creep testing procedure

- Sample measured and threads treated
- Thermocouples attached to sample surface at top, middle and bottom.
- Extensometer mounted on the ‘ribs’ and the specimen placed in the furnace.
- Cold Modulus measured using half test load
- Furnace to temperature at 5°C/min, extensometer soaks
- When stable (>1hr) Hot Modulus measured with half test load
- Load applied manually with selected weight increment (loading rate varies for each creep frame and stress)

Results

P265GH Creep Strain Curves



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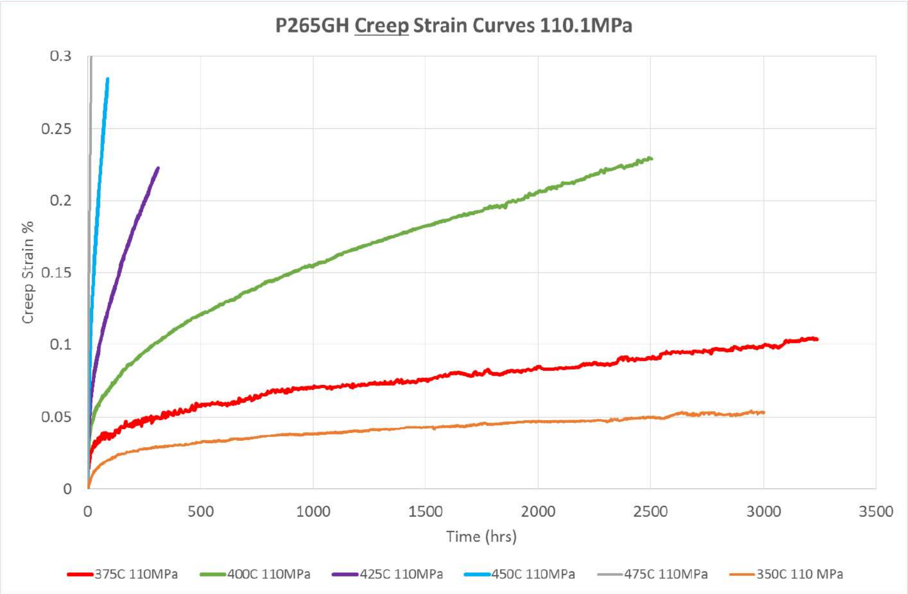
P265GH Creep Strain Curves 110.1MPa



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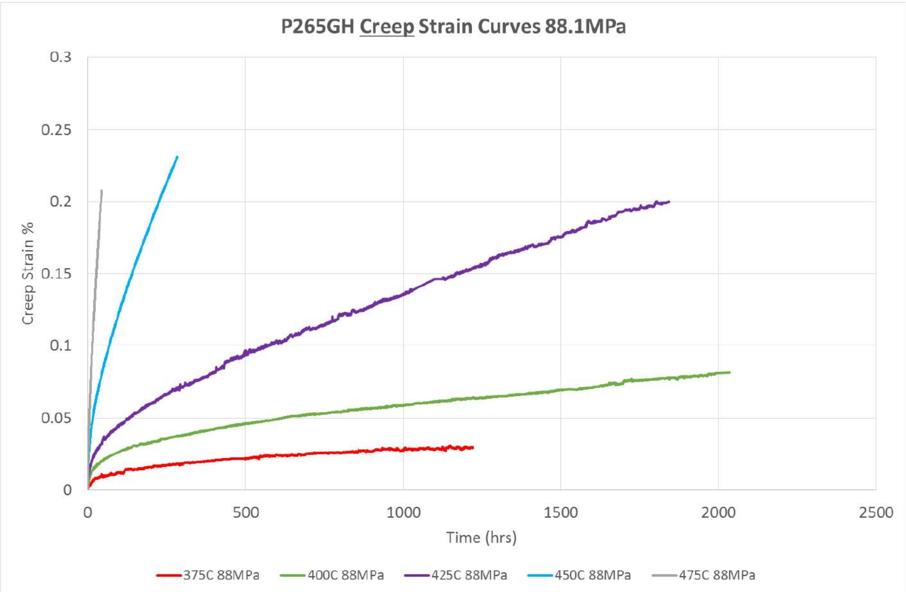
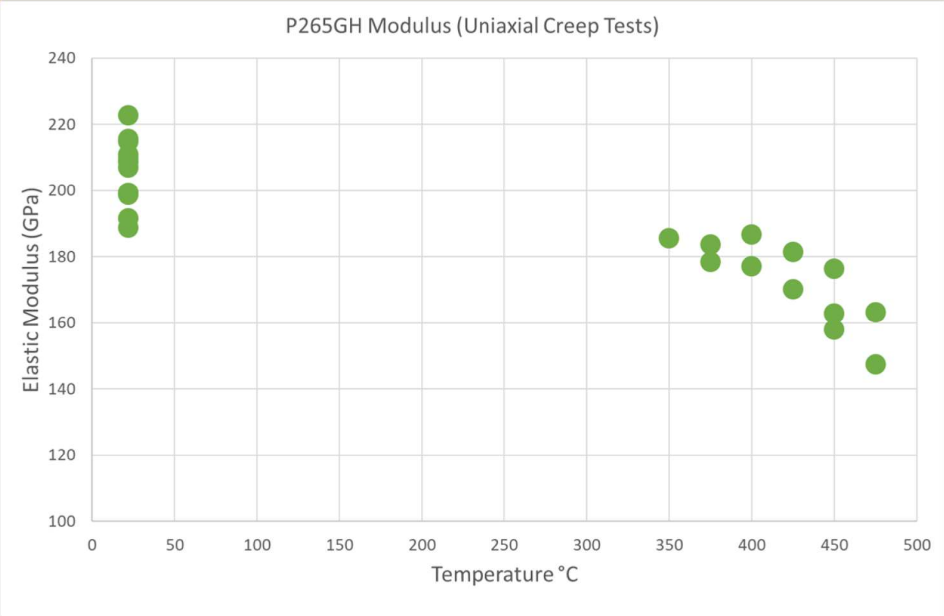
P265GH Creep Strain Curves 88.1MPa



Modulus from Creep Tests



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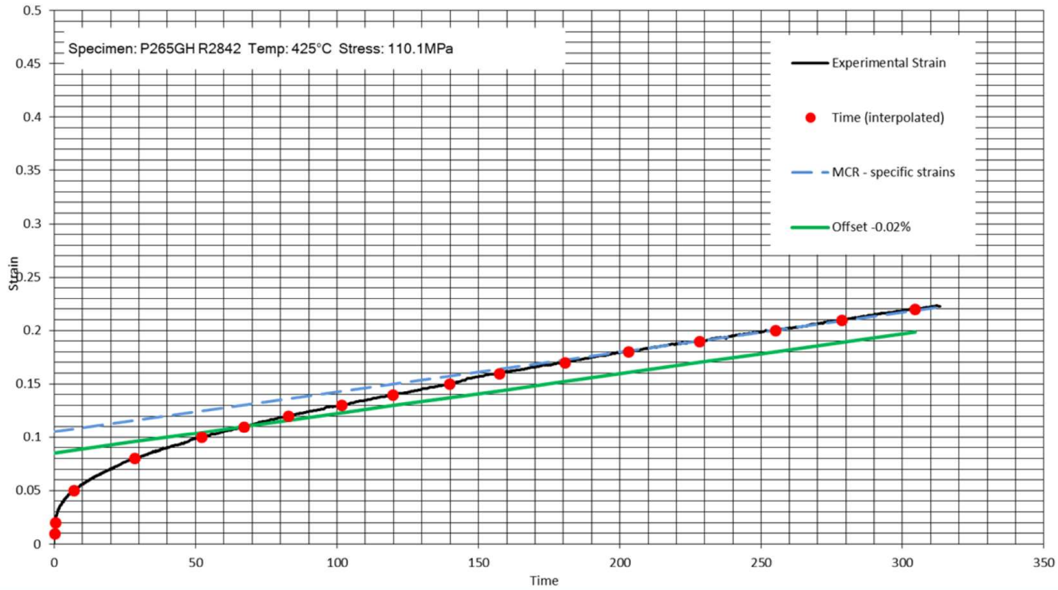
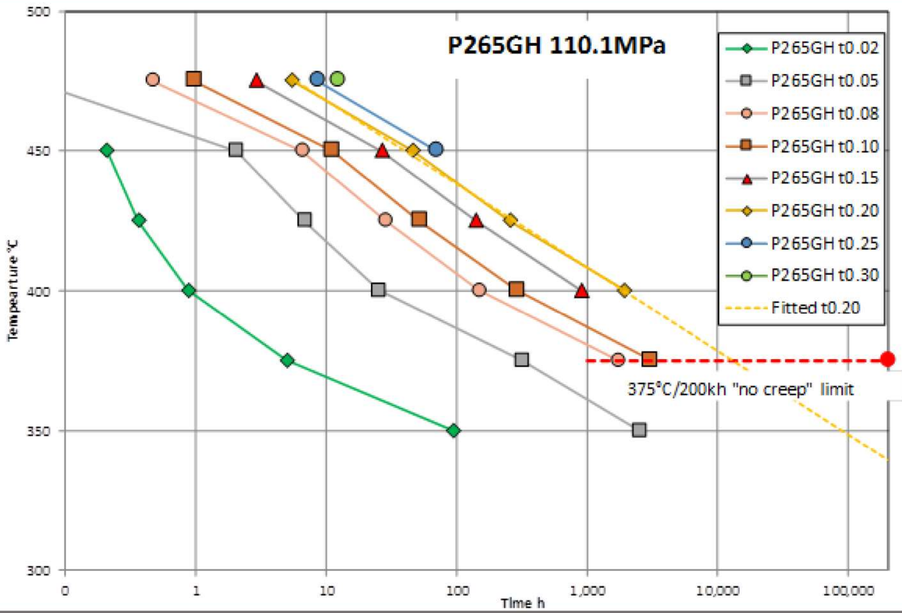
Times to specific strain for each curve



DIN 50118 interpolation and geometric mean method used

Extrapolation limited to <10% where used

P265GH Stress 1



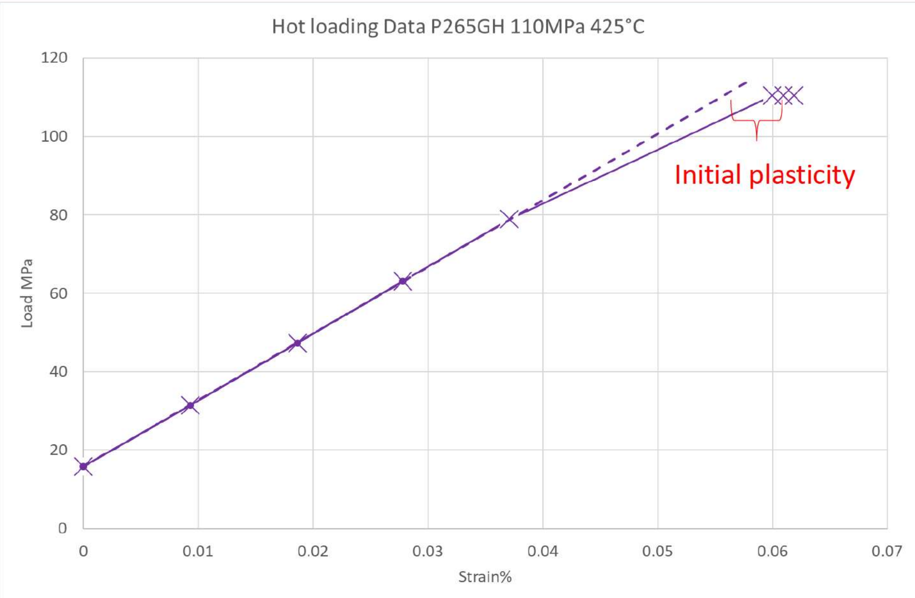
Linear relation appears valid (at least when t > few hours)

Extrapolating the parallel line for tp0.2 indicates intersection of 200khr@~340°C (T_{NC})

This indicates a higher ref stress should have been applied.

Initial Plasticity on loading >400°C

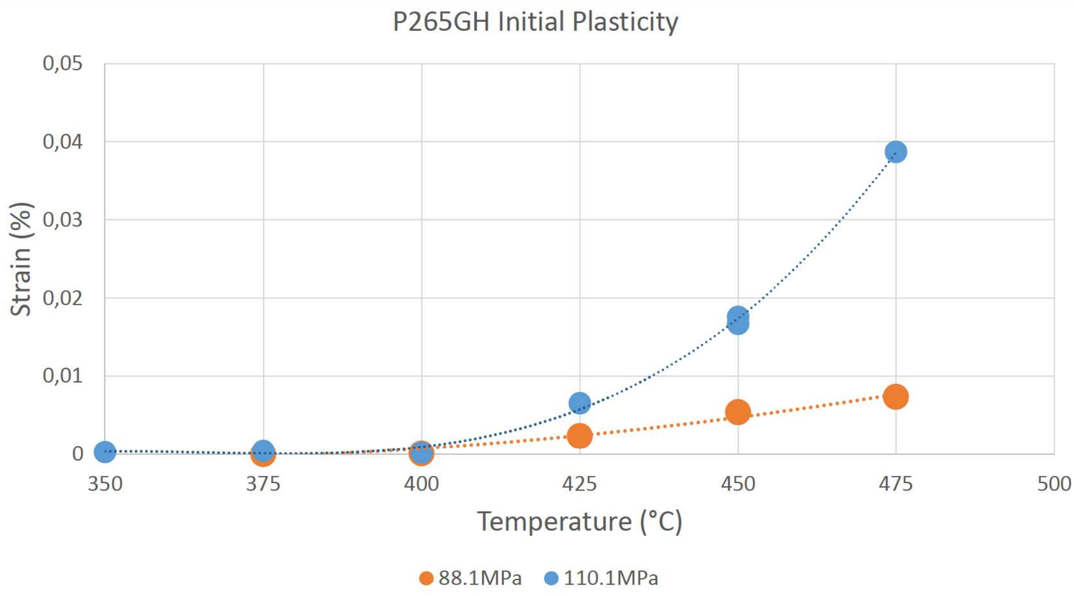
Initial Plasticity



Manual loading – time to physically load the sample stably

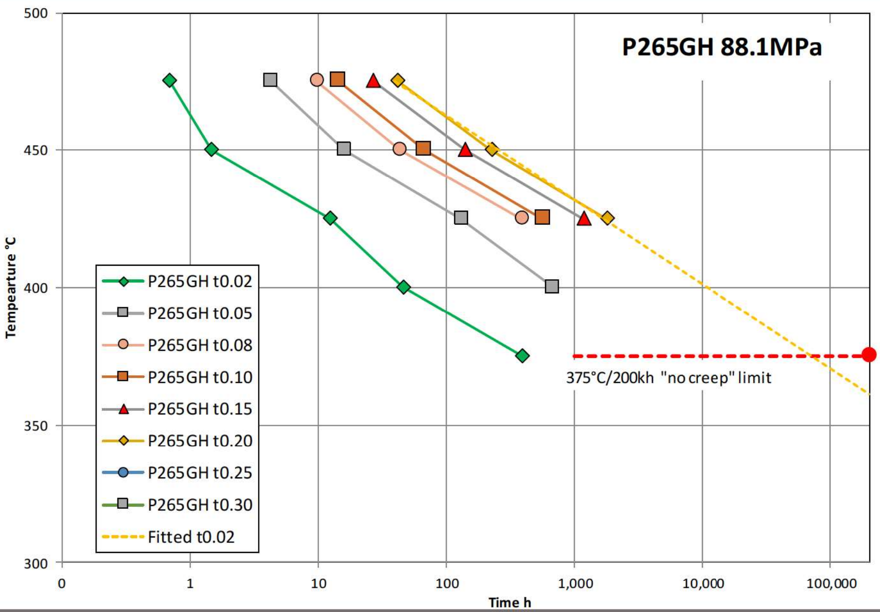
Lever ratio of creep frame

Initial Plasticity



Limited initial plasticity (at least < 425°C (110.1MPa))

P265GH Stress 2



Linear relation appears valid (even at the higher temp low creep strains)

Limited initial plasticity

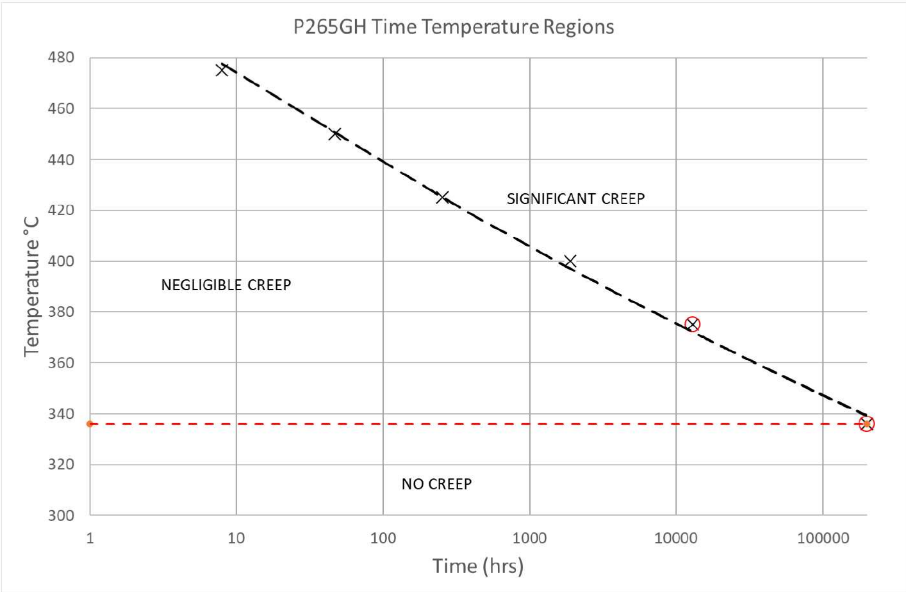
Extrapolating the parallel line for tp0.2 indicates intersection of 200khr @ ~ 365°C (T_{NC})

P265GH Time Temperature Regions

~320°C using RTF factor and min 0.2% proof strength (103MPa) from standard (Holmstrom 2017)

~340°C using MH4 and Wilshire models & VDEh data extrapolated (Bullough, Smith & Holmstrom 2019)

~336.2°C using material specific experimental data (112.7MPa) and extrapolated linear temperature relation (Smith, Bullough & Gill 2019)
After adjustment for lower ref stress



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References

- Holmström S., (2016) Defining a negligible creep temperature curve for Gr. 91 steel, International Journal of Pressure Vessels and Piping, 146: 198-202
- Holmström, S. (2017), *Negligible creep temperature curves for EN-13445*, EUR 28564 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-68046-5, doi:10.2760/957726, JRC106159.
- VDEh (1969) Werstoffedatenbank Verein Deutscher Eisenhuttenleute, VDEh, Dusseldorf, West Germany

Samples available

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