EPERC Conference TG Creep

28 January 2020

Activities of CEN TC54 WG59 “Creep” / Priorities for the Future - Agenda

1. Designing against creep failure
2. Recent work to revise EN13445-3 (Annex R, V)
   - Work to review/revise collection of creep parameters
   - Technical report on T_{NC} – no creep temperatures
2. Approach to creep properties in international design codes
3. A holistic treatment of design / life assessment
   - What has been done elsewhere, how to integrate / collaborate?
4. Which properties are really important for design?
5. In an ideal world, we would …
6. Prioritisation of short-term, and longer-term actions

Designing Against Creep Failure

Designing against creep failure

Up to now, most creep design has been "code-based" – allowable stress based on minimum material properties x safety factor.

- Often based on rupture data
- OK for pipework (maybe) but not OK for rotating parts (rotors, blades), casings, bolts etc.

Increasing use of design by (finite element) analysis – removes conservatism, but requires better descriptions of materials behaviour.

Impact of Renewables on HT Power Plant

UK Energy Mix – 2019 So Far

Coal pushed to seasonal margins

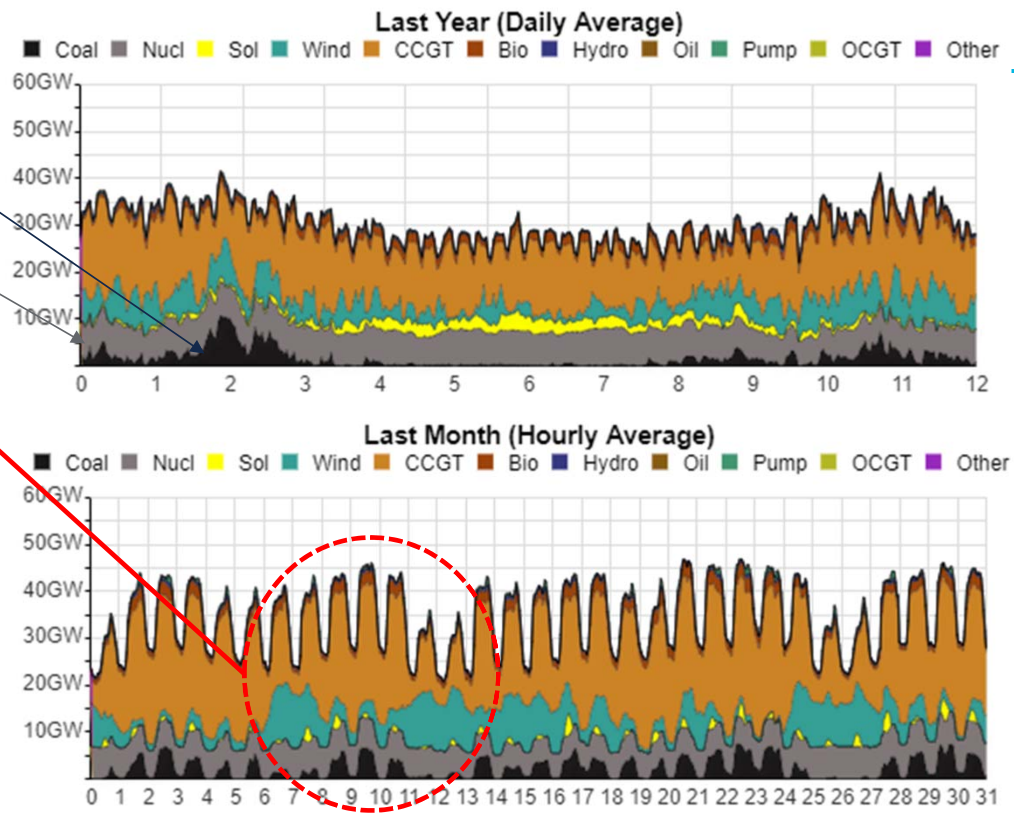
Nuclear running baseload

Wind & solar on-line when available

CCGT (combined cycle gas turbine) flexing around renewables.

Energy requirements depend on
- seasonal, weekly cycle
- weather on the day
- economy (long term), social factors (medium), short-term demands

Impact on HT power plant is need to design to and monitor to reflect cyclic operation
- creep design still necessary
- creep-fatigue interaction becoming dominant in both design & life assessment



2018 daily average (upper) Jan 2019 hourly average (lower)
Source: gridwatch.co.uk

Creep Properties in EN Standards

Design Properties in EN Standards - #1 Current Status

Steel name	Steel number	Nominal thickness[b] t (mm)	Minimum 0,2 % proof strength $R_{p0,2}$ MPa at a temperature in °C of 50	100	150	200	250	300	350	400	450	500
13CrMo4-5	1.7335	≤ 16	294	285	269	252	234	216	200	186	175	164
		16 < t ≤ 60	285	275	260	243	226	209	194	180	169	159
		60 < t ≤ 100	265	256	242	227	210	195	180	168	157	148
		100 < t ≤ 150	250	242	229	214	199	184	170	159	148	139
		150 < t ≤ 250	235	223	215	211	199	184	170	159	148	139

Steel grade		Temperature	Strength for 1 % (plastic)creep strain in MPa for		Creep rupture strength in MPa for		
Steel name	Steel number	°C	10 000 h	100 000 h	10 000 h	100 000 h	200 000 h
13CrMo4-5	1.7335	450	245	191	370	285	260
		460	228	172	348	251	226
		470	210	152	328	220	195
		480	193	133	304	190	167
		490	173	116	273	163	139
		500	157	98	239	137	115
		510	139	83	209	116	96
		520	122	70	179	94	76
		530	106	57	154	78	62
		540	90	46	129	61	50
		550	76	36	109	49	39
		560	64	30	91	40	32
		570	53	24	76	33	26
		450		209		[illegible]	

Examples from EN10028-2:

- Table 4 – Tensile (upper)
- Annex C – Creep (lower)

- Address limit load calculations, but not design by analysis (eg lifetime calculations)
- Often generated from older datasets, poor traceability to: materials, data, assessment method
  - Origins: mainly UK/DE 1980's + new materials
  - … little appetite to improve
- But, will they cause us problems in creep design?
- … are they sufficient for creep-fatigue interaction?

Creep Properties in EN Standards –#2 EN13445-3 Annex R

Table R-2 — Constants for creep-rupture equations

MATERIAL IDENTIFICATIONS Grade from Refs [1], [2], [5]	EN Material Number		[illegible]		R	T	β₀	β₁	[illegible]
C semi and Si killed, C7-C24	-	[illegible]	[illegible]	MH4	[illegible]	[illegible]	[illegible]	[illegible]614840508	-2,0583
C Si and Al killed	P235GH P265GH	[illegible]	[illegible]	LM3	[illegible]	[illegible]	[illegible]	[illegible]1945,41016	-5041
C-Mn	P355GH	1.0473	1,2	MH4	1	500	-0,66564015	1,416657686	-1,151
0.5% Mo	(16Mo3)	(1.5415)	1	LM2	-1	650	-15,9188[illegible]75	1638,47802	-587
½%Cr½%Mo¼%V	(12MoCrV6-2-2)	(1.7767)	2,6	MC			-17,6265460	-3,423511490	-0,0022
1%CrMo (Norm)	25CrMo4	1.7218	1	MR3	-1	600	7297,777344	-7238,72168	3306
1%CrMo (Norm, +T)	13CrMo4-5	1.7335	1	MH3	1	280	0,066684094	-0,143434107	0,07
[illegible]	(13CrMo4-5)	(1.7335)	1	MH3	1	280	0,066684094	-0,143434107	0,0737
[illegible]	42CrMo5-6	1.7233	1	MR4	-1	650	-58488,13213	107347,2301	-71842
[illegible]	40CrMoV4-6+NT	(1.7711)	1	MH4	1	650	-29,5491581	49,96889496	-31,702
[illegible]	20CrMoVTiB4-10	1.7729	2	MH4	1	590	-4,46561718	8,252388	-5,727
[illegible]	10CrMo9-10+NT	1.7380	1	MH4	1	610	-1,386920571	2,832926035	-2,196
2¼%CrMo (Norm, +T[illegible]750°C)	10CrMo9-10+NT	1.7380	1	MH4	1	610	-0,524605751	1,04690969	-0,8192
9%CrMo (Annealed)	X11CrMo9-1+I1	1.7386 +I	1	MH4	1	600	-0,806423008	1,757547379	-1,45
9%CrMo (Norm, +T)	[illegible]	[illegible]	1	[illegible]	1	560	-0,11[illegible]408	[illegible]	0,11

Werkstoff numbers added, bracketed if not exact

Parameters checked, and corrected if necessary

Duplicates removed, updates added.

Table R-3 — Original limits of application for creep-rupture equations

MATERIAL IDENTIFICATIONS			Year	Temp, min, °C	Temp, max, °C	Stress, min, MPa	Stress, max, MPa	t, min, h	t, max, h
C semi and Si killed, C7-C24	-		1974	350	520	39	277	10000	250000
C Si and Al killed	P235GH P265GH	1.0345 1.0425	[illegible]	[illegible]	[illegible]	[illegible]	213	10000	250000
C-Mn	P355GH	1.0473	[illegible]	[illegible]	[illegible]	[illegible]	291	10000	250000
0.5% Mo	(16Mo3)	(1.5415)	[illegible]	[illegible]	[illegible]	[illegible]	327	10000	250000
½%Cr½%Mo¼%V	(12MoCrV6-2-2)	(1.7767)	2014	450	600	32	377	10000	250000
1%CrMo (Norm)	25CrMo4	1.7218	1988	450	620	31	406	10000	250000
1%CrMo (Norm, +T)	13CrMo4-5	1.7335	1988	450	630	27	363	10000	250000
1¼%CrMo (Norm, +T)	(13CrMo4-5)	(1.7335)	1988	450	630	27	363	10000	250000
0.4%C1¼%CrMo (D900)	42CrMo5-6	1.7233	1975	450	550	86	498	10000	100000
0.4%C1¼%CrMoV	40CrMoV4-6+NT	(1.7711)	1979	450	550	151	534	10000	100000
1%CrMoVTiB (D1055)	20CrMoVTiB4-10	1.7729	1996	450	600	93	520	10000	200000
2¼%CrMo (Norm, +T<720˚C)	10CrMo9-10+NT	1.7380	1988	470	610	47	275	10000	250000

Temperature, Stress & Time Limits introduced

Review in CEN TC 54 / WG59 “Creep” 2015-2018

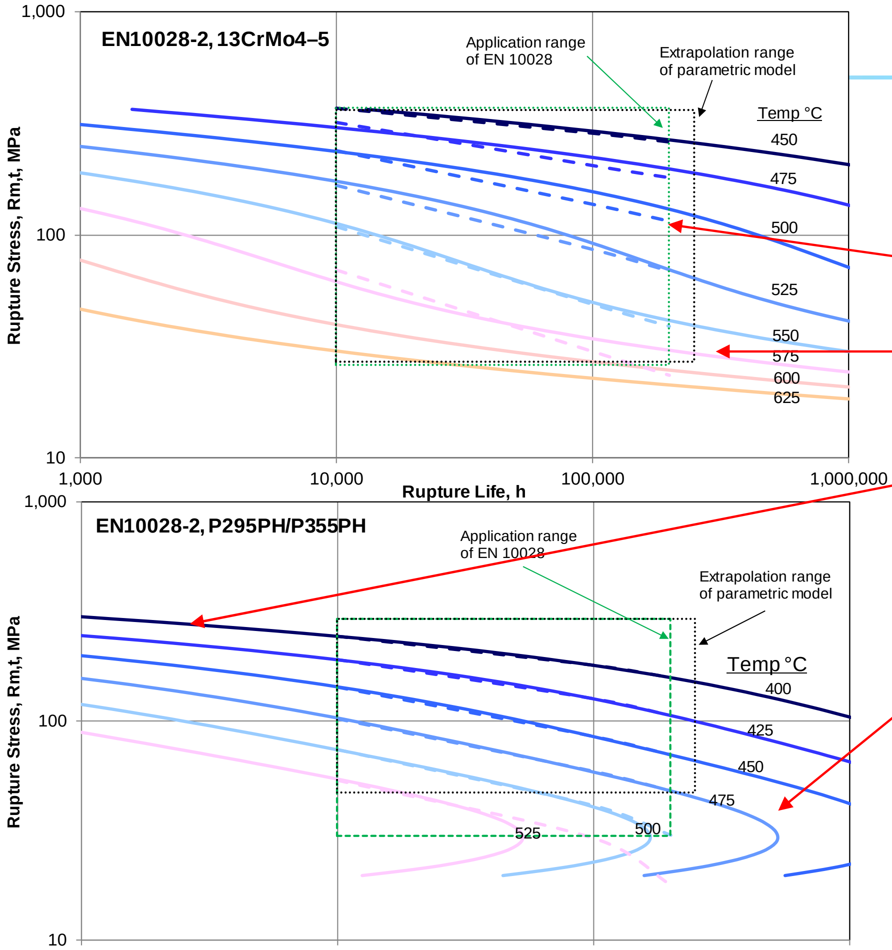
Improved identification of materials => EN 13445-2.

Check , correction and updating of parameters.

Inclusion of extrapolation limits

Still some work to do to improve traceability, stability, accuracy.

Creep properties in standards - #3 – typical problems in extrapolation



Published creep parameters, eg EN13445-3 Annex R (solid lines)

- do not coincide with strength table (dashed lines)
- some “plateau” at low stresses, giving too-high strengths in extrapolation
- Some give excessively high strengths at short times, higher than proof and even tensile strengths => unrealistic, and difficult to use for eg creep-fatigue interaction calculations
- Others turn-back, making extrapolation impossible at long times / low stresses
- Many are poor in extrapolating to low temperatures

• *Polynomials both a boon and a curse!*

Creep Properties in EN Standards #4
- “Best practice” for data assessments

Improve test data and material pedigree collation, exchange and archiving (for life of the plant).

State what is required from an assessment (range of application? include hot tensile, parameters, times to specific strain, creep rates, ductilities …?)

Employ stable, physically realistic models; consistent with eg tensile properties

Control of assessment procedure, technical review (ePATS), documentation lasting 50 years.

Review periodically, apply industry knowledge.

Theoretical Approach to Determine "No-creep" Temperatures

Background – why are "no-creep" temperatures of interest?

Design codes, including EN 13445-3, have no-creep temperatures, T_{NC}:

- ferritic and martensitic steels 375°C
- austenitic steels 425°C
- nickel alloys (under consideration) ??? °C

Design below T_{NC} – no need to consider creep;
above T_{NC} – creep considered in both creep and lifetime monitoring.

Question #1 – do any steels have T_{NC} below 375°C (Maybe?)
Question #2 – do C-Mn steels and Grade 91 have the same T_{NC}? (No! See also …. & …. & ….)
Question #3 – can I use a better grade to avoid creep design (Probably, but how?)
Question #4 – how can I determine T_{NC} quickly and cheaply (See next section!)

CEN WG59 "Creep" developing: *EN 13445-3 Annex V. Determination of Negligible Creep Temperatures*

Technical report being prepared [1,2,3].

Determination of “no-creep” temperatures

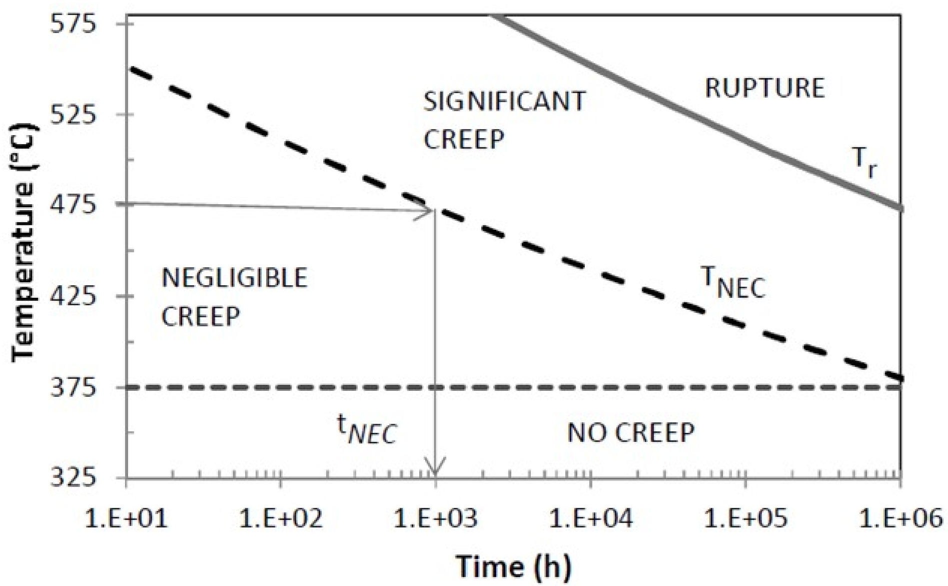
EN 13445-3 Reference Stress, σ_{ref}
Ferritic steel $1/1.5 \cdot R_{p0.2,min}$ Austenitic steel $1/1.2 \cdot R_{p0.2,min}$

“No-creep” definition	Comments
No creep, $T=T_{NC}$, t=200kh $R_{p0.2,T,t,\ min} > \sigma_{ref}$	Time-independent design
Negligible creep, $T=T_{NEC}$ at t<200kh $R_{p0.2,T,t} > \sigma_{ref}$	Time-independent design at t<200kh

EN 13445-3 of “no creep” temperature, T_{NC}, and negligible creep temperature, T_{NEC}

Calculation of a limiting reference stress, and comparison with 0.2% creep strain strength

- Single “no-creep” temperature at 200kh
- “Negligible creep” temperature higher than T_{NC} dependent on shorter design life



Concept development from Holmstrom, 2016. Here t=10^6h was taken as no creep duration.

Determination of “no-creep” temperatures

A conversation

To apply the approach we need either:

- 0.2% creep strain strengths $Rp_{0.2,T,t}$ at or close to T_{NC}
- Validated relationships between rupture and creep strain properties applicable at lower temperatures

“OK! Let’s test a dozen heats of each material to 0.2% strain out to 70kh at 375°C …”

“Wait a minute!! That will fill up our labs with tests doing nothing, on materials that were developed 30-50 years ago. We don’t even know what stresses to apply …”

“What about our existing datasets, can they tell us something?”

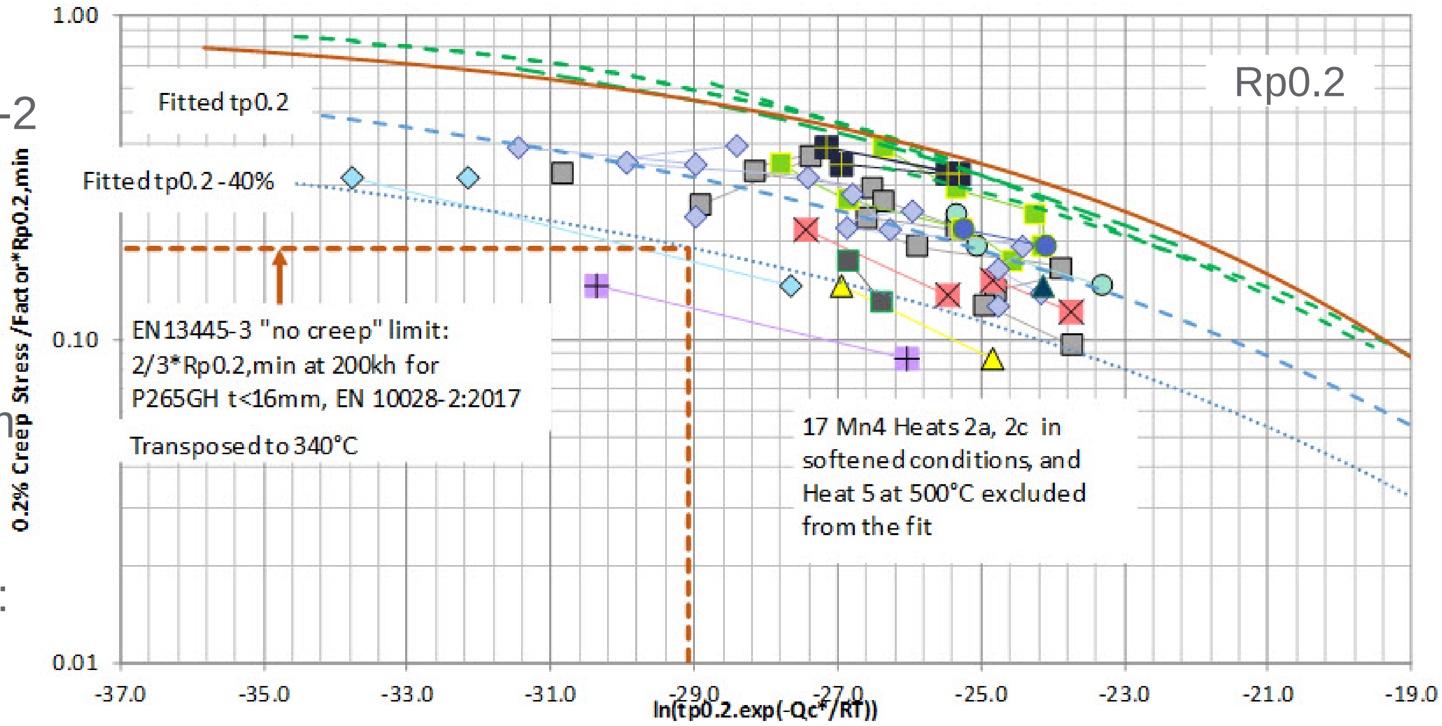
“Hmmm. We could apply our existing parameters, but there could be instability problems at lower temperatures …”

“Let’s try the Wilshire-Equations, stable to low temperatures, and related to tensile properties. *Let’s go!*”

Determining “No-creep” Temperatures – Practical Examples

VDEh 1969 CMn steels – Wilshire Equations
Practical Determination of T_{NC} from Older Datasets [Ref 4]

- -VDEh dataset ~P265GH/P295GH in EN13445-2
- -Wilshire Equation with derived minimum (0.60* mean)
- -Temperature extrapolation improved by (σ/A.$Rp_{0.2,T}$)
- -Relatively few data, mostly from ≥450°C. Data on non-standard heats 2a,2c shown, but ignored.
- -Transposed data, T varied until:
- -T_{NC} = **340°C**



Lines: solid orange– Rm fit; dashed green – VDEh Rm isothermals; dashed blue Rp0.2 fit

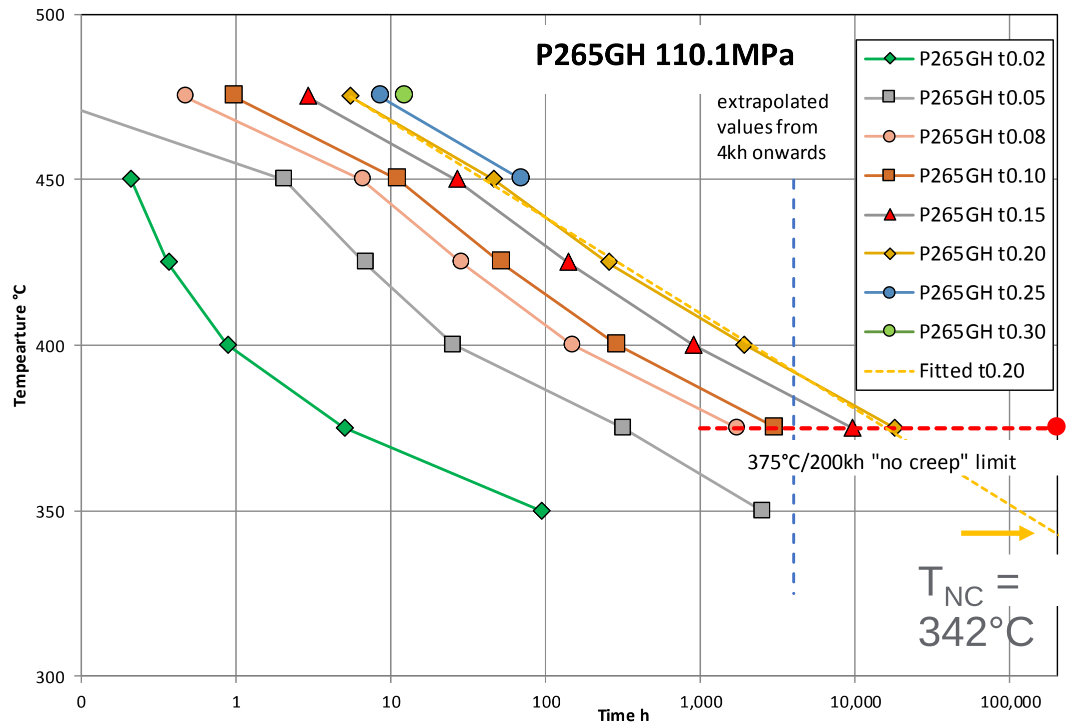
VDEh 1969 CMn steels – Wilshire Equations Recent Use of Isostress Testing [Ref 5]

-New heat of P265GH tested at 101MPa & 88MPa in an isostress matrix

-Linear extrapolation with respect to temperature

-T_{NC} = **342°C** (see Ref [3]) at 101MPa.

- Work continuing on Grade 91, Type 316L(N) steels.



Lines: solid orange– Rm fit; dashed green – VDEh Rm isothermals; dashed blue Rp0.2 fit

EN13445-3 Annex V – T_{NC}/T_{NEC}

1. CEN Technical Report in preparation [3] to include
   - Definition of negligible creep & The Industrial Need for Negligible and No Creep Temperatures
   - Previous Code Approaches
   - Development & Use of Wilshire Equations to Determine T_{NEC}
   - Test Methods to Determine T_{NEC}
   - Calculated T_{NC} and T_{NEC} References
   - Worked Examples and Reference Data
2. Revise EN13445-3 (Annex V)
   - Explanation of the use of T_{NC}/T_{NEC}
   - Method of derivation from published data, or by testing
   - Tabular values of T_{NC}/T_{NEC} for a range of material grades

Creep Properties in the Design Codes – *what's missing?*

Approach to creep properties in international design codes, elsewhere

1. EN Product Standards vs ASME Section II
   - EN product standards include minimum tensile proof stresses, mean creep rupture strengths
   - EN design codes include safety factors to calculate allowable stresses
   - ASME BPV Section II contains Design Allowables directly for all material grades permitted within the BPV code – already “factored”.
   - Which is the *best approach*? (Eg. Speed of release, consistency, factors changeable, load limits “old fashioned” / “insufficient” (eg creep-fatigue)? …)
2. Pressure vessels seldom rupture, so why design to rupture data (move to creep strain limits?)
3. Can we integrate design and life assessment?
4. Which properties are really important for design?
5. We will shortly us nickel-alloys in power plant – how to deal with lower ductilities? … lower charpy impact values?

Approach to creep properties in international design codes, elsewhere

6. Considerable background work in other bodies including TRD rules, Fitnet, R5…
7. How to prioritise work in creep field (some suggestions). *In an ideal world …*

- should we perform further testing to determine T_{NC} (which materials? Involve ECCC?)
- we would somehow assess tensile/creep/fatigue properties together (current work in CEN TC54 / WG59 and ECCC)

therefore, combined approaches such as Wilshire Equations (rupture, specific creep strain, min creep rate should be further developed? (1-2yrs?)

how to deal with sparse data? (missing tensile data, little or no times to specific strain …)

- creep life monitoring will be considered as part of design, perhaps having published equations (+ ECCC?)

therefore, publish models and their coefficients to enable that? (would need to be developed/validated – 2-3 yrs?). Issue in reports, spreadsheets, databases, UMATs … ?

- creep and fatigue, dominate high temperature failure (+ ECCC? Nuclear bodies, incl. RCC MRx development)

therefore, work on softening effect of fatigue, forward creep/creep relaxation compatibility (3-5yrs?).

- if the focus is remanent life, then how to gauge the reliability of on-site life-assessment techniques? (+ ETD, CSM, INAIL, others?)

Prioritisation of short-term & longer term actions

1. Identify: partners, objectives, deliverables

Conclusions

1. Designing against creep failure is possible (EN13445 and EN12952)
2. Recent work to revise EN13445-3 (Annex R, V) was addressed
   - Work to review/revise collection of creep parameters
   - Technical report on T_{NC} – no creep temperatures
2. Approach to creep properties in international design codes
3. A holistic treatment of design / life assessment
   - What has been done elsewhere, how to integrate / collaborate? Open questions!
4. Prioritisation of short-term, and longer-term actions: EPERC TG

Conclusions

References

1) S. Holmström, ‘Negligible creep temperature curve verification (TC54/CREEP) for steels 10CrMoV9-10 and X2CrMoNiMo17-12-2’, JRC Report, June 2015.

2) S. Holmström, ‘Negligible creep temperature curves for EN-13445’, Baltica X, International Conference on Life Management and Maintenance for Power Plants vol. VTT TECHNOLOGY 261.

3) (In preparation) S. Holmström, C. Bullough, A. Tonti, G. Baylac, C. Forot, “New approaches to determine negligible creep for EN 13445”, CEN TC54 Technical Report, January 2020.

4) C. Bullough, W. Smith, S. Holmström, ‘Provision of Materials Creep Properties for Design of High Temperature Plant to EN13445-3’, EPERC Conference: Pressure Equipment Innovation and Safety, Rome, April 2019.

5) W. Smith, C. Bullough, S. Gill, ‘Determination of No-Creep and Negligible Creep Temperatures using Accelerated Testing Methods’, EPERC Conference: Pressure Equipment Innovation and Safety, Rome, April 2019.