Karlsruhe Institute of Technology

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Development of EUROFER97 Database and Material Property Handbook

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EUROfusion

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EUROfusion Material Database & Handbook (MD&H)

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Realization of in-vessel components for DEMO

- Development of sound **material databases (MD)** on **structural, armour** and **functional materials**
- Development of **DEMO Design Criteria (DDC)** for in-vessel components

EUROfusion / PPPT / WPMAT

EDDI-MD&H Group

Materia Database (MD) →

- Raw data collection
- Data review & evaluation process
  ⇒ Qualified data

Material Property Handbook (MPH) →

- Summarising the database content at a higher level
- Calculation of the design allowables according to internationally accepted methodologies

EDDI-DDC Group

Development of DEMO Design Criteria (DDC)

- DEMO specific design criteria for **Blankets and Diverters**
- Assess the **structural integrity** of all of the concept designs

Objective: Development of **Material Database** & **Material Property Handbook** on **Reduced Activation Ferritic/Martensitic** steel **EUROFER97**

European Reference RAFM Steel for ITER TBM and DEMO
EUROFER 97

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Chemical composition – Main alloying elements (targeted values in [])

	C	Cr	W	Mn	V	Ta	N2	P	S	B	O2
Specified (mass%)	0.09-0.12 [0.11]	8.5-9.5 [9.0]	1.0-1.2 [1.1]	0.20-0.60 [0.40]	0.15-0.25	0.10-0.14 [0.12]	0.015-0.045 [0.030]	<0.005	<0.005	<0.001	<0.01
Achieved (mass%)	0.11-0.12	8.82-8.96	1.07-1.15	0.38-0.49	0.018-0.034	0.13-0.15	0.018-0.034	0.004-0.005	0.003-0.004	0.0005-0.0009	0.0013-0.0018

Chemical composition – Radiologically undesired elements

	Nb	Mo	Ni	Cu	Al	Ti	Si	Co
Specified (µg/g)	<10	<50	< 50	<50	< 100	< 100	<500	<50
Achieved (µg/g)	2-7	10-32	70-280	15-220	60-90	50-90	400-700	30-70

R. Lindau, Fus. Eng. Des. 75-79 (2005)

- Production of large industrial batches: EUROFER 97-1, EUROFER 97-2, EUROFER97-3
- Availability of different product forms: plates, rods, tubes
- Examination & characterization by several European Research Units (RUs)
- Development of joining technologies
- Investigation of irradiation influence

EUROFER data source for Material Database

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- Data generated by participant RUs in the course of EFDA/EUROfusion Work Programmes
- Data published in the open literature

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EUROFER97 database accounting ~3000 data records

Data qualification

Data review against Data Quality Thresholds

Data collection templates

MATERIAL IDENTIFICATION

- manufacturer
- heat/product/sub-product
- thermo-mechanical treatment …

SPECIMEN IDENTIFICATION

- geometry
- extraction direction
- surface finish …

IRRADIATION CONDITION

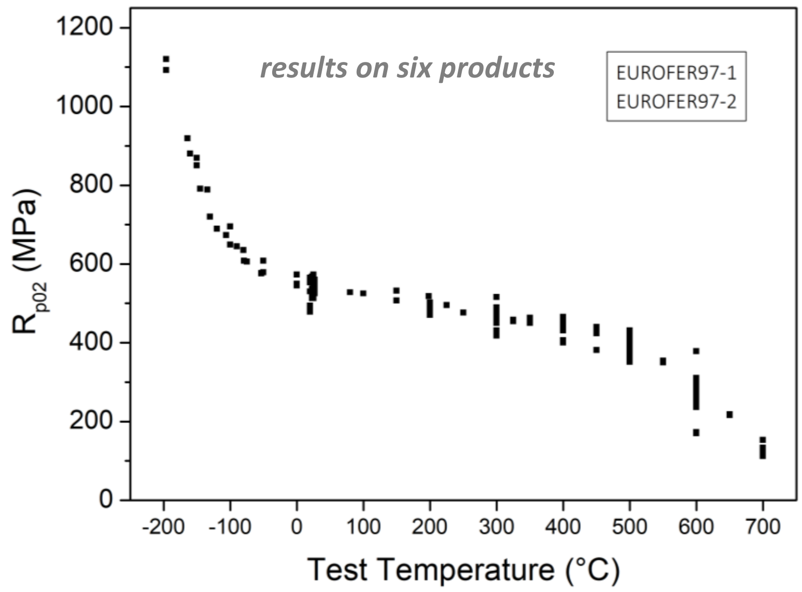
- irradiation facility
- temperature
- dose ...

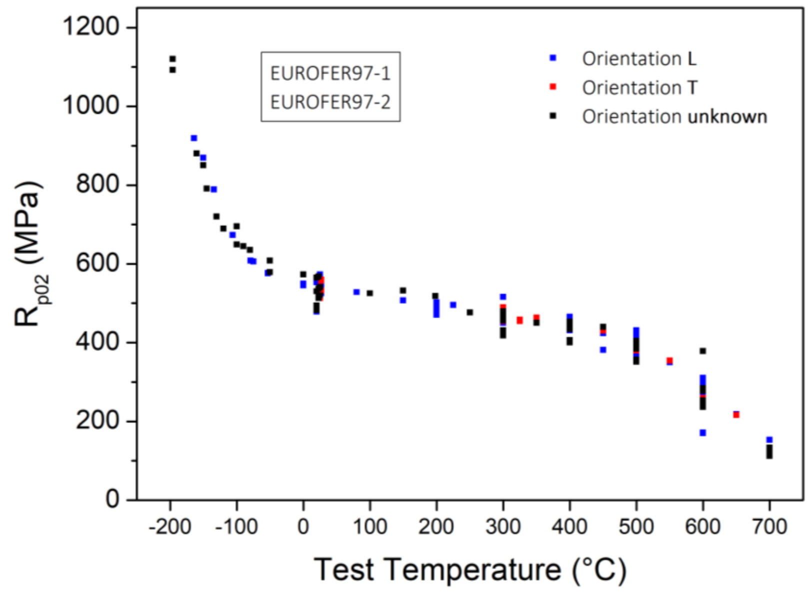
TESTING and RESULTS

- testing standard, parameter
- temperature
- environment
- results, validity …

Calculation of design allowables with **Qualified Data**

Data qualification
Tensile properties

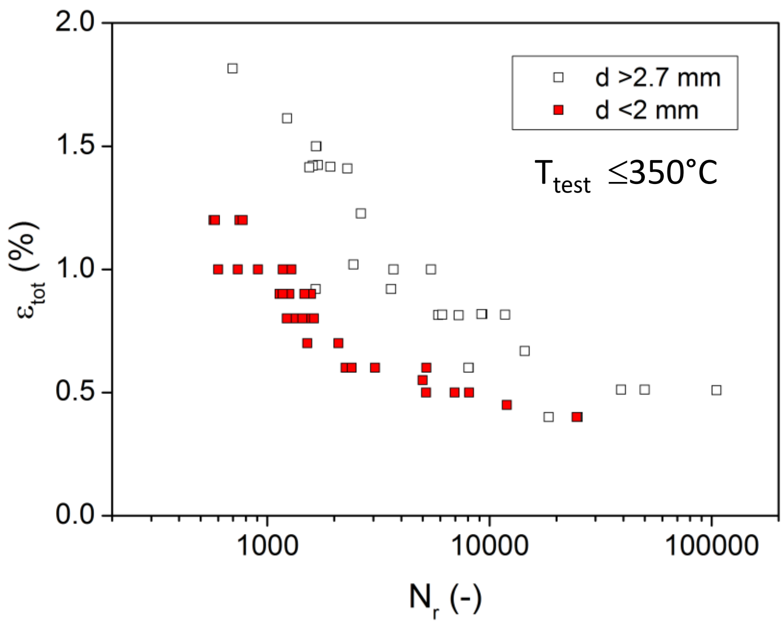




Approach for MPH

- No differentiation between different heats
- No differentiation between different orientations
- Thermally aged data excluded from allowable calculation
- Irradiation data excluded from allowable calculation

Data qualification
LCF properties



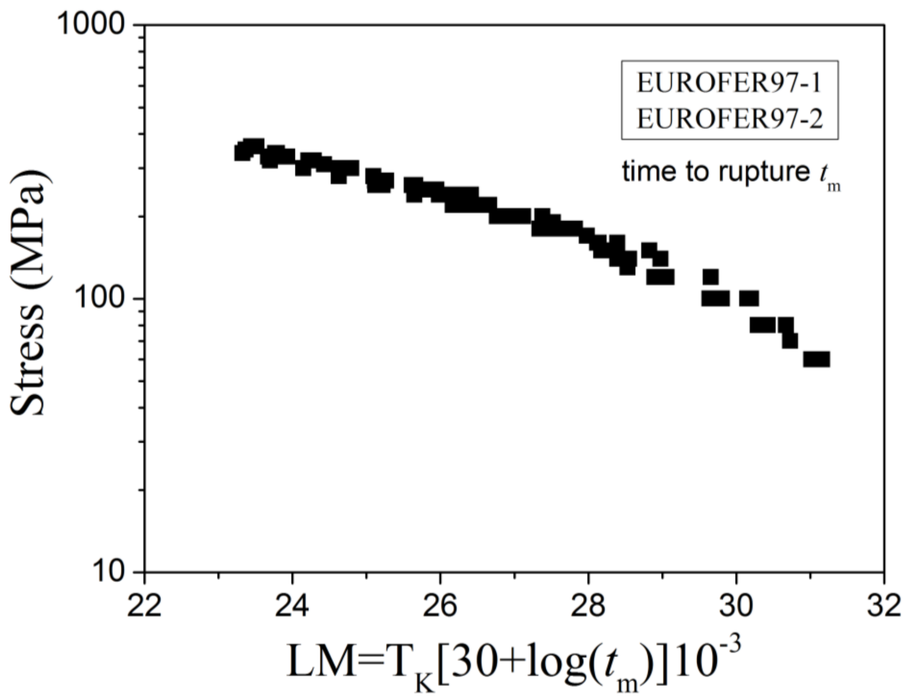
SSTT vs. large specimen

Considerable underestimation of fatigue lifetime in the reference unirradiated state by SSTT

Approach for MPH

- No differentiation between different heats
- No differentiation between different orientations
- Differentiation between '*small*' and '*large*' specimens

Data qualification
Thermal creep properties



Approximately 140 original creep curves analysed with respect to the design relevant parameters

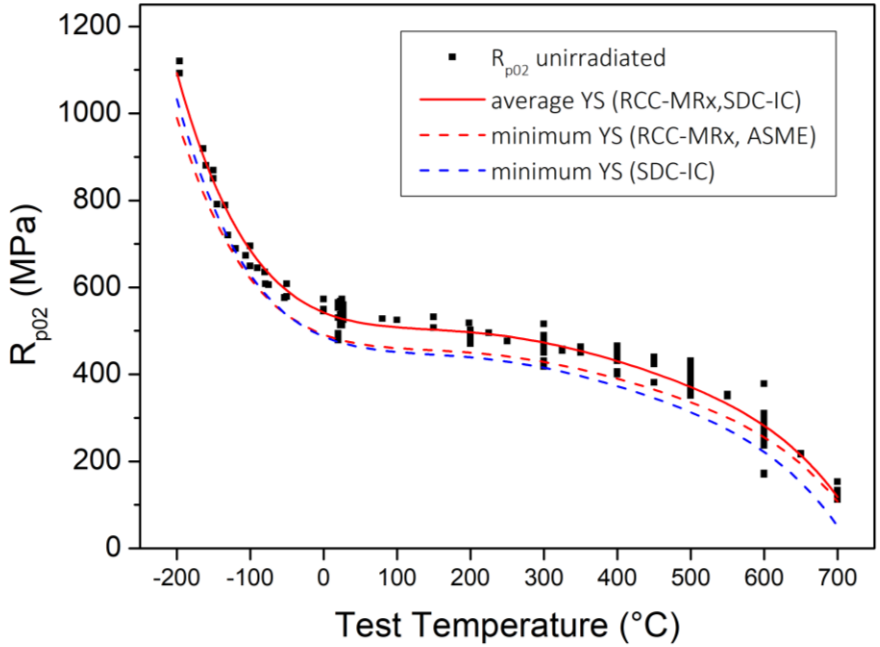
- Onset of the tertiary creep
- Time to reach 1% total strain
- Time to reach 0.05% creep strain
- …

Approach for MPH

- No differentiation between different heats

Allowable calculation

Average and minimum Yield Strength at 0.2% offset



- Determination of the ***average values*** by means of statistical analysis (best fit)
- Determination of the ***minimum values*** followed internationally established methodologies

RCC-MRx

- The average values determined by a statistical method
- Determination of the ratio minimum yield strength at RT to average yield strength at RT

$$R_{p02,min\,(RCC-MRx,)}(T) = \frac{R_{p02,min}(RT)}{R_{p02,av}(RT)} R_{p02,av}(T)$$

ITER SDC-IC

- Calculate an average $S_{y,av}$ curve by a statistical method
- Built the minimum curve according to ITER SDC-IC

$$S_{y,min}(T) = S_{y,av}(T) - 1.96\sigma$$

Material Property Handbook - Pilot project on EUROFER97

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Content

Partners:

and joined universities

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Over 20 DEMO design relevant material properties on base metal EUROFER97

Material EUROFER
Property Composition

Karlsruhe Institute of Technology

EUROfusion
POWER PLANT PHYSICS & TECHNOLOGY DEPARTMENT

DEMO MATERIAL PROPERTIES HANDBOOK

MATERIAL EUROFER97	PROPERTY 4.COMPOSITION

4. Chemical composition

Standard nominal composition

EUROFER97 presently is a research material under development for use in nuclear and fusion facilities. The composition of the presently tested heat is given in table 4.1. [1] This analyses may slightly differ from the present and future composition given by the nuclear codes. In case of documents preparation for the authority please check the relevant code.

Table 4.1. The chemical composition of EUROFER97 in wt %

	C%	S%	P%	Si%	Mn%	Ni%	Cr%	Mo%	W%
min	0.09	-	-	-	0.20	-	8.5	-	1.00
max	0.12	0.005	0.005	0.050	0.60	0.005	9.5	0.005	1.20
	Ta%	V%	Nb%	Cu%	B%	Al%	Co%	N_2%	Fe%-
min	0.10	0.15	-	-	-	-	-	0.015	Balance
max	0.14	0.25	0.001	0.005	0.001	0.01	0.005	0.045	Balance-

References

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PROPERTY PARAGRAPH STRUCTURE

- MATERIAL identification
- PROPERTY identification
- PROPERTY description
- Relevant plots and tables
- Property temperature or dose evolution formula
- Allowables
- References

Material EUROFER

Property Yield Strength

Table 6.3. Average and minimum yield strength for as-received EUROFER97, and allowable stress values

Temperature °C	$R_{p02\ average}$ Mpa	$R_{p02\ min}$ Mpa	Sm MPa	S MPa	S_{mB} MPa
-200	1093	990			
-150	843	764			
-100	685	621			
-50	593	537			
0	543	492			
20	531	481	206	155	160
50	519	470	206	155	157
100	508	460	206	155	153
150	503	455	206	155	152
200	497	450	203	152	150
250	487	441	198	148	147
300	473	428	191	143	143
350	454	411	182	137	137
400	430	390	172	129	130
450	403	365	158	119	122
500	371	336	142	107	112
550	332	300	124	93	100
600	282	255	102	77	85
700	118	107	-	-	-

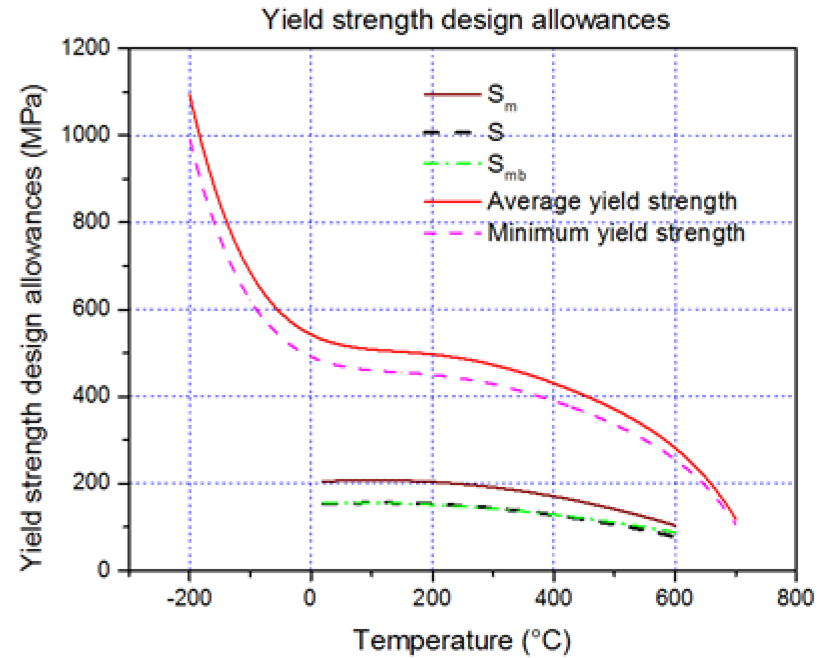
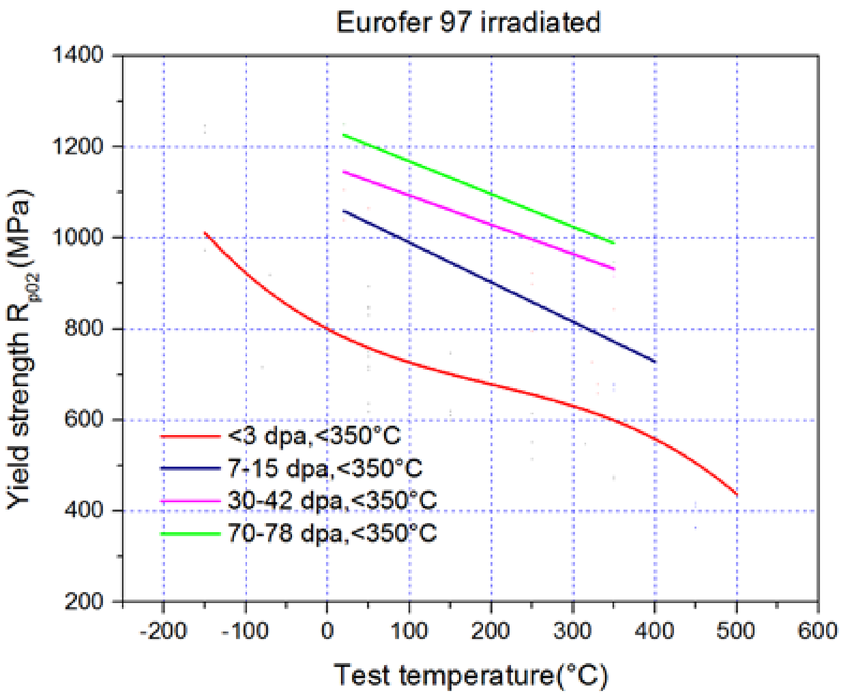


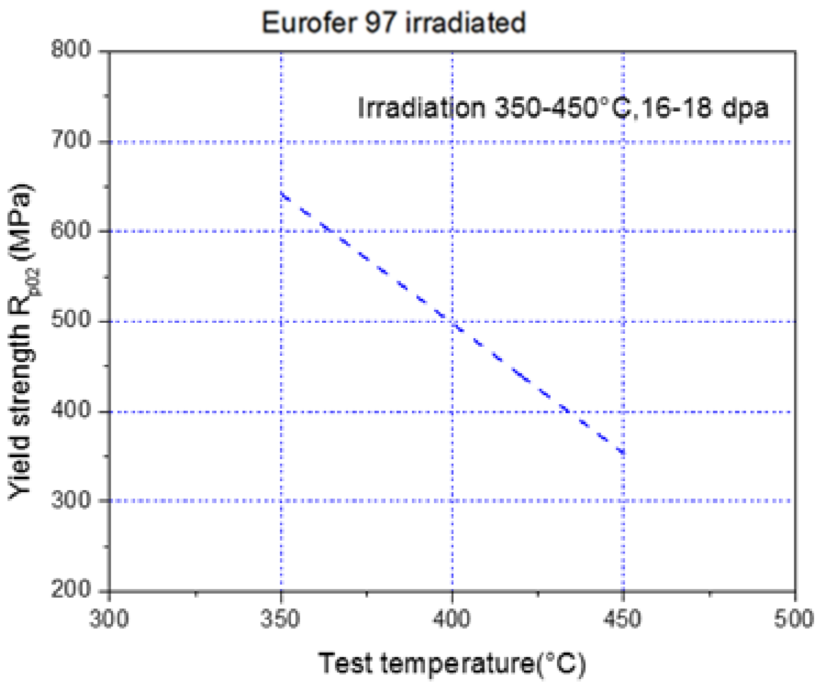
Table 6.4. Design strength allowances trend curves

Design allowance	Polynom for calculation
Average yield strength	$542.69-0.692*T+0.00512*T^2-1.926E-5*T^3+2.96E-8*T^4-1.755E-11*T^5$
Minimum yield strength	$491.5-0.627*T+0.00464*T^2-1.744E-5*T^3+2.68E-8*T^4-1.59E-11*T^5$
S_m	$203.3+0.087*T-4.2E-4*T^2$
S	$152.45+0.065*T-3.16E-4*T^2$
S_{mB}	$156+0.022*T-2.26E-4*T^2$

Material EUROFER

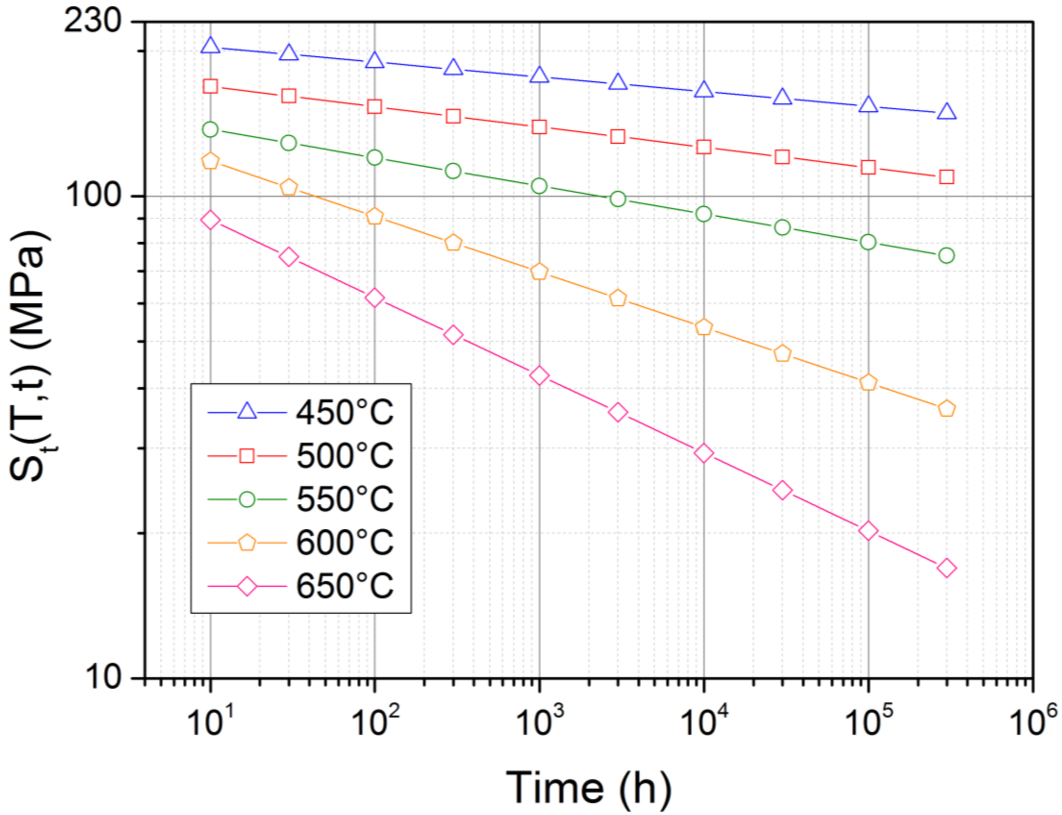
Property Yield Strength – Aged (irradiated) values





- Data grouping according to irradiation conditions
- Calculation of Yield Strength trend curves

Material EUROFER
Property Creep



S_t (T,t) defined as the least of

1) 2/3 of the minimum stress corresponding to average creep rupture time t at T
2) 80% of the minimum stress corresponding to time t and temperature T for onset of tertiary creep
3) Stress inducing total strain (elastic +plastic +creep) of 1%. This stress being derived from the tensile hardening rule and from the creep strain law. A minimum value equal to 0.8 times the average value.

S_t(T, t) are governed by 2/3 of minimum stress to rupture

EUROFER97 MPH - Gaps analysis

Unirradiated

- **Fracture Mechanical (FM)** properties (J_{Ic}, J-R …)
- **Creep-fatigue** properties
  - Isothermal LCF tests with long hold times under tension, compression
- Effects of **cycling softening** on **tensile & creep**
- **Ratchetting**
  - Isothermal uniaxial ratchetting tests (stress controlled with mean stress)
  - Lab tests with combined primary and secondary loads
- **Fatigue crack growth**
  - Investigate the effects of R-value, temperature & environment
- **Thermal aging** effects (tensile, Charpy-V, FM)
- **Mechanical properties** on **weldments** for proper PWHT (tensile, LCF, FM, creep)

Irradiated

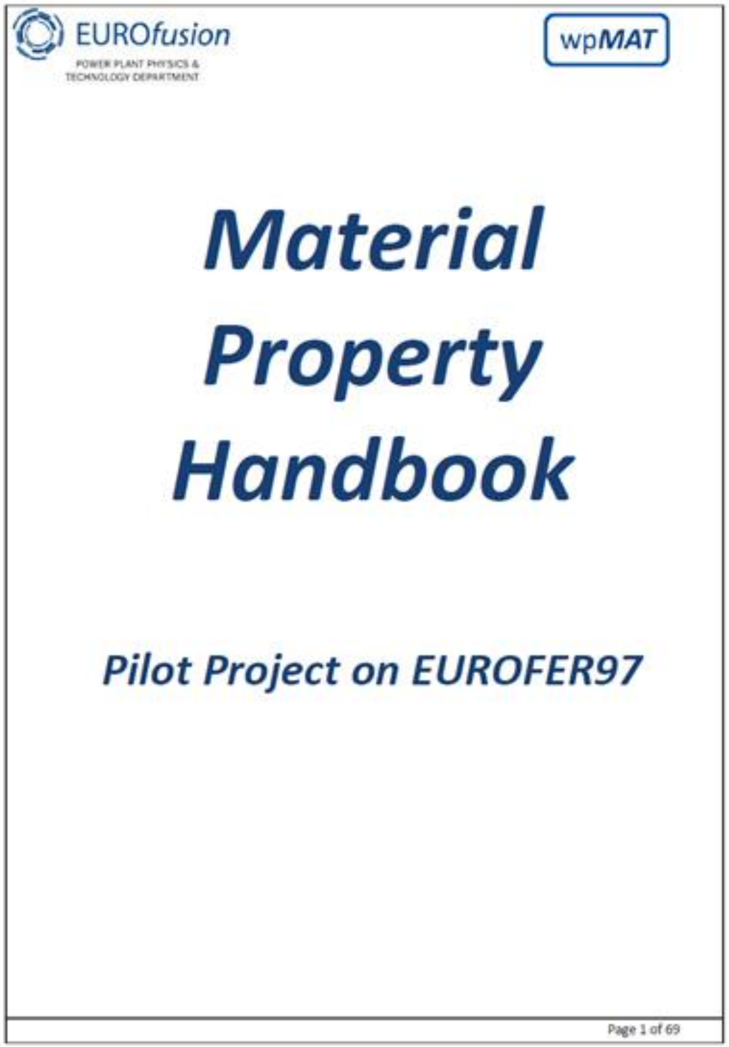
- **Baseline data** (tensile, LCF) in a **wide temperature** (T_{irr}=200-550°C) and **dose** range
- **Fracture Mechanical (FM)** properties (J_{Ic}, J-R …)
- Isothermal **LCF tests** with hold times
- **Swelling & Helium** effects
- **Irradiation creep**
- **Mechanical properties** on **weldments** for proper PWHT (tensile, FM)

Summary

- EUROfusion EUROFER97 database with about 3000 records
- Application of data reviewing procedure for qualification of data for MPH
- Calculation of design allowables
- ERUFOER MPH covering over 20 DEMO design relevant properties on base metal EUROFER97
- Gaps analysis with respect to the further development of the MPH

Thank you for your attention!

Material Property Handbook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Material Property Handbook

Pilot Project on EUROFER97

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Final Report on Deliverable

Partners:

and joined universities

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