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Analysis of potential factors influencing the relation between small punch and conventional creep tests

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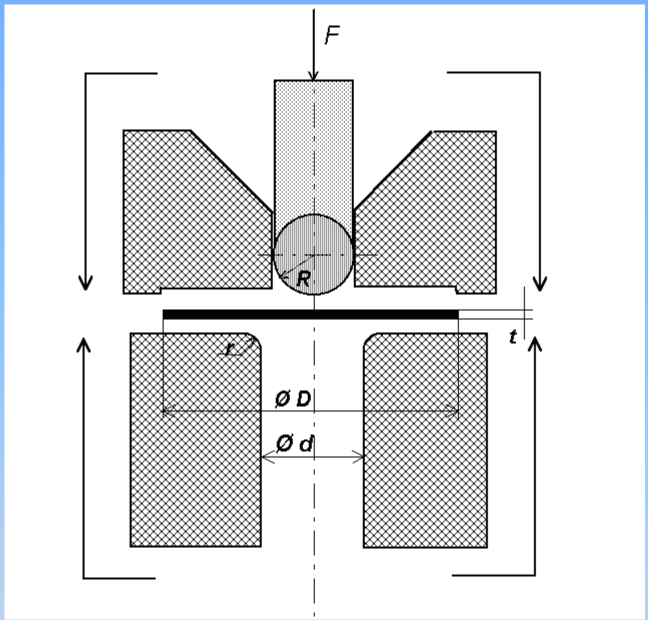
SPT arrangement and possibilities



IPM Brno - ability to perform both basic SP tests:

constant force *F* - CF $\Rightarrow \delta = \delta(t)$ ("creep")

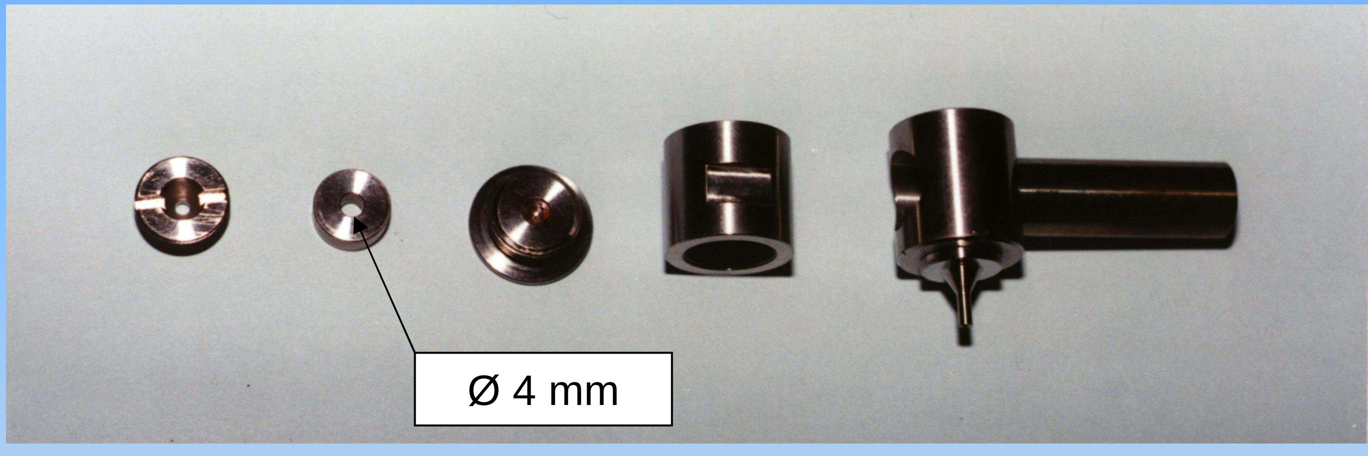
constant rate $\partial\delta / \partial t$ - CDR $\Rightarrow F = F(\delta)$

(similar to static tensile testing)

SPT dimensions (according to CWA 15627):

Disk diameter *D* (mm)	Disk thickness *t* (mm)	Lower die hole diameter *d* (mm)	Puncher ball diameter *R* (mm)	Radius (or chamfer) *r* (mm)
8	0.5 ±0.005	4	1.25	0.2 (0.2)

SPT arrangement



The arrangement is put into an adapted cantilever creep machine for compressive creep tests (IPM Brno).

<u>Material of parts of arrangement:</u> Inconel 718

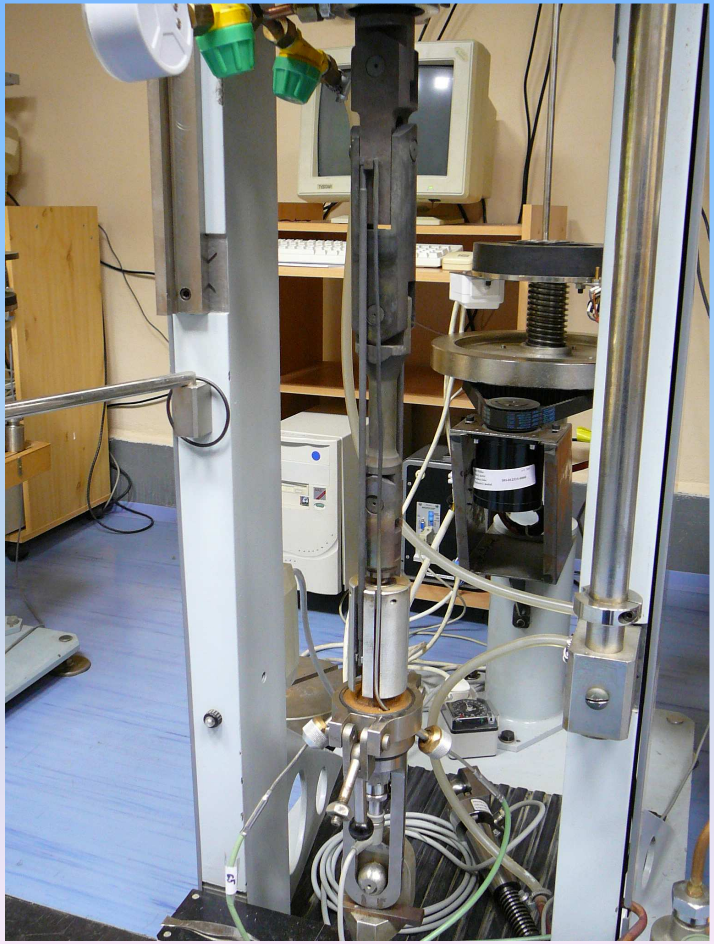
<u>Protective atmosphere:</u> Argon

<u>Lever ratio</u>: either 10:1 or 2:1

The IPM machine allows to perform both types of SP tests.

SPT machine

- **SPT Adapted Creep machine**: lever ratio 10:1, stepper motor,
- protective argon atmosphere in the furnace up to 1000℃



Experimental material

P91: Conventional and SP specimens were prepared from a pipe segments with an outer radius of 165 mm and a wall thickness of 16 mm.

The heat treatment was normalization (1050℃/1h) followed by tempering (760℃/2h).

P92: Conventional and SP specimens were prepared from a pipe segments with an outer radius of 800 mm and a wall thickness of 78 mm.

The heat treatment was normalization (1060℃/1h) followed by tempering (760℃/2h).

Tab. Chemical composition of tested steels

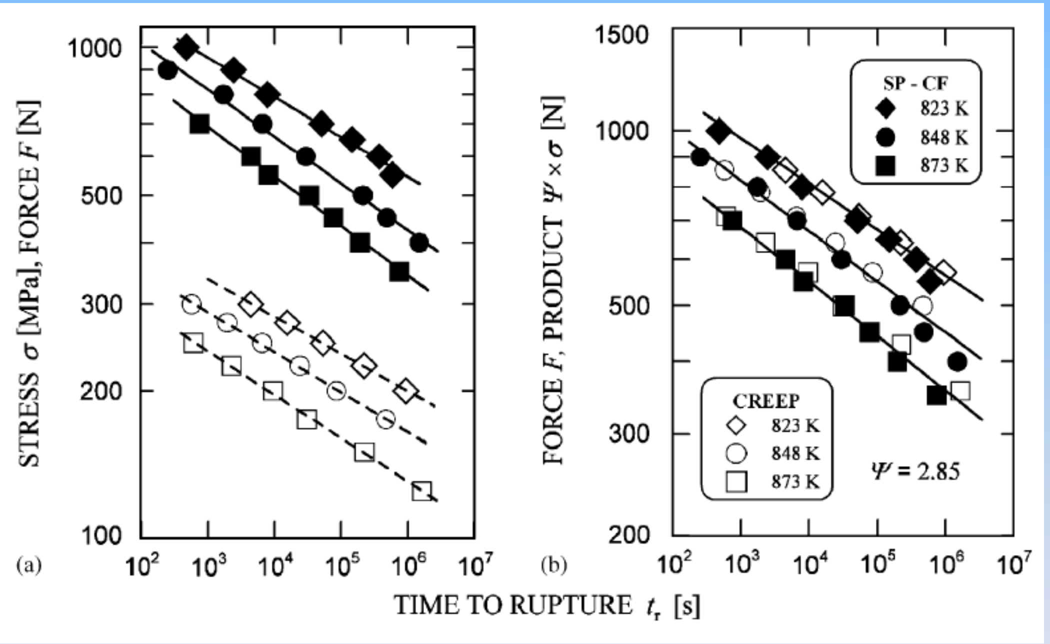
Steel	**C**	**Cr**	**Mn**	**Mo**	**Ni**	**P**	**Si**	**V**	**W**	**S**	**Nb**	**N**	**B**	**Al**
P91	0.10	8.50	0.40	0.88	0.10	-	-	0.23	-	-	0.10	0.045	-	-
P92	0.09	8.85	0.50	0.50	0.31	0.019	0.34	0.21	1.90	0.003	0.084	0.0595	0.004	0.008

Tab. Basic mechanical properties

Properties of steel at T = 873 K	**Young modulus E (GPa)**	**Poisson const. ν (–)**	**Yield stress $R_{p0,2}$ (MPa)**
P91	160	0.3	268
P92	167	0.3	301

Experimental results: conventional creep testing *vs.* SPT

Comparison of the stress and force at identical time to fracture of P91 steel conventional creep tests and SPT:



$$F = \Psi\sigma$$

The factor Ψ reaches value $\Psi \cong 2.85$ was for P91 steel

Ψ units: N/MPa = mm^2

K. Milička, F. Dobeš: International Journal of Pressure Vessels and Piping 83 (2006), pp 625-634

Fig.: Dependences of the stress and the force *F* on the time to rupture of P91 (a) and (b) the result of the application of Eq.: $F = \Psi\sigma$

Experimental data

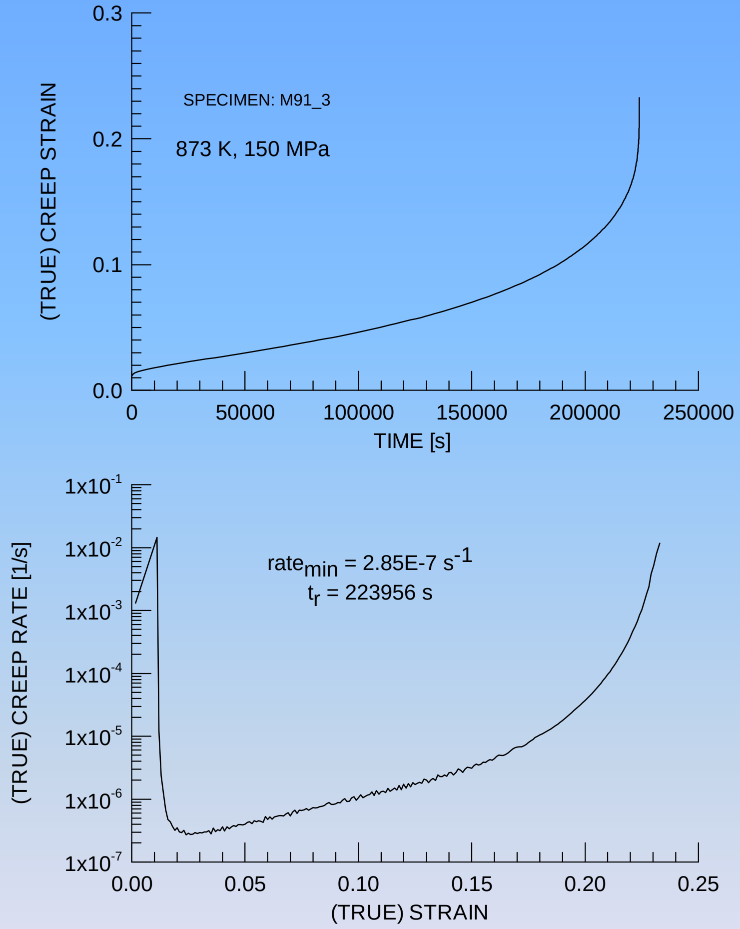


Fig.: Experimental curves obtained from conventional creep test of P91 steel at σ = 150 MPa

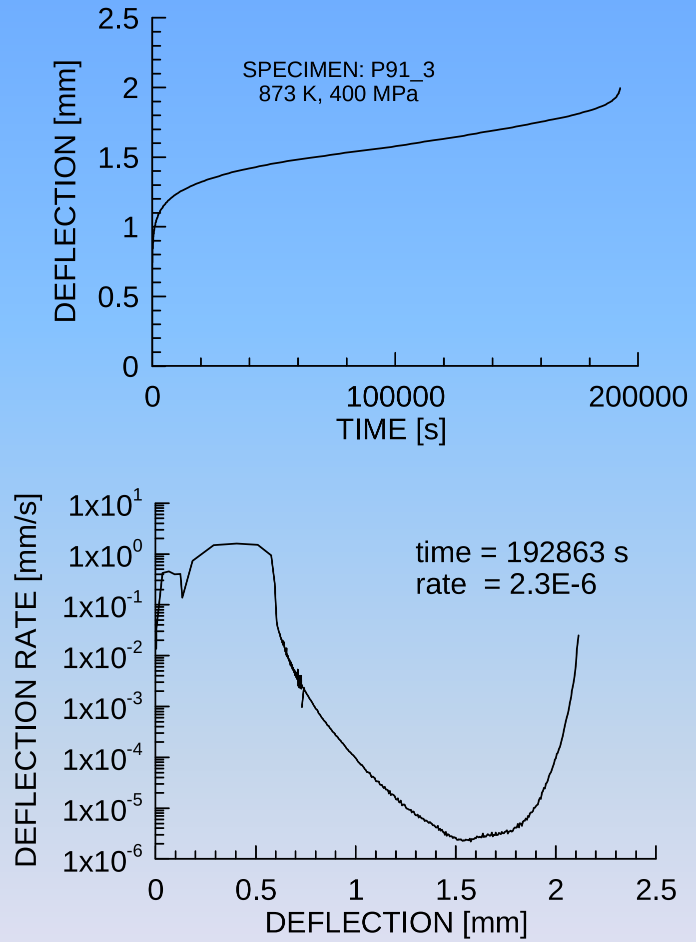


Fig.: Experimental curves obtained from SPT of P91 steel at F = 400 N

Experimental data

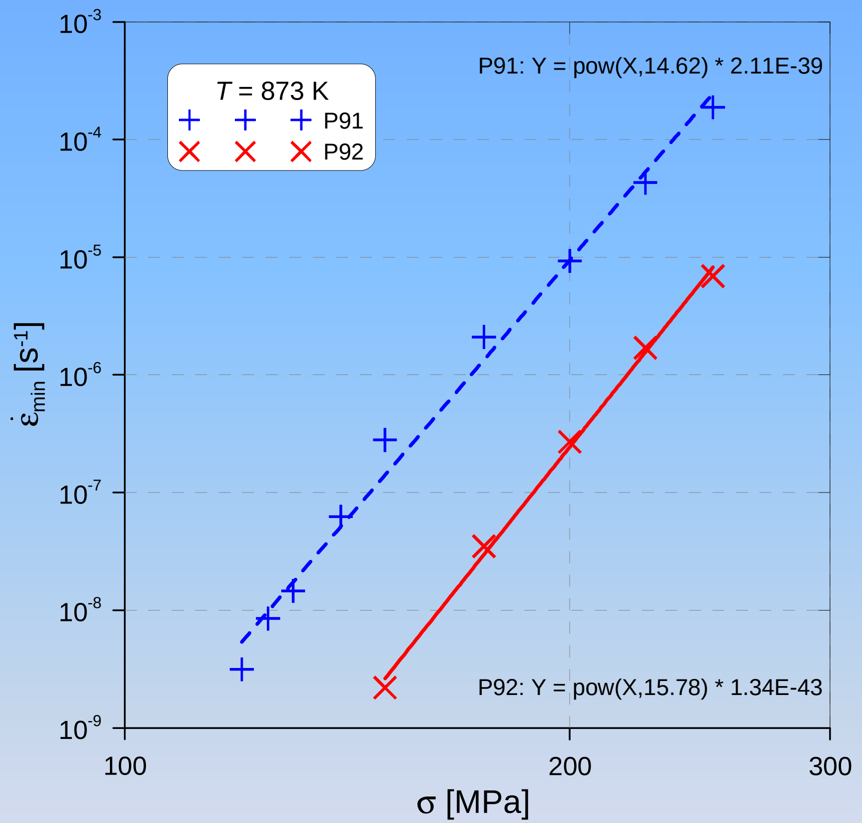


Fig.: Minimum creep rate *vs.* applied stress for tested steels

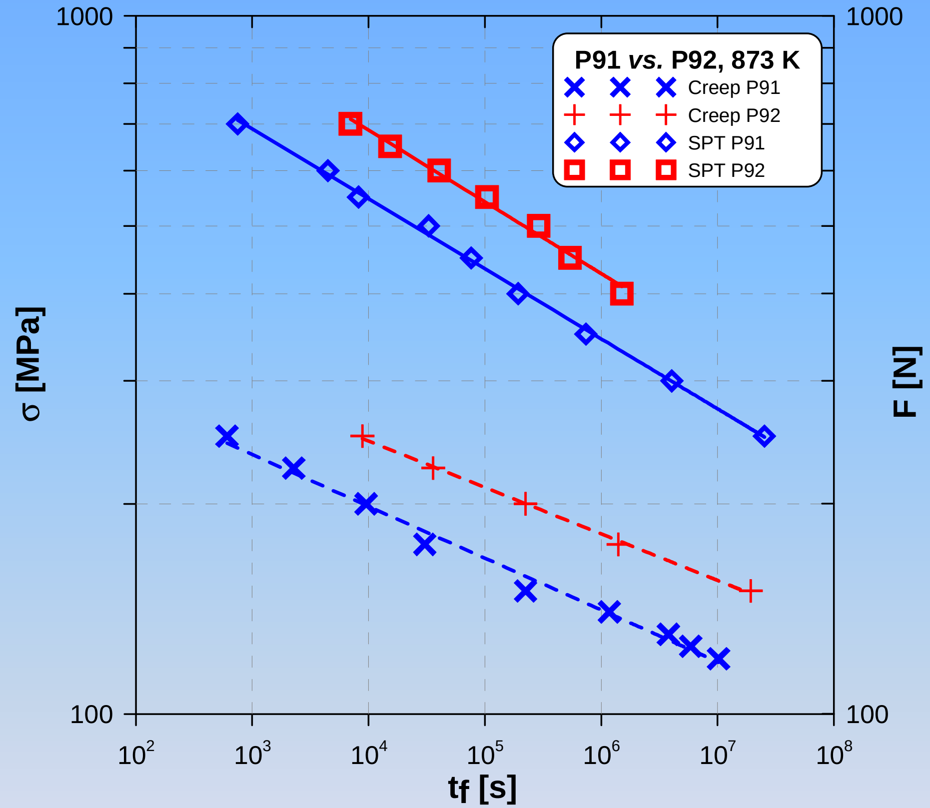


Fig.: Comparison of creep stress and SPT force at identical time to fracture

Factor Ψ - stress dependent

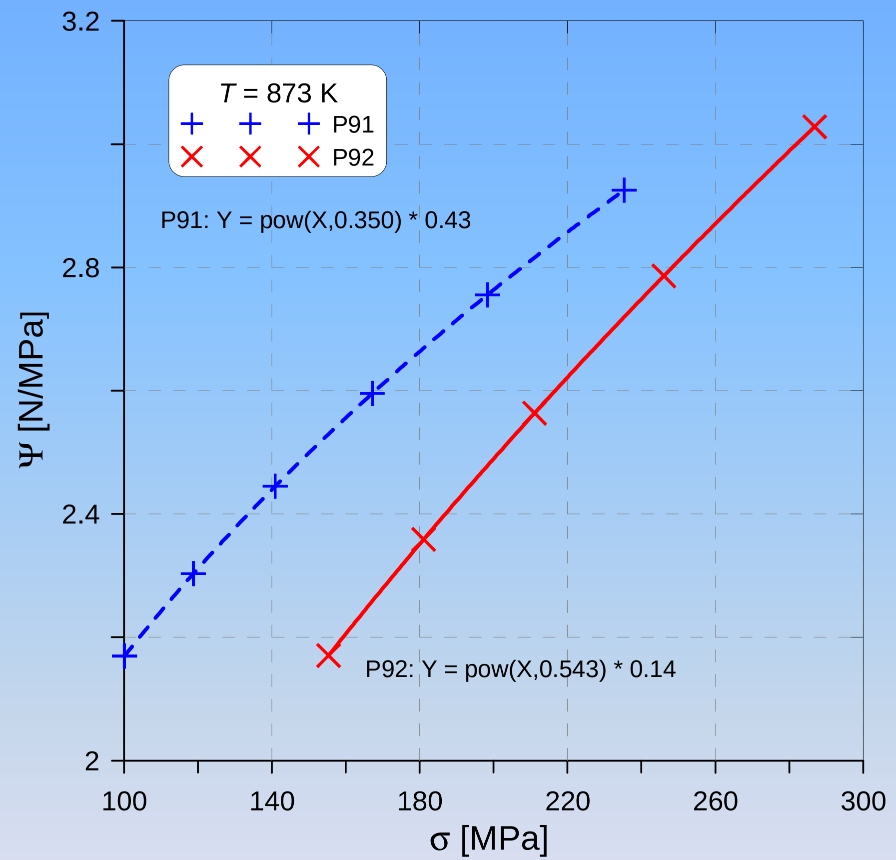


Fig.: Factor Ψ depending on applied stress obtained for identical time to fracture in creep tests and SPT

$$\Psi = const\ \sigma^{n}$$

P91 at 873 K:

$$\Psi = 0.43\ \sigma^{0.350}$$

P92 at 873 K:

$$\Psi = 0.14\ \sigma^{0.543}$$

In the tested interval of σ:

$\Psi \cong$ **2.2 to 3**

Factor Ψ [N/MPa = mm²]

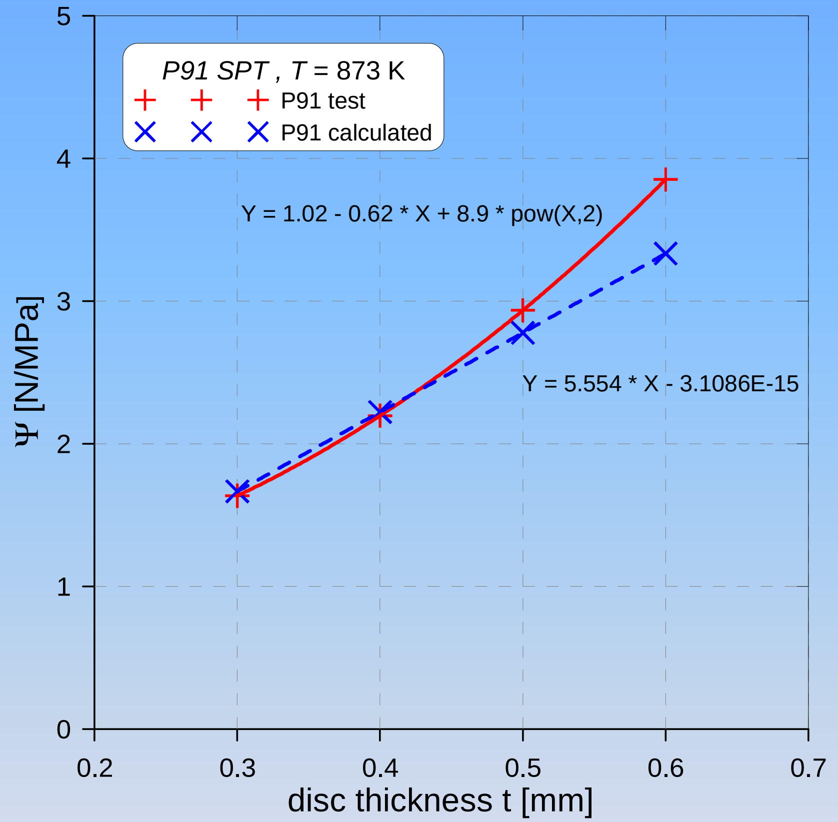
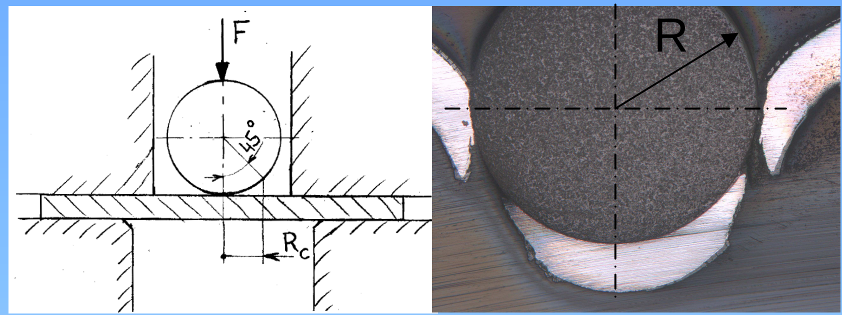


Fig.: Dependence of factor Ψ on specimen thickness *t*



Since the crack is circular a cylindrical surface may represent "effective area of resistance" :

$$\boldsymbol{D_c = 2\,R \sin 45° = 1.77\ \text{mm}},$$

where R = 1.25 mm (ball radius)

the cylindrical surface then is:

$$\boldsymbol{A_c = \pi\, D_c\, t = 2.78\ \text{mm}^2}$$

rough estimation of the crack surface in Fig. gives R_c = 1.8 mm, t = 0.5 mm, therefore $\Psi \cong 2.83$.

Principal difficulties in comparing other parameters than time to fracture...

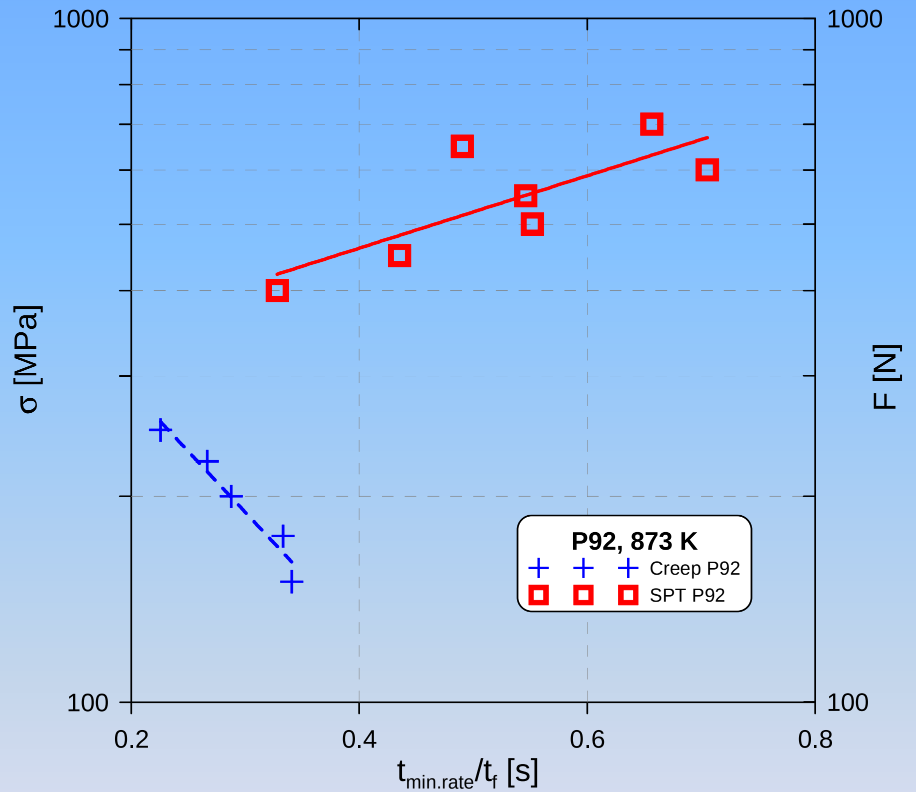


Fig.: Stress σ and SP force *F vs.* time at min rate/ time to fracture

While for conventional creep tests the time ratio decreases with stress and is in low values around 0.2 to 0.3 for SPT-CF the ratio increases with force and values of time ratio are significantly higher. This points out to principal difficulties in comparing other parameters than time to fracture for both types of tests.

Contact surface

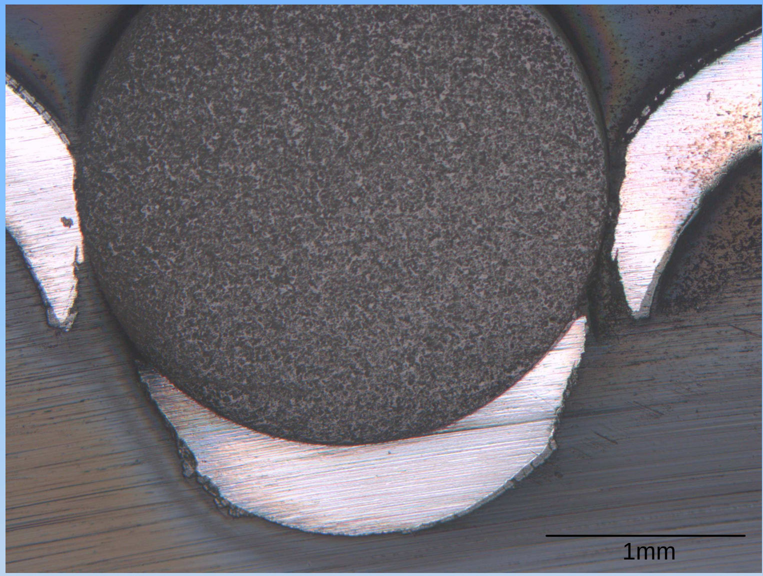


Fig.: Section of punched specimen from P91 steel

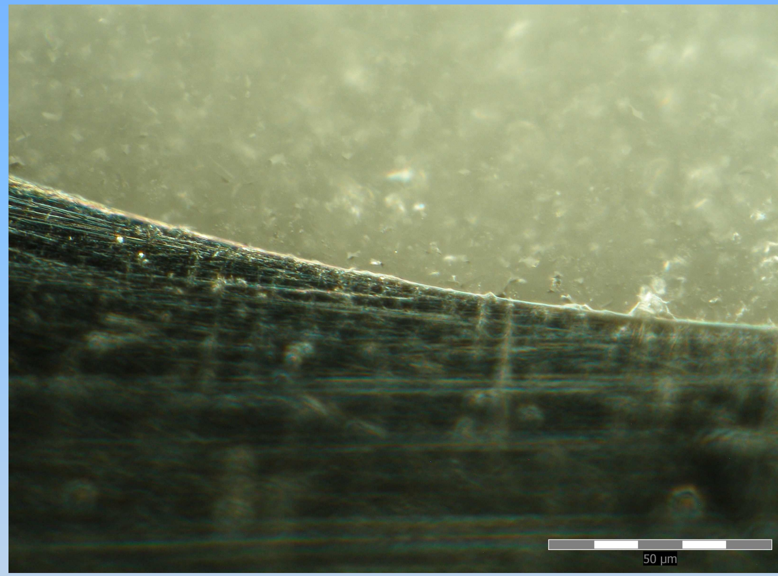


Fig.: Close-up of interface between the ceramic ball and the specimen after 1100 h of testing

Friction measurement

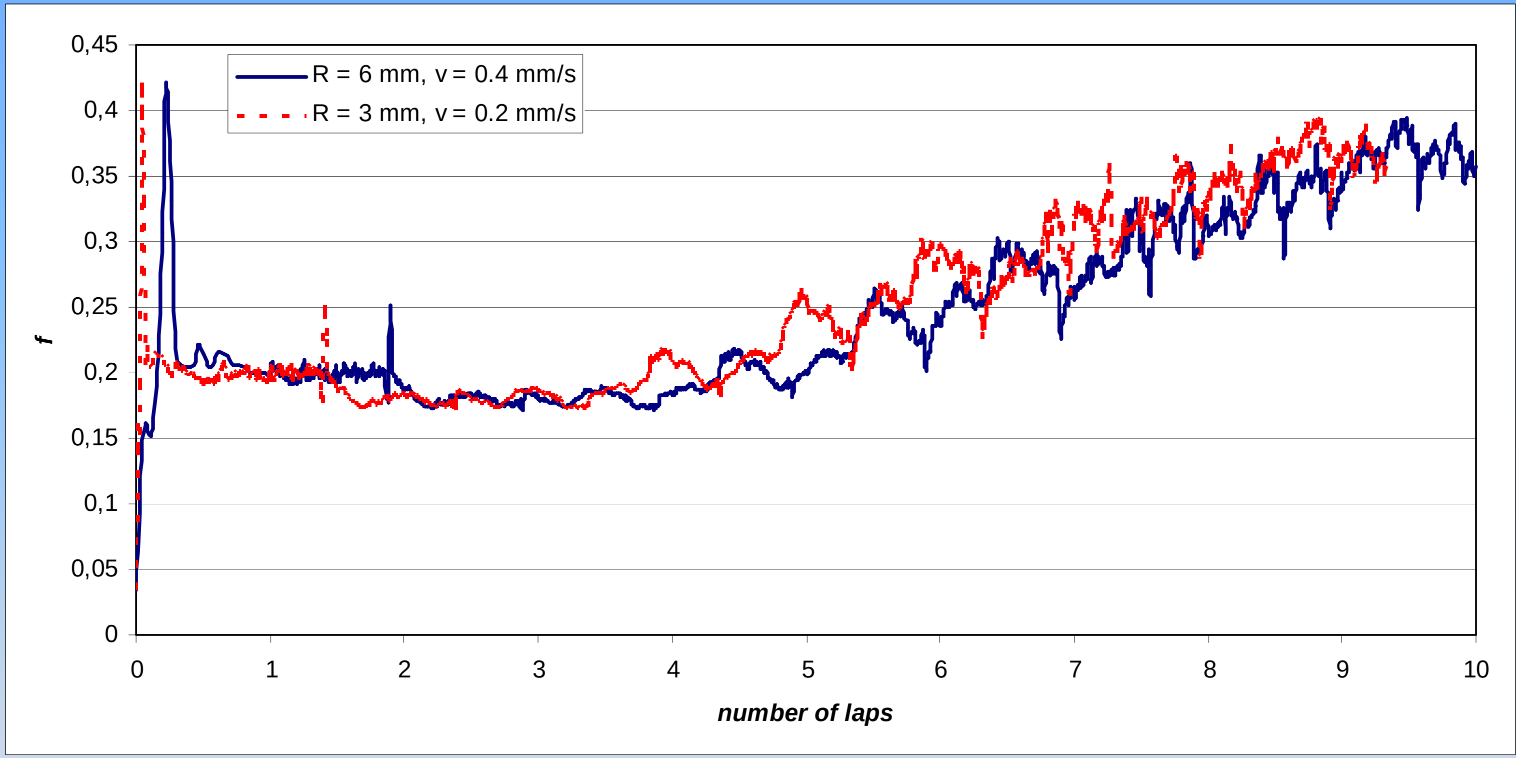


Fig.: Frialit (99.7%Al_2O_3) ball on P92 disc friction measurement at room temperature, vertical force *F* = 30N, room temperature, elevated temperature TBD...

Some notes

There might be other potential factors except the geometry of SPT setup and material properties that could influence the factor Ψ:

- **influence of protective atmosphere, air, vacuum (oxidation of specimen surface)**
- **influence of specimen surface preparation**
- **influence of eventual lubrication**
- **other ?**

There are two typical situations after the test:

a) specimen cap detaches completely and stays attached on the ceramic ball (typical for longer-term tests over 1000h)

b) specimen stays with cap partly attached and the ball is detached (typical for short-term tests - up to 1000h)

Conclusions

- **A simple empirical approach of relation between SPT and conventional uniaxial creep tests gives useful tool how to relate results of these two methods.**
- **Factor Ψ may represent a effective area of resistance. Its relation to circular crack radius or the crack initiation location needs to be further investigated.**
- **Factor Ψ may appear constant for most steels at given temperature and limited range of SP forces (applied stress in conventional tests).**
- **At larger range of SP forces factor Ψ does not have constant value and its dependence on stress can be determined.**

Conclusions

List of tasks TBD:

- **Tribometric measurement of static and dynamic friction coefficient between puncher ball and specimen surface at various temperatures. Evaluation of long term friction characteristics and its relation to oxidation –> important input to FEA**
- **Study influence of protective atmosphere on SPT (argon *vs.* hydrogen *vs.* air *vs.* vacuum)**
- **SPT tests on various advanced steels, intermetallics, aluminum or magnesium alloys and their composites**
- **More cracked specimens need to be evaluated from point of view of crack shape, its diameter and its relation to factor Ψ**

Thank you for your attention!

Acknowledgement

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