Lifetime Assessment of a Steam Pipeline

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Abstract

The aim of this paper is to design a method for assessing the life of steam pipes for Czech power plants. The most widely-used material in Czech power plants is steel 15 128. Our findings may also be applied for international equivalents of this steel. The paper shows the classification of cavitation damage and microstructure classification status, based on the German VGB Act, with references to EPRI law in the USA. Calculations of remaining life on the basis of Russian experience are also shown. The possibility of applying this method to increase the operating parameters for power plants is discussed.

Keywords: life assessment of a steam pipeline, creep damage, assessment of microstructure damage.

1 Introduction

A switchover to high-parametric power plants requires an assessment of the remaining life of existing steam piping. In creep conditions, this requires a large amount of information on operating conditions (temperature, pressure, time), material characteristics (microstructure, creep strength, creep strain rate, etc.) It is also important to monitor the stress in exposed parts and weld joints. The greatest influence on component life is the formation and joining of internal defects, i.e. cavities. It is therefore necessary to provide a sophisticated method for observing and evaluating internal defects. This paper deals mainly with steel type 15 128, because the vast majority of the steam piping currently operating in the Czech Republic is made from this material.

2 Material 15 128 (14MOV6-3)

This is a low-alloy heat-resistant CrMoV steel with guaranteed weldability. The main use of this steel is for steam piping, superheaters and boiler tubes operating at temperatures up to 580 °C.

The microstructure of steel in the initial state depends on the heat treatment that it has undergone. The initial state of 15 128.5 has a ferritic-bainitic microstructure with fine dispersion of globular carbides of M_4C_3 or MC type, respectively, precipitated in the ferritic matrix. The initial state of 15 128.9 is formed by a fine carbide-bainitic microstructure. The two initial states differ in their mechanical properties; see Table 3 [1].

Table 1: Equivalent materials according to international standards

ČSN	DIN		GOST	ASTM
	W. nr.	marking		
15 128	1.771 5	14MoV6-3	12Ch1MF	Gr. P24

Table 2: Chemical composition of the material according to the standard

Identification according to ČSN	Chemical composition [weight %]								
	C	Mn	Si	Cr	Mo	V	P	S	Al
15 128	0.10 0.18	0.45 0.70	0.15 0.40	0.50 0.75	0.40 0.60	0.22 0.35	max. 0.040	max. 0.040	max. 0.025

Table 3: Mechanical properties of steel 15 128 in dependence on heat treatment

State *)	R_m [MPa]	$R_{p0,2}$ [MPa]	A_5 [%]	HB	$R_{mT}/10^5$ hrs [MPa]			$R_{mT}/2.5 \cdot 10^5$ hrs [MPa]		
					550 °C	575 °C	600 °C	550 °C	575 °C	600 °C
.5	490 690	min. 365	min. 18	140 197	89	64	45	73	51	35
.9	570 740	min. 430	min. 17	163 223	107	75	(51)	88	59	(38)

*) 15 128.5–960 °C/30 min/air + 710 °C/1hour/air

   15 128.9–970 °C/30 min/water + 720 °C/1hour/air

Table 4: Summary of tests for steam piping [2]

Type of samples	Test methodology		Obtained data	
Pipeline (non-destructive tests)	Replicas	Visual tests	Cavity formation	Cracking
	Ultrasonic methods	Hardness testing	Density of inclusions	Spheroidization
	Penetration test	Mag. powder test	Segregation of sulphides	Hardness
	Optical fibre measurement	Chemical analysis	Size and type of grain	
Metallographical samples (destructive tests)	Replicas	Hardness testing	Fusion line cracking	Cavities formation
	Light microscopy	Electron microscopy	Hardness	Spheroidization
	Cryo-cracking	Cross-weld stress rupture test	Fine-grain HAZ damage	Damage to weld metal
			Density of inclusions	Size and type of grain

3 Monitoring the operating parameters, service life management

The main parameters that should be monitored over time are the temperature and the pressure of steam in the steam pipeline. Regular monitoring of the operating parameters several times a year is most advantageous in terms of creep lifetime.

3.1 According to epri (USA) [2]

A three-stage approach is used for evaluating the lifetime of steam pipelines. At each stage, the estimated remaining life and the desired service life of the steam pipeline are compared.

STAGE 1: Includes general calculations based on operating history and especially exploring the possibility of degradation of components. The main contents of this stage are the relevant technical drawings, material properties, operating hours and cycles, history of inspections and maintenance, failure history (details of failures and repairs to failures), operational parameters and their maximum values (temperature and pressure).

STAGE 2: Includes non-destructive testing of components, the results of which can improve the evaluation of the lifetime in STAGE 1. For tests carried out at this stage, see Table 4. Visual examination includes observation of geometric inaccuracies (e.g. buckling). This includes geometry measurements (wall thickness, ovality) and measurements of the position of selected hinges and supports. If cracks are found by capillary tests, an ultrasonic examination is to be made. The replica method provides a preliminary estimate of the lifetime of the steam piping (welded joints).
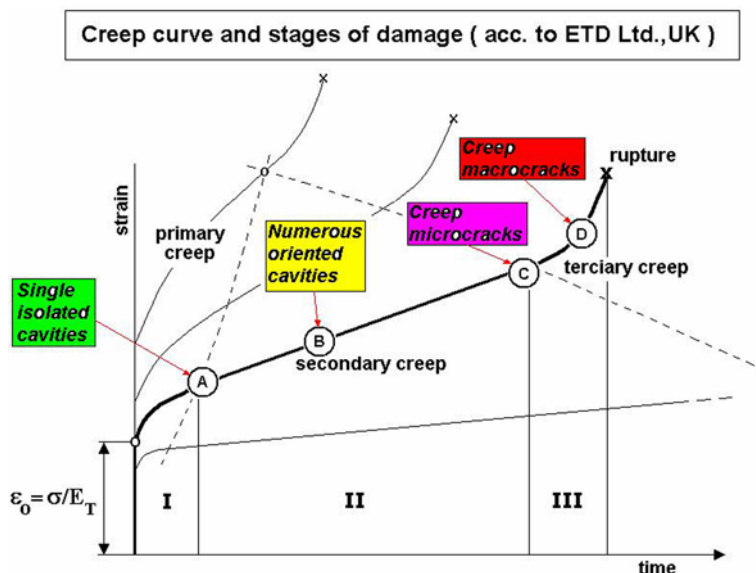
Figure 1: Creep curve with states of cavitation damage marked on it [3]

STAGE 3: Includes destructive testing and detailed analysis of the samples. It is necessary to interrupt the operation and remove a part of the steam pipeline. This stage provides the most accurate estimate of the remaining life of the samples. The observed data is compared with the data determined in STAGE 2. The tests are presented in Table 4. The high cost of this type of evaluation needs to be taken into account. (For example, is it better to replace or repair a part of the steam piping, or is it better to operate under lower conditions?)

According to [3], the replica method can be used on properly prepared surfaces. Two to three replicas should be taken from each site. Microstructure and cavitation (creep) damage is evaluated on the basis of an evaluation of the replicas. Figure 1 shows a creep curve with states of cavitation damage marked on it. The structural condition is assessed according to the etalons. Resistance to corrosion attack can also be assessed with the use of electrochemical polarization measurements.

3.2 Russian approach (material 12CH1MF)

3.2.1 Operation and inspection

On the straight parts of steam pipelines operating at temperatures from 450 to 545 °C it is necessary to measure the residual deformation 200 thousand hours after the pipeline came into operation. For steam pipelines operating at temperatures from 546 to 570 °C, analogous measurements should be performed after 150 thousand hours. If the residual deformation exceeds 0.75 %, an assessment of the material is made in terms of mechanical properties and chemical composition.

On the bent parts of the steam piping, measurements of the residual deformation, magnetic powder and ultrasonic flaw detection must be performed after 150 thousand hours. In operating temperature ranges from 546 to 570 °C, this measurement is performed after 100 thousand hours.

For welded joints, the degree of fatigue life τ_{ho}/τ_{lp} is evaluated in accordance with the range of structures and their microdamange for welded joints (τ_{ho} – hours of operation; τ_{ls} – limit service life at the stage of microcrack discovery). The residual service life (τ_{rs}) can be calculated from the difference $\tau_{rs} = \tau_{ls} - \tau_{ho}$ [4]. Typical damaged places of welded joints in the creep region are found mainly along the outside of the heat-affected zone of the material.

3.2.2 Service life calculation

The lifetime of a steam pipeline operated in the creep region is assessed according to the degree of micro-damage within the structure of the material. The basic parameter for calculating the lifetime is the number of micropores in a unit area of the metallographic scratch pattern (replica). Figure 2 shows an example of data processing for steel 12Ch1MF at 600 °C. For a reliable extrapolation of long-term strength at 100 000 hrs, it is necessary to start from an experiment planned for at least 4 000–5 000 hrs. In [5], the calculation was based on 50-300 thousand hrs in creep conditions, steam piping energy blocks 250–800 MW at 515–560 °C and 3.7 to 25.5 MPa.
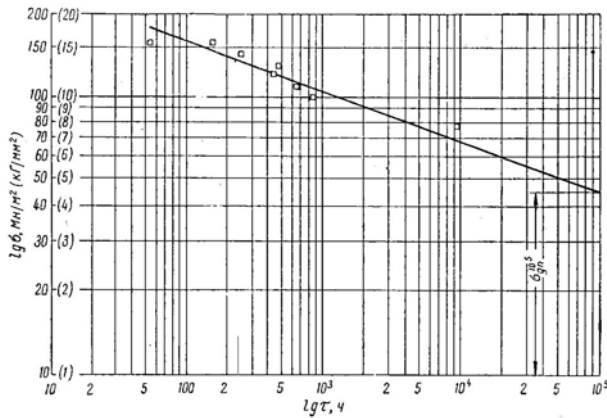
Figure 2: Example of experimental data processing in double logarithmic coordinates after tests on steel 12Ch1MF for term strength at 600 °C [6]

3.2.3 Creep time

The creep time from pore creation to the development of a macro-crack for 12Ch1MF can be one half of the total operating time, which is $(1–3) \times 10^5$ hrs (in the course of a year the plant works for $(7–8) \times 10^3$ hrs). Information on the degree of harmfulness of the metal therefore allows the uptime capacity to be calculated. At the present time, the diagnostics is carried out mostly by metallographic methods when the energy blocks are shut down, or during an overhaul. The high work difficulty involved in preparing the metallographic sample reduces the control performance, and extensive repairs are needed. It is therefore necessary to introduce more progressive express methods.

4 Increasing the operating parameters

The Russian literature [4,7], presents examples of service life extension by up to an additional 100 thousand hours after appropriate repairs to the welds on the basis of microstructure analysis and degree of damage. Cyclic heat treatment (3 to 10 cycles) with heating up to 980 °C and cooling effectively regenerates the operating characteristics if the material damage does not exceed 10–15 % in relation to the original state, when $\Delta\rho/\rho \leq 0.1$-0.2 % [?]. For 12Ch1MF steel with 0.13 % damage just 2–3 cycles; at 0.5 % damage, 4–6 cycles; 1 % (total damage state), 8–10 cycles.

Other specific cases for increasing the operational parameters are very difficult to access. Most of the results and experience gained in relation to this issue are covered by trade secrecy. However, it is obvious that even a small change in operating parameters (e.g. a temperature increase) has a significantly negative effect on the residual service life.

5 Assessment of microstructure damage

In our proposal for the metallographic evaluation of a structure, we utilize the classification degrees used by Neubauer, ISQ, and VGB Nordtest, a detailed description of which, and a comparison, are given in Table 5 [3]. Figure 3 shows various states of material 14MoV6-3 damage.

Table 5: Microstructure rating class [3]

| Nordtest NT NDT010	VGB TW507	Neuber and Waddel	Description	Recommendation (Nordtest)	Consumed Life-Fraction (EPRI)
	0		As-received		
1	1		No creep cavitation	None	0–0.14
2		A	Single cavities	Re-examine after 20 000 hrs	0.05–0.47
	2a		Isolated cavities		
	2b		Numerous cavities, no preferred orientation		
3			Coherent cavities	Re-examine after 15 000 hrs	
	3a	B	Numerous oriented cavities		0.27–0.53
	3b		Chain of cavities		
4	4	C	Creep cracks (micro)	Re-examine after 10 000 hrs	0.29–0.84
5	5	D	Creep macrocracks	Issue immediate warning	0.7–1.0
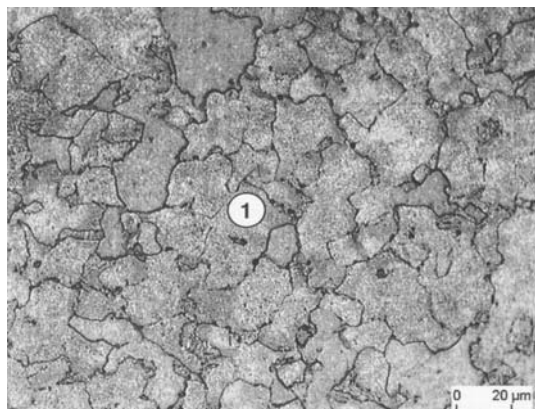
Assessment class 1: No creep cavitation
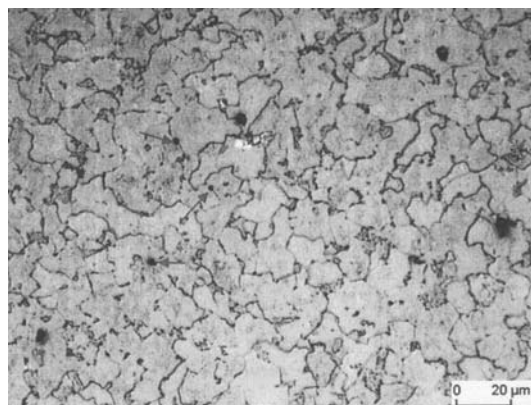
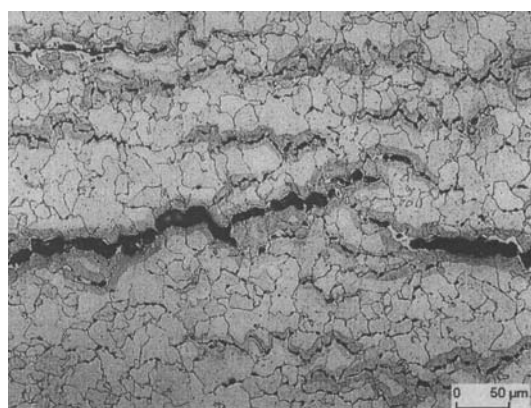Assessment class 2a: Single cavities
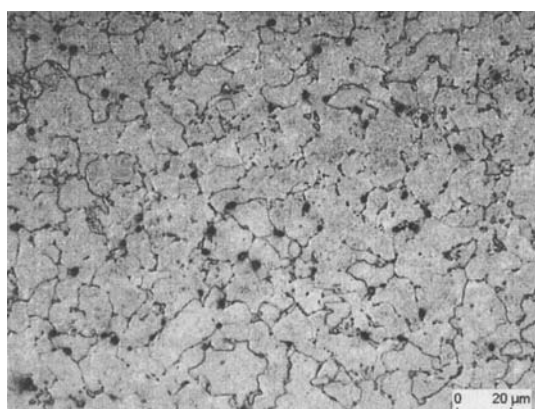
Assessment class 2b: Numerous cavities
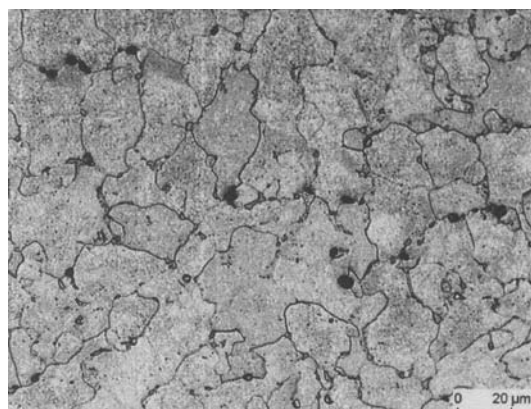
Assessment class 3a: Numerous oriented cavities
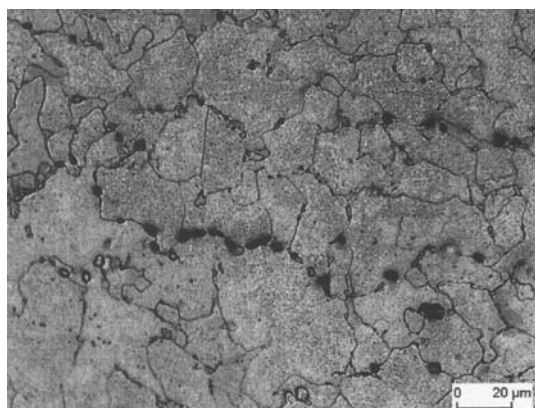
Assessment class 3b: Chain of cavities

Assessment class 4: Creep microcracks

Figure 3: States of material 14MoV6-3 damage [8]

6 Conclusion

Our proposal for Czech power plants anticipates a shift in service life from grade 3a to 3b, i.e. to allowed length of string cavitation 100 μm at a density of 20 microcracks/mm^2 for steel 15 128 or its international EN equivalents. The proposal is based on an experimental evaluation of microstructures, creep behavior and changes in wall thickness of bends and pipes at 6 CEZ power plants operated for a period of 25 to 35 years.

Another topic for research is the design of checks on the service life of steam pipelines in the area of creep damage and damage assessment of the microstructures of grade 15 steels and the new class of T23, T24, P91, P92 and E911 steels.

References

[1] Svobodová, M., Tůmová, D., Čmakal, J.: *Dílčí odborná rešerše "Přehled materiálových vlastností oceli 15 128 z databáze UJP PRAHA, a. s.".* [Zpráva UJP 1450] UJP PRAHA, a. s., Praha : listopad 2011, 22 s.

[2] *Fossil Plant High-Energy Piping Damage: Theory and Practice, Volume 1: Piping Fundamentals.* EPRI, Palo Alto, CA: 2007. 1012201.K.

[3] Mentl, V.: *Řízení životnosti parovodů v energetice.* [Technická zpráva – Rešerše č. 16/2011/ KMM] KMM FS ZČU v Plzni, Plzeň : listopad 2011, 239 s.

[4] Hromchenko, F. A.: *Životnost svarových spojů parovodů.* Moskva : Mashinostrojenie, 2002, 246 s. ISBN 5217031263.

[5] Калигин, Р. Н.: *Прогнозирование Остаточного Ресурса Длительно Експлуатируюшихся Сбарных Соединений Паропроводов в Условиях Ползучести по Структурному Факторы.* Бсероссийский теплотехнический научно-исследовательскуй институт. Москва : 2008.

[6] Antikajp, P. A.: *Metallovedenie.* Moskva : Metalurgija, 1972, 183 s.

[7] Изюмский, Н. А.: *Повышение надежности паровых котлов и паропроводов.*

[8] VGB–TW 507 – Teil2/Part2 Richtreihen/Rating Charts, Januar 2005.