EAN 2017
55th conference on experimental stress analysis

Evaluation of the Influence of Corrosion Fatigue on Steel Alloy for Steam Turbines

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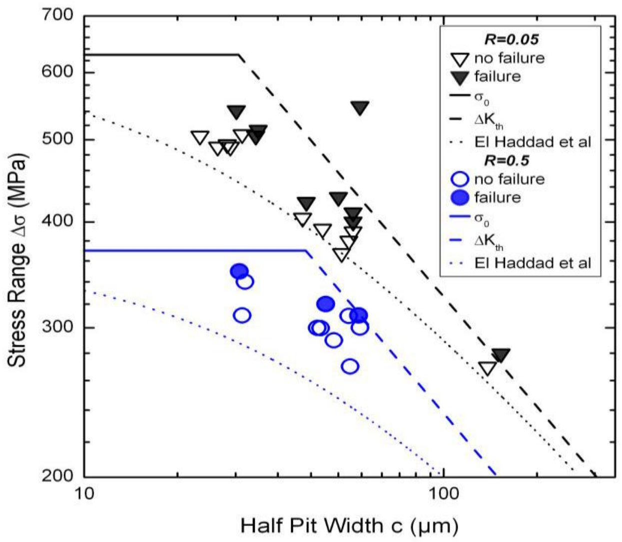
Introduction

To evaluate the influence of corrosion pits on fatigue [1], linear elastic fracture mechanics (LEFM) is used. It has been observed, that most pits have roughly a semielliptical shape with the width at the surface, 2c, and the pit depth. Investigations show that the pits can be treated as semi-circular surface cracks with a geometry described above.
Fatigue failure in steam turbine blades is a critical issue since high frequency fatigue loading is induced by unsteady steam flow. The cyclic stresses are low compared to centrifugal forces due to the rotation which leads to high stress ratios.
In the low pressure part of engines, fatigue crack initiation at corrosion pits is a frequently observed cause of damage. Especially in the last two blading stages – where transition from dry to wet steam takes place – pitting may occur when unexpected operating conditions, for example, due to leaking of the condenser are present.

Modeling of corrosion fatigue damage

Since fatigue crack is expected to nucleate at the mouth of the pit (i.e. at the end of the c axis), the dimension c (half pit) will be used to represent the pit or crack size. With this approximation and that the pit size is small in terms of crack behavior, the stress intensity factor of pits ΔK , FCGR diagram for long cracks and cracks that were initiated at corrosion pits (Fig.1) and finally a Kitagawa- Takahashi (K-T) diagram can be created.
The shown diagram is for 403/410 12% Cr martensitic steel and temperature 90°C. The K-T diagram correlates pit-to-crack fatigue data with the use of the approach El Haddad for short cracks (Fig.2). The data are shown for specific values of R (ratio of minimum to maximum stress for combined steady and cyclic stress). As a result, K-T diagrams can be used for assessment of the fatigue limit and life-time of corroded parts of steam turbines.



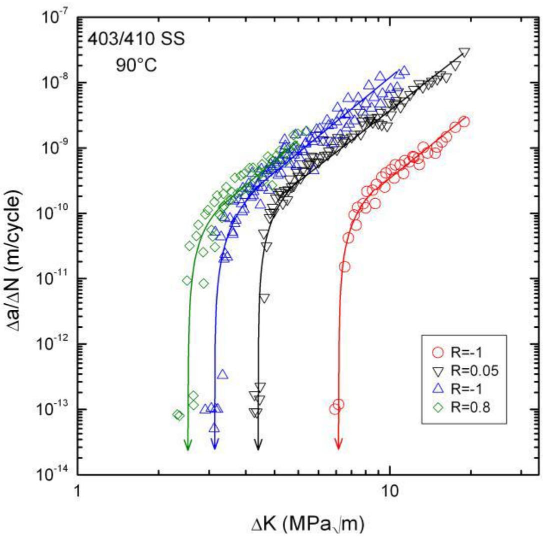


Fig. 1: Fatigue Crack Growth Rate (FCGR)

Fig.2 Kitagawa- Takahashi Diagram

An important parameter in the diagram is R, which is the ratio of minimum to maximum stress in a combined steady and cyclic stress environment, as shown in following relation

$$R \equiv \frac{\sigma_m - \sigma_a}{\sigma_m + \sigma_a}$$

where:

σ_m is the steady (mean) stress, and
σ_a is the cyclic (alternating) stress.

Further, stress intensity factor ΔK of the corrosion pits in the diagram can be calculated from the relationship:

$$\Delta K = \Delta\sigma\sqrt{\pi \cdot (c + c_0)} \cdot Y$$

where the geometry factor, Y , for semi-circular surface cracks is 0,65 and c_0 depends on the material according to empirical relationship, c is half pit width.

$$c_0 = \frac{1}{\pi} \cdot \left(\frac{\Delta K_{th,lc}}{Y \cdot \Delta\sigma_0} \right)^2$$

where $\Delta K_{th,Ic}$ ist he treshold stress intensity factor for long cracks.

The description of true pit geometry has been published by author earlier [2]. The max. and min. depths of pits and their densities have been found. In [3] are shown the mentioned characteristics and Table 1 comprises the parameters of corrosion evaluated for part of turbine packing ETU23 (alloy X22CrMoV12-1).

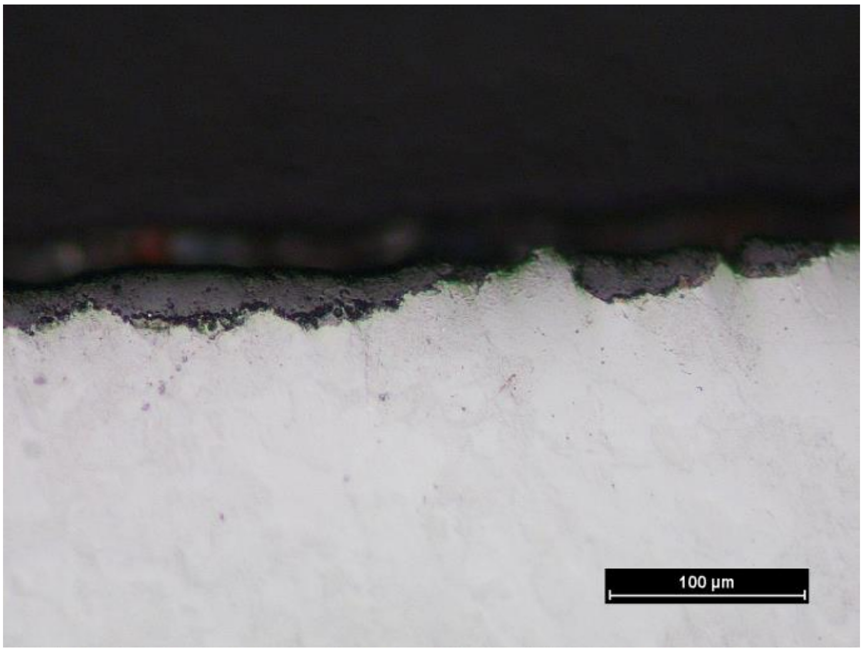


Fig. 3. Pitting corrosion after 6700 hr in 650 °C steam

Table 1. Parameters of pitting observed by microscopy Nikon Eclipse ME600 and image analysis by Nikon Elements

Area	No of Pits	Σ L i [mm]	Density	Oxide [%]	Depth [µm]			
					Max	Min	Mean	St.Deviation
1	40	4.1944	9.54	80.48	27.04	8.45	18.57	4.944
2	58	6.6833	8.68	68.26	29.54	7.87	20.71	5.381
3	17	3.3763	5.04	83.93	30.05	13.02	21.36	4.900
4	28	2.0299	13.79	63.79	31.33	11.13	20.66	5.028
5	18	2.4452	7.36	78.46	29.57	9.68	21.36	4.815
6		N/A						
7	39	2.8553	13.66	49.98	35.68	8.72	19.52	5.855
8	14	1.5375	9.11	80.08	31.88	18.06	24.11	3.682

Acknowledgement

The presented work has been supported by grant No TE01020068.

References

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[2] Černý M.: Localized Corrosion in Alloy Steel of Steam Turbines, Applied Mechanics and Materials, vol.827, Trans Tech Publications (2016) doi:10.428/www.scientific.net/AMM.827.177

[3] Černý M.: Modeling of Corrosion Fatigue Crack Initiation in Steel Alloy for Steam Turbines, Conference EAN 2016, Proceedings (2016)