Allowed Stress Range Prediction of Fatigue Loading for Steel Alloy in Steam Turbines

M. J. CERNY[1,a]

[1] *Czech Technical University in Prague, Klokner Institute, Solinova 7, 166 08 Prague 6, Czech Republic*
[a] *cerny@hppro.klok.cvut.cz*

Abstract: Corrosion pitting is responsible for the initiation of fatigue cracks in alloy steel used in steam turbines. In the paper the criteria for prediction of allowed stress range of cyclic loading will be given.

Keywords: corrosion; fatigue; cracks; steel alloy; steam turbines.

1 Introduction

Knowledge of corrosion pitting is basic for the nucleation and propagation of fatigue cracks in steel alloy of steam turbine blades [1]. For quantifying pitting-induced corrosion fatigue, various models have been proposed to characterize the corrosion fatigue crack nucleation.

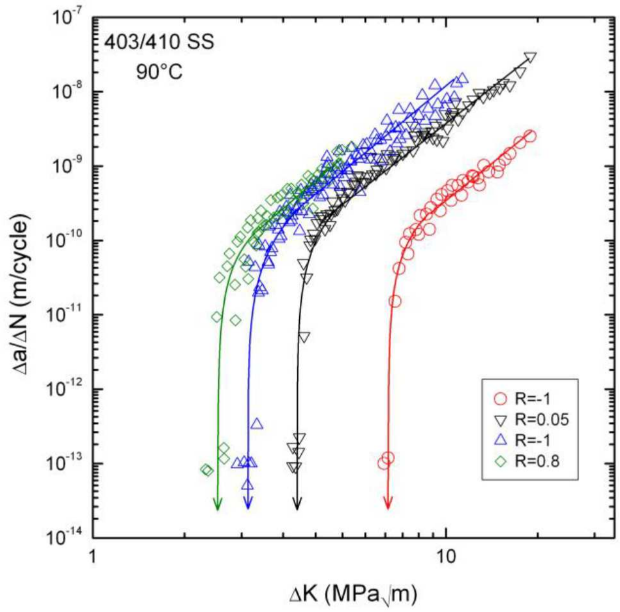

Fig. 1: Fatigue Crack Growth Rate (FCGR)

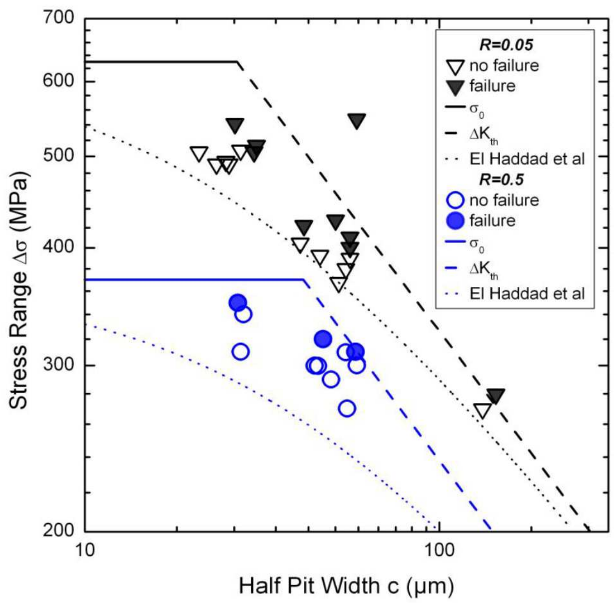

Fig. 2: Kitagawa Diagram (90°C Air at R=0.05, 0.5)

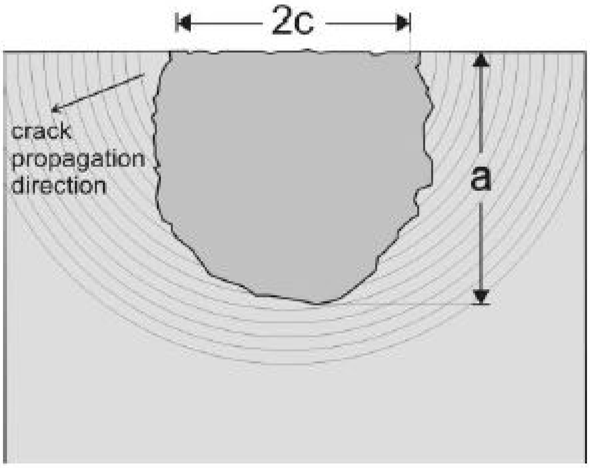

Fig. 3: Schematic Illustration of Pit Geometry

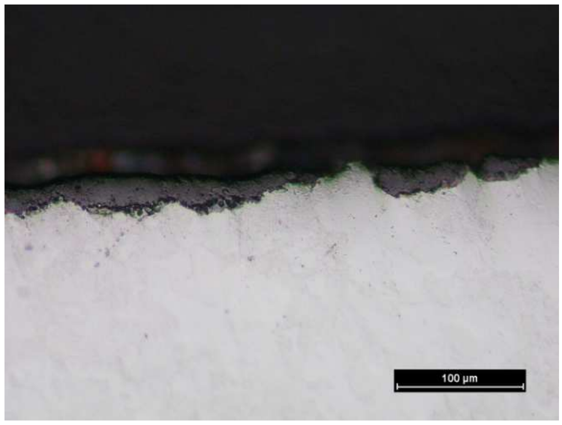

Fig. 4: True Geometry (steam 650°C,6700 hrs)

2 Fracture Mechanics and Kitagawa- Takahashi Diagram

To evaluate the influence of corrosion pits on fatigue, linear elastic fracture mechanics 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, a (Fig.3). Investigations show that the pits can be treated as semi-circular surface cracks with a geometry described above. With this approximation and that the pit size is small in terms of crack behavior, the stress intensity factor of pits ΔK , FCGR diagram (Fig.1) and finally a Kitagawa- Takahashi (K-T) diagram (Fig.2) can be created for 403/410 12% Cr martensitic steel [3]. The K-T diagram correlates pit-to-crack fatigue data. The data can be obtained 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.

A key parameter referred to frequently in this paper is R, which is the ratio of minimum to maximum stress in a combined steady and cyclic stress environment, as shown in Equation 2.

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

Where:

σ_m is the steady (mean) stress, and
σ_a is the cyclic (alternating) stress.
Note that the stress range ($\Delta\sigma$) is equal to 2x the cyclic stress amplitude.

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 for areas shown at Fig.2. Table 1 comprises the parameters of corrosion evaluated for part of turbine packing ETU23 (alloy X22CrMoV12-1).

A FCGR line can be drawn through the crack growth data. This characteristic shape is consistent with data for many materials. The three-component straight line is defined as follows:

- ***Region 1:*** This is the slow growth portion of the curve. The fatigue crack threshold (ΔK_{th}), corresponds to the stress intensity factor range, below which cracks do not propagate.
- ***Region 2:*** This is the power law growth region (also known as the “Paris” region).
- ***Region 3:*** Rapid unstable crack growth just prior to failure.

$$\Delta K \equiv Y \Delta\sigma \sqrt{\pi c}$$

where:

ΔK is the cyclic stress intensity factor, MPa√m,
$\Delta\sigma$ is the cyclic stress range, MPa,
c is the instantaneous crack size, meters and
Y is a geometry factor (for this case Y = 0.65).

The values shown are for illustrative purposes to demonstrate Region 1 behavior.

During this research, the concern has been to identify the conditions so that the risk of initiating a crack (Region 1) is quantified. The left portion of Fig.1 shows that for a small value of cyclic stress intensity factor ($\Delta K < \Delta K_{th}$), there would be no growth of an incipient fatigue crack. When the cyclic stress intensity factor is maintained below the threshold value, then a crack will not initiate or grow.

Table 1 Parameters of pitting determined experimentally

					Depth [μm]			
Area	**No of Pits**	**Σ L i [mm]**	**Density**	**Oxide [%]**	**Max**	**Min**	**Mean**	**St. Deviation**
1	6	1.5567	3.85	79.00	35.39	13.06	25.95	6.997
2	31	3.9507	7.85	66.74	36.39	5.65	21.58	7.825
3	17	0.7627	22.29	12.09	29.05	5.80	19.73	5.802
4	15	0.8248	18.19	33.35	30.00	14.52	20.78	5.079
5	18	0.8534	21.09	28.19	28.08	7.40	19.05	5.113
6	3	2.8381	1.06	99.22	32.88	29.19	30.81	1.540
7	42	5.3321	7.88	64.00	39.71	4.35	21.91	8.932
8	29	2.4345	11.91	41.68	36.76	9.67	22.65	7.453

As a result, from Kitagawa- Takahashi diagram we get - for area 4 and R= 0.5 - stress range is 280 MPa, what is 47% of material yield strength. This stress range can be understood as limit for stresses induced by loading in steam turbine. Allowed stress range will be different, as the K-T diagram is valid actually only for 90°C air.

3. Conclusion

In the presented paper the prediction of allowed stress range of cyclic loading with consideration of cracks due to corrosion – fatigue in steam turbine blades is described. The prediction is based on description of true pit geometry. The method follows the Kitagawa- Takahashi diagram.

Acknowledgement

The presented work has been supported by grant No TE01020068.

References

[1] Černý M.: Damage and Localized Corrosion in Steam Turbines, Conference EAN 2014, Proceedings

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

[3] Salzman R., Gandy D., Rieger N., Schönbauer B., Tchegg S., Zhou S., Turnbull A.: Corrosion-fatigue Prediction Methodology for Steam Turbine Blades, Energy-tech, December 2013