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Stress Intensity Factor for Corrosion Fatigue on Steel Alloy in Steam Turbines

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Abstract. The corrosion pits in steel alloy for steam turbines can be considered as surface cracks for determining threshold limits for fatigue cracking. The threshold can be defined using linear elastic fracture mechanics (LEFM). Then the stress intensity factor should be used even for evaluating the influence of corrosion pits on fatigue such materials.

Introduction

The corrosion pits in steel alloy for steam turbines can be considered as surface cracks for determination of threshold limits for fatigue cracking. The threshold can be defined using linear elastic fracture mechanics (LEFM). Then the stress intensity factor should be used even for evaluating the influence of corrosion pits on fatigue such materials.

It has been observed, that most pits have roughly a semi-elliptical shape with the width at the surface, *2c*, and the pit depth *a*. Further, 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 steam turbines, fatigue crack initiation at corrosion pits is a very 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.

Stress intensity factor ΔK

Calculation of the threshold stress intensity factor ΔK_{th} for the corrosion pits can be calculated from the relationship:

$$\Delta K_{th} = \alpha.\Delta\sigma_{th}.\sqrt{\pi a}$$

ΔK_{th} is the range of the threshold stress intensity factor, $\Delta\sigma_{th}$ is the threshold fatigue strength, a is the pit depth and α is a geometry factor. For semi-circular surface cracks, α is approximated by 0.67.

For a semi-elliptical defect the threshold stress intensity factor is following:

$$\Delta K_{th} = \frac{\Delta\sigma_{th}\sqrt{\pi a}[1.13 - 0.07(a/c)^{1/2}]}{[1 + 1.47(a/c)^{1.64}]^{1/2}}$$

where c is half pit width.

Because above equations are based on linear elastic fracture mechanics, ΔK_{th} should be a constant independent of crack size. This is clearly not the case.

The limitation of LEFM is not surprising as the overall 'crack' length including the pit is small; a non-propagating crack formed at the pit may have an overall length which includes the pit but does not have the plastic wake history of a crack of the same length, the crack will be contained within the plastic field of the pit.

In order to account for the breakdown of the LEFM concept for small crack sizes, El Haddad and co-workers proposed an empirical relationship for the stress intensity factor range based on the notion of an effective crack length (a+a0):

$$\Delta K_{th} = \alpha.\Delta\sigma_{th}\sqrt{\pi(a + a_0)}$$

where ΔK is the range of the stress intensity factor, $\Delta\sigma_{th}$ is the threshold fatigue strength and a_0 is a constant.

This relationship has been shown to describe short crack and pit behaviour well for a range of systems, and a_0 provides a link to long cracks. The a_0 value can be evaluated from the limiting condition where the physical crack size, a, approaches zero, i.e. $a_0 \gg a$ and giving

$$a_0 = \frac{1}{\pi}\left(\frac{\Delta K_{th}}{\alpha.\Delta\sigma_0}\right)^2$$

where $\Delta\sigma_0$ is the fatigue limit of a smooth specimen.

Kitagawa- Takahashi Diagram

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 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.

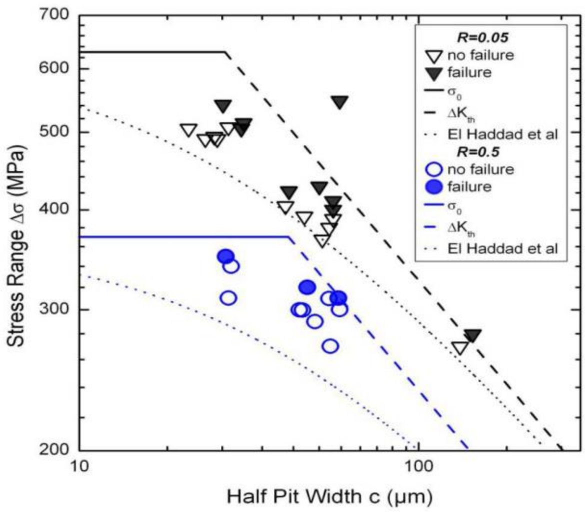

Fig.1 Kitagawa- Takahashi Diagram

True pit geometry

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 in [3] comprises the parameters of corrosion evaluated for part of steam turbine at power plant ETU (alloy X22CrMoV12-1).

A microscopy system Nikon Eclipse ME600 with image analysis software Nikon Elements has been used [2], [3]. The max. and min. depths of pits and their densities have been found for eight areas. Table 1 comprises the parameters of corrosion evaluated for part of turbine packing ETU23 (alloy X22CrMoV12-1).

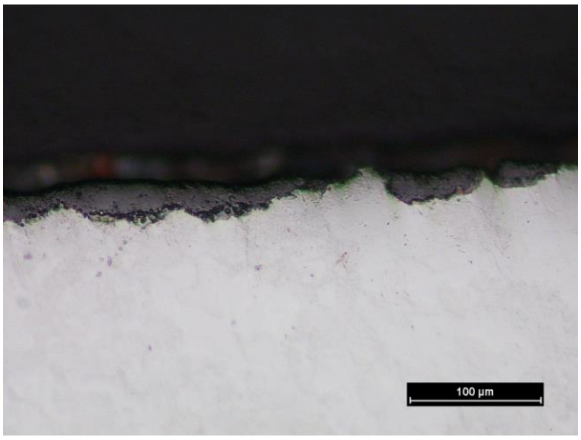

Fig.2 True geometry of corrosion

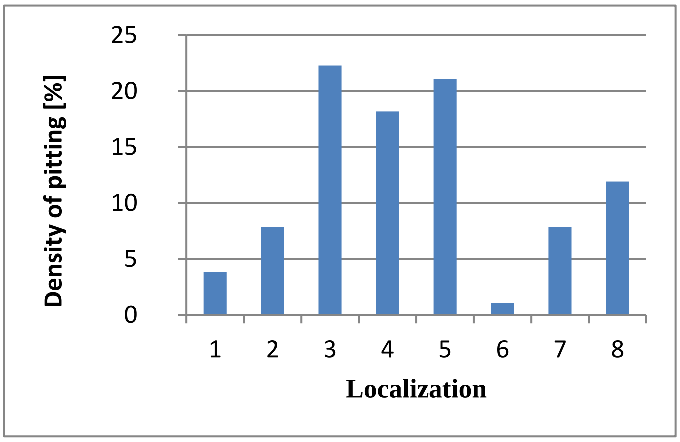

Fig.3 Density of pitting

Stress intensity factor for 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 is 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 for long cracks and cracks that were initiated at corrosion pits can be created.

The calculation for pit depth and different aspect ratio for 403/410 12% Cr martensitic steel and temperature 90°C has shown threshold stress intensity factors (a=20, ΔK_{th}=4,959, a=30, ΔK_{th}=5,693) and corresponding stresses.

Acknowledgement

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Conclusions

The threshold limits for fatigue cracking can be defined using linear elastic fracture mechanics (LEFM). Then the stress intensity factor should be used even for evaluating the influence of corrosion pits on fatigue such materials.

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