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Fatigue assessment of corroded turbine blade steels

B.M. Schönbauer[a], A. Perlega, U.P. Karr and S.E. Stanzl-Tschegg

Institute of Physics and Materials Science, BOKU, Peter-Jordan-Str. 82, 1190 Vienna, Austria

1. Introduction

Pitting corrosion is a critical issue for steam turbine operators since localised surface degradation causes stress concentration which may lead to fatigue failure. Dual certified 403/410 martensitic 12% Cr steel – which is a standard material for steam turbine blades in the low pressure part – was tested using ultrasonic fatigue testing technique. Experiments were performed up to the very high cycle fatigue regime on both smooth and pre-pitted specimens. For the latter, corrosion pits of defined size comparable to those found in failed turbine blades were generated artificially. Test environments were air at 90 °C and aerated 6 ppm Cl^- solution at 90 °C (for details see [1]).

In this work, the results of extensive fatigue tests [1, 2] are evaluated using two different approaches. Fatigue assessment was performed using the $\sqrt{area}$ parameter model developed by Murakami and Endo [3] and the small-crack model by El Haddad *et al.* [4]. The prediction equation for the first model is expressed as

$$\Delta\sigma_w = \frac{a(H_v + 120)}{\left(\sqrt{area}\right)^{1/6}} \cdot \left(\frac{1-R}{2}\right)^{\alpha} \tag{1}$$

where $\Delta\sigma_w$ is the fatigue limit, H_v is the Vickers hardness, R is the stress ratio $\sqrt{area}$, the square root of the projection area of a defect and a is 1.43 for surface defects and 1.56 for internal three-dimensional defects. The exponent α is defined by $\alpha = 0.226 + H_v \cdot 10^{-4}$.

El Haddad et al. proposed an equation of the form

$$\Delta\sigma_w = \Delta\sigma_0 \left(\frac{l_0}{l + l_0}\right)^{1/2} \tag{2}$$

where $\Delta\sigma_0$ is the fatigue limit for smooth specimens, l is the crack/defect length and l_0 is the fictitious crack length $l_0 = \frac{1}{\pi} \cdot \left(\frac{\Delta K_{th,lc}}{Y \cdot \sigma_0}\right)^2$ with the threshold stress intensity factor for long cracks $\Delta K_{\mathrm{th,lc}}$ and the geometry factor Y.

2. Results and discussion

Figure 1a shows the fatigue life curves using the model by Murakami and Endo [3] according to Eq. (1). For smooth specimens in air, non-metallic inclusions were found at the crack initiation sites, and the

[a] Corresponding author: bernd.schoenbauer@boku.ac.at

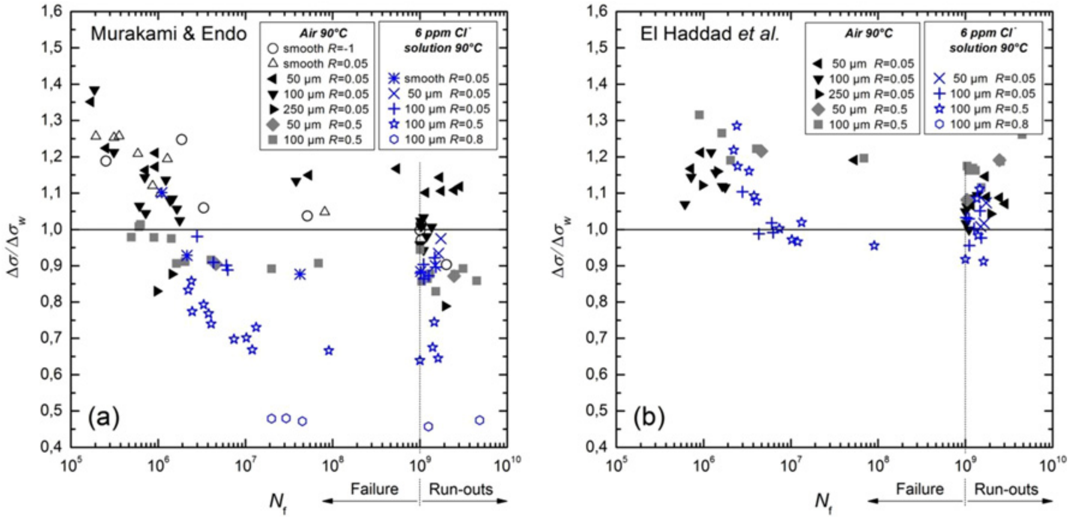

Figure 1. Number of cycles to failure N_f vs. normalised stress range $\Delta\sigma/\Delta\sigma_w$ using the model by Murakami and Endo (a) and El Haddad *et al*. (b). For pre-pitted specimens, the pit size is indicated.

prediction using Eq. (1) provided good results. For pre-pitted specimens in air, the prediction error is within ca. $\pm 20\%$ (for pit sizes of $50\,\mu$m ($+14\%$ at $R = 0.05$ and -13% at $R = 0.5$), $100\,\mu$m ($+2\%$ at $R = 0.05$ and -14% at $R = 0.5$) and $250\,\mu$m (-21% at $R = 0.05$)). Nevertheless, no acceptable results were found for 6 ppm Cl^- solution where the prediction error is as high as -53%. This is not surprising since the model´s main parameter is the Vickers hardness which is a material constant and any environmental dependence is not considered.

In Figure 1b, the test data for pre-pitted specimens were evaluated using Eq. (2) according to El Haddad *et al*. [4]. Half of the pit width on the surface was used as the defect size l and the geometry factor was empirically determined ($Y = 0.65$) as discussed in [1]. $\Delta\sigma_0$ and $\Delta K_{\mathrm{th,lc}}$ were experimentally determined for different R-ratios and environments. The prediction error is significantly lower compared to the $\sqrt{area}$ model. Although there is an underestimation in air at $R = 0.5$ of 18%, the prediction error is mostly within $\pm 10\%$.

3. Conclusions

Comparison of the predictive models by Murakami and Endo [3] and El Haddad *et al*. [4] were made. Whereas the $\sqrt{area}$ model is well applicable to failure resulting from inclusions in smooth specimens, the El Haddad *et al.* approach shows a higher accuracy for pre-pitted specimens. Furthermore, its main advantage is the applicability to different environmental conditions.

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