Fatigue assessment of corroded turbine blade steels

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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 √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

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

where \(\Delta \sigma_w\) is the fatigue limit, \(H_v\) is the Vickers hardness, \(R\) is the stress ratio \(\sqrt{\text{area}}\), 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 \(z\) is defined by \(z = 0.226 + H_v \cdot 10^{-4}\).

El Haddad et al. proposed an equation of the form

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

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 \(l_0 = \frac{1}{\pi} \cdot \left(\frac{\Delta K_{\text{th,lc}}}{\sigma_0}\right)^2\) with the threshold stress intensity factor for long cracks \(\Delta K_{\text{th,lc}}\) 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

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prediction using Eq. (1) provided good results. For pre-pitted specimens in air, the prediction error is within ca. ±20% (for pit sizes of 50 μm (+14% at R = 0.05 and −13% at R = 0.5), 100 μm (+2% at R = 0.05 and −14% at R = 0.5) and 250 μm (−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 $\Delta K_{th,lc}$ were experimentally determined for different R-ratios and environments. The prediction error is significantly lower compared to the $\sqrt{\text{area}}$ model. Although there is an underestimation in air at R = 0.5 of 18%, the prediction error is mostly within ±10%.

3. Conclusions
Comparison of the predictive models by Murakami and Endo [3] and El Haddad et al. [4] were made. Whereas the $\sqrt{\text{area}}$ 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.

References
