APPLICATION OF MINIATURE SPECIMEN TESTING TO LIFETIME ASSESSMENT OF STEAM TURBINE ROTORS

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1. Introduction

The residual lifetime assessment and potential of failure of steam turbine components is a critical issue in the safety and reliability analysis of power plants. The bulk of lifetime assessment studies of high-temperature components is based on theoretical damage calculations, non-destructive tests and metallographic investigations [1]. Components' residual lifetime, and, in particular steam turbine rotors, can be rarely evaluated with the traditional mechanical test techniques, because there is usually insufficient material to sample non-invasively from the component [2]. Instead of these well-standardized techniques, various innovative techniques based on miniaturized specimens can be effectively employed for determining material properties and assessing residual lifetime. Among these, a small punch test (SPT) technique significantly developed over the last years, is an efficient and cost-effective method suitable for industrial applications.

The paper presents a case study of a steam turbine lifetime assessment where the small punch test technique was applied and supported a more accurate residual lifetime determination.

2. Small punch testing of the rotor

Lifetime assessment study performed for the high-temperature rotor of a 55 MW steam turbine revealed a high level of creep damage in the first stage disc. The damage was evaluated using the time fraction method assuming minimum creep rupture strengths for determining the time to rupture [1]. Crack initiation life was exhausted at the bottom of the disc, but non-destructive tests did not reveal any cracks or advanced microstructural damage. The creep damage was close to the permissible limit at the disc periphery in the blade groove which was not accessible for non-destructive examination. In order to determine tensile and fracture toughness properties of the rotor after long-term operation, small punch tests were performed [3]. Five material samples were taken from disc 1, which was found to be life-limiting, and for reference, also five samples were taken from disc 19 which operates at low temperature and is not subject to creep damage (Fig. 1). The extracted material samples were used for determination of chemical composition, metallographic examination and manufacture of disc-shaped punch test specimens of 8 mm diameter and 0.5 mm thickness. The following mechanical properties were estimated by SPT: yield stress, tensile strength, elongation, FATT and fracture toughness.

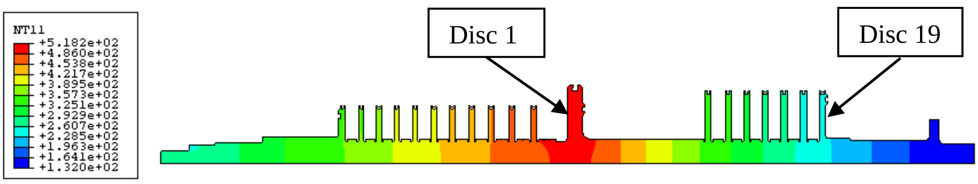

Figure 1: Rotor temperature distribution with indicated areas for SPT.

The chemical analysis confirmed the rotor steel composition to agree with the material standard requirements, while the metallographic examination confirmed the correct microstructure - tempered bainite. Comparison of tensile properties shown in Table 1 reveals no significant differences in the properties of the two discs and confirms compliance with the material standard requirements.

Source	Yield stress [MPa]	Tensile strength [MPa]	Elongation [%]
Disc 1	545	678	29-31
Disc 19	528	708	27-32
Standard	440	640	16

Table 1: Mechanical properties measured by SPT and required by the applicable standard.

The fracture appearance transition temperature evaluated by SPT is FATT = -3.7°C and the lower bound fracture toughness at room temperature corresponding to FATT is K_{Ic} = 121 MPa·m$^{1/2}$. The low value of FATT and high value of K_{Ic} confirm good fracture resistance and no visible degradation of the rotor material due to long-term operation at high temperature under creep conditions.

3. Residual lifetime assessment

Residual lifetime of the rotor was assessed by assuming the existence of small cracks in critical areas, not detectable by NDT, and calculating their growth until the critical size. For critical crack size estimation, the real fracture properties obtained from SPT were adopted, among others. As high fracture toughness was estimated by SPT, it could not be excluded that brittle fracture will not be the main failure mechanism, and due to this also ductile failure was taken into account by estimating the critical crack size. Crack growth due to creep, fatigue and their interaction was calculated assuming real operating conditions of the rotor. Based on the calculated crack propagation rate, the residual life of the rotor was estimated at approximately 200 000 hours and limited by the creep damage in disc 1.

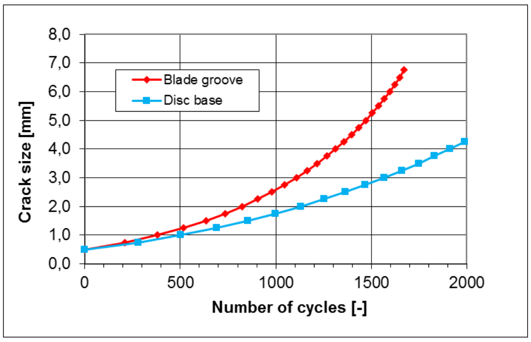

Figure 2: Crack propagation in disc 1.

6. Summary

The lifetime assessment performed using conventional methods showed complete lifetime exhaustion of the rotor. The use of SPT enabled determining the real material properties and performing more accurate residual lifetime assessment with the help of fracture mechanics methods. The performed comprehensive investigations allowed for significant lifetime extension of the rotor with a controlled risk of failure.

References

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