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Failure analysis of high nickel alloy steel seal ring used in turbomachinery

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ABSTRACT

The purpose of this study is to identify the failure cause of the steel seal ring used in nuclear steam turbines. New high nickel steel alloy seal ring was compared with the failed seal ring. Metallographic analysis, scanning electron microscopy, nanoindentation and in-situ tensile testing were used to analyze the reasons of the seal ring failure at both macroscopic and microscopic scales. The main reason of the seal ring failure is a combination of stress and elevated temperature during turbine operation. Complex work environment caused recrystallization and recovery, resulting in grain refinement and secondary phases precipitation. Many secondary phase precipitates appeared at grain boundaries during use, causing formation of microvoids and cracks, ultimately leading to ring failure.

1. Introduction

Seal ring is one of the important parts of power steam turbines, which is an elastic metal ring operating on the principle of outward expansion. Gas or liquid pressure is needed to form a good seal, as shown schematically in Fig. 1 [1]. The seal ring performance directly affects the safety and proper operation of the whole steam turbine unit. During operation, seal ring can be damaged due to long-term cyclic deformation, finally causing leakage. This article describes examples of the failure of the seal ring used in nuclear power turbines. The seal ring is made from the high nickel alloy steel, grade GH163 (YB/T 5351–2006 Chinese standard) [2]. The ring failure was manifested by high-frequency metal noise coming from the working nuclear power turbine. When the used free-standing seal ring was hit, similar crisp metal sound could be heard. Inspection revealed insufficient tension of the seal ring, associated with an incomplete seal. Designed opening gap length of the seal ring is 30–40 mm in the free state. Measured opening gap length of the used upper seal ring was 24 mm and the lower seal ring was 16 mm. As a result, the seal rings could not form a complete seal, causing leakage.

This study was commissioned to identify factors causing the seal ring failure. The seal ring failure was characterized using a series of experiments conducted at both macroscopic and microscopic scales. The same tests and characterization conducted with the new ring helped to analyze the failure mechanisms.

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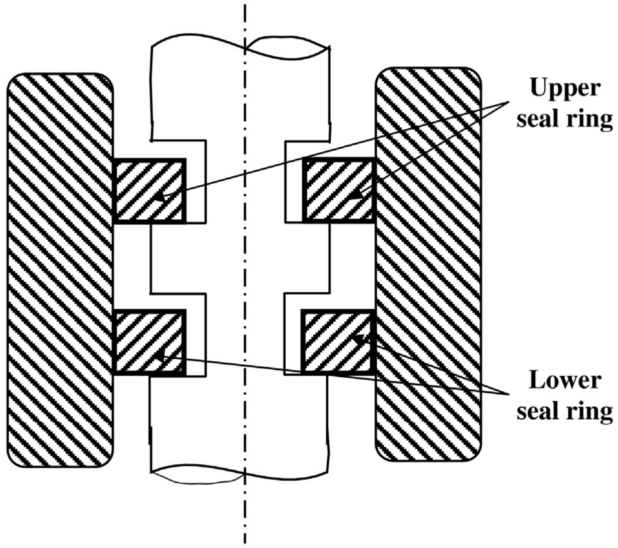

Fig. 1. Schematics of the seal rings in the nuclear power turbine system.

2. Methodology

Specimens were cut from the new and failed seal rings (Fig. 2), grinded with emery paper to 2000 grade and polished. In order to observe the microstructure, specimens were etched in mixed acid glycerin solution ($HCl:C_3H_8O_3:HNO_3 = 3:3:1$ ratio) for 20 s [3].

Macroscopic ring dimensions were measured using calipers. Hardness and elastic modulus of the seal ring material were measured using nanoindentation. Specimens' microstructure, along with crack initiation and propagation were investigated by means of optical microscopy, scanning electron microscopy (SEM) equipped with energy-dispersive spectrometer (EDS) and in-situ SEM tensile testing (Camscan 3400).

3. Results and discussion

3.1. Macroscopic dimensions examination

Macroscopic and microscopic analyses were used to identify material failure. Table 1 lists measured diameter, width, opening gap length and gap lateral displacement of the failed and the new seal rings, shown in Fig. 3. While there are no obvious differences in the rings diameter, the opening gap length of the failed ring is larger, along with the gap lateral displacement. Thus, it is apparent that the used rings have undergone macroscopic plastic deformation, contributing to seal ring failure.

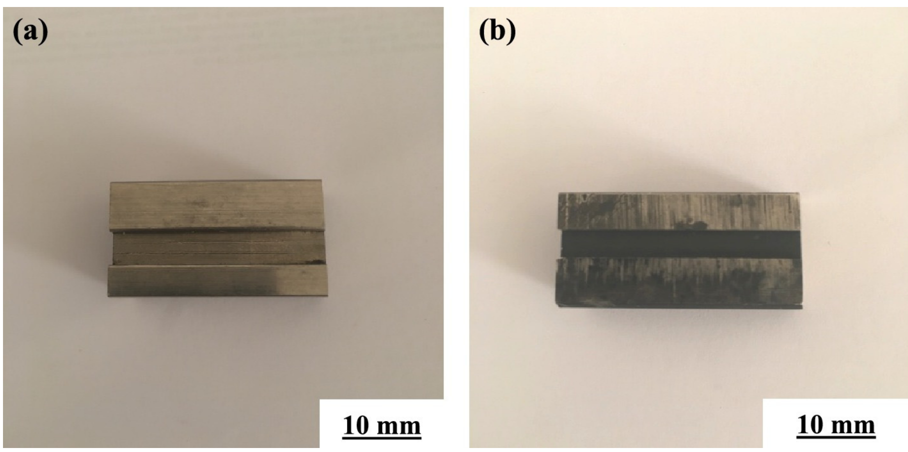

Fig. 2. Specimens cut from: (a) New seal ring; (b) Used seal ring.

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