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Mechanism-related modelling of pit evaluation in the CrNiMoV steel in simulated environment of low pressure nuclear steam turbine

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ABSTRACT

Pit initiation and growth in a 25Cr2Ni2MoV welded joint in the simulated environment of a low pressure nuclear steam turbine was addressed by using U-bend samples. Different pit densities in various zones of the welded joint were observed with the order: weld near heat affected zone > base metal near heat affected zone > heat affected zone. This was partly ascribed to the galvanic effect and material difference. Pits in the base metal emanated from local deep grooves of surface machining, while they nucleated from surface inclusions in weld metal. A model for pit distribution of the welded joint was developed and verified accordingly.

1. Introduction

With the increasing capacity of steam turbines, advanced welding technology has become a critical tool for the manufacture of large components such as rotors in practice [1]. For the welded rotor of a steam turbine, several advantages such as reduced thermal stress during the start-up period, the elimination of bore and keyways and the usage of low yield strength materials with high resistance to stress corrosion cracking (SCC) have been realized [2–4]. Nevertheless, the appearance of SCC is still a potential risk due to the complicated chemical compositions, inhomogeneous microstructures and mechanical properties of the welded joint in practice.

For the steam turbine rotor steel, it has been well recognized that SCC generally emanates from the surface corrosion pits [5–7]. Around the corrosion pit, locally extreme chemistry and stress concentration provide an aggressive condition for preferential cracking. As the majority of component life is dominated by pitting stage [8], it is critical to accurately predict the evolution of pitting. In the past several years, several models for pit evolution have been developed under the probability framework [9–11]. In terms of the simplification of a hemispherical pit, Wei [12] proposed an expression for the evolution of pit depth with exposure time. Considering the real geometry of a pit, Turnbull et al. [13] developed a statistical model for the evolution of pit depth distribution. It should be noted that parameters in the proposed model were curve-fitted based on different samples in the parallel systems [14]. In fact, the characteristic distribution of different specimens exhibits the inherent uncertainty supposing that the sampling area is relatively too small. As a result, the predicted pit density may be decreased with the increase of exposure time.

On the other hand, the assumption of all pits initiated simultaneously has been employed in the aforementioned statistical models. Actually, the logical model should involve the difference of pit nucleation and the specific pit growth rate in terms of the mechanism of pit initiation and propagation. For steam turbine disc steels, it has been realized that pits generally nucleate from surface inclusions [14–16]. However, for the welded joint, factors which trigger a pit and the evolution process of pitting may be different. During the past years, considerable efforts have been devoted to the pitting susceptibility in the welded joint of some specific steels. It has been reported that a heat affected zone (HAZ) exhibited the minimum corrosion resistance in the welded joints of $\times 70$ pipeline steel [17] and $\times 80$ pipeline steel [18]. Vignal et al. [19] revealed that the secondary HAZ was the weak point of the stainless steel welded joint for which both the average pit density and the average pit surface area were significantly larger than those in other regions. Chen et al. [20] concluded that the weld in the 9Cr based martensitic steels was one of the weakest sections to pitting corrosion. Sánchez-Tovar et al. [21] reported that the susceptibility to pitting attack increased in the weld of LiBr as indicated by the large negative open circuit potential. The corrosion properties in base metal, weld metal and regions near the heat affected zone are different definitely and may lead to different mechanisms of pit initiation.

In this work, the exposure test of a welded joint of 25Cr2Ni2MoV rotor steel was conducted firstly in an autoclave at 180 °C in a 3.5 wt.% NaCl solution. The distribution and evolution of pit depth in different regions of the welded joint have been measured by using an Infinite Focus Microscope (IFM) after various exposure times. The mechanisms of pit

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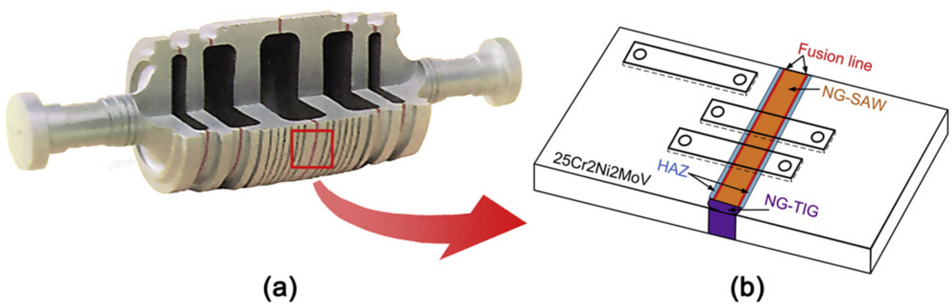

Fig. 1. (a) An image of a real welded rotor and (b) a magnification diagram of three types of samples located in the welded joint.

Table 1
Chemical compositions of base metal and weld metal (wt.%).

Materials	C	Si	Mn	P	S	Cr	Ni	Mo	V
BM	0.23	0.10	0.16	0.005	0.005	2.35	2.15	0.70	0.1
WM	0.12	0.20	1.48	0.005	0.005	0.57	2.18	0.51	–

initiation and propagation in the welded joint of the 25Cr2Ni2MoV rotor steel were addressed. Accordingly, a model for the pit depth distribution in the welded joint was proposed based on the statistical approach and the pit initiation mechanism.

2. Samples and experiments

2.1. Samples

The welded joint of forging rotor steel 25Cr2Ni2MoV, fabricated by the narrow gap tungsten insert gas (NG-TIG) combined with the narrow gap multilayer submerged arc welding (NG-SAW) techniques, is selected as the samples, as seen in Fig. 1(a). The chemical compositions of base metal (BM) and weld metal (WM) are listed in Table 1. To remove any influence of residual stress resulting from welding or machining, all specimens are stress relieved in vacuum for 2 h at 625 °C. The yield strength

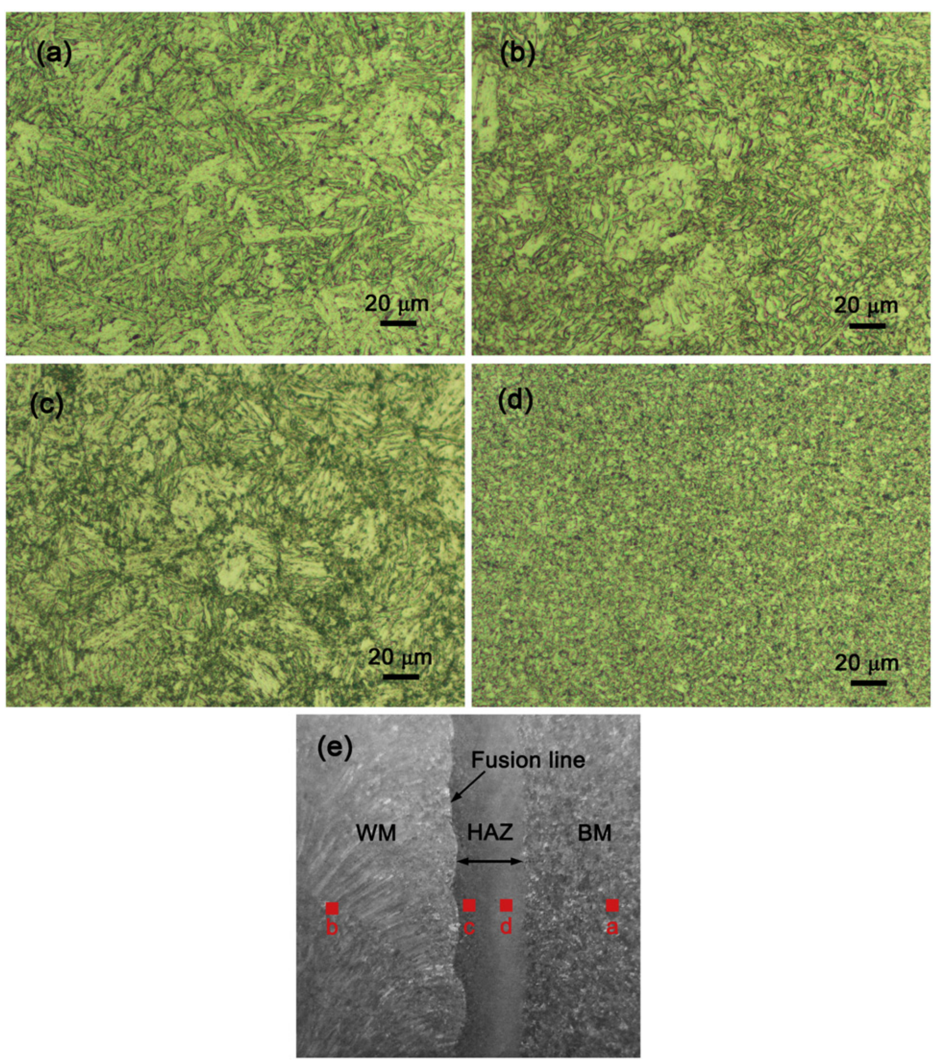

Fig. 2. Microstructures of (a) BM, (b) WM, (c) HAZ close to WM and (d) HAZ close to BM with (e) each position in the welded joint marked.