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Analysis on the stress corrosion crack inception based on pit shape and size of the FV520B tensile specimen

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ABSTRACT

The influence of pit shape and size on local stress concentration in the tensile specimen and the stress corrosion cracks inception was studied by employing the element remove technique. The maximum stress located in the bottom of pit on FV520B tensile specimen. The location of maximum strain was near the mouth of the pit or the shoulder and plastic strain existed in this region. Stress concentration factor and plastic deformation on four different geometrical shape pits of hemisphere, semi-ellipsoid, bullet and butterfly were numerically investigated, respectively. The simulation results showed that butterfly pit got the biggest stress concentration factor. The plastic strain rate during pit growth was in the sensitivity range of stress corrosion cracks inception, indicating that stress corrosion cracks were more likely to nucleate near the pit tip or the shoulder.

Introduction

The pits are the discontinuous regions on the surface of stress corrosion specimens, which changes the distribution of local stress and strain. The local stress concentration easily occurs during the stretching process, and the pit leads to the accumulating of hydrogen and corrosive medium at the same time, which accelerates the process of hydrogen diffusion and oxide film failure. Thus, the stress corrosion cracks are more likely to nucleate near the pits. It becomes a big challenge that the evolution of cracks from pit to stress corrosion nucleation and subsequent growth can be predicted. Kondo [1] proposed that two conditions should be met to make the pits become stress corrosion cracks. The depth of pits must be greater than the specified threshold value, and the rate of stress corrosion crack propagation is greater than the growth rate of pits. Qidwai [2] presented a numerical modeling of two-dimensional stable corrosion pit growth by solving the Laplace equation which defined the electric potential within the electrolyte. Microstructural features representative of a 316 stainless steel provided the matrix in which the pit grown. Real microstructural features were incorporated into the computational model to determine the influence of the microstructure, specifically crystallographic orientation, on the shape of the pit as it grown over time. The high-resolution definition of the microstructure was obtained by the orientation image microscopy technique and was incorporated into the finite element model through a grid-based interpolation functionality. Engelhardt [3,4] studied the nucleation, growth, and death in localized corrosion of low pressure steam turbines. Turnbull [5] developed a model based on deterministic equations with statistically distributed input parameters for simulating the evolution of the pit depth distribution at different exposure times and the percentage of pits that transform to stress corrosion cracks. Horner [6] explored stress corrosion crack in turbine disc steels exposed to simulated steam-condensate tending to nucleate preferentially from corrosion pit precursors. Unique three-dimensional X-ray micro-tomographic images had confirmed that cracks developed predominantly at the shoulder of the pit, near the pit/surface interface, for specimens stressed to 50–90% $\sigma_{0.2}$. In support of this observation, FEA of model pits indicated that strain was a maximum on the pit wall just below the pit mouth. Turnbull [7] applied a mathematical model to simulate the evolution of stress corrosion cracks from corrosion pits in the short and long crack domains. The distribution of crack-depths in the short crack domain was well represented and some unique features of pit and crack profiles reproduced under the assumption of the initial distribution of stable pit depths was defined by the three-parameter Weibull distribution. Huang [8] investigated the quantitative correlation between the stress state and geometric features of a corrosion pit idealized as a semi-ellipsoidal pit. The stress concentration factor (SCF) increased linearly with the ratio of pit width to length and the maximum possible SCF was indepen-

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Table 1
The components of martensitic stainless steel FV520B (mass fraction, %).

Steel	C	Cr	Ni	Cu	Mn	Si	Mo	Nb	Fe
FV520B	0.02–0.07	13–14.5	5–6	1.3–1.8	0.3–1	0.15–0.7	1.3–1.8	0.25–0.45	Bal.

Table 2
The mechanical properties of FV520B.

Steel	E/GPa	v	σ_s/MPa	σ_b/MPa
FV520B	210	0.3	1092	1172

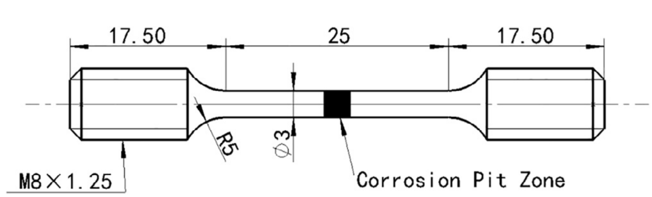

Fig. 1. The shape and size of slow strain rate tensile test specimen.

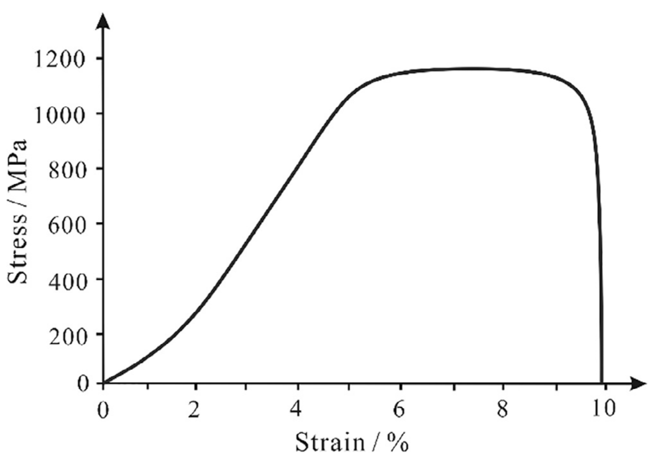

Fig. 2. The tensile stress-strain curve of FV520B at normal temperature and pressure.

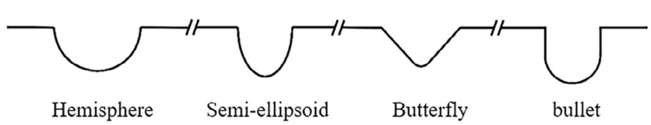

Fig. 3. Geometrical shapes of pits on the specimen surface.

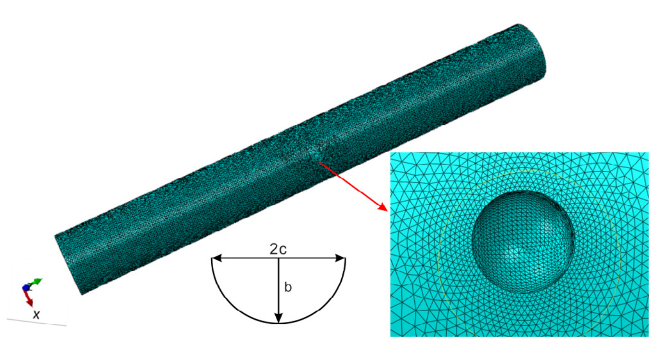

Fig. 4. Finite element grid model.

dent of the ratio of pit depth to half-length. Turnbull [9] proposed a preliminary mathematical model based on deterministic equations with statistically variable input parameters for simulating the evolution of the pit depth distribution at different exposure times, and the transformation to stress corrosion cracks was based on the Kondo criteria. He suggested that the transition from a pit to a crack was more complex than that could be accounted for by the Kondo approach.

From all the research articles above, it is summarized that the location where stress corrosion easily nucleates isn't at the bottom of pits but near the mouth of pits, which is mainly due to the fact that the maximum stress concentration location is usually found near the mouth of pits. Besides, the existence of acidity zone here accelerates the process of stress corrosion and provides a favorable condition for stress corrosion crack nucleation. The appearances of pits make the specimens discontinuous and the stress-strain distribution of them become more complicated. The stress-strain distribution at the pits is mainly affected by geometry of pits (depth-diameter ratio) and strain rate.

Finite element method (FEM) simulation has achieved great success in elasto-plastic numerical analysis of materials, and ABAQUS is a set of engineering FEM software, which is able to solve the problem ranging from relatively simple linear analysis to complex nonlinear problems. Element remove technique is a kind of element failure function provided by ABAQUS. It is an effective method to overcome its own defects in FEM and can solve the problem of material crack failure and geometric discontinuity such as removing materials subjectively. Taking foundation pits and tunnels simulation as an example, some part of simulation element will fail or disappear inevitably [10]. The application of element remove technology in stress corrosion is mainly reflected in the simulation of pits. For example, Wang [11] applied element remove technique to simulate the composite cylinder that contains pits of different sizes on the inner wall. The results show that it is reasonable when the remaining thickness is more than 50% of the design wall thickness. Sun [12] simulated the corrosion progress of corroded casings in thermal production wells and evaluated their remaining service life. Turnbull [13] investigated the stress-strain distribution around a single pit in a stressed cylindrical 3NiCrMoV specimen at high applied stress with finite element analysis. The plastic strain was localized on the pit walls below the pit mouth rather than at the pit base. For these high stress conditions, the stress was maximized towards the crack base away from the shoulder. An approximate approach was presented to account for pit growth getting predictions of plastic strain rates on the pit shoulder which susceptibility to stress corrosion cracking was often significant.

In this paper, the test background is natural gas compressor impellers and impellers in working condition usually contain four different geometrical shape pits of hemisphere, semi-ellipsoid, bullet and butterfly. Thus, the stretching process of FV520B rod specimens containing above-mentioned pits taken 50%, 70% and 90% of yield stress as tensile stress were numerically investigated respec-