Stress corrosion cracking investigation of FV520B stainless using digital image correlation and the J-integral.

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Abstract. Presented is a methodology to investigate stress corrosion cracking (SCC) in bolt loaded compact tension (CT) specimens using digital image correlation (DIC) and the J-integral. FV520B precipitation hardened stainless steel in a heat-treated condition is submerged in a 3.5% sodium chloride solution that is maintained at a temperature of 90°C. Images of the sample surfaces are analysed to obtain full field deformation maps that in turn are post-processed to obtain a J-integral based stress intensity factor to investigate SCC crack growth rates.

Introduction
The reliability of power stations is mostly governed by the lifetime of critical components, such as steam pipework systems or turbine blades, which are exposed to high stresses, elevated temperatures and corrosive environments. Under such conditions SCC may result in critical failures with costly consequences. To better understand and predict SCC failure, laboratory tests are undertaken that simulate operating conditions. Through such tests crack growth rates as well as threshold stress intensity factors are obtained, which in turn may be used to predict component life.

Conventional techniques for investigating SCC, as for example stipulated in ASTM standards, rely on specimen compliance and crack length monitoring methods to obtain stress intensity factor (SIF) estimates. However, such methods can be erroneous due to the assumptions made with respect to specimen loading and specimen compliance [1]. New measurement techniques such as DIC allow for non-contact, quantitative, full-field strain mapping. DIC has allowed the extraction of material properties under test conditions where conventional test methods are not possible [2-3].

Presented is the current work in investigating SCC in FV520B precipitation hardened stainless steel. Bolt loaded CT specimens were heat treated, loaded and submerged in a 3.5% sodium chloride solution that is maintained at a temperature of 90°C. Specimens were inspected on a regular basis by taking images of the area around the crack tip. Subsequently a DIC based SCC characterisation technique was developed to obtain SIF’s as a function of crack length $a$. The preliminary SCC data obtained from both the ASTM standard E1681-03 and the proposed DIC methodology are presented and compared.

Experimental methodology
Bolt loaded type compact tension (CT) specimens were machined from stock bar corresponding to the dimension $w = 28$ mm (width) and $B = 11$ mm (thickness) as per ASTM E1681-03 designation [4]. The loading tub and bolt were manufactured from the same material to prevent galvanic reactions during testing. The machined specimens were heat-treated using an electric box furnace according to a three step heat treatment process: 1) homogenisation at $1050°C$ for 30 min, solution treatment at $790°C$ for 2 hours and precipitation hardening for 6 hours at $430°C$ (each heat treatment step was followed by air cooling). After heat-treatment, the oxide layer was removed by grinding followed by polishing to a 1 μm finish. Subsequently, fatigue pre-cracking was undertaken to obtain a sharp crack tip. Due to the high strength levels of the specimens, a force-shedding (SIF decreasing) method [5] was used to keep SIF’s during fatiguing below 60% of the expected SCC threshold value of 4 MPa$\sqrt{m}$.

To allow for DIC measurements of the surface around the crack tip, the polished specimens were laser etched a 10mm diameter random pattern centred at the crack tip on both sides the specimen. The marking was done using a Thales SAGA-HP Nd:YAG laser from Dr. Guipont’s group at the “Centre des Matériaux, Mines ParisTech”. The pulse energy ranged between 1.69 J and 1.72 J for a pulse duration of 5 ns. The optics were set to impact the sample on a circular surface of diameter 10 mm thus achieving a choc fluency of 4.3 TW/m². The etching was made on acetone-cleaned mirror-polished samples using an acetate stencil onto which a negative of the pattern to be applied, laser printed in black ink at a resolution setting of 1200 dpi. A metal-coated mirror was used to prevent the reflected component of the beam from damaging the optical systems. Due to the corrosive test environment, the laser etched pattern was shielded using a transparent vinyl lacquer coating. Care was taken not to cover the crack, but only the adjacent laser etched area.
Figure 1: (a) Experimental setup for SCC environment. (b) Full field displacement map in the y-direction (vertical). (c) DIC obtained and ASTM obtained SIF plotted against crack extension. Note, two unloaded images were used to obtain an error estimate in SIFs of 4 MPa√m.

Subsequently, the specimens were loaded by tightening the bolt to the desired SIF according to the procedure outlined by Wei and Novak [6]. Loaded specimens were then immersed in the heated 3.5% sodium chloride aqueous solution. The SCC setup, seen in Fig. 1a, consisted of a round bottom flask containing the test solution heated by a heating mantle. The concentration of the test solution was maintained by pumping water from a separate water tank to a reflux condenser attached to the round bottom flask. The closed loop circulation of water prevented evaporation of the test solution.

Specimens were inspected periodically at predetermined time intervals, the frequency of which decreased as testing progressed. Images of the laser etched region were taken by removing the sample from the solution and placing them onto a calibrated fixture underneath an Olympus SZX7 stereo microscope. Crack length measurements were done optically using the captured images.

Results and discussion
Post-processing of the recorded images was done using LaVision’s DaVis software (ver. 8.2) to obtain full field deformation maps, as shown in Fig. 1b. For this a 91 pixel subset size, a 9 pixel step size and a zero-normalised sum of squared differences correlation algorithm with 6th order spline interpolation was used. A Matlab script was written to obtain; (i) Full field strain maps using a central difference approximation; (ii) full field stress maps using a Ramberg-Osgood material relationship to best capture plastic deformation ahead of the crack tip; and (iii) the J-integral through an integration contour path in either the elastic or elastic-plastic region [7]. The J-integral results were subsequently converted to an equivalent SIF assuming a linear-elastic material.

Fig. 1c shows the obtained SCC data, plotted as the ASTM obtained and DIC calculated SIFs against the crack growth ∆a. The data shows good correlation between the methods. A typical over estimation in the through DIC calculated SIF can be observed, which is in the order of 10%. This may be attributed to plane stress conditions at the specimen surface where measurements are taken.

Conclusion
A technique for extracting SIF from digital image correlation for SCC crack growth rate investigations was presented. The technique does not require compliance and load estimates to obtain SIF values. Primary data shows a good correlation compared to conventional ASTM methods.

References