STUDIES ON THE MECHANISM OF STRESS CORROSION CRACKING IN AUSTENITIC STAINLESS STEELS BY ACOUSTIC EMISSION TECHNIQUE

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ABSTRACT

This paper deals with the analysis of acoustic emission (AE) signals to determine the mechanism of stress corrosion cracking (SCC) in AISI type 316LN stainless steel (SS) in boiling 45% MgCl₂ solution at 413 K. AE with amplitudes ranging from 27.6 to 46.5 dB with different counts, energy and rise times occurred during SCC of type 316LN SS. The analysis of the AE signals in conjunction with fractography indicated that a surge in the AE counts and energy corresponded to initiation of SCC. AE was found to be continuous prior to the initiation. AE events occurred in bursts during crack growth. Plastic deformation ahead of the crack tip was determined to be the major source of AE during SCC of type 316LN SS.

Keywords: Stress corrosion cracking, Acoustic emission, Plastic deformation

INTRODUCTION

AE has been extensively used in structural integrity monitoring and in research on localized corrosion, specifically SCC. Yuyama [1] reported that several processes, such as hydrogen gas evolution, breakdown of thick oxide film, fracture or decohesion of precipitate and inclusions, plastic deformation by slip or twin, martensitic transformation, and micro/macro cracking were responsible for AE during SCC and corrosion fatigue. Each of these has a definite range of amplitudes and could also reported that during APC mechanism of SCC and in the incubation period of HE, continuous AE signals of small amplitude were emitted; while during macroscopic crack propagation during HE, AE signals of large amplitudes appeared in bursts. Khatak et al. [5] reported discontinuous bursts of AE signals during crack growth by HE in type 304LN SS. Cakir et al. [6] reported that during SCC under potentiostatic conditions, increasing anodic applied potentials was accompanied by a dramatic increase in AE activity at potentials above the pitting potential. Gerberich et al. [7] reported a decrease in AE event rate with increasing area of IGSCC during crack extension by mixed TGSCC + IGSCC mode during SCC of type 304 SS.

The present study aims to study the processes that dominantly cause AE during stress corrosion cracking of type 316LN stainless steel and to understand the mechanism of cracking based on the signatures of the AE.

EXPERIMENTAL PROCEDURES

Compact tension specimens of annealed AISI type 316LN SS (C=0.027%; Cr=17.4%; Ni=11.2%; Mo=1.8%; N=0.11%) were precracked and then subjected to SCC testing in 45% MgCl₂ solution at 413 K in the range of stress intensity factors, KI, of 13-26 MPa m⁰.⁵ using the constant load testing method. The tests were carried out at 413 K to eliminate boiling of the environment. Crack growth was monitored optically by a low magnification lens. Since the specimen was immersed in a corrosive environment, the AE probe could not be placed on it. Instead a wave guide was welded on to the specimen and the AE generated during the test were monitored with respect to time using a Vallen AMS3 system with a broad band frequency sensor. 21.6 dB was taken as the threshold amplitude and the gain was 34 dB. The AE system was calibrated by breaking the lead of a 0.5 mm 2H pencil on the wave guide very near the AE probe and observing the magnitude of the signal to be between 85 – 90 dB.

RESULTS AND DISCUSSIONS

Fig. 1 shows that the average plateau crack growth rate (da/dt) of type 316LN SS was 2.33 x 10⁻⁸ m/s in MgCl₂ at 413 K. AE monitoring of all the SCC tests was carried out. Similar trends as discussed below were observed in all the tests. One typical result is analysed for understanding the SCC behaviour. Monitoring of the AE during the SCC tests indicated that both the AE counts and AE energy increased with time (Figs. 2 and
A sudden increment in AE counts and energy was observed at the same time. The cause of this sudden burst of AE counts and energy was investigated by interrupting some SCC tests some time after such a burst in AE counts and energy was observed followed by fractography. The low magnification fractograph in Fig. 4 shows the initiated SCC corresponding to the burst of AE counts and energy. In their work on SCC of type 304 stainless steel precurred by crevice corrosion, Yuyama et al. [8] attributed the sudden increment in acoustic energy to crack initiation. Figs. 2 and 3 also show that the rate of AE counts and AE cumulative energy decreased after the initiation, which is in agreement with the observations reported by Yuyama et al. [8]. During the SCC test, significant amount of hydrogen evolution was observed on the surface of the CT specimen for some time, which was much earlier to the crack initiation time. The hydrogen evolution ceased much before SCC initiation occurred. This behaviour was also reported earlier [9,10].

SCC Region

During the SCC test, AE with amplitudes in the range of 27.6 to 46.5 dB with different counts, energy and rise times occurred. The observed acoustic activity (Figs. 2 and 3) was studied in detail for better understanding of the SCC phenomenon in four different regimes of the test viz. at start of the test (Region I), during SCC initiation (Region II), during the early stages of SCC crack growth (Region III) and during later stages of crack growth (Region IV). Fig. 5 (a) shows that during the start of the test (Region I), low amplitude (< 39.8 dB) AE events were more than the high amplitude (> 39.8 dB) AE events. The higher amplitude signals had higher counts and higher energies, and had both higher and lower rise times associated with them, though the shorter rise time (< 120 μs) signals were dominant.
Fig. 5 (b) shows that as initiation was approached (later time period in Region II), the rate of production of AE events reduced as seen by the larger time gap between two events in the higher time region as compared to the lower time region. In Region II, both the small and large amplitude AE events had more counts, more energy and possessed a wider range of rise times than in Region I. As the initiation stage approached, there was a reduction in the larger amplitude signals. However, the number of counts per event and the energies of these low amplitude signals just prior to initiation were much higher. It is thus seen that the production of low amplitude AE events with higher counts and energies has caused the initiation of the SCC process. However, Yuyama et al. [1] reported the sudden increment in AE energy during initiation of SCC in type 304 SS was associated with high amplitude AE signals.

Fig. 5 (c) shows that after initiation, the rate of production of AE events reduced further during the initial stages of crack growth (Region III). It was observed that the time period between two AE events increased significantly vis-à-vis Regions I and II, while the AE counts and AE energy dropped significantly. Higher amplitude AE signals with high rise time (>120 μs) did not occur. Fig. 5 (d) shows the AE emissions during the later stages of crack growth (Region IV), the time period between two AE events increased further vis-à-vis region III. Like in Region III, low amplitude AE signals were found to dominate. The counts and energy of high amplitude AE dropped drastically as compared to region III. Like in Region III, higher amplitude AE signals with high rise time (>120 μs) did not occur.

To which processes do these signals of various amplitudes belong? During SCC, the amplitude of the AE signals could be arranged in the following order: dissolution of metal and breakdown of passive film < slip deformation, twin deformation, hydrogen gas evolution < micro-cracking (by hydrogen) < macro-cracking (by cleavage or coalescence of micro-cracks) [1]. From Fig. 5, it is clear that right through the tests AE with amplitudes 27.6 to 39.8 dB were found to occur, with maximum AE signals occurring at 31.2 dB. Mazille et al. [11] reported a majority of AE activity in the amplitude range of 28-38 dB during pitting corrosion of type 316L SS.

Fig. 6 : AE amplitude vs. time data obtained under constant loading in absence of environment.
Mukhopadhyay et al. [14] reported absence of AE during the post necking period of the ductile failure of austenitic SS during tensile testing. However, they reported AE due to dislocation motion during plastic deformation in the region between yield stress and ultimate tensile stress. This suggested that the AE observed in our study was due to dislocation motion during plastic deformation. The maximum AE activity of dislocation motion was observed at 31.2 dB. Monitoring of AE during tests conducted in absence of corrosive medium (Fig. 6) showed that the whole range of AE amplitudes which occurred due to plastic deformation of the precrack tip had rise times of less than 120 $\mu$s, with maximum emissions occurring in the range 31 to 34 dB. It was very difficult to identify the source of AE of amplitudes in the range of 40.9 to 46.5 dB that were observed in Region I of Figs 2 and 3. The disappearance of AE signals of these amplitudes with higher rise times during the crack growth process corresponded with cessation of hydrogen evolution, thus implying that the AE signals corresponding to these amplitudes and rise times were due to hydrogen evolution.

Though the cumulative AE parameters, such as events, counts and energy, increased with increasing crack length (Fig. 7), the rate of AE parameters decreased with increasing $da/dt$ (Fig. 8). This could be explained as follows: The material ahead of the crack tip, where the yield stress is exceeded, yields to produce a plastic zone, which blunts the crack. Larger the length of the crack, higher is the value of $K_I$ resulting in greater stress concentration due to which larger plastic zone forms ahead of the crack tip. This results in greater blunting of the crack tip. Larger plastic zone would imply that longer times would be required for crack to resharpen for further crack propagation to occur. This explains the larger time gaps between two AE events during later stages of crack growth and the reduced AE rate with increasing $da/dt$. Each AE event could be attributed to the process of formation of plastic zone. The time period between two AE events corresponded to the period of material dissolution that caused crack growth. The decrease in the rates of AE counts and energy with increasing $K_I$ (Fig. 9) could again be related to formation of larger plastic.
zones ahead of the crack tip with increasing $K_I$. This corroborates our explanation above that it was the formation of the plastic zone by plastic deformation of the crack tip, which was responsible for the AE.

Since no hydrogen evolution occurred during crack growth and since crack growth involved plastic deformation at the crack tip, HE was ruled out as the mechanism for SCC of the type 316LN SS. Based on the above arguments, it was concluded that dissolution controlled mechanism caused the SCC of type 316LN SS. Khatak et al. [5,15] reported discontinuous AE signals during HE of type 304LN SS. Monden et al. [4] reported that during macroscopic crack propagation by HE, AE signals of large amplitudes appeared in bursts. However, from this work, it can be inferred that burst type signals could be possible even for SCC by dissolution controlled mechanism.

REFERENCES