Evaluation of Stress Corrosion Cracking Phenomenon in an AISI type 316 LN Stainless Steel using Acoustic Emission Technique

**EXECUTIVE SUMMARY**

This work deals with the analysis of the acoustic emission (AE) signals to determine the micro-process during stress corrosion cracking (SCC) of AISI type 316LN stainless steel that cause the AE, and thus the mechanism of the SCC process. AE with amplitudes ranging from 27.6 to 46.5 dB with different counts, energy and rise times occurred during SCC of type 316LN stainless steel in 45% MgCl₂ at 413 K. The analysis of the AE signals in conjunction with fractography indicated that a surge in the AE counts and energy indicated initiation of SCC. AE was found to be continuous prior to the initiation. The time gap between AE events increased during 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 propagation of SCC in type 316LN stainless steel. The cracking was determined to be dissolution controlled.

**OUTLINE**

The present study aims to understand the mechanism of SCC based on the signatures of the AE. Compact tension (CT) specimens of annealed AISI type 316LN stainless steels were subjected to SCC testing in 45% magnesium chloride solution at 413 K in the range of stress intensity factor of 13-26 MPa.m⁰. The AE generated during the test were monitored with respect to time using a broad band frequency sensor. Monitoring of AE during the SCC tests indicated that both the AE counts and AE energy increased with time (Fig. 1). A sudden increment in AE counts and energy was observed at the same time. This burst in AE counts and energy was attributed to crack initiation. During the SCC test, significant amount of hydrogen evolution was observed on the surface of the CT specimen for some time much earlier to the crack initiation time. During crack initiation and propagation, hydrogen evolution ceased. Fig. 2 (a) shows that the AE signals were continuous during the start of the test (Region I in Fig. 1). As crack initiation approached (Region II of Fig. 1), a larger time gap between two events in the higher time region was observed (Fig. 2 (b)). As the initiation stage was approached, the number of counts per event and the energies of the low amplitude signals just prior to initiation were much higher than the large amplitude signals. This indicated that the production of low amplitude AE events with higher counts and energies has caused the initiation of the SCC process. Fig. 2 (c) shows that during early stages of crack growth (Region III in Fig. 1), 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 (> 39.8 dB) with high rise time (>120μs) did not occur. During the later stages of crack growth (Region IV of Fig. 1), the time period between two AE events increased further vis-à-vis region III and low amplitude AE signals dominated. From Fig. 2, it was clear that right through the tests AE with amplitudes 27.6 to 39.8 dB occurred, with maximum AE signals occurring at 31.2 dB. In another set of experiments, AE monitoring under load in absence of corrosive medium showed that the whole range of AE amplitudes, which occurred only due to plastic deformation of the precrack tip, had rise times of less than 120μs, with maximum emissions occurring in the range 31 to 34 dB. This indicated that maximum AE during SCC occurred by plastic deformation of the crack tip. The disappearance of AE of amplitudes in the range of 40.9 to 46.5 dB with higher rise times (>120μs) that were observed in Region I of Fig. 1, corresponded to ceasing of hydrogen evolution, thus implying that the AE signals of 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, the rate of AE parameters decreased with increasing crack growth rate. This could be explained as follows: There exists a triaxial state of stress ahead of the crack-tip. 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, (at the value of load applied on specimen) 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 by dissolution 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 crack growth rate. 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. Hence, from this work, it was concluded that burst type signals could occur during SCC by dissolution controlled mechanism.
Corrosion processes present an attractive proposition for detection and characterization by AE technique. During SCC and corrosion fatigue, 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 produce AE. Each of these has definite range of amplitudes and can be distinguished by the amplitudes and frequencies of occurrence. In low strength steels, AE monitoring has been disappointing because the crack growth process is more chemical than mechanical and the emissions are sporadic and low in amplitude. Stainless steels and titanium alloys are borderline cases. During SCC of titanium alloys heat treated to low strength levels, major crack movements without detectable emissions were observed while the same material heat treated to higher strength levels gave substantial emissions that could be correlated to crack velocity, load drop and stress intensity factor.

AE technique has been used to differentiate between active path corrosion (APC) and hydrogen embrittlement (HE) mechanisms. During APC mechanism of SCC and in the incubation period of HE, continuous AE signals of small amplitude are emitted; while during macroscopic crack propagation during HE, AE signals of large amplitudes appeared in bursts. AE is more intense during intergranular SCC (IGSCC) than during transgranular SCC (TGSCC), suggesting that larger areas of crack growth occur per event during IGSCC.

Fig. 3 shows the AE amplitude distribution produced by microprocesses that may operate in connection with SCC or corrosion fatigue. AE generated by several of these microprocesses can occur at amplitude levels comparable with those produced by hydrogen gas evolution. Hence, detailed AE signal analysis is needed before positive mechanistic identification is made concerning CF or SCC operative in stainless steels.

This study has proved that SCC by active path corrosion or dissolution based mechanism occurs in bursts. This is contrary to what has been so far believed that SCC by dissolution controlled mechanism was a continuous cracking process and only hydrogen embrittlement occurred in bursts. In words of the reviewer of this paper which was submitted to the journal 'Corrosion Science', this work has provided new insight into the mechanism of stress corrosion cracking.


Further inquiries:
Shri Hasan Shaikh, Corrosion Science and Technology Division Metallurgy and Materials Group, IGCAR, e-mail: hasan@igcar.gov.in