Review

A Review on the Applications of Acoustic Emission Technique in the Study of Stress Corrosion Cracking

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Abstract: The complex nature of the damage evolution in stress corrosion cracking (SCC) leads to explore for new investigation technologies in order to better identify the mechanisms that supervise the initiation and evolution of the damage as well to provide an improvement of knowledge on this critical localized corrosion form during time. Research activities concerning the use of acoustic emission (AE) technique to assess SCC has acquiring considerably relevance in recent decades. The non-invasiveness and the possibility to provide a continuous in situ monitoring of structures and components make this non-destructive technique clearly promising in the field of structural health monitoring. In this concern, this paper aims to be a focused overview on the evaluation of SCC phenomena by AE technique. The main topic of this review is centered on the approaches that can be used in elaborating AE data to better discriminate the mechanisms that contribute to damage propagation in SCC conditions. Based on available literature, investigation approaches assessing AE waveform parameters were classified, evidencing, furthermore, the identified mechanisms that synergistically take place during the material degradation. Eventually, a brief summary and a future trend evaluation was also reported.

Keywords: corrosion monitoring; acoustic emission; stress corrosion cracking; pitting; nondestructive testing

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1. Introduction

The acoustic emission (AE) technique has been widely used as research tool in industrial engineering field in order to assess the damage evolution of the materials and structures [1–3], extending its applicability in the structural health monitoring of structure (SHM) mainly in civil [4], aeronautical [5] or industrial [6] and applications. In recent years, this activity has been oriented, in an increasingly targeted way, towards the corrosion issue monitoring of systems and components, representing a critical factor in ensuring the structural industrial integrity [7–10].

The AE has the advantage to be used as non-invasive and passive technique to monitor the evolution of local damage in the structure. This allowed to enhance its use as a SHM approach in the structural and environmental structure degradation induced by corrosion.

Even if early evidence on material transformations and AE (the so-called tin and zinc cry) can be date in the early '20s of the last century [11] the technology of AE traditionally had its beginning in 1950 with the work of Joseph Kaiser, the father of modern AE technology. Indeed, Kaiser conducted the first really exhaustive investigation on AE phenomena, but Kaiser's most significant discovery was the irreversibility phenomenon which now bears his name: Kaiser effect [12].

One of the first applications of the AE technology for corrosion monitoring was carried out by Rettig [13] and Mansfeld [14] at the end of the '70s. Later Weng et al. [15] in 1982 applied the AE to detection of reinforcing steel corrosion in concrete in a series of controlled laboratory tests. The results highlighted the sensitivity of the proposed approach as a corrosion damage monitoring technique in order to assess the deterioration process of

these structures. The AE technique was already used in the 1980s for SHM mainly in the civil, automotive and aeronautical sectors, suggesting the predictive capabilities of the technique [16–20].

Therefore, the research on intelligent structures capable of predicting damage using AE sensors is not a new concept. Already over 35 years ago [21], this idea was proposed by Crawley et al. Subsequently, an evolution of the technique and a greater understanding of the correlation between the acoustic and mechanical parameters allowed to enhance the experimental results over time and to gradually extend its application fields [22–25].

Based on this driving force, AE technology has played an increasingly important role in the study of the degradation mechanisms of structures, with particular emphasis on the corrosion-induced phenomena, for which this approach has highlighted significant development margins.

AE technology is nowadays widely used. Several standards have been defined and issued even if mainly related to specific application fields [26], e.g., in ASME [27] for evaluation and testing of metallic and fiber reinforced plastic vessels, in ASTM [28] for welding testing, pressure vessel testing and AE instrument and sensor verification. Additionally, CEN standards [29] are mainly focused on proof testing of pressure vessel and piping, while ISO standards [30] are centered on sensor calibration, terminology and general guidelines.

Specific recommendation practices have been published for monitoring of reinforced concrete structures, e.g., the NDIS 2421 standard by the Japanese Society for Non-Destructive Inspection [31] and recommendation by RILEM TC 212-ACD [32].

Among the different corrosion mechanisms, stress corrosion cracking (SCC) is one of the most critical one from the point of view of structure safety since it can lead to premature catastrophic failures of structural components without any clear warning signals. Due to the unpredictable consequences and catastrophic effects of SCC, the safe application of new materials is a major challenge for oil & gas fixture [33] as well as for aerospace and aeronautic industry [34]. Thus, research activities focused on non-invasive monitoring of SCC mechanisms have a significant practical importance in these fields.

Aim of this review is to assess the applications of acoustic emission technique in the identification of the damage mechanisms induced by SCC. Based on the current state of the art, the most suitable approaches for the evaluation of the SCC phenomenon by means of the AE features have been investigated. Further purpose of the paper is to assess integrated approaches to analyze the acoustic variables in order to better discriminate the various damage phenomena that take place during the complex SCC phenomenon.

2. Acoustic Emission (AE) Testing

2.1. Acoustic Emission Principles

The fracture phenomenon of a material takes place with the release of the stored strain energy, which is consumed mainly with the formation of new external surfaces (cracks) and by the emission of elastic waves. This latter is defined as acoustic emission (AE). These elastic waves propagate through the material and can be acquired by a high frequency sensor, as schemed in Figure 1.

Elastic waves (generated by material deformation, transformation or cracking propagate through the media) are detected on the metal surface by the AE sensor, that acts as a vibration-to-electrical signal conversion module. Part of the surface vibrations are released in the air, and depending on the signal origins, a sonic wave can be possibly heard (i.e., the classical failure sound).

The origin of the acoustic wave mechanisms can be seen, by similarity, with the earthquake ones.

Figure 1. Principle of the acoustic emission wave detection.

On this latter, the sudden sliding occurring between two boundary plaques, when the acting forces exceed the friction forces, represents the nucleating action of the phenomenon. As a consequence, a shear failure (by sliding or tearing mode) is triggered. Concerning the AE events, two mechanisms are responsible of the crack activation and propagation: i) tensile mode, related to crack opening mode ii) in-plane and out-of-plane shear mode related to slip crack motion. The former is a tensile crack and corresponds to an opening dislocation. Instead, the latter is referred as shear crack and it is referred to the in-plane shear dislocation.

During the AE phenomenon, high-frequency mechanical waves (up to several MHz) are emitted. The location of the event that originates the AE wave (AE source) and its magnitude can be estimated by AE waveform, acquired by sensors, to assess the damage and its propagation. A schematic of AE equipment set-up for a reference SCC test is shown in Figure 2.

Figure 2. Schematic of AE equipment set-up for a typical SCC test.

2.2. AE Waveform Parameters

The identification of the AE waveform is a simple and well consolidated approach to characterize and to discriminate the AE sources [24]. Figure 3 graphically schemes the common signal measurement parameters that can be related to an AE signal waveform.

Figure 3. Schematic of an Acoustic Emission event and related parameters.

<i>Amplitude:</i>	Amplitude (A) is the highest peak of the measured voltage signal and it is measured in decibels (dB). This is an important parameter in NDT inspection since it determines the signal detectability.
<i>Threshold:</i>	Threshold is a setting parameter that is applied for the elimination of electronic and environmental background noises. Only AE waveforms with amplitude higher than the set threshold value will be recorded. Higher threshold values reduce the risks of noises acquisition. Although, a balance needs to be identified in order to not eliminate even weak but useful AE events coupled to low amplitude background noises.
<i>Duration:</i>	Duration (D) is defined as the interval between the first and last time the signal waveform crossing the threshold value. This parameter, therefore, identifies how long the event can be considered acoustically relevant.
<i>Risetime:</i>	Risetime (R) is the time interval between the first threshold crossing and the amplitude (maximum signal peak). It is related to the propagation of the AE wave from the source location toward the sensor.
<i>Energy:</i>	The energy (E), is the measure of the area under the envelope of the AE voltage signal waveform.
<i>Counts:</i>	Counts (CNT, or N) refers to the number of amplitude peaks greater than the threshold value. Counts depends on the magnitude of the AE event, reverberant nature of the sensor, and the material characteristics. It does not provide explicit information on the nature of the event, however combined with amplitude and/or duration measurements it is able to rely information about the shape of a AE waveform (hit signal).
<i>Average Frequency:</i>	It is an indirect parameter identified by AE waveform. The average frequency (AVG, or AF) can be defined as the ratio between counts and duration.
<i>RA:</i>	the RA value is defined as the ratio between risetime and amplitude. RA, coupled to AF, can be used to assess tensile/shear cracks classification.
<i>b-value; Ib-value:</i>	These parameters represent a not conventional approach based on the event cumulative frequency–magnitude distribution that was tailored on seismic applications. b-Value algorithm was developed to charac-

terize earthquake data populations, but it was successfully applied in corrosion field [35].

The b-value is defined as:

$$\log N = a - b \left(\frac{A_{dB}}{20} \right) \quad (1)$$

where A_{dB} is the event magnitude, N is the number of events with an amplitude higher than A_{dB} . b is the so-called b-value. To overcome the issues related to define amplitude range and N the improved b-value (Ib-value) was proposed [36]:

$$Ib = \frac{(\log_{10} N(\omega_1) - \log_{10} N(\omega_2))}{(\sigma(\alpha_1 + \alpha_2))} \quad (2)$$

where $N(\omega_1)$ and $N(\omega_2)$ are the cumulative number of AE events with amplitude higher than $\mu - \alpha_1 \sigma$, and $\mu + \alpha_2 \sigma$, respectively. σ is the standard deviation of the magnitude distribution for each group of events, μ is the mean value of the magnitude distribution for the same group of events, α_1 and α_2 are empiric constants [37].

A summary of the aforementioned AE parameters with a short variable description, classified based on waveform feature, is listed in Table 1.

Table 1. AE Variables data-set, classified based on waveform feature.

Waveform Feature	Variable Name	Variable Description	Unit	Code
Direct	Amplitude	Value of the maximum peak of the signal waveform. It indicates magnitude of the waveform.	dB	A
	Threshold	Threshold value such that signals with amplitude higher than this value will be recorded.	dB	–
	Duration	Time between the start and end of the signal referred to a predefined threshold	$\mu\sigma$	D
	Risetime	Time between the first overshoot of the defined threshold and the peak amplitude.	$\mu\sigma$	R
	Energy	Area under the envelope of the AE voltage signal waveform.	Eu or V ² s	E
Indirect	Counts	Number of time (counts) that AE signal crossed the amplitude threshold.	Absolute number	CNT; N
	Average Frequency	Ratio between Counts and Duration.	kHz	AVG; AF
	RA	Ratio between Risetime and Amplitude. Useful to classify the type of cracks.	ms/V	RA
	b-value; Ib-value	approach based on the event cumulative frequency–magnitude distribution	–	b-value; Ib-value
Cumulative	Cumulative	Cumulative value for specific parameters, such as hits, counts and energy	–	–

3. Detection of SCC Phenomena by AE Technique

3.1. Stress Corrosion Cracking

SCC is one of the most critical corrosion types; SCC can also cause premature failures of structural components and should not be neglected in damage risk managements.

It induces the fracture in working condition of structural components subjected to the combined action of an apparently not aggressive corrosive environment and constant or variable mechanical stresses in quasi-static conditions. Crack propagation that leads to premature fracture of the material is the result of the synergistic combination of mechanical stresses and corrosion reactions.

SCC is a relevant cause of failure of metal component or plant fault in a wide range of industrial sectors. Thus, the reliable evaluation of the service life of these components and structures needs to predict the activation and propagation stages of SCC phenomenon.

The SCC involves chemical and mechanical damage mechanisms that synergistically acts to induce a continuous evolution of the damage toward the final fracture of the component. Parkins [38] firstly introduced the “stress corrosion spectrum” concept in order to assess a continuous spectrum of SCC mechanism, controlled by a mutable contribute both from electrochemical and mechanical factors, depending on the evolving SCC damage mechanisms.

Figure 4 shows schematically a three-stage model for SCC damage mechanism based on Parkins Stress Corrosion Spectrum [39].

Figure 4. Schematic diagram of a three-stage model for SCC progression [39].

Despite the SCC mechanism implies a synergistic complex interaction of mechanical conditions, type of alloy and characteristics of the environment, usually it starts with the early localized corrosion or mechanical defects (such as pitting, local intergranular attack, scratches or other pre-existing surface defects) [40]. These, subsequently, evolve in short cracks with slow propagation rate, until reaching a long crack regime which finally leads to the component failure.

The evolution of the whole damage path is generally slow and long time consuming, consequently, an in-situ monitoring of the transition from initiation to propagation is very useful in order to estimate the SCC risks.

Despite the complexity of concurrent events that take place during the damage propagation in SCC [41], AE is a most powerful technique that can be applied to assess the SCC damage mechanisms. Although, considering the several SCC induced AE sources, a specific AE signal feature is not enough consistent in discriminating the mechanical and electrochemical corrosion phenomena occurring during the SCC [42].

Cassagne et al. observed, monitoring SCC in high-temperature water by using AE technique of Alloy 600, that applied load and cracks propagation are relevant factors in the identification of univocal AE signal features [43].

Furthermore, as observed by Xu [44], the intergranular or transgranular crack propagation could influence the AE activity. Both plastic deformation and crack propagation imply active AE signals during the transgranular cracking. Instead during the intergranular

cracking, the acoustic emissivity is favored mainly by plastic deformation in the proximity of the crack tip [45].

The assessment on transgranular SCC of annealed 304 SS evidenced that two clusters of AE waveform take place: burst type and continuous type, related to crack propagation and plastic deformation at the crack tip, respectively [46]. However, more research activity, evidenced conversely, that no relevant difference can be highlighted between the amplitude and rise-time of the AE signals acquired during the transgranular and intergranular SCC (TG-SCC and IG-SCC, respectively) crack propagation [47,48].

The present results clarify that some contradictions are still present concerning the AE pattern related to the cracks activation and propagation.

A simplified approach to qualitatively discriminate the SCC mechanisms is to correlate the AE signals (characterized by specific waveform features) with the mechanical or electrochemical corrosion behavior occurring during the SCC.

3.2. Main AE Sources in SCC Phenomena

Depending on the corrosion mechanism, specific AE events are generated which can be univocally correlated to the corrosive processes in progress [49].

Several corrosion forms, such as uniform corrosion, pitting, crevice, SCC, tribocorrosion, corrosion fatigue, has been studied by AE technique, indicating that this technology can be used to detect corrosion phenomena [50–55].

In the middle of 70s some papers were specifically oriented on the evaluation of SCC by using AE technique, by using this technique mainly to corroborate the metallographic experimental results [56,57].

In these years, for safety reasons and environmental risk reduction, continuous monitoring by AE become common in hydrostatic testing pressure vessels and nozzle attachments for stress corrosion [58,59].

Yuyama et al. [60], in one of its pioneering paper on this topic, illustrate schematically the possible AE sources identifiable during SCC or corrosion fatigue (CF) processes (Figure 5). As schemed in figure, several phenomena occur during these stress-assisted corrosion damage mechanisms. In particular, main AE sources can be identified: crack initiation and growth; hydrogen bubble evolution due to cathodic reaction; breakdown of thick, surface oxide films. Further specific AE sources can be argued at the crack tip plastic zone: slip deformation, twinning, and the fracture or decohesion of precipitates, second-phase particles, or nonmetallic inclusions.

Figure 5. Schematic of possible AE sources during corrosion, stress corrosion cracking and corrosion fatigue processes (adapted from [60], Copyright 2020, with permission from Springer Nature).

The role of these factors in the corrosion damage evolution and in its induced acoustic activity depends toughly on environmental conditions (that could favor hydrogen embrittlement or local metal dissolution), mechanical conditions (constant or cyclic stress, stress triaxiality), and materials factors (heat treatment conditions or nonmetallic inclusions). Only the synergistic action of these factors identifies the AE behavior of SCC or CF process.

The magnitude and number of AE events differs depending on the occurring corrosion mechanism.

Figure 6 shows the various AE sources observed during the SCC and CF processes of 304 stainless steel, experienced by Yuyama et al. in [60]. Based on these classifications:

- the lowest AE energy level (proportional to peak voltage) can be related to dissolution of metal or breakdown of thin passive film (amplitude less than $-10 \mu\text{V}$). These events are not detectable by AE sensors.
- However, hydrogen bubble evolution (as the cathodic reaction coupled to the anodic metal dissolution) can induce AE events with higher energy level (amplitude about 0.1–1 mV). Quite similar AE energy level can be observed during slip or twin deformation. All these events compared, to dissolution mechanism are characterized by lower event counts.
- Micro-cracking processes like cleavage or intergranular cracking and separations identify an intermediate magnitude AE energy events (amplitude about 1–10 mV).
- Finally, AE energy level of macro-cracking, e.g., because of large-scale cleavage or coalescence of micro-cracks) may reach magnitude above 10 mV.

Figure 6. Various AE sources during SCC or CF processes and their energy levels drawn on amplitude distribution (adapted from [60], Copyright 2020, with permission from Springer Nature).

3.2.1. AE Source Identification by Direct Waveform Features

Basically, an affordable approach to distinguish among different AE sources is to compare at least two direct waveform parameters. A first parameter related to the energy magnitude of the AE waveform (energy or amplitude) and a second parameter related to the waveform length or shape (risetime or duration).

The coupling of these parameters allows to roughly define the key factors that describe the AE waveform and consequently can be used for a preliminary discrimination of the degradation phenomena that take place during SCC.

Figure 7 shows the Cartesian plot of absolute energy ($1 \text{ aJ} = 10^{-18} \text{ J}$) versus duration for a HIC test carried out on in a H_2S environment on a X65 SwS specimen [61]. The hydrogen bubble evolution phenomena generate AE events with low energy and duration. Instead, the growth of the FeS oxide layer was distinguished from H_2 evolution signals

by energy magnitude (higher than about 100 aJ). Finally, the AE hits related to the crack propagation (hydrogen induced cracking) are characterized by high energy and duration.

Figure 7. Correlation chart representing absolute energy versus duration for a HIC test conducted in the EFC 16 solution at pH 4.5 under 1 bar H₂S, on a X65 SwS specimen, reprinted from [61] (Copyright 2020, with permission from Springer Nature).

Furthermore, Hwang et al. [62] proposed to assess the evolution, during time, of Energy amplitude and risetime parameters. In Figure 8 their evolution with time during stress corrosion crack of AISI 304 stainless steel in 1M Na₂S and 4M NaOH aqueous solution is shown.

Figure 8. Energy, amplitude, and rise time distribution with time during stress corrosion crack of AISI 304 stainless steel in 1M Na₂S and 4M NaOH aqueous solution [62].

The variation of these AE direct waveform features allows to divide the SCC process in four stages: (i) The first stage is related to the triggering of the test. During this region homogenization and chemical stabilization in the corrosive electrolyte takes place. (ii) The second stage (region B) can be defined as SCC initiation and propagation. It is characterized by a low amount of AE events with very low magnitude. (iii) At increasing time, during the SCC test a more relevant AE activity occurs. This step identifies the region C, due to the combination of several damage mechanisms such as: rupture of the passive film, metal dissolution, repassivation, plastic deformation. All events are characterized by high amplitude, risetime and energy. (iv) The last step (region D) can be related to the sample failure and it is dominated by the plastic crack propagation that affects the AE

signal generation. This step is characterized by AE events with high risetime, low energy and amplitude.

The comparison of different waveform features represents an effective strategy to trigger a qualified discrimination of corrosion-induced degradation phenomena. Interesting consideration can be argued evaluating Figure 9 that shows the distribution of some significant AE parameters for distinct corrosion mechanisms developing on different corrosion resistant alloys in a 10% by weight FeCl_3 solution [63]. In particular, blue dots are related to X12Cr13 events, mainly related to uniform corrosion. Red dots are referred to 17-4 PH events, mostly due to SCC phenomena. Green dots are related to X4CrNiMo16-5-1 events, mostly related to crevice/pitting.

Figure 9. Cartesian plot of some AE variables during SCC test. Blue dots are related to X12Cr13 events, mostly uniform corrosion events. Red dots are related to 17-4 PH events, mostly SCC events. Green dots are related to X4CrNiMo16-5-1 events, mostly crevice/pitting events [63].

AE waveform related to dominating uniform corrosion (predominant in X12Cr13 stainless steel, blue dots) can be identified by low amplitude, medium duration and a relatively high RA value.

Waveforms due to pitting/crevice (identified on X4CrNiMo16-5-1 stainless steel, green dots) are mainly characterized by high amplitude and energy parameters. The authors proposed that high and low RA values for this cluster could be related to crevice/pitting activation and hydrogen evolution bubbling, respectively. Finally, the AE waveforms due to SCC phenomenon (17-4PH events, red dots) are characterized by a wide disperse AE parameters. A first sub-cluster related to low/medium amplitude, energy and RA are induced by pitting activation. Afterwards AE events with high amplitude, energy and duration can be related to SCC crack activation and propagation phenomena [64].

This approach, although effective for providing a comparative study between different acoustic events, does not allow to extend the research to an effective discrimination of specific corrosion phenomena. Furthermore, not univocal information about the triggering conditions of these AE clusters can be acquired.

Consequently, a specific way in integrating the information of several variables is necessary in order to better identify and to discriminate the clusters of the different corrosion forms occurring during SCC.

3.2.2. AE Source Identification by Indirect Waveform Features

The AE sources can be also classified in terms of RA value and average frequency (AF) in order to discriminate tensile and shear crack propagation [65–67]. This method evidenced effective results on corrosion degradation phenomena in steel reinforced concrete structures [68–70]. However the same approach evidenced suitable results also in stainless steel specimens [71,72].

As observed in Figure 10, relating the AF and RA value at increasing time during SCC test it is possible to assess the modification of the crack propagation from shear to tensile mode during SCC test. AE events characterized by low AF and high RA can be correlated

to a tensile crack propagation [73]. Instead, AE signals characterized by high AF and low RA identify a shear crack propagation mechanism [73]. Assessing this plot, consideration concerning the corrosion damage evolution was identified.

- Incubation Period. During the first stages of SCC tests (identified as incubation period), the AE events are characterized by very high RA value and low AF.
- Activation/coalescence Period. At increasing time, the magnitude of AF parameter grows up, and a gradual decrease of the RA value occurs. This region is representative of mode I crack opening mode. It was identified as the activation and coalescence period.
- Failure. At long time, near to failure onset, a slight modification of the trend occurs. This stage is characterized by low RA values and low AF and it represents a possible evolution from tensile type to shear type of fracture mode. This stage can be related to the crack propagation before catastrophic failure occurs.

Figure 10. Evolution of crack propagation mechanism by using AF vs. RA value plot for a eutectoid cold drawn steel during SCC test, black arrows indicate time evolution [72].

Equally interesting results for the evaluation of SCC-induced damage were acquired using b - and I_b -values as damage descriptor of evolving corrosion phenomena. As reference, in Figure 11, b -value and I_b -value trend during SCC test on martensitic stainless steel X12Cr13 at varying the dog bone specimen location is shown [74].

The Authors observed that a variation in b -value occurs at varying the occurred damage mechanism. Instead, a constant trend of these variables was related to a non-relevant change of the corrosion mechanisms.

This aspect is related to the mathematical nature of the b - and I_b -values. These features are mainly influenced by the distribution of the amplitude events. Their variation can be considered as a discriminating factor for triggering or evolving fracture processes. Therefore, the increase of b - and I_b -value could give advice concerning micro-cracking evolution with large magnitude variation for the transition from activation to propagation stage [37,75].

An effective approach to discriminate the different waveforms associated with the different occurring SCC mechanisms is the use of fast Fourier transform (FFT) to convert the signal from a time domain to a frequency domain. This technique implies that the whole acoustic waveform needs to be recorded, thus leading to a relevant increase in the calculation data processing. However, the information that can be acquired can be particularly useful. Figure 12 shows the waveform and the referred FFT for three different phenomena: hydrogen gas evolution (Figure 12a,b), rupture of passive film (Figure 12c,d) and metal dissolution (Figure 12e,f) [76]. For each of these phenomena a characteristic

frequency can be identified. The passive film rupture AE events are characterized by a frequency of about 50 kHz and very low magnitude in amplitude. Instead, the cathode hydrogen bubble evolution and anodic dissolution events are characterized a frequency peak about 50 and 70 kHz, respectively. Instead, these events showed a very relevant frequency selectivity and magnitude, the peak is very narrow, and its magnitude is one order of magnitude higher than film rupture, pointing out the greater acoustic waveform regularity associated with these phenomena.

Figure 11. b-value (red marker) and Ib-value (green marker) evolution for six specimen spatial regions during SCC test on martensitic stainless steel X12Cr13 [74].

Considering that several secondary AE events occurs during the crack propagation [77], the frequency spectrum could become complicated to be discriminated. However, considering that the AE spectrum is accurate against deformation and fracture phenomena, its magnitude is related usually to the defects size during nucleation and growth stages. As evidenced in [78] the difference in the high frequency peak in FFT spectra may be related to the mode of crack initiation and its size. In addition, microcracks generation and propagation might form peaks at low frequency thus influencing the FFT spectrum [79]. To overcome these interpretation issues, further experiments or analysis procedures should be required to better interpret during post-processing the AE data.

Figure 12. (a) Typical AE waveform observed during hydrogen gas evolution, (b) Frequency spectrum of AE signal during hydrogen gas evolution, (c) Typical AE waveform observed during rupture of the passive film, (d) Frequency spectrum of AE signal during passivation, (e) Typical AE waveform observed during metal dissolution, (f) Frequency spectrum of AE signal during metal dissolution [76].

3.2.3. AE Source Identification by Cumulative Parameter Features

Considering that the evolution of the complex SCC damage path is generally slow and long time consuming, a strategy is to introduce the time as significant parameter. On this concern the assessment of cumulative value for specific AE parameters, such as hits, counts and energy was identified as a suitable approach in order to evaluate the damage evolution induced by SCC. The use of the cumulative parameters related to the AE waveform shape may be more effective for discriminating energetically significant events during the SCC test [62,80–82].

Figure 13 shows the evolution of AE hit energy (open circles) and cumulative AE hit energy (continuous line) during time on 17-4 PH stainless steel.

From the figure it is possible to deduce that the temporal regions in which there is the greatest acoustic activity are slight above 10^3 and 10^4 s. However, from the energetic point of view, the events that have a greater magnitude are located in an intermediate time segment between them. This region (range 5×10^3 – 1×10^4 s) identifies a critical damage region, suitably highlighted by cumulative hits plot. Similarly, the fracture zone, characterized by few acoustic events (generally a few dozen of AE hits with full-scale energy magnitude), is better discriminated.

Figure 13. Evolution of AE hit energy (open circles) and cumulative AE hit energy (continuous line) during time on 17-4 PH stainless steel [82] (Copyright 2020, with permission from Elsevier).

Since SCC is a combination of electrochemical and mechanical damage phenomena, a suitable improvement on the discrimination of the corrosion mechanisms can be acquired coupling electrochemical noise (EN) and AE techniques [83–86]. According to the SCC damage evolution scheme reported in Figure 13 the SCC initiation and the subsequent crack propagation can be recorded by electrochemical and acoustic techniques, respectively.

Figure 14 shows the cumulative energy and cumulative shot noise charge q versus time trends during SCC tests on 17-4 PH stainless steel [82]. In particular, the shot noise theory assumption is that the current noise signal can be considered as packets of charge. The charge of each electrochemical event can be determined evaluating both potential and current noise signals [87].

Figure 14. Cumulative AE energy and cumulative shot noise electrochemical charge q vs. time and the four damage stages on 17-4 PH stainless steel [82] (Copyright 2020, with permission from Elsevier).

The stage I is defined as electrochemical activation step. Preliminarily, a local and gradual thinning of the passive oxide film up to the local surface depassivation of the metal occurs. This process could take place at short time, depending on the electrolyte aggressiveness. Afterwards, the electrochemical activity becomes progressively relevant, as a consequence of several pits on the metal surface. This phenomenon can be identified by an increase of the EN cumulative trend. Instead, considering that the damage phenomenon is dominated by an electrochemical mechanism, AE cumulative energy trend shows a low growth rate. The few acquired AE events, during this phase, can be ascribed to hydrogen reduction reaction (bubble gas evolution) in the cathodic area [88].

Stage II is the propagation step. The cumulative electrochemical trend continues to increase due to the triggering and growth of stable pits. However, a concomitant increase in the cumulative AE energy trend was exhibited. This is due to the crack initiation and propagation by SCC (sub-step IIa). The local surface defects evolve from pit to crack (1500–2500 s). Afterwards, a sub-step (sub-step IIb) was defined as short-range crack propagation.

Stage III shows quite low AE activity. The AE events are not energetically relevant. It is the so-called AE quiescence phase [89]. The crack growth increases the plastic deformation at the crack tip leading to a reduction in the AE activity [45]. However, the cumulative electrochemical curve undergoes a further increase indicating that electrochemical phenomena, such as dissolution within the crack, are still taking place. This step was defined as long-range crack propagation stage. Finally the stage IV is referred to the specimen failure, where few AE hits, with very high energy magnitude, can be identified.

3.2.4. AE Source Identification by Multivariate Analysis

All these phenomena generate AE events characterized by specific waveforms. The population of AE events is intrinsically heterogeneous, considering the large amount of damage phenomena that occurs during SCC degradation. This makes it difficult to interpret the data or to properly cluster the damage stages in the structure.

On this concern, conventional univariate data analysis approaches are not able to well discriminate the damage mechanisms of the structure. The use of multivariate statistical methods is useful to better classify the main waveform parameters related to each specific damage or corrosion form. Pattern recognition techniques can be applied for this purpose [90]. Signal processing is there managed by digital filtering [91], Fourier transforms [92] or other post-processing approaches such as wavelet transform [93], or by AE features selection [94]. A multivariate statistical technique can be applied in order to better interpret the recorded AE data, grouping hits into sub-clusters related to a specific degradation condition.

An artificial neural network (ANN) coupled to wavelet transform (WT) was applied to determine the AE features for corrosion the forms recognition [80,95,96].

This approach was applied in [80] to discriminate the main differences on the waveform features of micro- and macro-crack pattern on SCC AE data. In particular, Figure 15 compare the time-frequency 2D wavelet for micro-cracks and macro-cracks AE pattern for SCC on aboveground storage tank floor steel.

The frequency of the micro-crack AE signals (Figure 15a) is mainly characterized by frequency in the range 100–200 kHz. Maximum energy areas (regions colored in red) were located about at 140 kHz. In particular, two peaks were identified at 10 μ s and 75 μ s, respectively. Instead, the macro-crack AE signals are composed by high frequency components (250–350 kHz). The energy peak (at 320 kHz and 25 μ s) was much higher than the microcrack-one, thus indicating that the macrocracks exhibit higher energy concentrations.

Calabrese et al. [72,82] assessed the SCC mechanisms on martensitic stainless steel by coupling Kohonen self-organizing map (SOM analysis) and principal component analysis, showing that the SCC mechanism was related to specific and significant AE patterns.

Figure 15. Time-frequency Wavelet 2D diagrams of (a) micro-cracks and (b) macro-crack AE signals for stress corrosion cracking on aboveground storage tank floor steel [80] (Copyright 2020, with permission from Elsevier).

The choice of the SOM algorithm is based on the opportunity to obtain a topological map (U-matrix) that can be used to discriminate intuitively the different damage phases. Each area of the map can be related to specific centroids of the waveform features used to train the neural network [97].

Figure 16 shows, as reference, the damage mechanism map (U-matrix) for a corroded post-tensioned concrete beam [97]. The map was divided into specific damage mechanism areas, in which the activation, propagation and critical damage areas, can be identified. Furthermore, despite the other post-processing approaches (Cumulative Parameter Features in Figure 13) by using neural network method the quiescence phase was identified. In particular, some relevant sub-steps were highlighted. (i) quiescent events occurred after the electrochemical activation of the metal surface. This cluster is characterized by high level of average frequency and it is located in bottom side of the map. (ii) a pre-critical damaging quiescent area was instead characterized by low event frequency and middle duration events. It is located in the top side of the map (iii) a further post-critical damaging area was located on the right of the map and was related to the quiescent phase following the critical damaging. This cluster of AE events are characterized mainly by high amplitude values.

Figure 16. Damage mechanisms map by U-matrix for a corroded post-tensioned concrete beam [97] (Copyright 2020, with permission from Elsevier).

Therefore, a neural network approach such as the SOM algorithms, that is supported by the use of topological Kohonen map representation of data distribution (U-matrix map), can be identified as powerful technique in order to better analyze a multivariate AE dataset. In particular, a synergistic integration of univariate and multivariate approach allowed to validate the preliminary evaluation acquired on the basis of the univariate waveform feature analysis. The neural network approach also permitted to discriminate different damage phenomena occurring during SCC mechanism relating each stage to a specific AE wave attributes, identifiable as AE feature fingerprint for each damage phenomenon.

4. Summarizing Remarks

Even if, in the last year several analytical tools and different approach for data analysis have been developed there is no accordance in literature about unambiguous identification of AE source identification in corrosion or SCC mechanism.

Table 2 summarizes a brief state of the art, from 2001 to the present, on paper dealing with SCC evaluation and monitoring by AE techniques.

Table 2. Brief state of art (2001–2020) in acoustic emission technique for SCC monitoring. Details of the applied waveform feature.

Ref	Year	Authors	Material	Environment	Waveform Features			Multivariate Analysis	Discriminated Mechanisms
					Direct	Indirect	Cumulative		
[98]	2001	Yang et al.	37SiMnCrNiMoV		Hits, E, R, D				
[99]	2001	Na et al.	HT-60 Steel	Seawater	N, A				
[100]	2002	Ferrer et al.	316L SS	35 wt.% MgCl ₂ sol.	Hits, N, A,	AVG	Hits		Crack propagation
[101]	2003	Na et al.	HT-60 Steel	Seawater	N, A		N		Plastic quiescence
[102]	2004	Fujimoto et al.	304 SS	35 wt.% MgCl ₂ sol.			Hits		Pitting Crevice
[103]	2005	Yonezu et al.	304 SS	35 wt.% MgCl ₂ sol.	E	FFT	N	Wavelet	surface friction falling-off grains crack propagation
[84]	2006	Yonezu et al.	304 SS	35 wt.% MgCl ₂ sol.		FFT	N	Wavelet	Hydrogen gas evolution falling-off grains crack propagation
[104]	2006	Proverbio et al.	steel	Chloride sol.	Hit, D		Hits		Crack propagation
[105]	2006	Yonezu et al.	304 SS	MgCl ₂ sol.	A	FFT	N		Hydrogen evolution falling-off grains crack propagation
[106]	2006	Kagayama et al.	DP-3 steel	35 wt.% MgCl ₂ sol.		FFT	N		crack propagation Crack activation
[45]	2007	Shaikh et al.	16LN SS	45 wt.% MgCl ₂ sol.	A, N, R		NE		Crack propagation
[85]	2007	Kovac et al.	steel	NH ₄ SCN sol.	A		Hits		Plastic quiescence
[49]	2007	Jomdecha et al.	304 SS	3% NaCl sol. (ph 2)	Hits, A, N				Uniform Corrosion passive film breakdown Hydrogen evolution Pitting Crevice Crack propagation
[107]	2007	Kovac et al.	304 SS	Na ₂ S ₂ O ₃ sol.	A		Hits		
[108]	2007	Lapitz et al.	α-brass	NaNO ₂ sol. Mattsson's sol.	A, R	b-value	Hits		Crack propagation
[109]	2007	Kim et al.	SPPH SS		Hits, A				Crack propagation
[47]	2008	Alvarez et al.	304 SS	1 M NaCl + 1 M HCl sol.	A, R	b-value			Crack propagation
[110]	2008	Zhang et al.	304H SS	K ₂ O ₆ S ₄ sol.	Hits, A, E		N, E		Crack propagation localized corrosion
[94]	2008	Ramadan et al.	Steel	NaCl+NaOH sol.	A, N, D		Hits	PCA Wavelet	Crack activation Crack propagation localized corrosion
[111]	2008	Ramadan et al.	Steel	Cl ⁻ + SO ₄ ²⁻ + SCN ⁻ + KOH sol.	A, N, R	FFT	Hits		Crack activation Crack propagation

Table 2. Cont.

Ref	Year	Authors	Material	Environment	Waveform Features			Multivariate Analysis	Discriminated Mechanisms
					Direct	Indirect	Cumulative		
[112]	2008	Fregonese et al.	Zircaloy-4	iodine methanol sol.	A		Hits	Wavelet	Crack activation Crack propagation passive film breakdown
[113]	2008	Perrin et al.	Steel	NH ₄ SCN sol.	A, D, N		Hits, E		Hydrogen evolution Crack activation Crack propagation
[114]	2009	Shiwa et al.	304 SS	25 wt.% MgCl ₂ sol.	A		Hits		Crack propagation Crack propagation
[115]	2009	Van Dijck et al.	Steel				E		Uniform Pitting
[116]	2010	Rozhonov et al.	Zircaloy-4	iodine methanol sol.	A		E		Crack propagation
[117]	2010	Rozhonov et al.	Zircaloy-4	iodine methanol sol.			E	Wavelet	
[118]	2010	Ito et al.	304 SS	MgCl ₂ sol	A				
[119]	2010	Kovac et al.	304 SS	Na ₂ S ₂ O ₃ sol.	A	FFT	Hits		localized corrosion Crack activation Crack propagation localized corrosion
[120]	2010	Du et al.	304 SS	NaCl + H ₂ SO ₄ sol.	N	FFT			Uniform Crack propagation passive film breakdown metal layer peeling
[121]	2010	Perrin et al.	steel	NH ₄ SCN sol.	Hits, A, E, D, N	FFT			Hydrogen evolution Crack activation Crack propagation Quiescence
[122]	2010	Inoue et al.	410, 410S SS		A				Hydrogen embrittlement passive film breakdown Crack propagation
[61]	2010	Smanio et al.	X65 SS	NaCl + CH ₃ COONa+H ₂ S sol.	E, D	AVG	E		Hydrogen embrittlement Hydrogen evolution Corrosion products Crack propagation
[123]	2011	Shiwa et al.	304 SS	25 wt.% MgCl ₂ sol.	A	FFT	Hits, N		Hydrogen embrittlement Pitting Snake-like corrosion Crack activation Crack propagation

Table 2. Cont.

Ref	Year	Authors	Material	Environment	Waveform Features			Multivariate Analysis	Discriminated Mechanisms
					Direct	Indirect	Cumulative		
[83]	2011	Du et al.	304 SS	NaCl + H ₂ SO ₄ sol.	N		N	k-means	Hydrogen evolution Pitting Corrosion products Crack propagation
[124]	2011	Van Dijck et al.	Steel		A			Wavelet	Uniform Pitting Crack propagation
[125]	2011	Leinonen et al.	304 SS	NaCl + CaCl ₂ sol.	A, R, D		E, N		Crevice Crack initiation Crack propagation
[46]	2012	Xu et al.	304 SS	H ₃ BO ₃ LiOH sol.	A, R, D	b value	Hits, N		Crevice Crack initiation Crack propagation
[126]	2012	Kovac et al.	304 SS	Na ₂ S ₂ O ₃ sol.	A	FFT	hits		Plastic deformation Short range crack propagation Long range crack propagation
[127]	2012	Li et al.	304 SS	NaCl + H ₂ SO ₄ sol.	N		N	Wavelet, k-means	Hydrogen evolution Pitting Crack activation
[48]	2012	Alvarez et al.	Ag–10Au	KCl sol.	A, R	b value			Crack propagation Crack propagation Crevice
[44]	2013	Xu et al.	304 SS	KSCN + H ₂ SO ₄ sol.	A, D		hits		Crack initiation Crack propagation Plastic deformation
[76]	2013	Djeddi et al.	steel	NH ₄ SCN sol.	A, E, R, N, D	FFT	N		passive film breakdown hydrogen evolution metal dissolution hydrogen embrittlement
[81]	2013	Yonezu et al.	304 SS	K ₂ S ₄ O ₆ sol.	E		N		Crack propagation Metal dissolution Hydrogen evolution
[128]	2013	Mao et al.	304 SS	Na ₂ S ₂ O ₃ sol.	Hits, A		hits	wavelet	falling-off grains crack propagation Metal dissolution plastic deformation crack propagation

Table 2. Cont.

Ref	Year	Authors	Material	Environment	Waveform Features			Multivariate Analysis	Discriminated Mechanisms
					Direct	Indirect	Cumulative		
[129]	2014	Shiwa et al.	304 SS	25 wt.% MgCl ₂ sol.	Hits, A	AVG		PCA SOM	crack propagation
[130]	2014	Filippov et al.	04Kh20N6G11M2AFB 09Kh20N6G11M2AFB	3.5% NaCl sol.	hits				
[72]	2014	Calabrese et al.	steel	Chloride sol.	A, R	AVG, RA	N		Metal dissolution passive film breakdown quiescence crack propagation Metal dissolution passive film breakdown quiescence
[82]	2015	Calabrese et al.	17-4 PH SS	30 wt.% MgCl ₂ sol.	A, D, E, R, N	AVG, RA	E	PCA SOM	crack activation short range crack propagation long range crack propagation short range crack propagation long range crack propagation Metal dissolution Hydrogen evolution passive film breakdown quiescence
[131]	2015	Kovac et al.	304 SS	Na ₂ S ₂ O ₃ sol.	E	PSD			crack activation tensile crack propagation shear crack propagation Crack activation Crack propagation Crack coalescence Metal dissolution Hydrogen evolution passive film breakdown
[71]	2015	Calabrese et al.	17-4 PH SS	30 wt.% MgCl ₂ sol.	A, D	AVG, RA			Crack activation Crack propagation Crack coalescence Metal dissolution Hydrogen evolution passive film breakdown
[132]	2015	Matsuo et al.	304 SS		A, D	FFT	hits		Crack activation Crack propagation Crack coalescence Metal dissolution Hydrogen evolution passive film breakdown
[62]	2015	Hwang et al.	304 SS	Na ₂ S + NaOH	A, R, E		CNT		Crack activation Crack propagation Plastic deformation

Table 2. Cont.

Ref	Year	Authors	Material	Environment	Waveform Features			Multivariate Analysis	Discriminated Mechanisms
					Direct	Indirect	Cumulative		
[42]	2016	Calabrese et al.	X12Cr13	NaCl + CH ₃ COOH + Na ₂ S ₂ O ₃ sol	A, D, E, R, N	AVG, RA CI	hits	PCA SOM	Metal dissolution Pit initiation Pit growth Hydrogen evolution Crack opening Crack propagation Metal dissolution Pit initiation Pit growth
[133]	2016	Delaunois et al.	304L SS	3% NaCl sol.	A, R, N	AVG, FFT	hits		passive film breakdown crack initiation crack propagation Uniform
[64]	2017	Calabrese et al.	17-4PH X4CrNiMo16-5-1 X12Cr13	10 wt.% FeCl ₃ sol.	A, E, R, D	AVG, RA CI			Pitting Crevice Crack initiation Crack propagation Metal dissolution Corrosion products
[35]	2017	Calabrese et al.	X12Cr13	NaCl + CH ₃ COOH + Na ₂ S ₂ O ₃ sol	A, R	AVG, RA b value Ib value	hits		Pitting/crevice quiescence Crack initiation Crack propagation Hydrogen evolution
[134]	2017	Li et al.	steel	5% NaCl sol.	Hits, N, E, R, D	AVG			Pitting Crack activation Crack propagation
[135]	2017	Li et al.	316LN SS						Crack propagation
[136]	2018	Kang et al.	304 SS	Na ₂ SO ₄ + NaOH sol.	A, E, R,		N		Crack activation Crack propagation Pit/crack nucleation Hydrogen evolution Corrosion products
[89]	2018	Calabrese et al.	X12Cr13	NaCl + CH ₃ COOH + Na ₂ S ₂ O ₃ sol	E, R	AVG CI	E		Crevice Oxide scale cracking Micro-crack activation Crack propagation

Table 2. Cont.

Ref	Year	Authors	Material	Environment	Waveform Features			Multivariate Analysis	Discriminated Mechanisms
					Direct	Indirect	Cumulative		
[39]	2019	Wu et al.	SUS420J2 SS	NaCl sol.	A		hits	k-means	Pitting Crack activation Slow Crack propagation Rapid Crack propagation Plastic deformation Hydrogen embrittlement
[137]	2019	Martelo et al.	Ni-alloy 625+	H ₂ SO ₄ sol	A, N, E, D		N		Elastic regime Plastic regime
[138]	2019	Zhang et al.	304 SS	A, R, D, N, E			hits	RQA k-means	Crack activation Crack propagation Hydrogen evolution Localized corrosion
[139]	2019	Wu et al.	SUS420J2 SS	1 wt.% NaCl sol.	A	AVG	hits		Slow Crack propagation Rapid Crack propagation Plastic deformation Hydrogen evolution
[140]	2019	Zhang et al.	304 SS		A, R, N, D	AVG	hits		Crack activation Crack propagation Plastic deformation Metal dissolution
[141]	2020	Calabrese et al.	17-4 PH SS	30 wt.% MgCl ₂ sol.		AVG, RA	E	SOM	passive film breakdown Pitting Crack activation Crack propagation
[80]	2020	Bi et al.	steel	3% NaCl sol. (ph 2)	A, R, D, N, E		N, E	Wavelet	Pitting Micro-Crack activation Micro-Crack propagation Macro-Crack propagation

The table has been structured to highlight for each specific proposed test set up (metallic alloy and environmental conditions applied in the stress corrosion test have been indicated) the analysis approaches used for AE data post-processing. This aspect was, indeed, already raised in literature (e.g., [142]) however, in the analyzed papers, when indicated, wide bandwidth (ranging from 100 kHz up to 1 MHz) AE sensors are generally adopted, thus limiting its discriminating contribute.

In particular, the waveform features were discriminated in the three main distinct classes: direct, indirect and cumulative. At the same time, evidence of multivariate approaches has been highlighted.

The table shows how the evolution of this NDT technique has been strongly stimulated by technological innovations in the IT sector. In particular, thanks to increasingly powerful data analysis systems, AE post-processing techniques have progressively evolved from direct waveform feature investigations towards increasingly complex analysis frequency domain and multivariate techniques (in some case by means also of neural network analysis) able to allow simultaneously the interaction of several variables.

In such a context, in 05'–06' Yonezu et al. [84,103] discussed SCC results on butt-welded 304 stainless steel pipes in a concentrated magnesium chloride solution by using the coupled action of univariate and multivariate technique. In particular, wavelet spectral analysis allowed to discriminate with suitable results different types of AE signals. Indeed, comparing the information summarized in Table 2, the wavelet technique is the most common post-processing choice to discriminate AE events. In fact, this investigation strategy was proposed also [94,115,118,124,128,135] in order to assess competing SCC phenomena evolving from metal dissolution and pitting toward crack activation and propagation up to plastic deformation and sample fracture.

Given the versatility of these mechanisms, an important need to better assess the different mechanisms that take place is to discriminate the AE event cluster related to a specific damage. An approach based on the analysis of direct variables, developed effectively up to date, allows to provide relevant information on the damage status of the structure. Furthermore, integrated with additional information, often metallography, it can provide a valid tool for identifying specific features related to crack initiation and propagation mechanisms.

However, a structured study with the integration of univariate and multivariate approaches proved to be more effective in defining much larger damage clusters, also allowing to better define the representative features of the recognized damage mechanisms. In particular, Calabrese et al. [71] integrating univariate, principal component analysis (PCA) and self organizing map (SOM) neural network were able to discriminate several evolving damage stages, such as hydrogen bubble evolution (due to cathodic reaction related to metal dissolution) or passive film breakdown up to mechanical fracture mechanisms, such as crack activation and propagation. On this concern a discrimination of tensile and shear crack was furthermore addressed. A similar strategy was proposed by the same research group in [64,72] in different stainless-steel alloys.

Analogously, Wu et al. [39] assessed the SCC evolution in aSUS420J2 stainless steel alloy exposed to chloride droplet corrosion. Coupling in-situ optical microscopy and AE analysis a main dominant crack evolution was observed highlighting a transition from a slow crack initiation (this path activation phenomenon was configured as corrosion-dominant cracking) to a rapid crack propagation (related to hydrogen-assisted cracking).

A cluster analysis of the AE features coupling conventional, waveform parameters, FFT frequency components was performed by using a multivariate statistical approach (k-means algorithm) allowing to better discriminate initiation and propagation stages of the SCC damage.

Recently, Bi et al. [80] has further validated the relevance of integrated different AE data analysis methods to better study the SCC damage phenomenon. In their paper, AE direct and cumulative features were analyzed, sharing this information with the signal time-frequency local features, extracted by using wavelet algorithm. The results evidenced

a good relationship between corrosion damage evolution and sensitive variation of the AE events and activity. Micro-crack activation and macro-crack propagation were discriminated by coupling the waveform features and frequency spectrum of the AE events.

The continuous research evolution in this field, considering the acquired relevant and promising results, may be useful for a targeted diagnosis of the corrosion-induced damage severity and the recognition of corrosion sources through the AE online inspection and monitoring. This will help, in an increasingly tangible way, the identification of damage risks in structures associated with SCC and it will further provide an assessment of its structural integrity.

5. Conclusions and Future Trends

More than 50 years passed from the first application of AE technology to studying material transformation, degradation and corrosion. During these years technology and computational capacity had an incredible growth giving to researchers sophisticated, highly sensitive equipment supported by powerful software. Several analytical tools, post processing algorithms and data mining practices has been developed particularly in specific application fields (e.g., concrete structure testing, material testing, etc.). Nevertheless, the evaluation by AE monitoring of the complex mechanisms acting during SCC is still far from a clear, well accepted interpretation.

Literature results are still controversial, the approaches used by the different authors are frequently unlike and difficult to compare and match. However, it is well accepted that the main mechanisms responsible for the AE activities are pitting initiation, crack initiation and propagation, also on other secondary mechanisms there is an almost unanimous concordance such as hydrogen evolution (mainly bubble friction on crack walls) and fracturing and detachment of debris and corrosion products on metal surface. On the other hand, very questionable are some linking of AE activity to electrochemical process acting on metal surface such as metal dissolution or cathodic reactions (excluding of course the mechanical noise generated by bubble evolution).

The use of analytical tools such as wavelet or Hilbert Huang transformations coupled to the highly increased informatics storage capability allow detailed spectral analysis, in order to evaluate large multivariate population data leading to specific AE parameter clustering, not possible before. This promising perspective triggers innovative research scenarios aimed at stimulating new interpretative approaches to better discriminate acoustic events and to correlate them with the damage mechanisms that take place during the SCC phenomenon.

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