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A Review on Application of Acoustic Emission Analysis in Friction Stir Welding

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ABSTRACT

Acoustic emission technique is a fruitful technique in process and machine condition monitoring due to its good sensitivity in great affectability signal domain. Friction stir welding (FSW) is a solid-state welding process that is ideally suitable for joining materials with low melting point, such as aluminium alloys, which could be well assessed by this technique. This paper exhibits a brief review of contemporary literature on application of acoustic emission technique in the analysis of friction stir welding process. It was observed from the literature that the various acoustic emission parameters were well influenced by this process. Commonly used AE signal analysis methods are addressed. There is a scope for enhanced study of the process using the AE signals, which will lead to the development of intelligent adaptive real time control system to get defect free high strength weld in all varying process conditions.

KEYWORDS: Acoustic emission, Friction stir weld, AE sensor, weld strength, Condition monitoring.

1. INTRODUCTION

Acoustic emission (AE) is a phenomenon arising from a rapid release of strain energy within a material. Acoustic emissions are transient elastic waves inside a material created by the release of restricted stress energy. The part of the energy radiates from the source in the form of elastic waves, which can be detected at the material surface (Heiple and Carpenter, 1987). The major sources of acoustic emission can be mechanical, thermal, and metallurgical processes acting upon the material (ASTM 1972; Deutche, 1978). AE can likewise come about because of the start and development of splits, slip and separation developments, twinning, or stage changes in metals. Acoustic Emission is an exceptionally adaptable, non-obtrusive approach to gather data concerning material research, for example, examination of material properties, breakdown components and harm conduct. The use of acoustic emanation procedures is broadly acknowledged in an assortment of modern fields to screen their procedures. The utilization of acoustic emanation methods is generally acknowledged in an assortment of mechanical fields to screen their procedures. AE offers the vital preferred standpoint of enhanced affectability over customary checking instruments, for example, vibration and clamor investigation for the early recognition and forecast of material disappointments. AE is transient versatile waves discharged by restricted sources inside a material as it experiences twisting. It is a to a great degree delicate system for watching the procedures including plastic disfigurement, for example, friction blend welding and split proliferation in structures and machine components. AE includes a sensor, which changes over non-capable of being heard versatile waves from the misshaping structure/component into electrical yield to a quantifiable variable. The run of the mill sensor for this emanation is a piezo electric transducer mounted adjacent the AE zone. The recurrence of structure-borne discharge is normally from 50 kHz to 200 kHz.

AE Sensor: In acoustic outflow checking method, the high recurrence versatile waves are identified and changed over to electrical signs by specifically coupling piezoelectric transducers on the surface of material structure under test. The affectability of piezo-electric sensors can achieve estimations of up to 1000 V/mm. Figure.1, demonstrates the interior parts and photographic perspective of a run of the mill AE sensor.

Figure.1. AE sensor

Acoustic outflow sensor, with proper recurrence reach is chosen and mounted on base of the structure with a couplant liquid. The sensor has a clay base, which keeps the impact of warmth from the base plate, where the sensor is mounted. The couplant is utilized between the AE sensor and base plate surface for a compelling identification of the signs. Table 1 shows the regular AE sensor details, which can be utilized for FSW process.

Table.1. Typical AE sensor specification

Description	Range of values
AE Sensor Model	General purpose R80D
Dimensions (Diameter x Height) in mm	18 x 17
Weight (gm)	8
Operating Temperature (°C)	- 65 to 177
Shock limit (g)	10000
Case material	SS304 Stainless steel
Face material	Ceramic
Connector type	Dual BNC
Peak sensitivity dB ref. 1V/(m/sec)	58 [-62]
Operating frequency range (kHz)	200-1000
Grounding	B
Seal type	Epoxy

AE Measurement System: Acoustic wave created by AE source is caught in a controlled way to study and utilized as a part of examination, quality control, framework input and process checking. AE sensors are connected by method for a couplant and secured with tape, glue bonds or attractive grasps (Dornfeld, 1999). The AE sensors contain preamplifier and the enhanced AE sign is transmitted to the AE framework through a sign link. The force supply for the pre-intensifiers is nourished through the sign link from the information procurement framework. Figure.2, demonstrates the piece outline of a run of the mill AE estimation framework.

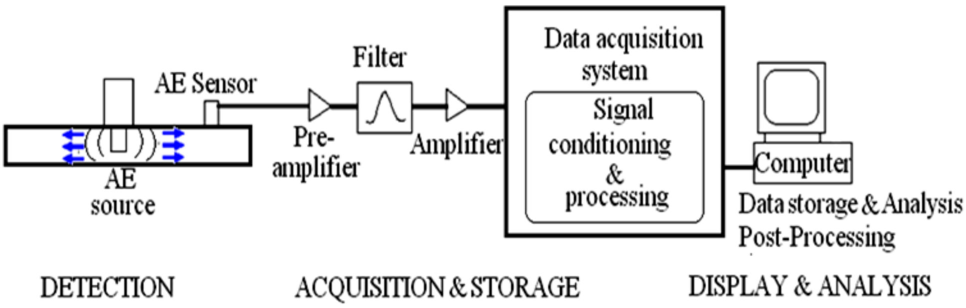


Figure.2. AE measurement system

The yield sign of a piezoelectric AE sensor are further intensified through a low-clamor intensifier, incidental commotion are separated and encourage prepared by reasonable electronic instrumentation, which gives the measure of AE sign parameters with time.

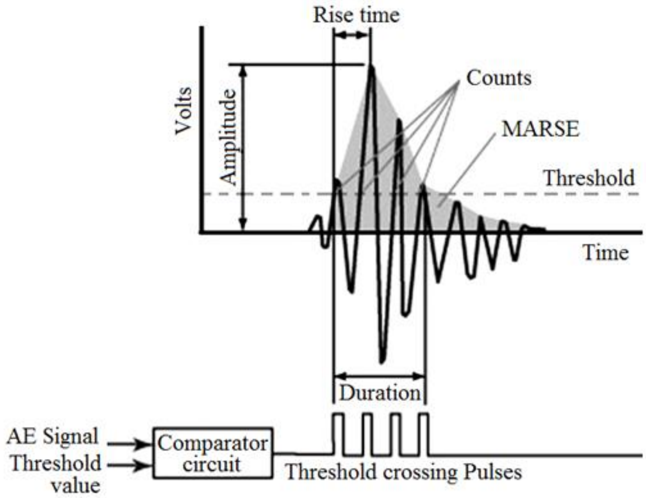


Figure.3. General features of a typical AE signal

Figure.3, delineates different AE signal parameters. At the point when a valuable AE sign is acquired, the sign parameters, for example, AE hits, sufficiency, normal checks, normal recurrence, vitality, Measured Area under the Rectified Signal Envelope (MARSE) and rise time can be figured utilizing time space and recurrence area investigation. These sign parameters gives important data about the beginning and ramifications of an intermittence in a material.

AE Acquisition in FSW Process: Acoustic Emission estimation method has been connected for studies on assembling procedures and AE information have been connected with the state of machining operations. The Friction blend welding a non-customary welding process as a rule did in machine instruments. In material preparing, AE comes about primarily from the plastic mechanical procedures of metal development and surface erosion. In FSW, both material development and surface contact created by the pivoting instrument impacts the AE signal parameters. It is additionally generally utilized in-procedure observing and control of welding procedures (Gu and Duley, 1996). Figure.4, demonstrates the course of action of AE information securing setup and AE sensor, which is mounted in the base plate of FSW installation. A voltage pre-speaker is utilized for opening up the AE signal. The AE information procurement card (18 bit ADC, 40 M Samples/sec) is appended to PCI opening of a desktop PC and controlled utilizing DAQ programming. A limit estimation of 40 dB is altered to sift through the commotion. The AE signs are gained for the run of the mill procedure conditions and put away utilizing DAQ programming.

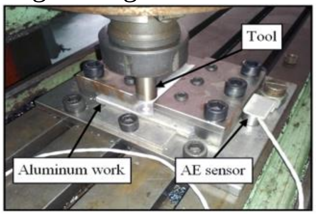


Figure.4. AE sensor and FSW fixture (Senthilkumar, 2013)

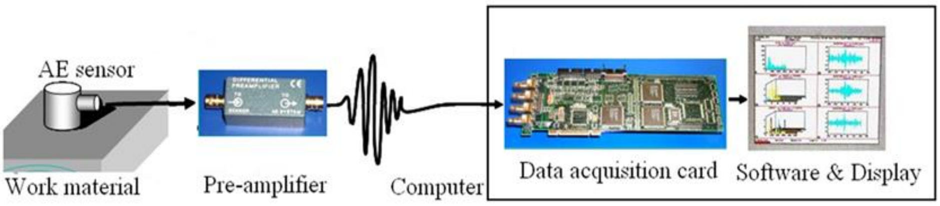


Figure.5. AE data acquisition system hardware components

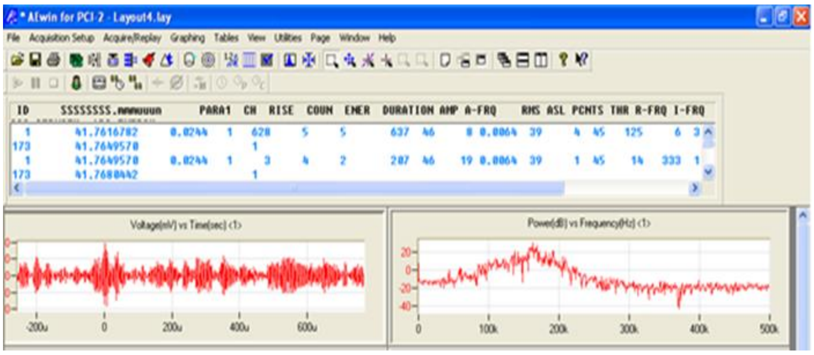
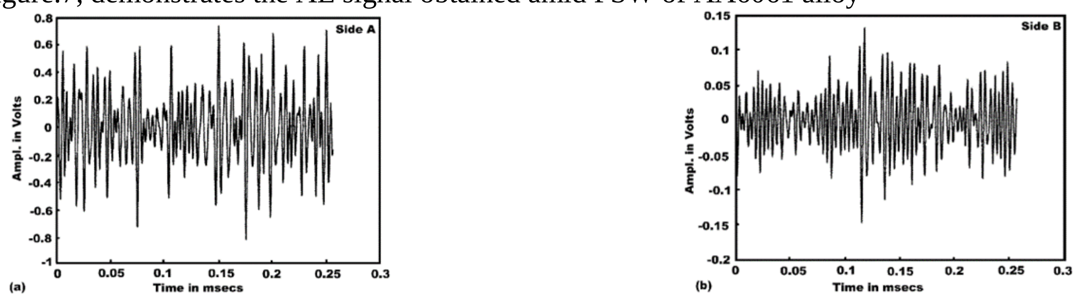


Figure.6. Screen layout AEWin software (Senthilkumar and Denis Ashok , 2014)

Figure.5, and Figure.6, show the snapshot of AEwin DAQ software layout during the AE data acquisition. The time domain and frequency domain signals are captured during each trial of the FSW experiments and recorded using the data acquisition system. The various AE parameters, such as total hits, average counts, energy, average frequency and duration are extracted from the acquired signals using AE data acquisition software and tabulated for subsequent data analysis.

Studies on Application of Acoustic Emission in FSW: Friction stir welding is a strong state welding process. It utilizes the frictional warmth created at the rubbing surfaces to raise the temperature at the interface. It is sufficiently high to bring about the two surfaces to be fashioned together under high weight, which produces AE amid the procedure. The significant worry in utilizing rubbing welding is the dependability of the weld quality. Acoustic emanation is the wonder by which transient flexible waves are produced by quick arrival of vitality from confined sources inside a distorting material. Acoustic outflow observing method has been utilized broadly to examine different distortion and welding forms in various materials (Raj and Jayakumar, 1990; Raj, 1998).

Feasibility Studies: The components of a normal AE signs are number of hits, rise time, abundancy, checks, span and recurrence. Aggregate AE checks were quantitatively associated with the joint quality of welds amid welding process (Sae-Kyoo, 1982). Ouyang and Kovacevic (2002) examined the material stream and microstructure in the rubbing mix butt welds of the same and unique aluminum composites with procured AE signal on both sides of weldline. Figure.7, demonstrates the AE signal obtained amid FSW of AA6061 alloy



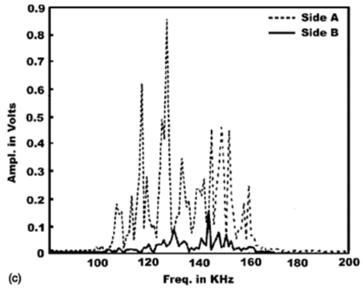


Figure.7. AE recorded at both sides of the weld of 6061-Al alloy (a) AE signals at Advancing side; (b) AE signals at retreating side; (c) Processed AE signals. (Ouyang and Kovacevic, 2002))

Chen (2003), explored the likelihood of using AE method for the in-procedure checking of FSW procedure. AA6061Aluminium composite plates were butt-welded utilizing a fast pivoting instrument navigating similarly separated indents adjusted along the joint line of the plates. The wavelet change (WT) was utilized to break down the AE signal into various discrete arrangement of successions over different recurrence groups. It was accounted for that there are extensive sudden changes in the band vitality when the apparatus reaches the plates. The band vitality variety amid the instrument navigate over the deserted district mirrors the area and size of the weld surrenders. A 3D representation of band vitality with time gave commendable data on weld deserts amid grating mix welding. A shape map representation was utilized for checking the transient welding state and provoke distinguishing proof of hole deformities. FSW prepare by and large delivers flags that speak to blast acoustic discharges, which describes the shaky procedures (Soundararajan, 2006). The AE burst is fundamentally ascribed to plastic distortion of the material. It was found that a connection exits between the aggregate number of AE tallies and the quality of rubbing welds. The test concentrates on uncovered that the recurrence range considered for the grating mix welding procedure is between 100 kHz and 300 kHz. The schematic chart for information obtaining and the molding circuit is appeared in Figure 8.

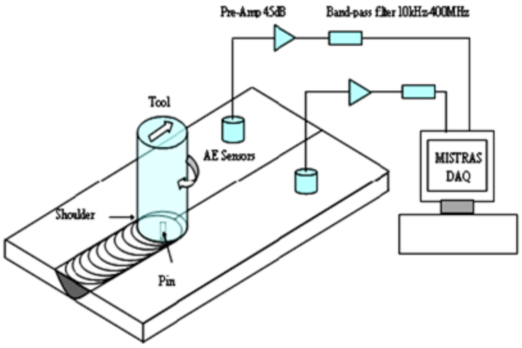


Figure.8. AE signal acquisition and pre-processing in FSW (Soundararajan, 2006)

Herbelot (2013), assesed the harm systems under strain shear stacking in grating mix spot welding utilizing AE estimation information. AE procedure is observed to be a doable methodology for identifying apparatus profile, material stream design, microstructures, and mechanical properties in FSW process (Suresha, 2011).

Welding Process Monitoring using AE: Yoon (2006), have considered the relationship between the elasticity of weld joint and weld parameters utilizing AE method. A strategy was produced to perform in-procedure continuous weld quality assessment utilizing acoustic outflow for disparate contact welding of atomic reactor segments. Figure 9 demonstrates the AE aggregate check varieties with elasticity. It was affirmed tentatively that ongoing quality assessment of a weld was conceivable by acoustic emanation (AE) procedure. It implies this can prompt the improvement of an in-procedure ongoing quality observing (assessment) framework taking into account the quantity of acoustic emanation occasions.

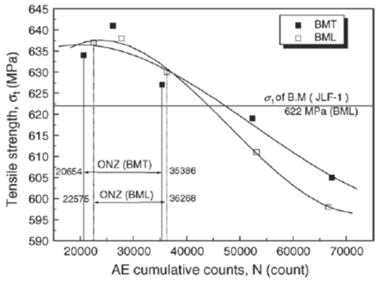


Figure.9. AE cumulative count and tensile strength

Chen (2003), have worked with cutting edge signal handling procedures for observing the FSW procedure utilizing the acoustic emanation signals. Acoustic outflow signs are distinguished and broke down to research the achievability of applying the AE strategy for the in-procedure checking of FSW procedure. The AE sign was deteriorated into different discrete arrangement of groupings over various recurrence groups utilizing wavelet change method and components were separated for recognition of FSW device breakage. Zeng (2006), explored different avenues regarding diverse exhausted apparatuses to weld 6061 aluminum compound utilizing FSW process. The acoustic discharge detecting, metallographic segmenting and pliable testing were utilized to break down the procedure. The relationship between structure of the weld chunk and apparatus wear was investigated. Minton and Mynors (2006), watched the AE of machine devices to screen apparatus diving power and the shaft engine load condition amid FSW tests. Soundararajan (2006), explored the likelihood of applying the AE method for internet checking of the rubbing mix welding process and dissected the AE signals. FSW trials were completed for joining comparative and unique metals utilizing a rapid pivoting apparatus under different procedure parameters. The aftereffects of Fast Fourier Transform (FFT) demonstrated the plentifulness of the AE signal in the recurrence space is delicate to the instrument entrance profundity. Discrete wavelet change demonstrated the adjustments in the decayed sign in the lower recurrence ranges amid the apparatus shoulder contact with workpieces. The recognizable proof of AE frequencies amid the procedure and examination of the disintegrated wavelet signals in different recurrence groups makes it conceivable to screen the procedure changes viably. Suresha (2009), inspected the use of AE strategy to break down the FSW procedure. The Figure 8 demonstrates the AE signal parameters, for example, Amplitude, RMS, Counts and Energy. Abundancy (An) is the most astounding top voltage accomplished by an AE waveform. Root Mean Square (RMS) is the redressed, time found the middle value of AE sign (voltage) measured persistently on a straight scale into the AE framework. Tallies (N) are the limit crossing beats. Vitality (E) is the deliberate range under the redressed signal envelope. Edge estimations of AE signs were removed along great and imperfection weld areas. A model was created to screen FSW handle and survey the weld quality on-line. Figure 10 demonstrates the run of the mill AE parameters with edge esteem. Figure.11, demonstrates the procured AE paramerters information.

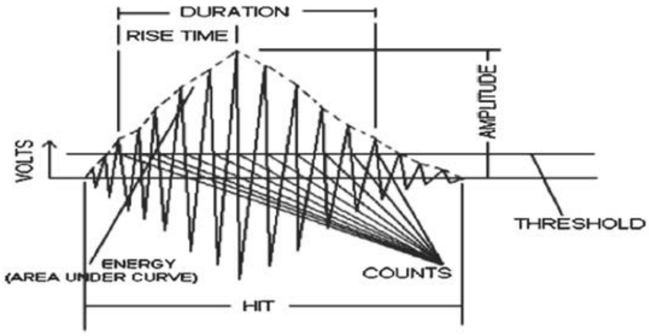


Figure.10. AE parameters (Suresha, 2009)

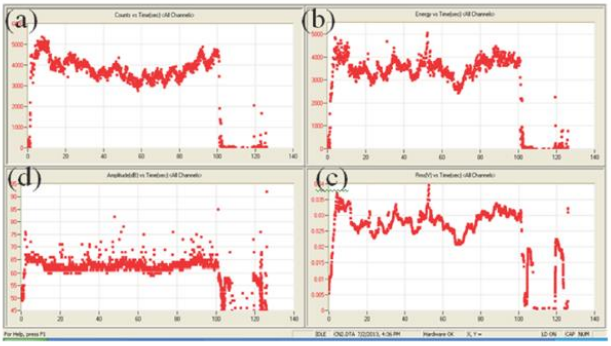


Figure.11. AE Signal data (a) Counts (b) Energy (c) RMS (d) Amplitude (Suresha, 2009)

Kong (2011), explored the mechanical properties of erosion welded joints of 15 mm distance across strong bars of Mg amalgam. AE system was connected to acquire the ideal condition for contact welding. The AE check and vitality parameters were valuable for assessing the rigidity.

Kong (2013), conceived a strategy for online expectation of elasticity by utilizing the acoustic discharge signals as a part of grating welding process. Taguchi's technique was utilized at trial and examination results to confirm the impact of procedure parameters on the rigidity of friction welding welded joints. From the deliberate acoustic emanation signals amid the rubbing welding of Al6061 aluminum compound material, were utilized to characterize root mean square and change of signs. The elasticity expectation model was produced with these dimensionless coefficient and online forecast on rigidity of grating welded joints was led. The elasticity online expectation by utilizing acoustic outflow signs was seen as a helpful and exact technique for contact welded joints of the Al6061 aluminum combination material.

The helpful data from of the acoustic discharge signs were acquired by Root Mean Square (RMS). The square of the RMS in the acoustic outflow signs was utilized as a critical sign parameter in a friction welding welding process, which is characterized in Equation 1.

$$RMS = \sqrt{\frac{1}{T}\int_0^T T(t)^2 dt}$$ ……….……. Eq. (1)

$$\frac{dE}{dt} \propto RMS^2$$ ……………….. …..Eq. (2)

Where,
T is measuring time and

V(t) is magnitude of the signals measured at a time t.
E is Acoustic Emission Energy

RMS in the acoustic outflow signs is straightly relative to a vitality (E) variety created in the process amid certain time interim, characterized in Equation.2, (He, 2009). The elasticity estimation of the friction welding welded joints was evaluated through the investigation of the acoustic discharge signals measured amid the fiction welding process. Another sign parameter with dimensionless coefficient (φAE) of the acoustic emanation signs is characterized by the Equation 3 as:

$$\phi_{AE} = \frac{\frac{1}{m}\sum_{j=1}^{m}(RMS^2)_j}{\frac{1}{n}\sum_{i=1}^{n}(\bar{V}-V_i)^2} \quad \text{……………………… (3)}$$

where, Vi is a variance of the acoustic emission signals (He, 2009)

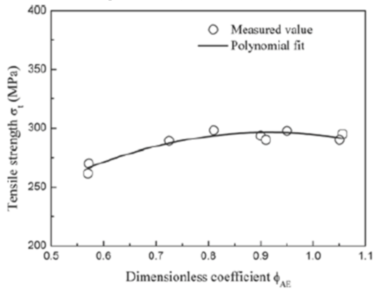


Figure.12. Dimensionless coefficient (φ_{AE}) vs Tensile strength (He, 2009)

The φAE acquired from the acoustic outflow signals delineates the variety of rigidity of joint created amid the rubbing welding process as appeared in Figure 12. The use of cutting edge signal preparing techniques, for example, Kurtosis and Spectral Kurtosis were utilized for checking dynamic frameworks like AE marks. It was observed to be compelling in de-noising procured signals. Acoustic Emission ended up being a potential instrument to distinguish both blemished and non-inadequate conditions amid a procedure (Sutowski, 2012). Rajaprakash, (2013) endeavored the use of AE to screen FSW procedure to create deformity free welds and concentrated on the conduct of AE information amid FSW of comparative and disparate materials. Allen Jose (2013), concentrated on the acoustic outflow signals obtained amid FSW tries different things with aluminum 7075 combination joined by a rapid pivoting device steel apparatus. Quick Fourier Transform Discrete Wavelet Transform and different systems were connected on the signs to recognize the surface imperfections. Jimenez (2013), endeavored portrayal of the contact blend welding procedure and demonstrating in light of neural systems and acoustic discharge. Emilio (2014), broke down the connection between's the acoustic emanation signals and the parameters of rubbing mix welding process in light of simulated neural systems (ANNs). Measurable and fleeting parameters of bothered acoustic emanation signals utilizing Wavelet Transform were utilized as contribution of the ANN. The yields of the ANN model incorporate the parameters of hardware revolution speed and travel speed, instrument profile and elasticity. A multilayer sustain forward neural system has been chosen and prepared, utilizing Leven berg-Marquardt calculation for various system models. The model acquired can be utilized to build up a programmed control of FSW procedure parameters in light of the acoustic discharge signals.

AE Analysis in Material Testing: Oh, (2000) directed a test study to streamline the grating welding conditions for the different warmth opposing materials of turbine impeller and to examine the relationship between the weld nature of quality and strength and the aggregate number of acoustic emanation (AE) tallies. It was found that a relationship between's the aggregate number of AE tallies and the weld quality exist, and the weld quality can be distinguished progressively amid preparing by AE strategies.

Charunetratsamee (2013), connected AE procedure for observing metal discontinuities amid hot splitting. Shrama (2015), examined AE signals in mellow steel examples experiencing uniaxial weariness stacking and relate it to harm components. AE was observed in the tests, to permit both the recognition and area of signs, and Digital picture connection (DIC) pictures were caught intermittently to give an unmistakable delineation of the surface strain field advancement. Han (2011), researched the AE conduct amid weakness split engendering in the weld of steel. The impacts of split spread amid weariness on acoustic emanation were considered. It was watched that the acoustic outflow was more touchy to the adjustments in crack and could be utilized to screen the basic weariness harm. The relationship between the AE parameters and weariness split engendering was communicated by the Equation 4:

$dC/dN = B\Delta K^p$, or $\log (dC/dN) = \log B + p \log \Delta K$ ………………… Eq. (4)

Where,

dC/dN AE counts rate

ΔK Stress intensity factor range

B and p constants for material and test condition.

The equation has been well established in the steels and Al alloys. (Roberts and Talebzadeh, 2003; Chang, 2009; Yu, 2011)

AE signals created amid the weariness tests were recorded and examined by two broadband piezoelectric transducers with a band pass channel from 10 kHz to 2 MHz were utilized to get these AE signals. The sensors were appended to the example with a ring-formed magnet. Vaseline was utilized at the interface between the sensors and the example surface to acquire appropriate signs. A preamplifier with 40 dB pick up and a suited channel (10 kHz–2 MHz) were utilized to catch AE signals. A spurious example without a score was tried under the same stacking conditions and the AE vitality and normal recurrence edges were set to dispose of grating commotions. The straight AE source area was utilized to guarantee that the acquired signs were created from the split area. The AE numbers rates amid exhaustion split engendering for the weld were additionally higher than the base metal.

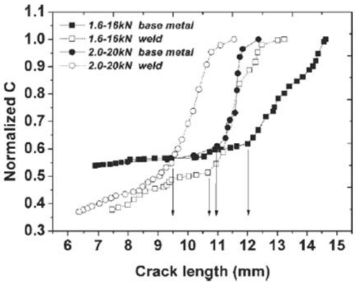


Figure.13. Crack length vs AE counts

Standardized AE checks versus split lengths for the base metal and weld under the crest burdens are appeared in Figure.13. Rajashekar and Rajaprakash (2016) built up the consolidated model utilizing picture information of weld districts and AE information to assess the weld quality. The model is utilized to relate surface composition of grating mix weld to interior structure of weld. It was watched that the weld quality got along the weld areas indicated comparable varieties in procured AE information amid welding.

2. CONCLUSION

Acoustic outflow system is one of the progressed nondestructive assessment devices, which have the potential application for constant procedure observing. From the accessible writing, AE system is observed to be a possible methodology for identifying material wear, stream design, microstructure varieties in FSW process. The FSW exploratory studies have shown that the AE detecting gives a possibly powerful strategy to on-line observing of FSW procedure. As it requires basic trial game plans, it can be effortlessly executed for observing the FSW procedure. The FSW device profile and process parameters are affecting the era of AE signs amid the procedure. The writing uncovers that among the different AE parameters, normal tallies and vitality are found to give better process data. With legitimate choice of AE transducers and different segments, an AE observing framework could be produced for distinguishing the nature of erosion welds. The writing demonstrates that different delicate registering systems, for example, FFT, Wavelet and RMS based measurable strategies were utilized to handle AE information, which are fundamental for comprehension and displaying the FSW procedure. The models were utilized for procedure improvement and distinguishing huge commitment of procedure parameters. The writing affirms that AE can be utilized as a part of conjunction with other wise assessment procedures to survey material quality. The fluffy rationale and neural system methodology is broadly received for observing complex and non-direct procedures, for example, FSW. The advances in deterministic and factual examination strategies empower AE information to be translated in subtle element to think about the procedure conduct. The AE mark of procedures is utilized as a supplementary indicative method for the investigation of element occasions, for example, imperfection development. This empowers advancement of observing framework for FSW process with controlled parameters to guarantee the nature of welded joints.

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