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STUDIES OF ACOUSTIC EMISSION SIGNATURES FOR QUALITY ASSURANCE OF SS 316L WELDED SAMPLES UNDER DYNAMIC LOAD CONDITIONS

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Abstract

Acoustic Emission (AE) signatures of various weld defects of stainless steel 316L nuclear grade weld material are investigated. The samples are fabricated by Tungsten Inert Gas (TIG) Welding Method have final dimension of 140 mm x 15 mm x 10 mm. AE signals from weld defects such as Pinhole, Porosity, Lack of Penetration, Lack of Side Fusion and Slag are recorded under dynamic load conditions by specially designed mechanical jig. AE features of the weld defects were attained using Linear Location Technique (LLT). The results from this study concluded that, stress release and structure deformation between the sections in welding area are load conditions major part of Acoustic Emission activity during loading.

Keywords: Acoustic emission, Tungsten inert gas, Welding method, Stainless steel 316L, Linear location Technique.

1. Introduction

Acoustic Emission (AE) is the study and practical use of elastic waves generated by a material subjected to an external stress or load conditions [1-6]. Kaiser, investigated the signals produced by samples undergoing tensile testing and discovered the Kaiser effect, i.e., no signals were generated by a sample upon the second loading until the previous maximum load was exceeded. According to ASTM, Acoustic Emission refers to the generation of transient elastic waves during the rapid release of energy from localized sources within a material [7]. The main function of an Acoustic Emission test is to identify flaw growth in a

Abbreviations

AE	Acoustic Emission
ASTM	American Society for Testing Material
LLT	Linear Location Technique
LOP	Lack of Penetration
LSF	Lack of Side Wall Fusion
MMA	Manual Metal Arc Welding
SS	Stainless Steel
TIG	Tungsten Inert Gas Welding

structure as it undergoes an increasing or continuing stress. Ideally, the test should locate the flaws and describe their growth rate as the stress level increases or the stress state continues in time. On simple structures, a single sensor based AE system can be enough to study the structure behaving under test conditions. However, complex structures will have many possible flaw locations but these will be analyzed with multiple sensors [8]. The multiple sensor techniques are employed for the analysis of large structures under load conditions to identify the defective regions by monitoring the acoustic emission signals. The basic idea in source location technique is to cover a surface with a network of sensors. If one can determine the arrival time of an emission signal at several sensors by knowing the acoustic velocity [9], it is possible to triangulate back to the location of the source of that emission. The Most Acoustic Emission mechanisms involve a permanent change in the micro structure of the material [10] due to the plastic deformation. When a micro fracture occurs once, it will not occur again unless there is some sort of healing mechanism.

2. Materials and Equipment

The experiments were carried out to study the effect of different weld defects response to acoustic emission events generated due to the dynamic loading conditions. The experimental set up was used with a specially designed Mechanical Jig system which comprises with a uniform dynamic loading on to the test specimens to activate the acoustic emission in the weld sample [11]. The weld samples of SS 316L are fabricated of 10 mm thick plates joined with TIG welding and Manual Metal Arc weld (MMA) processes with different weld defects induced within the welds. The weld defects like lack of fusion, lack of side wall fusions, porosity and slag inclusions are introduced into the welds by performing the deliberate faulty weld technique to generate the weld defects in the samples. The porosity inclusions were employed while filler pass is made without cleaning and keeping carbon ashes on the filling portions of welds. No defect samples were fabricated with actual preparatory weld procedure. All these samples are used for the AE studies to be conducted. The details are given in the Table 1 of the prepared samples and identified defects. The final welded plates after joining have dimensions of 300 mm × 140 mm × 10 mm.

The samples characterized for the weld defects are shown in Fig. 1. The weld samples were subjected to visual, ultrasonic and X-ray radiographic examinations in details before subjected to the Acoustic Emission tests. The defect location and magnitude were well established by these conventional non-destructive test methods. It is necessary to apply external loading on these samples, in order to make the defects active and generate Acoustic Emission (AE) signals during AE characterization process. The generated AE signals are monitored with the help of two transducers by "Linear Localization" mode technique [12] for locating the defects.

Table 1. Materials and procedure used for samples development.

Plate material	SS316 L
Weld Plate dimensions (final)	300 mm × 140 mm ×10 mm
Main welding method used	TIG (Welding-current ~ 110 to 130 Amperes)
Other welding methods used (For creating porosity and slag defects)	manual metal arc (MMA) Weld welding-current use 200 Amperes)
Type of weld defects included	Lack of fusion, lack of side wall fusion, pin hole defects, porosity, slag
Acoustic emission set-up	2 channel system withsensors Frequency range : 100 kHz

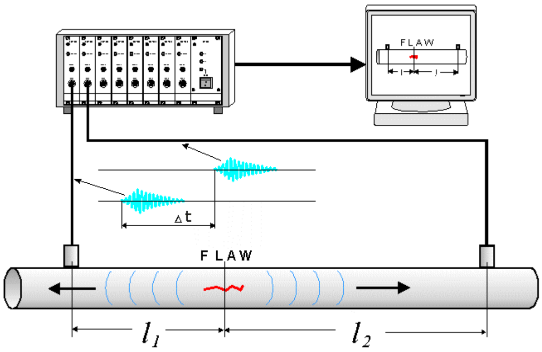


Fig. 1. Setup for linear localization of AE from a flaw.

2.1. Details of mechanical jig system

This special mechanical jig (shown in Fig. 2) is designed for experiments with incremental loading and to minimize the external noise. Acoustic emission measurements are highly sensitive to the noise and it is difficult to differentiate the signals generated from the actual events. This jig system has provision for placement of the samples on an anvil at the lower side and in the centre. This anvil has two vertical supports with rounded tops on which the sample can be placed and loaded to obtain local deformations. The mandrel attached to a screw loading system can be lowered on to the anvil for subjecting to uniform mechanical load on the test samples. The weld samples are placed on the anvil in a flat position and the mandrel is lowered slowly by rotating the lever attached to the screw, thus loading the samples. As shown in Fig. 3, the specimens bent to less than 45^0 between their two legs change in external pressure or load and trigger the release of energy in form of AE events due to the plastic deformation sources [13]. If any weld defects exist, they start releasing stress energy in the form of cracks / openings from defect zones during the stress load conditions. In the present case of the mechanical jig, if bending of sample beyond 45^0 is done, the defects propagation can be indicated and measured in the form of acoustic emission signals. Hence this angle is sufficient to check the crack/openings initiation and propagation effects if at all exist in the weld samples. The jig designed to incorporate the calibration of the load and experimental unit as per desired.

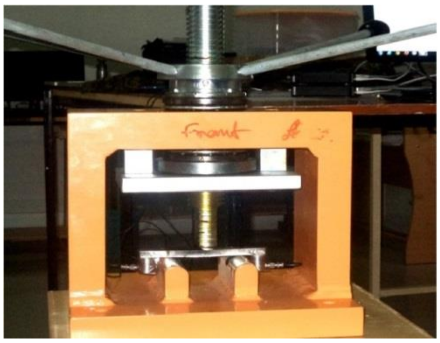


Fig. 2. Sensors attached with sample.

Fig. 3. Condition of sample after bending.

2.2. Acoustic Emission System

The dimensions of the sample are shown in Fig. 4. Two broad band Acoustic sensors were placed on either side of the sample or Acoustic Emission data was collected while slowly loading the samples. Linear Location Technique programme was used while collecting the data. Suitable filters were put to avoid unwanted noise from various sources. AE signatures are recorded in terms of Energy, Count, and Amplitude. The test experiments were carried out with five sets of similar samples from each of the weld category for the repeated examination of the data analysis. Even after conducting the test on defects for several times Plastic deformation of the strain often takes longer durations. Some of the deformation is immediate but some of it is delayed as observed in earlier reports [14, 15].

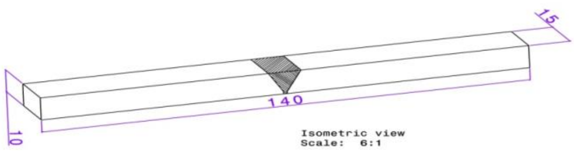


Fig. 4. Schematic diagram of sample dimensions and weld region.

2.3. AE Hardware and Software

The USB-AE Node System is a true high performance, computerized Acoustic Emission (AE) System packaged in a small anodized aluminum case. Once linked with a PC running AEwin USB software, the USB-AE node system has all the performance features of a larger, more expensive AE system including AE bandwidth, speed, AE Features, sampling rates and waveform processing capabilities. The USB-AE Node System is capable of performing any AE application which is one of our larger AE systems. It is an excellent field survey tool especially in situations where plug-in power is not readily available but a notebook or PC computer for use in the laboratory capable of carrying out tests by utilizing its AE channel for correlating load or stress with AE activity. Typical Daisy-chain Configuration is shown in Fig. 5 and schematic diagram for AE testing process is shown in Fig. 6. This experiment was carried out with cyclic loading using fixed calibrated load. The primary emission from active crack growth occurred only at the peak load levels. In fact, the emission that occurred at the peak load levels, secondary emission and noise that occurred at lower load levels were gated out. At first when the crack was still small, not every cycle produced emission. But later as the crack approached the critical length for unstable propagation, every cycle produced emission, as shown in Fig. 7. This fits well with the behavior of statically loaded specimens discussed above, that insignificant flaws tend to show the Kaiser Effect while structurally significant flaws tend to show the Felicity Effect. Damage assessment has been feasible because AE activities undergo parameters such as stress level in the crack zone. AE activity can be directly related to fracture mechanics parameters which can be further related to crack growth rate and fatigue failure. Locating the source of significant Acoustic Emissions is often the main goal of an inspection. Although the magnitude of the damage may be unknown after AE analysis, follow up testing at source locations can provide these answers.

2.4. Linear location Technique (LLT)

Linear Location technique (LLT) in Acoustic Emission (AE) analysis is often used to evaluate strut on bridges. When the source is located at the midpoint, the time of arrival difference for the wave at the two sensors is zero [16]. If the source is closer to one of the sensors, a difference in arrival time is measured. To calculate the distance of the source location from the midpoint, the arrival time is multiplied by the wave velocity. Whether the location lies to the right or left of the midpoint is determined by which sensor [17] first records the hit. This is a linear relationship and applies to any event sources between the sensors. The above scenario, implicitly assumes that the source is on a line passing through the two sensors and it is only valid for a linear problem.

2.5. Calibration of AE Setup

This test consists of breaking a 0.5 mm (alternatively 0.3 mm) diameter pencil lead approximately 3 mm (+/- 0.5 mm) from its tip by pressing it against the surface of the piece. This generates an intense acoustic signal, quite similar to a natural AE source that the sensors detect as a strong burst. The purpose of this test is twofold. First, it ensures that the transducers are in good acoustic contact with the part being monitored. Generally, the lead breaks should register amplitudes of at least 80 dB for a reference voltage of 1 mV and a total system gain of 80 dB. Second, it checks the accuracy of the source location setup. The last purpose involves indirectly determining the actual value of the acoustic wave speed for the object being monitored. Calibration is done for each sample before test in to check the event formation. The formation of event in correct region when pencil lead break method is applied on same location of sample is considered as proper calibration.

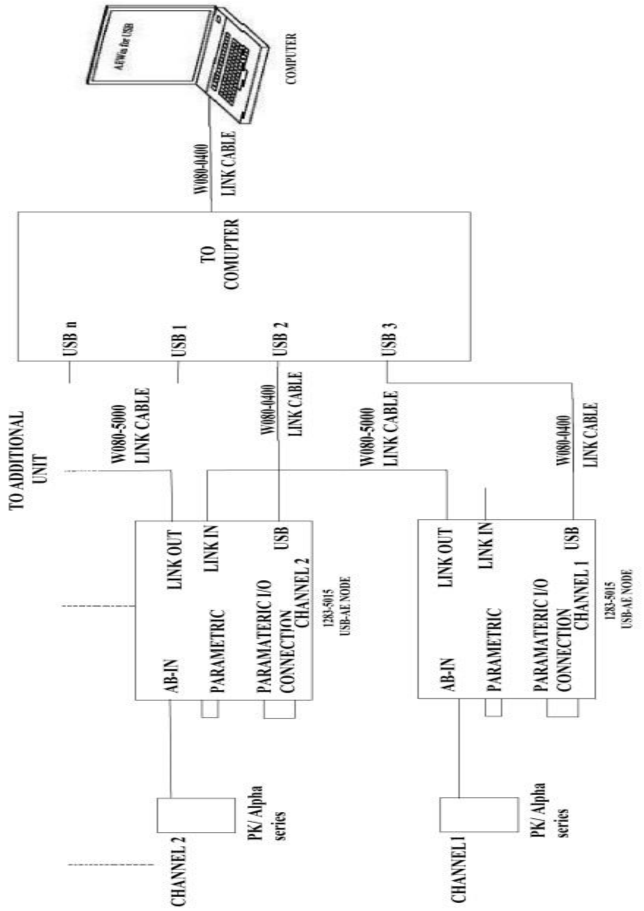


Fig. 5. USB-AE node and accessories -Typical Daisy-chain configuration.

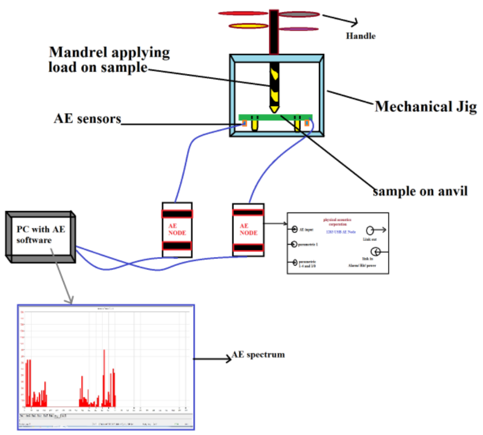


Fig. 6. Schematic diagram for AE testing process.

3. Experimental Procedure

The welded specimens are subjected to the dynamic loading by keeping the samples weld region on to the mechanical jig position such that the fracture has been initiated from the weld zone conditions. The number of samples used is five for each type of weld set samples and the repetition is checked subjected to loading during the fracture with the AE set-up as shown in Fig. 6. The active events generated during the fracture are recorded with the two channel AE sensors which are located on the sample at equal distance from the centre by using Linear Location Technique. The samples are having weld defects like lack of fusion, lack of side wall fusion, pin hole, porosity, and slag as listed in Fig. 1 which are used for the experimental study.

The events are recorded with the software from the AE sensors response in terms of energy released during the fracture during loaded condition due to the plastic deformation occurred in the sample as shown in Fig. 7. The stress released during the test condition from each type weld specimens are recorded with Energy with respect to position, Counts, Cumulative energy with time, Cumulative Hits with time and repeated for each type of sample. The results reveal significant variation of the Acoustic Emission measurements which are detected in each type with repetition. Hence this experimental procedure establishes the examination of different kinds of weld defects during the failure of structure with calibrated Acoustic Emission setup to identify with respect to the energy release in terms of intensity.

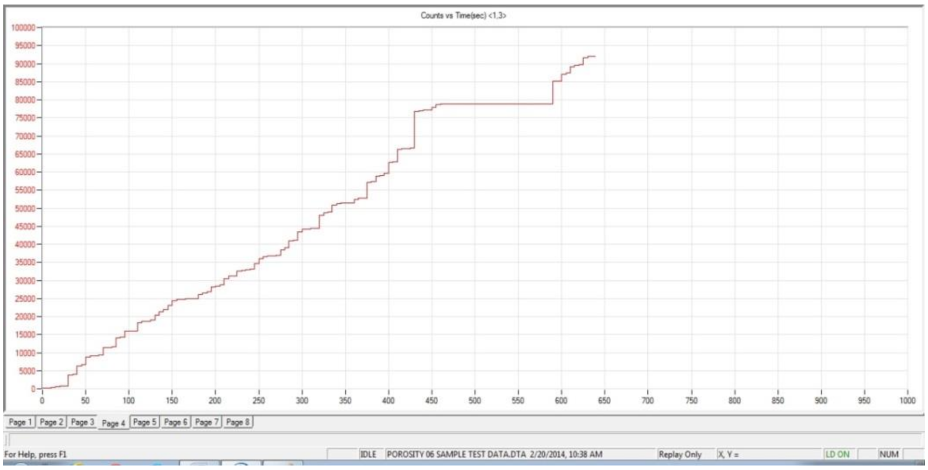


Fig. 7. Emission continuing during load hold indicates instability.

4. Results and Observations

The AE tests were carried out on five samples from each category which were defective and good samples and shown in Fig. 8. While the samples are being loaded, the events were recorded with reference to the position of transducers placed on either end of the samples. First, an attempt was made to get clear Acoustic Emission signals by getting higher signal to noise ratios with good results and then shifted to the monitoring of different parameters. The first data monitored was the "events versus the x- position". In addition to this, the data was monitored in different configurations. The detail of the various modes in which data was obtained, compiled and analyzed is discussed below.

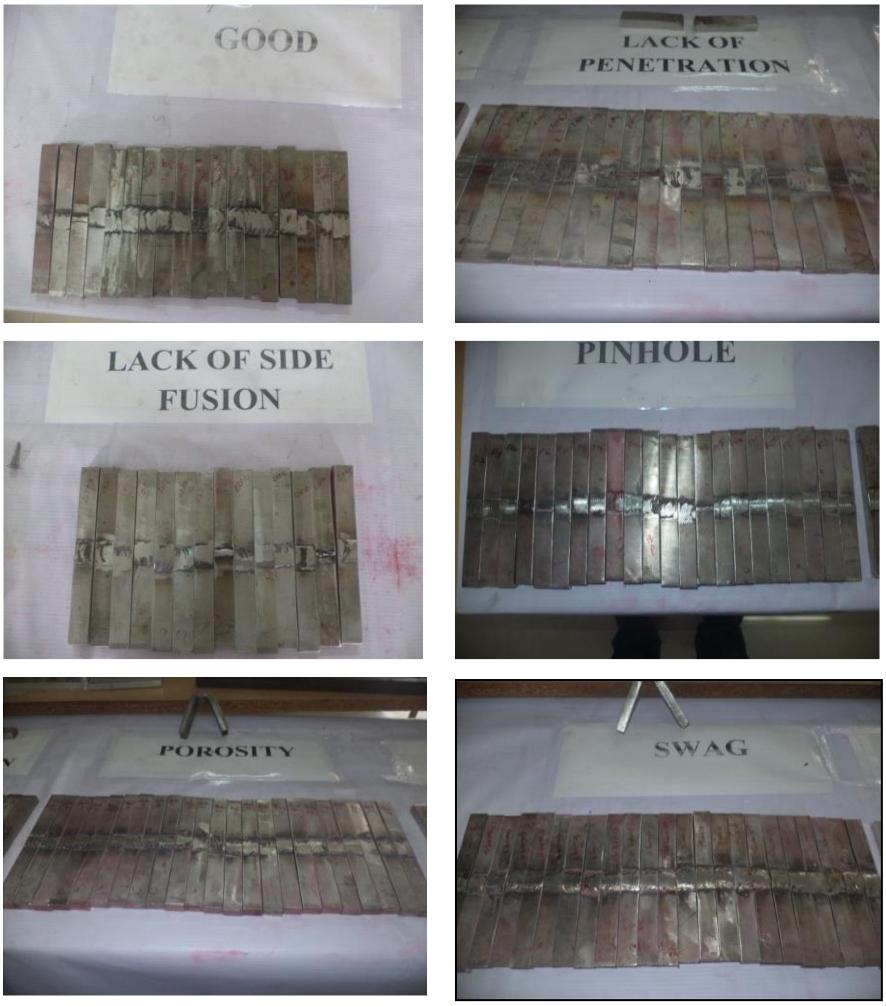
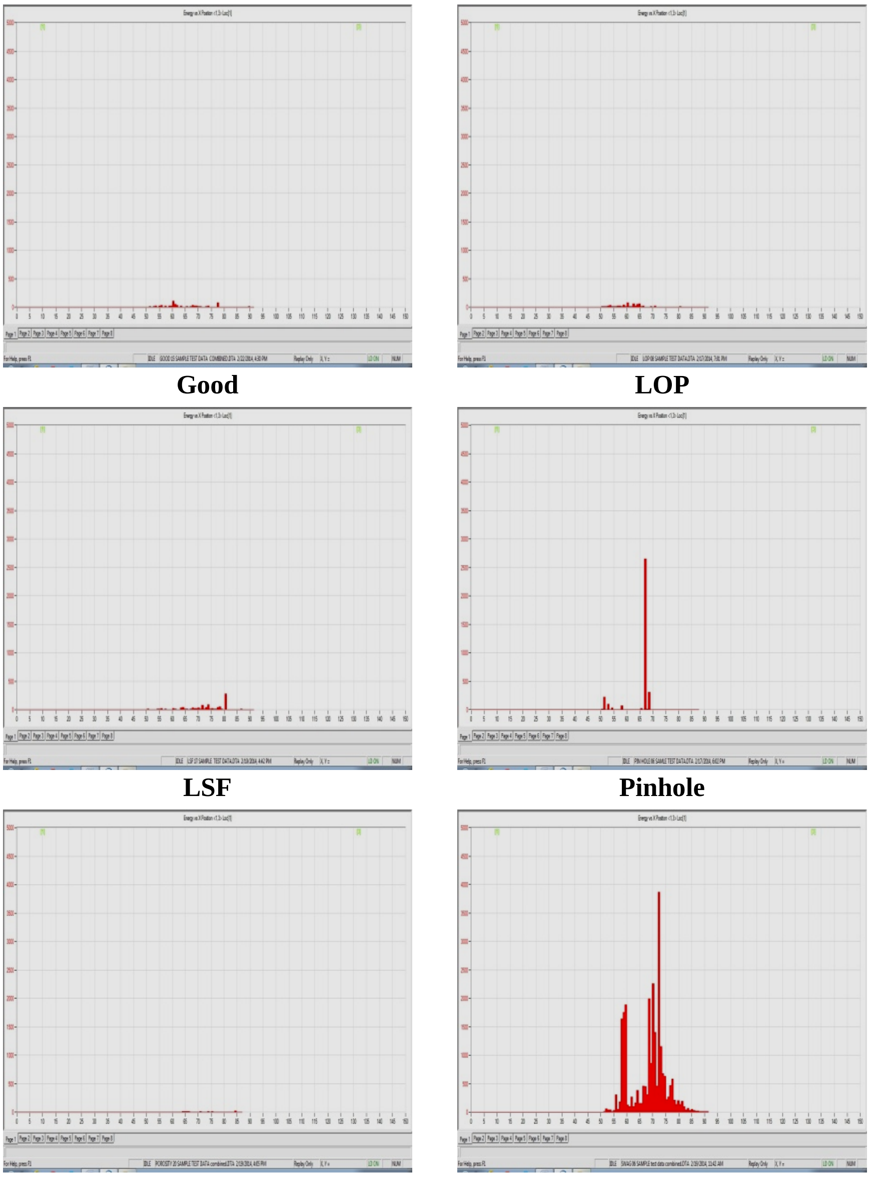


Fig. 8. Samples containing different implanted defects for AE Study under stress or load.

Observations made from the data analysis

4.1. Energy versus x-position

From Fig. 9, it is observed that all the samples recorded a good no. of events coming from the central position of the sample. The second sample was found having lack of side wall fusion defect which did not show many events. This must be an aberration of the experiment rather than a characteristic feature of the defect. It is found that other samples having the same defect exhibited different AE signatures.



Good **LOP**

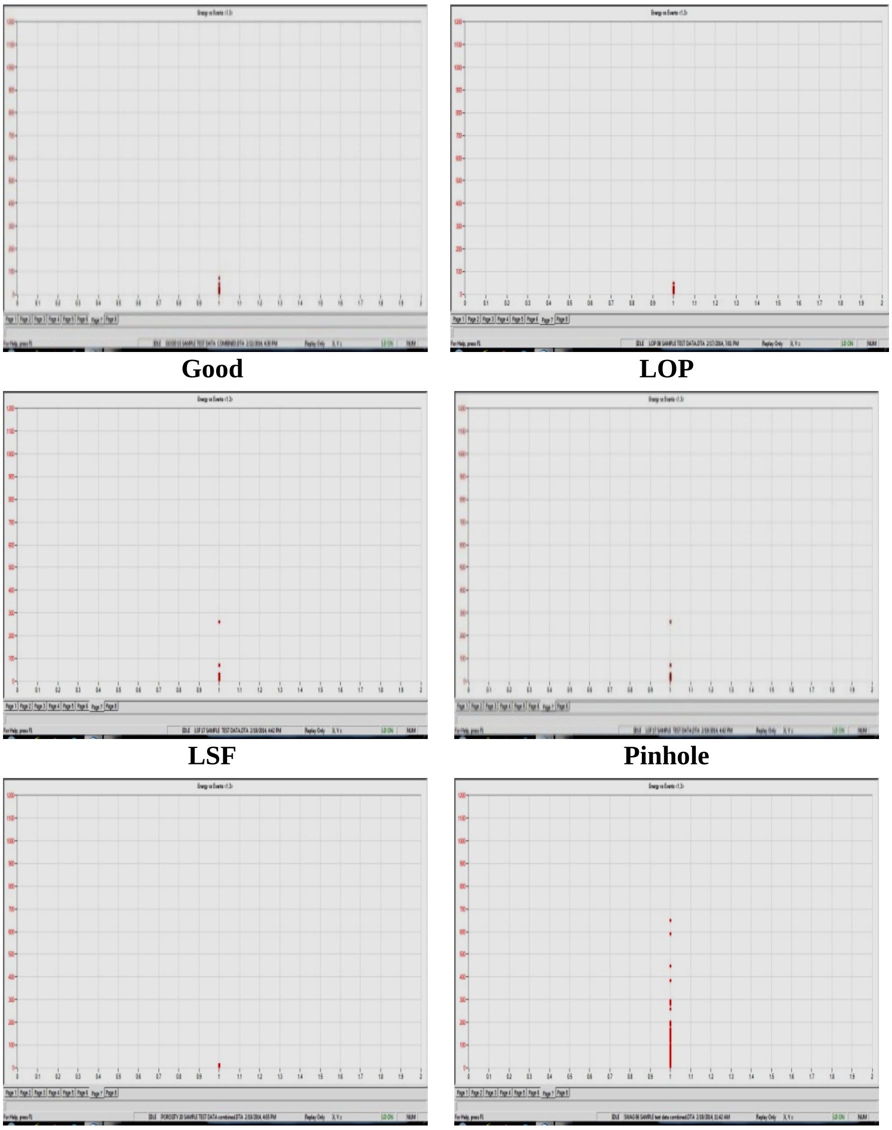
LSF **Pinhole**

Porosity **Slag**

Fig. 9. Energy vs. x-position corresponds to various defects.

4.2. Energy versus events

The recorded events for these parameters are shown in Fig. 10. The response observed is not much of deviation for all tested samples except the weld samples with slag defect which recorded many more events with high energy when compared to the others. The other samples have shown similar range of energy release. The samples with slag defect indicated the highest energy release during the dynamic loading which attributes to the irreversible plastic deformation happening in the weld zone.



Good LOP

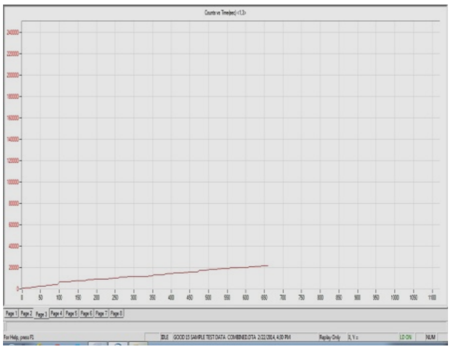
LSF Pinhole

Porosity Slag

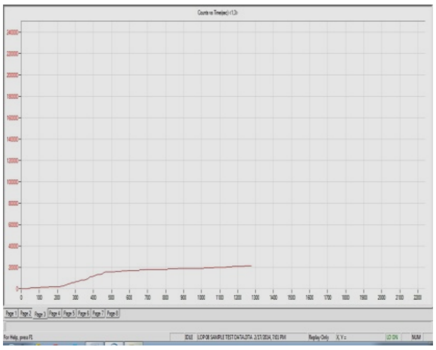
Fig. 10. Energy vs. events corresponds to various defects.

4.3. Cumulative counts versus time

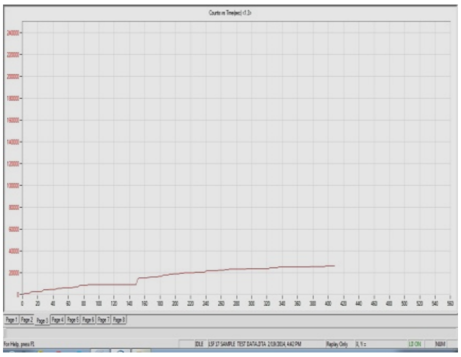
The good samples and the defects like lack of side fusion and lack of penetration confirmed lower rate of count accumulation while the defects, porosity and slag defect showed very high rate of count accumulation. The pinhole defect showed in Fig. 11 medium rate of count accumulation. The response with porosity and slag have attributed towards the release of large stress level during the loading conditions.



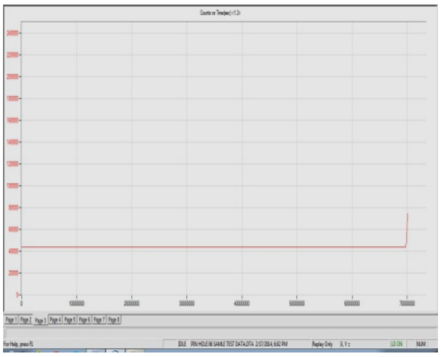
Good



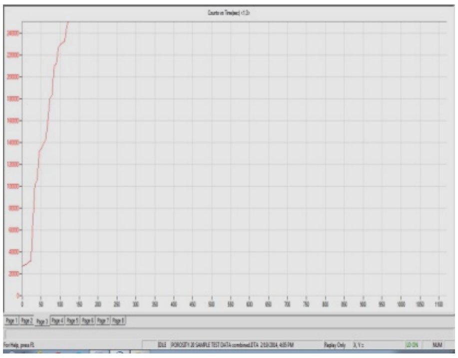
LOP



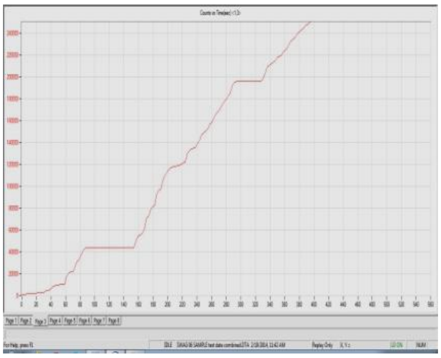
LSF



Pinhole



Porosity



Slag

Fig. 11. Test samples shown cumulative counts vs. time corresponds to various defects.

4.4. Cumulative energy versus time

During the dynamic loading condition, this type of data has shown similar trend and level of recorded data with respect to the normal samples and the other weld defect samples like lack of fusion, side wall fusion defect and pinhole. The samples with porosity and slag defects gave the highest rate of cumulative energy with respect to time showed in Fig. 12.

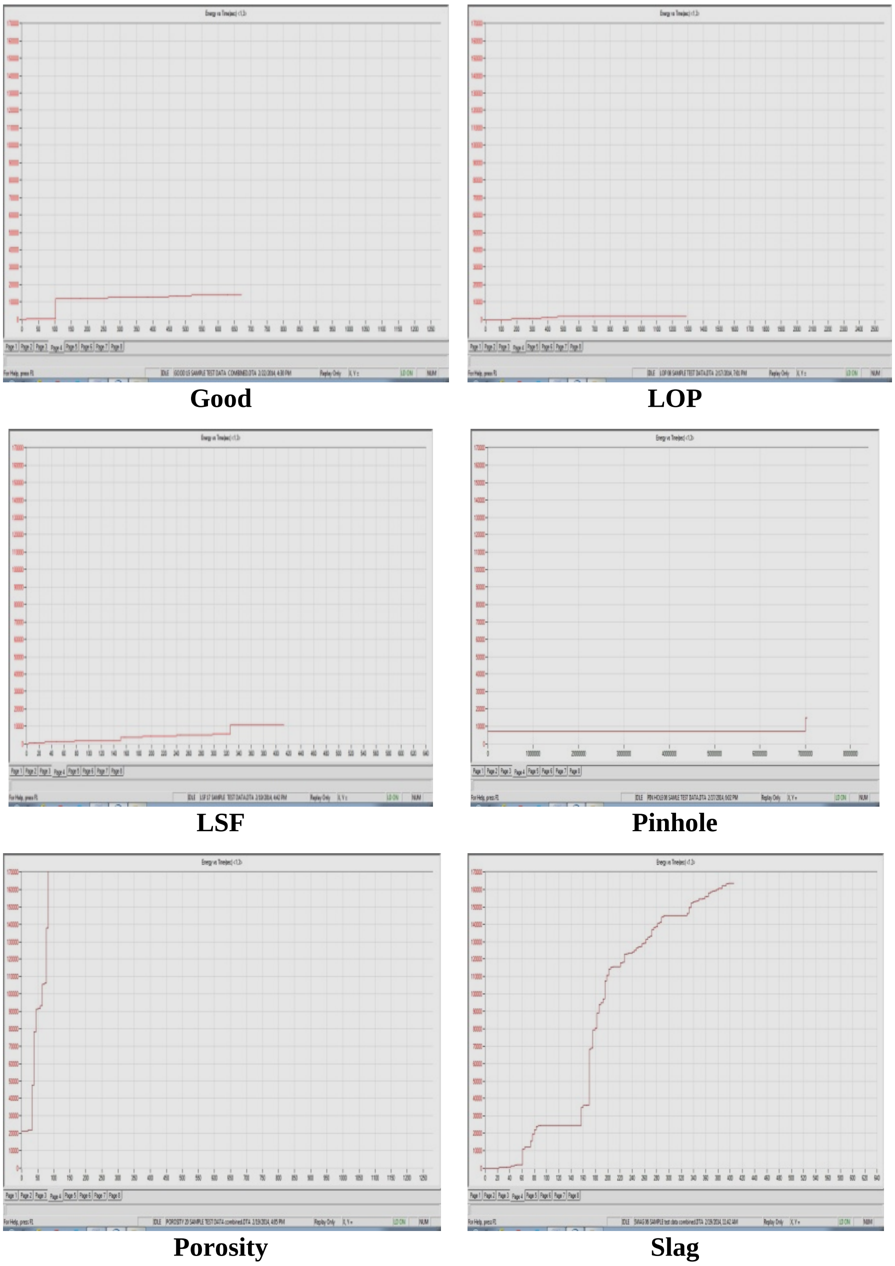


Fig. 12. Cumulative energy vs. time corresponds to various defects.

4.5. Hits versus time

As shown in Fig. 13, the slag defect recorded the highest no. of Hits versus time while the second sample having pinholes recorded the next highest hits.

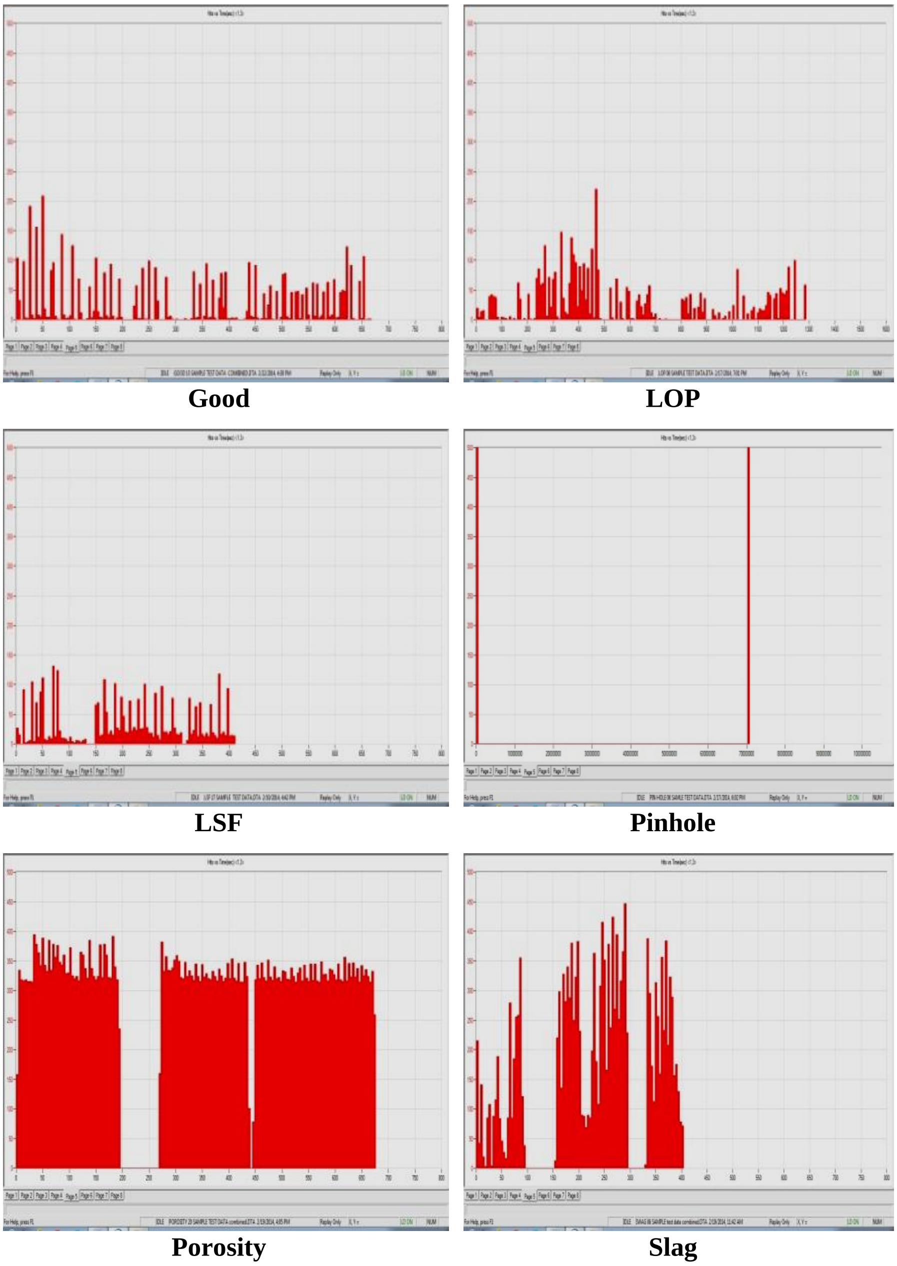


Fig. 13. Hits vs. time correspond to various defects.

4.6. Energy versus time

It is seen from Fig. 14 that the defects like pinholes, porosity and slag have recorded the highest energy with respect to time. The good samples as well as those with lack of side fusion have recorded only isolated events with high energy. Samples with lack of penetration showed the minimum energy.

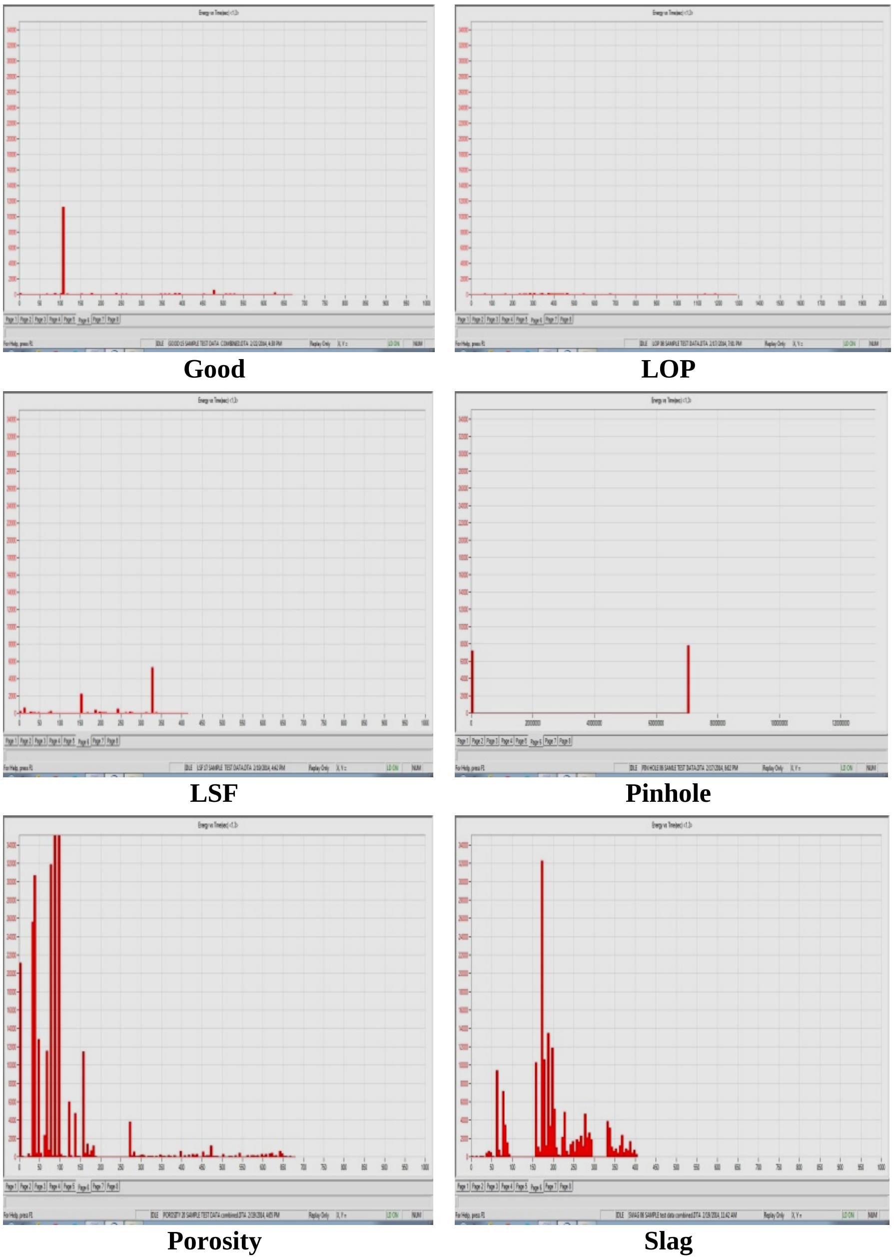


Fig. 14. Energy vs. Time corresponds to various defects.

4.7. Counts versus time

It was observed that the samples having porosity and slag defect showed the highest number of counts with respect to time. The pinhole defect showed more counts than other defects. The good samples and lack of side fusion defect showed high counts only at certain event of time as shown Fig. 15. Lack of penetration defect showed the least counts versus time.

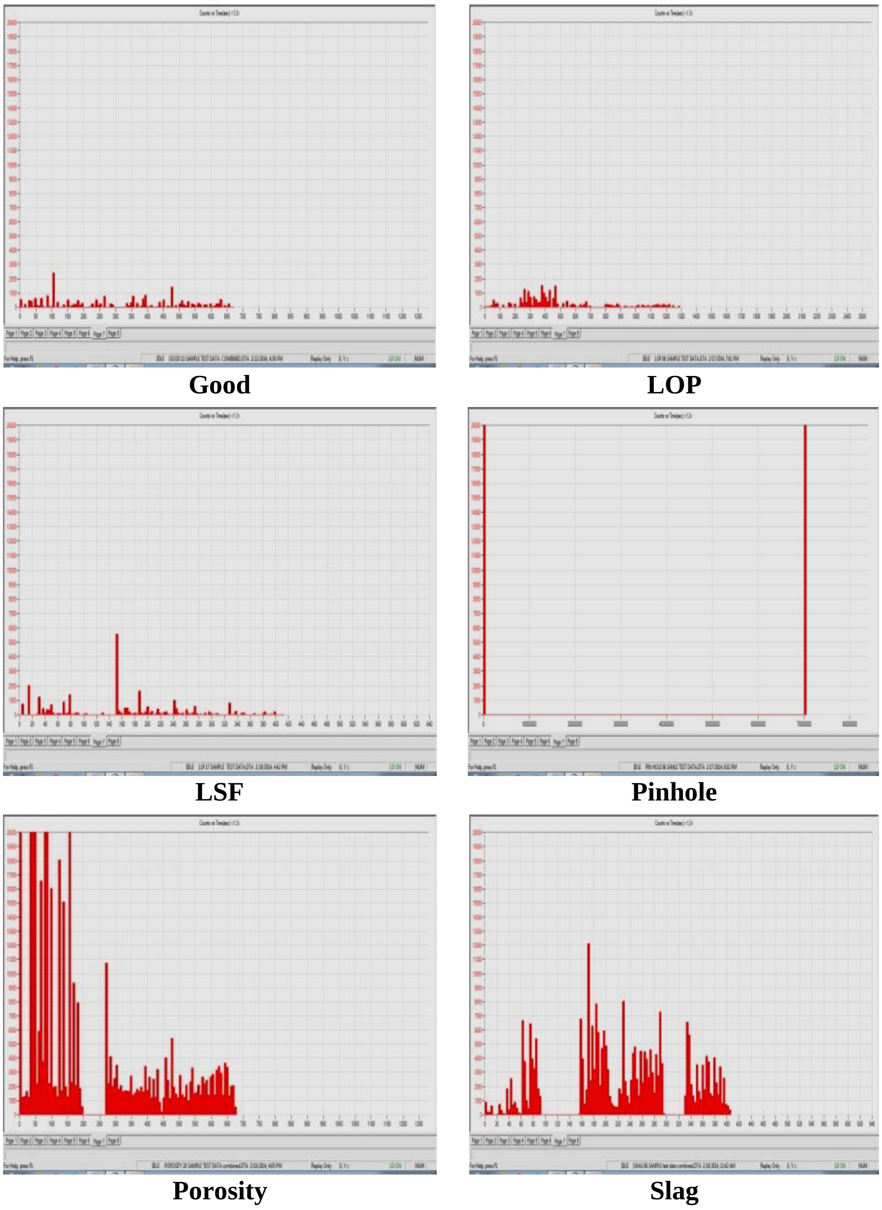


Fig. 15. Counts vs. Time correspond to various defects.

4.8. Counts versus amplitude

This particular parameter showed very distinctive differences for different defects and also this particular parameter is dependable for segregation and characterization of different defects in conjunction with other parameters. It can be readily seen that the good samples have recorded the least amplitudes along with other defects like lack of side fusion and lack of penetration. The defects like pin hole, porosity and slag have recorded the highest count Vs amplitude as shown in Fig. 16.

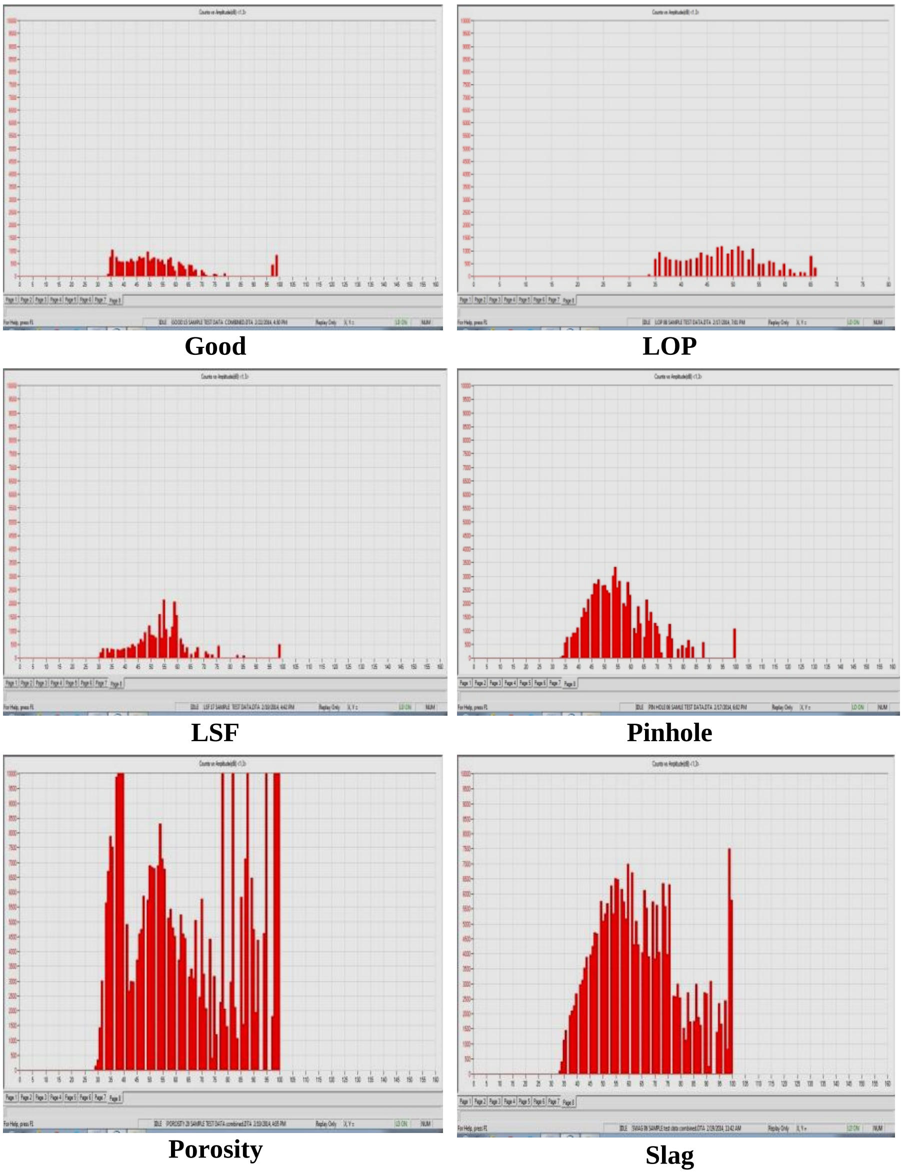


Fig. 16. Counts vs. amplitude correspond to various defects.

5. Discussion

The experiments carried out with dynamic loading conditions with Mechanical Jig have revealed the distinctive response of the weld defects with Acoustic Emission data. The sample without weld defect showed normal counts. In case of the weld defect samples like lack of penetration, incomplete side wall fusion, and pinhole defects showed similar range which will be difficult to differentiate with the kind of signatures. However, the porosity and slag inclusion samples that showed significant raise in each recorded events with acoustic emission and release of the strain energy during the dynamic load conditions revealed the burst counts and cumulative energy release count showing the highest levels.

The detailed observed signals comparison and different levels are shown in Table 2. This is attributed to the response of the Acoustic Emission with reference to two point bend static loading stress conditions subjected uniformly. This study can be employed for the investigation of post failure analysis while keeping the AE system with calibration for large structures and can be a preventive maintenance which are under continuous loads or stress conditions. The welded parts are invariant in the large structural components like chemical or nuclear power plants. it is beneficial to adapt this technique for implementation where structural and thermal loads will have severe effects on performance of the components. Some more efforts are needed for online analysis to confirm the weld defects during their load conditions for the structure failures.

Table 2. Observation of various acoustic emission data.

Type of weld sample	Energy vs. x-position	Energy vs. events	Cumulative counts vs. time	Cumulative energy vs. time	Hits vs. time	Counts vs. time	Counts vs. Amplitude	Energy vs. time
No defect	Low	Low	Low	Medium	Medium	Low	Low	Medium
Lack of penetration	Low	Low	Low	Low	Medium	Low	Low	Low
Lack of Side wall fusion	Low	Medium	Low	Low	Low	Medium	Low	Low
Pinhole	Medium	Medium	Medium	Low	High	Medium	Medium	Medium
Porosity	High	Low	High	High	High	High	High	High
Slag	High	High	High	High	High	High	High	High

6. Conclusion

Data analysis was carried out for various parameters obtained from testing of five sets of samples with good welds as well as various other weld defects. Comparison of various AE parameters showed that there was definite type of events generation with respect to the type of weld defects. It was observed that the parameter “counts versus amplitude” has given the widest distinction with respect to the type of defects indication of the plastic deformation occurrence during the stress loading conditions. It can be seen that, the good weld was mostly milder in expression with respect to any of the parameters monitored. The defects like pinholes, porosity and slag have given the highest expression in that order with respect to any of the parameters monitored. It is observed that the good weld specimens have shown low AE events in comparison to any other tested weld defect specimens with the parameters tested. This defect showed the highest amplitude versus counts and also highest amplitude with respect to frequency of the events. Acoustic emission system implementation can be a good diagnostic tool for the preventive maintenance of the structures which are under continuous load conditions like nuclear reactors and pressure vessels.

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References

1. Bassim, M.N. (1985). Assessment of fatigue damage with acoustic emission. *Journal of Acoustic Emission*, 4(5), 224-225.
2. Kishi, T.; Yamaguchi, K.;and Sakakibara, Y. (1986). Applicability of AE monitoring technique to evaluate structural integrity of fast breeder reactor piping component. *Nuclear Engineering and Design*, 94(3), 365-374
3. Mukhopadhyay, C.; Kasiviswanathan, K.V.; Jayakumar, T.; Raj, B.; and Jayakumar, T. (1993). Acoustic emission during tensile deformation of annealed and cold-worked AISI type 304 austenitic stainless steel. *Journal of Materials Science.* 28 (1), 145-154.
4. Lee, J.K.; Bae, D.S.; Lee, S.P.; and Lee, J.H. (2014). Evaluation on defect in the weld of stainless steel materials using non destructive technique. *Fusion Engineering and Design*, 89(7-8), 1739-1745.
5. Yoon, H.K.; Kong, Y.S.; and Kim, S.J.; and Kohayama, A. (2006). Mechanical properties of friction welds of RAFS (JLF-1) to SUS304 steel as measured by the acoustic emission technique. *Fusion Engineering and Design*, 81(1), 945-950.
6. Ai, Q.; Liu, C.-X.; Chen, X.-R.; He, P.; and Wang, Y. (2010). Acoustic emission of fatigue crack in pressure pipe under cyclic pressure. *Nuclear Engineering and Design*, 240, 3616-3620.
7. Raj, B.; Subramanian, C.V.; and Jayakumar, T. (2000). *Non-destructive testing of* weld. New York: Woodhead Publishing.
8. Gregory, C.; McLaskey Steven.; and Glaser, D. (2012). Acoustic emission sensor calibration for absolute source measurements. *Journal of Non-Destructive Evaluation*, 31(3), 157-168.
9. Moorthy, V.; Jayakumar, T.; and Raj, B. (1995). Acoustic emission technique for detecting micro- and macro yielding in solution-annealed AISI Type 316 austenitic stainless steel. *International Journal of Pressure Vessels and Piping Volume*, 64(2), 161-168
10. Camerini, C.S.; and Rebello, J.M.A.; Soares, S.D. (1992). Relationship between Acoustic Emission and CTOD testing for a structural steel, *NDT & E International*, 25(3), 127-133.
11. Ranganayakulu, S.V.; Shiva Raju, J.; Kuchedludu, A.; and Ramesh Kumar, B (2014). Acoustic emission studies on weld bead defects in nuclear grade SS 316L materials. *Open Journal of Acoustics*, 4(3), 115-130.
12. Dia, S.; Monnier, T.; Godin, N.; and Zhang, F. (2012). Primary calibration of acoustic emission sensors by the method of reciprocity, theoretical and experimental considerations. *Proceedings of 30th European Conference on*

Acoustic Emission Testing & 7th International Conference on Acoustic Emission, Granada, Spain, 286-293.

13. Keprt, J.; and Benes, P. (2007). Determination of uncertainty in calibration of acoustic emission sensors. *Proceedings of 4th International conference on NDT*, Chania, crete-greece, 251-258.
14. Armentrout, D.L.; and Carpenter, S.H. (1997). An investigation of Lüders band deformation and the associated acoustic emission in Al-4.5% Mg alloys. *Journal of Acoustic Emission*, 15(1-4), 43-52.
15. Carpenter, S.H.; Kanji, O.; and Armentrout, D. (2006). Acoustic emission of sensitized 304 stainless steel with simultaneous hydrogen charging. *Journal of Acoustic Emission*, 24(1), 119-126.
16. Sotirios, J.V. (1964).Acoustic emission: A new but sound NDE technique and not a panacea. *Proceedings of the First Joint Belgian-Hellenic Conference on Non Destructive testing*, Patras, Greece, 101-116.
17. Keprt, I.; and Benes, P. (2008). A comparison of AE sensor calibration methods. *Journal of Acoustic Emission*, 26(1), 60-71.