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Online Monitoring of Electron Beam Welding of TI6AL4V Alloy Through Acoustic Emission

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Abstract

Acoustic Emission (AE) Technique is the only Non Destructive Testing (NDT) method that can be thought of to be used as an online monitoring tool for detection, location and characterization of various kinds of active defects during any process. An effective approach of quality control is defect detection during welding process itself rather than by NDT of component after welding. Weld defects generated during an Electron Beam Welding (EBW) process can be monitored through on-line acoustic emission analysis (AEA). The principle of AEA is based on the fact that the formation of defects in a material is accompanied by dissipation of energy in the form of acoustic waves, which can be detected by piezo-electric sensors, mounted on the surface of the component. After detection the acoustic waves are analyzed, to obtain the information about the nature and location of the defect formed. In the present work, an attempt is made to monitor formation of defects during EBW of Titanium alloys sheets using AEA and the results of this study are presented in this paper.

Keywords: *Acoustic emission, Defect, Depth of penetration, Titanium, Weldment*

1. Introduction

Ti6Al4V alloy, the workhorse of titanium alloy family, is extensively used in aerospace sector owing to its very high specific strength coupled with excellent corrosion resistance. This alloy is widely used in Indian Space Programs both for launch vehicles and satellites applications, as high pressure gas bottles and propellant tanks.

Ti6Al4V components are processed through forming / forging, machining and welding route. EBW is one of the main welding processes used for joining the titanium alloys.

In EBW as in all other welding processes, weld discontinuities can be divided into two major categories; (1) those that are open to or at the surface; and (2) those that occur below the surface. Surface discontinuities such as undercut, mismatch and underfill are macroscopic discontinuities and may be detected visually or dimensionally.

Subsurface discontinuities are more difficult to detect than surface discontinuities because observation is indirect. Volume discontinuities such as porosities, voids and bursts are detected by radiographic or ultrasonic inspection. But these conventional techniques can be used only after the completion of the welding and there is no scope of corrective measure to apply then and there itself during the process.

Acoustic Emission (AE) is a relatively new technique that appears well suited to detect the defect occurring during the welding process. AE monitoring enables necessary diagnosis to be made during each welding pass, so that remedial action can be taken at minimum cost, while the component is still mounted and under vacuum. Real-time discontinuity detection and characterization of welds is the major advantage of AE.

Real time AE monitoring during EBW of titanium alloy components is very attractive, to achieve good quality welds for aerospace systems [1]. Various welding parameters (such as beam current and position of beam focus) are amenable to feedback control during the weld pass [2]. The principal goal of this work is to provide a diagnosis of the weld in real time and to indicate the remedial action in the form of a second welding pass. This remedial action can be applied immediately, without disrupting the welding process.

2. Experiment

2.1 Electron Beam Welding Machine

The specifications of the EBW machine used for the study are given in Table 1.

2.2 Weld Specimen

The specimens were made of Mill Annealed Ti6Al4V Alloy and milled to a plate of 150 x 30 x 3 mm dimensions, see Fig. 1. The butt joint configuration was used, as the butt joint is one of the most widely used joint in welding and is generally recommended for EBW [2]. The specimens were placed side by side to each other with the butting edges prepared for EBW. Total 10 specimens, i.e., 5 sets of weldments were prepared. Refer Fig. 1.

2.3 Pre-weld Cleaning Procedure

For minimizing the porosities in Ti alloy EB welds following procedure was adopted:

i. Mopping with Isopropyl Alcohol (IPA).

ii. Etching with (HNO3 1510 g/ lit) + (HF 12ml/lit) + Balance Water (5 minutes).

iii. Rinsing with running water.

iv. Dip in 2% Na2CO3 solutions for 2 minutes.

v. Wash with running water thoroughly.

vi. Drying thoroughly.

2.4 AE Instrumentation Details

The details of AE instrumentation used for this study are given in Table 2. The location of AE sensors during the weld setup is shown in Fig. 2.

2.5 Process Parameter Selection

Before doing the actual weld on the specimens a sample of Ti6Al4V (115 x 75 x 3 mm) was made for carrying out the trial welds. Total 6 number of trial welds, with different weld parameters, were carried out on this sample. The results of these trial welds are listed in the Table 3.

The general criteria for weld parameter optimization are, (i) single pass weld bead, (ii) full weld penetration, (iii) minimal undercut in over-bead area and minimal drop-through in the under-bead area, (iv) low unit length weld energy input, and (v) low ripple profiles in over-bead & under-bead areas [3].

From the above trial welds, parameters for the test specimen were finalized as:

Accelerating Voltage: 60 kV

Beam Current : 19 mA

Gun Travel (Speed) : 1000 mm/min

The choice of these parameters was based on the fact that, with these settings a good bead of weld was obtained for the Ti6Al4V alloy for the thickness of 3 mm.

3. Results and Discussion

In EBW machine, specimen positioned with the help of a locating fixture was kept inside the vacuum chamber of the machine. For monitoring AE signals, the transducer has to be fixed on the surface of specimen. Therefore, coaxial cables from the transducer should come out of the vacuum chamber without breaking the vacuum seal. Hence the incoming coaxial cables from the transducer are soldered to the one of the connectors inside the machine, which was meant for an extra lamp in the machine. This connector was having a provision outside the machine from which the preamplifier was connected.

While welding considerable EMI noise (65 dB) was observed from the connectors, as the pre-amplifier was initially placed outside the vacuum chamber. Later the pre-amplifier was placed inside the vacuum chamber and the EMI noise could be eliminated. Total elimination of noise was checked and confirmed by keeping one additional transducer as control inside the machine [4].

When the specimens were welded with one pass, as the electron beam moved from one end, a slight gap was observed between the weld edges of the specimen at the far end. To avoid this situation for the other sets of specimens, before the actual weld (full penetration); spot welding was done at the ends and a seam weld (beam current 4 mA) was carried out initially.

First two sets of specimen were welded in single pass, i.e., full weld depth was achieved in single pass. For the third set of specimen first spot welding, followed by the seam welding (0.2 mm depth) and then full welding was done. Finally for the next two sets, first a seam welding (0.2 mm depth) and then full welding was done.

As typical defects are not always encountered during the actual process, some of the defects were deliberately introduced in the last set of specimen. A cotton thread (for inclusion), silicon grease (for porosity) and a metallic wire (for cracking) were inserted at different locations between the welding edges [3].

AE performance of all the 5 specimen sets is given in the form of graphs. For each specimen, six different AE parameters {Amplitude (dB), Duration (ms), Event, Count, Energy, and RMS (V)} are plotted against the time. Refer Fig. 3 – 10 for these graphs. The observations from these graphs are given below:

3.1 General Observations

For all the specimens in each of the six AE graphs, welding time and the solidification time are clearly visible as two activities (Refer Fig. 4, ellipsed part).

3.2 Observations during Full Welding Process

Welding duration is clearly identifiable by the increase in signals (Refer Fig. 4, circled area).

During welding process continuous high amplitude signals of 85 – 100 dB were observed (Refer Fig. 4, circled area).

Event duration parameter during welding was observed constant around 120 – 125 milliseconds (Refer Fig. 4, circled area).

Increase in number of events, counts, RMS voltage and energy is also very high during welding time (Refer Fig. 4, circled area).

Similar kind of activity is seen while welding specimen 2 (Refer Fig. 5, circled area).

Table 1: Electron Beam Welding Machine Specifications

Make	Techmeta, France
Maximum Power	6 KW
Accelerating voltage	0 - 60 kV
Beam current	0 – 100 mA
Penetration in stainless steel	25 mm
Beam alignment accuracy	± 50 microns
Weld chamber size	800 X 800 X 800 mm
Chamber vacuum	Better than 1 X 10^{-3} Torr
Job manipulation	Rotary (Horizontal & Angular) on 3-jaw chuck for circumferential welding. CNC controlled XY axis motion by Gun/Working Table movements for face welding of linear joints and contours.
Table size	700 X 280 mm
Travel	500 mm – X axis 450 mm – Y axis

Table 2: AE Instrumentation Specifications

Acoustic Sensor Type	R 15 – 150 KHz Resonant (single ended)
Pre amplifier	PAC – 1220 AST with Filter (20 – 1200 KHz)
Data acquisition system	MISTRAS, Physical Acoustic Corporation
Frequency	20 – 400 KHz
Sampling Rate	4 MHz
Threshold	30 dB

Table 3: EBW Process Parameter Selection

Sl. No.	EB Welding (Trial Welds)		
	Current (mA)	Speed (mm/min)	Voltage (KV)
1	48	2500	60
2	18	1000	60
3	9	500	60
4	9	500	60
5	48	2500	60
6	19	1000	60

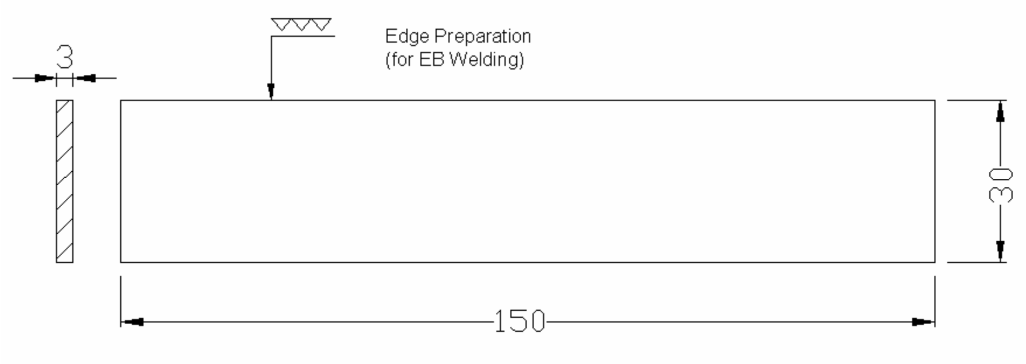

Fig. 1: Mill Annealed Ti6Al4V Weld Specimen

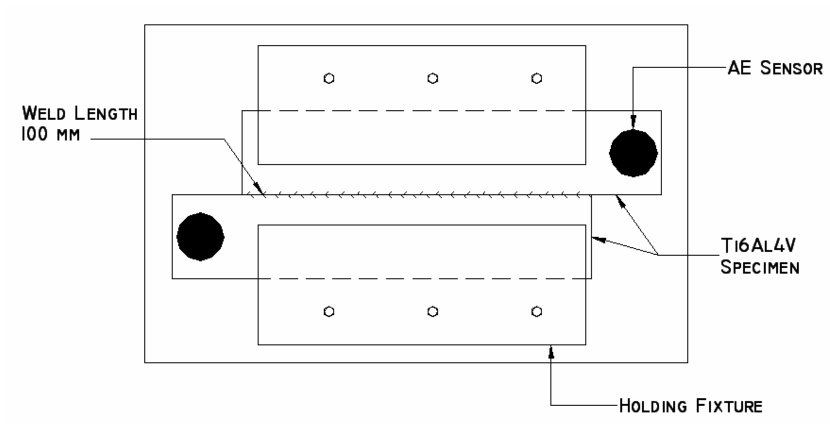

Fig. 2: Ti6Al4V Weld Specimens with AE Sensors

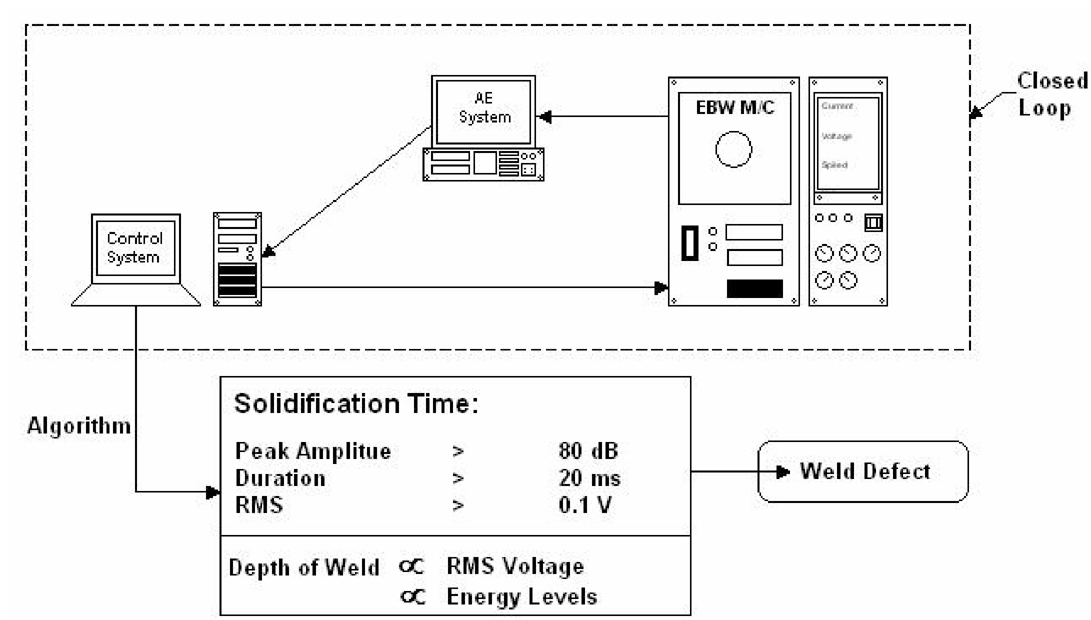

Fig. 3: Online Monitoring of EBW Process by using AE technique

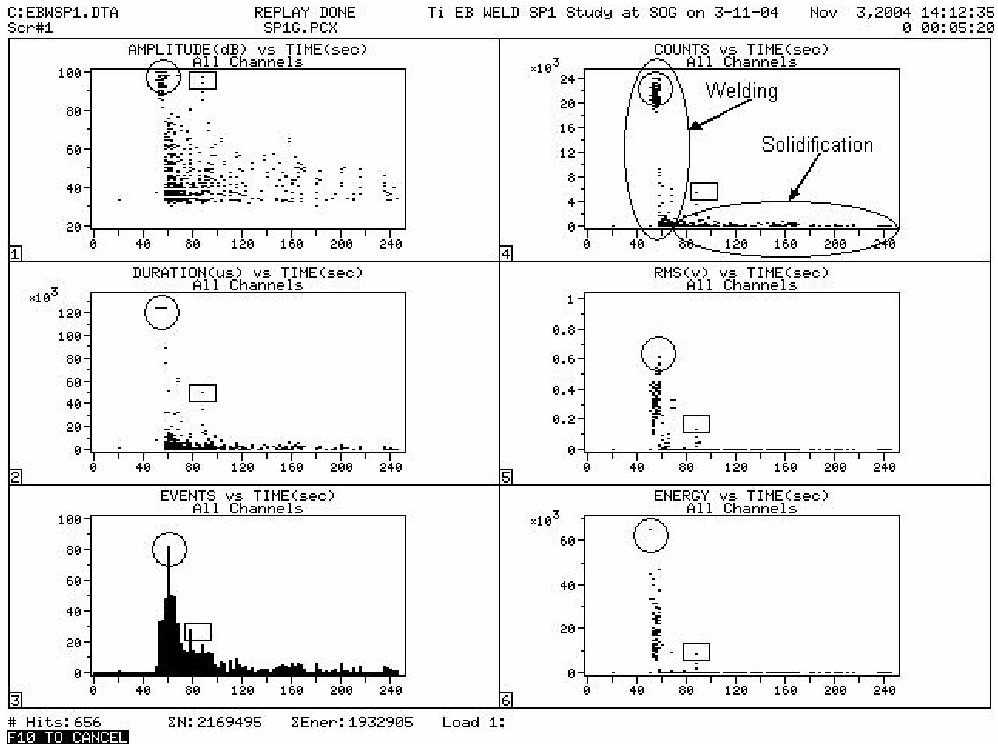

Fig. 4: AE Performance of Specimen 1 (Full Weld)

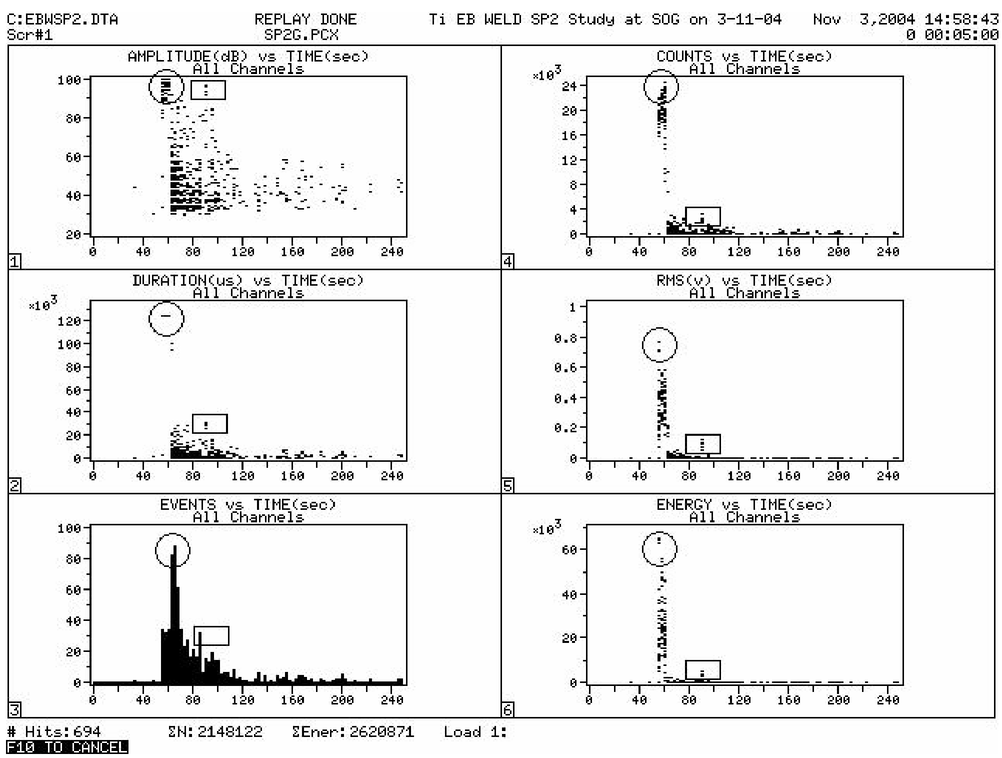

Fig. 5: AE Performance of Specimen 2 (Full Weld)

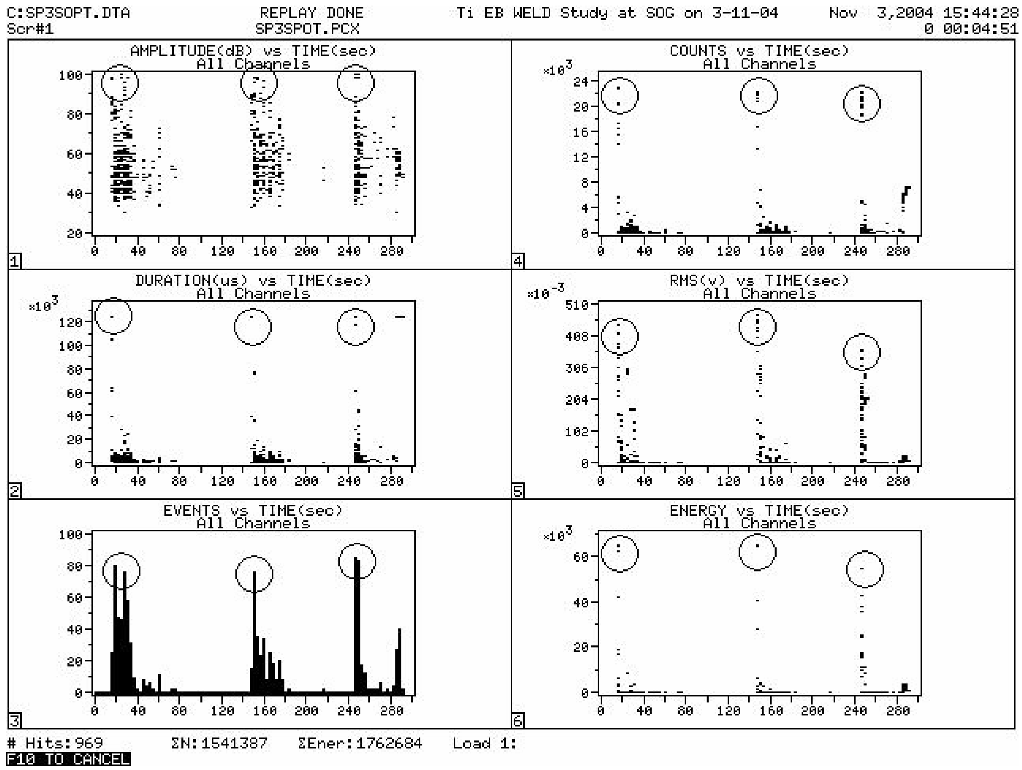

Fig. 6: AE Performance of Specimen 3 (Spot Weld)

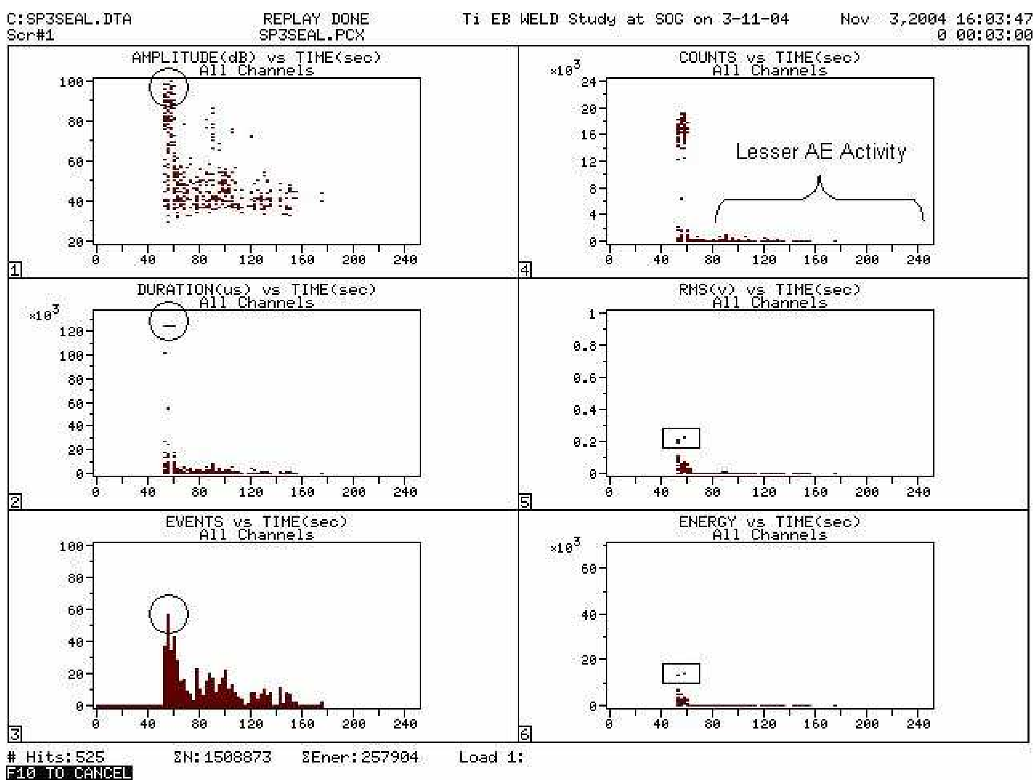

Fig. 7: AE Performance of Specimen 3 (Seam Weld)

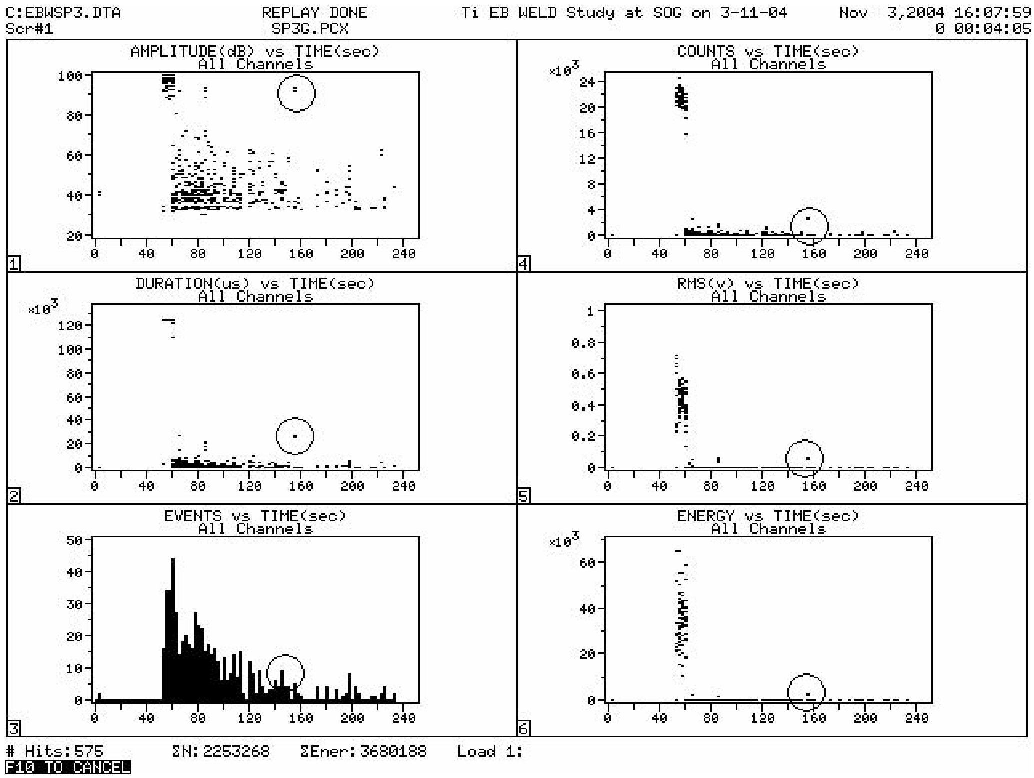

Fig. 8: AE Performance of Specimen 3 (Full Weld)

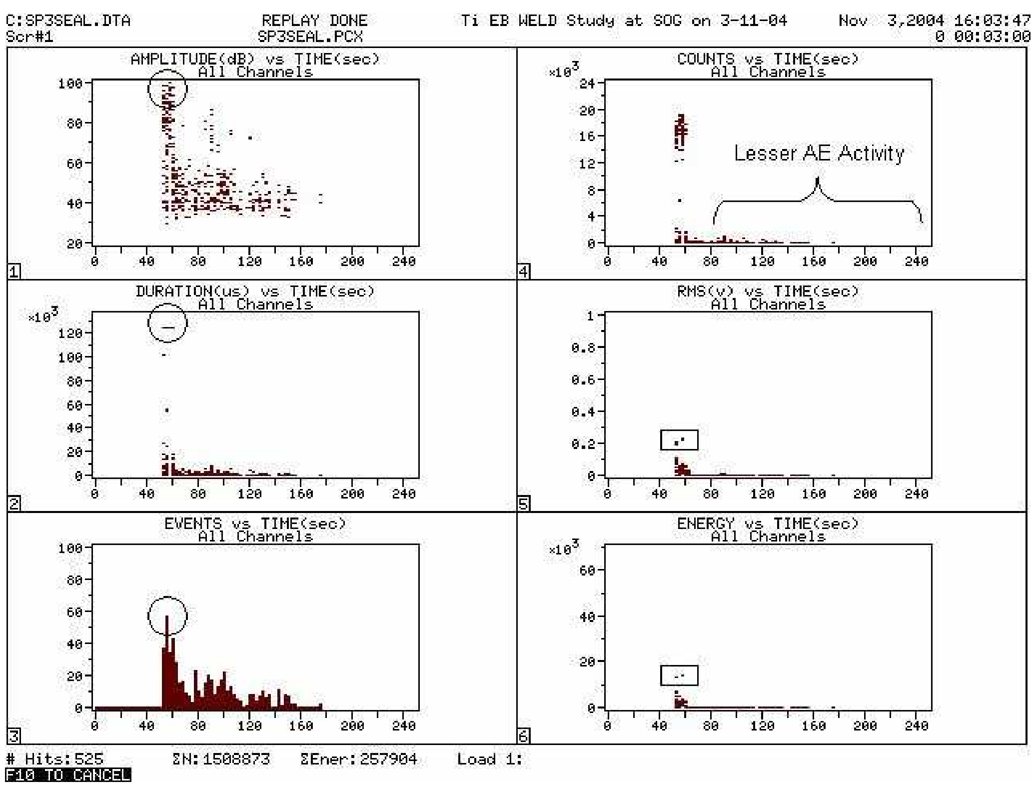

Fig. 9: AE Performance of Specimen 4 (Seam Weld)

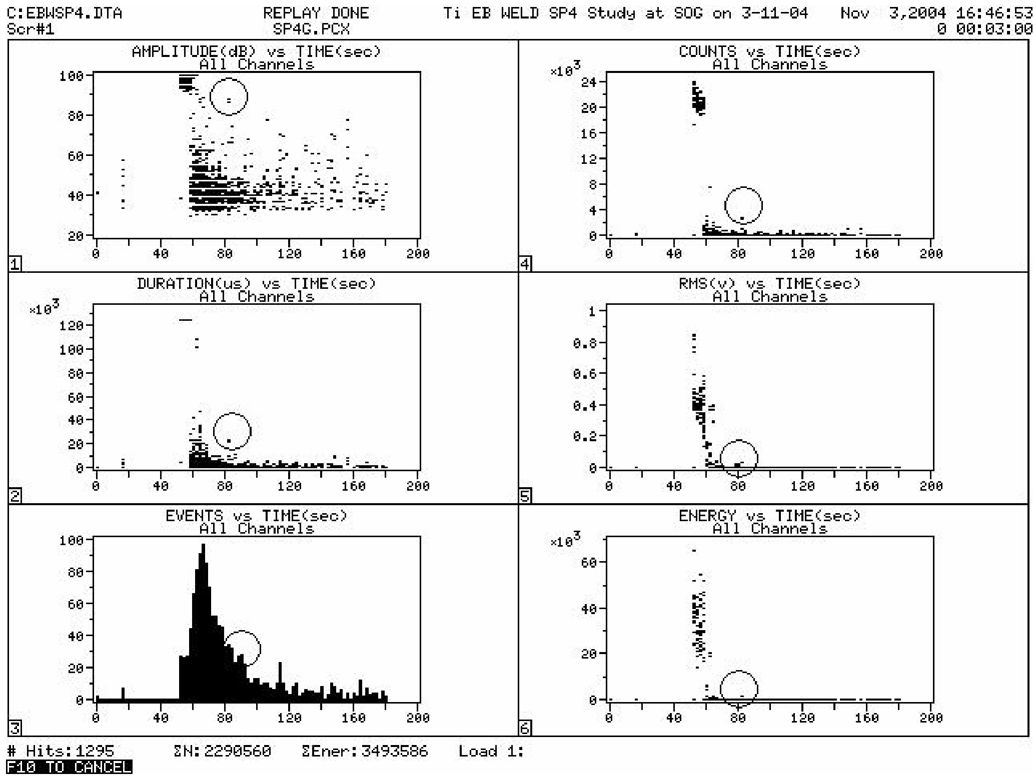

Fig. 10: AE Performance of Specimen 4 (Full Weld)

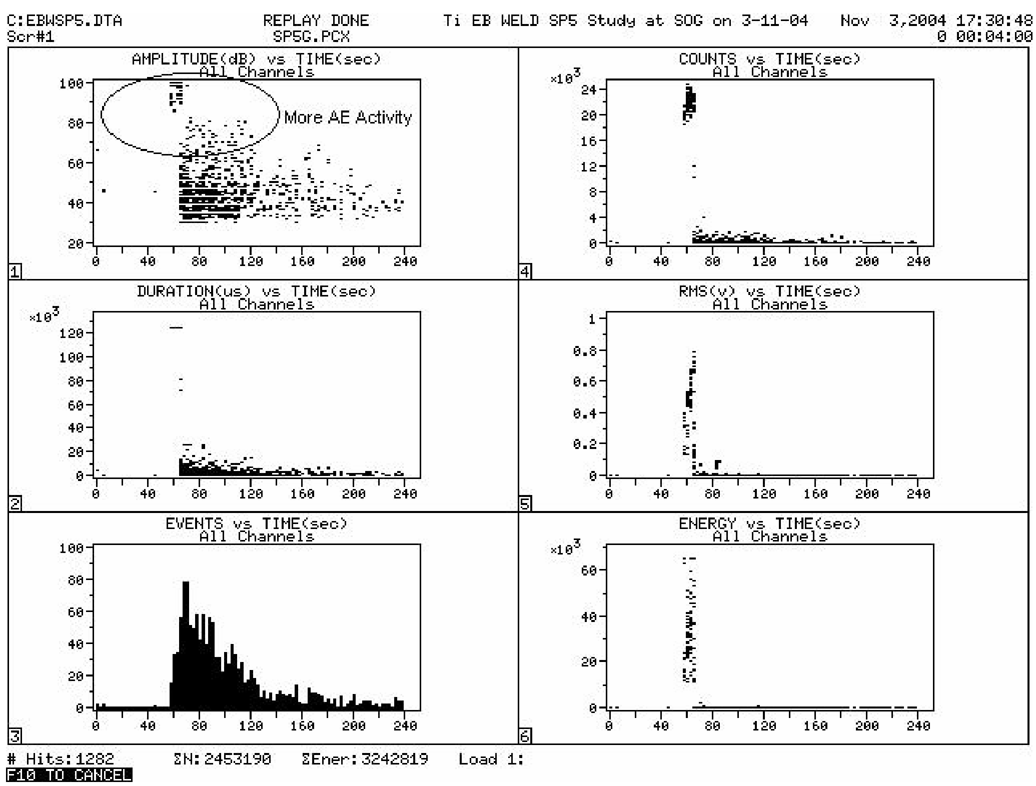

Fig. 11: AE Performance of Specimen 5 (Full Weld)

Formation of defect could not be detected during welding process, but during solidification defect formation was detected. It may be due to the reason that defects like porosity, crack, shrinkage, etc may have occurred during the solidification stage.

3.3 Observations during Seam Welding Process

For specimen 3, prior to the seam welding spot welding was carried out at three locations on the weld joint. These spot welds are clearly identifiable with increased AE activity (Refer Fig. 6, circled areas).

During seam welding of specimen 3, as penetration was very low (0.2 mm) very less solidification time (100 sec) was observed. All AE parameters were of low values and formation of defect also could not be observed (Refer Fig. 7, braced area).

During seam welding of specimen 3, amplitude was about 100 dB and duration was 120 milli seconds, same as in the case of full welding. But RMS voltage and energy levels were very low, as compared to full depth weld. Thus, by analyzing the variation of the RMS voltage and energy levels, variation in depth of weld can be found out (Refer Fig. 7, circled area).

Similar kind of activity is seen while seam welding of specimen 4 (Refer Fig. 9, circled area).

3.4 Observations from Radiographic Results

3.4.1 Bad Welds

In specimen 1 (Refer Fig. 4, circled area), high Amplitude signal of 95 dB is noticed at 83 seconds, i.e., during solidification process. This sudden rise in amplitude is associated with increase in duration time (50 ms), no of counts and RMS voltage (0.1 V). This indicates that some activity has occurred at that particular time in the weld zone. Radiographic results of the specimen show presence of porosity, depression and lack of fill in the weld area.

A similar kind of activity is seen while welding specimen 2 (Refer Fig. 5, circled area) at 90 seconds. Radiographic results of the specimen show presence of very fine porosity, spatters and concavity in the weld area. This indicates that formation of defect is associated with AE activity and could be detected by AE monitoring.

For specimen 5, radiographic results confirm pores and spatters at the locations of insertion of cotton thread and silicon grease. An undercut was seen at the location where metallic wire was inserted. The results of this weld was also comparable with that of specimen 1 & 2, but with a difference that in this case the duration of high amplitude signals and corresponding activity was more (Refer Fig. 11, ellipsed area).

3.4.2 Good Welds

After full welding of Specimen 3, high amplitude signal of about 90dB was seen at 80 seconds and 160 seconds (Refer Fig. 8, circled area). At the same time, duration was about 20 milli seconds. But the RMS voltage and energy level were very low. Radiographic result showed that specimen has good weld with minimum defects. It was noticed that higher amplitude signal and more duration does not confirm to a defect. But at the same time, if RMS voltage and energy levels are high, it may correspond to a defect (as in the specimen 1 & 2). A similar kind of activity is seen while full welding of specimen 4 (Refer Fig. 10, circled area). For both specimens 3 & 4, welds were found good with lesser porosities as seen from the radiographic results.

3.5 Observations during Solidification Process

Usually air is pumped inside the vacuum chamber after 10 seconds of completion of welding, but as per AE indications, it takes nearly 180 seconds for completion of solidification. So it is expected that some micro structural (martensitic transformation) changes may happen due to early air admittance [5].

With the limited amount of data generated during this study, it is difficult to establish any relation without ascertaining creditability and repeatability. But it may be hinted by this study that during the solidification process if AE parameters are as follows:

Peak Amplitude > 80dB, Duration > 20 milliseconds, and RMS > 0.1 V, then it signifies some form of defect formation.

From the results it follows that the output of AE sensor can be fed to a central computer [2], which can verify the weld criteria based on AE parameters. If any deviation is observed, the central computer will give command to EBW machine for correction. The defect can be corrected by varying the EBW parameters like, beam current, gun travel speed, focus current etc. Thus a closed loop consisting of AE system, EBW machine and a control unit can result in good weld with minimum cost and time (Refer Fig. 3).

4. Conclusion

This study shows that correlation of defect characteristics with AE parameters is feasible. However for developing a routine AE monitoring system for EBW, more specimen level studies are to be carried out.

Empirically, the parameters for AE may be related to welding as stated in Fig. 3. All specimen welds have confirmed this criterion. Once the above AE criteria is established, occurrence of defect in the weld can be confirmed instantly and correction or repair in the weld zone can be done immediately, without disturbing the job setting in the EB machine. Hence, this method of evaluation of defect and online monitoring can save considerable time and cost during the welding.

5. References

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