Characterization Of Appendage Weld Quality By On Line Monitoring Of Electrical Parameters

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Abstract

Resistance projection welding of zirconium alloy appendages is one of the most critical processes in the PHWR fuel fabrication. Appendages like Spacers and Bearing pads having multi projections are joined to the fuel sheath using capacitor discharge power source. Variations in the projection sizes, weld parameters and cleanliness of the work pieces have significant effect on the weld quality, in addition to material properties like hardness, tensile strength and surface finish.

Defects like metal expulsion and weak welds are occasionally observed in appendage welding process, which need to be identified and segregated. Though numerous off-line inspection methods are available for the weld quality evaluation, on-line monitoring of weld quality is essential for identifying defective welds. For this purpose, various monitoring techniques like acoustic emission, analyzing derived electrical parameters and weld upset/deformation measurements are employed. The derived electrical parameters like A^2-Sec and Ohm-Sec can also be monitored.

The present paper highlights development of suitable acceptance criteria for the monitoring technique by employing derived electrical parameters covering a wide range of weld variables like watt-sec and squeeze force. Excellent correlation could be achieved in identifying the weak welds and weld expulsion defects in mass production.

1.0 INTRODUCTION

Resistance projection welding is generally used for joining either different thickness or dissimilar materials, which has other advantages like low HAZ, high speed, and suitability for automation [1]. Zirconium alloy appendages having multiple projections are welded to the thin wall fuel sheath by employing resistance projection welding process. With the usage of inert gas shielding, short weld times and pre/post heating, the weldability of zirconium alloy is enhanced. At present appendage weld quality is being evaluated by off-line testing methods like visual inspection, shear strength testing and dimensional inspection. The main weld process parameters, that affects the weld quality are electrode force and heat, which are optimized based on number of variables like electrical contact resistance, base material characteristic etc. Occasional defects like weak welds and metal expulsions are observed in the process resulting in rejection of finished fuel element. Main reasons for these defects are due to variations in welding parameters and component dimensions. Initially, qualifying this technique was observed to be difficult because of parallel and simultaneous welding of multiple projections with single electrode, which results in wide variations in initial contact resistance and shear strength values. Adoption of individual electrodes for each projection welding solved this problem.

On-line monitoring of resistance welding process has been attempted by employing non-destructive methods like UT, Acoustic Emission Technique (AET) and also measuring weld upset, dynamic resistance and electrical parameters. These methods are used either to indicate the weld quality or to control the weld quality by on-line correction of one or more of the machine controlled welding parameters. UT and AET methods are high cost and fragile in nature, which make them un-suitable for mass production. [4]. In the present appendage welding process, due to short weld times and thin components to be joined, weld upset is very small and its usage for on-line monitoring of weld quality is not reliable. Monitoring of dynamic electrical parameters is cost effective and reliable, hence best suitable for this type of mass production applications. The advantage of this technique is that this does not require complicated sensors. Characterization of resistance welding process using initial / static resistances and RMS currents is not representing the complete picture of weld quality. For complete characterization of the resistance welding process, a continuous or dynamic monitoring system is required. This system monitors and records the instantaneous changes taking place in the electrical parameters during welding operation [2-6]. In the present appendage welding process, which employs capacitor discharge power source with short weld times and close projections, it is very difficult to identify good and bad welds using conventional RMS current and watt-sec measurements. To over come this problem a new technique, using electrical parameters like A^2Sec and Ohm-Sec are selected.

The objective of present study is to characterize the appendage welding quality with the help of a technique that monitors dynamic electrical parameters, from the logged current and voltage values. Electrical parameters like A^2Sec and Ohm-Sec are derived and displayed in the weld sentry. In the present process only A^2Sec and Ohm-sec parameters are selected, because the percentage variation from the acceptable average is very high and they are very sensitive to small changes in the process. The following sections of the paper describe the weld acceptance criterion evolved with the help of above electrical parameters, for the on-line monitoring of weld quality in mass production.

2.0 EXISTING WELD QUALITY EVALUATION AND CONTROLLING METHODS

Presently process quality is being evaluated by following off-line destructive and non-destructive testing methods. Statistical quality control tools are used for controlling the regular process quality.

a. Visual Inspection: Appendage welds are inspected visually for colouration, sparking, arc gouging etc.
b. Shear strength testing: This test tells about the actual shear strength of the weld. Minimum 60 Kgf shear strength is required with less than 0.05mm sheath indentation on the ID of tube. No single sample should report low strength (less than 60 Kgf) and also Mean-2*sigma should be greater than or equal to 60 Kgf with sigma less than 6. Optimum weld parameters are achieved by 100% strength testing of production-simulated samples.
c. Dimensional inspection: Appendages are welded to the fuel sheath at specified locations and with pre-determined orientation. For ensuring the machine settings, dimensional inspection is carried out.

3.0 EXPERIMENTS

The experimental procedure was divided into three stages, 1.Analysis of production runs 2. Analysis of process deviations 3. Analysis of electrical parameters under above conditions. Welding was performed on pneumatically operated split electrode resistance welding machine using 500 watt-sec capacitor discharge power source. The electrical parameters were monitored with the weld sentry devices connected to each electrode.

The data obtained by using this technique has been analyzed to correlate these parameters with the defect occurring in the welding process. During experimentation, parameters like hardness, surface finish and material properties are taken as constant and uniform. For evolving the new acceptance criteria of appendage welding process, both normal and abnormal (deviated) process conditions were experimented. On production machine and with optimized weld parameters, the data of electrical parameters was logged for standardizing the acceptable upper and lower limits. Under abnormal process conditions, variations in heat (Watt-Sec), force and secondary circuit resistance were taken into consideration. Voltage and currents are logged from the secondary side of pulse transformer using weld sentry of 25 K sample rate capacity, which in turn calculates the derived electrical parameters and are transferred to a computer for generating average, standard deviation and their graphical presentation.

3.1 PRODUCTION RUNS

Welding equipment is used for regular mass production after optimizing the weld parameters and machine settings. The optimized weld parameters for this critical operation are heat for both electrodes using single source is 90 watt-sec and Squeeze pressure is 2.0 Kg/Sq.cm on each electrode. Process quality is evaluated and maintained by destructive shear strength testing of set-up, process and random welds at regular intervals. The results of these production welds tested by existing methods are shown in Table 1.

TABLE 1: RESULTS OF PRODUCTION WELDS EVALUATED BY EXISTING METHODS

S.No	Inspection Method	Left Electrode	Right Electrode
1	**Visual**		
	(a) Weld Impression	OK	OK
	(b) Colouration	NO	NO
	(c) Sparking	NO	NO
	(d) Arc Gouging	NO	NO
2	**Dimensional**		
	(a) Orientation	OK	OK
	(b) Location	OK	OK
	(c) Sheath ID Depression	With in Limits	With in Limits
3	**Shear Strength**		
	(a) Average	88.82	86.2
	(b) Std.Dev.	5.15	4.22
	(c) Mean-2 sigma	78.5	77.74

3.2 PROCESS DEVIATIONS

In actual mass production, deviations in weld parameters and material conditions occur, which influences the weld quality. These process deviations are acceptable up to certain limits and beyond which welds are treated as defective and requires identification either for removal or for correcting the process. Generally variations in weld parameters are the reasons for defects like weak welds and metal expulsion. Defects due to reverse spacer pad welding, which are occasional in nature and are also taken into consideration. All these process deviations are simulated for their identification using this new technique.

3.2.1 Effect of Heat (Watt-Sec):In order to examine the effect of varying heat levels on weld quality, number of welds were made with different heat values. Lower heat gives weak welds up to certain value and there after increases the weld strength. Higher heat results in weld expulsion defect. Both weak weld and weld expulsion conditions are not acceptable in the regular production. Heat values set for combined electrodes at common source are varied from 70 to 130 watt-sec with 10 watt-sec increments by keeping all other process variables constant. Electrical parameters were collected for the both electrodes and are compared with acceptable average and percentage variations are given in Table 2.

3.2.2 Effect of squeeze force: In order to examine the effect of electrode force on the weld quality, welds were made by varying squeeze pressure from1.5 to 3.5 Kg/sq.cm, keeping all other process variables constant. In general, variation in electrode force happens due to leakage in seals or increase in the friction of moving electrodes. Lower force gives metal expulsion and weak welds and higher force gives weak welds and more ID indentation. Data of the electrical parameters and the percentage deviation from the acceptable average for each electrical parameter are given in Table 2.

3.2.3 Effect of secondary circuit resistance: Secondary circuit resistance is one among the weld parameters that were standardized for a given set of optimized machine settings. Increase in secondary circuit resistance (1100 micro ohms) influences the weld quality very much due to increase in heat losses leaving less heat generation at the weld joint, which leads to weak welds. The data of electrical parameters are given in the Table 2.0 along with percentage variation from the acceptable average.

3.2.4 Reverse spacer pad welding: In the existing welding process, due to small size of appendages, occasionally spacer pads are positioned in reverse direction leading to rejection of the element. Even though this can be identified by visual inspection, a miss will result in spacer pad detachment during subsequent operations, which is very expensive. The data of electrical parameters for this condition, along with the percentage variation from the acceptable average are given Table 2.

TABLE 2: ELECTRODE WISE PRODUCTION WELDS AND PROCESS DEVIATION WELDS ELECTRICAL PARAMETERS DATA.

Right Electrode weld Data				
Combined Heat (Watt-Sec)	**Ohm-Sec**	**% Variation**	**A^2-Sec**	**% Variation**
70	7.02E-05	19	4430	-30
80	6.50E-05	11	5245	-17
100	5.61E-05	-5	7084	12
110	5.44E-05	-7	7638	21
120	5.32E-05	-10	8434	34
130	4.67E-05	-21	9337	48

Sq.Pressure (Kg/sq.cm)				
1.5	5.68E-05	-3	5913	-6
2.5	5.10E-05	-13	6432	2
3.5	5.14E-05	-13	6299	0
Secondary Circuit Resistance (micro-ohm)				
1100	5.58E-05	-5	6047	-4
Reverse Spacer	**5.30E-05**	**-10**	**6741**	**7**
Left Electrode Weld Data				
Combined Heat (Watt-Sec)				
70	4.90E-05	-9	4880	-27
80	4.75E-05	6	5556	-17
100	4.39E-05	-2	7479	12
110	4.20E-05	-7	8262	24
120	4.10E-05	-9	8780	32
130	3.90E-05	-13	9679	45
Sq. Pressure (Kg/sq.cm)				
1.5	4.60E-05	2	6311	-5
2.5	3.90E-05	-13	7389	11
3.5	3.70E-05	-18	7719	16
Secondary circuit Resistance (micro-ohms)				
1100	4.70E-05	4	5998	-10
Reverse Spacer pad	**5.40E-05**	**20**	**4740**	**-29**

4.0 ANALYSIS AND RESULTS

The data of shear strengths and electrical parameters for individual electrodes is collected for all the welds, for analysis purpose. The results of the production welds and corresponding electrical parameters were analyzed for fixing the acceptable upper and lower control limits. A^2Sec and Ohm-Sec parameters are used for on-line controlling of the appendage welding process.

Based on the higher percentage deviation for left electrode, A^2Sec is monitored and this value should be with in **6486.22 to 6854.64** and Ohm-Sec parameter should be with in **4.40E-05 to 4.63E-05,** are best suitable for identifying process variations in the regular mass production as shown in Table 3. Similarly limits are given for right electrode in Table 3. **A^2Sec** identifies variations in heat as shown in Figure 1. **Ohm-Sec** identifies variations in force, secondary circuit resistance and also reverse spacer conditions in the present process as shown in the Figure 2. Figure 3 and Figure 4 depicts the variation of **A^2Sec** and **Ohm-sec** with time.

TABLE 3:
ELECTRODE WISE ACCEPTABLE LIMITS FOR PRODUCTION WELDS

	Statistical parameters	**A^2Sec**	**Ohm-Sec**
Left	Average	6670.43	4.52E-05
	Standard Deviation	277.92	2.05E-05
	UCL	6854.64	4.63E-05
	LCL	6486.22	4.40E-05
Right	Average	6300.56	5.9E-05
	Standard Deviation	192.76	1.9E-05
	UCL	6424.80	5.9E-05
	LCL	6176	5.7E-05

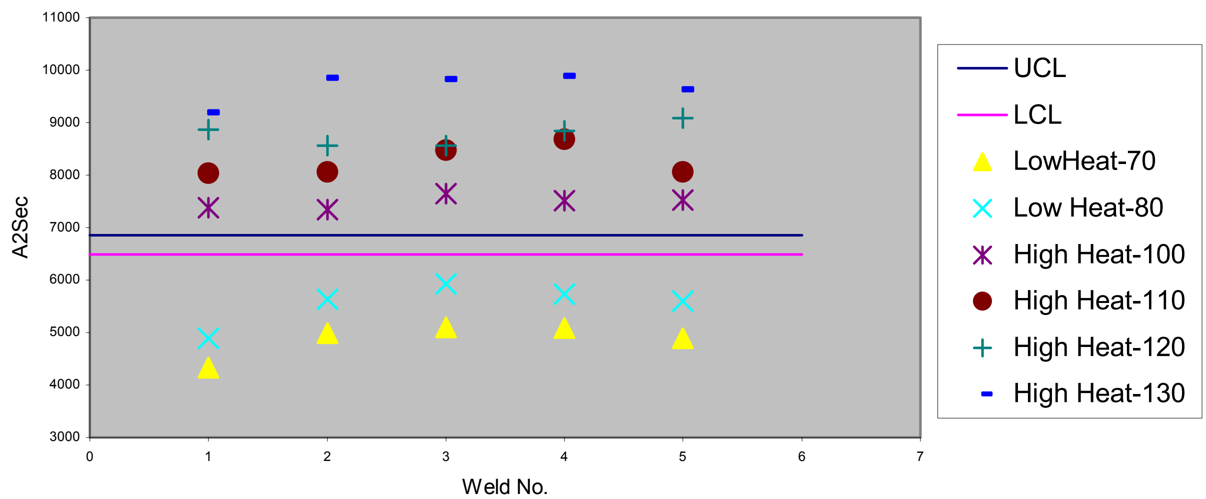

FIG. 1 MONITORING OF HEAT VARIATIONS USING A^2Sec PARAMETER.

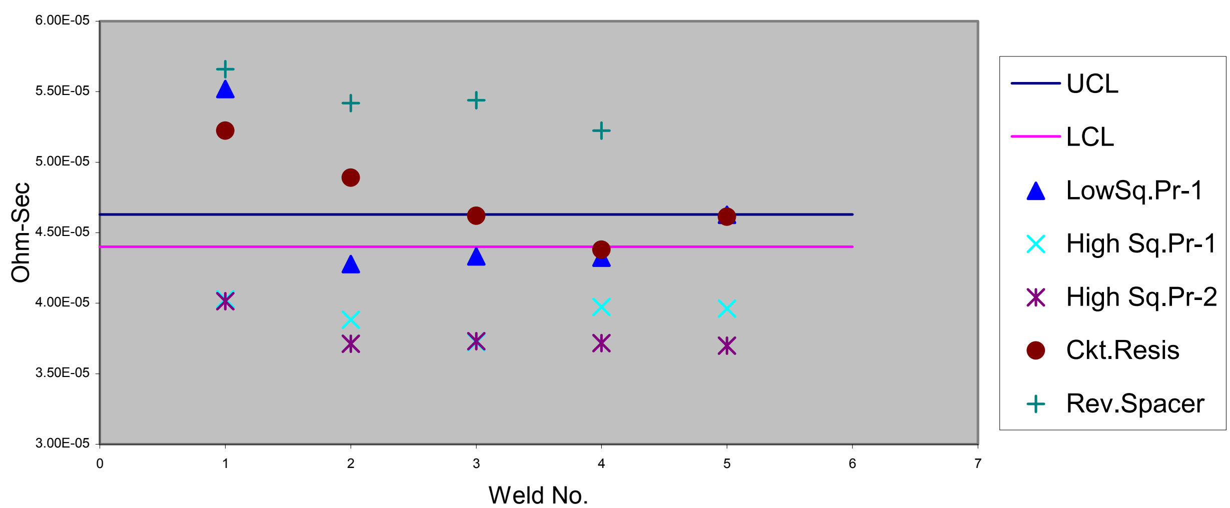

FIG.2 MONITORING OF FORCE, CIRCUIT RESISTANCE AND REVERSE SPACER CONDITIONS USING OHM-SEC PARAMETER

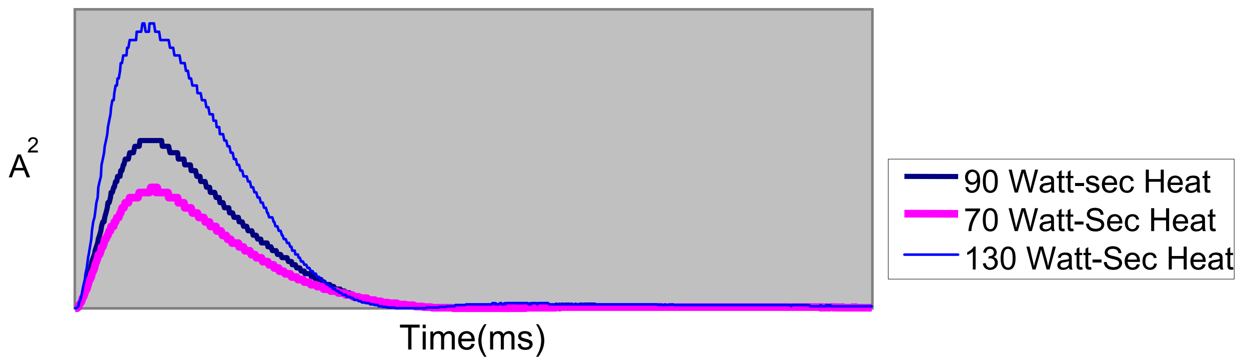

Fig. 3 A^2 Vs TIME

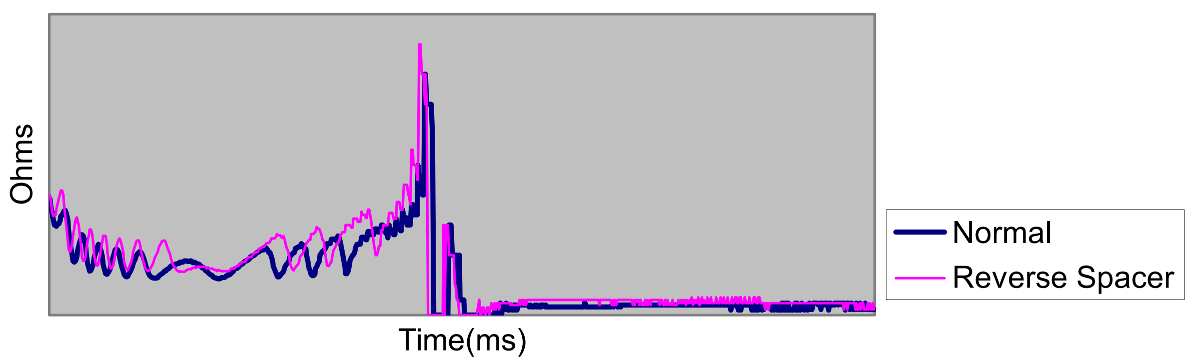

Fig. 4: WELD JOINT RESISTANCE Vs TIME

5.0 CONCLUSIONS

1. Presently appendage weld quality is maintained by off-line testing methods like visual, dimensional and strength testing.
2. Compared to UT, AET and Weld Upset Measurement techniques, electrical parameters monitoring is best suited for the tiny zirconium alloy appendage welding process, which uses capacitor discharge type power source and short weld durations.
3. Variations in heat are best identified by A^2Sec parameter.
4. Variations in force, secondary circuit resistance and reverse spacer conditions are well identified by Ohm-Sec parameter.

6.0 SCOPE OF FURTHER WORK

In the present study only spacer pad welding operation is selected for evolving suitable acceptance criteria using the electrical parameter monitoring technique on the split electrode type-welding machine. Based on the encouraging results in identifying process deviations, the same technique can be used on bearing pad-welding process also. Remote monitoring of the process is possible by connecting the weld sentry out put to a net-computer for analyzing the transferred data and is compared with acceptable limits, which are already specified.

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