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Monitoring and Quality Control of Stud Welding

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Abstract

This study is conducted to carry out a straightforward way appropriate for quality monitoring and stability of arc stud welding process, followed by a number of procedures to control the quality of welded samples, namely torque destructive testing and visual inspection context. Those procedures were being performed to support the monitoring system and verify its validity. Thus, continuous on-line monitoring guarantees earlier discovering stud welding defects and avoiding weld repeatability. On-line welding electronic monitoring system is for non destructive determining if a just completed weld is satisfactory or unsatisfactory, depending on welding current peak value detected by the system. Also, it has been observed significant harmonize which is mutually linking the monitored current peak values and quality control measures. So this concept is accordingly contributed in the process of supporting the fundamental objective of this research. On the other hand, two feed-forward neural networks have been developed for monitoring and control arc stud welding quality. First network predicts two output quality parameters (current peak value) and (torque testing value at failure). Second, predicts one output quality parameter (visual inspection). Networks have been trained to a set of data, which made them ready to receive new information for subsequent quality parameters prediction. Both networks showed up good response and acceptable results.

Keywords: (Arc stud welding, Current peak value, Electronic Welding monitoring system, Stud welding torque test, Neural Networks)

1. Introduction

Arc stud welding (SW) is a welding process in which a metal fastener (weld stud) is joined to a workpiece. The metal fastener is joined under pressure once sufficiently heated with an electric arc. The weld stud is positioned for welding through the use of a stud gun. When the operator activates the stud gun trigger, the fastener (electrode) is welded to the workpiece without the use of filler metal. The welding duration of SW is typically one second or less. One end of a SW fastener is prepared for welding. A ceramic ferrule surrounding the weld end of the fastener provides partial shielding of the weld. The ferrule also dams the molten metal to form a fillet type weld [1]. Figure (1) shows a schematic diagram of stud welding setup. SW is a well established process for attaching studs to a variety of material thicknesses and coating combinations in automotive construction. The application of arc stud welding is consistent with new automotive designs and manufacturing strategies that continually focus on ways to reduce costs [2].

Ferrule also dams the molten metal to form a fillet type weld [1]. Figure (1) shows a schematic diagram of stud welding setup. SW is a well established process for attaching studs to a variety of material thicknesses and coating combinations in automotive construction. The application of arc stud welding is consistent with new automotive designs and manufacturing strategies that continually focus on ways to reduce costs [2].

Monitoring weld quality in real time is increasingly important since great financial savings are possible, especially in manufacturing where defective welds lead to losses in production and necessitate time-consuming and expensive repair. The task of a weld monitoring system is to use captured signals to classify a weld into defective or nondefective groups. The signals of the welding process such as welding voltage and current can be used as variables. However, external sensors are expensive and restrict the mobility and flexibility of some automated arc welding systems. By comparison, welding voltage and current are inherent process parameters and are easy to measure. Moreover, their curves reflect many peculiarities of the welding process in their shape. Each kind of arc welding process is characterized by certain shapes of the welding voltage and current typical for the process. Any disturbances or occurrences of faults during welding inevitably result in variation of these curves to some extent [3]. Therefore, quality assurance in arc stud welding may be achieved through examining welding voltage and current.

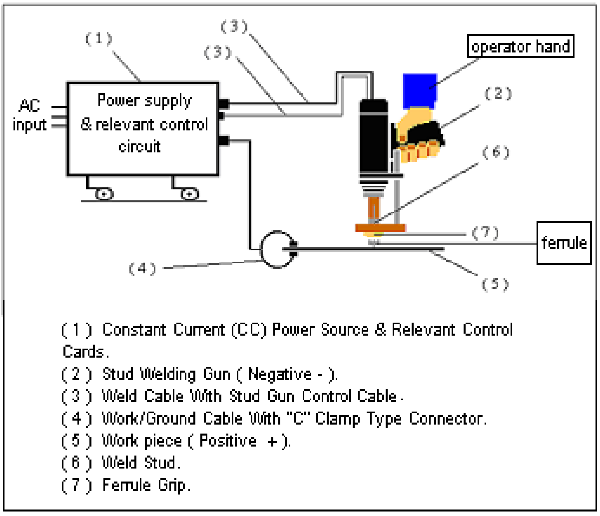


Fig.1. General Stud Welding Setup

Weld voltage and current comprise the basic welding electrical parameters. All other electrical parameters such as resistance and power are calculated from these two parameters. Common measurement techniques include: peak value, root-mean-square (RMS), average, and time integration. Peak value measurements are more sensitive to potential changes in the welding process and noise spikes. RMS, average, and integration measurements filter out the noise spikes, but may mask potential weld quality information [4]. In this work, current peak value is adopted as a main for monitoring and investigating the SW quality.

In [2] conducted to evaluate the robustness of the arc stud welding process as applied to a range of uncoated and galvanized sheets. Within this literature, a range of process, manufacturing, and materials variables were investigated including type of stud coating, level of collets wear, polarity of the stud, type of power supply used, design of the welding stud, thickness of the substrate sheet, presence of any surface oils, and coating condition of the steel. Measures of weld quality in this study included shear, tensile, torsion, and bend testing. Some metallographic support work was also done. While [3] introduced a fuzzy logic system that is able to recognize common disturbances during automatic gas metal arc welding (GMAW) using measured welding voltage and current signals. In [5] described the technical features of four electro-optic sensors for the monitoring of arc welding. The energy released in the process determines the formation of a strongly radiative plasma in the interaction zone. While [6] proposed a new approach for real-time weld quality monitoring based on the combination of optical sensors with fuzzy logic classification algorithms. The sensing hardware encompassed A/D converters and photodiodes measuring the radiations emitted by the plasma surrounding the welding arc. In [7] presented an efficient approach to identify the stability and quality of short-circuit gas metal arc welding (GMAW) by using power spectral analysis and time-frequency spectral analysis methods. A systematic analysis based on experimental data showed that the short circuiting frequency is a determining factor on weld process stability. The relationship between the short-circuiting frequency and the process stability was established. While [8] presented a real-time ultrasound-based system for controlling robotic weld quality by monitoring the weld. The weld penetration depth is one of the most important geometric parameters that define weld quality, hence, remains a key control quantity. The sensing system was based on using a laser phased array technique to generate focused and steered ultrasound, and an electromagnetic acoustic transducer (EMAT) as a receiver. In [9] described exploratory experimental procedures implemented for the development of a non-intrusive and real-time sensor for weld defect tracking which uses emission spectrometry for measuring the electromagnetic content of the plasma-weld pool interface in the GMA welding arc. The welding process monitoring was carried out by calculating the iron (Fe) and the manganese (Mn) electronic temperatures within the welding arc column, admitting that the observed region is at local thermodynamic equilibrium. The temperature was calculated by utilizing the relative intensity method, which is based on the Boltzmann and the Saha Laws and on the definition of the emission line intensity. While [10] conducted to evaluate reducing manufacturing process variability by the use of experimental design technique for stud welding process. Design of Experiment (DoE) is a structural and organized method for determining relationships between factors affecting a process and output of the process itself. It shows that systematic optimization techniques are always preferable. Tensile strength quality is one of the key properties in achieving good welding process. It focuses on reducing tensile strength variation of this type of arc welding process that lead to improve weld quality. In [11] developed a system and method for predicting weld quality in a stud welding system by measuring the displacement of a movable shaft with respect to the gun body during the weld process. A sensor was positioned with respect to the welding system in order to produce a series of discrete signal values each indicative of this displacement. These values were plotted graphically and used to produce a weld "signature" which can be compared with signatures of welds of known quality to more accurately predict the quality of the current weld. While [12] developed a weld monitoring and evaluating circuit for non-destructively determining if a just-completed weld is a satisfactory or an unsatisfactory weld. The circuit was used to derive the temperature at the weld zone in real time by determining the total power input to the weld zone, taking into account losses experienced at the weld zone, and dividing the result by the thermal mass of the weld zone. The predicted temperature at the weld zone was compared against an electrical signal representing at least a minimum desired welding temperature needed to be attained at the weld zone to produce a satisfactory weld at the time that the stud contacts the weld pool (e.g., the "plunge event").

Many types of sensors, based on thermal, sonic, ultrasonic, infrared, or optical radiations, have been suggested and developed in weld monitoring. However, it is important to mention that because the measurement of the welding arc signature near the weld is obstructed by a number of phenomena like high temperature, spattering, fuming and electromagnetic noise, and the relatively high installation cost of available sensing systems [13], the *current sensor (Current Transformer) is used in this study*, as a weld quality sensor to monitor weld quality.

2. Theory of Arc Stud Welding Quality Control and Monitoring

Current peak value reached during initiation of arc stud welding is representing the key factor reflects welding quality [12]. Referring to figure (2), the relationship between the arc voltage and current generated by the welding power supply at various steps of welding process is shown. This value is affected by a number of variables, may cause it to change depending on type and number of those variables, like changing welding conditions, misuse of welding equipments and/or equipments faults. In case finding a visible variation in current peak value, this leads to doubt in welding quality and that means welding process should be altered for more investigations and troubleshooting.

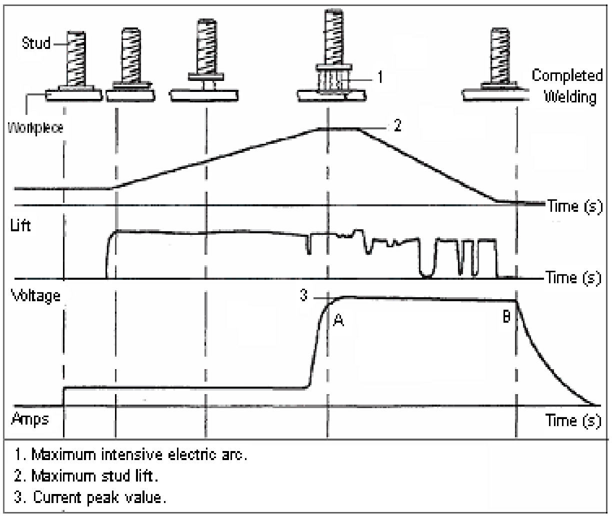


Fig.2. During Welding Cycle, This Graph Illustrates Relationship Between the Stud Lift, arc Voltage and Welding Current at Various Points of Stud Travel Relative to the Surface to Which Stud is Being Welded [12].

Sketches shown in figure (3) represent the standard weld investigations which are adopted in this work. Importance of amperage on welding quality with weld defects resulting from welding current variation can be observed. Sketch (A) represents welds problem when plunge of stud is too short or weld encounters high amperage, *plunge is the portion of the stud to be used in forming the weld fillet*. This occurs when the stud base is partially melted away and the stud appears to be perched on a small portion of its base metal. Sketches (C) and (D) represent the weld problem when not enough or too much amperage is consumed, where (C) is named a cold weld in which the weld fillet is not formed completely. Where (D) is called a hot weld and can be identified by a concave that is close to workpiece surface [1, 14].

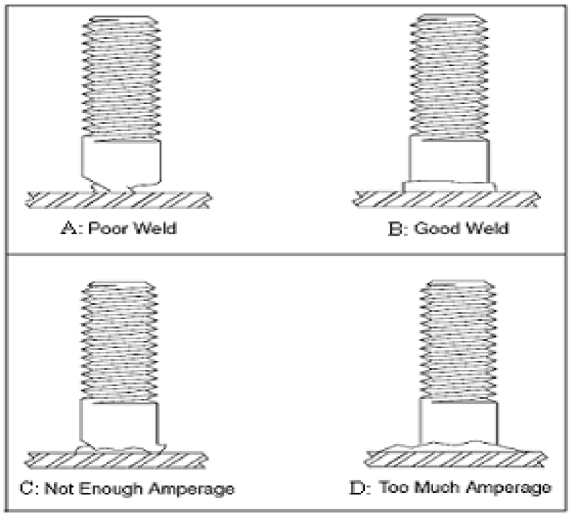


Fig. 3. Common SW Problems [1].

Also, destructive torque test and visual investigation are developed for welded stud samples and are taken as a proof which supports good performance of the monitoring system which is used in the present paper [1, 2, 8, 14, 15, 16].

Neural networks offer improved performance over conventional technologies in areas which includes: manufacturing process control, product design and analysis, process and machine diagnosis, real-time particle identification, visual quality inspection systems, welding quality analysis, paper quality prediction, computer-chip quality analysis, analysis of grinding operations, chemical product design analysis, machine maintenance analysis, project bidding, planning and management, dynamic modeling of chemical process system [17].

For the purpose of performing reliable processing to the results obtained in this research, it has been established two separate neural networks:

1. Developing ANN model utilizing quality parameters (welding current peak value – torque test value at failure).
2. Developing ANN model utilizing visual inspection parameters.

3. Experimental Work

Experimental work will be carried out according to a plan developed for this purpose which is shown in figure (4). It begins on performing (Monitoring) by an electronic system, followed by procedures implementing both (quality control) and (quality investigation). Obtained data are then processed through the use of ANN, designed for this objective.

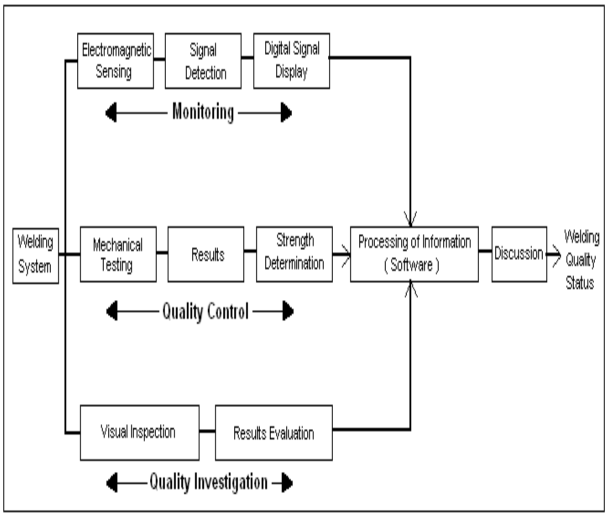


Fig.4. SW and Quality Monitoring and Control (Experimental Plane).

3.1 Experimental Procedures of Monitoring & Control Process:

For the purpose of well performing monitoring process of (SW), there is a need to select parameters that clearly reflect the quality and validity of welding sequence. These parameters can be achieved through the following steps:

- First: performing welding process on the selected sets of studs and workpieces under different welding conditions. Those conditions have been determined as follows:

1. Studs of three different diameters.
2. Workpiece of three different thicknesses.
3. Selecting four current ranges.
4. Choosing different welding time durations.

(Table (1) presents the Experimental parts & conditions).

- Second: Availability of electronic and mechanical equipments of qualified technical specifications ensures good fit to the present requirements and successful monitoring and control of the welding process. Table (2) shows the instruments used to achieve SW quality monitoring. Where, CPM is electronic device which is used to measure welding current peak value during SW operation. It has high response sensing capability which is needed to meet the requirements of SW monitoring process. The CPM works as follows: during welding cycle, the device receives electrical signals from the current transformer (CT). It detects the peak value reached among these signals, the detected value is then stored and displayed on digital screen for a period of (1 minutes), which is sufficient for operator to record reading. The device is then ready to push reset button for subsequent welding cycle.

Table 1,
Experimental Parts and Conditions.

Conditions and components	Description
Stud Welding Machine	DABOTEK – DT1000
Welding Current Range	Four ranges (2, 3, 4, 5); setting by a current selector switch
Welding Time	(0.1 to 0.55) sec; setting by time selector knob
Studs	(ASTM 40CrMnMoS8-6 steel),(D:8,10, 12)mm
Workpieces	(ASTM K14358 steel) (non–Galvanized) (T:2,4,6)mm
Ferrule Grip	Metallic; 5 pieces; (manufactured in local market)
Ferrule	Ceramic ferrules (modified in local market)

Table 2,
Instruments Used.

Instruments	Description	Mounting
Current sensor	Current transformer (CT); Type: MSQ-60, Class: 1, VA=10, Ratio: 1000/5 A	Around welding cable
Current Peak Monitor	An electronic system (CPM)	Components and cards are mounted in a separate case
Torque Wrench	Beam type with scaled indicator	Used in stud welding torque test

3.2 Experimental Setup & Operation:

The details of experimental set up and instrumentation are clearly shown in figure (5). The procedure of working operation begins on:

1. Selection welding conditions for each welding run (stud diameter, workpiece thickness, current range and welding time settings) as in tables (3 ~ 5).
2. Setting up stud gun in accordance with manufacturer's recommendations and adjusting gun legs so that stud extension beyond ferrule is as recommended.
3. Workpiece should be well fixed by a suitable vise in the horizontal level, prior to the welding process.
4. Cleaning area where stud is to be placed and grinding or scraping area to remove any surface contaminants.
5. Stud gun should be positioned perpendicular to the workpiece and depressed until the ferrule is firmly seated against the workpiece. The ferrule should remain firmly seated until the trigger is actuated.
6. The trigger should be actuated once and released.
7. At the completion of the weld time, the gun should be held in position momentarily to allow solidification of molten metal. Then gun has to be removed and ferrule chipped away.
8. Meanwhile during each welding cycle, the welding current hits a peak during very short period of time (fraction of second). By current peak monitor (CPM), it will be possible to detect and display the current peak value on the digital screen. The monitored reading is then recorded by the operator.
9. Performing weld visual inspection to investigate the welding quality of the experimental samples according to the global standards and to ensure whether our welding is consistently conforming or not the quality requirements.
10. Destructive torque test is then performed to check weldment durability and strength. Torque is applied to the wrench arm by the operator. While applying the force, the operator continues watching wrench scale until failure occurs, at this moment the reading should be immediately recorded.

Twenty welding runs have been conducted in the laboratory for different welding conditions prepared in advance for this purpose. *Seven runs* carried out on a set of studs (8 mm) diameter, *seven* on studs (10 mm) diameter, and *six* on studs (12 mm) diameter.

Table 3,
Runs for Stud of (8 mm) Diameter.

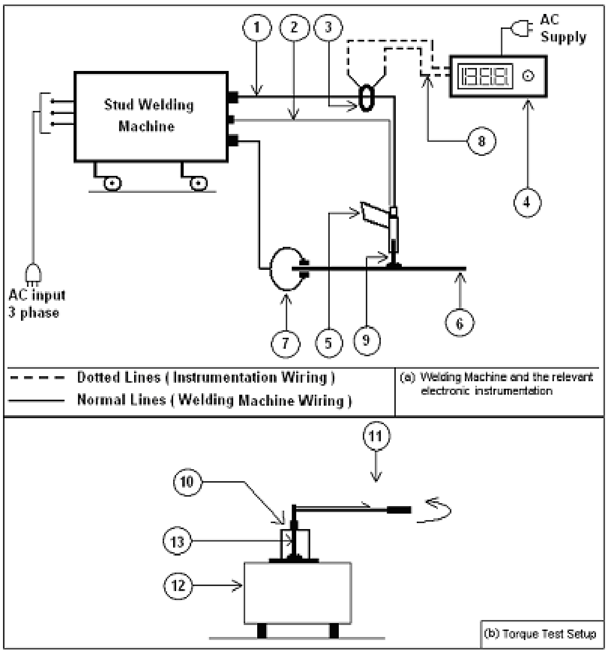
Run	Welding Status	Welding Time Setting (Sec.)	Sheet Thickness (mm)	Current Range Setting - Positions (1 → 5)
1	Recommended Welding Conditions	0.25	4	3
2	Lower Current Range	0.25	4	2
3	Higher Current Range	0.25	4	4
4	Less Sheet thickness	0.25	2	3
5	More Sheet thickness	0.25	6	3
6	Less Welding time	0.1	4	3
7	More Welding time	0.4	4	3

Table 4,
Runs for Stud of (10 mm) Diameter.

Run	Welding Status	Welding Time Setting (Sec.)	Sheet Thickness (mm)	Current Range Setting -Positions (1 → 5)
1	Recommended Welding Conditions	0.3	6	4
2	Lower Current Range	0.3	6	3
3	Higher Current Range	0.3	6	5
4	Less Sheet thickness	0.3	2	4
5	More Sheet thickness	0.3	4	4
6	Less Welding time	0.15	6	4
7	More Welding time	0.45	6	4

Table 5,
Runs for Stud of (12 mm) Diameter.

Run	Welding Status	Welding Time Setting (Sec.)	Sheet Thickness (mm)	Current Range Setting - Positions (1 → 5)
1	Recommended Welding Conditions	0.4	6	5
2	Lower Current Range	0.4	6	4
3	Less Sheet thickness	0.4	2	5
4	More Sheet thickness	0.4	4	5
5	Less Welding time	0.25	6	5
6	More Welding time	0.55	6	5



1. Welding Current Cable
2. Pistol Control Cable
3. Current Sensor (CT)
4. Current Peak Monitor (CPM)
5. Pistol
6. Workpiece
7. Welding earth clamps
8. Connecting wire (Current Sensor – Current Peak Monitor)
9. Stud
10. Torque Test Assembly
11. Torque Wrench
12. Table & Vise
13. Welded Stud to be tested

Fig.5. Experimental Setup and Instrumentation.

3.3 SW Monitoring Using Neural Networks:

Neural network models are powerful nonlinear regression analysis methods that can relate input variables like welding process parameters and material properties with weld characteristics such as weld pool geometry. The previous efforts to model the welding processes using a neural network were based on training the network with experimental data. Since the volume of experimental data required to train a neural network depends on the number of input and output variables, most previous efforts considered only a few input parameters to keep the necessary volume of experimental data tractable [18]. To develop a neural-network model, input and output parameters of the component should be identified in order to generate and preprocess data, and then use this data to carry out ANN training. Also, quality measures of neural models are needed to be established [19]. The main steps and issues in neural stud welding model development will be described in the next paragraph.

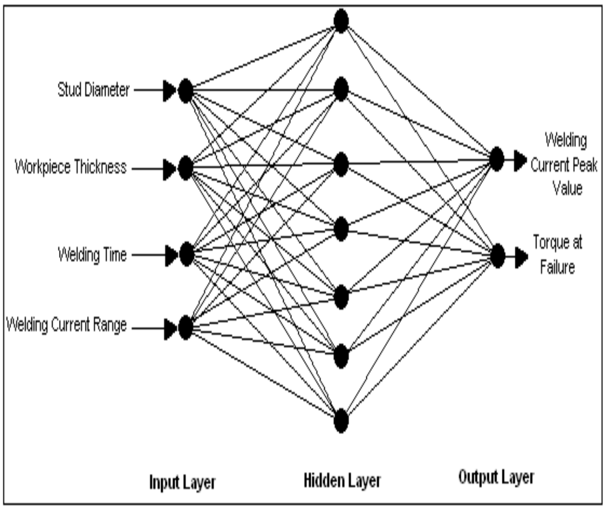


Fig.6. Developed ANN Model Utilizing Quality Parameters (Welding Current Peak Value – Torque test Value at Failure).

In figure (6), setting Artificial Neural Network prediction parameters utilizing (welding current peak value and torque testing at failure), in which input variables are stud diameter, workpiece thickness, welding time and welding current range, therefore number of input nodes is set to 4. Output variables are welding current peak value and torque testing at failure, therefore number of output nodes is set to 2. Number of hidden nodes is set to 7. Log-Sigmoid is used as activation functions for hidden layer and Linear function for output layer. Levenberg-Marquardt (LM) is used as training method, where twenty experimental sets are taken as training data. In figure (7), setting Artificial Neural Network prediction parameters utilizing data of visual inspection, in which input variables are stud diameter, workpiece thickness, welding time and welding current range, therefore number of input nodes is set to 4. Output variable is only visual inspection data, therefore number of output nodes is set to 1. Number of hidden nodes is set to 10. Log-Sigmoid is used as activation functions for hidden layer and Linear function for output layer. Levenberg-Marquardt (LM) is used as training method, where twenty experimental sets are taken as training data. Eventually, creating ANN programs by MATLAB (V7).

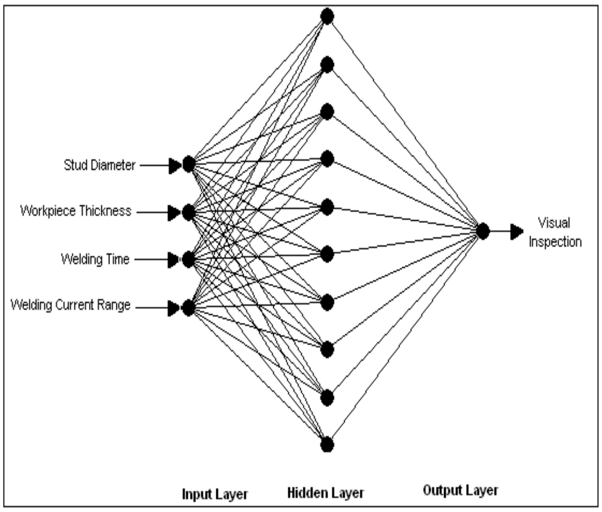


Fig.7. Developed ANN Model Utilizing Visual Inspection Parameters.

4. Experimental Results and Discussion:

Welding experiments had shown several practical variables gave clear indications for welding quality norms. These variables have been emerged as follows:

1. Current peak value readings.
2. Torque test readings obtained at failure.
3. Evaluations obtained from weld samples visual inspection.

As shown in tables (6 ~ 8), quality monitoring and control processes have been implemented by adopting variable welding conditions, in order to know the end influence of changing these conditions on weld quality. Welding condition include: (current range setting, welding time setting, workpiece thickness, stud diameter and sustainability of ceramic ferrules).

Table 6,
Results for Stud of 8 mm Diameter.

Run	Welding Status	Welding Time Setting (Sec.)	Sheet Thickness (mm)	Current Range Setting – Positions (1–5)	Trial (1)		Trial (2)	
					Monitored Current Peak Value (A)	Torque Test Value at failure (N m)	Monitored Current Peak Value (A)	Torque Test Value at failure (N m)
1	Recommended welding conditions	0.25	4	3	396	42.7	–	–
2	Lower current range	0.25	4	2	360	36.6	370	39.3
3	Higher current range	0.25	4	4	390	40.7	_	_
4	Less sheet thickness	0.25	2	3	310	9.1	320	12.2
5	More sheet thickness	0.25	6	3	380	33.9	386	36.6
6	Less welding time	0.1	4	3	323	24.4	_	_
7	More welding time	0.4	4	3	385	35.2	387	38

Table 6, Continue

Run	Visual Inspection Parameters							
	Penetration		Spattering		Stud Screw Contamination		Fillet Uniformity	
	Trial (1)	Trial (2)	Trial (1)	Trial (2)	Trial (1)	Trial (2)	Trial (1)	Trial (2)
1	Non	–	Non	–	Non	–	Partially Uniform	–
2	Non	Non	Non	Non	Non	Non	Non	Non
3	Non	_	Non	_	Non	–	Partially Uniform	–
4	Yes	Non	Non	Non	Non	Non	Partially Uniform	Partially Uniform
5	Non	Non	Non	Non	Non	Non	Uniform	Partially Uniform
6	Non	_	Non	_	Non	–	Partially Uniform	–
7	Non	Non	Non	Non	Non	Non	Non	Partially Uniform

Stud of (8 mm) Diameter:

1. Recommended Current Peak Value: 420 A.
2. Recommended Torque Test Value before failure: 12.5 N m,
3. Recommended Torque Test Value at failure: 14.8 N m.
4. Protrusion: 3 mm.

For table (6), run (1) can be considered as *satisfactory* weld experiment because the recorded Current Peak Value (CPV) is (396 A) which has a minor reduction of (24 A) less than recommended value, and the torque test value is (42.7 N m) which has a noticeable rise in weld strength of (27.9 N m) more than standard level. The visual inspection of run (1) showed partially uniform fillet. The main cause of the satisfactory weld is by selecting welding conditions according to the recommended norms, also ceramic ferrule *had sustained* the internally generated high welding gas pressure and thermal shock. For table (6), run (4): trial (1) can be considered as *unsatisfactory* weld experiment because the recorded CPV is (310 A) which has a sharp decline of (110 A) less than recommended value, and the torque test value is (9.1 N m) which has a reduction in weld strength of (5.7 N m) less than standard level. The visual inspection of run (4): trial (1) showed partially uniform fillet and penetration. The main cause of the non satisfactory weld is by selecting workpiece of (2 mm) thickness which is relatively low, further more ceramic ferrule *had not sufficiently sustained* the internally generated high welding gas pressure and thermal shock..

For table (7), run (7): trial (1) can be considered as satisfactory weld experiment because the recorded CPV is (574 A) which has minor reduction of (6 A) less than recommended value, and the torque test value is (46.1 N m) which has a rise in weld strength of (21 N m) more than standard level. The visual inspection of run (7): trial (1) showed uniform fillet. The main cause of the satisfactory weld is by setting welding time to (0.45 sec) which is relatively commensurate with workpiece thickness, also ceramic ferrule *had sustained* the internally generated high welding gas pressure and thermal shock. For table (7), run (3): trial (2) can be considered as unsatisfactory weld experiment because the recorded CPV is (220 A) has a sharp decline of (360 A) less than recommended value, and the torque test value is (6.1 N m) has a reduction in weld strength of (19 N m) less than standard level. The visual inspection of run (3): trial (2) showed non uniform fillet and spattering. The main cause of the non satisfactory weld is due to the ferrule which *had not sufficiently sustained* the internally generated high welding gas pressure and thermal shock. For table (8), run (4): trial (2) can be considered as satisfactory weld experiment because the recorded CPV is (652 A) which has a reduction of (68 A) less than recommended value, and the torque test value is (74.6 N m) which has a rise in weld strength of (22.6 N m) more than standard level. The visual inspection of run (4): trial (2) showed uniform fillet. The main cause of the satisfactory weld is due to the ceramic ferrule which *had sustained* the internally generated high welding gas pressure and thermal shock. For table (8), run (5): trial (1) can be considered as unsatisfactory weld experiment because the recorded CPV is (511 A) has a sharp decline of (209 A) less than recommended value, and the torque test value is (38 N m) has a reduction in weld strength of (14 N m) less than standard level. The visual inspection of run (5): trial (1) showed partially uniform fillet. The main cause of the non satisfactory weld is by setting welding time to (0.25 sec) which is relatively low. Also ceramic ferrule *had not sufficiently sustained* the internally generated high welding gas pressure and thermal shock.

From results tables and figure (8), the following limits can be pointed out:

- Stud of (8 mm) diameter has recorded current peak value ranging from (310 to 396 A).
- Stud of (10 mm) diameter has recorded current peak value ranging from (220 to 574 A).
- Stud of (12 mm) diameter has recorded current peak value ranging from (511 to 652 A).

This shows that the rates of welding current peaks in general increase with increasing stud dimensions, namely the rate of welding current and stud diameter have a direct correlation. It was also observed that *some* welding current rates did not reach exactly the standard level due to the application of used ceramic ferrules.

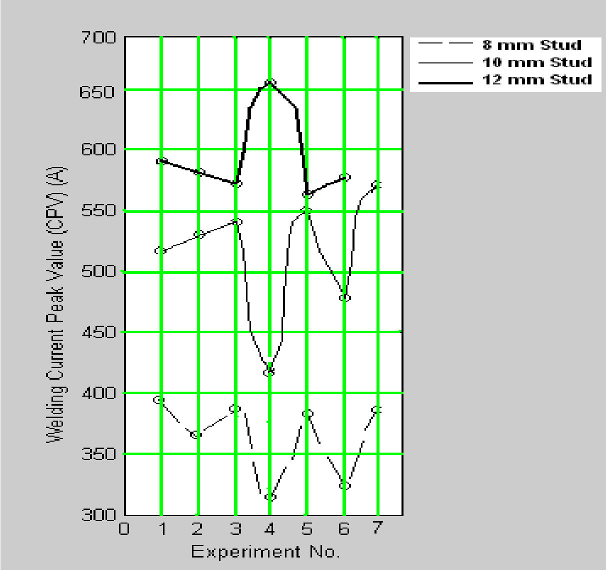


Fig.8. Welding Current–Stud Diameter Correlation.

Table 7,
Results for Stud of 10 mm Diameter.

Run	Welding Status	Welding Time Setting (Sec.)	Sheet Thickness (mm)	Current Range Setting – Positions (1–5)	Trial 1		Trial 2	
					Monitored Current Peak Value (A)	Torque Test Value at failure (N m)	Monitored Current Peak Value (A)	Torque Test Value at failure (N m)
1	Recommended welding conditions	0.3	6	4	522	32.5	510	28.8
2	Lower current range	0.3	6	3	535	44.7	530	42
3	Higher current range	0.3	6	5	520	36.6	220 **T3:** 540	6.1 **T3:**40.7
4	Less sheet thickness	0.3	2	4	385	27	421	32.5
5	Partially more sheet thickness	0.3	4	4	550	42	310	2
6	Less welding time	0.15	6	4	477	29.8	379	2
7	More welding time	0.45	6	4	574	46.1	510	32.5

Table 7, Continue

Run	Visual Inspection Parameters							
	Penetration		Spattering		Stud Screw Contamination		Fillet Uniformity	
	Trial (1)	Trial (2)	Trial (1)	Trial (2)	Trial (1)	Trial (2)	Trial (1)	Trial (2)
1	Non	Non	Non	Non	Yes	Non	Non	Uniform
2	Non	Non	Non	Non	Non	Non	Partially Uniform	Uniform
3	Non	Non **T3:** Non	Non	Yes **T3:** Non	Non	No **T3:** Non	Uniform	Non **T3:** Uniform
4	Yes	Yes	Yes	Non	Non	Non	Non	Non
5	Non	Non	Yes	Non	Non	Yes	Non	Non
6	Non	Non	Non	Non	Yes	Yes	Non	Partially Uniform
7	Non	Non	Non	Non	Non	Non	Uniform	Non

Stud of (10 mm) Diameter:

1. Recommended Current Peak Value: 580 A.
2. Recommended Torque Test Value Before Failure: 21.2 N m.
3. Recommended Torque Value at Failure: 25.1 N m.
4. Protrusion: 4 mm

Table 8,
Results for Stud of 12 mm Diameter.

Run	Welding Status	Welding Time Setting (Sec.)	Sheet Thickness (mm)	Current Range Setting – Positions (1–5)	Trial (1)		Trial (2)	
					Monitored Current Peak Value (A)	Torque Test Value at failure (N m)	Monitored Current Peak Value (A)	Torque Test Value at failure (N m)
1	Recommended welding conditions	0.4	6	5	590	61	_	_
2	Lower current range	0.4	6	4	581	78.6	580	81.3
3	Less sheet thickness	0.4	2	5	574	52.9	_	_
4	Partially more sheet thickness	0.4	4	5	620	69	652	74.6
5	Less welding time	0.25	6	5	511	38	554	40.7
6	More welding time	0.55	6	5	577	0.065	_	_

Table 8, Continue

Run	Visual Inspection Parameters							
	Penetration		Spattering		Stud Screw Contamination		Fillet Uniformity	
	Trial (1)	Trial (2)	Trial (1)	Trial (2)	Trial (1)	Trial (2)	Trial (1)	Trial (2)
1	Non	_	Yes	_	Non	_	Non	_
2	Non	Non	Non	Non	Non	Non	Uniform	Partially Uniform
3	Yes	_	Yes	_	Non	_	Non	_
4	Yes	Non	Non	Non	Non	Non	Non	Uniform
5	Non	Non	Non	Non	Non	Non	Partially Uniform	Partially Uniform
6	Non	_	Non	_	Non	_	Non	_

Stud of (12 mm) Diameter:

1. Recommended Current Peak Value: 720 A.
2. Recommended Torque Test Value before failure: 44.1 N m.
3. Recommended Torque Test Value at failure: 52 N m.
4. Protrusion: 4.5 mm.

Several experimental runs had recorded sharp decline in rates of welding current peak values, which are affected the welding quality. These effects are also emerged in the torque tests and visual inspection. After verifications, it was noticed that the main reason for emergence of such acute decline in current peak values are due to the variations in welding conditions. Hence, for the purpose of achieving acceptable levels of quality, it is recommended to check and diagnose the negative effects in each welding process then modifying the welding terms accordingly.

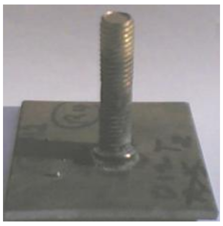
From above, it is observed that there is a relationship between the monitored current peak values and welding conditions, which showed clear advantage of the current peak monitor.

4.1 Effect of Changing Welding Conditions on Weld Quality:

4.1.1 Welding time setting:

Welding operations showed that the selected time on the welding machine had a significant impact on the welding quality as seen in the following illustrations:

- When time set is *equal* to recommended value, it leads to the availability of time interval required to generate heat for the purpose of accomplishing complete welding cycle (melting of solid metal, dipping stud in the welding pool and then creating weld fillet) on a regular basis as shown in figure (9).
- When time set is *less* than the recommended value, the process is entirely reversed as shown in figures (10) and (11).
- When time set is *more* than the recommended value, it may lead to the over fill phenomenon with molten metal in the ceramic ferrule of small interior chamber and thus obtained adhesion of liquid on the upper teeth of the stud as shown in figure (12).



Stud diameter: 12 mm
Run: 4, Trial: 2
Monitored Current
Peak Value: 652 A

Fig. 9. Good Weld Fillet

Stud diameter: 8 mm
Run: 4, Trial: 2
Monitored Current
Peak Value: 320 A

Fig. 10. Partially Uniformed Weld Fillet

Stud diameter: 12 mm
Run: 6, Trial: 1
Monitored Current
Peak Value: 577 A

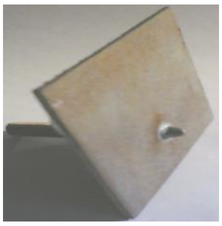
Fig.11. Non Uniformed Weld Fillet

Stud diameter: 10 mm
Run: 6, Trial: 1
Monitored Current
Peak Value: 477 A

Fig.12. Over Fill (Stud Screw Contamination)

4.1.2 Workpiece Thickness:

Workpieces of less thickness don't sustain machine time setting more than the recommended value or more stud diameter because of substantial likelihood of (penetration) as shown in figure (13). Therefore, it is required to make a balance between all conditions to obtain successful welding quality.



Stud diameter: 8 mm
Run: 4, Trial: 1
Monitored Current
Peak Value: 311 A

Fig.13. Penetration

4.1.3 Stud Diameter:

The stud diameter influenced the working area of the stud surface. This factor was found to affect the welding current peak value and torque result, as well as contribute as a significant factor to the other measures of weld quality. Clearly, larger studs are going to have a greater bonding area and subsequently greater current peak values and strengths.

4.1.4 Ceramic Ferrules:

Type and dimensions of ceramic ferrule have influence on the following factors:

- Welding current peak value.

- Regularity of weld fillet and surface contamination.

The ceramic ferrules which have been supplied from the local market are generally matching the technical specifications listed in the manufacturer's commandments, but sometimes they don’t sustain thermal shock and high pressure caused by electric arc. For this reason, there have been simple variation in the form of the weld fillet and welding current, but on the whole it didn’t affect the strength and quality of the welded parts.

The main specifications of the used ferrules can be illustrated as following:

1. Standard ferrules possess regular round neck used to fix the ferrule to the ferrule grip, while this advantage is not available in local one. So, when the operator triggers, vertically pushes down the pistol on the surface of the workpiece. Sometimes lateral slip or movements between the ferrule and its grip is occurred. These movements may cause loss of match centers, which may partially affect the welding quality.
2. Standard ferrules possess a zigzag round tip in vicinity of the front edge made originally one piece with the ferrule body. (Zigzag) advantage lies in the following aspects:
   A - Properly supports the stress of welding pistol while the operator starts the welding cycle.
   B - As shown in figure (14)**,** zigzag works as safety valve that discharges gases and expanded air to the external surrounding after the impact of electric arc which reduces the possibility of ferrule shatters during welding operation and thus reduces the likelihood of spattering.

Zigzag tip was not developed in local ferrules, because of the limited possibility of ceramic cutting, further more doing Zigzag by cutting machines, weakens the piece and makes it prone to break during a welding cycle.

3. In the standard ferrules the interior chamber is well designed in order to commensurate different studs diameters. This advantage can not be accommodated through the use of narrow interior chambers local ferrules. It was noted as in figure (12) that ferrules of less chamber dimensions leads to a speedy chamber over fill, and thus in several cases were obtained few adhesion of liquid metal on the upper teeth of the stud or what is called a (stud screws contamination), but as it was mentioned previously anyhow they did the task well.

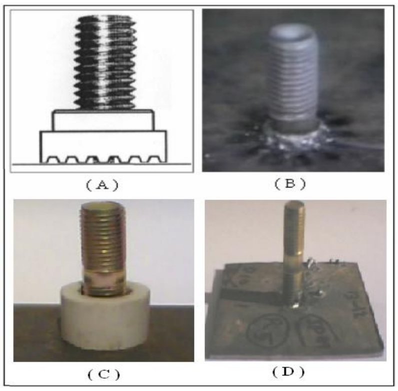


Fig.14. (A) Zig Zag, (B) Trace of Air Pressure Drain through Standard Zig Zag Ferrules, (C) Stud and Local Ceramic Ferrule Setup, (D) Spattering Phenomena.

4.1.5 Current Range Setting:

Welding operations showed that changing the setting of the current range on the welding machine leads to the following illustration:

As seen in the design of DABOTEK DT1000 [20], setting the current range doesn’t necessarily indicate the precise peak value of the current which is concretely consumed during the implementation of the welding operation, but it only puts the machine over a proper welding current course, while the current peak monitor can do this task instead of welding machine and precisely detect and display the welding current peak value. Here, it is important to mention that welding current peak value is falling as a key factor in determining the welding quality.

The following illustrative example shows that raising the range setting is not affecting welding regularity, but decreasing the range has a noticeable affect.

4.2 Effect of Electric Arc on Welding CPV:

CPV is recorded and monitored by the electronic device which is developed for this purpose. Earlier paragraphs are clearly showed the importance of welding current peak value and their significant impact on welding quality and process stability. It is also important to emphasize that each reading (value) is governed by a number of factors, these are:

A - Type of ceramic ferrule
B - Machine welding time setting

C - Machine welding current range setting.
D - Workpiece thickness.
E - Stud diameter.
F - Selection of right stud protrusion. Protrusion: is the amount of stud, which protrudes beyond the ferrule when the stud in its normal state. This represents the portion of the stud to be used in forming the weld fillet [14].
G - Proper selection of stud and workpiece materials.

4.3 Results Achieved of Neural Networks:

It has been established two separate neural networks, first ANN was developed utilizing quality parameters (welding current peak value – torque test value at failure). Second ANN was developed utilizing visual inspection parameters. Making use of experimental data (welding current peak value, findings of torque testing and visual inspection) have been trained a neural networks for a process model which can predict the level of quality for different welding conditions as shown in table (9).

Running the networks gives an important advantage showing their ability to predict additional readings of quality parameters besides the original ones obtained from the experimental work.

Upon inserting new interface values of welding conditions taken within the employed ranges, it will be noticed that the network also predicts new interface readings of quality parameters (welding current peaks, destructive torque test at failure and visual inspection) approaching the values to those obtained from the experimental runs.

Stud (8 mm):

In table (10), input no. (1), the developed ANN utilizing quality parameters (welding current peak value – torque test value at failure) yielded CPV of (340.5066 A) and torque test at failure (26.0018 N m). In table (11), the developed ANN utilizing visual inspection parameters yielded visual inspection level of (1.2405). On the other hand the set of values derived from experimental results table (6), run (6), shows CPV of (323 A), torque test at failure (24.4 N m) and visual inspection level of (1.2).Comparison of the two sets, shows that both groups are *close*.

Stud (10 mm):

In table (10), input no. (6), the ANN utilizing quality parameters yielded CPV of (515.7694 A) and torque test at failure (39.8981 N m). In table (11), the ANN utilizing visual inspection parameters yielded visual inspection level of (1.6879). On the other hand the set of values derived from experimental results table (7), run (3), shows CPV of (520 A), torque test at failure (36.6 N m) and visual inspection level of (1.65). It is seen that both groups are *close*.

Stud (12 mm):

In table (10), input no. (10), the ANN utilizing quality parameters yielded CPV of (576.8645 A) and torque test at failure (0.0765 N m). In table (11), the ANN utilizing visual inspection parameters yielded visual inspection level of (1.2036). On the other hand the set of values derived from experimental results table (8), run (6), shows CPV of (577 A), torque test at failure (0.065 N m) and visual inspection level of (1.2). However they are *close*.

The neural networks which have been trained to a set of data namely (welding conditions and quality parameters) derived from the practical experimental runs, made the networks ready to receive new data for subsequent prediction. New data should be accordingly set as input parameters, which represents only the welding conditions within the limits adopted in this study. Consequent outputs are new rates represent only quality parameters which are predicted by the pre-trained neural networks.

Notably, agreement of the total values and convergence readings of each set to the other shows that the trained neural networks are ready to predict quality parameters whenever it is required. Some networks results were found far from reasonable values due to inadequate neural network training data, because of the limited availability and high cost of used ceramic ferrules.

5. Conclusions

The main conclusions of this research could be stated in the following terms:

1. <u>SW Quality and Online Current Peak Monitor System:</u> it could be deduced as follows:
    - The system has high response sensing capability which is needed to meet the requirements of SW monitoring process.
    - The developed monitoring system can be installed directly to the welding machine without leaving a negative impact on the efficiency of the machine or cause technical obstacle prevents the operator from performing his duty well.

Table 9,
Experiment Results Adapted for ANN Training.

Experiment No.	**Run**	**ANN's Inputs**				**Outputs of ANN (1)**		**Outputs of ANN (2)**
		Stud Diameter (mm)	**Welding Time (sec.)**	**Sheet Thickness (mm)**	**Current Range (1 → 5) positions**	**Monitored Current Peak Value (A)**	**Torque at Failure (N m)**	**Visual Inspection (Smut Level)**
1	1	8	0.25	4	3	396	42.7	1.2
2	2	8	0.25	4	2	365	37.95	1.2
3	3	8	0.25	4	4	390	40.7	1.2
4	4	8	0.25	2	3	315	10.65	1.4
5	5	8	0.25	6	3	383	35.25	1.2
6	6	8	0.1	4	3	323	24.4	1.2
7	7	8	0.4	4	3	386	36.6	1.2
8	1	10	0.3	6	4	516	30.65	1.2
9	2	10	0.3	6	3	532.5	43.35	1.2
10	3	10	0.3	6	5	426.7	27.8	1.65
11	4	10	0.3	2	4	403	29.75	2.05
12	5	10	0.3	4	4	430	22	1.85
13	6	10	0.15	6	4	428	15.9	1.4
14	7	10	0.45	6	4	542	39.3	1.2
15	1	12	0.4	6	5	590	61	1.85
16	2	12	0.4	6	4	580.5	79.95	1.2
17	3	12	0.4	2	5	574	52.9	2.05
18	4	12	0.4	4	5	636	71.8	1.2
19	5	12	0.25	6	5	532.5	39.35	1.2
20	6	12	0.55	6	5	577	0.065	1.2

Table 10,
ANN Output Utilizing Quality Parameters (Welding Current Peak Value – Torque Test Value at Failure)

Input No.	**Stud Diameter (mm)**	**Welding Time (sec.)**	**Workpiece thickness (mm)**	**Welding Current Range (1→5) positions**	**Welding Current Peak value (A)**	**Stud Torque test value at failure (N m)**
1	8.0000	0.1000	2.0000	2.0000	340.5066	26.0018
2	8.4444	0.1500	2.4444	2.3333	342.7456	27.4073
3	8.8889	0.2000	2.8889	2.6667	348.4093	30.8607
4	9.3333	0.2500	3.3333	3.0000	366.6527	40.2357
5	9.7778	0.3000	3.7778	3.3333	439.2554	66.8864
6	10.2222	0.3500	4.2222	3.6667	515.7694	39.8981
7	10.6667	0.4000	4.6667	4.0000	621.0430	87.9288
8	11.1111	0.4500	5.1111	4.3333	698.2108	131.3336
9	11.5556	0.5000	5.5556	4.6667	671.5627	107.8229
10	12.0000	0.5500	6.0000	5.0000	576.8645	0.0765

Table 11,
ANN Output Utilizing Visual Inspection Parameters

Input No.	Stud Diameter (mm)	Welding Time (sec.)	Workpiece thickness (mm)	Welding Current Range (1→5) positions	Visual inspection (smut level)
1	8.0000	0.1000	2.0000	2.0000	1.2405
2	8.4444	0.1500	2.4444	2.3333	1.3362
3	8.8889	0.2000	2.8889	2.6667	1.6141
4	9.3333	0.2500	3.3333	3.0000	1.9525
5	9.7778	0.3000	3.7778	3.3333	1.9173
6	10.2222	0.3500	4.2222	3.6667	1.6879
7	10.6667	0.4000	4.6667	4.0000	1.3230
8	11.1111	0.4500	5.1111	4.3333	1.0407
9	11.5556	0.5000	5.5556	4.6667	1.0277
10	12.0000	0.5500	6.0000	5.0000	1.2036

- It provides the operator an opportunity to watch and monitor the welding current peak value for each welding trial individually from a distance not less than 5 meters.
- The system supports quality control procedures and welding productivity without the need to stop the production sequence or doing more periodic destructive mechanical testing to dozens of samples. Here, it can be noted which *economical* gains could be achieved in utilizing such electronic surveillance feature.

2. SW Quality Control: It can be deduced that there is an increase in weld strength when welding current peaks recorded values within the standard limits.
3. Setting of Welding Current Range: The solely function performed by the machine through this feature is to reduce the risk probability in the case of abrupt welding current rise for any reason during the welding process
4. Ceramic Ferrules: Ceramic ferrules have significant impact on welding current peak value, therefore some recorded readings of current peak values showed up limits less than the standard rates.
5.
6. Welding Conditions: (welding time setting, welding current range setting, workpiece thickness and stud diameter) were found to be a dominant factor that affects welding current peak value and thus welding quality level.

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المراقبه و السيطره على جودة لحام البراغي

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الخلاصة

تم في هذا البحث تصميم و تصنيع منظومه لمراقبة جوده لحام البراغي من خلال قياس قيمة التيار العظمى عند عملية اللحام. حيث ان استخدام منظومة المراقبه المباشره يضمن اكتشاف مبكر لعيوب اللحام و بالتالي ضمان جوده مقبوله لعملية اللحام. تم تنفيذ عدد من اجراءات السيطره النوعيه للعينات الملحومه المتمثله بفحص العزم الاتلافي و اجراءات الفحص بالبصر (Visual Inspection) لبيان فعالية المنظومه و دراسة بعض الخصائص و العيوب المحتمل حدوثها في عملية لحام البراغي. ان منظومة المراقبه المباشره عباره عن نظام الكتروني ، هدفه تحديد حالة اللحام الناتج فيما اذا كانت ناجحه او فاشله بطريقه غير تدميريه اعتمادا على قيمة التيار العظمى التي تعرضها المنظومه لحظيا عند اكتمال اللحام. تتكون المنظومه من جزئين رئيسسين ، الجزء الاول: متحسس التيار او مايسمى بمحول التيار (CT) ، و الجزء الثاني عباره عن جهاز مراقبة قيمة التيار العظمى (CPM). في دائره متحسس التيار(CT) يتم تحسس الموجات الكهرومغناطيسيه المتولده حول كابل اللحام و يحولها الى اشارة تيار كهربائي بنسبه تحويل (١٠٠٠\٥). في دائره (CPM) ، تمر اشارة التيار بعدد من الدوائر الالكترونيه لاجل كشف و ايجاد قيمة التيار العظمى و عرضها على هيئة ارقام عشريه (9 → 0) مباشره خلال عمليه تنفيذ دوره اللحام الواحده. تم ملاحظة علاقة توافقيه متبادله تربط قيمة التيار العظمى باجراءات السيطره النوعيه و تقييم مستوى جودة اللحام الذي يؤكد صلاحية استخدام نظام المراقبه الالكتروني المباشر و يدعم الهدف الرئيسي لهذه الدراسه. ايضا تم اعداد شبكتين عصبيتين لمراقبة مستوى الجوده في عملية لحام البراغي بالقوس الكهربائي. الشبكه الاولى تنبأت بعاملين من عوامل جودة اللحام و هي (القيمه العظمى للتيار) و(قيمة فحص العزم الاتلافي عند نقطة الفشل) بينما الشبكه الثانيه تنبأت بعامل جوده واحد و هو (مستوى الفحص بالبصر). دربت الشبكتان على مجموعه من البيانات التي اخذت من التجارب العمليه و اظهرت نتائج مقبوله.