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Enhancing Welded Joint Integrity through MIG Welding Parameter Optimization

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Abstract: *The present work, failure case of welded joint for energy storage device is analyzed. The energy storage devices are made up of AISI 1040 steel cases or boxes. Bulging effects in these boxes exerts tensile load on welded joint and breaks them. Root cause analysis is done and found the root cause as improper throat thickness of weld. To find out the solution, problem is analyzed theoretically by using strength equation also it is simulated in ANSYS R18.1 software for a constant tensile load of 16 KN. Simulation shows that there is a linear correlation between strength of welded joint and throat thickness. These results are validated in actual experimentation by taking tensile test on the sample specimens. The design of experiment by Taguchi is done on three variables VIZ weld current, arc voltage and wire feed rate. The results of experimentation are compared with the result from ANSYS and previous result. Throat thickness of welded joints at value 5mm gives required solution. Samples are also tested for liquid penetration test, microstructure test and hardness test to validate the optimized parameters and to check the quality of welded joints. Finally Optimized parameters are implemented for the welding of boxes. Performance of the device under modified parameters are examined, presented and discussed in this project report.*

Keywords: MIG Welding, Tensile Test, Mini Tab, Taguchi Test

I. INTRODUCTION

Deafness The problem that has faced the manufacturer is the control of the process input parameters to obtain a good welded joint with the required weld quality. Traditionally, it has been necessary to study the weld input parameters for welded product to obtain a welded joint with the required quality. To do so, requires a time-consuming trial and error development method. Then welds are examined whether they meet the requirement or not. Finally, the weld parameters can be chosen to produce a welded joint that closely meets the joint qualities. Also, what is not achieved or often considered is an optimized welding parameters combination, since welds can often be formed with very different parameters. In other words, there is often a more ideal welding input parameters combination, which can be used. In this thesis, the influence of welding parameters like welding current, welding voltage, welding speed on ultimate tensile strength (UTS) of AISI 1050 mild steel material during welding. A plan of experiments based on Taguchi technique has been used. An Orthogonal array, signal to noise (S/N) ratio and analysis of variance (ANOVA) are employed to study the welding characteristics of material & optimize the welding parameters. The result computed is in form of contribution from each parameter, through which optimal parameters are identified for maximum tensile strength. From this study, it is observed that welding current and welding speed are major parameters which influence on the tensile strength of welded joint.

Welding is a fabrication or sculptural process that joins materials, usually metals or thermoplastics, by using high heat to melt the parts together and allowing them to cool causing fusion. Welding is distinct from lower temperature metal-joining techniques such as brazing and soldering, which do not melt the base metal. In addition to melting the base metal, a filler material is typically added to the joint to form a pool of molten material (the weld pool) that cools to form a joint that, based on weld configuration (butt, full penetration, fillet, etc.), can be stronger than the base material (parent metal). Pressure may also be used in conjunction with heat, or by itself, to produce a weld. Welding also requires a form of shield to protect the filler metals or melted metals from being contaminated or oxidized.

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Problem Definition

Capacitors are generally used at locomotives converter to store the energy or to improve the power factor. These devices consist of electrical parts which are covered with insulated sheet of polypropylene. This assembly is then inserted into the hollow case of AISI 1040 steel and finally it is closed with MIG welding.

These devices are subjected to high voltage continuously. The SF6 gas is filled inside the devices to acts as a dielectric material. After a very high voltage pulse (more than rated voltage 5000volts) temperature of a gas increases this expands a gas. Expansion of a gas exerts a tensile force on the butt welding of the case. In one incidence a manufacturer of energy storage device has faced a major customer complaint that this device is busted a certain locomotive and acted like a bomb. Manufacturer of device has to pay a huge fine for thatby analysing cause effect diagram; following causes are considered as major causes of accident:

- Improper weld current
- Improper arc voltage
- Incorrect bead geometry
- Incorrect design
- More torch travel speed

Fig. 1.Photograph of Failed Energy Storage Device

Objective

The main objective of this project is to predict and optimize MIG welding of some economically important similar materials or dissimilar materials in industry through applying Minitab software, develop mathematical models and optimize the welding operation. This was achieved by controlling selected welding parameters; welding feed, welding current and welding voltage position, to relate the ultimate tensile strength, hardness and impact strength to the selected input welding parameters. The materials studied in this work are EN 28 steel.

II. LITERATURE SURVEY

Ajit Hooda, Ashwani Dhingra and Satpal Sharma [1] investigated the maximum yield strength both transverse and longitudinal, at the optimum values of process variables welding voltage, welding current, wire speed and gas flow rate was experimented. The longitudinal yield strength is greater than the transverse yield strength.

Diganta Kalita, Parimal Bakul Barua [2] investigate the effect of the three process parameters of Metal Inert Gas Welding (MIG), welding current, voltage and shielding gas flow rate on tensile strength of welded joints having Grade C20 Carbon Steel as parent metal and ER70S-4 electrode. An experiment has been designed using Taguchi‘s Orthogonal Array L9.

P. Srinivasa Rao, O. P. Gupta, S. S. N. Murty, A. B. Koteswara Rao [3] have investigated the weld bead plays an important role in determining the mechanical properties of the weld. Its geometric parameters, viz., width, reinforcement height, and penetration, are decided according to the welding process parameters, such as wire feed rate, welding speed, pulse current magnitude, frequency (cycle time), etc. Therefore, to produce good weld bead geometry, it is important to set the proper welding process parameters.

Ravi Bharadwaj, M.K. Gaur, Saurabh Agrawal, Vedansh Chaturvedi [4] suggested the effect of MIG welding parameters specifically Welding current, Voltage, Gas flow rate and Plate thickness during welding of AISI-304 stainless steel Material on MIG welding machine at different level presents in this work. All the welding parameters are modeled using Taguchi-based Principle Component Analysis (PCA).

Nabendu Ghosh, Pradip Kumar and Goutam Nandi [5] suggested welding input process parameters play a very significant role in determining the quality of the welded joint. Only by properly controlling every element of the process can product quality be controlled. The quality of the weld has been evaluated in terms of yield strength, ultimate tensile strength and percentage of elongation of the welded specimens. They also investigated [6] To study and analyze the effects of welding parameters: welding current, gas flow rate and nozzle to plate distance, on ultimate tensile strength (UTS) and Yield Strength (YS) in MIG welding of AISI409 ferritic stainless steel to AISI 316L Austenitic Stainless Steel materials. Experiments have been conducted as per L9 orthogonal array of Taguchi method.

P. Pavani, Mr. P. Sivasankar, Mr. P. Lokanadham, Mr. P. Uma Mhahesh [7] studied Manual Metal Arc Welding of carbon steel plates were studied. The finite element analysis of residual stresses in butt welding of two similar plates is performed with the ANSYS software. This analysis includes a finite element model for the thermal and mechanical welding simulation.

DragiStamenković and Ivana Vasović [8] studied Manual Metal Arc Welding of carbon steel plates were studied. The finite element analysis of residual stresses in butt welding of two similar plates is performed with the ANSYS software. This analysis includes a finite element model for the thermal and mechanical welding simulation.

ClaudiuRodean, Livia Dana Beju, And Paul Dan Brindasu [9] studied that the testing of a non-removable assembly is done using a special instrument which is based on the detection of helium. Shyamji, Dr. Suresh Prasad [10] investigated that the exact procedure for liquid penetrant testing can vary from case to case depending on several factors such as the penetrant system being used, the size and material of the component being inspected, the type of discontinuities being expected in the component and the condition and environment under which the inspection is performed.

III. METHODOLOGY

The investigation of MIG welding process parameter optimization for weld zone tensile strength, hardness and impact strength using TAGUCHI and ANOVA technology. The parameters that are machine controlled are the wire feed speed, the arc voltage, gas flow rate and the diameter of the wire. During the welding process, the MIG welding set will adjust the relationship between these parameters.

- Identification of Problem
- Selection of Machine work piece and tool
- Choosing of welding parameters
- Voltage, wire speed feed and gas flow rate
- Create the DOE (Design of Experiments) with help of MINITAB 18 software.
- Conduct the experiments (welding process)
- Conduct the tests (tensile, hardness and impact strength)
- Optimization of process.

Working Principle of MIG Welding

As shown in fig. the electrode in this process is in the form of coil and continuously fed towards the work during the process. At the same time inert gas (e.g. argon, helium) is passed around electrode from the same torch. Inert gas usually argon, helium, or a suitable mixture of these is used to prevent the atmosphere from contacting the molten metal

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and HAZ. When gas is supplied, it gets ionized and an arc is initiated in between electrode and work piece. Heat is therefore produced. Electrode melts due to the heat and molten filler metal falls on the heated joint. The arc may be produced between a continuously fed wire and the work. Continuous welding with coiled wire helps high metal depositions rate and high welding speed. The filler wire is generally connected to the positive polarity of DC source forming one of the electrodes. The work piece is connected to the negative polarity. The power source could be constant voltage DC power source, with electrode positive and it yields a stable arc and smooth metal transfer with least spatter for the entire current range.

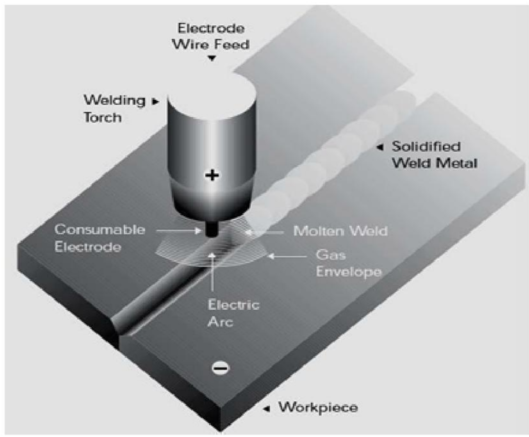

Fig. 2.Basic Working Principles

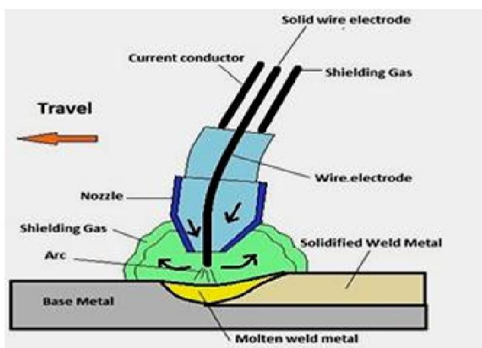

Fig. 3.Schematic of GAMW

GAMW/MIG Welding Application

Image MIG may be operated in semiautomatic, machine, or automatic modes. All commercially important applicable metals such as carbon steel, high-strength, low-alloy steel, and stainless steel, aluminum, copper, titanium, and nickel alloys can be welded in all positions with this process by choosing the appropriate shielding gas, electrode, and welding variables.

MIG Welding effecting parameter

Weld quality and weld deposition rate both are influenced very much by the various welding parameters and joint geometry. Essentially a welded joint can be produced by various combinations of welding parameters as well as joint geometries. These parameters are the process variables which control the weld deposition rate and weld quality. The weld bead geometry, depth of penetration and overall weld quality depends on the following operating variables. • Electrode size, Welding current, Arc voltage • Arc travel speed, welding position • Gas Flow rate, Shielding Gas composition

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Electrode Size

The electrode diameter influences the weld bead configuration (such as the size), the depth of penetration, bead width and has a consequent effect on the travel speed of welding. As a general rule, for the same welding current (wire feed speed setting) the arc becomes more penetrating as the electrode diameter decreases. To get the maximum deposition rate at a given current, one should have the smallest wire possible that provides the necessary penetration of the weld. The larger electrode diameters create weld with less penetration but welder in width.

Welding Current

The value of welding current used in MIG has the greatest effect on the deposition rate, the weld bead size, shape and penetration. In MIG welding, metals are generally welded with direct current polarity electrode positive (DCEP, opposite to TIG welding), because it provides the maximum heat input to the work and therefore a relatively deep penetration can be obtained. When all the other welding parameters are held constant, increasing the current will increase the depth and the width of the weld penetration and the size of the weld bead.

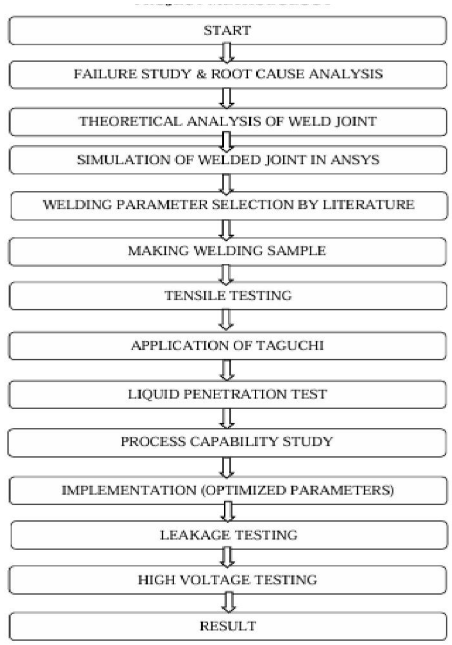
Welding Voltage

The arc length (arc voltage) is one of the most important variables in MIG that must be held under control. When all the variables such as the electrode composition and sizes, the type of shielding gas and the welding technique are held constant, the arc length is directly related to the arc voltage. High and low voltages cause an unstable arc. Excessive voltage causes the formation of excessive spatter and porosity, in fillet welds it increases undercut and produces narrower beads with greater convexity, but an excessive low voltage may cause porosity and overlapping at the edges of the weld bead.

Shielding Gas

The primary function of shielding gas is to protect the arc and molten weld, pool from atmosphere oxygen and nitrogen. If not properly protected it forms oxides and nitrites and result in weld deficiencies such as porosity, slag inclusion and weld embrittlement.

IV. EXPERIMENTAL PROCEDURE



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Material

The material used for Gas metal arc welding (GMAW) is EN8 steel. The entire specimens were machined into the dimensions of 200mm long x 75mm x 10 mm thick. The details composition (weight %) of specimens is shown in Table7. This metal had very good welding characteristics and could be welded by all of the common welding techniques.

Welding Machine

This sections provides the important specifications of the tool used in the welding process

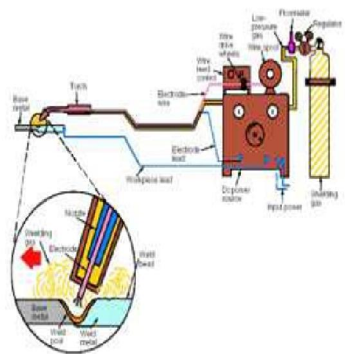

Fig. 4.Gas metal Arc welding M/C

Welding Process parameter selection

Based on literature review following is the range selected for three process parameter

Parameter selection

Process parameter	Process Designation	Level 1	Level 2	Level 3
Welding Current (Amp)	A	180	210	240
Arc Voltage (volts)	B	24	27	30
Wire Feed Rate (m/min)	C	2	3	4

V. RESULT & DISCUSSION

From overall results it can be seen that there is only single failure in the welded joint among nine samples. Rest all other samples are failed at a base metal. So the value of welding strength for further comparison is taken from sample No. 4 which is 726.71 Mpa. Also it is observed that all the samples which failed at base metal have ultimate tensile strength value is more than theoretical UTS value of 653 Mpa and which is much more than the UTS value of a filler metal which is 583 Mpa.

- By comparing the experimentation results with simulated values it has been observed that due to increase in the throat thickness of the weld will also increase ability of the base metal to resist the failure beyond its actual value of UTS of 653 Mpa.
- Signal to noise ratios are analyzed for the result from analysis it can be said that the parameter which affects mostly on the welding strength is arc voltage, second is weld current and lastly the wire feed rate. Analysis shows following are the best possible parameters to attain required weld strength. • Weld current: 240Amp • Arc voltage: 30 Volts • Wire feed rate: 3 m/min

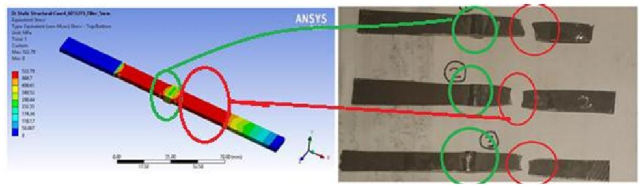

Fig. 1.*Fig. 5* a) FEA analysis of sample for 5mm throat thickness b) broken samples in tensile testing

Result of Microstructure test

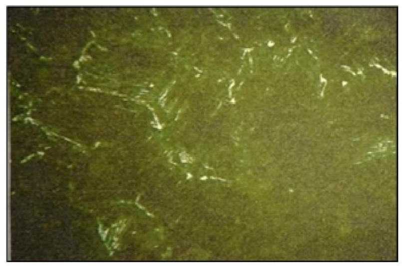

Fig. 6.Microscopic image for base metal

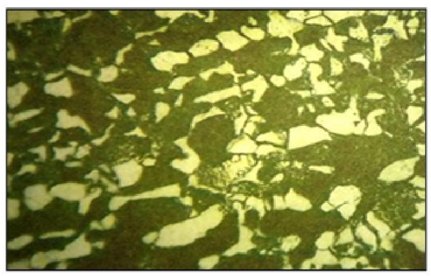

Fig. 7.Microscopic image for weld joint

By observing the results of microscopic test, base metal structure consists of Pearlite & ferrite banding which implies that it is a softer material and weld metal structure consists of fine tempered Martensite which means it is a stronger and harder than a base metal. As temperature in MIG welding is more than 1000 Deg Celsius, it will be treated as heat treatment for weld joint and it will be converted into fine tempered Martensite.

Result of Hardness test

hardness value of sample

Sample No	Vickers Hardness Number		
	BM	HAZ	FZ
1	215	231	243
2	203	226	239
3	198	213	235
4	207	229	240
5	224	240	251
6	205	227	241
7	193	219	238
8	218	235	247
9	209	227	242

By observing the values of hardness it is clearly seen that maximum hardness values for base metal is 224, for heat affected zone i.e. neighbour area of the welding is 240 and for welding joint i.e. for fusion zone it is 251 which

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indicates that the joint has a more hardness than heat affected zone and even base metal. So during the working process base metal remains soft while welding joint remains hard.

Comparison in terms of input variables

Table: Input variable

Sr No	Parameters / Result	Before	After
1	Weld current	150 amp	240 amp
2	Arc voltage	20 volts	30 volts
3	Wire feed rate	2 m/min	3 m/min
4	Gas flow rate	12 Lit/min	12 Lit/min
5	Gun height	1.5 mm	1.5 mm
6	Gun travel speed	450 mm/min	350 mm/min
7	Throat thickness	3mm	5mm

Implementation of the actual parameters which are optimized in experimentation is carried out on the actual device weld current, arc voltage, wire feed rate, throat thickness has increased from previous value and gun travel speed or welding speed has reduced from 450mm/min to 350 mm/min to achieve throat thickness of 5mm.

Result of Leakage test & high voltage test

Table: Performance outcome variables

Parameters / Result	Before	After	Remark
Leakage rate (mbar.Lit/sec)	0.01041	0.01096	Increased but within specifications
Size of bulging due to applied voltage	16mm over 1m length approx	4mm over 1m length approx	Considerably reduced got the desired results.
Capacitance Value minimum (µF)	4521	4425	Reduced but within specifications
Tan d losses maximum	0.581	0.597	Increased but within specifications
Leakage current (mA)	60.12	63.53	Increased but within specifications

From leakage rates results it can be said that the maximum leak rate was found at butt welding at bottom and the value is 0.01096 mbar. Lit/sec. That is more from before value but within specifications.

VI. CONCLUSION

The root cause of failure is identified as incorrect design and less throat thickness of the welded joint by using cause – effect diagram and brain storming. 2) Simulation of welded joint is done in ANSYS which shows that for throat thickness of 5mm there is minimum amount of stress acts on the welded joint. Hence the design is safe. 3) Actual samples are welded of base metal AISI 1040 and filler metal ER 70S-6 with a throat thickness of 5mm and the combinations of three process variables weld current, arc voltage and wire feed rate by using design of experiment by Taguchi L9 array. Except one sample all other samples are broken at base metal with ultimate tensile strength more than base metal strength. 4) Samples are tested for liquid penetration, hardness & microstructure and found as crack free, better hardness and microstructures. 5) Following parameters are optimized from design of experiment and which are Weld current: 240Amp, Arc voltage: 30 Volts, Wire feed rate: 3 m/min. 6) Implementation of above parameters is done and performance parameters are evaluated. Parameters such as leakage current, capacitance and tan d losses are also varied within specifications. There is no adverse effect of change in welding parameters on functioning of capacitor.

Future Scope:

- Similar study is required for corner welding of the capacitors. Also some of the other types of capacitors have aluminium material for casing. To set their values of weld strength some experimentation is required.
- An insulation assembly is inserted inside the capacitor. When such a high value of current is used to weld, it will produce heat & can damage the inner insulating assembly. To avoid it temperature profile after welding over a distance is to be measured and corresponding cooling arrangement is to be given.

ACKNOWLEDGMENT

It gives us great pleasure in presenting the paper on "Optimizing MIG Welding Parameters Improving Strength of Welded Joints". We would like to take this opportunity to thank our guide, Prof. Bhagwat Randhavan, Professor, Department of Mechanical Engineering Department, Sahyadri Valley College of Engineering Rajuri., for giving us all the help and guidance we needed. We are grateful to him for his kind support, and valuable suggestions were very helpful.

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