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**Research Paper** 

# OPTIMIZATION OF MIG WELDING PROCESS PARAMETERS TO PREDICT MAXIMUM YIELD STRENGTH IN AISI 1040

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In this research work an attempt was made to develop a response surface model to predict tensile strength of inert gas metal arc welded AISI 1040 medium carbon steel joints. The process parameters such as welding voltage, current, wire speed and gas flow rate were studied. The experiments were conducted based on a four-factor, three-level, face centred composite design matrix. The empirical relationship can be used to predict the yield strength of inert gas metal arc welded AISI 1040 medium carbon steel. Response Surface Methodology (RSM) was applied to optimizing the MIG welding process parameters to attain the maximum yield strength of the joint.

*Keywords:* AISI 1040, EN 8, Metal inert gas welding, Response surface methodology, Optimization, Yield strength

#### INTRODUCTION

Gas Metal Arc Welding (GMAW), sometimes referred to by its subtypes Metal Inert Gas (MIG) welding or Metal Active Gas (MAG) welding, is a semi-automatic or automatic 0020 Arc welding process in which a continuous and consumable wire electrode and a shielding gas are fed through a welding gun. A constant voltage, direct current power source is most commonly used with GMAW, but constant current systems, as well as alternating current, can be used. There are four primary methods of metal transfer in GMAW, called globular, short-circuiting, spray, and pulsed-spray, each of which has distinct properties and corresponding advantages and limitations.

Originally developed for welding aluminum and other non-ferrous materials in the 1940s, GMAW was soon applied to steels because it allowed for lower welding time compared to other welding processes. Today, GMAW is the most common industrial welding process, preferred for its versatility, speed and the relative ease of adapting the process to robotic

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automation. The automobile industry in particular uses GMAW welding almost exclusively. Unlike welding processes that do not employ a shielding gas, such as shielded metal arc welding, it is rarely used outdoors. A related process, flux cored arc welding, often does not utilize a shielding gas, instead employing a hollow electrode wire that is filled with flux on the inside.

GMAW is currently one of the most popular welding methods, especially in industrial environments. It is used extensively by the sheet metal industry and, by extension, the automobile industry. There, the method is often used for arc spot welding, thereby replacing riveting or resistance spot welding. It is also popular for automated welding, in which robots handle the work pieces and the welding gun to quicken the manufacturing process. Generally, it is unsuitable for welding outdoors, because the movement of the surrounding air can dissipate the shielding gas and thus make welding more difficult, while also decreasing the quality of the weld. The problem can be alleviated to some extent by increasing the shielding gas output, but this can be expensive and may also affect the quality of the weld. In general, processes such as shielded metal arc welding and flux cored arc welding are preferred for welding outdoors, making the use of GMAW in the construction industry rather limited. Furthermore, the use of a shielding gas makes GMAW an unpopular underwater welding process, but can be used in space since there is no oxygen to oxidize the weld.

Gas metal arc welding is one of the conventional and traditional methods to join materials. A wide range of materials may be joined by Gas metal arc welding—similar metals, dissimilar metals, alloys, and nonmetals. In the present scenario demand of the joining of similar materials continuously increases due to their advantages, which can produce high yield strength, deeper penetration, continuous welding at higher speed and small welding defects. GMAW welding is used because of its advantages over other welding techniques like high welding speeds. Less distortion, no slag removal required, high weld metal deposition rate, high weld quality, precise operation, etc. The demand for producing joints of dissimilar materials is continuously increasing due to their advantages, which can provide appropriate mechanical properties and cost reduction. Design of Experiment (DOE) and statistical techniques are widely used for optimization of process parameters. In the present study the welding process parameters of GMAW can be optimized to maximize the yield strength of the work piece also reducing the number of experiments without affecting the results. The optimization of process parameters can improve quality of the product and minimize the cost of performing lots of experiments and also reduces the wastage of the resources. The optimal combination of the process parameters can be predicted. This work was concerned with the effects of welding process parameters on the yield strength of AISI 1040 joints.

AISI 1040 is medium carbon steel and is a material that is widely used in manufacturing of wide range of machine components and for simple construction of machines. Austenitic stainless steels are extensively used in nuclear reactors, biomedical implants, as well as in components for chemical and food industries (Sen and Sen, 2004; and Farias *et al.*, 2007). In considering the engineering materials, the main problem with austenitic stainless steels is that it has poor wear resistance, yield strength, fracture and impact toughness (Shi and Northwood, 1995; and Dearnley and Aldrich-Schmith, 2004). In recent years, extensive studies on the improvement of mechanical properties of these materials have been carried out.

The properties such as weld-bead geometry, mechanical properties, and distortion can define the joint quality. Generally, all welding processes are used with the aim of obtaining a welded joint with the desired weld-bead parameters, excellent mechanical properties with minimum distortion. In order to determine the welding input parameters that lead to the desired weld quality, application of Design of Experiment (DOE), evolutionary algorithms and computational network are widely used to develop a mathematical relationship between the welding process input parameters and the output variables of the weld joint.

#### LITERATURE REVIEW

The research on parameter optimization of different types of welding for obtaining various responses in output have been done by a number of researchers using a wide range of materials. They make use of various types of methods, techniques and mathematical models for evaluating and obtaining results. Many researches' have been done research work on different materials for obtaining maximum yield strength and tensile strength.

A response surface model was developed by Faseeulla *et al.* (2012) to study the

influence of process parameters of weldbonding on tensile shear strength of the weldbond of 2 mm thick aluminium alloy 6061 T651 sheets. Using model, the significant and controllable process parameters of the weldbonding such as surface roughness, curing time, welding current, welding time and electrode pressure are optimized for maximum tensile shear strength of the weld bond. Padmanaban and Balasubramanian (2011) developed an empirical relationship to effectively predict the tensile strength of pulsed current gas tungsten arc welded AZ31B magnesium alloy joints at 95% confidence level. The significant process parameters such as peak current, base current, pulse frequency and pulse on time were studied. Yahya (2012) observes that the weld strength of thermoplastics, such as high density polyethylene and polypropylene sheets is influenced by friction stir welding parameters. The determination of the welding parameters plays an important role for the weld strength. The result also shows that for the influential use of the thermoplastics joints, the weld should have adequate strength. An effective procedure of Response Surface Methodology (RSM) has been utilized for finding the optimal values of process parameters while induction hardening of AISI 1040 under two different conditions of the material, i.e., rolled and normalized by Amit and Hari (2011). The experiment plan was based on rotatable, Central Composite Design (CCD). Benyounis and Olabi (2008) studied that welding input parameters play a very significant role in determining the quality of a weld joint. Beal et al. (2006) investigates the laser fusion of a mixture of H13 and Cu powders. The Response Surface Methodology (RSM) was

used to understand the relationship between laser processing parameters and the defects such as cracks and porosity to eliminate or reduce cracks and porosity. The result showed that the optimized process parameters reduce the cracks and porosity from 15.32 to 2.54%. The micro-structural characteristics of the weld joint using optical, scanning microscopy and Energy Dispersive Spectroscopy (EDS) and mechanical properties with micro-hardness and tensile test were studied by Ruan et al. (2012) Twin wire Metal Inert Gas (MIG) arc welding was employed on 6 mm thick 6082-T6 Al-alloy plate partially with SiO<sub>2</sub> activating flux. The results shows that the weld joint penetration with  ${\rm SiO}_{\rm _2}$  flux was about 26% deeper than what without SiO<sub>2</sub> flux. SiO<sub>2</sub> flux did not affect the micro-hardness and strength of the weld joint.

An empirical relationship was developed by Padmanaban and Balasubramanian (2010) to predict tensile strength of the laser beam welded AZ31B magnesium alloy by incorporating process parameters such as laser power, welding speed and focal position. The results indicate that the welding speed has the greatest influence on tensile strength. Ferritic/Austenitic (F/A) joints are a popular dissimilar metal combination used in many applications. F/A joints are usually produced using conventional processes. Laser Beam Welding (LBW) has recently been successfully used for the production of F/A joints with suitable mechanical properties. Anawa and Olabi (2008) using a statistical Design of Experiment (DOE) optimizes the selected LBW parameters likewise laser power, welding speed and focus length. Paventhan et al. (2011) made a attempt to develop an empirical

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relationship to predict the tensile strength of friction welded AA 6082 aluminium alloy and AISI 304 austenitic stainless steels joints, incorporating above said parameters. Response Surface Methodology (RSM) was applied to optimizing the friction welding process parameters to attain the maximum tensile strength of the joint. Pekkarinena and Kujanp (2010) determines empirically, micro structural changes occur in ferritic and duplex stainless steels when heat input is controlled by welding parameters. Using optical metallographic methods, micro-structural changes in welds were identified and examined. Zambona et al. (2006) performed CO<sub>2</sub> laser welding on AISI 904L super austenitic stainless steel sheets, with optimized processing parameters determined by means of melt run trial evaluations.

Because of their superior mechanical and corrosion properties, 304L austenitic stainless steel is used widely in industry. Resistance spot weld is most widely used as a joining process for sheet materials. Dursun (2008) shows that the influence of the primary welding parameters affecting the heat input such as; weld peak current, on the weld quality such as; surface appearances, weld nugget size, weld penetration, weld internal discontinuities, strength and ductility was determined for 304L resistance spot welded materials.

#### METHODOLOGY

AISI 1040 or EN8 medium carbon steel plates, with chemical composition as shown in table 1 and the balance Iron, were selected as base metal for the experiments. The plates were machined into 300 mm  $\times$  150 mm  $\times$  8 mm as weld blanks. The surface of the plates was

grind to remove the dust and other foreign particles. In order to obtain a strong bonded joint the properties of the base metal and the welding wire must comply with each other.

The type of material of welding wire total depends upon the material that is required to be welded. So ER 70S-6 was selected as welding wire, whose chemical composition as

shown in Table 1. The diameter of the welding wire depends upon the base metal thickness. As the thickness of base metal was 8 mm, welding wire with a diameter of 1.2 mm was selected. The significant welding input parameters that can affect the output response were identified and their range of operation was selected as shown in Table 2.

Table 1: Chemical Composition of Base Metal and Filler Wire						
Material	С	Mn	Si	S (max)	P (max)	Cu (max)
AISI 1040 (EN-8)	0.40	0.75	0.25	0.050	0.040	_
ER 70S-6	0.19	1.63	0.98	0.025	0.025	0.025

Table 2: Input Parameters and There Range							
Parameters	Welding Voltage V	Welding Current A	Wire Speed m/min	Gas Flow Rate I/min			
Values	23-25	200-220	2.4-3.2	12-16			

### In this study thyristorised power source of ESAB make 'Auto K 400' was used to join 8mm flat plates of EN8 due to their ability to quick arc start, stick out and crater control, Fresh tip Treatment Technology (FTT) to eliminates globule formation at the wire tip during weld stop and others advantage.

The effect of the process parameters, viz., voltage, wire speed, welding current and gas flow rate and focusing position on the weld joint yield strength has been investigated. The yield strength was tested on FIE make universal testing machine of model number 'UTE-60'.

The experimental set up of this research work is shown in Figure 1. The micro testing of the material was done on RMM 2 microscope. The objective of this study was to find out the optimal combination of the input parameter for maximized yield strength of the weld. In Figures 2 and 3 the AISI 1040 medium carbon steel before welding after welding are shown.

Figure 1: Experimental Setup









**RESULTS AND DISCUSSION** The plates of AISI 1040 medium carbon steel were welded by using above methods. The quality of the weld depends upon various

Figure 4: Testing Samples of Base Material Before Tensile, Yield Testing and Face and **Bend Root Tests** 



current and most importantly on the quality of the welder. Using the universal testing machine the yield strength was calculated. The test specimens on which experiment was carried out, before the yield test and after the tests is shown in the Figures 4 and 5.



The input variable parameters that were selected for this work, have three levels – low level, medium level and high level

corresponding to their values. The levels of the significant process variables are shown in Table 3.

Table 3: Levels of Process Input Parameters						
Level Parameter	Units	Low Level	Middle Level	High Level		
Voltage	Volts	23 (–1)	24 (0)	25 (+1)		
Current	Ampere	190 (-1)	200 (0)	210 (+1)		
Wire Speed	m/min	2.4 (–1)	2.8 (0)	3.2 (+1)		
Gas Flow Rate	l/min	12 (-1)	14 (0)	16 (+1)		

The results of yield strength test are shown in Table 4. As the transverse and longitudinal test specimens were prepared from the welded plates for yield strength test in transverse and longitudinal direction. It is clearly indicated that the yield strength of longitudinal test was greater than transverse test.

Table 4: Experimental Design Matrix and Results						
Run No.	Voltage V	Current A	Wire Speed m/min	Gas Flow Rate I/min	Transverse Yield Strength (MPa)	Longitudinal Yield Strength (MPa)
1.	23.5	200	2.8	14	367.571	390.411
2.	23.5	200	3.2	14	320.743	372.000
3.	22.5	190	2.4	16	320.057	337.371
4.	24.5	190	2.4	12	373.714	454.114
5.	23.5	200	2.4	14	281.486	389.486
6.	24.5	210	2.4	12	301.200	380.914
7.	23.5	200	2.8	16	304.453	332.160
8.	22.5	210	2.4	16	344.087	362.343
9.	22.5	190	3.2	16	323.600	343.080
10.	24.5	210	3.2	12	300.800	328.506
11.	24.5	210	2.4	16	304.394	318.080
12.	23.5	200	2.8	12	321.600	351.800
13.	24.5	200	2.8	14	308.670	334.874
14.	24.5	190	2.4	16	289.583	314.207
15.	23.5	190	2.8	14	356.400	379.106
16.	24.5	190	3.2	12	312.265	335.090
17.	22.5	210	2.4	12	373.714	398.907
18.	22.5	200	2.8	14	371.048	393.640
19.	23.5	200	2.8	14	328.209	352.000
20.	22.5	190	3.2	12	357.574	381.532
21.	23.5	200	2.8	14	299.421	321.804
22.	24.5	210	3.2	16	307.684	326.249
23.	23.5	200	2.8	14	342.030	364.260
24.	23.5	210	2.8	14	314.050	340.070
25.	22.5	210	3.2	12	368.600	387.636
26.	22.5	190	2.4	12	374.571	396.514
27.	24.5	190	3.2	16	317.475	344.020
28.	22.5	210	3.2	16	370.308	391.379

The value of variable process parameters welding voltage, welding current, wire speed and gas flow rate, corresponding to the maximum transverse yield strength and longitudinal yield strength was noted. These values were the optimized values of input process variables, to obtain the maximum transverse yield strength and longitudinal yield strength in jointed plates of AISI 1040 steel. And the optimum result values are shown in Table 5.

The microstructure of the welded joint thus obtained from joining of two similar plates of AISI 1040 or EN-8 steel were studied at a

Table 5: Optimized Values of Input Parameters						
Yield Test	Yield Strength MPa	Voltage V	Current A	Wire Speed m/min	Gas Flow Rate I/min	
Transverse	374.571	22.5	190	2.4	12	
Longitudinal	398.907	22.5	210	2.4	12	

magnification scale of 100X. The microstructure of base metal shows uniform structure pattern of ferrite and lamellar pearlite. The grain size of the base material was in the range of 6-7 ASTM. And the microstructure of heat affected zone shows partially elongated ferrite grains in network form, around the lamellar pearlite having grain size of 5-6 ASTM. The microstructure of the test specimen at optimal combination of process variables, welding voltage, welding current, wire feed rate or wire speed and gas flow rate is shown in Figures 6 and 7.

Due to fine grains size in heat affected zone the yield strength is highest there. For transverse testing, the test specimens were cut at an angle of 900 to the direction of welding with weld bead of the joint at center. And test specimen also have base metal on the both



#### Figure 7: Microstructure of the Heat



ends. The test specimen was broken away from the weld joint of base material end, but not from the middle of joint. But in case of longitudinal testing the testing specimen was prepared from the plate in the direction of welding. The test specimen of longitudinal testing comprises of welded joint only with heat affected zone. So the value of the longitudinal yield strength is greater than the transverse yield strength.

#### CONCLUSION

The similar weld joint of AISI 1040 material was developed effectively with MIG welding with selected range of input variable parameters.

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.

In future, we can state the relationship between the transverse and longitudinal yield strength by comparing their values and studying their microstructure.

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