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EXPERIMENTAL INVESTIGATION OF WELDING PARAMETERS AND MECHANICAL PROPERTIES BY TAGUCHI METHOD OF TIG WELDED EN 31 STEEL AND MILD STEEL

Er. Iqbaljeet Singh Grewal,
Research scholar,
G.V.I.E.T, Banur, Punjab (India)

Er. Amrinder Singh
HOD Mechanical Engineering Department,
LPC, KUBE (SAMRALA), Punjab (India)

Er. Prabhjot Singh
Department of Mechanical Engg.
Gulzar Group of Institute,
Ludhiana, Punjab, India

Abstract - **Welding is widely used by manufacturing engineers and production personnel for the manufacturing of new products. TIG welding process is most widely used welding processes in the industrial purpose for the dissimilar metal welds (DMW). The welding of the dissimilar materials is complicated because of the difference in the melting points of two dissimilar materials. The coefficient of thermal expansion and thermal conductivity of two dissimilar materials are different. Dissimilar metal welds provide good combination of mechanical properties (such as tensile strength and impact toughness) with lower cost. The dissimilar metal joints have been used as a structural material for various industrial applications such as in ships, pressure vessel and nuclear power plant. In the present work, the mechanical behavior of TIG welded joints of dissimilar materials was studied using the plates of EN 31 steel and Mild Steel having 12 mm thickness each. The mild steel plates were welded with EN 31 steel plates using different filler metals. The mechanical properties such as tensile strength and impact toughness of the welded joints are evaluated using Taguchi method using (welding current, gas flow rate and filler metal) as three input parameters each having three levels each (low, medium and high). The tensile properties of the weld metal have been identifying using Universal Testing Machine (UTM) and impact toughness has been identifying using Charpy test. The results indicates that the tensile strength and impact toughness of welded joints are maximum at 150 A current than values at 130A and 170A, thus recommending the use of 150A current during welding together of these two metals for obtaining best mechanical properties of welded joint.**

Keywords - **Tungsten inert gas welding (TIG), EN31 steel, Mild Steel, Ultimate tensile strength, Impact Toughness**

I. INTRODUCTION

It has been known that the difficult of dissimilar metals joining between mild steel and EN 31 steel. The TIG welding process is used for joining dissimilar metals and Taguchi's method is used for optimize the result.

1.1 TIG Welding Process

Tungsten inert gas (TIG) welding is the arc welding process in which the arc is formed between the non-consumable tungsten electrode and work-pieces with the envelope of inert shielding

gases around it. The shielding gases such as argon, helium and their mixtures are used to protect the tungsten electrode and weld pool from the effect of atmospheric gases such as nitrogen and oxygen. The principles of TIG welding are as shown in figure 1.
The selection of shielding gases takes into account chemical-metallurgical processes between the gases and the weld pool that occur during welding. The arc region is protected by the inert gas or the mixture of gases. The TIG welding is done with a single electrode; it may be sometimes done with several electrodes. The electrode during the welding is not consumed, therefore to balance the heat from the arc, the filler metals are dipped in the weld pool. Filler metals may be used or may not be used for the welding. For the joining of thick work-pieces, the filler metals are used having the composition is same as that of base metal. The filler metals are not necessary for the welding of very thin work-pieces also known as autogenously welding.

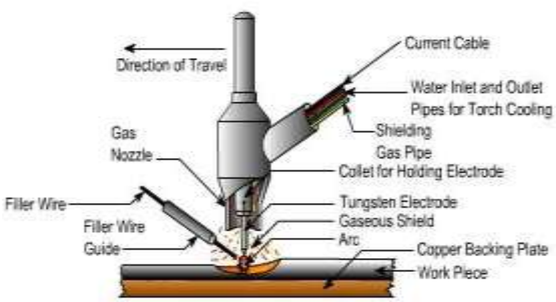

Fig. 1. Principle of TIG Welding

Process parameters of TIG welding

- Welding current
- Welding voltage
- Shielding gases
- Welding speed
- Electrode
- Filler metal

1.2 Taguchi's Method
The implementation of Taguchi's concept sees them working on the principle that when designing a product, it should be designed with minimum loss, with the relative product being designed as close to the optimum value as is feasibly possible. This would result in the product being manufactured in regards to its life cycle and customer satisfaction from the design stages. It would also mean that less repair work would be required in the long run. Dr. Taguchi's find Signal-to-Noise ratios (S/N), which is log functions for optimization help in data analysis and prediction of optimum result. This concept can be realized by designing and building a quality into the product itself. Taguchi employs design experiments using special constructed table, known as "Orthogonal Arrays (OA)" to treat the design process, such that the quality is build into the product during the product design stage.
Steps in designing, conducting and analyzing an experiment

- Selection of factors
- Selection of number of levels for the factor
- Selection of appropriate Orthogonal Array
- Assignment of factor and to columns
- Analyze result.

II. EXPERIMENTAL METHODOLOGY

2.1 Equipments used: - For preparing the TIG welded joint between two materials and for the testing, the following equipments are used:

a) Power hacksaw
b) Surface grinder
c) TIG welding machine
d) Milling machine
e) Universal testing machine
f) Impact testing machine

2.2 MATERIAL USED FOR THE WELDING: -Brief descriptions about the materials used in TIG welding are provided below:

a) EN 31 EN31 high carbons steel uses in Ball and Roller Bearings, Spinning tools, Beading Rolls, Punches and Dies. By its character this type of steel has high resisting nature against wear and can be used for components which are subjected to severe abrasion, wear or high surface loading. EN31 is continuously used in automobile industries, aircraft industries, pipes and pipes fitting.

b) MILD STEEL Mild Steel is one of the most common of all metals and one of the least expensive steels used. It is to be found in almost every product created from metal. It is easily weld able, very durable. Having less than 2 % carbon, it will magnetize well and being relatively inexpensive can be used in most projects requiring a lot of steel. Anything from cookware, motorcycle frames through to motor car chassis, use this metal in their construction. Because of its poor resistance to corrosion, it must be protected by painting or otherwise sealed to prevent it from rusting. At worst a coat of oil or grease will help seal it from exposure, and help prevent rusting.

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Table 1: Chemical composition (wt. %) of base metal

Element	EN 31	MILD STEEL
Carbon	0.9073	0.1953
Manganese	0.4515	0.4981
Phosphorus	0.02041	0.01168
Sulphur	0.05254	0.03513
Silicon	0.2054	0.1315
Copper	0.0947	0.0199
Nickel	0.1099	0.0023
Chromium	1.060	0.0175
Vanadium	0.0210	0.0125
Molybdenum	0.601	0.393

(c) Filler Metals used for welding
The filler metal ER 309 L, ER 308 L AND ER 4121 having diameter 3 mm has been used for the welding.
ER 309 L (f1) ER309L has the same qualities as ER309 but with the lower carbon content deemed necessary in many chemical applications. ER309L is preferred over ER309 for cladding over carbon or low alloy steels, or dissimilar joints that are heat treated.
ER 308 L (f2) ER308L has the same analysis as type 308 except the carbon content has been held to a maximum of .03% to reduce the possibility of intergranular carbide precipitation.
ER 4121 (f3) A medium coated all position mild steel ER 4121 electrode, gives normal penetration, fine rippled beads and stag easy to detach are its special characteristics. It‘s use in structure, building construction vessel and tanks.

Table 2: Chemical composition (wt. %) of filler metals

ELEMENT	Types of Filler Metal		
	ER 309 L (f1)	ER 308 L (f2)	ER 4121 (f3)
Carbon	0.03	0.03	0.10
Manganese	1.0	1.0	0.2
Phosphorus	0.03	0.03	0.03
Sulphur	0.03	0.03	0.03
Silicon	0.30	0.30	0.30
Copper	0.75	0.75	Nil
Nickel	14.0	9.0	Nil
Chromium	23.0	19.5	Nil
Molybdenum	0.75	0.75	Nil

2.3 WELDING PROCEDURE
(a) Power Hacksaw has been used for cutting the large size of metals such as EN 31 steel and mild steel. Then, the small plates having size 100 x 100 x 12mm is achieved during cutting.

Fig. 2. Plates after cutting

b) The grinding machine was used for preparing the groove on the double transverse side of the plates of Mild Steel and EN 31 steel. Subsequently single ‘V’ groove angles (30 degree) were cut in the plates with 2 mm root faces for a total of 60 degree inclined angle between two plates as shown in figure 5.3 the marking of pieces at 30 degree
c) After the V-groove preparation, the Mild Steel and EN 31 plates were ready for the welding. The mild steel and EN 31 plates were tightly clamped during welding. The root gap of 2 mm is provided between the two plates while performed for the welding. The V-groove butt welding is performed during TIG welding process.

Fig. 3: V-Groove Schematic geometry
(d) The tungsten non consumable electrode having diameter 3 mm was used in experiment. The argon gas is used as a shielding gas. The water cooled torch has been used to prevent the overheating. The pressure regulator has been used to adjust the gas flow rate during operation. The filler metal ER309L, ER308 L and ER 4121 having diameter 2 mm has been used for the welding. The direct current electrode positive (reverse polarity) has been used for the welding. The positive terminal of the power supply is connected to the electrode acts as anode. The negative terminal of the power supply is connected to the work pieces acts as cathode. The

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welding parameters such as welding current, gas flow rate and filler metal are selected in order to determine the mechanical properties of the welded joint. The value of welding current, gas flow rate and filler metal are varied in different samples to determine the mechanical properties of the welded joint.

Fig. 4: TIG welding machine at Deep Engineering Industries, Chandigarh

2.3.1 PARAMETERS FOR WELDING

A number of parameters are varied in the experiment. Also many parameters are kept constant during the welding process.

1) Varied Parameters

Table 3: Factors and their levels

Symbol	Control Parameter	LEVEL 1	LEVEL 2	LEVEL3
A	Welding current(A)	130	150	170
B	Gas flow rate (L/min.)	3	5	7
C	Filler metal	ER 309L (f 1)	ER 308L (f 2)	ER4121 (f 3)

a) Welding Current: Current is the most effective parameter during the welding. Too much current damages the work pieces during the welding. Current limiting helps to prevent splatter when the tungsten tip accidentally comes too close or in contact with the work piece.

b) Gas flow rate: Most importantly it also affects the finished weld penetration depth and subsurface profile, surface profile, composition, porosity, corrosion resistance, strength, ductility, hardness and brittleness.

c) filler Metals: The filler metal ER 309 L, ER 308 L AND ER 4121 having diameter 3 mm has been used for the welding.

2) Fixed Parameters

a. welding voltage
b. welding speed
c. electrode diameter

2.3.2 Design of Experiment

As in our experimentation many factors such as welding current, gas flow rate and filler metals are supposed to be considered. As the experimentation is going on, elimination of some factors is necessary to decrease the total degree of freedom in the experiment and we have intact the three major parameters such as welding current, gas flow rate and filler metal to do the experiment. So, in accordance with number of parameters in the experiment we have taken three numbers of levels for each factor, which basically depends on the orthogonal arrays that we will discuss in the next few steps.

Now for the present experiment number of levels = 3

Number of factor = 3 (welding current, gas flow rate and filler metal)

When a particular OA is selected for an experiment the following inequality must be satisfied.

Table 4: L9 Orthogonal array

Experimental run	**LEVEL**		
	Welding current	Gas flow rate	Filler metal
1	1	1	f 1
2	1	2	f 2
3	1	3	f 3
4	2	1	f 2
5	2	2	f 3
6	2	3	f 1
7	3	1	f 3
8	3	2	f 1
9	3	3	f 2

After assigning the factor, next step is to conduct the various tests and analyze the result showing the effects of factors on the part quality of SLS parts. The main purpose of this analysis is to estimate the effects that each factor has on the final results. First we have calculate the signal to noise (S/N) ratio, then calculated the mean of (S/N) ratio and the means of the result to find its effect on each factor level.

Design the Taguchi orthogonal array method welding the pieces with varied parameters.

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Fig. 5: Welded pieces

2.4 Testing for Experiment

The tensile and impact toughness of welded joints are calculated to determine the quality of welded joints. The tensile testing machine and impact toughness testing machine are setup in CITCO –IDFC Chandigarh.

2.4.1 Tensile Strength Test

The most common testing machine used in tensile testing is the universal testing machine. This type of machine has two crossheads; one is adjusted for the length of the specimen and the other is driven to apply tension to the test specimen. There are three main parameters: force capacity, speed, and precision and accuracy.

This machine is located in CITCO-IDFC Chandigarh. Specification of machine is UTE100, Capacity 1000KN, Resolution 0.05KN and Make – FIE.

Size for specimen used in this machine 195 x 25 x 12 mm

Fig. 6: Sample for tensile testing

2.4.2 Impact Test

The impact toughness (AKA Impact strength) of a material can be determined with a Charpy or Izod test. . Impact properties are not directly used in fracture mechanics calculations, but the economical impact tests continue to be used as a quality control method to assess notch sensitivity and for comparing the relative toughness of engineering materials. The two tests use different specimens and methods of holding the specimens, but both tests make use of a pendulum-testing machine.

This machine is located in CITCO-IDFC Chandigarh. Specification of machine is Range-1 to 300J, L.C-0.5J and Make – FIE.

Size for specimen used in this machine 55 x 10 x 10 mm.

Fig.7: Specimens for Impact Toughness

III. RESULTS AND DISCUSSION

The Taguchi method of design of experiment using L9 orthogonal array to map effects of parameters on TIG WELDING PROCESS was proposed. In this topic calculation work including the tables and graphs was discussed.

3.1 Experimental Analysis for TENSILE STRENGTH TESTING OF WELDED JOINTS

Table 5: Result of Tensile Strength Test Results and S/N Values for the Welded Parts

Exp.no.	Current (a)	Gas flow rate (l/min.)	Filler Metal	Tensile strength ts 1 (kn/mm²)	Tensile strength TS 2 (KN/mm²)	S/N Ratio	Mean
1	130	3	f1	302	325	49.9072	313.5
2	130	5	f2	315	330	50.1635	322.5
3	130	7	f3	318	299	49.7727	308.5
4	150	3	f2	312	300	49.7094	306.0
5	150	5	f3	346	350	50.8312	348.0
6	150	7	f1	326	334	50.3684	330.0
7	170	3	f3	278	290	49.0606	284.0
8	170	5	f1	275	283	48.9094	279.0
9	170	7	f2	265	280	48.6975	272.5

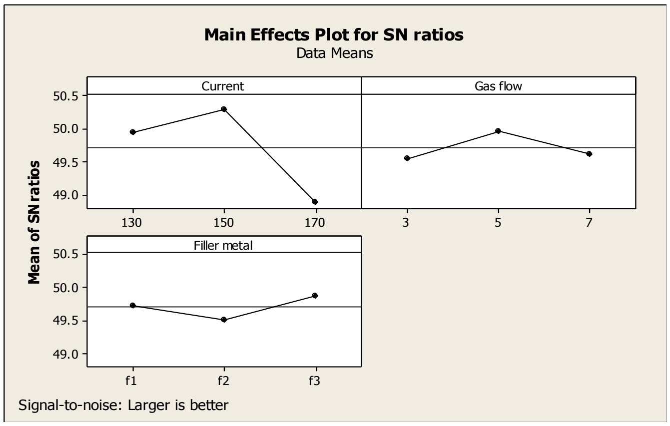

Fig. 8: SN ratios graph for Tensile Strength Testing

In figure 6.1 shows the graphical data for SN ratio were maximum when the welding current 150A, gas flow rate 5 L/min. and filler metal f3 was used the more tensile strength was occurred in the specimen.

Table 6: Analysis of Variance for S/N ratio in Tensile Strength test

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of Contribution
Welding current	2	3.2459	3.2459	1.6230	11.42	0.080	80.607
Gas flow rate	2	0.2963	0.2963	0.1482	1.04	0.490	7.358
Filler metal	2	0.2005	0.2005	0.1002	0.71	0.586	4.979
Error	2	0.2841	0.2841	0.1421			7.055
Total	8	4.0268					

Table 7: Response Table for Signal to Noise Ratios Tensile Strength

Level	Current (A)	Gas Flow Rate (L/min.)	Filler Metal
1	314.8	301.2	307.5
2	328.0	316.5	300.3
3	278.5	303.7	313.5
Delta	49.5	15.3	13.2
Rank	1	2	3

In the tensile strength the current affects the welding joint, in the response table the current has occupies first rank than other parameters. The three welding currents were used for welding like 130,150 and 170 ampere. The welding currents of maximum tensile strength like 150 ampere. Gas flow has second rank and filler metal has third rank for maximum tensile strength.

3.2 Experimental Analysis for Charpy V-notch testing of Welded Joints

Table 8: Charpy V-notch Test Results and S/N Values for the Welded Parts

EXP.NO.	CURRENT (A)	GAS FLOW RATE (L/min)	FILLER METAL	Charpy V-notch test (CV 1) (J/m^2)	Charpy V-notch test (CV 2) (J/m^2)	S/N RATIO	MEAN
1	130	3	f1	29.4	24.6	28.5242	27.00
2	130	5	f2	28.5	32.6	29.6415	30.55
3	130	7	f3	24.6	20.4	26.9300	22.50
4	150	3	f2	30.4	26.3	28.9829	28.35
5	150	5	f3	34.5	28.2	29.7930	31.35
6	150	7	f1	27.2	23.3	27.9674	25.25
7	170	3	f3	12.6	16.4	23.0030	14.50
8	170	5	f1	15.6	10.4	21.7540	13.00
9	170	7	f2	8.7	16.4	20.7238	12.55

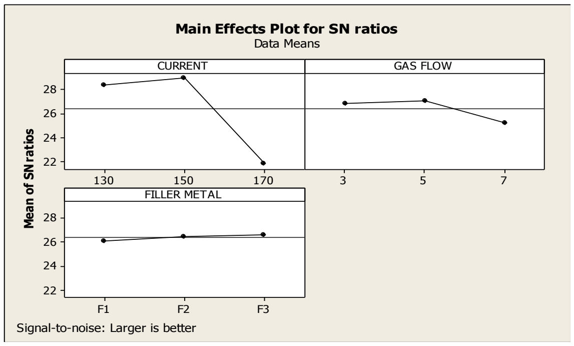

Fig. 9: S/N ratios graph for Charpy V-Notch Test

In figure 6.2 shows the graphical data for SN ratio were maximums when the welding current was 150 A; gas flow rate 5 L/min. and filler metal f3 was created more toughness than other parameters.

Table 9: Analysis of Variance for S/N ratio in Charpy V-notch Test

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% of Contribution
Welding current	2	93.284	93.284	46.6421	64.43	0.015	92.107
Gas flow rate	2	6.151	6.151	3.0753	4.25	0.191	6.073
Filler metal	2	0.394	0.394	0.1972	0.27	0.786	0.389
Error	2	1.448	1.448	0.7239			1.429
Total	8	101.277					

Table 10: Response Table for Signal to Noise Ratios Impact Toughness

Level	Current (A)	Gas Flow Rate (L/min.)	Filler Metal
1	28.37	26.84	26.08
2	28.91	27.06	26.45
3	21.83	25.21	26.58
Delta	7.09	1.86	0.49
Rank	1	2	3

In the impact toughness testing response table 6.6 shows the current affects the more toughness of the work piece, in this table rank wise for responsible for more toughness current has first rank, gas flow rate has second rank and filler metal has third rank in the impact toughness testing. The welding current 150A has created more toughness. In the impact toughness test the response table shows the maximum toughness at current is 150 A.

IV. CONCLUSION

This study investigates some factors affecting the joint performance of TIG welded joints of EN31 to mild steel and the various tests were carried out to evaluate the joint performance. Based on the results produced through mechanical analysis, the following conclusions are obtained.TIG welding was successfully used for the welding of dissimilar material of mild steel to EN 31 steel using different types of filler metals for welding. The design of experimentation the L9 orthogonal array was used with three welding parameters to be conducted with a sample of 09 specimens.

a) From the tensile test results, it was clear that the maximum tensile strength of 346 KN/mm² is obtained at 150 A current, 5 L/min gas flow rate and ER 4121 filler metal was used.
b) From the impact toughness test results, it was clear that the maximum impact toughness of 34.5 J is obtained at 150 A current, 5 L/min gas flow rate and ER 4121 filler metal was used.
c) On the basis of mechanical properties such as tensile strength, impact toughness and Vickers hardness of the best welding quality of the welded joints is obtained at 150 A current as compare to 130 A and 170 A current.

V. SCOPE FOR FUTURE WORK

The future scope of the study is discussed in steps such as shown below:

1. In the present study welding current, gas flow rate and filler metals are taken into account as input parameters. The other welding parameters such as arc voltage, heat input, stand of distance can be investigated and change the readings of the input parameters.
2. The different base metals are used to achieve better result.
3. The welding procedure for various thickness of the base metal.
4. The hardness at heat affected zone and welded zone of the specimens at micro level.

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