Parametric Optimization of TIG Welding of Stainless Steel(316) and Mild Steel, by Taguchi Method and Investigation of Mechanical Properties by Destructive Testing

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Abstract— Dissimilar materials joints provide very good combination of mechanical properties for industrial applications. TIG welding is best suitable for welding dissimilar materials like, Carbon steel, stainless steel and their alloys. In this study Stainless steel (316) and Mild steel are selected for welding operation. Welding current, Voltage, Gas flow rate, are three parameters selected TIG welding operation. To understand the effect of these parameters on selected materials we have used Taguchi L9 orthogonal array method to achieve a optimized parametric combination of TIG welding. We have calculate Tensile Strength, Hardness, of 9 welded specimens by destructive testing method, results of these experiments shows that Specimen L5 has highest strength among all specimens.

Keywords: TIG, Tensile Strength, Hardness, Stainless Steel, Mild Steel, Destructive Testing

I. INTRODUCTION

Welding is the process of permanent joining of similar or dissimilar metal at their contacting surfaces by application of heat. TIG welding process is an Arc welding process developed in late 1930s.

TIG welding used when a good weld joint, appearance, a high quality weld and stability in the wide range of welding applications are required.

TIG welding is a process that melts and joins metals by heating them with an arc established between non-consumable tungsten electrodes and the work piece under a shielding gas.

Shielded metal arc welding (SMAW), Tungsten Inert Gas (TIG) welding and Metal Inert Gas (MIG) welding processes shows improve mechanical properties of stainless steel and low carbon joints. TIG welding provides greater control over SMAW and MIG weld process, provides higher quality welds in a wide variety of metal and alloys.

TIG welding is widely used for welding of metals like stainless steel, some alloy grades of Aluminium, Mg materials. It is used in critical applications like for precision welding in nuclear structural materials fabrication, air craft, chemical, petroleum, automobile and space craft industries. The Tungsten arc process is being employed widely from the precision joining of critical components which require controlled heat input. The small intense heat provided by the Tungsten arc is ideally suited to the controlled melting of the thin sheets, some times without filler rods. Advantages of TIG welding are concentrated arc, no slag, no splatter, little smoke or fumes, good weld penetration, preferred for stainless steel alloys. Disadvantages are slow process, good skill requirement for manual operation.

II. SELECTION OF MATERIAL

The stainless steel (316) is one of the most popular materials for structural applications, due to their excellent physical properties but increase the structural cost.

ELEMENT	Wt%
C	0.03
Mn	1.58
Si	0.29
P	0.027
S	0.003
Cr	16.25
Mo	2.27
Ni	11.90

Table 1: Composition of SS316

ELEMENT	Wt%
C	0.18
Mn	0.80
Si	0.40
S	0.04
P	0.04

Table 2: Composition of Mild steel

III. LITERATURE REVIEW

A. *Radha Raman Mishra & Visnu Kumar Tiwari*

Topic: A study of tensile strength of MIG and TIG welded dissimilar joints of mild steel and stainless steel, (2014)
In their research, stainless steel of grades 202, 304, 310 and 316 were welded with mild steel by Tungsten Inert Gas (TIG) and Metal Inert Gas (MIG) welding processes. The percentage dilutions of joints were calculated and tensile strength of dissimilar metal joints was investigated. The results were compared for different joints made by TIG and MIG welding processes and it was observed that TIG welded dissimilar metal joints have better physical properties than MIG welded joints.

B. *P. Bharatha, V.G. Sridhar,*

Topic: Optimization of 316 Stainless Steel Weld Joint Characteristics using Taguchi Technique, (2014)
The objective of his research is to determine the influence of various welding parameters on the weld bead of AISI 316 welded joint. In this research work the ANOVA technique is used to identify the influence of the welding speed, current, electrode, root gap on the strength of the material. The result shows that speed is most influencing factor to have highest bend strength and current that is to be used while welding is the most influencing factor to get higher tensile strength. Based on Analysis of variance (ANOVA) it is found that welding speed (46.51% contribution) has greater influence on bend strength and current (96.75%) has highest influence on

tensile strength. Further it has found that root gaps has some influence on both tensile and bend strength.

C. Sanjay Kumar, Pravin Kumar Singh, Dharmendra Patel

Topic: Optimization of TIG welding process parameters using Taguchi's analysis and response surface methodology, (2017)
In their present investigation a best set of process parameters for TIG welding is observed using Taguchi's L27 orthogonal. The selected input parameters are Current, Voltage, Root Gap and Gas flow rate. Further the mechanical testing was performed. Bending strength and micro-hardness values are chosen as the response values. The regression relation between input parameters and response values are designed with the help of Response surface methodology. Investigation shows the affect of each process parameters on the response values. Result shows that Hardness property is most affected by the Welding voltage, Strength of the weld joints is enhancing with reducing the welding voltage and same is maximum at 70 Amp of current.

IV. METHODOLOGY

A. Taguchi Method

The selection of weld process parameters for the best weld sample production and weld quality are very important. As the number of parameters are increased the cost and experimentation procedures get added up.

Taguchi method is a powerful tool that uses a special design to study the parameter space with small number of experiments through orthogonal arrays. In the factorial design, the number of levels and factors increases the number of factors and levels increases exponentially. This technique provides an efficient, simple and systematic approach to optimize design for quality, performance and cost. Large number of experiments has to be done, when the factors and levels increases. To solve the problem, an orthogonal array is developed in Taguchi method to study entire parameters. These results are transformed by using S/N (signal to noise)ratio. This S/N ratio can be characterized into three categories i.e., nominal-the better, lower-the better, larger-the better. In this research larger-the-better is chosen to get the final strength that should be maximum.

Larger the better: S/N ratio = $-10 \log_{10} (\mathcal{E}(1/y^2)/n)$

Taguchi method uses a special design of experiments called Orthogonal Arrays. It gives a statistically equivalent full factorial study of the entire parameter range with minimum number of experiments. In addition, it also evaluates the interaction of main parameters in changing the output response variations. This method has become popular in industry as it is feasible to evaluate, optimize and control the mean & variation in production processes. The first step in Taguchi process is to do two level factors experiments to see the control parameters, called system design. System Design leads to understanding the contribution of critical parameters within the process, feasible levels of control factors, are obtained as was aimed in the present study.

In the present experimental study special attention is given towards the joint strength. Taguchi L9 experiments were conducted, with Weld current, voltage, and Argon gas flow were the main factors selected as System Design.

Sl No	Parameters	Specification	TIG
1	Shielding gas	Type Flow Rate	Argon (10-20Lit/min)
2	Current	Type Polarity Current Range Voltage Range	DC Electrod(+Ve) 100-200 (A) 10-14 (V)
3	Electrodes	Diameter Type	1.6 mm Tungsten
4	Filler Rod	Type	Rod, E316

Table 3: Parameters used for welding

Sample No	Welding current(A)	Voltage(V)	Gas Flow Rate(Lit/min)
1	100	10	10
2	100	12	15
3	100	14	20
4	150	10	10
5	150	12	15
6	150	14	20
7	200	10	10
8	200	12	15
9	200	14	20

Table 4: Taguchi's L9 Orthogonal Array

S/N Ratio calculation for L1 specimen
S/N ratio = $-10 \log_{10} (\mathcal{E}(1/y2)/n)$
$= -10\log_{10}((1/(527.170)^{20})/1)$
$= -10\log_{10}(3.598*10^{-6})$
S/N Ratio=54.4

V. TIG WELDING PROCESS PARAMETERS

The effect of different welding parameters on the weld and its quality are explained below.

A. Welding Current and Polarity

The welding current corresponds to the amount of heat applied to the part to affect the weld, and it depends on the material to be welded, material thickness, welding speed, and shield gas. The objective is to achieve defect-free welds with the required penetration. Current has direct influence on weld bead shape, on welding speed and quality of the weld. Most GTAW welds employ direct current on electrode negative (DCEN) (straight polarity) because it produces higher weld penetration depth and higher travel speed than on electrode positive (DCEP) (reverse polarity). Besides, reverse polarity produces rapid heating and degradation of the electrode tip, because anode is more heated than cathode in gas tungsten electric arc.

B. Voltage

Voltage controls the length of welding arc and resulting width and volume of arc cone. As voltage increases arc length gets longer (and arc cone broader), while as it decreases, the arc length gets shorter (and arc cone narrower). A high initial voltage allows for easy arc initiation and allows for greater range of working tip distance. Depth of penetration decreases as voltage increases. In GTAW welding process filler feeding or Filler melt off rate should be kept constant since it is manual process. Voltage is a controlling variable in manual processes because in manual process it is very difficult to consistently maintain the same arc length.

C. Type of Shielding Gas and Its Flow Rate

The choice of proper shielding gas for TIG welding can significantly affect weld quality and welding speed. Argon, helium and argon-helium mixtures use most widely as they are not reactive on tungsten electrodes. They are not producing any adverse effect on the quality of the weld.

Argon gas as a Shielding gas medium is more widely preferred as it provides a softer arc, which is smooth and stable it is being less expensive,. Argon is better for welding specially aluminium and magnesium alloy. Flow rate of shielding gas is also major parameter affect the weld quality and it is depending upon types of material and thickness of the same.

VI. RESULTS AND DISCUSSIONS

The welding of stainless steels 316 was carried out with Mild steel. The tensile test and Hardness test was conducted for each welded samples of TIG welding process, to calculate Tensile strength and Hardness.

A. Tensile Test

Tensile testing were carried out using Universal Testing Machine of 400 KN capacity and the geometry of the test specimen is as shown in Fig.1. Mechanical proprieties of TIG welded dissimilar welds of stainless steel and mild steel after tensile test are tabulated in Table-5.

Tensile strengths of welded test samples vary from 520 to579 N/mm^2 depending upon the welding conditions. All the specimens broke in the weld region and parentage of elongation, and yield stress, measured across the weldment. The Time series plot for tensile strength confirms that specimen L5 has highest tensile strength and its stress-strain plot is shown in Fig.2.

Sample No	Tensile Strength	S/N Ratio
L1	527.170	54.40
L2	480.126	53.62
L3	566.360	55.00
L4	457.125	53.20
L5	579.889	55.25
L6	577.505	55.23
L7	473.821	53.51
L8	569.830	55.10
L9	574.332	55.18

Table 5: Rsults of Tensile Test

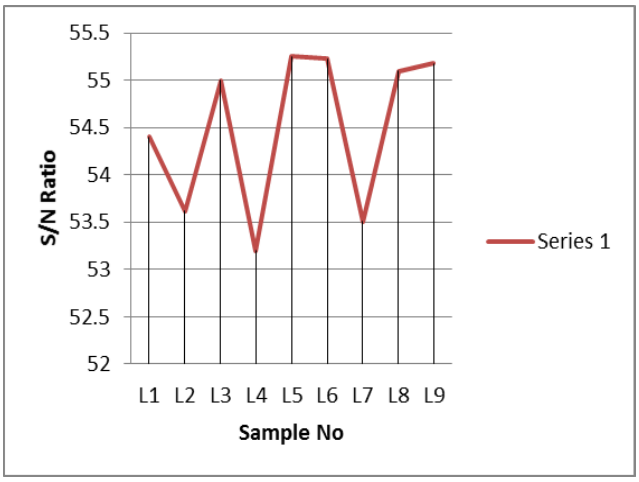

Fig. 1: Graph of S/N Ratio for various samples.

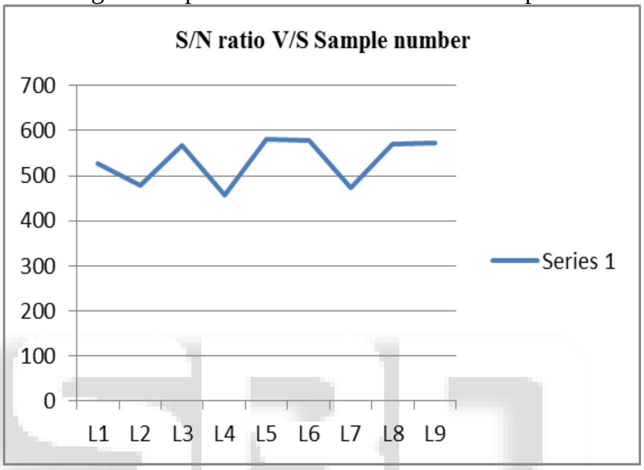

Fig. 2: graph of tensile strength of various samples.

Levels	Current	Voltage	Gas flow Rate
1	54.34	53.70	53.70
2	54.56	54.65	54.65
3	54.59	55.13	55.13
Delta	0.25	1.43	1.43
Rank	2	1	1

Table 7: Response Table for S/N Ratio(Tensile strength, Larger is better)

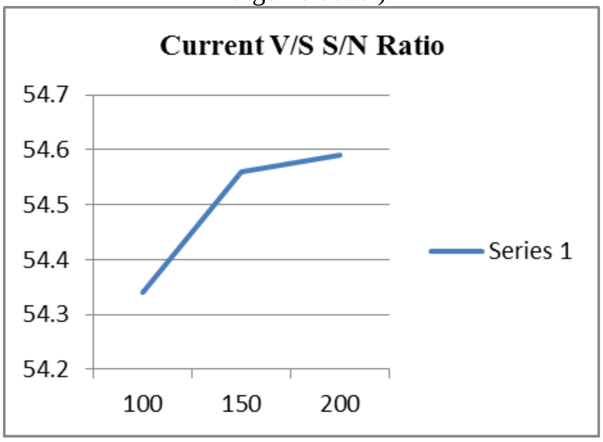

Fig. 4: Current V/S S/N Ratio

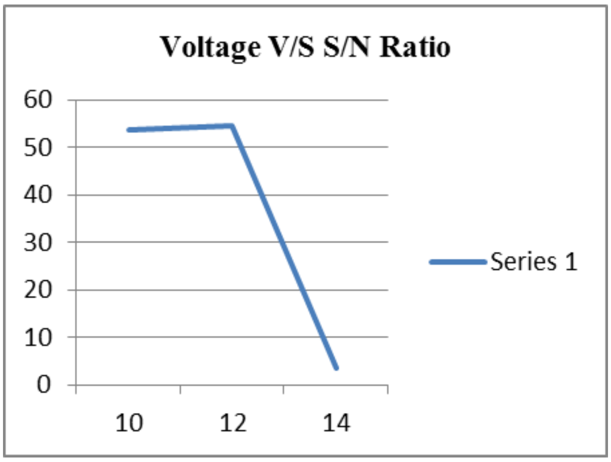

Fig. 5: Voltage V/S S/N Ratio

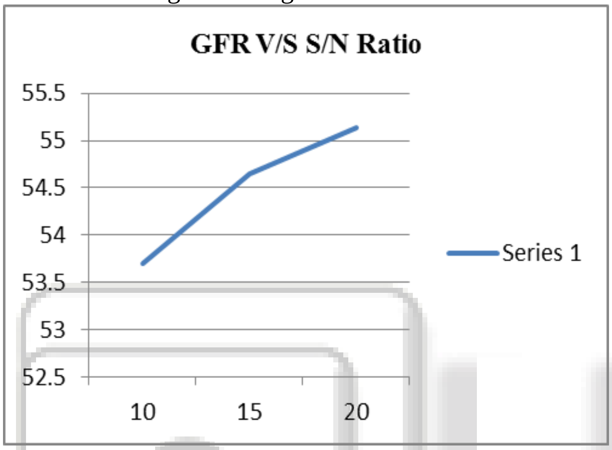

Fig. 6: GFR V/S S/N Ratio

Table.7 shows the experimental analysis for Tensile strength. In our experimental analysis, the rank indicates that Voltage and GFR has greater influence than welding current for both S/N ratio and mean.

B. *Hardness Test*

Brinell Hardness Testing is a hardness measurement based on the net increase in depth of impression as a load is applied. Hardness machine with load 250Kgf and Indenter of 5mm diameter is used. Hardness values of all specimens are measured and their S/N Ratio is calculated as shown in Table.6

Sample No	Hardness(HBN)	S/N Ratio
L1	150	43.52
L2	152	43.63
L3	155	43.80
L4	155	43.80
L5	155	43.80
L6	159	44.03
L7	155	43.80
L8	159	44.03
L9	155	43.80

Table 6: Hardness and S/N Ratio of Various Samples

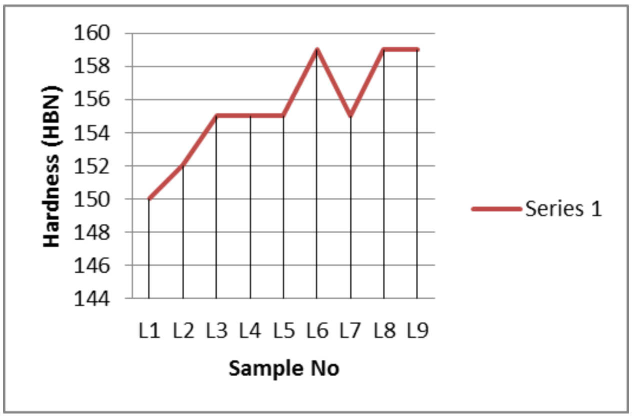

Fig. 7: Graph of Hardness V/S Sample Number.

VII. Conclusion

As per results it is clear that, Current, Voltage and GFR plays a crucial rule in increasing tensile strength of materials. As per results the maximum tensile strength is achieved in specimen L5 which is at 200 amp, 12V, and 15 lit/min. by observing the rank obtained in table5 it is clear that voltage & GFR plays major rule in increasing tensile strength.

Maximum Hardness is achieved in specimen L6 (150amp, 14V, 20lit/min) & L8 (200amp, 12V, 15lit/min).

Taguchi design of experiment can be very efficiently used in the optimization of welding parameters in manufacturing operations. Thus design of experiment by Taguchi method was successfully used to find optimum parameters for Tensile Strength & Hardness.

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