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# Influence of Process Parameter of GTA Welding On Metal Deposition Rate and Mechanical Properties of Super Duplex Stainless Steel Using Design of Experiment

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***ABSTRACT***
*GTA welding is a well-known welding technique for joining two or more metal pieces either of same material or of different material. GTAW provides very good quality joints in less time and in better quality. It can be used for a wide variety of materials. No flux is used but the arc and the molten metal are shielded by an inert gas, which may be argon, helium, hydrogen, nitrogen, or mixtures of some of these gases. GTAW technique is still evolving to get better day by day with the improvement in the materials developed that can be easily used in oil and gas industries. The present study is undertaken as to study the Influence of process parameter of GTAW technique on metal deposition rate and mechanical properties of super duplex stainless steel using design on experimentation Taguchi L9 method by varying parameter like current, gas flow, arc length, welding speed to obtain optimized value of response for Hardness and metal deposition rate (MDR).*

***Keywords: -*** *Gas tungsten arc welding, Metal Deposition Rate, L9 orthogonal array method, S/N Ratio.*

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## I. INTRODUCTION

In early 1940s Northrop Aircraft was developing an experimental aircraft from magnesium designated XP-56, for which Vladimir Pavlecka, Tom Piper and Russell Meredith developed a welding process named Heli arc because it used a tungsten electrode arc and helium as a shielding gas (the torch design was patented by Meredith in 1941). It is now often referred to as tungsten inert gas welding (TIG), especially in Europe, but the American Welding Society's official term is gas tungsten arc welding (GTAW). With the increasing demand of toughness, hardness etc. of joint further improvements are introduced which developed and increased the importance of GTAW technique for joining metals. TIG welding is applied in all industrial sectors but is especially suitable for high quality welding. Super-duplex stainless steel (SDSS) is widely used in various industries due to its good mechanical properties and high corrosion resistance. Its corrosion resistance is due to the increase in Cr, Mo, and N alloying contents. Welding is important for SDSS, but it can negatively affect the microstructure and corrosion resistance of welded joints. Different welding techniques have been successfully applied, but heat input during welding alters the mechanical and corrosion properties of welded joints. Low heat input leads to higher ferrite content and higher chromium nitride precipitation, while high heat input promotes the precipitation of brittle phases. The influence of heat input on the nanoindentation response and corrosion behaviors of SDSS is still poorly understood.

### 1.1 GTA WELDING PROCESS

During the TIG welding process, an arc is formed between the tungsten electrode and the work. The arc that is produced by the electrode is intense and makes TIG welding perfect for high-quality welds. The electrode is not consumed during the welding. TIG welding requires great precision. The tungsten electrode heats up the objects enough so they can form a bond. TIG welding enables the joining of objects without the use of filler, though a filler metal is commonly used in TIG welding. TIG welding can be used for direct metal-to-metal welds and results in neater, spatter-free welds that are generally free of defects.

GTA welding process are dependent upon the parameters which are used for carrying out various experimental procedure to get the required result these are some parameters used in this experimental work:

**1.1.1 Welding current** is the most influential variable in the arc welding process which controls the electrode burn off rate, the depth of fusion and geometry of the weldments. 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. Higher current in GTA welding can lead to splatter and work piece become damage. Again, lower current setting in GTA welding led to sticking of the filler wire. Sometimes larger heat affected areas can be found for lower welding current, as high temperatures need to apply for longer periods of time to deposit the same amount of filling materials. [1][2]

**1.1.2** This is the electrical potential difference between the tip of the welding wire and the surface of the molten weld pool. **Welding voltage** can be fixed or adjustable depending on the GTA welding equipment. It determines the shape of the fusion zone and weld reinforcement. A high initial voltage allows for easy arc initiation and a greater range of working tip distance. However, it produces wider, flatter and less deeply penetrating welds than low welding voltages, depth of penetration is maximum at optimum arc voltage, to high voltage on the other hand will lead to large variable in welding quality. [3]

**1.1.3** **Speed of welding** is defined as the rate of travel of the electrode along the seam or the rate of the travel of the work under the electrode along the seam. [4] Weld Travel Speed = Travel of electrode/arc time, mm/min. [5] The weld speed increase produces a decrease in the weld cross section area, and consequently penetration depth (D) and weld width (W) also decrease, but the D/W ratio has a weak dependence on travel speed. These results suggest that the travel speed does not influence the mechanisms involved in the weld pool formation, it only influences the volume of melted material. Normal welding speeds are from 100 to 500 mm/min depending on current, material type and plate thickness. [6]

**1.1.4** Electrode extension or also called stick-out length or stick-out distance refers to the length of the welding wire that extends outside the contact tube. The welding electrode/ filler wire extension by the stick-out length influences the burn- off rate and the weld bead profile. Welding current and voltage are related to the electrode stick-out length.

### 1.2 Mechanical and Physical Properties of Base metal

Super Duplex Stainless steel combines high tensile and impact strength with a low coefficient of thermal expansion and high thermal conductivity. These properties are suitable for many structural and mechanical components. The low, ambient, and elevated temperature mechanical properties of 2507 sheet and plate are shown below. All the test data shown are for samples in the annealed and quenched condition.2507 SS is not recommended for applications which require long exposures to temperatures more than 570°F because of the increased risk of a reduction in toughness. The data listed here are typical for wrought products and should not be regarded as a maximum or minimum value unless specifically stated.

## II. METHODOLOGY

Increasing productivity & improving quality are important goals in any project. Methods for determining productivity & improving quality are evolving. They have changed from costly & time-consuming trial & error searches to powerful, elegant & cost-effective statistical methods. Designing experiments is centered around factors, responses & runs. It helps you determine how a factor affects a response.

### 2.1 Taguchi Experimental design and Analysis

Dr. Genichi Taguchi is regarded as the foremost proponent of robust parameter design, which is an engineering method for product or process design that focuses on minimizing variation and/or sensitivity to noise. When used properly, Taguchi designs provide a powerful and efficient method for designing products that operate consistently and optimally over a variety of conditions. Taguchi proposed several approaches to experimental designs that are sometimes called "Taguchi Methods." These methods utilize two-, three-, four-, five-, and mixed-level fractional factorial designs. Taguchi refers to experimental design as "off-line quality control" because it is a method of ensuring good performance in the design stage of products or processes.

### 2.2 Taguchi design experiments in MINITAB

MINITAB provides both static and dynamic response experiments in a static response experiment; the quality characteristic of interest has a fixed level. The goal of robust experimentation is to find an optimal combination of control factor settings that achieve robustness against (insensitivity to) noise factors.

2.3 Experimental Plan The first phase in utilizing the DOE techniques is planning the experiment. There are a few important things that need to be followed to plan a successful experiment. This step defines the process objective, a target value for a performance major of the process. Determine the design 16 parameters affecting the process. Parameters are variables within the process that affect the performance measure that can be easily controlled. The no. of levels that the parameters should be varied to must be specified. Increasing the number of levels to vary a parameter increases the number of experiments to be conducted.

### 2.4 Response variables

In this step, the process objective needs to be more specified, so the experiment can be set up properly for the purpose of achieving the process objectives. To achieve the project objectives, the method of how to evaluate those objectives must be considered so that no error will compromise the data which can lead to wrong conclusion of experiment. The objectives in this work are optimizing the response variables, which are Material Deposition Rate (MDR), and hardness (WM and HAZ).

### 2.5 Objective function

The objective function can be of two kinds. Either the objective function is to be minimized or it must be maximized. In this paper, minimization and maximization are considered as objective functions. The characteristics of response are shown as follows:

1. Hardness at HAZ zone
2. Hardness at weld metal
3. Metal Deposition Rate

### 2.6 Design factors

From the past studies and other research done by others, it was decided that only four parameters will be taken into consideration. In this step, welding factors(parameters) are considered to influence the response of the system. In this case, GTA welding response will be studied. The experimental plan has four selected design factors are:

1.Current, I (A)
2.Gas Flow Rate (lpm)
3.Arc Length (mm)
4.Welding speed (mm/s)

### 2.7 Determine the number of levels and the level values.

In this step, the number of levels and its value will be determined carefully. If curved or higher order polynomial relationship between the parameters under the study and the response is expected, at least three levels for each parameter should be considered. It is desirable to have three minimum levels of the process parameters to reflect the true behavior of output parameters of study. Therefore, the number of levels is set to the three levels of each parameter. The levels of the individual process parameters/factors are given in table 1.

| Factors | Welding parameter | Units | Symbol | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|---|---|
| A | Current | Ampere | A | 95 | 110 | 125 |
| B | Gas Flow Rate | lmp | GFR | 10 | 12 | 14 |
| C | Welding speed | m/min | WS | 0.09 | 0.12 | 0.15 |
| D | Arc length | mm | L | 2.9 | 3.3 | 3.9 |

Table 1: Welding Parameters & their level values.

### 2.8 Determining parameters using orthogonal array.

The effects of many different parameters on the performance characteristic in a condensed set of experiments can be examined by using orthogonal array experimental design proposed by Taguchi. Once the parameters affecting a process that can be controlled have been determined, the levels at which these parameters should be varied must be determined. Determining what levels of a variable to test requires an in-depth understanding of the process, including the minimum, maximum and current value of the parameter. If the difference between the maximum and minimum value of a parameter is large, the values being tested can be further apart or more values can be tested. If the range of a parameter is small, then less values can be tested or the values tested can be closer together.

### 2.9 L9 Orthogonal array for this experiment

The experiment has 4 variables at 3 different settings. A full factorial experiment would require 3^4=81 experiments. We conducted an orthogonal array (9 tests, 4 variables, 3 levels).

| S. No. | Current (A) | Gas Flow Rate (lmp) | Welding Speed (m/min) | Arc length (mm) |
|---|---|---|---|---|
| 1. | 95 | 10 | 0.09 | 2.9 |
| 2. | 95 | 12 | 0.15 | 3.3 |
| 3. | 95 | 14 | 0.12 | 3.7 |
| 4. | 110 | 10 | 0.15 | 3.7 |

| | | | | |
|---|---|---|---|---|
| 5. | 110 | 12 | 0.12 | 2.9 |
| 6. | 110 | 14 | 0.09 | 3.3 |
| 7. | 125 | 10 | 0.12 | 3.3 |
| 8. | 125 | 12 | 0.09 | 3.7 |
| 9. | 125 | 14 | 0.15 | 2.9 |

Table 2: L9 orthogonal array

## III. EXPERIMENTAL PROCEEDURE

1. All 18 samples of size 130mm x 30mm x 6mm are prepared for welding operation.
2. Then Pair of samples are taken separately with their welding parameter to perform experimental work.
3. Current, Gas flow rate, welding speed, and arc length were the welding parameters which are varied.
4. Hardness at HAZ zone and Weld metal. And Metal Deposition Rate were the response parameters which were studied.

Experiments were accomplished on GTA welding machine. Following steps were followed in welding operation.

1) Firstly, the Workpiece and filler rod were taken according to the run and measured the initial weight of workpiece (Sample pairs).
2) Welding Parameters were set on the welding machine, gas regulator, and pug machine to perform the welding operation.
3) The Workpiece were mounted and clamped on the workspace.
4) Confirm the parameters and define the welding speed and length.
5) Finally start the spark and completes the operation.
6) Measure the final weight of workpiece after the welding operation.
7) Repeat the above steps to perform all 9 pairs of workpieces.

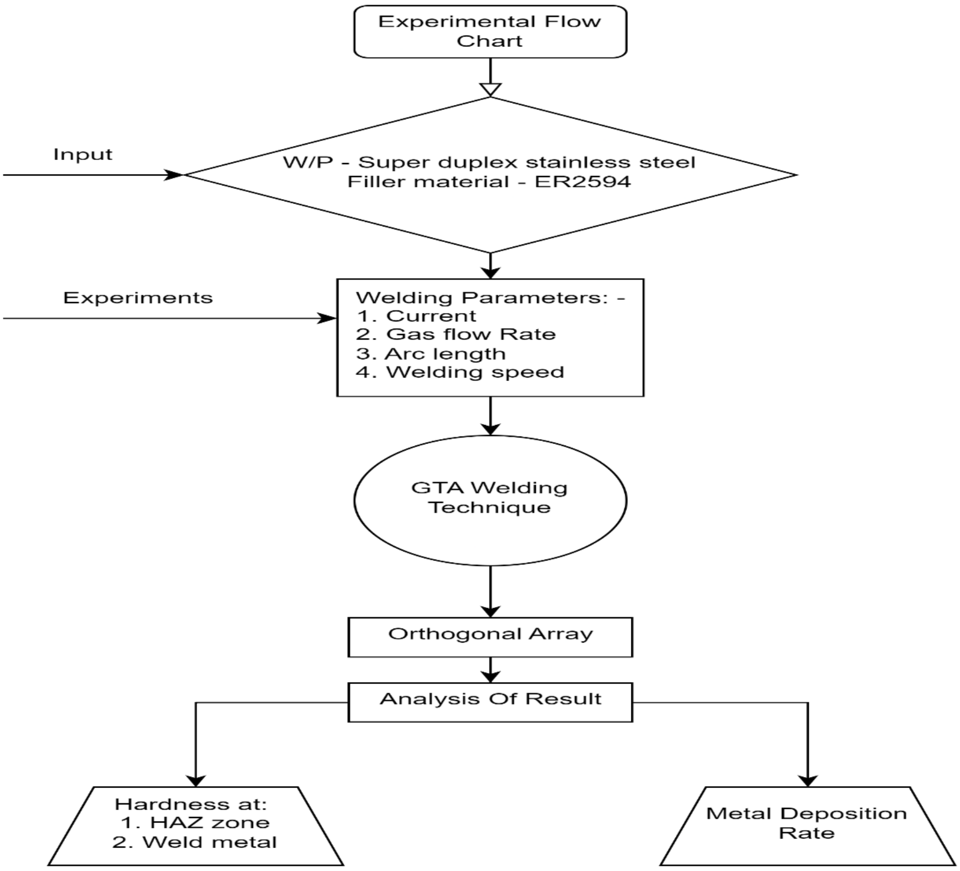

**Fig.1** Experimental flow chart

## IV. CALCULATION OF RESPONSE PARAMETERS

In this project, there are two type of response variables taken for the optimization purpose which is given below:

A) Hardness at HAZ zone and weld metal

B) Metal Deposition Rate

### 4.1 METAL DEPOSITION RATE

The deposition rate is the measure of how much material is deposited in a unit of time. This is usually expressed in either pound per hour (lb./h) or kilograms per hour (kg/h). The deposition rate is an important consideration in welding, as it can impact both the speed and quality of the weld.

### CALCULATION FOR MDR

A material MDR (gm/min) is expressed as the ratio of the difference of weight of workpiece before welding and after welding to the welding time. It is given by,

MDR = (Difference in weight of workpiece before and after welding) / (welding time)

By using the above relation, the MDR was calculated of all runs at different parameters setting 9 workpieces as table:

| Current(I) | Gas Flow(lmp) | Weld Speed(m/min) | Arc Gap(mm) | Initial Weight (gm) | Final Weight (gm) | Time Taken (sec) | Metal Deposition Rate(gm/min) |
|---|---|---|---|---|---|---|---|
| 95 | 10 | 0.09 | 2.9 | 700 | 719 | 86.66 | 13.150 |
| 95 | 12 | 0.15 | 3.3 | 700 | 721.4 | 52 | 24.690 |
| 95 | 14 | 0.12 | 3.7 | 699 | 724 | 65 | 23.030 |
| 110 | 10 | 0.15 | 3.7 | 698 | 720 | 52 | 25.380 |
| 110 | 12 | 0.12 | 2.9 | 699 | 722 | 65 | 21.230 |
| 110 | 14 | 0.09 | 3.3 | 699 | 725 | 86.66 | 18.001 |
| 125 | 10 | 0.12 | 3.3 | 701 | 721 | 65 | 18.460 |
| 125 | 12 | 0.09 | 3.7 | 700 | 723 | 86.66 | 15.920 |
| 125 | 14 | 0.15 | 2.9 | 700 | 726 | 52 | 30.000 |

Table 3: Calculation For MDR

### 4.2 HARDNESS

In materials science, **hardness** is the ability to withstand **surface indentation** (**localized plastic deformation**) and **scratching**. **Hardness** is probably the most poorly defined material property because it may indicate resistance to scratching, resistance to abrasion, resistance to indentation or even resistance to shaping or localized plastic deformation. Hardness is important from an engineering standpoint because resistance to wear by either friction or erosion by steam, oil, and water generally increases with hardness.

This Hardness test is performed using Micro Vickers hardness Tester. Micro Vickers Hardness Testers are capable of accurate measurement of hardness numbers using state-of-the-art image processing technology. They can test a variety of products from soft metals to hardened steel with high accuracy. For loading and unloading, they have a motorized cycle and for load selection, manual machines have external knobs.

Specifications of Micro Vickers Hardness Tester are as Follows:

1. Horizontally rotating turret with four slots for magnification lenses and two for indenters
2. Indent Reading:
    Auto: Automatic focus with auto reading
    Semi: Manual focus with auto reading
    Manual: Manual focus and manual reading
3. Load forces are applied through load cells and controlled in “Closed Loop” with a frequency of 1 kHz, assuring perfect linearity in every range.
4. Motorized table 100 x 60 mm or 200 x 100 mm (automatic) with 0.5 µm step.
5. Test Loads: from 1 gf to 2 kgf (from 0,0098 to 19,614 N)
6. The ergonomic and handy wheel on the tester side controls the Z stroke.
7. The vertically sliding chromed spindle provides stable support for the specimen.
8. Perform reliable tests even on multilevel or misaligned sample surfaces.

Testing Results obtained from Micro Vickers hardness tester for Hardness HAZ zone and Weld metal at different parameters on 9 workpieces are shown in table below:

| Current(A) | Gas Flow(lmp) | Weld Speed(m/min) | Arc Gap(mm) | Hardness (HAZ zone) | Hardness (Weld Metal) |
|---|---|---|---|---|---|
| 95 | 10 | 0.09 | 2.9 | 277.5 | 262.5 |
| 95 | 12 | 0.15 | 3.3 | 272.5 | 257.5 |
| 95 | 14 | 0.12 | 3.7 | 285.0 | 277.5 |
| 110 | 10 | 0.15 | 3.7 | 287.5 | 277.5 |
| 110 | 12 | 0.12 | 2.9 | 285.0 | 275.0 |
| 110 | 14 | 0.09 | 3.3 | 285.0 | 275.0 |
| 125 | 10 | 0.12 | 3.3 | 295.0 | 285.0 |

| | | | | | |
|---|---|---|---|---|---|
| 125 | 12 | 0.09 | 3.7 | 292.5 | 282.5 |
| 125 | 14 | 0.15 | 2.9 | 282.5 | 267.5 |

Table 4: Testing Results for Hardness

## V. RESULT AND DISCUSSION

The welding operation was carried out on super duplex stainless steel test-pieces as per the parameters incurred by the Taguchi's orthogonal array (L9) as given in table 5. The Vickers hardness values (HV) were measured using micro hardness Testing machine and metal deposition rate were measured using precision weighing machine and all those values have been shown in Table 5.

The measured response material deposition rate (MDR), Hardness at HAZ zone and weld metal along with the input processes parameters is given in table 5.

| EXP. NO. | Current (A) | Gas Flow(lmp) | Weld Speed(m/min) | Arc Gap (mm) | Hardness (HAZ zone) | Hardness (Weld Metal) | Metal Deposition Rate(gm/min) |
|---|---|---|---|---|---|---|---|
| 1. | 95 | 10 | 0.09 | 2.9 | 277.5 | 262.5 | 13.150 |
| 2. | 95 | 12 | 0.15 | 3.3 | 272.5 | 257.5 | 24.690 |
| 3. | 95 | 14 | 0.12 | 3.7 | 285.0 | 277.5 | 23.030 |
| 4. | 110 | 10 | 0.15 | 3.7 | 287.5 | 277.5 | 25.380 |
| 5. | 110 | 12 | 0.12 | 2.9 | 285.0 | 275.0 | 21.230 |
| 6. | 110 | 14 | 0.09 | 3.3 | 285.0 | 275.0 | 18.001 |
| 7. | 125 | 10 | 0.12 | 3.3 | 295.0 | 285.0 | 18.460 |
| 8. | 125 | 12 | 0.09 | 3.7 | 292.5 | 282.5 | 15.920 |
| 9. | 125 | 14 | 0.15 | 2.9 | 282.5 | 267.5 | 30.000 |

Table 5: Hardness values (Weld and HAZ) and metal deposition rate (MDR) of TIG welded super duplex stainless steel plate.

### 5.1 Effect of welding parameters on hardness (Weld metal) of TIG welded super duplex stainless steel plate.

L9 OA has been designed as per Taguchi's design of experiment. It is expected to get an optimized level for each factor. The signal-to noise ratio (S/N ratio) is kept high to get minimum value of distortion. The S/N ratio is obtained using negative of logarithmic value of distortion calculated experimentally, which is continuously decreasing function. So, the signal-to-noise ratio is always kept at maximum value. The calculation of S/N ratio is based on higher-the-better model. A larger value of S/N ratio corresponds to better quality characteristics.

| Level | I(A) | GFR (LPM) | WS(m/min) | AG (mm) |
|---|---|---|---|---|
| 1 | 48.49 | 48.78 | 48.73 | 48.57 |
| 2 | 48.81 | 48.67 | 48.54 | 48.70 |
| 3 | 48.89 | 48.73 | 48.92 | 48.92 |
| Delta | 0.40 | 0.11 | 0.37 | 0.35 |
| Rank | 1 | 4 | 2 | 3 |

Table 6: Response Table for S/N ratio for hardness (WM) (higher-the-better)

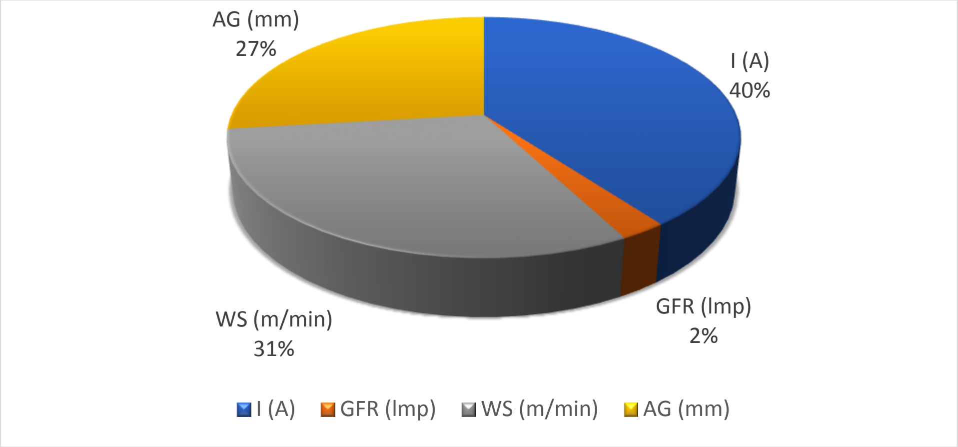

Fig. 7: Percentage Contribution of factors affecting distortion.

| Level | I(A) | GFR (LPM) | WS(M/MIN) | AG (MM) |
|---|---|---|---|---|
| 1 | 265.8 | 275.0 | 273.5 | 268.3 |
| 2 | 275.8 | 271.7 | 267.5 | 272.5 |
| 3 | 278.3 | 273.3 | 279.2 | 279.2 |
| Delta | 12.5 | 3.3 | 11.7 | 10.8 |

| | | | | |
|---|---|---|---|---|
| Rank | 1 | 4 | 2 | 3 |

Table 7: Response Table for mean for hardness (WM)

| Sources | DOF | SS | MS | %P |
|---|---|---|---|---|
| I(A) | 2 | 0.271391 | 0.135695 | 39.853 |
| GFR (lpm) | 2 | 0.01734 | 0.008674 | 2.546 |
| WS (m/min) | 2 | 0.209639 | 0.104820 | 30.785 |
| AG (mm) | 2 | 0.182600 | 0.091300 | 26.814 |
| Error | 0 | | | |
| Total | 8 | 0.680977 | | 100.000 |

Table 8: ANOVA table for hardness (WM)

Therefore, optimized level is the level with largest value of S/N ratio. Response table for S/N ratio of hardness of weld metal is shown in table 6. The meaning of hardness has been shown in Table 7. From table 6, it is found that welding current (I) and welding speed (WS) have maximum effect on hardness of weld metal of TIG welded super duplex stainless steel plate (2507). The above table gives the values of control factors at each level. Fig.6 gives the relative percentage of parameters of welding current, gas flow rate, welding speed and arc gap. It is understood further that there are comparatively higher effects of welding current and welding speed on hardness of welded metal zone of welded joints. Fig.7 and Fig.8 show the S/N ratio and mean plot demonstrating effects of each parameter on hardness (WM) of TIG welded super duplex stainless steel plate. The ANOVA table for hardness of weld metal has been depicted in Table 8. It is observed that gas flow rate and arc gap have relatively less effects on hardness (WM).

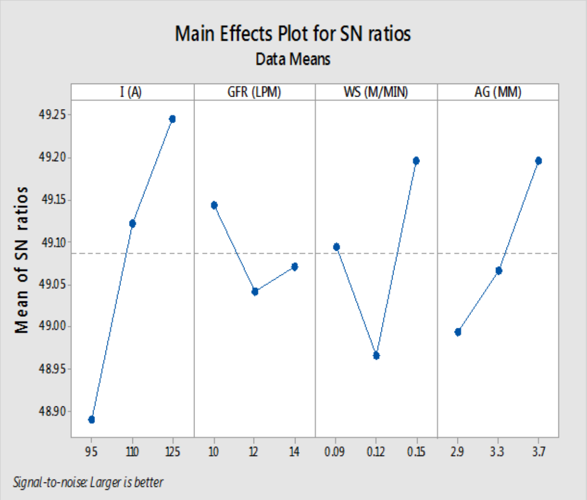

Fig. 8: Main effects plot of S/N ratio

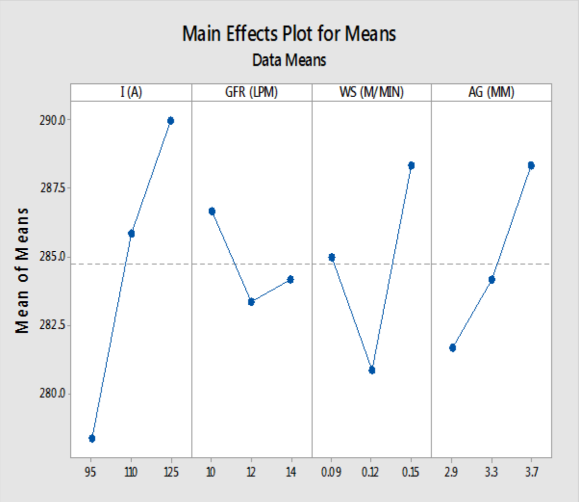

Fig. 9: Main effects plot of Mean (WM hardness) (WM hardness)

The analysis of variance (ANOVA) for the factors indicated in the table 5 shows that the welding current (I) is the most contributing factor in effecting the average hardness of weld metal of TIG welded super duplex stainless steel plate and welding speed (WS), gas flow rate (GFR) and arc gap (AG) have their contribution in decreasing order for hardness of weld metal. Fig.6 shows percentage contribution of factors affecting distortion. With decrease of welding speed, the heat input and consequently heat transferred to welding increases. This increase of heat to the weld enhances the relative amount of melting base metal resulting in an increase of hardness of weld pool. Also, as welding speed increases, heat input decreases and this will give rise to relatively lower heating of upper portion of weld metal and so the hardness enhances with increase of welding speed of welded super duplex stainless steel plate.

**Optimal value of average hardness value of WM in the welded specimen**

From S/N ratio plot an optimized value for minimum distortion was found at I(A) at third level, GFR (lpm) at first level, root face (mm) at third level and welding speed at third level. The average of nine experimental results of distortion is $(\text{distortion})_{avg}=0.7933$ mm. The optimum value of distortion is calculated as shown below:

$(\text{Avg. hardness of WM})_{\text{optimum}} = (I)_{3\text{Avg.}} + (GFR)_{1\text{Avg.}} + (WS)_{3\text{Avg.}} + (AG)_{3\text{Avg.}} - 3(\text{Total avg. hardness of WM})_{\text{avg.}}$ ----- (1)

$(I)_{3\text{Avg}}=278.333$

$(GFR)_{1Avg}=275$
$(WS)_{3Avg.}=279.167$
$(AG)_{3Avg.}=279.167$
3(Total avg. hardness of WM)$_{avg.}=3\text{x}273.334=819.999$
(Avg. hardness of WM)$_{optimal}= 278.333+275+279.167+279.167-819.999=291.668$ VHN

**Confirmation test for Avg. hardness values of WM**

The values from final confirmation run and obtained avg. hardness value are mentioned in Table 9. From analysis of result, it is observed that the calculated error is small of the order of approximately 4.28% which is under acceptable limit.

| Performance measure | Optimal setting of parameters | Predicted and Experimental results | | |
|---|---|---|---|---|
| | | Predicted optimal value (mm) | Experimental value (mm) | %Error |
| Distortion | $I_3GFR_1WS_3AG_3$ | 291.668 | 278.017 | 4.68% |

Table 9: Values from final confirmation run and obtained avg. hardness value of WM.

**5.2 Effect of welding parameters on hardness (HAZ) of TIG welded super duplex stainless steel plate.**

L9 OA has been designed as per Taguchi's design of experiment. It is expected to get an optimized level for each factor. The signal-to noise ratio (S/N ratio) is kept high to get minimum value of distortion. The S/N ratio is obtained using negative of logarithmic value of distortion calculated experimentally, which is continuously decreasing function. So, the signal-to-noise ratio is always kept at maximum value. The calculation of S/N ratio is based on higher-the-better model. A larger value of S/N ratio corresponds to better quality characteristics.

| Level | I(A) | GFR (LPM) | WS(m/min) | AG (mm) |
|---|---|---|---|---|
| 1 | 48.89 | 49.14 | 49.09 | 48.99 |
| 2 | 49.12 | 49.04 | 48.97 | 49.07 |
| 3 | 49.25 | 49.07 | 49.20 | 49.20 |
| Delta | 0.36 | 0.10 | 0.23 | 0.20 |
| Rank | 1 | 4 | 2 | 3 |

Table 10: Response Table for S/N ratio for hardness (HAZ) (higher-the-better)

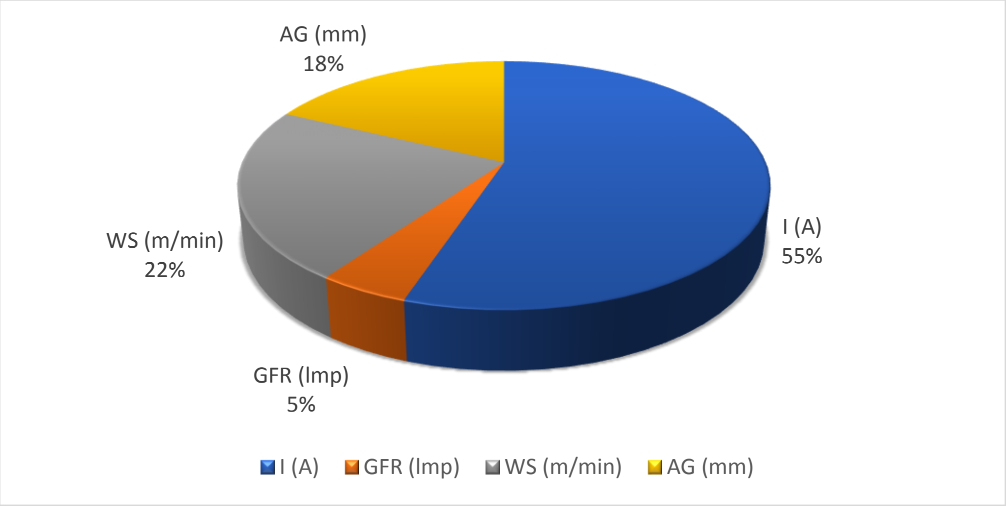

Fig.10: Percentage contribution of Factor affecting distortion.

| Level | I(A) | GFR (LPM) | WS(M/MIN) | AG (MM) |
|---|---|---|---|---|
| 1 | 278.3 | 286.7 | 285.0 | 281.7 |
| 2 | 285.8 | 283.3 | 280.8 | 284.2 |
| 3 | 290.0 | 284.2 | 288.3 | 288.3 |
| Delta | 11.7 | 3.3 | 7.5 | 6.7 |
| Rank | 1 | 4 | 2 | 3 |

Table 11: Response table for mean for Hardness (HAZ)

| Sources | DOF | SS | MS | %P |
|---|---|---|---|---|
| I(A) | 2 | 0.196602 | 0.098301 | 55.129 |
| GFR (lpm) | 2 | 0.016762 | 0.008381 | 4.700 |
| WS (m/min) | 2 | 0.079647 | 0.039821 | 22.333 |

| | | | | |
|---|---|---|---|---|
| AG (mm) | 2 | 0.063614 | 0.031807 | 17.837 |
| Error | 0 | | | |
| Total | 8 | 0.356621 | | 100.000 |

Table 12: ANOVA table for hardness (HAZ)

Therefore, optimized level is the level with largest value of S/N ratio. Response table for S/N ratio of hardness of HAZ is shown in table 9. The mean of hardness has been shown in Table 10. From table 9, it is found that welding current (I) and welding speed (WS) have maximum effect on hardness of weld metal of TIG welded super duplex stainless steel plate (2507). The above table gives the values of control factors at each level. Fig. 9 gives the relative percentage of parameters of welding current, gas flow rate, welding speed and arc gap. It is understood further that there are comparatively higher effects of welding current and welding speed on hardness of weld metal zone of welded joints. Fig.10 and Fig.11 show the S/N ratio and mean plot demonstrating effects of each parameter on hardness (HAZ) of TIG welded super duplex stainless steel plate. The ANOVA table for hardness of weld metal has been depicted in Table 11. It is observed that gas flow rate and arc gap have relatively less effects on hardness (WM).

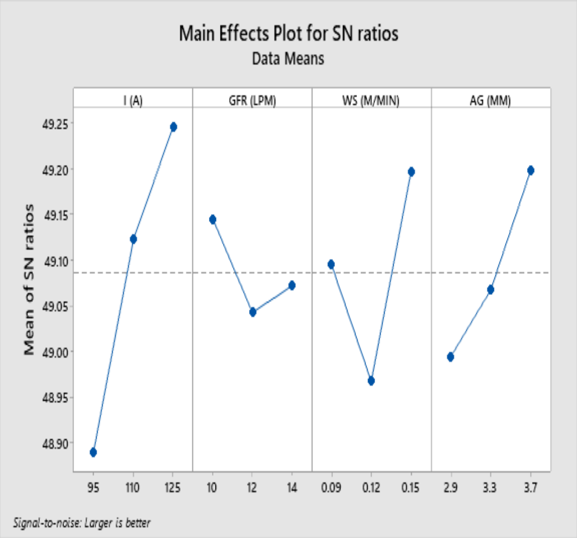

Fig.11: Main effects plot of S/N ratio HAZ)

Fig. 12: Main effects plot of Mean (hardness (Hardness HAZ)

The analysis of variance (ANOVA) for the factors indicated in the table 11 shows that the welding current (I) is the most contributing factor in effecting the average hardness of weld metal of TIG welded super duplex stainless steel plate and welding speed (WS), gas flow rate (GFR) and arc gap (AG) have their contribution in decreasing order for hardness of weld metal. Fig.9 shows percentage contribution of factors affecting distortion. With decrease of welding speed, the heat input and consequently heat transferred to welding increases. This increase of heat to the weld enhances the relative amount of melting base metal resulting in an increase of hardness of weld pool. Also, as welding speed increases, heat input decreases and this will give rise to relatively lower heating of upper portion of weld metal and so the hardness enhances with increase of welding speed of welded super duplex stainless steel plate.

**Optimal value of average hardness value of HAZ in the welded specimen**

From S/N ratio plot an optimized value for minimum distortion was found at I(A) at first level, GFR (lpm) at second level, root face (mm) at first level and welding speed at third level. The average of nine experimental results of distortion is $(\text{distortion})_{avg}=0.7933$ mm. The optimum value of distortion is calculated as shown below:

$(\text{Avg. hardness of HAZ})_{optimum}= (I)_{3Avg.} + (GFR)_{1Avg.} + (WS)_{3Avg.} + (AG)_{3Avg.} – 3(\text{Total avg. hardness of HAZ})_{avg.}$ ----- (2)

$(I)_{3Avg}=290$
$(GFR)_{1Avg}=286.7$
$(WS)_{3Avg.}=288.3$
$(AG)_{3Avg.}=288.3$
$3(\text{Total avg. hardness of WM})_{avg.}=3 \times 284.2 = 852.6$
$(\text{Avg. hardness of WM})_{optimal}= 290 + 286.7 + 288.3 + 288.3 - 852.6 = 300.7$ VHN

**Confirmation test for Avg. hardness values of HAZ**

The values from final confirmation run and obtained avg. hardness value is mentioned in Table 12. From analysis of results, it is observed that the calculated error is small of the order of approximately 4.16% which is under acceptable limit.

| Performance measure | Optimal setting of parameters | Predicted and Experimental results | | |
|---|---|---|---|---|
| | | Predicted optimal value (mm) | Experimental value (mm) | %Error |
| Distortion | $I_3GFR_1WS_3AG_3$ | 300.7 | 287.46 | 4.37% |

Table 13: Values from final confirmation run and obtained avg. hardness value of HAZ.

### 5.3 Effect of welding parameters on MDR of TIG welded super duplex stainless steel plate.

L9 OA has been designed as per Taguchi's design of experiment. It is expected to get an optimized level for each factor. The signal-to noise ratio (S/N ratio) is kept high to get minimum value of distortion. The S/N ratio is obtained using negative of logarithmic value of distortion calculated experimentally, which is continuously decreasing function. So, the signal-to-noise ratio is always kept at maximum value. The calculation of S/N ratio is based on higher-the-better model. A larger value of S/N ratio corresponds to better quality characteristics.

| Level | I(A) | GFR (LPM) | WS(m/min) | AG (mm) |
|---|---|---|---|---|
| 1 | 26.35 | 26.33 | 26.42 | 27.22 |
| 2 | 26.07 | 26.93 | 27.66 | 25.57 |
| 3 | 27.92 | 27.08 | 26.26 | 27.54 |
| Delta | 1.85 | 0.75 | 1.40 | 1.97 |
| Rank | 2 | 4 | 3 | 1 |

Table 14: Response Table for S/N ratio for MDR (higher-the-better)

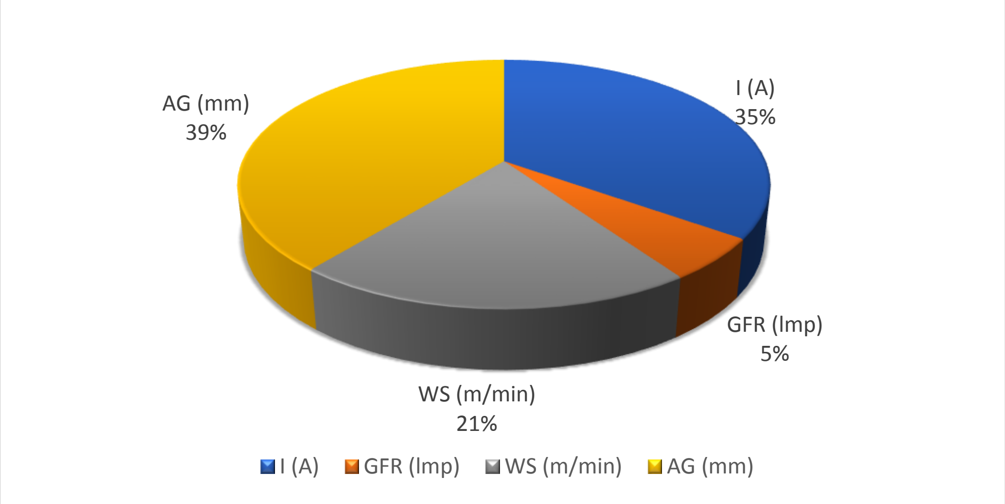

Fig.13: Percentage contribution of Factor affecting distortion.

| Level | I(A) | GFR (LPM) | WS (M/MIN) | AG (MM) |
|---|---|---|---|---|
| 1 | 20.80 | 20.79 | 21.27 | 33.40 |
| 2 | 20.24 | 22.38 | 24.48 | 19.04 |
| 3 | 25.29 | 23.17 | 20.59 | 23.90 |
| Delta | 5.05 | 2.38 | 3.88 | 4.86 |
| Rank | 1 | 4 | 3 | 2 |

Table 15: Response Table for Mean for MDR

| Sources | DOF | SS | MS | %P |
|---|---|---|---|---|
| I(A) | 2 | 5.9566 | 2.97828 | 34.82 |
| GFR (lpm) | 2 | 0.9386 | 0.46931 | 5.48 |
| WS (m/min) | 2 | 3.5230 | 1.76151 | 20.59 |
| AG (mm) | 2 | 6.6838 | 3.34191 | 39.08 |
| Error | 0 | | | |
| Total | | 17.1020 | | 100 |

Table 16: ANOVA table for MDR

Therefore, optimized level is the level with largest value of S/N ratio. Response table for S/N ratio of hardness of weld metal is shown in table 13. The mean of MDR has been shown in Table 14. From table 13, it is found that arc gap (AG) and welding current (I) have maximum effect on hardness of weld metal of TIG welded super duplex stainless steel plate (2507). The above table gives the values of control factors at each level. Fig.13 gives the relative percentage of parameters of welding current, gas flow rate, welding speed and arc gap. It is understood further that there are comparatively higher effects of welding current and Arc gap on of welded joints. Fig.14 and Fig.15 show the S/N ratio and mean plot demonstrating effects of each parameter on hardness (WM) of TIG welded super duplex stainless steel plate. The ANOVA table for hardness of weld metal has been depicted in Table 15. It is observed that gas flow rate and arc gap have relatively less effects on hardness (WM).

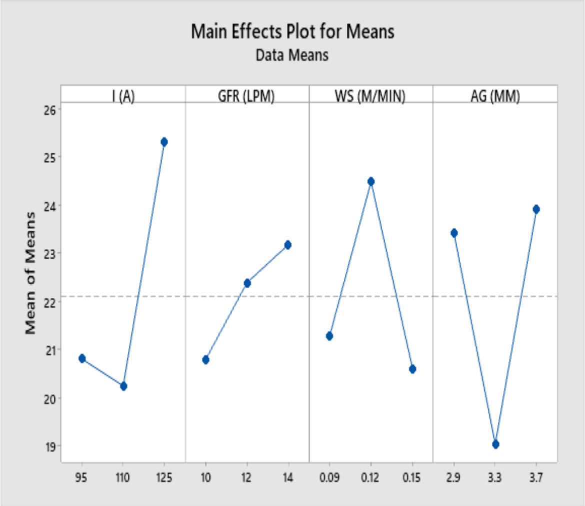

Fig.14: Main effects plot of S/N ratio HAZ)

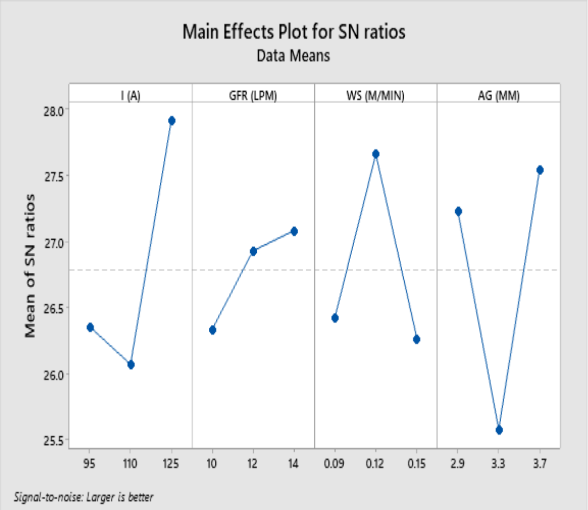

Fig. 15: Main effects plot of Mean (hardness (Hardness HAZ)

The analysis of variance (ANOVA) for the factors indicated in the table 15 and table 13 shows that the arc gap (AG) is the most contributing factor in effecting the average MDR of weld metal of TIG welded super duplex stainless steel plate and welding current (I), welding speed (WS), and gas flow rate (GFR) have their contribution in decreasing order for hardness of weld metal. Fig.13 shows percentage contribution of factors affecting distortion. With decrease of welding speed, the heat input and consequently heat transferred to welding increases. This increase of heat to the weld enhances the relative amount of melting filler metal resulting in increase of MDR of weld pool. Also, as welding speed increases, heat input decreases and this will give rise to relatively lower heating of upper portion of weld metal and so the metal deposition rate decreases with increase of welding speed of welded super duplex stainless steel plate.

**Optimal value of average hardness value of WM in the welded specimen**

From S/N ratio plot an optimized value for minimum distortion was found at I(A) at first level, GFR (lpm) at second level, root face (mm) at first level and welding speed at third level. The average of nine experimental results of distortion is $(\text{distortion})_{avg}=0.7933$ mm. The optimum value of distortion is calculated as shown below:

$(\text{Avg. hardness of WM})_{\text{optimum}}= (I)_{3Avg.} + (GFR)_{3Avg.} + (WS)_{2Avg.} + (AG)_{3Avg.} – 3(\text{Total avg. MDR})_{\text{avg.}}$ ----- (1)

$(I)_{3Avg}=27.92$

$(GFR)_{3Avg}=27.08$

$(WS)_{2Avg.} =27.66$

$(AG)_{3Avg.} =27.54$

$3(\text{Total avg. hardness of MDR})_{\text{avg.}} =3 \times 22.112 = 66.336$

$(\text{Avg. MDR})_{\text{optimal}}= 27.92 + 27.08 + 27.66 + 27.54 – 66.336 = 43.864$

**Confirmation test for Avg. MDR value**

The values from final confirmation run and obtained avg. MDR value is mentioned in Table 12. From analysis of the results, it is observed that the calculated error is small of the order of approximately 5.27% which is under acceptable limit.

| Performance measure | Optimal setting of parameters | Predicted and Experimental results | | |
|---|---|---|---|---|
| | | Predicted optimal value (mm) | Experimental value (mm) | %Error |
| Distortion | $I_3GFR_3WS_2AG_3$ | 43.864 | 41.49 | 5.43% |

Table 17: Values from final confirmation run and obtained avg. MDR value.

## VI. CONCLUSION

In the present study, the effect of welding parameters on responses MDR and Hardness (Weld metal and HAZ) of the Super duplex Stainless Steel component using the GTA welding process. The experiments were conducted under various parameters setting of welding Current(I), gas flow rate, welding speed and arc gap. L-9 OA based on Taguchi design was performed. Minitab software was used for analysis of the result and these responses were partially validated experimentally. The following conclusion has been obtained.

1. It is found that welding current (I) and welding speed (WS) have maximum effect on hardness of weld metal of TIG welded super duplex stainless steel plate (2507). It is found that welding current (I) and welding speed (WS) have maximum effect on hardness of weld metal of TIG welded super duplex stainless steel plate (2507).
2. That the arc gap (AG) is the most contributing factor in effecting the average MDR of weld metal of TIG welded super duplex stainless steel plate and welding current (I), welding speed (WS), and gas flow rate (GFR) have their contribution in decreasing order for hardness of weld metal.
3. The normality plot for selected response variables such as Hardness and MDR which is normally distributed because set of values of all two response are mostly close to the mid value.
4. The error between experimental and predicted values for Hardness (WM and HAZ) is 4.68% and 4.37%.
5. The error between experimental and predicted values for MDR is 5.43%.

### FUTURE SCOPE

To optimize all the objectives i.e., MDR and hardness simultaneously, mathematical models using the nonlinear regression model must be developed. In this present study we have considered a few parameters affecting a few performance measures but keeping the view of future scope. We can select other parameters like voltage, polarity, shielding gas of different kinds and many more for extended work. Despite ER2594 filler, we can select other filler or without filler for further experimentation. The confirmation step for the present experimental work can be done as a future scope.

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