Journal of Material Science and Mechanical Engineering (JMSME)
p-ISSN: 2393-9095; e-ISSN: 2393-9109; Volume 2, Issue 13; October-December, 2015 pp. 32-40

http://www.krishisanskriti.org/Publication.html

# Optimizations of TIG Welding Process Parameters on Angular Distortion of Stainless Steel 301 Alloy Weldments

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**Abstract—***The present work deals with optimization of Tungsten Inert Gas welding process on Stainless steel (SS 301) and the microstructure analysis of weld metal. Welding is an important technology in Stainless steel alloy application where the quality control is too important. Taguchi L9 orthogonal array method was employed to optimization the welding process parameters of SS 301 weld for decreasing the angular distortion after weld and improving equal percentage of ferrite and austenite content in weld metal. Descriptions of angle of deviation measurement techniques and data analysis are presented. The effect of welding current, gas flow rate, root gap and electrode diameter on angular distortion was also studied. Microstructures and hardness of all the weld zone and heat affected zone were investigated and correlated with the angular distortion. The signal to noise ratios and main effects plots were analyzed.*

**Keywords***: Welding, angular distortion, Microstructure*

## 1. INTRODUCTION

Tungsten Inert Gas welding is an electric arc welding process, in which the fusion energy is produced by an electric arc burning between the work piece and the tungsten electrode. During the welding process the electrode, the arc and the weld pool are protected against the damaging effects of the atmospheric air by an inert shielding gas as Argon. Stainless steel 301 is widely used in sheet metal fabrication, especially in automotive, chemical and rail coach manufacturing, mainly due to its excellent corrosion resistance and better strength to weight ratio. The activated TIG process can increase the joint penetration and the weld depth-to-width ratio, and tends to reduced the angular distortion of grade 2205 Stainless Steel weldments.TIG with $SiO_2$ flux produced a full joint penetration and the angular distortion value was almost zero[1]. SS 301 is a generic name covering a group of metallic alloys with chromium content in excess of 10.5 percent and a maximum carbon content of 1.2 percent and often includes other elements, such as nickel and molybdenum. Due to formation of a passive layer, this is 1 to 2 nanometers thick; this metal exhibits excellent corrosion resistance. The least distortion was achieved at the same processing parameters for samples with 0.8 chamfered depth and at included angle of $60^0$.The joint strength and ductile behavior of laser welded samples were found to be close to the base material. Vickers micro-hardness measurement across the weld zone showed the variation of 10% in hardness in base material and fusion zone [2]. Any metal joining process involves application of heat in highly localized areas of the weld joint. Due to this, steep temperature gradients are realized in the weld and adjoining regions of the material. In particular, temperature as high as melting point is reached in the vicinity of the weld region with arc welding process. This cause non uniform expansion of the regions, which, when hindered by the restraint of the remaining part of the section or external restraint, results in plastic deformation. As a consequence, the whole part undergoes a shape change satisfying the mechanical equilibrium conditions on cooling. These shape changes which are manifested over the whole material is known as distortion [3].

Distortion causes many problems during the manufacturing stage and during service, as well. In manufacturing, welding distortion can cause assembly related problems by adversely affecting the dimensional tolerances required. Joint misalignments and increased root gap would make manufacturing more difficult. I may also adversely affect further operation like machining. Presence of distortion may adversely affect the load carrying capacity and buckling strength of the weld structures. Sometimes, it can make the structure dimensionally unstable due to the release of inertia stress while in service. In view of these reasons, it is necessary to either minimize or eliminate the distortion to make the weldments suitable for the intended service.

Hardness in the fusion zone is lowest due to the as-cast nature of the microstructure. The portion of the HAZ close to the weld is harder than the rest of the HAZ, but still softer than the base metal. The microstructure observation of the condition set i.e. welding current-100A, welding speed-210 mm/min, amplitude-0.6 mm and frequency-2 Hz is resulted in coarse grain structure [4].During welding many factors affect shrinkage of weld and parent metal and make accurate prediction of distortion difficult. Physical and mechanical properties change as heat is applied.

The HAZ of the AISI 444 Stainless steel welded with the AWS E309MoL-16 covered electrode exhibited significant grain growth with respect to the base metal in the partially-melted zone [5].Microstructure variation caused by TIG welding are mainly responsible for the alterations in oxidation morphology and behavior of weld metal zone as compared to base metal of 316 L weldment. Weld metal zone is less protective than base metal at high temperature in oxidizing atmosphere [6].The weldability of duplex stainless steels improve by using dual torch technique. Microstructure changes, and weld surface will become smooth to overcome undercut problem in keyhole and produce a better weld bead profile [7]. The effect of copper addition is more beneficial than titanium addition in altering the Grain structure of the fusion zone to equi-axed morphology. The weld strength improved as the retained austenite content increased [8]. The ferrite-austenite ratio also depends on the energy input in welding, and hence the extents of the diffusion-based ferrite-austenite transformation. Heat input has a key role on the microstructure and corrosion resistance of duplex stainless steel welds [9].The percentage volume of ferrite is less in weld metal in case of shield gas is Ar+5% $N_2$ following solution heat-treatment. The resistance to pitting corrosion of the solution heat-treated HDSS tube after welding with $N_2$ supplemented Ar shielding gas was greatly increased due to the dissolution of $Cr_2N$ in the ferrite phase following the diffusion of N atoms from the ferrite phase to the austenite phase and increase of the austenite phase in the weld metal and HAZ [10].The laser welding and hybrid welding are suitable for welding 304 stainless steel in industry application owing to high welding speed and excellent mechanical properties as compare with TIG[11].The common application of SS 301 are aircraft structure parts, trailer bodies, Architectural roof drainage and door frame. As a result it is shown by this experimental investigation that the use of the Taguchi method analysis can greatly simplify the optimization procedure for determining the optimal welding parameters with the multiple performance characteristics in TIG welding process. In the following, an overview of the optimization of the performance characteristics by the Taguchi method is given and the selection of TIG welding parameters and evaluation of angular distortion, Rockwell hardness, microstructure analysis i.e. ferrite and austenite percentage of weld zone and Heat affected zone of nine weld specimens are discussed. The chemical composition of base material SS301 is shown in Table 1.

**Table 1: Chemical composition of base Material (wt %) Stainless Steel 301)**

| Base Material | C | Cr | Si | Mn | P | S | Mo | Ni | Fe | cu |
|---|---|---|---|---|---|---|---|---|---|---|
| SS 301 | 0.0582 | 16.06 | 0.3670 | 1.93 | 0.0649 | 0.005 | 3.22 | 6.56 | Rem | 0.73 |

**Table 2: Chemical composition of Filler metal (wt %) ER310**

| Filler Material | C | Cr | Si | Mn | P | S | Mo | Ni | Fe | Cu |
|---|---|---|---|---|---|---|---|---|---|---|
| ER 310 | 0.08 | 25.5 | 0.49 | 1.75 | 0.03 | 0.03 | 0.75 | 20.5 | Rem | 0.75 |

## 2. TAGUCHI METHOD FOR OPTIMIZATION OF TIG WELDING PROCESS PARAMETERS:

Optimization of process parameters is the best step in the Taguchi method in achieving high quality weld with less angular distortion. Every experimenter has to plan and conduct experiments to obtain enough and relevant data so that to improve productivity and reduce welding cost. The following are the few approach

### 2.1 Trial-and-error approach

Performing a series of experiments each of which gives some understanding. This requires making measurements after every experiment so that analysis of observed data will allow him to decide what to do next - "Which parameters should be varied and by how much". Many a times such series does not progress much as negative results may discourage or will not allow a selection of parameters which ought to be changed in the next experiment. Therefore, such experimentation usually ends well before the number of experiments reaches a double digit! The data is insufficient to draw any significant conclusions and the main problem (of understanding the science) still remains unsolved and cost of welding also increases more.

### 2.2 Design of experiments (DOE):

A well planned set of experiments, in which all parameters of interest are varied over a specified range, is a much better approach to obtain systematic data. Mathematically speaking, such a complete set of experiments ought to give desired results. Usually the number of experiments and resources (materials and time) required are prohibitively large. Often the experimenter decides to perform a subset of the complete set of experiments to save on time and money! However, it does not easily lend itself to understanding of science behind the phenomenon. The analysis is not very easy (though it may be easy for the mathematician/statistician) and thus effects of various parameters on the observed data are not readily apparent. In many cases, particularly those in which some optimization is required, the method does not point to the BEST settings of parameters. A classic example illustrating the drawback of design of experiments is found in the planning of a world cup event, say football. While all matches are well arranged with respect to the different teams and different venues on different dates and yet the planning does not care about the result of any match (win or lose)!!!! Obviously, such a strategy is not desirable for conducting scientific experiments [12] (except for co-ordinating various institutions, committees, people, equipment, materials etc.)

### 2.3 Taguchi Method

Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on “orthogonal array” experiments which gives much reduced “variance” for the experiment with “optimum settings “of control parameters. Thus the marriage of Design of Experiments with optimization of control parameters to obtain BEST results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

### 2.4 Taguchi Method treats optimization problems in two categories.

### 2.4.1 Static Problems

Generally, a process to be optimized has several control factors which directly decide the target or desired value of the output. The optimization then involves determining the best control factor levels so that the output is at the target value. Such a problem is called as a "Static Problem".

This is best explained using a P-Diagram which is shown below ("P" stands for Process or Product). Noise is shown to be present in the process but should have no effect on the output! This is the primary aim of the Taguchi experiments - to minimize variations in output even though noise is present in the process. The process is then said to have become ROBUST.

**2.4.2** ***(Batch Process Optimization)*****:**
There are 3 Signal-to-Noise ratios of common interest for optimization of Static Problems;

### 2.4.3 Smaller-the-better:

n = -10 $Log_{10}$ [mean of sum of squares of measured data]

This is usually the chosen S/N ratio for all undesirable characteristics like “defects “etc. for which the ideal value is zero. Also, when an ideal value is finite and its maximum or minimum value is defined (like maximum purity is 100% or maximum Tc is 92K or minimum time for making a telephone connection is 1 sec) then the difference between measured data and ideal value is expected to be as small as possible. The generic form of S/N ratio then becomes,

n = -10 $Log_{10}$ [mean of sum of squares of {measured - ideal} ]

**2.4.4 Larger-the-better:** n = -10 $Log_{10}$ [mean of sum squares of reciprocal of measured data]**.**This case has been converted to smaller-the-better by taking the reciprocals of measured data and then taking the S/N ratio as in the smaller-the-better case.

2.4.5 **Nominal-the-best:** n = 10 $Log_{10}$ [Square of mean/Variance].This case ar**i**ses when a specified value is MOST desired, meaning that neither a smaller nor a larger value is desirable.

### 2.5. Dynamic Problems

If the product to be optimized has a signal input that directly decides the output, the optimization involves determining the best control factor levels so that the "input signal / output" ratio is closest to the desired relationship. Such a problem is called as a "Dynamic Problem". This is best explained by a P-Diagram which is shown below. Again, the primary aim of the Taguchi experiments - to minimize variations in output even though noise is present in the process- is achieved by getting improved linearity in the input/output relationship.

**2.5.1 Dynamic problem (**Technology development*)***:** In dynamic problems, we come across many applications where the output is supposed to follow input signal in a predetermined manner. Generally, a linear relationship between "input" "output" is desirable.

### 2.5.2-Steps in Taguchi methodology

Taguchi method is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipment, and facilities. These improvements are aimed at improving the desired characteristics and simultaneously reducing the number of defects by studying the key variables controlling the process and optimizing the procedures or design to yield the best results. The method is applicable over a wide range of engineering fields that include processes that manufacture raw materials, sub systems, products for professional and consumer markets. In fact, the method can be applied to any process be it engineering fabrication, computer-aided-design, banking and service sectors etc. Taguchi method is useful for 'tuning' a given process for 'best' results.Taguchi proposed a standard 8-step procedure for applying his method for optimizing any process,

Step-1: Identify the main function, side effects and failure mode.

Step-2: Identify the noise factors, testing conditions and quality characteristics.

Step-3: Identify the objective function to be optimized.

Step-4: Identify the control factors and their levels.

Step-5: Select the orthogonal array matrix experiment.

Step-6: Conduct the matrix experiment.

Step-7: Analyze the data; predict the optimum levels and performance.

Step-8: Perform the verification experiment and plan the future action.

## 3. SELECTION OF TIG WELDING PROCESS PARAMETERS

In this present work, Stainless steel 301 alloy of dimension 200 mm x 75mm x 6mm plates was taken and the number of pieces were 18. The TIG welding process parameters are Root gap, Current, Electrode diameter and Gas flow rate. The choice and the selection of the parameter were decided by considering the objective of present study. Before selecting a particular OA to be used as a matrix for conducting the experiments. 1. The number of parameters and interactions of interest. 2. The numbers of levels of the parameter of interest. The non-linear behavior, if exists, among the process parameters can only be studied if more than two levels of the parameters are used. Therefore, each parameter was analyzed at three levels. The selected numbers of the process parameters and their levels are given in Table 3 For the sake of simplification, the second order interaction among the parameters is not considered.

**Table 3: TIG Welding process parameters and their levels**

| Symbol | Parameter | units | Level1 | Level2 | Level-3 |
|---|---|---|---|---|---|
| A | Root gap | mm | 1 | 2 | 3 |
| B | Current | Amp | 100 | 150 | 170 |
| C | Electrode diameter | mm | 1.6 | 2.5 | 3 |
| D | Gas flow rate | liters/ mint | 2 | 4 | 5 |

In this study, the use of the Taguchi method to determine the TIG welding process parameters is reported step-by-step. Optimal welding process parameters with consideration of the performance characteristics are obtained and verified. An $L_9$ orthogonal array with four columns and nine rows was used. Nine experiments are required to study the entire welding parameter space when the $L_9$ orthogonal array is used. The experiment layout for the welding process parameters using the $L_9$ array is shown in Table 4.

**Table 4: Experimental layout using $L_9$ orthogonal array.**

| Experiment Number | root gap (A) | Current (B) | Electrode Diameter | Gas flow rate |
|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 | 2 |
| 3 | 1 | 3 | 3 | 3 |
| 4 | 2 | 1 | 2 | 3 |
| 5 | 2 | 2 | 3 | 1 |
| 6 | 2 | 3 | 1 | 2 |
| 7 | 3 | 1 | 3 | 2 |
| 8 | 3 | 2 | 1 | 3 |
| 9 | 3 | 3 | 2 | 1 |

## 4. ANGULAR DISTORTION TEST

After performing the nine welding process, the experiments were carried out to measure the angular distortion in a bead on plate welded joint, the mean vertical displacement method measured the distortion. A stand was fabricated with mild steel material for measuring distortion as show in the Fig. 1.On top surface of stand frame, three pillars (one fixed and two adjustable) were arranged to adjust the horizontal level of the weld plate with the help of sprite level. Nine points were marked on A &B side of welded plate at 5 mm from both edges and nine points were marked nearer to weld bead 8 mm from the center line of weld bead as show in the Fig. 2. The dial gauge readings were taken from reference point to all nine points vertically at A, B, C and D respectively. One complete revolution of dial gauge indicator indicates 1 mm vertical displacement.

**Fig. 1: Stand set up of angular distortion test**

The vertical displacement caused by welding and the angular distortion value 'U' can be determined as

U = [(A+B) – (C+D)]/2, where A, B,C and D represent the mean vertical displacement values of each points as shown in the above Fig. $A= (A_1+A_2+A_3+......+A_9) / 9$,

$B= (B_1+B_2+B_3+....+ B_9) /9$, $C=(C_1+C_2+C_3+......+C_9) / 9$, $D=(D_1+D_2+D_3+......D_9) / 9$.

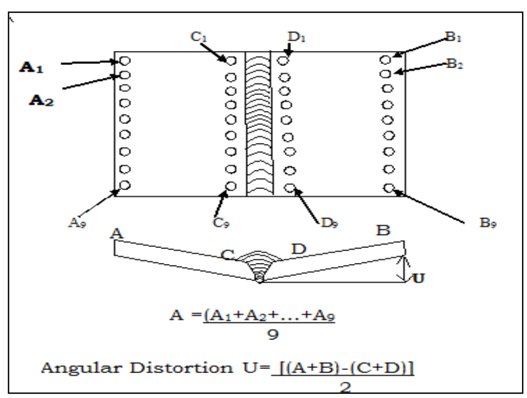



**Fig. 2: Top view and front view of welded plate.**

### 4.1 S/N ratio

**Signal-to-noise ratio** (abbreviated **SNR**) is a measure used in science and engineering that compares the level of a desired signal to the level of background noise. It is defined as the ratio of signal power to the noise power, often expressed in decibels. A ratio higher than 1:1 (greater than 0 dB) indicates more signal than noise. While SNR is commonly quoted for electrical signals, it can be applied to any form of signal (such as isotope levels in an ice core or biochemical signaling between cells).

### 4.2 S/N Ratio for Angular distortion

S/N Ratio $\eta = -10 \, \text{Log}_{10} \, ( 1/n \, \Sigma \, Y_i^2 )$(smaller the better)

### 4.3 S/N Ratio for Hardness

S/N Ratio $\eta = -10 \, \text{Log}_{10} \, ( 1/n \, \Sigma \, 1/Y_i^2 )$ (larger thebetter)

After nine TIG welding experiments as shown in tha table 4,the angular distorstion value were calculated using the above 'U'expression.The values of angular diatorsion,S/N ratio of Hardness of weld metal,S/N ration of Heat Affected Zone and S/N ratio of Base Matel as shown in the table5.

**Table 5: Angular distortion and S/N Ratio of distortion and S/N Ratio of Hardness of weld zone,HAZ,Base Metal.**

| Expt. No: | U=[(A+B)-(C+D)]/2 Angular Distortion (mm) | S/N Ratio of Angular Distortion | Hardness S/N Ratio of Weld Zone | Hardness S/N Ratio of HAZ | Hardness S/N Ratio of Base Metal |
|---|---|---|---|---|---|
| 1 | 0.2383 | 12.46 | 10.894 | 11.05 | 11.1 |
| 2 | 0.0283 | 30.96 | 10.979 | 11.07 | 10.993 |
| 3 | -0.039 | 28.21 | 10.909 | 11.05 | 10.993 |
| 4 | 0.1005 | 19.96 | 10.806 | 11.06 | 11.02 |
| 5 | -0.138 | 17.18 | 10.836 | 10.97 | 11.006 |
| 6 | 0.0494 | 26.2 | 10.923 | 10.85 | 10.865 |
| 7 | 0.0544 | 25.28 | 10.851 | 11.02 | 11.087 |
| 8 | -0.621 | 4.136 | 10.993 | 11.13 | 11.06 |
| 9 | -0.616 | 4.215 | 10.909 | 11.02 | 10.993 |

## 5. HARDNESS AND MICROSTRUCTURE SPECIMENS

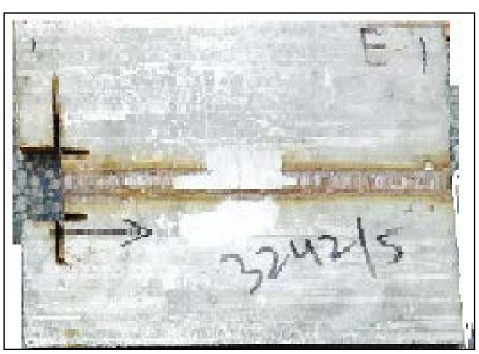


**Fig. 3: TIG welded Stainless steel plate.**

The flat weld was made at top bevels of 60 degree groove of 200 mm length, 6 mm thickness plate using TIG welding with argon and Filler Metal consumption of SS ASTM (310L) on a single pass. The welded plate is show in the Fig. 3.After measuring angular distortion from each nine welded plates, the microstructure specimens (30 mm x 10 mm x6 mm) were cut from all the nine welded plates. These specimens are shown in the Fig. 4.The polishing has been done with the help of four types of emery polishing paper Grade1/0, Grade 2/0, Grade 3/0 and Grade4/0 before taking microstructure in weld zone ,heat affected zone.

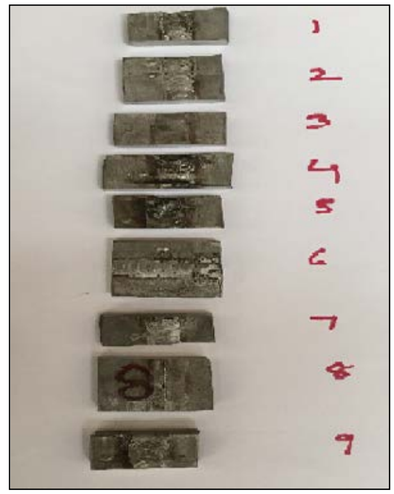


**Fig. 4: Nine welded specimen for Hardness test and microstructure analysis.**

The 10 X µm magnification of microstructure images has been taken on all nine weld bead specimens and the austenite phase and ferrite phase analysis as recorded using microstructure phase analysis software. The weld zone microstructure of experiment 01 to experiment 09 has shown in Fig. 8,1(a) to 9(a),the microstructure of heat affected zone were shown in Fig. 8,1(b) to 9(b) .

### 5.1 Main Effects Graphs of Hardness:

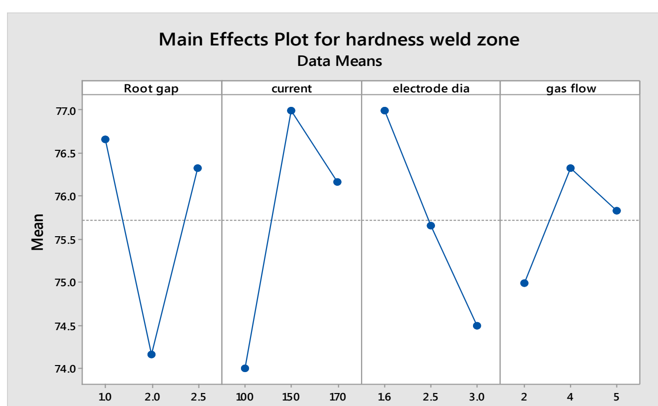



**Fig. 5: Main effect for hardness of weld zone response on different parameters.**

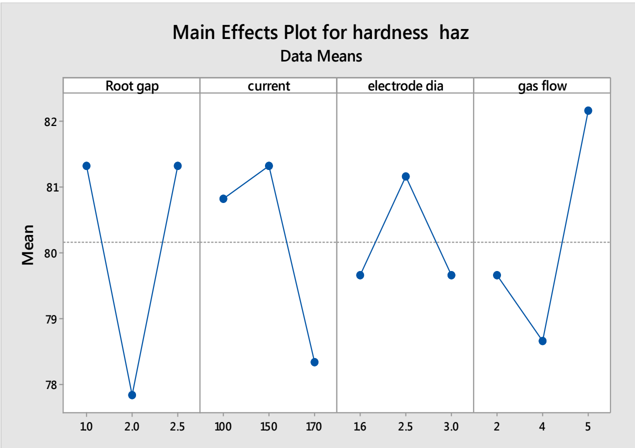



**Fig. 6: Main effect for hardness of HAZ response on different parameters.**

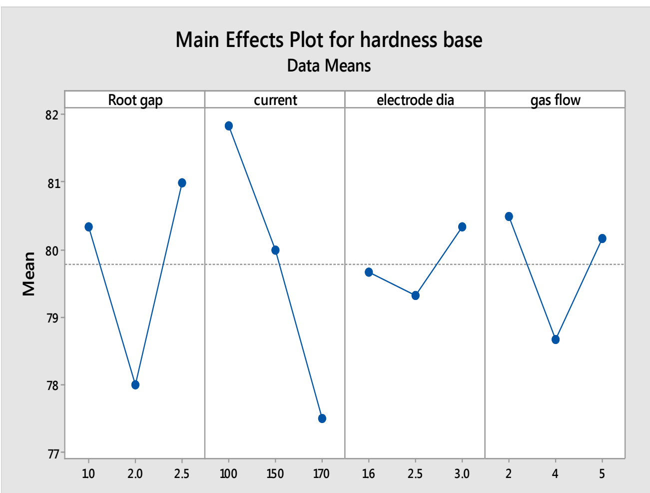
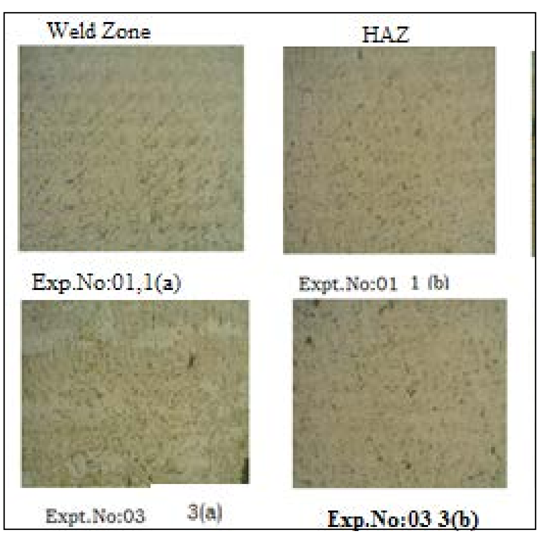



**Fig. 7: Main effect for hardness of Base Metal on different parameters.**



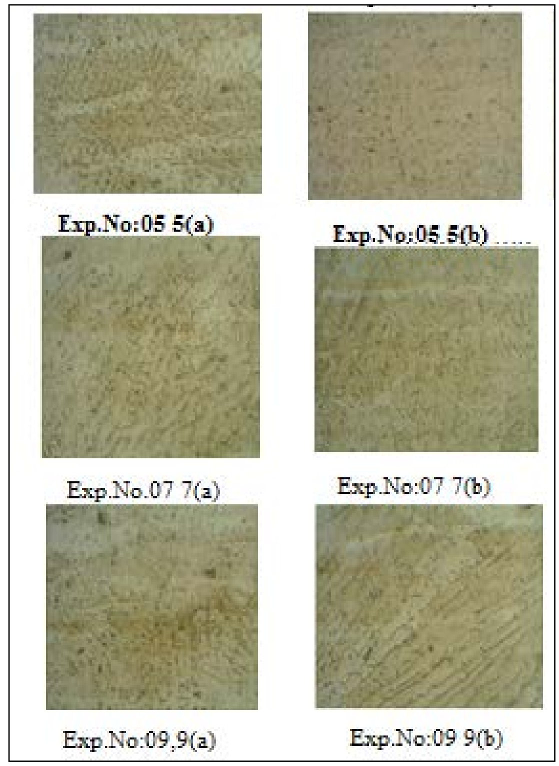
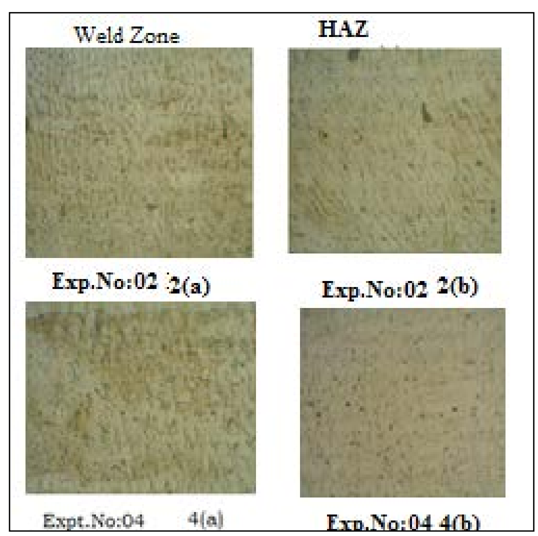




**Fig. 8: Microstructure of weld zone and Heat Affected Zone.**

Microstructure of all nine welded specimen has been captured after polishing on velvet cloth disc polishing machine and 2% Nital has used as etchant on welded Stainless Steel 301.The phase or volume fraction analysis for austenite percentage and ferrite percentage in weld metal and heat affected zone as shown in the Table 6. Analysed Area is 1.1269 sq mm as per the ASTM E 562 standard.Calibration:Object10x, Unit: µm,X:1.0785,Y:1.0785 (pixels/ µm).



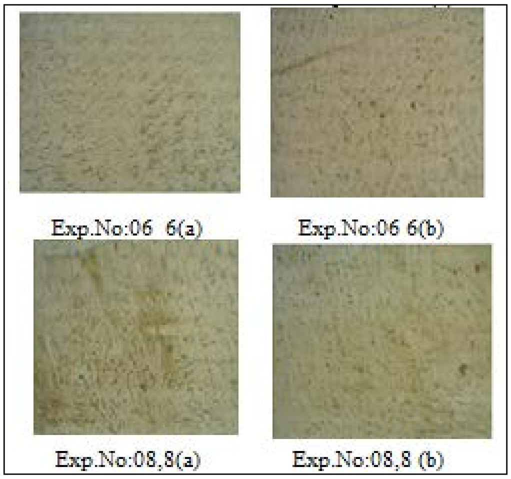



**Fig. 9: Microstructure of weld zone and heat affected zone.**

**Table 6: Austenite percentage and Ferrite percentage of Weld Zone and Heat Affected Zone.**

| Experiment Number | Weld zone | | Heat Affected Zone | |
|---|---|---|---|---|
| | Austenite % | Ferrite % | Austenite % | Ferrite % |
| 1 | 25.09 | 77.36 | 28.81 | 74.38 |
| 2 | 67.6 | 34.98 | 34.44 | 68.18 |
| 3 | 38.1 | 64.56 | 31.15 | 71.79 |
| 4 | 43.6 | 58.93 | 27.58 | 75.12 |
| 5 | 42.42 | 60.55 | 31.84 | 70.98 |
| 6 | 25.09 | 77.36 | 25.29 | 77.18 |
| 7 | 32.06 | 70.53 | 45.89 | 56.91 |
| 8 | 37.58 | 64.86 | 29.86 | 73.53 |
| 9 | 47.36 | 55.5 | 38.04 | 64.79 |
| Average | 39.878 | 62.737 | 32.544 | 70.318 |

**Table 7.Measured values of Rockwell Hardness of Weld zone, Heat Affected Zone and Base Metal from the test specimen.**

| Experiment .No | Root Gap(mm) | Current (Amp) | Electrode Diameter (mm) | Gas flow (Lts/mint) | Hardness of Weld Zone (Trail 1 &Trail2) | Hardness of HAZ (Trail 1 &Trail2) | Hardness of Base Metal(Trail1 &Trail2) |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 100 | 1.6 | 2 | 74,77 | 79,83 | 83,83 |
| 2 | 1 | 150 | 2.5 | 4 | 78,79 | 83,81 | 78,80 |
| 3 | 1 | 170 | 3 | 5 | 75,77 | 82,80 | 76,82 |
| 4 | 2 | 100 | 2.5 | 5 | 72,73 | 83,80 | 82,78 |
| 5 | 2 | 150 | 3 | 2 | 72,75 | 79,77 | 81,78 |
| 6 | 2 | 170 | 1.6 | 4 | 73,80 | 74,74 | 72,77 |
| 7 | 3 | 100 | 3 | 4 | 74,74 | 78,82 | 85,80 |
| 8 | 3 | 150 | 1.6 | 5 | 80,78 | 84,84 | 79,84 |
| 9 | 3 | 170 | 2.5 | 2 | 76,76 | 83,77 | 79,79 |

## 5.2 Main Effects Graphs of S/N Ratio of Angular distortion and hardness.

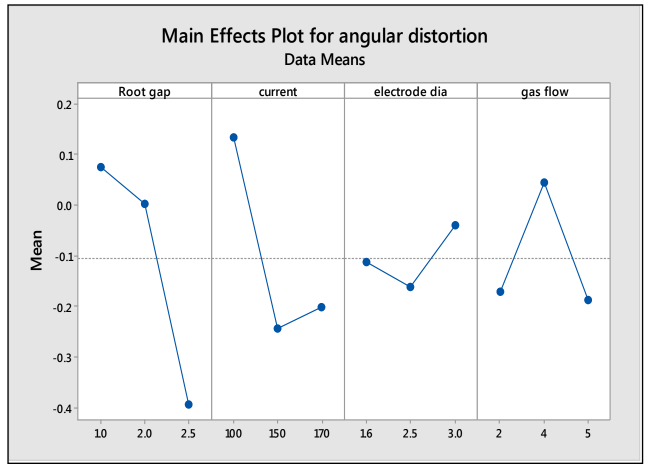



**Fig. 10: Mean effect for angular distortion**

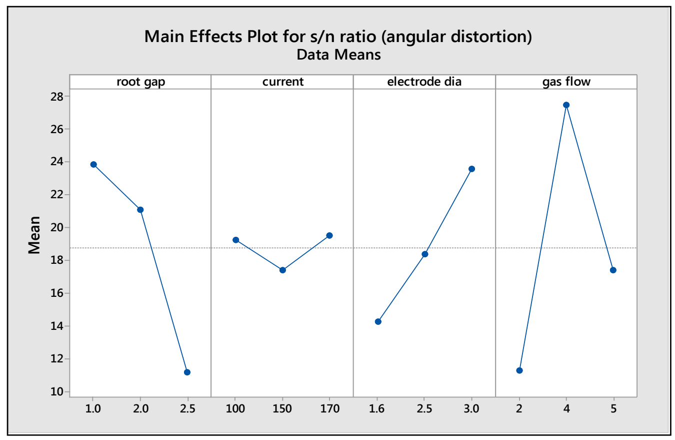



**Fig. 11.Mean effect of S/N ratio for angular distortion response on different parameters.**

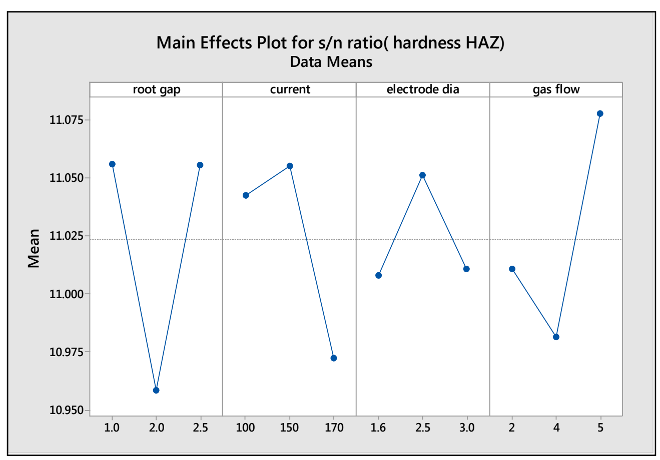



**Fig. 12: Mean effect of S/N ratio for hardness response on different parameters.**

## 6. RESULTS AND DISCUSSIONS

As per the Taguchi $L_9$ orthogonal experimental layout the inveatigation was done and from the measured values of Table 7 and the main affect graph show that the hardness in heat affected zone was more than hardness in weld zone and base metal.Microstructure phase analysis software results shown in Table 6.that the austenite percentage was more in weld zone than heat affected zone in most of weld metals and ferrite percentage was more in HAZ because austenite requires high temperature for its formation approx(300-375degree celsius).

From table 5 and Fig. 12 show that S/N ratio for hardness S/N Ratio $\eta = -10 \, Log_{10} ( 1/n \, \Sigma \, 1/Y_i^2 )$ (larger the better) was found in experiment number 8 where root ga was maximum 3mm, electrode diametre is 1.6 mm minimum and gas flow maximum 5 lt/mint .Main effect of S/N ratio for Angular distortion show that S/N Ratio $\eta = -10 \, Log_{10} ( 1/n \, \Sigma \, Y_i^2)$smaller the better was found in experiment 8 when root gap was max,electrode diameter is minimum and gas flow maximum.

The expermental data and main effect graphs showed and it was observed that,when root gap increases,angular distortion increases.Table 5 measured value show that experiment number 2 has less angular distortion where root gap is 1mm,current 150 Amp,electrode diameter is 2.5mm .When electrode dameter was increased hardness first increased then decreased.S/N ratio for hardness first decreased then again increased when root gap,gas flow increases S/N ratio for hardness first increased then decreased when current,electrode diameter increased.The signal to noise ratio for angular distortion increases when electrode diameter was increases.

The ferrite % was higher in heat affected zone because the ferrite contains only a small amount of carbon which means untransformed austenite will become more enriched with carbon as temperature decreases and more ferrite is formed.At the minimum value of root gap,current,electrode diameter angular distortion was minimum,when current and electrode diameter are increased,hardness first increases and then it stabilized.

The number of fields measured were 9,the standard used was ASTM E 562.The analyzed area was 10.1424 sq mm the calibration was set at 10 micro meters.in x ,y direction it was 1.0785(pixels/micro metre).The pictures indicate the volume percentage of ferrite,austenite matrix and other phases.The standard deviation was also measured .The averaged report of all the 9 samples,the austenite matrix was 64.38 %, ferrite was 32.51%,other phases was 3.11%.

## 7. CONCLUSIONS

In this paper from the measured expermental tabulated values that the optimum TIG welding process parameters were found in experiment number 8, in which the root gap was maximum value(3 mm),current is medium value (150 Amps),electrode diameter was minimum (1.6 mm) and gas flow rate was maximum (5 lt /mints).

The Heat affected zone region had higher hardness compared to weld zone and base metal.

Angular distortion was minimum when root gap was minimum (1mm) and it was maximum when welding current was maximum (170 Amp), electrode diameter was minimum(1.6 mm).

The S/N ratio for hardness(higher the better) was also found in experiment 8 for weld zone,heat affected zone and base metal in which root gap is maximum and current is 150 Amps.

The Austenite percentage was more in weld zone than heat affected zone in all most all nine experiments and ferrite content was more in HAZ.47.36 % of austenite and 55.5% of ferrite was found in experiment 9 were welding current is maximum 170 Amp,electrode diameter 2.5 mm,root gap is 3 mm.

The Ferrite content was higher as compare with austenite in heat affected zone because the ferrite contains only a small amount of carbon that means untransformed austenite will become more enriched with carbon as temperature decreases and more ferrite is formed

It is conculded that after all experimental investigation it was found that in the weld zone and heat affected zone had a higher hardness than the base metal.Angular distortion increases as welding current increase and it is not always possible to keep distortion within acceptable limits,especially when dealing with a new design for the first time.In spite of the most careful planning,distirtion may occur in excessive amounts.In such circumstances it is usually possible to rectify the distorted component by mechanical straightening and thermal straightening.

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