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Experimental Investigation of TIG Welding on Duplex Stainless Steel

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Abstract

Duplex stainless steel has the inimitable arrangement of two phase microstructure of 50% δ-ferrite and 50% austenite. TIG welding on DSS is more easy, comfortable and useful, if the process is precisely understood and controlled through development of the science & technology of the process in the context of DSS welding by extensive research. In present work, influence of welding current, speed of TIG welding and gas flow rate on quality of DSS weld has been examined through valuable experiments. After experiment its analysis has been done. A design of experimentations has been used which is constructed upon the Taguchi technique. Experimental data has been analyzed by Principal Component Method. Investigation of present-day experiments is scheduled to have various perceptions of Butt joints of TIG welding between UNS2205 duplex stainless steel (DSS) plates. The sole aim of the current investigation is to use the Taguchi analysis, in order to create the optimum combination of controllable factors for Tungsten Inert Gas (TIG) Welding on 2205 DSS. The Taguchi analysis is used to define the optimum design set indices like welding current, shielding gas flow rate and speed of the welding. The experimental readings have been studied; inferred and evaluated with the help of ultimate tensile strength, yield strength, percentage of elongation integrated with the help of Principal Component Analysis (PCA) technique. Butt welding joints of 2205 duplex stainless steel plates have been made. Recently, DSS weld has made sufficient responsiveness in many avenues, such as in oil and gas industries, water purification plants etc. The Principal Component Analysis technique is used to find the optimum set.

Keywords: Optimization; Butt joint; Duplex stainless steel; TIG welding; Tensile test; Principal component analysis (PCA)

1.0 Introduction

Duplex stainless steel use a substitute for austenitic stainless steels (ASS) in different areas of application like reaction vessels and pipelines of chemicals, water purification plants, oil refineries, and gas industries [1, 2]. The excellent set of double phase microstructure of austenite and δ-ferrite shows an effective combination of strength, better corrosion resistance and ease of fabrication. Ferrite phase presents good strength, corrosion resistance and hardness to the material. The different types of welding procedures are employed in duplex stainless steel welding. But the Tungsten Inert Gas (TIG) welding on duplex stainless steel is more easy, comfortable and scientific. TIG welding process on DSS may be found useful, easy and comfortable, if the process is precisely understood and controlled through development of the science [3-5]. From 1960's, duplex stainless steels have extensive application because of an attractive set of very outstanding mechanical properties like high strength, better corrosion resistance and relatively less expenses in comparison with other high performance materials. A reduced grain size and unique combination of double phase austenitic ferritic structure of DSS help to resist grain growth and also increase toughness and strength. Mechanical parameters of DSS rely deeply on the phase equilibrium. Duplex steels are also fit for most forming processes. Due to good mechanical properties of DSS, it is in more demand for the mechanical processes like deep drawing, spinning and stretch forming, as compared to Austenitic steel [6].

Some notable works of the previous researchers who performed extensive investigations on welding joints of different stainless steel materials using different welding processes are, in the field of studying the residual stress and angular deformation of DSS [7], study of metallurgical properties [8], optimization of weld parameters [9], etc. Duplex stainless steel is employed in the gas and oil refinery industry as the structural material, and is specially used in waste water treatment and marine engineering arenas for its better mechanical properties compared to other conventional materials [9]. Duplex stainless steels are characteristically doubly strong as compared to common austenitic stainless steel [10]. Mechanical properties of the DSS weld metal heavily rely on weld structure of DSS. These have been depended on welding conditions. Duplex steels are characterized by high strength. Apart from high strength fatigue properties are also very good in DSS [11]. Duplex stainless steels are the favorite material in many engineering fields like in the petroleum, refinery industries and also in transportation industries, for its better mechanical properties [7]. Recently duplex stainless steel can also be employed most successfully as consumables in order to weld ferritic stainless steel. In this type of weld, yield strength is higher, as compared to the use of austenitic stainless steel. An investigation has been done to study the impact of welding technique like Gas Tungsten Arc Welding (GTAW), Shielded Metal Arc Welding (SMAW) on mechanical properties like tensile, hardness, fatigue and impact properties of that ferritic stainless steel (AISI 409M) joints welded with the help of DSS consumables. The joints welded by GTAW process displayed higher tensile strength which is nearly 27% in comparison with SMAW joints. It has also exhibited higher impact strength values approximately 10% in comparison with SMAW. Very low hardness is shown in the GMAW which is 262 VHN and the extreme hardness is shown in GTAW which is 306 VHN. Lower hardness has been seen in the HAZ area cooperation with the weld metal and base metal areas [8]. The weld material hardness is the capacity to resist indentation or penetration by the point of a material which is harder than the weld being tested. The hardness of welding samples has been necessary to confirm that the weld is hard enough to resist mechanical wearing or ductile enough to resist stresses, subject to the usage of the weldment. Four different methods of measuring hardness are Brinell, Rockwell, Vickers and Shore hardness. In particular, Vickers hardness is most apt to measure the hardness distribution in the weld. Tensile parameters of weld joint like ultimate strength, yield and ductility can be obtained depending upon the requirement. Tensile test result must be buttressed by corresponding values of modulus of elasticity, elongation at fracture, yield and ultimate strength as shown in the engineering stress and strain diagram [12]. The oxygen content can be played as a significant role in mechanical properties of TIG welding on DSS and the ferritic steel. Amount of oxygen can be used in TIG welding process by controlling the shielding gas. If oxygen is increased, the shape of weld developed thin, deep for both the steels. But the Vickers hardness for above steels was not affected by varying the oxygen amount in shielding gas. Impact toughness of DSS has been reduced gradually, but the ferritic steel vividly reduced [12]. Mechanical properties of DSS are more than that of any single-phase ASS. DSS are more useful compared to single-phase austenitic or ferritic stainless steels for its better corrosion resistance as well as stress corrosion cracking [13-14]. The outstanding mechanical properties and extraordinary corrosion resistance set of DSS has been explicated by their chemical arrangement and balanced "duplex" structure of austenite and ferrite. The pitting corrosion resistance has been improved by the presence of Cr and Mo in its chemical composition. The dual phase microstructure gives higher opposition for pitting, stress corrosion cracking related with conventional stainless steel materials [14-15]. DSS with poorer coefficient of thermal expansion and greater thermal conductivity are not producing the equal higher value of thermal stresses at the welded ASS [16]. The thermal conductivity of DSS is also in-between carbon steels and the austenitic stainless steels [10]. Duplex stainless steel (DSS) specially consists of the microstructure in equal amounts of BCC ferrite and FCC austenite. These dual phases contain different attractions for alloy of duplex stainless steels [17-19]. No big variation was observed in the grain structure of the partly annealed zone though the welding operation affects locally the crystallographic structure of the heat affected zone. Certain changes were noted in the grain structure of overheated zone in comparison with the one of the base metal. The interrelated observed micro-structural developments are also fairly noticeable in this zone [7].

Relationship between TIG welding process parameters and weld-bead geometry parameters has been constructed. The aluminium weld quality founded on the output factors has been classified and shown by Fuzzy Clustering Method [20]. To get optimum parametric set for yielding satisfactory bead geometry of weld using Grey relation analysis and Taguchi analysis L16, orthogonal array have been used to perform the experiments in order to investigate multi- response optimization of TIG welding process [21]. At the time of welding the inducing vibration of the weld pool has been studied and targeted to know the normal activity of vibration in monitoring the microstructure of welded zone and mechanical properties [14, 22].

2.0 Experimental Scheme

In present study, Taguchi's Orthogonal Array Design of experiment, L9 is used in sequence to recognize optimal factor arrangement for preferred welding excellence. 9 butt joint TIG welded samples have been created, employing 3 levels of current, 3 levels of speed of welding and 3 levels of shielding gas flow rate, to determine the effects of ultimate tensile strength. In this study the interface effects have not been estimated. Filler rod is not utilized at the time of welding process. Taguchi Orthogonal Array (3rd level designs) has been shown in **Table 3** below.

Table 3 : Taguchi's 3rd level orthogonal array designs

L9 (3^3): Factors: 3: Runs: 9 : Columns of L9 (3^3) : Array1 2 3			
Run	Welding Current (C)	Shielding Gas Flow Rate (F)	Welding Speed (S)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Butt welded joints of duplex stainless steel (UNS2205) plates of measurements 75 mm × 50 mm × 3 mm being done under varied input factors like current, gas flow rate and speed of welding performed by TIG welding machine construct: IGBT DIGITAL WELDING INVERTER (400A, III PHASE) of ELECTRA ENGINEERING (INDIA) PVT. LIMITED. No edge preparation has been used for welding. The tensile tests samples have been investigated on tensile testing machine named Blue Star Engineering & Electronics Ltd., is with Model no. : BSUT-60-JD-SERVO, Serial no. : 2016/048, Maximum capacity: 600 KN. Photographic views of welding arrangement on welding table and TIG welded duplex stainless steel samples are presented in **Fig. 1** and **Fig. 2**.

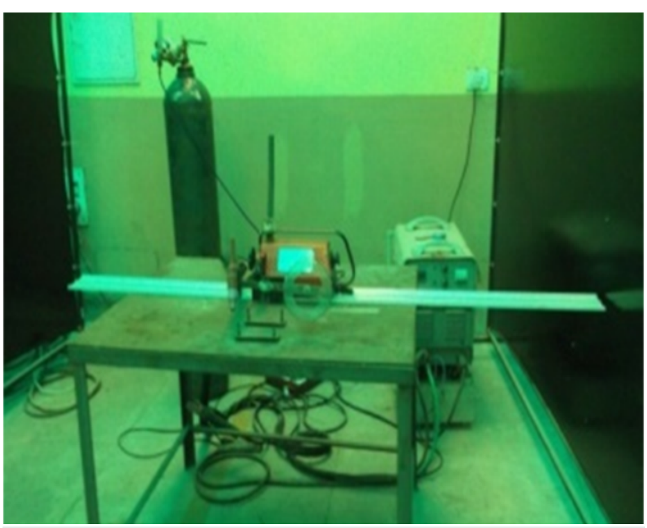


Fig. 1 : Photographic view of TIG welding set up

Fig. 2 : TIG welded duplex stainless steel sample

The controllable process factors of TIG welded DSS joints are current, gas flow rate, and speed of welding. The range of the process factors have been decided, based on the several investigational trials. Welding process factors and their levels are scheduled in **Table 1**.

Table 1 : Welding process factors and their levels

Factors	Unit	Notation	Levels		
			1	2	3
Welding Current	A	C	80	85	90
Gas Flow Rate	Lit./min	F	7	7.5	8
Speed of Welding	mm/sec	S	2.3	2.8	3.5

3.0 Observation of Visual inspection

Visual examination has been done for all welded samples. In few welded plates, defects have been seen through visual examination, like small undercut at the finish portion of weld bead, huge reinforcement height, insufficient penetration etc. The outcomes of visual examination of welded plates are plotted in **Table 2**.

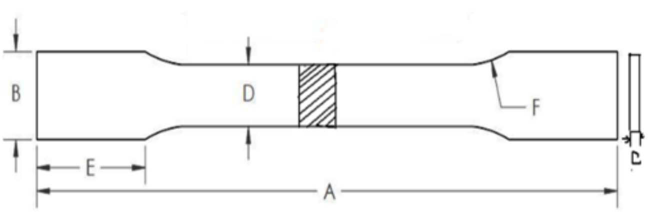
Undercut defect has arisen due to inappropriate joint configuration in few welding specimen. This welding defect may have been occurred caused by too much current, voltage, large arc gap as well. Lack of diffusion is a major defect which will have a great effect on the strength. It appears from quicker welding speed; inappropriately chosen currents, improper cleaning, present of oxide and additional adulterations, which have not been permitted the present impurity to coalesce appropriately with the mother metal.

Table 2 : Results Of Visual Inspection

Experimental run	Appearance of the weld bead
1.	Straight and narrow weld bead, low quality weld
2.	Uniform penetration and uniform weld beads.
3.	Straight uniform bead.
4.	Good penetration throughout.
5.	Little undercut at the end.
6.	Smooth uniform penetration.
7.	Good penetration throughout.
8.	Smooth uniform penetration.
9.	Good penetration throughout.

4.0 Results and Discussions

Tensile properties of TIG welding joints, like ultimate tensile strength (UTS), yield strength (YS), can be achieved relying upon the necessity. Tensile strength of TIG welding joints are achieved in taking samples from transverse way of TIG welding joints. Tensile test result must be buttressed by modulus of elasticity and elongated fracture, yield and ultimate strength, as shown in separate engineering stress and strain diagram. The schematic diagram of a tensile test sample as per ASTM E8 standard is presented in **Fig. 3** and tensile test results have been displayed in **Table 3**. It indicates that for many welded samples, test results are agreeable. Photographic view of tensile testing machine is shown in **Fig. 4**. Also, photographic observation of tensile specimen before testing and after testing are presented in **Figure 5 (a)** and **(b)**.



Where, A=100mm, B=10mm, C=3mm D=6.25mm, E=30mm, F=R6.25mm

Fig. 3 : Schematic diagram of tensile specimen with dimensions

Fig. 4 : Photographic vision of tensile testing machine

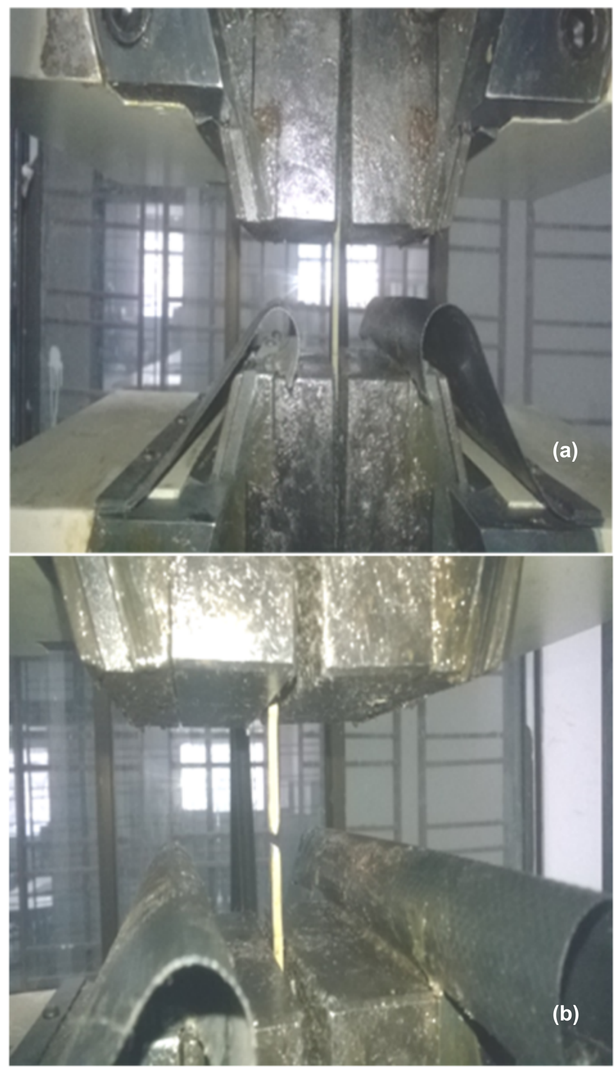


Fig. 5 : Photographic observation of TIG welded tensile specimen (a) before testing and (b) after testing

Table 3 : Tensile Test Results

Welded Sample No.	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)
1	183.3	460
2	236.7	595
3	253.3	635
4	243.3	610
5	260	645
6	253.3	630
7	256.7	640
8	243.3	610
9	260	650

5.0 Optimization by Principal Component Analysis

The experimental results of Yield strength (YS) and ultimate tensile strength (UTS) are converted into S/N ratio for analysis using PCA method. Principal Components and Calculated MPI are presented in **Table 4**. S/N ratio plot of MPI is presented in **Figure 6**. From Main Effect plots of the MPI (S/N ratio), the optimal parameter setting becomes C1F1S1.

The predicted value of S/N ratio for MPI becomes 33.1149 according to Taguchi's prediction whereas the value in confirmatory experimentation is obtained 34.0920. So quality has developed with the help of this optimal setting.

Table 4 : Principal component and calculated MPI

Welded Sample No.	SN- Yield Strength (MPa)	SN-Ultimate Tensile Strength (MPa)	Calculated MPI
1	-45.2632	-53.2552	-45.2632
2	-47.484	-55.4903	-47.484
3	-48.0727	-56.0555	-48.0727
4	-47.7228	-55.7066	-47.7228
5	-48.2995	-56.1912	-48.2995
6	-48.0727	-55.9868	-48.0727
7	-48.1885	-56.1236	-48.1885
8	-47.7228	-55.7066	-47.7228
9	-48.2995	-56.2583	-48.2995

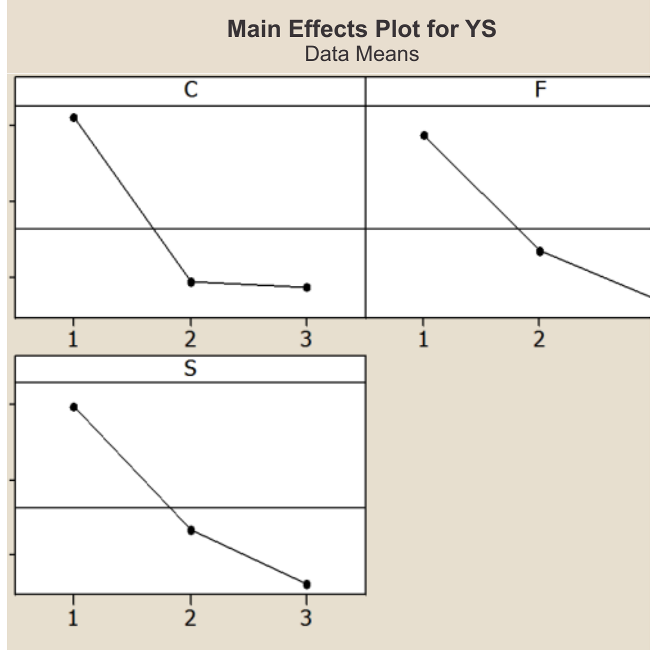


Fig. 6 : Main Effect plots of the MPI (S/N ratio)

6.0 Conclusions

Welding process factors like current, shielding gas flow rate, speed of welding etc., played an important part in mechanical properties of TIG weld like yield strength, ultimate tensile strength etc. In single objective optimization by Taguchi technique, the objective is to maximize ultimate tensile strength (UTS), percentage elongation (PE) individually. Taguchi's S/N ratio theory is employed and it is established as the optimum condition for maximum UTS. The best factor combination comes out as C1F1S1. It means welding current is 80 A, Gas flow rate is 7 lit.//min and Speed of welding is 2.3 mm/sec. Weld portion of Duplex stainless steel is showing better strength because proper welding current has been applied at the time of TIG weld joint. Gas flow rate has helped to resist any contamination at welding Zone. Welding speed is another vital parameter which has helped to create unbroken defect less welding. Strong weld has been produced using proper welding speed. The optimum conditions evaluated by Taguchi's single-objective optimization techniques and they have been confirmed by confirmatory tests.

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