Welding of two difficult to weld metals namely 2205 duplex stainless steel and boiler quality steel employing multipass GTAW process

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Abstract: Duplex stainless steel comprises of ferrite and austenite phase (50-50 %) shows its good strength and corrosion resistance properties in many aggressive environments. In many applications like liquid vessels, heat exchangers, steam pipes, ship building and in oil & gas industries instead of using the whole structure of the duplex material, use of the dissimilar material is increasing day by day. This provides a very good cost flexibility and utilization of properties of both materials. In this study, Gas tungsten arc welding (GTAW) of duplex stainless steel with boiler quality steel has been done by selecting suitable process parameters. Three parameters welding speed, welding current and shielding gas flow rate are taken in the experiments. Microstructural tests and Mechanical tests have been carried out. Analysis and optimization of process parameters have been carried out to improve quality and productivity of welding.

***IndexTerms* -** Duplex stainless steel, Boiler Quality steel, Dissimilar metal welding, Mechanical and metallurgical Properties

I. INTRODUCTION

The great success of duplex stainless steel compared to austenitic stainless steel is due to nickel price fluctuations. [1] In addition to that austenitic stainless steel has lower sustainability in many aggressive and corrosive environments. Therefore, industries are looking for better alternative with low Ni content and better performance in aggressive environments. [2] Duplex stainless steel gives very good performance in many aggressive and corrosive environments due to its half ferrite and half austenite contents. Duplex stainless steel finds its application in many areas like shipbuilding, offshore, chemical industries, paper and pulp industries, petro-chemical, desalination plants, oil and gas industries, etc. [3]

The selection of consumables plays an important role in similar or dissimilar welding of materials to enhance mechanical properties, to get proper phase ratio and to avoid solidification cracking. Generally, it is recommended that the welding filler metals have 2-4% more Ni than base metal. Ni helps to enhance austenite phase. At higher cooling rate, austenite content reduces and ferrite content increases, so to get proper ratio, filler metal with 2-4% more nickel is preferred. It improves mechanical and corrosion resistance properties of materials. The consumables like E/ER 2209, which is most popular and compatible with different processes for joining similar and dissimilar DSSs, shows better corrosion resistance and mechanical properties. [4] When E/ER2209 is compared with other filler metals like ER316LSi and ER308LSi, ER2209 weld showed better resistance to corrosion and better mechanical properties. [5] When E309 and E2209 electrodes are used to join 2205 DSS and low alloy steel dissimilar alloys using SMAW, E309L weld showed better general corrosion resistance than E2209 produced weld, because of austenitic microstructure, while, tensile and toughness was better in E2209 weld due to dual nature and proper phase balance. [6]

For welding of thick sections, interpass temperature is very important. Interpass temperature is the temperature of weld between two successive passes. The maximum interpass temperature should be below 150º C. If interpass temperature is higher than recommended, it increases HAZ dimensions and reduces tensile and yield strength of material. It is also reported that yield strength and tensile strength are the function of interpass temperature. For joining of thick sections, the researchers are trying to study the effect of interpass temperature on the properties of the joint. The recent new technique of joining implemented for joining pipeline of thick DSSs (21.4 mm) and reported the effect of interpass temperature (150 ◦ C and 290 ◦ C) on thick DSS2205 weld by applying SAW in filling and finishing passes. High interpass temperature (290 ◦ C) is more prone to corrosion and also lowers the impact toughness compared to150 ◦ C, this is due to the imbalance phase ratio and formation of more precipitates in the weld and HAZ. [7]

In general, for obtaining proper phase proportions in DSS, 0.5–2.0 kJ/mm heat input is recommended to control detrimental phases. Hertzman reported that the mechanical property of welded 2205 DSS does not vary considerably for normal heat input 0.3–2.0 kJ/mm. Further, heat input shows a significant effect on the bead geometry, metallurgical, mechanical and corrosion resistance properties of the welds. The exceeding range of heat input (0.66.2 kJ/mm) on 2205DSS by multi-pass GTAW welding improve pitting corrosion resistance up to 4.5 kJ/mm and then deteriorate.[8]

Dissimilar metal welding (DMW) is frequently employed to join two different materials where the transition in mechanical properties or performance services is required economically. Dissimilar metal welding is technically and scientifically more challenging when joining different metals and alloys i.e. (a)carbon migration from higher to lower carbon alloy steels (especially those which are highly alloyed), (b) the differences in thermal expansion coefficients, causing in differences in thermal residual stresses in different regions of weldments, (c) electrochemical property variations in the weldment, subsequent to environmentally assisted problems, which causes premature failure.[9] Klueh and King discussed about failure in fossil fuel boiler plant due to carbon migration.[10] Experimental analysis on 2205 DSS and 316L ASS dissimilar joint (3 mm thick plate) by SMAW process using E309L, E309LMo and E2209 electrode was demonstrated and reported that duplex E2209 electrode showed better structure–property correlationship than that of E309L and E309LMo due to balanced ferrite and austenite phases in the weld, which also showed higher corrosion resistance in chloride environments (3.5% NaCl).[11] Dissimilar joint (2205 DSS/16MnR steel) was reported with GTAW and SMAW process using ER2209 filler, in both processes joints produced by SMAW showed higher susceptibility to pitting corrosion in chloride solution (3.5% NaCl) than that of weldment produced by GTAW because of finer grains in GTAW process.[12]

II. EXPERIMENTAL PROCEDURE

2.1 Selection of workpiece material

The base metals (BMs) used for welding in the present investigation were 2205 duplex stainless steel and ASTM 516 grade 70 BQ steel. Plates of dimensions 125mm (length) x 125mm (width) x 10mm (thickness) were used in present study. Dissimilar GTAW welding was carried out using DSS ER2209 electrode (1.2 mm diameter). Chemical composition of DSS and BQ steel and an electrode was given in table 1 & 2. V- Butt joints with 2 mm plate gap were carried out for welding.

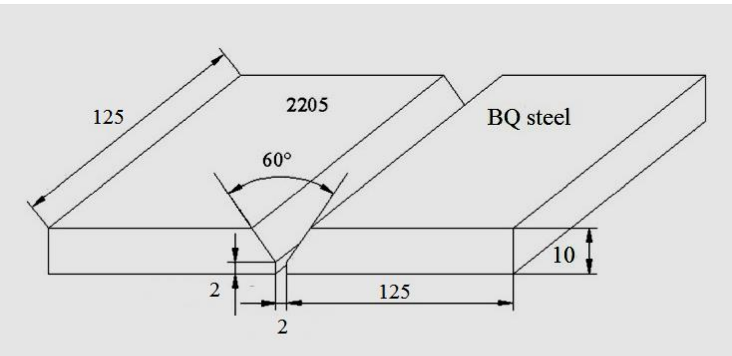
Table 1: Chemical composition of materials

Materials	C	Si	Mn	Cr	Mo	Ni	N	Al	Cb	Cu	Fe
2205	0.02	0.55	1.72	22.42	3.12	5.7	0.16	0.006	0.08	0.42	Bal.
ER2209	0.02	0.78	1.04	22.88	3.11	8.55	0.09	0.005	0.07	0.14	Bal.

Material	C	Si	Mn	Cr	Mo	Ni	Al	Cu	P	S	Nb	Ti	V	Fe
BQ steel	0.20	1.6	1.7	0.3	0.08	0.3	0.02	0.3	0.03	0.03	0.01	0.03	0.02	Bal.

2.2 Selection of Process parameters

The present work focuses on the investigation of the effect of various process parameters of dissimilar weld joint on mechanical and microstructural properties of the weldment. Figure 1 shows the geometry of weld joint.



All dimensions in mm.
Figure 1: Geometry of weld joint

Three different current 110 A, 120 A and 130 A were used in this study. Too high current melt the workpiece and too low current causes lack of penetration in the weld zone. Fast welding speed can be used for high current and slow welding speed can be used for low current. In this study, we have used three different welding speeds 100 mm/min, 110 mm/min and 120 mm/min. So optimum values of current and speed must be selected that gives best possible properties. When the shielding gas exits the nozzle, it has a different velocity than that of the atmospheric gases surrounding it. The different velocity and density between these two types of gases can cause currents to form, which can potentially turn the shielding gas column from a laminar flow (which is desirable) to a turbulent flow (which is less desirable). As the flow becomes turbulent, atmospheric gases can be pulled into the shielding gas column, leading to contamination of the weld. As shielding gas flow rate is increased, the laminar flow column becomes more turbulent, increasing the chances for the weld to become contaminated. As the flow rate is decreased, the shielding gas column becomes more laminar and less turbulent. Also very low flow rate can be easily disturbed, breaking down the shielding gas column and damage the weld. So, proper selection of gas flow rate is very important for achieving good quality welds. In this study, we have taken three different values of shielding gas flow rate i.e. 12 l/min, 14 l/min and 16 l/min.

Table 2: Levels of the Process parameters

Factor	**Level -1**	**Level 0**	**Level 1**
Current (A)	110	120	130
Welding speed (mm/min)	100	110	120
Gas flow rate (l/min)	12	14	16

2.3 Selection of Experimental design

Design of Experiments (DoE) is used to identify the significant active factors and investigate their effects on the output responses. Central composite design (CCD) of response surface methodology is used for conducting experimental runs. Here we have total 3 factors. All three are continuous variables with three levels. According to the CCD, total 15 experimental runs should be carried out. Table 3 shows design of experiment table.

Table 3: Values of the variables of the matrix of experiments

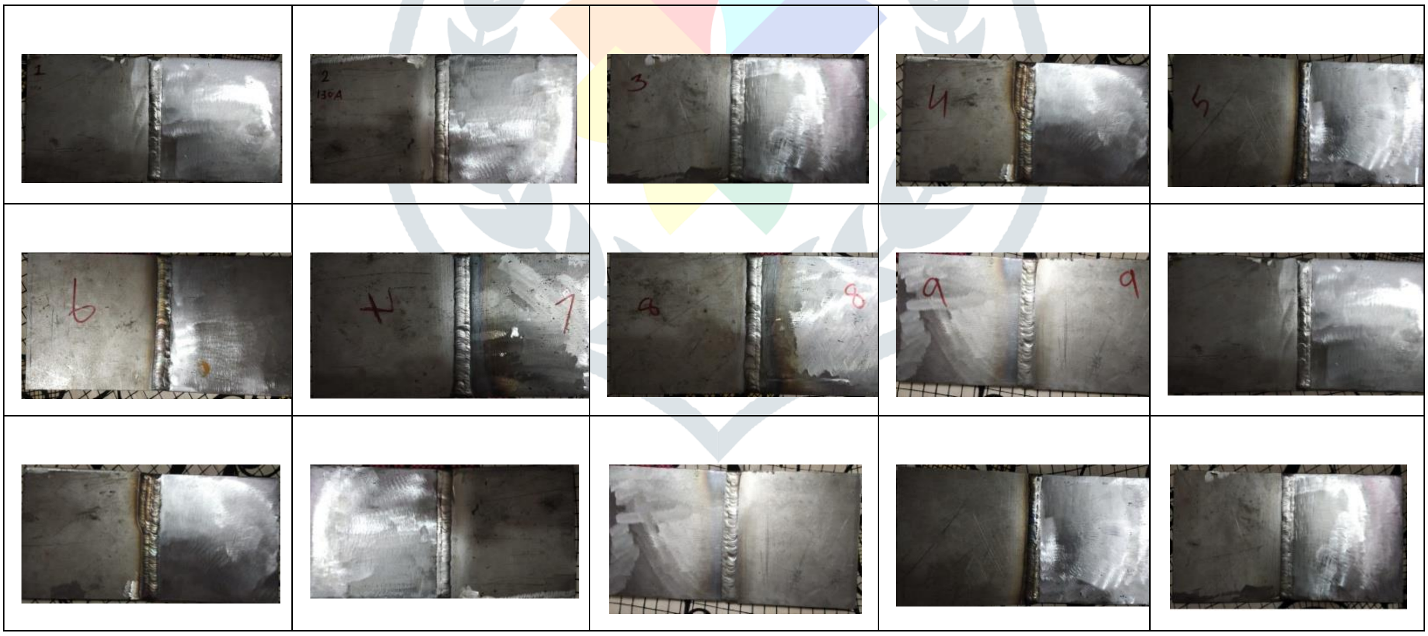
		Factor 1	Factor 2	Factor 3
Std order	Run order	A:Current	B:Welding Speed	C:shielding gas flow rate
		Ampere	mm/min	l/min
11	1	120	110	14
8	2	120	120	14
4	3	110	100	12
12	4	120	110	14
14	5	120	110	14
3	6	110	120	16
5	7	110	110	14
10	8	120	110	16
15	9	120	110	14
9	10	120	110	12
2	11	130	100	16
6	12	130	110	14
13	13	120	110	14
7	14	120	100	14
1	15	130	120	12

2.4 Experimental work

Tungsten Inert gas welding was used to join two dissimilar metals. Lanthenated electrode dia. 3.2 mm with tip angle 33^{o}was used as a non consumable electrode in welding process. 98% Argon + 2% N_2 gas was used as a shielding gas in the study. ER2209 filler wire of 1.2 mm diameter was used in the study. KUKA robot KR 16 with 6 axes was used to carry out TIG welding. After every pass, the weld was allowed to cool down upto 150º C. Figure 2 shows experimental setup of the welding. As per DOE matrix, total 15 experiments were conducted as shown in Table 4.

Figure 2: Experimental setup

Table 4: **Welding samples**



III. RESULTS AND DISCUSSION

3.1 Mechanical Testing

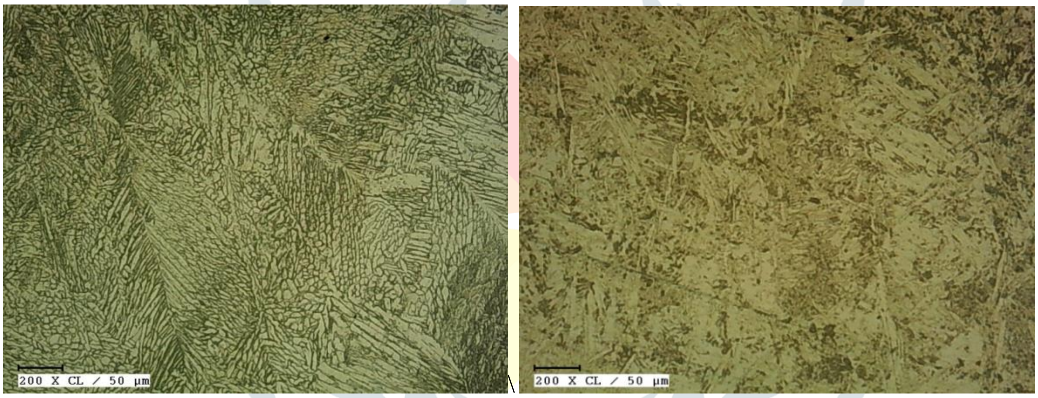
After welding under the required process parameters the specimens were tested using various mechanical and microstructural tests. Tensile specimens of the workpiece are shown in Figure 4. Locations of fracture are all at the side of HAZ of BQ steel base metal. Lowest value of tensile strength is 516.562 MPa and highest value is 642.232 MPa. For BQ steel, ASTM 516 grade 70 tensile strength requirements are in the range of 510 MPa to 650 MPa. Both minimum and maximum values are within the range. So, Tensile strength of weld joint is satisfactory.

Figure 4: Fractured Tensile test specimen

The Hardness of specimens was measured with Vicker's Hardness test machine. The Vicker's hardness test consists of indenting the welded test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 0.1 to 1 kg. Hardness value of weld metal is higher than BQ steel base metal and BQ steel HAZ. The highest value of hardness is 291.32 HV and lowest value is 270.75 HV.

3.2 Microstructural Testing

Microstructral testing of all 15 specimens has been carried out. Austenite and ferrite phase ratio in each specimen was also calculated through microstructural testing. Highest austenite phase was found in experiment 11. For this experiment, austenite phase was 68.415 and 31.585 ferrite phase. This Higher austenite phase is due to higher heat input because as heat input is higher it will take more time to cool and it gets more time in austenite phase. Heat input for this experiment no. 11 was around 0.702 KJ/mm. Also we get lowest hardness 261.12 HV for this experiment; this is due to higher amount of austenite in weld. Highest ferrite phase was found out in experiment no. 6. For this experiment, Ferrite phase is 69.356 and austenite phase is 30.644. This experiment has given highest value of hardness 291.32 HV, this is due to higher amount of ferrite content in weld. Heat input was 0.495 KJ/mm for this experiment.



Experiment 11 Experiment 6

Figure 5: Microstructure of experiment 6 and 11

3.3 Design of experiment

Using Design expert software (Version 11.0), the experimental data points were analyzed through Analysis of variance (ANOVA) and Lack of fit test. Mathematical modeling was carried out to find the relation between response variables and input parameters. Table 6 presents the input parameters and output responses for all experiments. Using Design expert software relationship between input parameters and output responses were obtained.

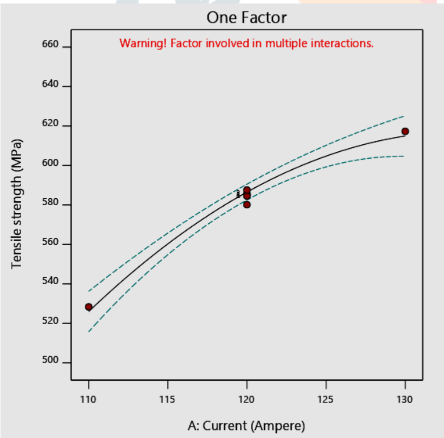
Table 6: Experimental results of Ultimate Tensile strength and hardness

		Input Parameters			**Output responses**	
		Factor 1	Factor 2	Factor 3	Response 1	Response 2
Std	Run	A:Current	B:speed	C:shielding gas	tensile strength	Hardness
		Ampere	mm/sec	l/min	MPa	HV
7	1	120	100	14	580.137	278.53
2	2	130	100	16	591.545	285.6

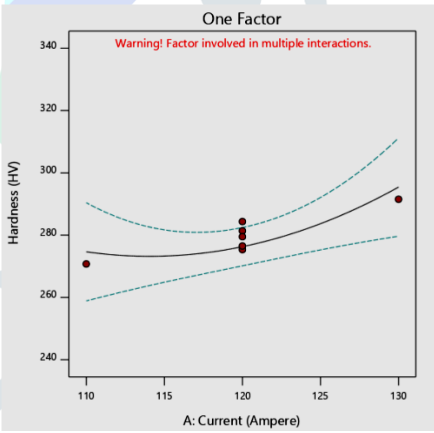
5	3	110	110	14	516.562	270.75
14	4	120	110	14	585.123	281.36
4	5	110	100	12	584.532	275.9
6	6	130	110	14	526.862	291.52
12	7	120	110	14	528.361	284.36
11	8	120	110	14	590.882	275.35
8	9	120	120	14	587.563	277.5
15	10	120	110	14	558.853	279.5
10	11	120	110	16	642.232	261.12
13	12	120	110	14	617.324	276.51
3	13	110	120	16	585.789	282.34
9	14	120	110	12	618.456	263.12
1	15	130	120	12	599.656	285.5

3.3.1 Effect of welding current on Ultimate tensile strength and Hardness:

The effect of welding current on UTS and hardness is shown in figure 6(a) and (b) respectively.



(a)

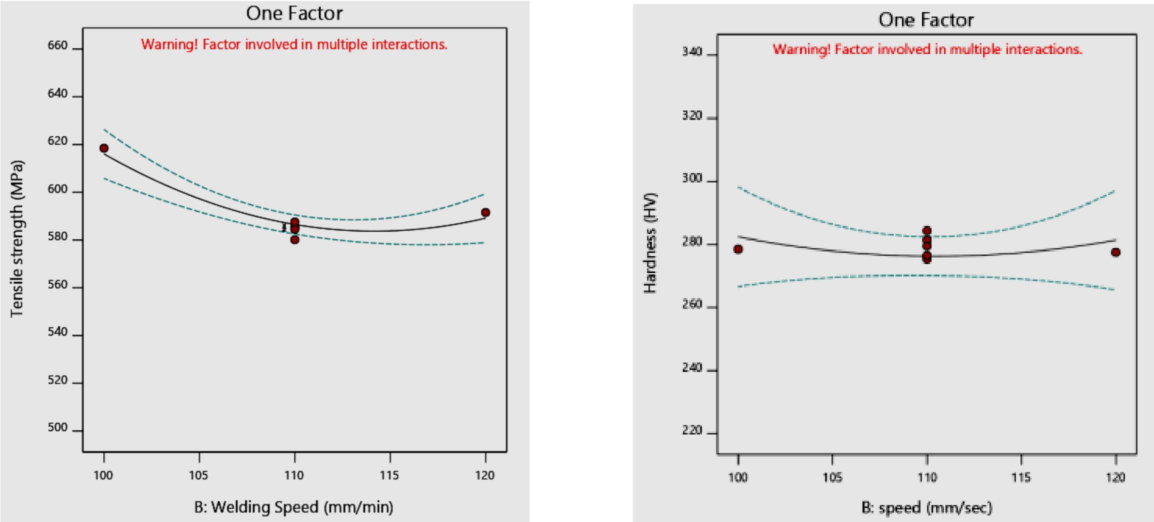


(b)

Figure 6: Effect of welding current on (a) Ultimate tensile strength, (b) Hardness

3.3.2 Effect of welding speed on Ultimate tensile strength and Hardness

The effect of root gap on UTS and Angular distortion is shown in Figure 7. (a) and (b) respectively.



(a) (b)

Figure 7: (a) Effect of welding speed on Ultimate tensile strength, (b) Effect of welding speed on Hardness

3.3.3 Effect of shielding gas flow rate on Ultimate tensile strength and Hardness:

The effect of shielding gas flow rate on UTS and Hardness is shown in Figure 7. (a) and (b) respectively.

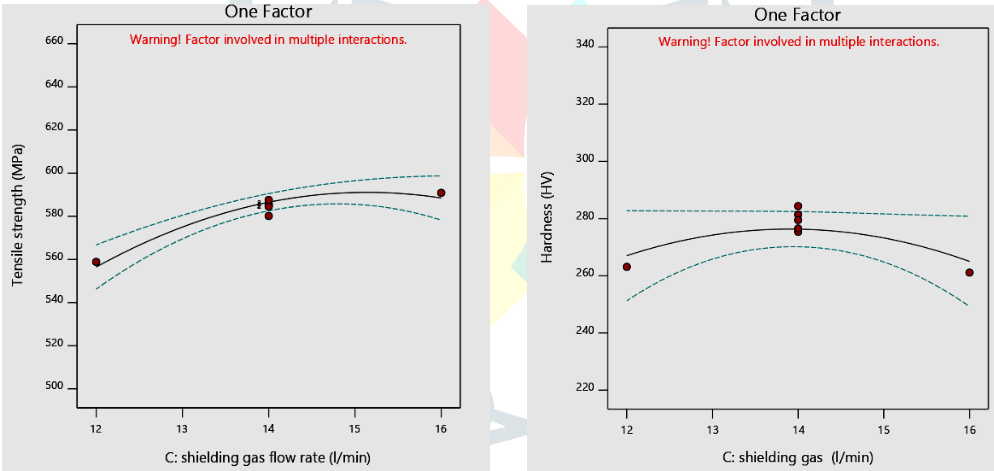


Figure 8: Effect of shielding gas flow rate on (a) Ultimate tensile strength, (b) Hardness

IV. CONCLUSIONS

The present study investigated the effect of various process parameters on welding of 2205 duplex stainless steel and BQ steel. 125 x 125 x 10 mm plates were taken for the study. The process parameters included welding current, welding speed and shielding gas flow rate. The effect of these three parameters on ultimate tensile strength, microstructure and on austenite ferrite balance have been studied. It was found that all three input parameters have a significant effect on response variables considered in present study. Also, an attempt has been made to derive an optimum set of process parameters for different cases of desired responses. From the investigation following conclusions can be arrived at;

- Welding current, Welding speed and shielding gas flow rate have a significant effect on Ultimate tensile strength, Hardness and microstructure.
- Among welding current, Welding speed and shielding gas flow rate, the effect of current and speed are more dominant.
- UTS of weld joint increases with increase in current upto a certain limit, then it starts decreasing. Hardness of weld joint decreases with increases in current upto a certain limit then again starts to increase.

- The effect of shielding gas flow rate on tensile strength and hardness is very little.
- Tensile strength decreases with increase in welding speed. Hardness value decreases with welding speed and reaches up to certain value and again starts to increase.
- Tensile strength increases slightly with increase in shielding gas flow rate, again it start decreasing slowly. Hardness value increases slightly with increase in shielding gas flow rate and then again decreases.
- Temperature management between subsequent passes plays an important role and help to reduce unnecessary detrimental phases and to get better properties.
- Process parameters that give higher tensile strength are 130 A current, 100 mm/min welding speed and 16 l/min gas flow rate. Process parameters that give lowest hardness are 120 A current, 110 mm/min welding speed and 16 l/min gas flow rate.
- Process parameters that give optimum tensile strength in single objective optimization are 129.924 A current, 100.272 mm/min welding speed and 14.371 l/min gas flow rate. Process parameters that give optimum hardness value in single objective optimization are 130 A current, 100 mm/min welding speed and 16 l/min gas flow rate.
- Process parameters that give optimum tensile strength in multi objective optimization are 130 A current, 100 mm/min welding speed and 16 l/min gas flow rate.

REFERENCES

[1] Oshima T, Habara Y, Kuroda K. Efforts to save nickel in austenitic stainless steels. ISIJ Int 2007;47:359–64.

[2] Boillot P, Peultier J. Use of stainless steels in the industry: recent and future developments. Procedia Eng 2014;83:309–21.

[3] J. Nowacki, Ferritic-austenitic steel and its weldability in large size constructions, Journal of Achievements in Materials and Manufacturing Engineering, vol.32, pp.115-141 2009.

[4] Practical Guidelines for the Fabrication of Duplex Stainless Steel, International Molybdenum Association (IMOA), London.

[5] Munez CJ, Utrilla MV, Urena A, Otero E. Influence of the filler mate-rial on pitting corrosion in welded duplex stainless steel 2205. Weld Int2010;24(2):105–10.

[6] BalaSrinivasan P, Muthupandi V, Dietzel W, Sivan V.,Microstructure and corrosion behavior of shielded metal arc-welded dissimilar joints comprising duplex stainless steel and low alloy steel, J Mater Eng Perform, vol.15, pp.758-764, 2006.

[7] Alvareza TR, Pavarinoa MRC, De Souza GC, Pardal JM, Tavares SSM, Fer-reira MLR. Influence of interpass temperature on the properties of duplexstainless steel during welding by submerged arc welding process. Weld Int2016;30:348–58.

[8] Hertzman S. The influence of nitrogen on microstructure and properties ofhighly alloyed stainless steel welds. ISIJ Int 2001;41(6):580–9.

[9] Jagesvar Verma, Ravindra Vasantrao Taiwade, Effect of welding processes and conditions on the microstructure, mechanical properties and corrosion resistance of duplex stainless steel weldments—A review, Journal of Manufacturing Processes, vol.25, pp.134-152, 2017.

[10] Klueh RL, King JF. Austenitic stainless steel-ferritic steel weld joint failures.Weld J 1982;61:302-s–11-s.

[11]Verma J, Taiwade RV. Effect of austenitic and austeno-ferritic electrodes on2205 duplex and 316l austenitic stainless steel dissimilar welds. J Mater EngPerform 2016;25:4706–17.

[12]Wang S, Ma Q, Li Y. Characterization of microstructure, mechanical proper-ties and corrosion resistance of dissimilar welded joint between 2205 duplexstainless steel and 16MnR. Mater Des 2011;32:831–7.

[13]ASM Handbook, Volume 06A Welding Fundamentals and Processes.

[14] Handbook, ASME section IX;

[15] Montgomery DC. Design and analysis of experiments. John Wiley & Sons;2017