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Characteristics Optimization of Different Welding Processes on Duplex Stainless Steels Using Statistical Approach and Taguchi Technique - A Review Guide

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Abstract:- Material characteristics and welding parameters play a very important role in determining the quality of a weld bead. Duplex stainless steel (DSS) consists of approximately equal proportions of ferrite (δ) and austenite (γ) phases. The DSS joint quality can be defined in terms of mechanical behavior, heat input, heat-cooling rate, weld oxide formation, sigma phase formation in weld metal and base metal. Different welding process is used with the aim of obtained a best welding joint with the desired input parameters, good mechanical properties with minimum defects. Generally welding thermal cycle, dual torch, aging, heat treatment techniques are more influence on quality of weld joint. In order to determine optimize process, design of experiment and computational network are widely using nowadays. A comprehensive review of the application of these techniques in the area of welding on different grades of duplex stainless steel has been introduced here in. This paper was classified according to the output features of the weld i.e. to optimize the mechanical properties by changing the relative amount of ferrite, austenite and martensite content in base metal and weld metal. This review shows many investigations and effects of phase transformation, heat treatment, dual torch technique on duplex stainless steel weldments and examined microstructure analysis at different experimental conditions in order to obtain superior welded joints.

Keywords: - Duplex stainless steel; Welding, Quality of weld metal; Ferrite-Austenite; Taguchi, Optimization.

I. INTRODUCTION

Duplex stainless steel(DSS) typically comprises microstructure consisting approximately equal proportion of Body-centered cubic ferrite (δ) and face centered cubic austenite (γ),which offers greater mechanical strength and high corrosion, pitting and fatigue resistance than most types of stainless steel. Duplex stainless steel is a common structural material in the oil, gas, manufacturing industries and has special application in chemical, wastewater, marine engineering field. An important limitation of the DSS is its maximum temperature of service, below 300^{0}C,due to the problem of brittleness at 475^{0}C.The performance of DSS can be significantly affected by welding technique-induced phase transformation and understanding of the evolution of microstructure during welding is need in order to predict the final weld properties. The quality of DSS weld joint is directly influenced by heat input parameters, type of welding process and type of technique, therefore welding can be considered as a multi-input multi-out put process. By changing chemical composition of base metal and filler metal of duplex stainless steel, it requires time-consuming trial and error development method for choosing best weld parameter to produce a welded joint that closely meets the required specification of joint. The various optimization methods of different welding process can be applied to define the desired output variables on DSS through developing design of experiment (DoE) technique, taguchi technique and statistical approaches have been used to such optimization. Sigma phase formation on duplex stainless steel weld metal is greatly influence by single pass and multi pass gas tungsten arc welding (GTA) without filler material in argon gas. Activated tungsten inert gas(ATIG) welding technique, which control the ferrite/austenite contents of the weld metal are very important for DSS to avoid degrade the strength and corrosion resistance. The optimal mechanical properties were obtained when precipitation of sigma and the γ-to-δ ferrite transformation are suppressed, i.e., at 1050^{0}C.Ni percentage on filler metal and weld oxide formation on DSS also improve the quality of weld and develop corrosion fatigue resistance. Effect of solution heat-treatment on DSS weld metal will increases pitting resistance and content of γ-phase in weld bead and in heat affected zone (HAZ) increases which promotes weldability, excellent mechanical properties.

In this paper a comprehensive detail review of the application of different optimize technique is presented. This literature review shows the relations between the welding input parameters and the output weld bead variables, the paper also present the characteristic optimization of the different welding process on duplex stainless steel through experimental microstructure analysis. The classification of the literature review will be according to the weld joint features.

II. PHASE FORMATION IN DSS WELD BEAD

The performance of duplex stainless steel can be significantly affected by welding induced phase transformations; hence formation of ferrite, austenite phases in weld metal and base metal after performing welding process is very important. Controlling of weld-bead phase is essential as the mechanical properties of welds are affected by the weld-bead phase. Therefore, it is clear that precise selection of the process parameters is necessary.

2.1 Ferrite formation

W.Zhang and T Debray [1] have highlighted to developed ferrite formation in duplex stain less steel by one-dimensional numerical diffusion model. DSS are two phase alloys consisting of approximately equal proportions of ferrite (δ) and austenite (γ) phase with high toughness, good weldability, satisfactory resistance and high tensile strength. Investigation on heat affected zone (HAZ) has been done to understand the phase formation, phase fraction, grain size during the weld heating and cooling cycles.

By using the numerical diffusion model and computed heating rates, time-temperature-transformation (TTT) and continuous-heating transformation (CHT) diagrams[2] for DSS were constructed and the kinetics of the γ-δ transportation at various locations in the HAZ could be calculate and validate by comparing the calculated result with data obtained using a spatially resolved X-ray diffraction (SRXRD) technique.2205 DSS consists of alternate layers of 54% δ ferrite and 46 % γ-austenite phases has been solution annealed at temperature of 1338 K for a period of 2.5 hours following by water quenching to ambient temp to achieve starting microstructure. The initial nitrogen concentration and total nitrogen concentration can be known using governing equations of nitrogen diffusion.

$$\frac{\partial N}{\partial t} = D_\delta \frac{\partial^2 N}{\partial X^2} \text{in } \delta \ (0 < x < M)$$

(1)

$$\frac{\partial N}{\partial t} = D_\gamma \frac{\partial^2 N}{\partial X^2} \text{in } \gamma \ (M < x < x_\gamma)$$

Where N is the nitrogen concentration, t is time, D_δ and D_γ are the diffusion coefficients of nitrogen in the δ and γ phases respectively.

2.2 Thermodynamics of γ-δ transformation

The equilibrium fraction of(γ)has been experimentally measured in the literature [3] by Hertzman for the number of duplex stainless steels. The relationship of f_γ as a function of temperature and composition is given as

$$f_\gamma = 0.01[75 - 6.8\times 10^{-15} \times T^5 + 190(C_C - 0.03) + 6(22 - Cr_C) + 9(Ni_C - 5) + 6.5(3 - Mo_C) + 160(N_C - 0.15)] \quad (2)$$

Where$C_C$is the carbon concentration, $Cr_C$is the chromium concentration $Ni_C$is the nitrogen concentration. The concentration of C, Cr, Ni, Mo and N in Eq (2) are the average concentrations of elements in the base metal determining by chemical analysis. It found that 1338 K is only a nominal start temperature and not the equilibrium temperature for the start of the γ-δ transition.

The spatially resolved X-ray diffraction (SRXRD) technique was used to obtain real-time kinetic data for the γ-δ transformation during welding gas tungsten arc (GTA) welds were made on 2205 duplex stainless steel cylindrical bar samples .During welding sample was irradiated with a high-intensity synchrotron beam, and the diffracted beam was collected to determine the crystal structure at discrete location. Additional details of the SRXRD experiments are available elsewhere [4, 5].It is found that the overall transformation rate is 30 % faster when the starting structure is uniform. The transformation rate increase with temperature and the non-uniform starting structure delays the completion of the phase transformation.

2.3 Sigma phase formation on DSS.

Yutaka S.Sato and Hiroyuki [6] have extended their study and examined the effect of chemical driving force on sigma phase formation in duplex stain less steel weld metals with different chemical compositions. The effort of crystallographic orientation relationship at δ/γ interface on sigma phase formation in a DSS weld metal, where the chemical element distribution is relatively uniform because of rapid cooling during weld thermal cycle. The chemical composition(Wt %) isFe-25.05%,Cr-4.7%,Ni-1.90%,Mo-0.4% of 50 × 150×90 mm in size of base metal plate was welded by sigle pass gas tungsten arc (GTA) welding without filler material in argon gas. Relationship between the pair of deviation angle $\Delta\theta_{K-S}$ of intergranular-austenite and the misorientation at prior ferrite grain boundary in the weld metals and relationship between frequency of α/γ interfaces and the deviation angle $\Delta\theta_{K-S}$ are examined. Sigma phase forms preferentially at one side of ferrite/austenite interface along intergranular austenite in a DSS weld metal annealed at 1100K[7].The minimum deviation angle for sigma phase formation is strongly influenced by the interfacial energy and the coherency of ferrite/austenite interface. High coherent and low energy ferrite/austenite interface can delay sigma phase formation.

2.3. Weld oxide formation on DSS

E.M.Westin and O.A.Olsson [8] have continued their previous study and successfully investigated the effect of weld oxide have a strong influence on corrosion resistance of Duplex stainless steel. Chromium dominates in the weld oxide formed at high temperature and reaches a maximum above 900^0C related the chromium reduction in heat tint formed at the highest temperatures to evaporation of chromium oxide, CrO-3.Best corrosion resistance accurse by mechanical cleaning followed by pickling.

Higher alloyed grade steels does not affect the corrosion resistance as compare with lower alloyed grade steels. Gas tungsten arc welding (GTAW) was performed on different welded duplex stainless steel grades (LDX 2101, 2304, 2205 and 2507) and followed by corrosion testing, ferroxyltest, electron probe micro analysis-ray photo electron spectroscopy test were carried out to examined the effect on corrosion resistance and weld oxide formation.

The influence of nitrogen, nickel, manganese on heat tint formation is more [9]. After examined all experimental test on all samples it shows that discoloration only for the welds in nitrogen-containing atmosphere, not those with argon. The reason seems to be the manganese or chromium oxynitrides formed in the former case and appear to be responsible for the staining.

III. HEAT TREATMENT ANALYSIS ON DSS.

Welding is usually done with the aim of getting a welded joint with best mechanical properties.

On any type of material, the property of base metal and quality of welded joint is greatly influence by the heat treatment process. The effect of heat treatment also have great change in microstructure and it balance the ferrite, austenite content in the weld metal and in heat affected zone (HAZ) which promotes weldability and excellent mechanical properties.

2.4 Effects of solution heat-treatment on DSS welds.

Soon-Tae Kim and Seok-Hwan Jang [10] have presented an experimental analysis of the effects of solution heat-treatment on hyper duplex stain less steel (HDSS) weldments. HDSS such has UNS 532707 is defined as a highly alloyed DSS with a PREN Value is greater than 45.After performing a solution heat-treatment on hyper DSS weld metal with an Argon shielding gas supplemented with N_2,the pitting resistance-phase in the weld metal and in heat affected zone was increase which promotes weldability, excellent mechanical properties. Post weld heat treatment (PWHT) is very important to control over the balance of a α, γ phases in the weld metal (WM) and HAZ. Nitrogen (N) is a strong γ-stabilizer and it increase the temperature at which the transformation of α-to γ phase occurs.

$$\text{PREN} = \text{wt \% Cr} + 33\ (\text{wt \% Mo} + 0.5 \times wt\ \%\ \text{W}) + 30 \times \text{wt. \%N}. \quad (3)$$

The formula in Eq (3) for DSS has been used by several researchers to investigate DSS's resistance to localized corrosion [11].

Metallographic examination, polarization test, critical pitting temperature test, scanning electron microscope and energy dispersive spectroscope (SEM-EDS) analysis and transmission electron microscope (TEM) analysis of Cr_2N precipitate were carried out and examined the effect of heat treatment on the resistance to pitting corrosion of a HDSS welds. The phase diagram and equilibrium fraction of each phase were calculated against the temperature for the HDSS alloy using a commercial thermo calculation software package. Based upon the $PREN_\gamma$ and $PREN_\alpha$[12] values calculated using a N factor of 30,pitting corrosion in the weld metals and HAZ'S in the solution heat-treatment HDSS tube after welding was selectively initiated at the α-phase, irrespective of the chemical compositions of the shielding gas. The pitting corrosion was finally propagated from the α-phase to the γ-phase.

2.5 Effects of Aging on DSS weldments.

Omyma Hassan Ibrahim and Ibrahim Soliman Ibrahim [13] have explain about the effect of aging heat treatment at (650,750 and 850^0C) on2205 duplex stain less steel after performing TIG (Tungsten inert gas) welding technique. DSS weldments are the degradation of corrosion and mechanical properties within certain high temperature due to the micro structural changes. In comparison to austenite stainless steel, precipitation of sigma phases in DSS accurse within the ferrite phase at shorter time, at higher temperature and with larger volume fractions.

Material with dimension of 55 mm $\times 10mm \times 4.5mm$ were subjected to solution heat treatment at 1050^0C and 1150^0C respectively for 1 hour and then water quenched and then isothermal aging treatment was applied to base and weld metals at 650^0,750^0 and 850^0C for 3hour followed by furnace cooling. Microstructure analysis, impact properties, load time plots for austenite stainless steel and duplex stainless steel weldments were verified and found that impact energy is higher for DSS in the un-aged conditions. The degree of embrittlement is greater with the increases of the aging temperature.[14]SEM examination reveals that the reduction in impact energy due to aging is associated with the formation of shallow ductile dimples and cleavage facets on the fracture surface of 316 L and duplex stainless steels, respectively.

2.6 Welding thermal cycles on DSS.

HuaTan and Zhiyuwang [15] have investigated the welding thermal cycle on 2305 DSS.Duplex stainless steel are widely used as alternatives to austenite stainless steels and nickel based alloys, which consists of approximately equivalent amount of γ and α-ferrite with an excellent combination of mechanical strength and corrosion. Different welding thermal cycles from single-pass to triple pass were performed on two kinds of 2304 DSS. The most typical problems of welded DSS are associated with heat-affected zone (HAZ), not with weld metal zone (WMZ), since the properties of WMZ could be modified by using high-alloyed filler metal and N_2 containing shield gas. More sophisticated and complicated microstructure evolution in HAZ during multi-pass welding.

Material is divided into several blooms with a dimension of 150mm×100mm ×42mm is heated in vacuum furnaces from 900 to 1200^0C temperature range and then reheated at 1250^0C for 2 hours and hot-rolled in to 12 mm thickness plates. Chemical composition of DSS.

Chemical composition of two kinds of duplex stainless steel 2304 (Wt %)

Element	Cr	Mo	N	N	Cu	C
2304-A	23.06	0.31	0.13	4.03	0.29	0.021
2304-B	23.82	0.91	0.18	4.50	0.35	0.02
Element	Mn	Si	P	S	Fe	
2304-A	1.56	0.40	0.010	0.004	Bal	
2304-B	1.52	0.38	0.008	0.004	Bal	

The above two grade specimens were solution –annealed for 12 mints at 1250^0C and 1050^0C respectively quenched in water. Electrochemical measurements-critical pitting temperature test is done at least three times for the same specimen and microstructure analysis also carried and it so that all the welding thermal simulated specimens exhibited impaired microstructure and pitting corrosion resistance compared with the corresponding base metal. As welding pass increases CPT value increases the ferrite phase fraction decrease and improvement of the microstructure and pitting corrosion resistance. PREN (pitting resistance equivalent number) increases.2304-B DSS with higher alloyed specimens [16] showed better microstructure and pitting corrosion resistance than the corresponding 2304-A specimen.

3.4. Hydrogen-enhanced cracking of DSS Welds

M.C.Young and S.L.I.Chan [17] have continued their investigation of the effects of hydrogen, nitrogen addition during laser welding to improve the weldability of duplex stainless steel. The susceptibility decreased with increasing austenite content in the weld metal of DSS. Slow displacement rate tensile tests were carried out to investigate the effect of hydrogen embrittlement on notched tensile strength (NTS) and fracture characteristics of 2205 DSS weld. Plastic deformation occurs more easily in low alloy DSS, resulting growth of stress corrosion cracks in the austenite. In highly alloyed DSS the strength of austenite is higher and cracking in the ferrite in chloride solution is promoted. By controlling the heat input and interpass temperature during welding are required to correct the α/γ ratio in the DSS weld. Laser welding offers many advantages over the conventional arc welding process on DSS, by varying welding parameters γ phase content in the fusion zone of a 2205 DSS is increases.

Microstructure observations, charpy impact test, notched tensile test, fracture morphology were carried out after laser welding on DSS and found the α/γ ratio in the fusion zone was drastically increased[18].The effect of N addition during laser welding also improved the weld's ability to resist impact fracture. Hydrogen embrittlement susceptibility is more obvious for the specimens containing a greater amount of α phase.SEM fractographs shows that all specimens underwent a significant change in fracture mode from ductile in air to mainly quasi-cleavage fracture in H_2.

3.5. Influence of heat input on DSS welds.

M.Yousefieh and M.Shamanian[19] have presented an experimentally the effect of heat input variations on the microstructure of a duplex stainless steel UNS S32760 in artificial sea water media. Approximately 0.95 k J / mm of heat input have the best corrosion characteristics which are the result for the lack of deleterious phases such as sigma and Cr_2N and balanced ferrite –austenite proportion. The pulsed current of gas tungsten arc welding (GTAW) process has a numerous advantages over the conventional GTA process, the ferrite-austenite ratio in base metal as well as in weld metal depends on the energy input in welding. After performing welding on four different size of DSS pipe, metallographic test done by scanning electron microscope (SEM) and energy dispersive X-ray spectrometer (EDX) test were performed to reveal the chemical composition of the phases present in the microstructure and polarization curves of various specimens can be analyzed.

The results of various test shows that formation of sigma and Cr_2N phases reduced corrosion potential. The lower austenite content due to the high heat input and sufficient time for ferrite-austenite transformation.

IV. MECHANICAL PROPERTIES.

Welding is usually done with the aim of getting a welded joint with excellent mechanical properties. By changing welding technique, input parameters, heat treatments, chemical composition of duplex stainless steel, the welded joint may be examined and investigate to improve their mechanical properties. To determine these welding combinations that would lead to excellent mechanical properties for DSS weldments. Different technique, methods, approaches and composition have been used to achieve this aim. The following is a review of some articles that utilized these techniques for the purpose of optimizing the welding process for DSS in order to achieve the desired mechanical properties of the welded joint.

4.1. Mechanical behavior in annealed DSS welds.

RiadBadji and MabroukBouabdallah [20] have examined the effect of annealing treatment of 2205 DSS on mechanical properties. The tube type DSS material of 170 diameter and 7 mm in wall thickness is welded using a gas tungsten arc welding process in multi pass with Ar+2%N_2 shielding gas and ER 2209 filler metal. After welding, series of heat treatment were performed from 8000^0C to1200^0C and then etched with solution like 10 ml HNo_3, 20ml glycerol and 30 ml Hcl.

By ZEISS optical microscope, optical micrograph of welded specimen over heated parts of the HAZ, and partially annealed region of the HAZ at different ranges was done. The EDX analysis technique has been used to identify the phases constituting each microstructure region [21]. The best combination of strength stress σ =775 MPa and elongation δl=36.45 % is obtained after annealing at 1050^0C.Asignificant change in the toughness and tensile properties has been observed as a consequence of precipitation phenomena or an increase of ferrite content. The optimal mechanical properties were obtained when precipitation of sigma and the γ-to-δ ferrite transformation are suppressed i.e. at 1050^0C.

4.2. Activated TIG welding on DSS.

Tsann-ShyiChern and Kuang-HungTseng [22] have continued their study and examined the tensile strength. The effect of the specific fluxes used in the Activated tungsten inert gas welding process on 6 mm thick duplex stainless steel also investigated. Penetration during TIG welding process depends upon weld current, weld speed, thickness of metal, material, flux used and type of electrode. By using activated flux, the 200%-300% deep penetration takes place. The technique that control the ferrite /austenite contents of the weld metal are very important for DSS to avoid degrade the strength and corrosion resistances. Effect of activated TIG welding on (surface, weld morphology, angular distortion, ferrite and austenite content) with flux and without flux has be experimental examine was done and finally mechanical properties found are tensile strength σ =765 Mpa, and 35 % elongation. By using SiO_2,MoO_2 and Cr_2O_3 flux penetration capacity increased and improved mechanical strength. The greater weld depth-to-width ratio take place with activated TIG welding process as compare with the normal TIG welding [23]. As a result arc voltage increases and the ferrite content in the welded bead is decreases.

4.3. Corrosion fatigue of DSS welds.

S.A Tavara and M.D.Chapetti [24] have stated that the duplex stainless steel of two phase microstructure austenite and delta ferrite in approximately similar percentages have greater yield strength than austenitic stainless steels. Welded parts has less resistance than base metal by control of carbon content(low carbon) and welding conditions to ensure austenite formation can make corrosion resistance of DSS equivalent to base metal.

Austenite/ferrite contents of welded DSS is dependent upon electrode composition, Ni plays an important role in the balance as austenite promoter. Corrosion fatigue in welded joints is considered a very dangerous type of propagation of defects in materials that are subjected to dynamic loads. Welding has performed on four different composition of base metal with four different filler metal (electrode A,B,C,D) and tested mechanical properties after heat treatment was made to 1050^0C for 1 hour. Three point bending fatigue test were carried out in a load control walking –beam fatigue machine in air and sea water of different frequency and found that Ni content has a direct relation to the number of cycles necessary to reach a depth of 1.5 mm.[25]The environmental contribution to the crack growth rate is:

$$(da/dN)_{cf}= (da/dN)_e – (da/dN)_r$$

Where $(da/dN)_e$ is the measured crack growth rate and $(da/dN)_r$ is the reference crack growth rate, corresponding to pure mechanical fatigue in air.

V. OPTIMIZATION TECHNIQUES.

Different methods, approach and techniques have been used to achieve excellent weld bead with best tensile strength on DSS, Low carbon steel, high carbon steel. The follow is a review of some researches that utilized these techniques for the purpose of optimizing the welding process.

2.7 Taguchi technique.

Juang and Tarng[26] have adopted a modified Taguchi method to analyze the effect of each welding process parameter (arc gap, flow rate, welding current and speed)on the weld pool geometry (front and back height, frontand back width) and then to determine the TIG welding process parameters combination associated with the optimal weld pool geometry. It was experimentally reported that, the four smaller-the-better quality characteristics,' four responses' of the weld pool in the TIG welding ofS304 stainless steel of 1.5 mm in thickness are greatly improved by using this approach.

Lee HK and Han HS. [27] have used the Taguchi method and regression analysis in order to optimize Nd-YAG laser welding parameters (nozzle type, rotating speed, title angle, focal position, pumping voltage, pulse frequency and pulse width) to seal an iodine-125 radioisotope seed into a titanium capsule. The accurate control of the melted length of the tube end was the most important to obtain a sound sealed state. It was demonstrated that the laser pulse width and focal position were the laser welding parameters that had the greatest effects on the S/N ratios of the melted length. The optimal welding conditions were obtained at a pulse width of 0.86 ms and a focal position of 3.18–3.35 mm. Furthermore, confirmation experiments were conducted at the optimal welding conditions, it can be said that the titanium tube ends were sealed perfectly

Laser butt-welding of a thin plate of magnesium alloy using the Taguchi method has been optimized by Panet al. [28]. They studied the effect of Nd-YAG laser welding parameters (shielding gas type, laser energy, conveying speed, laser focus, pulse frequency and pulse shape) on the ultimate tensile stress. Their result indicated that the pulse shape and energy of the laser contributed most to thin plate butt-welding. It was found that the optimal combination of welding parameters for laser welding were argon as a shielding gas, a 360 W laser energy, a work piece speed of 25 mm/s, a focus distance of 0 mm, a pulse frequency of 160 Hz and type III pulse shape. It was also found that the superior ultimate tension stress was169 MPa at an overlap of the welding zone of approximately75%.

2.8 Response surface methodology (RSM).

Wang and Rasmussen [29] have investigated the inertia welding process of low-carbon steels using RSM, with the purpose of establishing an empirical functional relationship between the process parameters (the axial pressure, the initial rubbing velocity and the total moment of inertia) and the breaking strength of the joint. It was concluded that a relatively wide range of operating conditions would produce successful welds. Also, they observed that the average micro hardness at the weld was about 27% higher than the base material and the ideal weld should be made with the least possible amount of kinetic energy as long as full penetration at the interface is achieved.

Benyounis and Bettamer[30] have proposed models using RSM to investigate the effect of welding parameters in SAW(welding current, arc voltage and welding speed) on the impact strength at two testing temperatures of 50 _C and27 _C. The aim was to predict and optimize the impact strength of the spiral-welded joints with respect to the process parameters. It was observed that the welding current was the most significant factor associated with the impact strength, then the welding speed, whereas the welding voltage has no significant effect within the factors domain investigated. They listed the optimal welding conditions that would lead to acceptable impact strength with improving the process productivity

2.9 Artificial neural networks (ANN).

Control of distortion and overall quality of welds were investigated by Casalino et al. [31] in order to select the GMAW process parameters that minimize thermal deformation and evaluate weld quality. They integrated the artificial intelligence techniques and FEM with the aid of experimental trials of bead-on-plate welds. The base metal was 1.6 mm thick low-carbon steel, a 0.9 mm diameter copper-coated wire was used as an electrode with a shielding gas consisting of a 75% Ar–25% CO2 mixture with flow rate of 10–15 ft3/h.
ANN was used at first to link the process parameters to the geometry of the molten zone, which allowed the geometries throughout a range of process parameters to be calculated. Then FEM was applied to predict the

residual stress value and distortion in the welded joint. Finally, fuzzy C-means clustering algorithm was applied to evaluate the quality joints. Mathematical models for GMAW were constructed. Experimentally butt welded joint were validated. It was concluded that the experimental result are in good agreement with the mathematical model.

5.4. Dual torch technique on DSS welds.

Z.Sun and M.Kuo [32] have investigated the effect of the dual-torque technique on the microstructure changes and corrosion properties of duplex stainless steel were examined. Ferrite percentage is very important to reduce stress-corrosion cracking resistance, therefore to control this technique uses two welding torches' (a plasma welding torch followed by a gas tungsten arc (GTA welding torch) simultaneously during welding.SAF 2205 DSS with 5.5 mm thickness material were performed dual torch technique, potentiodynamic measurements and electro chemical impedance spectroscopy were performed. Polarization curves of the base metal and weld metal are examined at different torch pitch (25,30 and 35 mm).Corrosion rates for the DSS welds also examined and demonstrated the potential of using dual torch plasma welds to improve weldability of duplex stain less steels.

VI. COMPARISON BETWEEN THE OPTIMIZATION TECHNIQUES

Derived from the above literature review some insight has been gained into the use of DoE, ANN, Dual torch technique, Taguchi method and other techniques for modelling and optimizing different welding processes on DSS. It was noted that Taguchi performs better than other techniques, especially ANN and RSM, when a large number of experiments are not affordable. The trend in the modelling using Taguchi method has a low order non-linear behavior with a regular experimental domain and relatively small factors region, due to its limitation in building a model to fit the data over an irregular experimental region. This ability is powerful in identifying the insignificant factors main effect, insignificant interactions or insignificant quadratic terms in the model and thereby can reduce the complexity of the problem. On the other hand, this technique required good definition of ranges for each factor to ensure that the response(s) under consideration is changing in a regular manner within this range.

The Taguchi method is one of the powerful optimization techniques comparing with RSM, ANN and Dual torch technique which characterize with improving the product quality and reliability at low cost. However, RMS analysis approach of SN may lead to non-optimal solutions, less flexibility and the conduction of needless experiments.

2.10 Comparison between RSM and ANNs Techniques.

Table 1

Comparison	Technique	
	ANNs	RSM
Time taken	long	Medium
Experimental domain	irregular	Irregular
Understanding	Difficult	Moderate
Optimization	Through model	Straight
Availability in software	Available	Available
Application	Rarely	Rarely

2.11 Comparison between Taguchi and Dual torch Techniques.

Table 2

Comparison	Technique	
	Taguchi	Dual torch
Time taken	Short	Long
Experimental domain	Regular	Regular
Understanding	Normal	Easy
Optimization	Through model	Straight
Availability in software	Available	Available
Application	Frequently	Not frequently

Table 1 and Table 2presents a comparison between the above mentioned common modelling /optimizing methods based on this literature review.

VII. CONCLUSION

1) In this paper the characteristics of duplex stainless steel and their mechanical behaviors, phase transformation from ferrite to austenite and their limitation, advantages in base metal as well as in weld metal was examined. Different welding process on DSS was proposed and it found that the overall phase transformation rate is fastest when the starting structure is uniform and non uniform starting structure delays the completion of the transformation.
2. An explanation for the difference in heat treatment process and their effort on DSS weldments was proposed based on (TEM) analysis, (SEM-EDS) analysis. The effort of nitrogen, aging, hydrogen-enhancing on DSS weld were examined and investigate the pitting resistance equivalent number (PREN).By performing heat treatment process-phase in the weld metal and in the HAZ is increases which promotes weldability.
3. This study systematically investigate the effects of different fluxes on surface appearance, weld morphology, ferrite/austenite content and mechanical properties of duplex stainless steel after performing different experimental methods with varying chemical composition for base metal and feller metal. It was found that the optimal mechanical properties were obtained when precipitation of sigma and the γ-to-δ ferrite transformation are suppressed i.e. at 1050^0C and 8.9% Ni electrode showed better performance.
4. The optimization method covered in this literature survey is appropriate for selecting design of experiment, control and optimizing the different welding process. The survey reveals that the adoption of RSM, ANNs, Taguchi and a Dual-torch technique on DSS was proposed. Generally there is a lack of comparative study regarding the performance of the optimization method. It was found that the Taguchi method is one of the powerful technique which characterize with improving the product quality and reliability at low cost. Combining two optimization techniques, such as RSM and Taguchi on Duplex stainless steel (DSS) would reveal good results for finding out the optimal welding conditions .Future work should focus on the application of these optimization techniques to find best optimal welding process for DSS, at which the process could be consider safe and economical.

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