International Journal of Scientific & Engineering Research, Volume 5, Issue 1, January-2014 1612
ISSN 2229-5518

Research on Gas Tungsten Arc Welding of Stainless Steel – An Overview

D.Devakumar, D. B Jabaraj

Abstract— Gas Tungsten Arc welding (GTAW) or Tungsten Inert Gas (TIG) is an electric arc welding process, which produces an arc between a non-consumable tungsten electrode and the work to be welded. TIG is used very commonly in areas, such as rail car manufacturing, automotive and chemical industries. Stainless steel is extensively used in industries as an important material, because of its excellent corrosion resistance. TIG welding is one of the welding processes, often used to weld similar and dissimilar stainless steel joints. In this paper, an attempt is made to review and consolidate the important research works done on GTAW of stainless steel in the past, by various researchers. It has been observed, that most of the works done, is on austenitic stainless steel, which is the most widely used type of stainless steel in the world. Major areas of research have been in characterization of weld, dissimilar metal welding, parameter optimization, process modeling, failure analysis and automation of TIG welding process. This paper is aimed at, to give a brief idea about the research works done in the past, on TIG welding of stainless steel by various researchers, by highlighting the important conclusions and results arrived at and thereby providing the right direction for fresh researchers for future research in this particular area.

Key words—Gas Tungsten Arc Welding, Dissimilar metal welding ,Stainless steel, Tungsten inert gas welding, Mechanical properties, Microstructure, optimization.

1. INTRODUCTION

GTAW 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. By means of a gas nozzle the shielding gas is lead to the welding zone where it replaces the atmospheric air. TIG welding differs from the other arc welding processes by the fact that the electrode is not consumed like the electrodes in other processes such as MIG / MAG and MM.

Stainless steel 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. Stainless steel 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 (according to European Standard EN 10088) 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 passive layer is self-healing, and therefore chemical or mechanical damages to it repassivate in oxidizing environments [1, 2]. Stainless steel has been widely used for rail vehicle body shell design for many years owing to its corrosion resistance, low life-cycle cost, high strength-to-weight ratio and fire resistance [3].

2. GAS TUNGSTEN ARC WELDING OF STAINLESS STEEL

GTAW is most commonly used to weld thin sections of stainless steel and non-ferrous metals such as aluminum, magnesium, and copper alloys. The process grants the operator greater control over the weld than competing processes such as shielded metal arc welding and gas metal arc welding, allowing for stronger, higher quality welds. Stainless steels have become increasingly attractive, to a number of industry sectors, due to their superior mechanical properties and corrosion characteristics relative to other structural steels. In this paper an attempt is made to consolidate and highlight the results obtained by various researchers on TIG of stainless steel in the past. The research works done in the past, on TIG welding of stainless steel can be grouped, broadly in to the following categories. They are,

1. Characterization of weld
2. Dissimilar metal welding
3. Parameter optimization

2.1. CHARACTERIZATION OF WELD

Many research works have been done on characterization of TIG welded stainless steel joints in the past. Researchers focused mainly on the properties of microstructure, mechanical properties and the effect of various input parameters on weld quality.

HalilIbrahim et al. [4] studied microstructure and mechanical properties of AISI 304 austenitic stainless steels, welded by TIG welding, using 308 grade filler metal. Microstructures of base metal, heat affected zone and weld metal were studied with microscopy. They reported, observing chromium carbide precipitation and dendrite structure in weld metal.

EslamRanjbarnodeh et al. [5] studied the microstructural characteristics of tungsten inert gas (TIG) welded AISI 409 ferritic stainless steel and effect of the welding parameters on grain size local misorientation and low angle grain boundaries were investigated. They concluded that the welding plastic strain is an increasing factor for local misorientation and low angle grain boundaries. It shows that the final state of strain is the result of the competition between welding plastic strains and stress relieving from recrystallization.

E.TABAN et al. [6] investigated the microstructural and toughness properties and mechanical properties of the gas metal arc welded 6 mm thick modified X2CrNi12 SS with two different heat input and concluded that the grain size has dominant effect on impact toughness. Grain coarsening has no adverse influence either on tensile properties or on a bend properties but the heat affected zone impact toughness for sub-zero temperature generally decreases and this depends on the amount of grain coarsened microstructure and eventual precipitates present.

A.K.Lakshminarayanan et al. [7] studied the effect of welding processes such as shielded metal arc welding, gas metal arc welding and gas tungsten arc welding on Tensile and Impact properties of the ferritic stainless steel confirming to AISI 409M grade. From this investigation it is found that gas tungsten arc welded joints of ferritic stainless steel have superior tensile and impact properties compared with shielded metal arc and gas metal arc welded joints and this mainly due to the presence of finer grains in fusion zone and heat affected zone.

WichanChuaiphan et al. [8] investigated the Effect of Welding speed on microstructures, mechanical properties and corrosion behavior of GTA welded AISI 201 stainless steel sheets. Three welding speeds designated as low (1.5mm/s), medium (2.5mm/s) and high (3.5mm/s) were operated during gas tungsten arc welding process and joints made were subjected to analysis. They concluded that the joints made using the high welding speed exhibited smaller weld bead size, higher tensile strength and elongation, higher hardness and higher pitting corrosion potentials than those welded with medium and low welding speeds.

Kuang-Hung Tseng et al. [9] investigated about "Performance of activated TIG process in austenitic stainless steel welds". An autogenous TIG welding was applied to 6mm thick stainless steel plates through a thin layer of flux to produce a bead on plate welded joint. The oxide fluxes used were packed in powdered form. The experimental results indicated that the Sio2 flux facilitated root pass joint penetration but Al2o3 flux led to the deterioration in the weld depth and bead width compared with conventional TIG process.

A.VinothJebaraj et al. [10] has studied Influence of microstructural changes on impact toughness of weldment and base metal of duplex stainless steel AISI 2205 for low temperature applications.DSS weld joints were fabricated using gas tungsten arc welding process with controlled welding parameters. Ferrite austenite ratio in the weld zone, heat affected zone and base metal was assessed by quantitative metallographic image analysis. The impact test results were correlated with the fractured surface and the microscope of the tested specimen.

J.j.del Coz Diaz et al. [11] studied "Comparative analysis of TIG welding distortions between austenite and duplex stainless steels by FEM. In this study, thermal stress analyses were performed in the tungsten inert gas welding process of two different stainless steel specimens in order to compare their distortion mode and magnitude. The growing presence of nonconventional stainless steel species like duplex family generates uncertainty about how their material properties could be affected under the welding process.

Kuang-Hung Tseng et al. [12] investigated on Development and application of oxide-based flux powder for tungsten inert gas welding of austenitic stainless steels. The experiment reported in this study involved using a new activated flux developed by the National Pingtung University of science and Technology to systematically investigate the influence of oxide based flux powder and carrier solvent composition on the surface appearance, geometric shape, angular distortion and ferrite content of austenitic 316L stainless steel tungsten inert gas welds.

G.R.Mirshekari et al. [13] investigated on "Microstructure and corrosion behavior of multipass gas tungsten arc welded 304L stainless steel. The purpose of this study is to discuss the effect of single pass and multipass gas tungsten arc welding on microstructure, hardness and corrosion behavior of 304L stainless steel. They concluded that the microstructure of fusion zones exhibited dendritic structure contained lathy and skeletal ferrite.

Subodh kumar et al. [14] Investigated the "Effect of heat input on the microstructure and mechanical properties of gas tungsten arc welded AISI 304 stainless steel joints. Three heat input combinations designated as low heat, medium heat and high heat were selected from the operating window of the GTAW process and weld joints made using these combinations were subjected to microstructural evaluations and tensile testing so as to analyze the effect of thermal arc energy on the microstructure and mechanical properties of these joints.

Tsann-ShyiChern et al. [15] has Studied characteristics of duplex stainless steel activated tungsten insert gas welds. The purpose of this study is to investigate the effects of the specific fluxes used in the tungsten inert gas process on surface appearance, weld morphology, angular distortion, mechanical properties and microstructures when welding 6mm thick duplex stainless steel. The activated TIG process can increase the joint penetration and the weld depth to width ratio and tends to reduce the angular distortion of grade 2205 stainless steel weldment.

A-H.I.Mourad et al. [16] investigated on Gas tungsten arc and laser beam welding processes effects on duplex stainless steel 2205 properties. A comparative study on the influence of gas tungsten arc welding and carbon dioxide laser beam welding processes on the size and microstructure of fusion zone, mechanical and corrosion properties of duplex stainless steel DSS grade 2205 plates of 6.4mm thickness was investigated. The ferrite-austenite balance of both weld metal and heat affected zone are influenced by heat input which is a function of welding process.

K.Shanmugam et al. [17] has studied "Effect of weld metal properties on fatigue crack growth behavior of GTAW welded AISI 409M grade ferritic stainless steel joints. The effect of filer metals such as austenitic stainless steel, ferritic stainless steel and duplex stainless steel on fatigue crack growth behavior of the gas tungsten arc welded ferritic stainless steel joints were investigated. From this investigation, it was found that the joints fabricated by duplex stainless steel filler metal showed superior fatigue crack growth resistance compared to the joints fabricated by austenitic and ferritic stainless steel filler metals.

M.O.H.Anuda et al. [18] investigated the effects by producing the welds on a 1.5mm thick plate of 16 wt% Cr FSS conforming to AISI 430 commercial grade, using TIG torch in argon environment at a heat flux between 1008W to 1584W and speed between 2.5mm/s and 3.5mm/s and concluded that, the width of the sensitization zone increases with increasing the heat input. The depth of the sensitization zone in the thickness direction is insignificant and it is generally within one half of a millimeter.

Du Toit M et al. [19] investigated the susceptibility of 12% chromium type 1.4003 ferritic stainless steel to heat affected zone sensitization and intergranular stress corrosion cracking and concluded that sensitization may lead to intergranular pitting and stress corrosion cracking within the heat -affected zone on exposure to a corrosive environment. Four distinct modes were identified.

M Yousefieh et al. [20] has studied Influence of heat input in pulsed current TIG welding process of Duplex Stainless Steel. The best general properties are obtained with approximately equal amounts of austenite and ferrite and the absence of third phases such as σ (sigma) and Cr2 N. In this work the effect of heat input variations on the microstructure and corrosion resistance of a DSS UNS S32760 in artificial sea water media were studied.

K.N. Krishnan et al. [21] studied the Effect of microstructure on stress corrosion cracking behavior of austenitic stainless steel weld metals. Austenitic stainless steel welds with different ferrite contents were produced using the submerged arc welding (SAW) strip-cladding process. The results revealed that when the ferrite network was discontinuous or globularized due to heat treatment, the SCC resistance was better than when the network was continuous. Welds deposited by the low heat input (GTAW) process showed better SCC resistance than their SAW counterparts because they had a finer ferrite network. The overall cracking was due to SCC in austenite and anodic dissolution of ferrite.

M.L.Greeef et al. [22] investigated the susceptibility of 11-12% chromium type EN 1.4003 ferritic stainless steel to sensitization during continuous cooling after welding at low heat input levels. It concluded that sensitization of type En 1.4003 ferritic stainless steel during continuous cooling after welding is possible if low heat input levels are used

E. Bayraktar et al. [23] analyzed the characterization of base metal and welded parts by hardness, Erichsen and impact tensile tests (ITT) of Ferritic Stainless steel based on the TIG and observed that the transition temperature and deep draw ability can be used for evaluating of the welding conditions and also of the material characteristics.

2.2 DISSIMILAR METAL WELDING

Despite the widespread application of dissimilar metal joining, there is a history of weld-related failures associated with dissimilar joints. Hence more focus to be given in order to eliminate the defects during welding process.

Shaogang Wang et al. [24] investigated on Characterization of microstructure, mechanical properties and corrosion resistance of dissimilar welded joint between 2205 duplex stainless steel and 16MnR. Mechanical properties of joints welded by the two kinds of welding technology are satisfied. However, the corrosion resistance of the weldment produced by GTAW is superior to that by SMAW in chloride solution. They concluded that GTAW is the suitable welding process for joining dissimilar metals between 2205 duplex stainless steel and 16MnR

N. Arivazhagan et al. [25] investigated on AISI 304 austenitic stainless steel to AISI 4140 low alloy steel dissimilar joints by gas tungsten arc, electron beam and friction welding. The results of the analysis shows that the joint made by EBW has the highest tensile strength (681 MPa) than the joint made by GTAW (635 Mpa) and FRW (494 Mpa). Moreover, the impact strength of weldment made by GTAW is higher compared to EBW and FRW.

Chih-Chun Hsieh et al. [26] studied Precipitation and strengthening behavior of massive δ-ferrite in dissimilar stainless steels during massive phase transformation. The purpose of this study is to discuss the micro structural evolution and mechanical property of the weld metal in the dissimilar stainless steels during the gas tungsten arc welding (GTAW) process. The massive precipitates and austenite phases were observed in the weld metal during the dissimilar stainless steels welding process.

Andrés L García Fuentes et al. [27] investigated Crack growth study of dissimilar steels (Stainless - Structural) butt-welded unions under cyclic loads. The research shows the study of the mechanisms of emergence and propagation of fatigue cracks caused by mechanical tension stress fluctuations in dissimilar steels butt-welded joints. Results showed a proper mechanical steel behavior under cyclic loads, in spite of showed high values of micro hardness, mainly in the fusion line between the welding and 304L stainless steel, as well inclusions between the structural and the stainless one.

Martin Nicholas et al. [28] investigated the subject of sensitization in unstabilized ferritic /martensitic dual phase 11-14% Cr steel in some detail after a number of failures in service due to accelerated corrosion and concluded that sensitization could occur due to a number of different mechanisms which were dependent on the heat treatment, no of thermal cycles and phases present in the material. All the detected modes of sensitization could be prevented by stabilization with titanium or niobium and suitable design of the material composition to produce a suitably high ferrite factor.

N.Arivazhagan et al. [29] studied "Investigation on AISI 304 austenitic stainless steel to AISI 4140 low alloy steel dissimilar joints by gas tungsten arc, Electron beam and Friction welding. For each of the weldments, detailed analysis was conducted on the phase composition, microstructure characteristics and mechanical properties. The results of the analysis shows that the joint made by EBW has the highest tensile strength than the joint made by GTAW and FRW.

Chih-Chun Hsieh et al. [30] investigated on "Precipitation and strengthening behavior of massive ferrite in dissimilar stainless steels during massive phase transformation". The purpose of this study is to discuss about the micro structural evolution and mechanical property of the weld metal in the dissimilar stainless steels during the GTAW process. The amounts of ferrite in the stainless steels weld metal also maintained a higher value after dissimilar welding.

2.3 Optimization of different welding processes using statistical and numerical approaches

In order to obtain high welding strength, Process parameter optimization plays an important role in welding process by identifying optimum process parameters and also helps to reduce the no of trails.

S.P.Gadewar et al. [31] investigated the effect of process parameters of TIG welding like weld current, gas flow rate, work piece thickness on the bead geometry of SS304. It was found that the process parameters considered affected the mechanical properties with great extent.

N.Lenin et al. [32] optimized the welding input process parameters for obtaining greater welding strength in manual metal arc welding of dissimilar metals. The higher-the-better quality characteristic was considered in the weld strength prediction. Taguchi method was used to analyze the effect of each welding process parameters and optimal process parameters were obtained.

K.Kishore et al. [33] analyzed the effect of process parameters for welding of AA 6351 using TIG welding. Several control factors were found to predominantly influence weld quality. The % contributions from each parameter were computed through which optimal parameters were identified. ANOVA method was used to check the adequacy of data obtained. The experiment revealed that low current values have created lack of penetration and high travel speed has caused lack of fusion in welding AA6351.

UgurEsme et al. [34] investigated the multi response optimization of TIG welding process to yield favorable bead geometry using Taguchi method and Grey relation analysis. The significance of the factors on overall quality characteristics of the weldment has been evaluated quantitatively by ANOVA. The experimental result shows that the tensile load, HAZ, area of penetration, bead width, and bead height are greatly improved by using grey relation analysis in combination with Taguchi method.

T.Senthil Kumar et al. [35] has studied the effect of pulsed TIG welding parameters and pitting corrosion potential of aluminum alloys. ANOVA method was used to find significant parameters and regression analysis has been used to develop the mathematical model to determine the pitting corrosion potential. It was found that peak current and pulse frequency have direct proportional relationship, while base current and pulse-on-time have inverse proportional relationship with the pitting corrosion resistance.

M.Yousefieh et al. [36] studied "Optimization of the pulsed current gas tungsten arc welding parameters for corrosion resistance of super duplex stainless steel welds using Taguchi method. In this present work, a design of experiment (DOE) technique, the Taguchi method, has been used to optimize the pulsed current gas tungsten arc welding parameters for the corrosion resistance of super duplex stainless steel welds. The optimum conditions were found as the second level of pulse current, second level of background current, third level of % on time and third level of pulse frequency

Ahmed Khalid Hussain et al. [37] has studied the influence of welding speed on tensile strength on welded joints in GTAW process of aluminum alloys. Experiments were conducted on specimens of single V butt joint having different bevel angles and bevel heights. The experimental result shows that depth of penetration of weld bead decreases with increase in bevel height. The tensile strength increased with lower weld speed and decreasing heat input rate. It was also found that bevel angle of the weld joint has profound effect on the tensile strength.

L.Suresh Kumar et al. [38] discussed the mechanical properties of austenitic stainless steel AISI 304 and 316 and found out the characteristics of welded metals using TIG & MIG welding process. Voltage was taken constant and various characteristics such as strength, hardness, ductility, grain structure, HAZ were observed in two processes, analyzed and finally concluded.

FarhadKolahan et al. [39] established input-output relationships for metal active gas welding for gas pipelines. Regression analysis was performed on data collected as per Taguchi design of experiments. Data adequacy was verified using ANOVA method.

S.Kumanan et al. [40] determined submerged arc welding process parameters using Taguchi method and regression analysis. The % contribution of each factor is validated by analysis of variance method. The planned experiments were conducted in the semi-automatic submerged arc welding machine and SN ratios are computed to determine the optimum parameters.

P.Atanda et al. [41] conducted sensitization study of normalized 316L stainless steel. The work was concerned with the study of the sensitization and desensitization of 316L steel at the normalizing temperatures of 750-950°C and soaking times of 05, 1, 2 and 8 hours.

A.K.Lakshminarayanan et al. [42] used two different methods, response surface methodology and artificial neutral network to predict the tensile strength of friction stir welded AA7039 aluminum alloy. Sensitivity analysis was carried out to identify critical parameters. The results obtained through response surface methodology were compared with those through artificial neutral network

A.M.Torbati et al. [43] has optimized a combination of current Intensity, welding speed, electrode angle and shielding gas parameters for better penetration and free from inner layer defects of duplex steel joints by Gas tungsten arc welding (GTAW).

Jose Maria Gomez de Salazar et al. [44] has studied the optimal content of N2 in the shield gas for MIG welding of duplex steel by examining their microstructure and mechanical properties.

R.B.Bhatt et al. [45] has investigated how the effect of nitrogen addition in shield gas of gas tungsten arc welding(GTAW) of Duplex steel and how it alters the micro structure properties like austenite-ferrite ratio and distribution of alloying elements were studied.

P.Sathiya et al. [46] has investigated the effect of shielding gases in gas tungsten arc welding on mechanical and metallurgical properties of Duplex Stainless Steel.

Huei-Sen Wang et al.[47]has investigated the influence of welding variables -wire feeding techniques, wire feeding rates and heat inputs on the cooling rate and heat affected zone (HAZ) areas of multi-pass weldments in a super duplex stainless steel. Microstructure analysis is done for the same.

3. CONCLUSION

In the foregoing sections, many of the research works carried out on TIG welding of stainless steel in the past, have been presented. Several aspects of Microstructure and corrosion resistance properties, dissimilar metal welding and Optimization of different welding processes using statistical and numerical approaches have been highlighted. Some of the important results are mentioned below.

1. It is recommended that low heat input should be preferred when welding AISI 304 stainless steel using GTAW process because of the reason that besides giving good tensile strength and ductility, the size of the HAZ and the extent of grain coarsening obtained in the weld joint is less.
2. Hardness is lower in the HAZ region compared to the weld metal and base metal regions irrespective of welding technique.
3. Joints fabricated by GTAW process exhibited higher impact strength values and the enhancement in strength value is approximately 10% compared to SMAW joints and 20% compared to GMAW joints.
4. Bowing distortion increases with increase in current due to widening of the bead width and decreases with increase in joint penetration.
5. The yield strength of dissimilar weldment made by EBW is higher as compared to GTAW and FRW.
6. The massive transformation from austenite to ferrite was observed in the dissimilar stainless steel weld metals.
7. The finite element method including the birth and death technique is an efficient procedure to analyze the vertical displacement evolution at different plate locations in the welding process of stainless steels, as well as their angular deformation and longitudinal bending
8. The hardness of weld metal is lower than that of base metal by all the joints and it is also observed that the hardness values of weld metals increase with welding speed increase.

It can be seen that most of the research works done to study metallurgical properties of various types of stainless steel on GTAW process. Varieties of stainless steel also finding more and more applications in rail, automobiles, and chemical industries, in depth studies of TIG welding of those varieties on different aspects mentioned above, assumes a lot of significance.

REFERENCES:

1. G.Thakur and V.M Nandedkar,2010,Application of Taguchi method to determine resistance spot welding conditions of austenitic stainless steel AISI 304,Journal of Scientific & Industrial Research, Vol 69,Sep 2010,pp 680-683.
2. Flavio Friesen and Pierre-Jean Cunat, "Application of Stainless Steel in Crash Structures of Vehicles," in proceedings from 2004 SAE World Congress, sponsored by SAE International, Detroit, March 8-11, 2004. International Stainless Steel Forum,SAE International™, 400 Common-wealth Drive, Warrendale, PA 15096, 724-776-4841, fax 724-776-5760
3. R. A.Smith ,Advanced Railway research Centre, The University of Sheffield, UK,"Impact performance of model spot welded stainless steel structures",Experimental Mechanics, Allison (ed.) © 1998 Balkema, Rotterdam, ISBN 90 5809 014 0
4. Study on Microstructure, Tensile Test and Hardness 304 Stainless Steel Jointed by TIG Welding - International Journal of Science and Technology Volume 2 No. 2, February, 2013 Halil Ibrahim

5. EslamRanjbarnodeh, 2010, "Investigation of the Effect of Welding Parameters on HAZ of AISI 409 Using EBSD", Journal of Material Science Vol.2, No. 1, 46-53.
6. E. Taban, E. Deleu, A. Dhooge,E. Kaluc. 2007, "Gas metal arc welding of modified X2CrNi12 ferritic stainless steel" Published in Kovove Mater.p.67-74.
7. A K Lakshminarayanan, K Shanmugam, V Balasubramanian.2009 "Effect of Welding Processes on Tensile and Impact Properties, Hardness and Microstructure of AISI 409M FSS Fabricated by Duplex Stainless Steel Filler Metal" journal of iron and steel research, international.p.66-72
8. WichanChuaiphan,LoeshpahnSrijaroenpramong."Effect of welding speed on microstructures,mechanical properties and corrosion behavior of GTA welded AISI 201 stainless steel sheets"Journal of Materials Processing technology 214 (2013) 402-408
9. Kuang-Hung Tseng,Chih-Yu Hsu."Performance of activated TIG process in austenitic stainless steel welds.Journal of Materials processing Technology 211(2011) 503-512
10. A.VinothJebaraj,L.Ajaykumar"Influence of microstructural changes on impact toughness of weldment and base meal of duplex stainless steel AISI 2205 for low temperature applications.Procedia Engineering 64 (2013) 456-466
11. J.J.del Coz Diaz, P.Menendez Rodriguez, P.J.Garcia Nieto, D.Castro-Fresno."Comparative analysis of TIG welding distortions between austenitic and duplex stainless steels by FEM". Applied Thermal Engineering 30(2010) 2448-2459
12. Kuang-Hung Tseng.'Development and application of oxide-based flux powder for tungsten inert gas welding of

austenitic stainless steels. Powder technology 233 (2013) 72-79
13.G.R.Mirshekari,E.Tavakoli,M.Atapour, B.Sadeghian."Microstructure and corrosion behavior of multipass gas tungsten arc welded 304L stainless steel".Materials and design 55 (2014)905-911

14. Subodh Kumar,A.S.Shahi."Effect of heat input on the microstructure and mechanical properties gas tungsten arc welded AISI 304 stainless steel joints'.Materials and design 32 (2011) 3617-3623

15. Tsann-ShyiChern,Kuang-Hung Tseng,Hsien-Lung Tsai."Study of the characteristics of duplex stainless steel activated tungsten inert gas welds. Materials and design 32 (2011) 255-263

16. A-H.I.Mourad,A.Khourshid.T.Sharef. "Gas Tungsten arc and laser beam welding processes effects on duplex stainless steel 2205 properties'.Material science and Engineering A 549 (2012) 105-113

17.K.Shanmugam,A.K.Lakshiminarayanan,V.Balasubramanian."Effect of weld metal properties on fatigue crack growth behavior of gas tungsten arc weded AISI 409M grade ferritic stainless steel'.International journal of pressure vessels and piping 86 (2009) 517-524.

18. M.O.H.Anuda; S. Mridha., 2011 "Analysis of sensitization profile in Medium Chromium Ferritic stainless steel (FSS) welds"Journal of Integrated Engineering,Vol. 3 No1 p.17-22.

19. Du Toit; M,VanRooyen G.T., Smith D. Nov.2006, "An overview of the heat-affected zone sensitization and stress corrosion cracking behavior of 12% chromium type 1.4003 ferritic stainless steel",Published in IIW Doc IX-2213

20. Influence of Heat Input in Pulsed Current GTAW Process on Microstructure and Corrosion Resistance of Duplex Stainless Steel Welds Original Research Article Journal of Iron and Steel Research, International, Volume 18, Issue 9, September 2011,Page 65-69 M Yousefieh, M Shamanian, A Saatchi

21. Effect of microstructure on stress corrosion cracking behavior of austenitic stainless steel weld metals Original Research Article Materials Science and Engineering: A, Volume 142, Issue 1, 15 August 1991, Pages 79-85 K.N. Krishnan, K. Prasad Rao

22. M.L.Greeef.,M. du Toit.2004, "Looking at the Sensitization of 11–12% Chromium EN 1.4003 Stainless Steels during Welding", welding journal. P.243-251

23. E. Bayraktar; 2004 "Effect of welding conditions on the formability characteristics of thin sheet steels: mechanical and metallurgical effects",International conference Achievements in mechanical and materials engineering

24. Characterization of microstructure, mechanical properties and corrosion resistance of dissimilar welded joint between 2205 duplex stainless steel and 16MnR Original Research Article Materials & Design, Volume 32, Issue 2, February 2011, Pages831-8 Shaogang Wang, Qihui Ma, Yan Li

25. Investigation on AISI 304 austenitic stainless steel to AISI 4140 low alloy steel dissimilar joints by gas tungsten arc, electron beam and friction welding Materials & Design, Volume 32, Issue 5, May 2011, Pages 3036-3050 N. Arivazhagan, Surendra Singh, Satya Prakash, G.M. Reddy

26. Precipitation and strengthening behavior of massive δ-ferrite in dissimilar stainless steels during massive phase transformation Original Research Article Materials Science and Engineering: A, Volume 477, Issues 1–2, 25 March 2008, Pages 328-333 Chih-Chun Hsieh, Dong-Yih Lin, Ming-Che Chen, Weite Wu

27. Crack growth study of dissimilar steels (Stainless - Structural) butt-welded unions under cyclic loads Original Research ArticleProcedia Engineering, Volume 10, 2011, Pages 1917-1923 Andrés L García Fuentes, Rafael Salas, LeiryCenteno, AlbertoVelásquezdel Rosario

28. Martin Nicholas Van Warmelo,2006. Thesis on "Susceptibility of 12% cr Steel to sensitization during welding of thick guage plate" Research online p.1-14.

29. N.Arivazhagan,SurendraSingh,SatyaPrakash,G.M. Reddy."Investigation on AISI 304 austenitic stainless steel to AISI 4140 low alloy steel dissimilar joints by gas tungsten arc,electron beam and friction welding'.Materials and design 32 (2011) 3036-3050

30. .Chih-Chun Hsieh,Dong-Yihlin,Ming-CheChen,WeiteWu."Precipitation and strengthening behavior of massive ferrite in dissimilar stainless steels during massive phase transformation'. Materials science and Engineering A 477 (2008) 328-333.

31. S.P.Gadewar, PeravliSwaminadhan, M.G.Harkare, S.H.Gawande, "Experimental investigation of weld characteristics for a single pass TIG welding with SS304", International Journal of Engineering Science and Technology, Vol. 2(8), 2010, 3676-3686.

32. Lenin N., Sivakumar M., Vigneshkumar.D, "Process parameter optimization in ARC welding of dissimilar metals", ThammasatInt.J.Sc. Tech, Vol.15, No.3, 2010.

33. K.Kishore, P.V.Gopal Krishna, K.Veladri, G.Kiran Kumar, "Analysis of defects in Gas Shielded Arc welding of AA 6351 using Taguchi methods", International Journal of Applied Engineering Research, Vol.5, pp.393-399, 2010.

34.UgurEsme, MelihBayramoglu, YugutKazancoglu, SuedaOzgun, "Optimization of weld bead geometry in TIG welding process using grey relation analysis and Taguchi method", Materials and technology 43 (2009) 3, 143-149.

35.T.Senthil Kumar, V.Balasubramanian, M.Y.Sanavullah, S.Babu, "Effect of pulsed current TIG welding parameters on pitting corrosion behavior of AA6061 aluminium alloy", Journal of Material Science Technology, Vol.23 No.2, 2007.

36. M.Yousefieh,M.Shamanian,A.Saatchi. ""Optimization of the pulsed current gas tungsten arc welding parameters for corrosion resistance of super duplex stainless steel welds using Taguchi method'. Journal of Alloys and compounds 509 (2011) 782-788

37. Ahmed Khalid Hussain, Abdul Lateef, MohdJaved, Pramesh.T, "Influence of welding speed on tensile strength of welded joint in TIG welding process", International Journal of Applied Engg Research, Vol.1 No.3, 2010.

38. L.Sureshkumar, S.M.Verma, P.Radhakrishna Prasad, P.Kiran Kumar, T.SivaShanker, "Experimental investigation for welding aspects of AISI 304 & 316 by Taguchi technique for the process of TIG & MIG welding", International Journal of Engineering Trends and Technology, Vol.2 issue 2, 2011.

39. FarhadKolahan, Mehdi Heidari, “Modeling and optimization of MAG welding for gas pipelines using regression analysis and simulated annealing algorithm”, Journal of Scientific & Industrial Research, Vol.69, April 2010, pp.259-265.

40. S.Kumanan, J.Edwin Raja Dhas&K.Gowthaman, “Determination of submerged arc welding process parameters using Taguchi method and regression analysis”, Indian Journal of Engineering & Material Sciences Vol.14, June 2007, pp.177-183.

41. P.Atanda, A.Fatudimu, O.Oluwole, “Sensitization study of normalized 316L stainless steel”, Journal of Minerals & Materials Characterization & Engineering, Vol.9, no.1, pp.13-23, 2010.

42. A.K.Lakshminarayanan, V.Balasubramanian, “Comparison of RSM with ANN in predicting tensile strength of FSW of AA7039”, Transactions of Nonferrous metals Society of China, vol.19, 9-18, 2009

43. Torbati, A.M., Miranda, R.M., Quintino, L., Williams, S. “Welding bimetal pipes in duplex stainless steel” ,The International Journal of Advanced Manufacturing Technology, Vol. 53,2011,pp. 1039-1047

44. Jose Maria Gomez de Salazar , Alicia Soria and Maria Isabel Barrena “The effect of N2 addition upon the MIG welding process of duplex steels” ,Journal of Material Science, Vol. 42,2007,pp. 4892-4898

45. Bhatt, R.B., Kamat, H.S., Ghosal S.K., and De, P.K. “ Influence of Nitrogen in the Shielding Gas on Corrosion Resistance of Duplex Stainless Steel Welds” ,Journal of Materials Engineering and Performance, Vol. 8,1999,pp. 591-597

46. Sathiya, P., Aravindan, S., Soundararajan, R. and NoorulHaq, A. “Effect of shielding gases on mechanical and metallurgical properties of duplex stainless-steel welds” ,Journal of Material Science, Vol. 44,2009,pp. 114-121

47. Huei-Sen Wang “Effect of Welding Variables on Cooling Rate and Pitting Corrosion Resistance in Super Duplex Stainless Weldments” ,Materials Transactions, Vol. 46,2003,pp. 593-601

1Department of Mechanical Engineering,
St. Peters University, Avadi, Chennai, India.
dasa_deva1971@yahoo.com
2Dept of Mechanical Engineering, Dr MGR Educational and Research Institute University, Chennai, India
jabaraj2009@yahoo.com