HCTL Open International Journal of Technology Innovations and Research (IJTIR)
http://ijtir.hctl.org
Volume 14, April 2015
e-ISSN: 2321-1814, ISBN (Print): 978-1-62951-946-3

Analysis of the Effect of Sensitization on Austenitic Stainless Steel 304L Welded by GTAW Process

Viranshu Kumar[1], Pradeep Joshi[2],Shivdayal Dhakad[3],Hirendra Shekhar[4] ,Sukhbaj Singh[5],Shailesh Kumar [6]

viranshukumar@gmail.com

Abstract

This paper deals with the effect of sensitization on the metallurgical properties of austenitic stainlesssteel. Austenitic stainless have Nickel and Chromium as basic constituents. It has excellent corrosion resistance properties and very good weldability. Austenitic stainless steels have a tendency to form chromium depleted zones at the grain boundaries during welding and heat treatment, where chromium combines with available carbon in the vicinity of the grain boundaries, to produce an area depleted in chromium, and thus becomes susceptible to intergranular corrosion. Austenitic stainless steel during welding GTAWhave been investigated and concluded that variation in normalize temprature, time and heat input due to welding and heat treatment resulted in significant changes in the mechanical properties of the austenitic stainless steels and due to the effect of sensitization mechanical properties (yield strength, ultimate tensile strength, hardness,Corrosion resistance) of the material will be changed.

Keywords

Mechanical Properties, Metallurgical properties, Sensitization

Introduction

Austenitic stainless steel

Austenitic stainless steels are used in the pressure vessels, chemical, transportation, medical industry due to their superior mechanical properties [1].ASS are chromium nickel alloys with face centered cubic crystal structure having chromium content more than 12 wt%. These steel exhibit good ductility and formability. Austenitic stainless steels are most commonly used due to its corrosion resistance (examples include transportation, chemical) [2].

Sensitization

Sensitization (grain boundary depletion of chromium and precipitation of chromium carbide near or at the grain boundaries) of the weldments is one of the potential problems in the welding of ASS. Sensitization leads to degradation of corrosion resistance as well as the mechanical properties [3, 4].Sensitization refers to the breakdown in corrosion resistance due to depletion of chromium by the formation, growth, and precipitation of chromium rich carbide particles in the grain boundaries where the steel encounters.temperatures in the range of about 450°C to around 850°C, most notably in the HAZ of a weld. In addition to the loss in corrosion resistance due to chromium depletion, weld sensitization also causes a loss of fracture toughness due to the fracture path provided by the complex carbides within and along HAZ grain boundaries. [5]Typically, the Cr carbide is a Cr-enriched M23C6, in which M represents Cr and some small amount of Fe. Within the sensitization temperature range carbon atoms rapidly diffuse to grain boundaries, where they combine with Cr to form Cr carbide. Because of Cr carbide precipitation at the grain boundary, the areas adjacent to the grain boundary are depleted of Cr, as shown schematically in fig. 1[6]

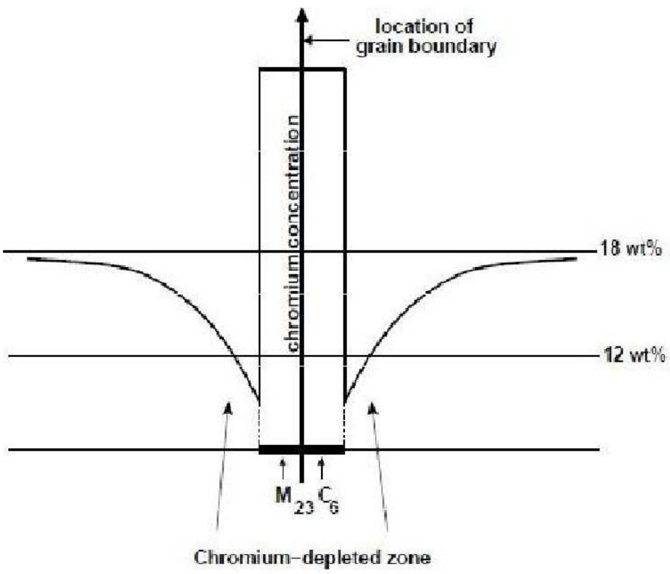


Figure 1: Grain boundary microstructure in sensitized austenitic stainless steel. [7]

Fusion welding

Welding is one of the method of joining processes in the industry and the properties of the weldments is different to the base metal. This may sometimes cause to the failure of the component.

In Fusion welding, heat is generated by an electric arc struck between a metal to be welded and electrode. Fusion welding arei) Gas Tungsten Arc Welding (GTAW), ii) SMAW (Shielded Metal Arc Welding), iii) (GMAW) Gas Metal Arc Welding. This welding is used in all cases, theweld zone is protected by a gas, slag or vacuum, from the atmosphere which is absolutely necessary to achieve high mechanical properties and optimum corrosion resistance of the joint.

HCTL Open International Journal of Technology Innovations and Research (IJTIR)
http://ijtir.hctl.org
Volume 14, April 2015
e-ISSN: 2321-1814, ISBN (Print): 978-1-62951-946-3

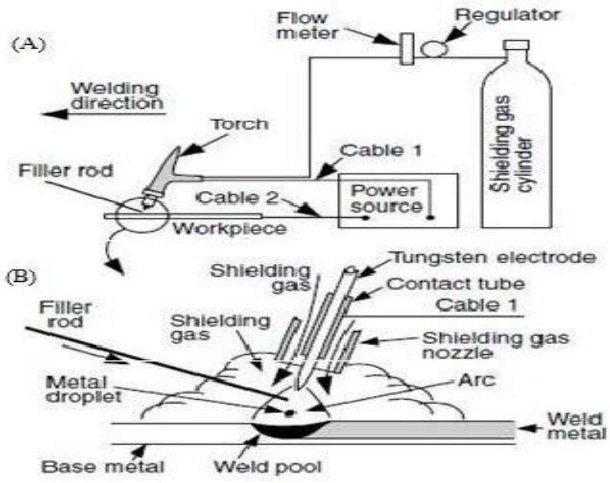


Figure 2: GTAW: (A) overall process, (B) welding area enlarged. [28]

I. MATERIAL AND METHOD

Material

304L stainless steel was obtained from the market for the purpose of this experimentation.

Welding

In this experimental work, the specimen is welded at three different levels of welding parameters i.e. current, voltage and welding speed as shown in Table I.

Table I Welding parameters and their levels

Parameters	**Current (A)**	**voltage (B)**	**Welding speed(C)**	**Heat input**
Unit	Amp	volt	mm/min	kJ/mm
Level 1	130	25	146	5.4
Level 1	160	25	152	6.3
Level 1	190	25	354	3.2

Heat treatment

Normalization heat treatments were performed on the samples with the help of muffle Furness by varying the soaking time and temperature. The following temperatures were used: 750, and 850°C. The different soaking times at these temperatures were 30 mints, 1 hour, and 2 hours.

Mounting and grinding

First, each specimen was grinding and polishing. The grinding of the specimens was done on silicon carbide paper. The silicon carbide papers used in achieving the proper grinding of the specimen were in the following grades 120, 240, 400 and 1000 grits, grinding respectively in that order of grades.

Polishing

The polishing was done on polishing cloth using alumina powder dissolved in water. Light pressure was applied until the surfaces were free of scratches. The sampleswere cleaned, dried and then examined under the microscope, using a magnification between 50 and 100 so as to check whether the samples were free of scratches.

Etching

After polishing, the samples were etched with 5gm of FeCl3 + 10ml of HCl + 50ml of H2O7-12.To etch these specimens, they were washed free of any adhering polishing compound and plunged into the etching solution, agitated vigorously for 7 minutes. After this, the specimens were observed under optical microscope and photomicrographs taken.

Testing

Microstructural studies, tensile and microhardness tests were performed on as welded and sensitized specimens. Firstly, testing was done on as welded samples to find out the welding parameters for further work on sensitization studies and further testing was carried out on sensitized (heat treated) specimens welded at parameters decided after testing of as welded samples.

Tensile Test

It is also called tension test and is used to determine tensile strength of the material when subjected under uniaxial loading. By pulling something, it will be very quickly determined how the material will react of forces being applied in tension. Tensile test helps in determining.

Tensile properties such as tensile strength.

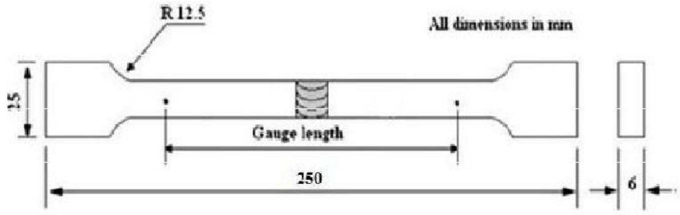


Figure 3:Tensile specimen.

e-ISSN: 2321-1814, ISBN (Print): 978-1-62951-946-3

Specimens for tensile were taken as perpendicular to weld direction. Tensile tests were conducted at Indiana Test, Calibration and Certification Services, Mohali, in accordance with IS 1608:2005. (Metallic materials - Tensile testing at ambient temperature.) Speed of tensile testing was 8 mm/min. The specimens were tested on FIE make Universal Testing Machine, UTE-60, shown in fig. 3.11, it is an electronic type, hydraulically controlled digital tensile testing machine of 600 /KN capacity. Fig. 4 shows the location of fracture of the as welded samples.

Figure 4.. Specimens after welding and tensile test.

Microhardness Measurements

The term microhardness tests usually refer to static indentation made with loads not exceeding 1 kgf. The surface being tested generally requires a metallographic finish; the smaller the load, the higher the surface finish is required. The procedure for microhardness testing is very similar to that of the standard Vickers hardness, except that it is done on a microscopic scale with higher precision instruments. Microhardness measurements were carried out across the HAZ using Vickers hardness testing machine in accordance with IS 1501:2002 (Method for Vickers hardness test for metallic materials) at Sunbeam Auto Pvt. Ltd. Gurgoan.

Microstructural Examination

In order to determine the microstructural changes taking place during welding under different heat input conditions and normalizing, microstructural examination was carried out on the cross section of the base metal, fusion boundary including both HAZ and weld metal and micrographs were captured with the help of optical microscope. Microstructural examinations were performed at Sunbeam Auto Pvt. Ltd. Gurgoan.

Sensitization Treatments

Performance of the samples welded at lowest heat input 3.2 kJ/mm (190 A) was found to be the best when tensile strength, microhardness, microstructure were compared among the welded samples (welded under different heat input conditions) and base metal. Therefore, 190 A current was selected for sensitization studies and one more test coupon of SS 304L, 400 mm long, 125 mm wide and 6 mm thick was prepared by using same parameters and procedure

Six set of samples for mechanical and microstructural studies were extracted from thewelded plate and sensitized by performing the normalized heat treatment by varying the temperature and soaking time. Temperatures used were 750 C and 850 C. The different soaking times at these temperatures were 30 minutes, 60 minutes, and 120 minutes. Samples were sensitized at six different time and temperature combinations.

750^0 C for 30 minutes
750^0 C for 60 minutes
750^0 C for 120 minutes
800^0 C for 30 minutes
800^0 C for 60 minutes
800^0 C for 120 minutes

Heat treatment was done in muffle furnace installed in metallurgy lab of our college. All the 12 specimens (6 tensile specimens + 6 specimens for microstructure and microhardness) extracted from a plate welded at 190 A were normalized by heated at above mention temperature and time followed by cooling in still air. For example : 2 specimens (1 tensile specimen + 1 microstructure and micro hardness) were heated at 750^0 C for 30 minutes and then air cooled and 2 specimens (1 tensile specimen + 1 specimen for microstructure and micro hardness) were heated at 750^0 C for 60 minutes and cooled in air and so on.

Testing after Sensitization

After normalizing samples were subject to same tests which were performed on as welded samples those were tensile test, microhardness and microstructure examination, fig. 4 shows the fractured sensitized tensile specimens. Detail about the testing procedure adopted and equipment used during testing was already mentioned.

Figure 4: Specimens after sensitization and tensile test.

Results and Discussions

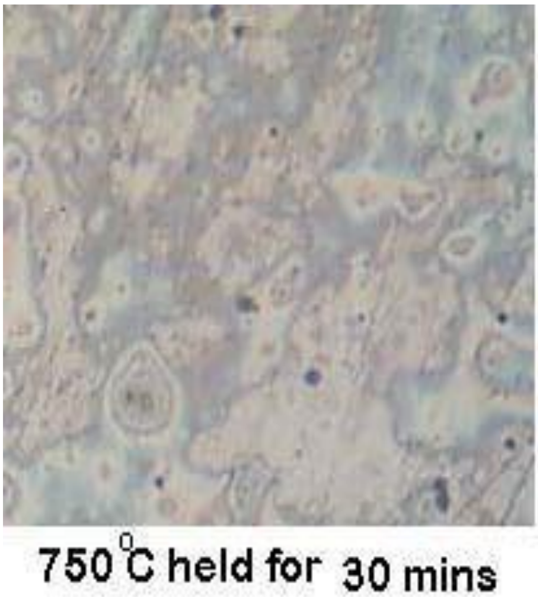
The data collected from the experiments is shown in table below and the form of photomicrographs on the next few pages. Results depict the behaviour of the material towards welding heat input and normalizing conditions.The photomicrographs of the normalized specimens are shown in Figs.5. Figs 5a-c show the photomicrographs of the normalized specimens from 750^0 C each held at the soaking temperature for 30 mins, 1hr and 2hrs respectively.Figs 6a-c show the photomicrographs of the normalized specimens from 800^0 C each held at thesoaking temperature for 30 mins, 1hr and 2hrs respectively.

Table 4.1. Experimental results

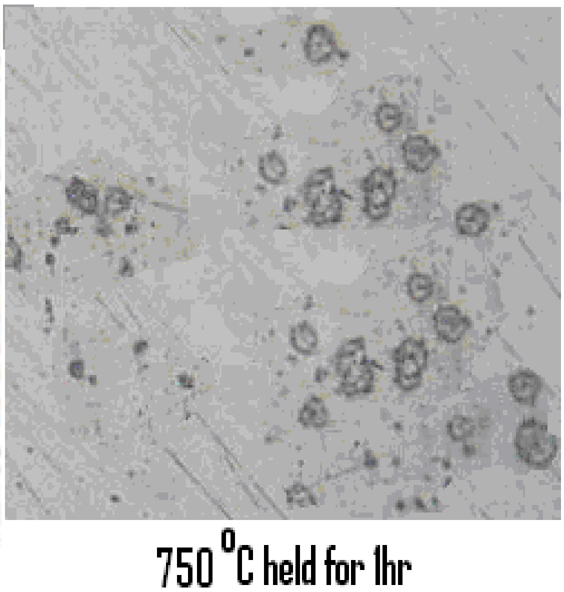
Description	Tensile Strength MPa	Yield Strength MPa	Microhardness HV
Base Metal	582.5	331.5	182
3.2 kJ/mm (190A)	549.216	288.431	193
5.4 kJ/mm (130A)	536.274	304.902	186
6.3 kJ/mm (160A)	544.902	296.471	226
750^0C for 30 min.	549.5	297.25	195
750^0C for 60 min.	551	295	178
750^0C for 120 min.	538.25	285.25	175
800^0C for 30 min.	551.75	303.75	170
800^0C for 60 min.	554.25	282.25	160
800^0C for 120 min.	548.75	281	155

HCTL Open International Journal of Technology Innovations and Research (IJTIR)
http://ijtir.hctl.org
Volume 14, April 2015
e-ISSN: 2321-1814, ISBN (Print): 978-1-62951-946-3

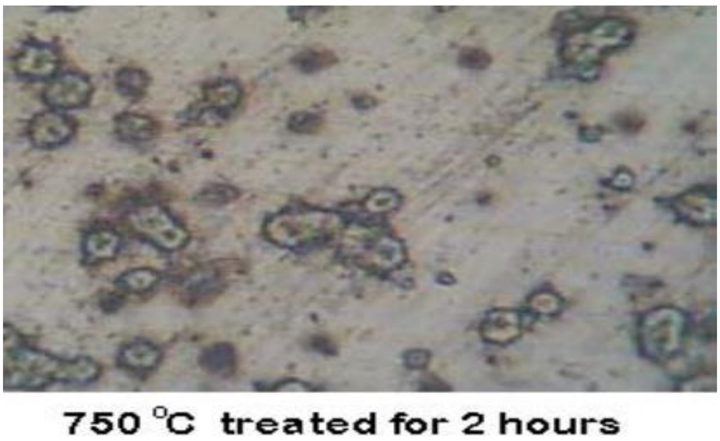
The photomicrographs of the normalized specimens are shown in Figs. 5. Figs 5a-c show the photomicrographs of the normalized specimens from 7500 C each held at the soakingtemperature for 30 mins, 1hr and 2hrs respectively.



(a)



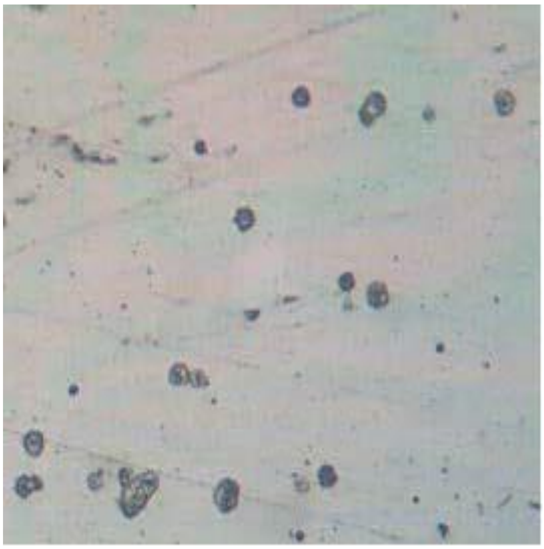
(b)



(c)

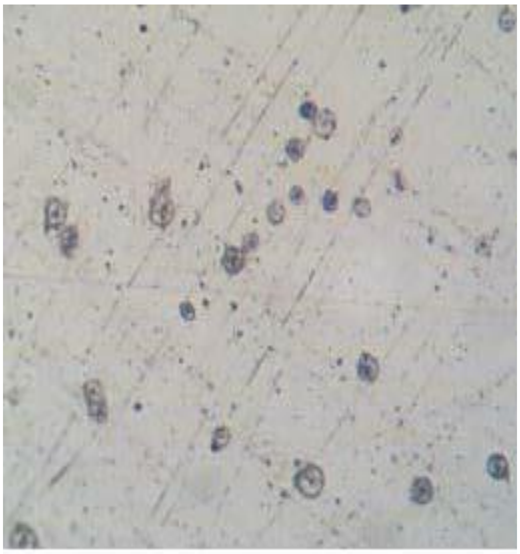
Figures 5. (a) Sample heated to 750 ^{0}C held for 30mins, (b) Sample heated to 750 ^{0}C held for 1hr,(c) Sample heated to 750 ^{0}C held for 2hrs

e-ISSN: 2321-1814, ISBN (Print): 978-1-62951-946-3



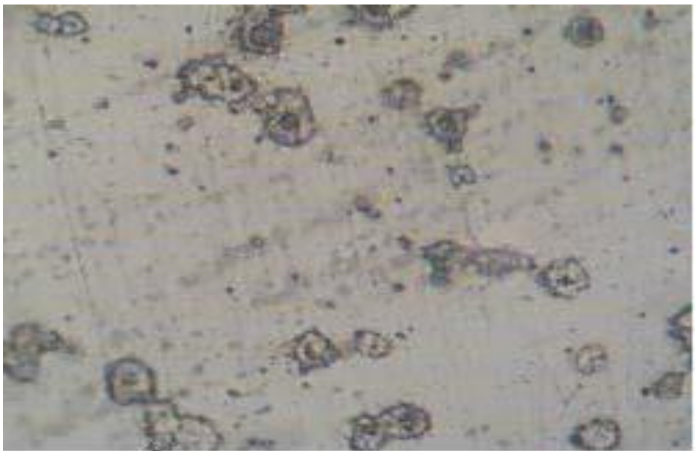
800°C held for 30 mins

(a)



800°C held for 1 hour

(b)



800°C held for 2 hours

(c)

Figures 6. (a) Sample heateed to 800^{0}C held for 30mins, (b) Sample heated to 800^{0}C held for1hr,(c) Sample heated to 800^{0}C held for 2hrs

Conclusion

304L stainless steel was observed to go into sensitization when heated to 750- 800 ^{0}C and held for short soaking times of 0.5 – 2 hrs before normalizing. Sensitization was observed at soaking times of 1 and 2 hrs before normalizing. The hardness of normalized 304L stainless steel was also observed to decrease with soaking time and normalization temperature. The tensile strength of normalized 304L stainless steel was also observed to decrease with soaking time and normalization temperature.

References

[1] ASM Speciality Handbook, Stainless Steels, Welding. Materials Park, OH: ASM International; 1994.

[2] Jong-Hyun Baek, Young-Pyo Kim, Woo-Sik Kim, Kho Young-Tai, "Fracture toughness And fatigue crack growth properties of the base metal and weld metal of a type 304 stainless steel pipeline for LNG transmission int J Press Vessel Pip." 2001;78:351-7.

[3] Lippold JC, Kotecki DJ. Welding metallurgy and weldability of stainless steels. New Jersey: Wiley Interscience; 2005.

[4] Kou S. Welding metallurgy2nd Ed.2003 [New Jersey].

[5] Korinko P.S and Malene S.H. 2001. "Consideration for weldability of type304L and 316L Stainless steel."ASM Int. 4 : 61-68.

[6] Sindou Kou.2003.Welding Metallurgy. 2nd Ed. A John Wiley and Sons, INC. Publication. New Jersey.

[7] Raghuvir Singh, Gautam Das, Singh P.K, Chattoraj I. 2009. "Low temperature The sensitization behavior of base, heat affected zone and weld pool in AISI 304 LN." The Minerals and Material Society and ASM Int. 40A : 1219 1234.

[8] Rahul Unnikrishnan, K.S.N.SatishIdury, T.P. Ismail, AlokBhadauria, S.K. Shekhawat, Rajesh K. Khatirkar, Sanjay G. support, " Effect of heat input on the microstructure, residual stresses and corrosion resistance of 304L austenitic stainless steel weldments. " (2014)10-23.

[9] El GyunNa,"Evaluation of sensitization and corrosive damages of the weldment for 316 stainless steel." (2013)2715- 2719.

[10] Parag M. Ahmedabadi,VivekanandKain, Bhupinder Kumar Dangi, I. Samajdar, "Role of grain boundary nature and residual strain in controlling sensitization of type 304 stainless." Corrosion Science 66 (2013)242– 255.

[11] MohdWarikhAbd Rashid, MironGakim, ZulkifliMohd, Rosli, MohdAsyadi-Azam,A.kermanpur, M.Shamanian, V.Esfahani-Yeganesh,"Formation of Cr23C6 during the Sensitization of AISI 304 Stainless Steel and its Effect to Pitting Corrosion." (2012) 9465-9477 .

[12] Pilar De Tiedra, Óscar Martín, Manuel López, Manuel San-Juan, "Use of EPR test to study the degree of sensitization in resistance spot welding joints of AISI stunts stainless steel Corrosion Science." 53 (2011) 1563–1570.

[13] Subodh Kumar and Shahi A.S. 2011. "Effect of heat input on the microstructure and mechanical properties of gas tungsten arc welded AISI 304 stainless steel joints. Material and Design." 32 : 3617 – 3623.

[14] Atanda P, Fatudimu A and Oluwole O. 2010. "Sensitization study of Normalized 316L Stainless Steel."J Minerals and Materials Characterization and Engg. 9 No.1: 13-23.

[15] K.H. Lo , D. Zeng, C.T. Kwok , "Effects of sensitisation-induced martensitic transformation on the tensile behaviour of 304 austenitic stainless steel." Materials Science and Engineering A 528 (2011) 1003–1007.

[16] Maria de jesus,perezerainalmanzacarlosrodrigomuniz,russell steel, "Analysis of sensitization phenomenon in friction stir welded 304 stainless steel."front.mater. sci. china 2010 4(4):415-419.

[17] Moura,Y.A.Kina,S.S.M.Tavares,M.S.G.de Faria,F.B.Mainier,"Investigation of cracks and sensitization in an AISI 304L stainless steel exposed to 500– 600 LC." Engineering Failure Analysis 16 (2010) 545–551.

[18] Lima A.S,NascimentoA.M,Abreu H.F.G,DeLima-NetoP.2005."Sensitizati- on evaluation of the austenitic stainless steel AISI 304L, 316L, 321 and 347." J Materials Science. 40 : 139-144.

[19] Wasnik D.N, Kain V, Samajdar I, Verlinden B and De P.K. 2003. "Controlling grain boundary energy to make austenitic stainless steel's resistance to intergranular stress corrosion cracking." ASM Int. 12 : 402- 407.

[20] Martin Matula, LudmilaHyspecka, Milan Svobada, VlastimilVodarek, CatherineDegbert, Jacques Galland, ZuzanaStonawska and LudekTuma. 2001. "Inter granular corrosion of AISI 316L steel." Material Characterization. 46: 203-210.

[21] KabSoo Lee, Kyehyun Cho, Tae Hoon Lim, Seong-Ahn Hong and Hwayong Kim. 1999. "Corrosion behavior of sensitized AISI-type 316L stainless steel in molten carbonate fuel cell in cathode-gas environment." J Power Sources. 83 : 32-40.

[22] Zumelzu E, Supulveda J, Ibarra M.1999. "Influence of microstructure on the mechanical behavior of welded 316L SS joint." J Materials Processing Technology. 94 : 36-40.

[23] Tsai N.S and Eagar T.W. 1984."The size of sensitization zone in 304 stainless steel welds." J. Materials for Energy Systems. 6 : 33-37.

[24] Ahmet Durgutlu. 2004. "Experimental investigation of the effect of hydrogen in argon as a shielding gas on TIG welding of austenitic stainless steel." Material and Design. 25 : 19-23.

[25] Jeong Sik Choi and Duk Yong Yoon. 2001. "The temperature dependence of abnormal grain growth and grain boundary faceting in 316L stainless steel." ISIJ Int. 41 No.5: 478-483.

[26] Karzov G.P, Timofeev B.T, and Chernaenko T.A. 2006. "Analysis of the events of the failure of pipelines made of austenitic steels in nuclear power generating industry." Strength of Materials. 30. No.4. 359-366.

[27] Kim Y.H, Lee D.J, Byun J.C, Jung K.H, Kim J.I, Lee H.J, Shin Y.T, Kim S.H, Lee H.W. 2011. "The effect of sigma phase formation depending on Cr/Ni equivalent ratio in AISI 316L weldments. Material and Design." 32 : 330-336.

[28] Korinko P.S and Malene S.H. 2001. "Consideration for weldability of type 304L and 316L stainless steel." ASM Int. 4 : 61-68.

[29] Raghuvir Singh, Gautam Das, Singh P.K, Chattoraj . 2009."Low temperature sensitization behaviour of base, heat affected zone and weld pool in AISI 304LN." The Minerals and Material Society and ASM Int. 40A : 1219-1234.

[30] Ramazan Yilmaz and HuseyinUzun. 2002. "Mechanical properties of austenitic stainless steels welded by GMAW and GTAW." J Marmana for pure and applied science. 18 : 97-113.