Anbar Journal of Engineering Science (AJES)
P-ISSN: 1997-9428; E-ISSN: 2705-7440

Vol. 11 , No. 1 (2020) , pp. 12 ~ 18
DOI:10.37649/aengs.2020.171279

Unviersty of Anbar

Anbar Journal Of Engineering Science©

journal homepage: http://www.uoanbar.edu.iq/Evaluate/

Mechanical Properties of Welded Martensitic Stainless Steel (AISI420) Subject to Different Heat Treatment

S. Hareer [a]*, H. Ali [b], and J. Jamal[a]

[a] *Materials Engineering Department, University of Technology, Iraq*
[b] *Materials Engineering Department, University of Technology, Iraq*
[c] *Materials Engineering Department, University of Technology, Iraq*

PAPER INFO

Paper history:
Received … … …
Received in revised form … … …
Accepted … … …

Keywords:
Martensitic Stainless Steel(MSS) ,
Cryogenic Treatment , Hardness ,
Post Weld Heat Treatment
(PWHT)

ABSTRACT

The aim of this article is to investigate the properties for joints of welded martensitic stainless steel (MSS) by ER 309 L filler wire, using tungsten arc welding (Tig). The regions of the base and welded materials were investigated by means of SEM, EDS, OP and HV were conducted to calculate the properties of the welded specimens. The influence of heat and cryogenic treatments also investigated, The best results from microstructure side occurrence epitaxial grains growth which was observed along the interface of weld-metal region, the maximum hardness was (414 HV) in conventional heat treated samples that tempered at 200°C, precipitation of small carbides were observed that this is responsible for the improvement in the mechanical properties of the material. Hardness at the HAZ region in state of DCT in all weldments was reduced as compared to hardness of HAZ region of CHT. The microhardness was at the highest value in the fusion zone.

1. Introduction

MSS used in applications where mechanical properties and corrosions resistance are required, such as in steam turbine blade, it is the only type of stainless steels that can be changed their properties when exposed to heat treatment [1].

Cryogenic treatments have been employed in the development of the most recent three decades in both high-alloy and tools steel to increase wear resistance [2]. They are progressively used for steels and another groups of alloys for enhancing their tribological performance [3]. After annealing MSS have having spheroidized carbides in a ferritic matrix. It is nessesary to control the procedure of treatment to get a fully martensitic structure, reduce retained austenite. MSS consists of martensite,undissolved carbides and ferrite. Therefore, for the given composition of the steel, the characteristic is influenced by the amount of carbon and other alloying elements in the austenite. MCMSS containing more than 0.2 wt.%, carbon totally dissolves in the matrix [4].

Welding is a process of joining two metal components through localized coalescence by intense heating. This is done by melting the work along the edge or surface and adding a filler material to form a pool of molten metal that cools to become a strong joint. [5]. GTAW is a common name, also known as the TIG (Tungsten Inert gas) that produces the electric arc maintained between non consumable tungsten electrode and the work piece. All parts including the molten metal, the heat affected zone and tungsten electrode shielded from atmospheric contamination by a blanket of inert gas (argon, helium, nitrogen, etc.) fed through the GTAW torch [6] Germán Prieto studied influence of a cryogenic treatment on the fracture toughness of an AISI 420

---

* Corresponding author. : S. Hareer ; Hareer.salman1@gmail.com +9647803426712

M.S.S, for both tool and high-alloy steels to develop their wear resistance, mainly within the transformation of retained austenite and the precipitation of fine carbides[3]. Johnpaul C. Ezechidelu, studied, the microstructures and mechanical properties of a welded AISI 410 MSS following different heat treatments, with purposes to restore the hardness and improve grain refinement of the materials. The outcomes reveal that the structures of the steel behind austenitizing treatment at 1020°C are of lath martensite mixed with a small amount of retained austenite. The result indicates also that the tempering regimens (500, 600 and 700°C) are improving the hardness and grain refinement leading to the existence of finely distributed carbide [7]. D.S.Nadig et al. debate the effects of cryogenic treatment on the wear behavior of MSS (SS410), it was found enrichment of wear properties and hardness after cryogenic treatment [8]. The main aims of this work are, studying the effect of heat and cryogenic treatment on welded MSS type AISI 420. A comparison of obtained microstructure and mechanical properties with that obtained after conventional heat treatment accomplished at different tempering temperatures. Hopping to minimize the retained austenite to lower values and increase carbides volume fraction percentage by adjusting many variables of the cryogenic treatments like; cryogenic temperature and soaking time .

2. Materials and Methods

2.1 Materials

In this investigation the used material is AISI 420 MSS which is provided from China. Table 1 displays the elements of AISI 420 alloys after analyses by spectroscopy.

2.2 Schaeffler and DeLong diagram

Schaeffler and DeLong summarised, the influence of the alloying elements on the microstructure of stainless steels, by an empirical diagram, as shown in Figure 1The diagram is constructed on the reality, that there were two types of alloying elements, first, ferrite-stabilisers and second, austenite-stabilisers. When austenite is form, this is related to the influence of Ni, means it is austenite-stabilisers, if the ferrite is form that is related to Cr, that has ability to promote ferrite-stabilisers, so, it probable to estimate the aggregate ferrite and austenite stabilizing effect of these elements in the steel.

So, it is probable to take the mutual influence of these elements into regard. The Schaeffler DeLong diagram was initially established for weld metal, i.e. it defines the structure after melting and fast cooling, however, it has also been found, to give a beneficial preview of the influence of the alloying elements, for wrought and annealed material [9, 10].

Based on Schaeffler diagram figure, martensitic class of stainless steels is characterized by limited percentage of Cr usually (11.5 % - 18 %) and C percentage usually (0.1 % - 1 %), Cr regarded a greatly ferriting element, while carbon is an austenitizing element. The structure of steel at high temprature was an austenitic while at ambient temperatures the structure will be martensitic, after tempering. It is important to mention that the percentage of carbon content in martensitic confirms a good level of hardness, also tends to assist the production of chromium carbides, that have different crystal structures with formulae ($M_{23}C_6$) and (M_7C_3) where: M signifies the (Fe) and (Cr). Among all types, martensitic stainless steel is the smallest resistance to corrosion, so that its application is finite to only slightly harsh environments [11, 12].

2.3 Welding Method

TIG is traditionally welding method, in fabrication of (MSS) structure, of size (400* 400* 3 mm), were used to prepare two weldment specimens, square butt joint was achieved using alternately sequenced weld pass.

2.4 Specimens preparation

The material was cut by water jet machine to get the final shape of samples, samples prepeared according to ASTM E8 specifications.

2.5 Heat treatment

In this research heat treatments were carried out by using laboratory furnace in Department of materials Engineering, university of technology. The heat treatment steps include the following:

1. Annealing.
2. Hardening in air.
3. Tempering.

While deep cryogenic treatments include:

1. Annealing.

2. Hardening in air.

3. Cryogenic treatments

4.Tempering.

All specimens were annealed by heating to austenitic temperature are (850°C), soaking for 15 min and then cooling in furnace. After that the samples were hardened by heating to austenitic temperature of 1000°C for 15 min cooling in air, and then either tempered at 200 °C or 500°C they are called CHT treatments, or before tempering , they are subject to cryogenic treatment with three sequence step temperature (-20,-70,-169°C) at three soaking times (4,5,24 hr) respectively, then are tempered at 200°C or 500°C in this case that are called DCT treatments

3. Results and Discussion

3.1 Effect heat and cryogenic treatment on the microstructure of Specimen welded by ER 309L filler wire (AISI 420 MSS/ ER 309L):

After welding, heat treatment was done, in order to achieve the matching properties in the weld metal and base metal, with enhanced mechanical properties and to obtain more homogenous structure along the cross section of specimen. After annealing, the microstructure of welded specimens (FZ) consisted of two phases: ferrite in the (dark etching) and austenite matrix (light etching), as shown in figure (2). Base, have a microstructure includes ferrite and M23C6 (where M=Fe or Cr) spherodized carbides, as shown in figure (3) as expected [4, 13]. After austenitizing because of a high fraction of carbides, chromium and other alloying elements are dissolved in the austenite solid solution, thereby making the steel hard and brittle as reported by [14], tempering treatment was carried out to obtain a more appropriate combination of strength and toughness and to change phase composition under the influence of tempering treatment. ER 309 weld-metal zone was found consisted of δ-ferrite fragmentation morphology (dark etching) and austenite matrix (light etching), as shown in figure (3). When compared with weld-metal zone in state of annealing treatment it was noted that δ-ferrite begins to disappear and loss vermicular morphology, due to at this heat treatment, δ-ferrite phase was transformed to γ-austenite, this was agreed with Ola[15].

While base metal consist from retained austenite, martensite and the disperased fine carbides for tempering at 200◦C and coarse carbides at tempering in 500◦C, this agree with[14] 500◦C, this agree with[14] Finally cryogenic treatment done on welded met-al at three different medium (refrigerator ,dry ice ,liquid nitrogen) when tempering at 200°C more carbides precipitate within austenite and at grain boundary as shown in figure (5a), while the micro-structural in FZ at 500 °C consist from fine carbides precipitates at grain boundaries as shown in figure (5b) with equaxied grains and austenite phase „. As compared these structures with those of CHT, it is revealed that cryogenic treatment refines carbides particles, and produce more homogeneous structure. Prieto et .al [2] obtained the same results.

Finally cryogenic treatment done on welded metal at three different medium (refrigerator ,dry ice ,liquid nitrogen) when tempering at 200°C more carbides precipitate within austenite and at grain boundary as shown in figure (5a), while the microstructural in FZ at 500 °C consist from fine carbides precipitates at grain boundaries as shown in figure (5b) with equaxied grains and austenite phase „. As compared these structures with those of CHT, it is revealed that cryogenic treatment refines carbides particles, and produce more homogeneous structure. Prieto et .al [2] obtained the same results.

3.2Micro EDS and SEM examination of welded specimens

Micro EDS results showed the chemical composition of weld zone, as can be noted from figures (6a,b) results were appeared (Fe,Cr and Ni) in the weld-metal zone center, (Cr) content was in percentage (18.6%) and, (Ni) was (5.6%). This supports the existence of austenite phase in all weld-metal regions. In addition, elements (C, Ni and Mn) are stabilized austenite phase, and due to the existence of C and Mo the boundary of the γ range is shift towards higher temperatures. The carbon contents are not observed because they are very low percentage (0.02%).

Figure (6b) illustrates the (EDS) analysis along the (HAZ) region after austenitizing at (1000°C/15min) and tempering (200 °C). This analysis shows the presence of (Fe, Cr, and Ni) along the (HAZ) region.

Carbide particle also, in the matrix. From this figure, it is clear that more carbon in the carbides than in traditional heat treatment.

3.3 Micro hardness evaluations

Typical micro-hardness profiles for (420 MSS/ ER 309L) weldment after PWHT (annealing, hardeining, tempering at 200 and 500°C/15min and Cryogenic treatments) are shown in figure (7). Results showed variation in micro hardness profile with treatment, the average hardness of the base region is increased from (HV 222.6) after annealing to HV (414) after hardening and tempering at 200 °C. The average hardness of (HAZ) increased from (319HV) after annealing to (389 HV) after hardening and tempering at 500 °C. Micro hardness test was also done on fusion zone, the maximum hardness was achieved after annealing treatment as a result of ferrite and carbide phases ,but after hardening tempering at 500°C and 200 °C , the hardness value is decrease to 484 HV and 502HV respectively due to the increase of retained austenite and decrease ferrite .After that the hardness reaches minimum values with hardening and cryogenic treatment.

Hardness increase for samples of AISI420 that treated cryogenically can be associated to the precipitation and distribution of finer small secondary carbides, within the Bulk of the material and the bigger strain state in the martensite, as reported by refrence [2]. The hardness increasing at tempering temperature of 500°C which is known as secondary hardening effect was reported by researchers [4]. It is believed that the precipitation of some new carbides was the main cause of this phenomenon associated with the formation of M7C3 carbides within the martensite lath.

In CHT after hardening and tempering temperature at 200°C, the amount of retained austenite was decreased. Reduction in the retained austenite could be attributed to the decomposition of austenite to ferrite and fine carbides. This resulted in a increment of hardness, At tempering temperature about of 500°C, the hardness profile was noticeably decreased. Decreasing in the hardness profile could be attributed to the martensite recovery as well as carbide coarsening and also spheroidization of the carbides. This Softening occurred when the M7C3 carbides started to coarsen and partially transform to M23C6 carbides [1].

High hardness value obtained can also be attributed to the fine martensitic matrix and low levels of retained austenite as well as the presence of a higher amount of carbide, which hardens the matrix when it dissolves. This increase in hardness is attributed to an increase in the carbon content of the martensite phase due to the partial dissolution of carbides. The martensite becomes harder due to its higher carbon content, but the amount of carbon and alloying elements in solid solution was not high enough to depress the martensite transformation range much be-low room temperature.

3.4 The Treatments on Tensile Test Properties (AISI 420 MSS/ ER 309L): The tensile properties of treated specimens are set in Table 2 Yield strength (YS), Ultimate tensile strength (UTS) and Elongation (% EL) values were determined. The maximum tensile strength was acquired for the specimen treated at 1000 ◦C and tempered at 200◦C is 997 MPa. The maximum value of yield strength 800 MPa, while the elongation is 12%. Elongation has maximum value in annealed condition that reaches 40 %, then it is decreased gradually with hardening and tempering at 200°C or 500°C be as 21% and 20 % respectively. After cryogenic treatment, and tempering at 200°C or 500°C recording values of elongation are 27% and 20 % respectively. To give it another way, tensile strength has minimum values in annealing treatment after that it is increased so reach highest amount at hardening and tempering at 200°C, decreasing in small amount in hardening and tempering at 500°C. Finally it is reduced in small amount at cryogenic and tempering with 500°C and 200°C, the behavior of yield strength is similar to tensile strength.

4. Conclusions

The effect of cryogenic and conventional heat treatments on the characteristic of AISI 420 MSS was studied and the following conclusions can be drawn:

1- DCT has enhanced the tensile and hardness properties, by the way of increasing precipitation of small size carbides

2- Micro EDS analyses showed that there is a depletion of elements (C and Cr) from base metal to carbide particle, in all heat treatment conditions.

3- Hardness of HAZ region in state of DCT in all weldments (by ER 309) was reduced as compared to that of HAZ region in the state of CHT.

4- Hardness of ER 309 weld-metal zone in case of welding by ER309L condition is higher than that in the state of CHT and DCT.

Abbreviations and Acronyms

DCT: Deep Cryogenic Treatments, CHT: Conventional Heat Treatments, Post weld heat treatment (PWHT), specimen symbol like Ehct (E=Welded metal, h= hardening, c=cryogenic, t=tempering).

Elements	AISI 420 data sheet	Actual chemical compostion of used steel
C	≥0.15	0.347
Si	≤1.00	0.422
Mn	≤1.00	0.332
S	≤0.03	0.03
P	≤0.03	0.0156
Cr	12-14	14.11
Fe	Balance	Balance

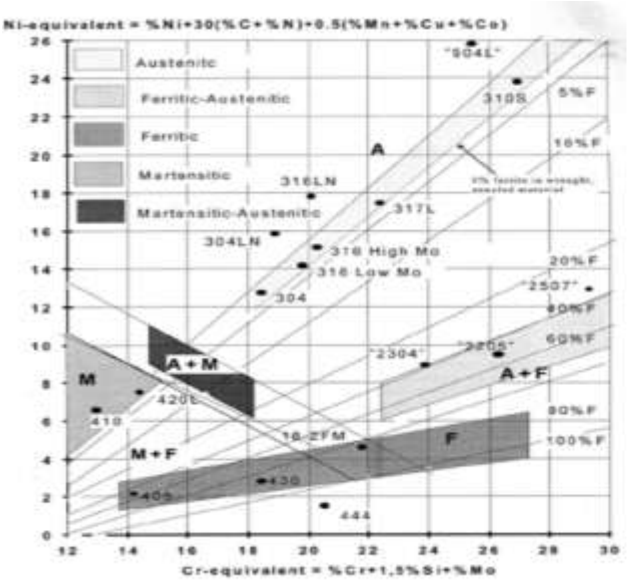


Figure 1. Schaeffler-Delong diagram, predicting the phase structure for different alloys and chemical compstion in ss [7].

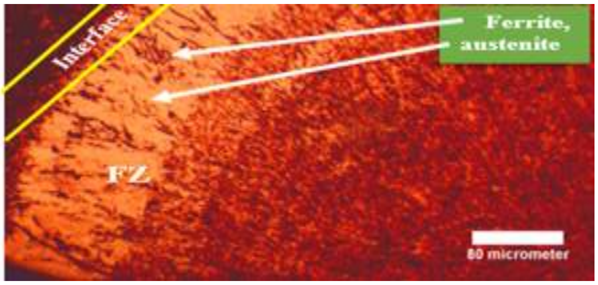


Figure 2. Fusion- metal zone for AISI 420 MSS/ ER 309L after annealing at 850°C/15 min.

Figure 3. base- metal zone for AISI 420 MSS after annealing at 850°C/15 min.

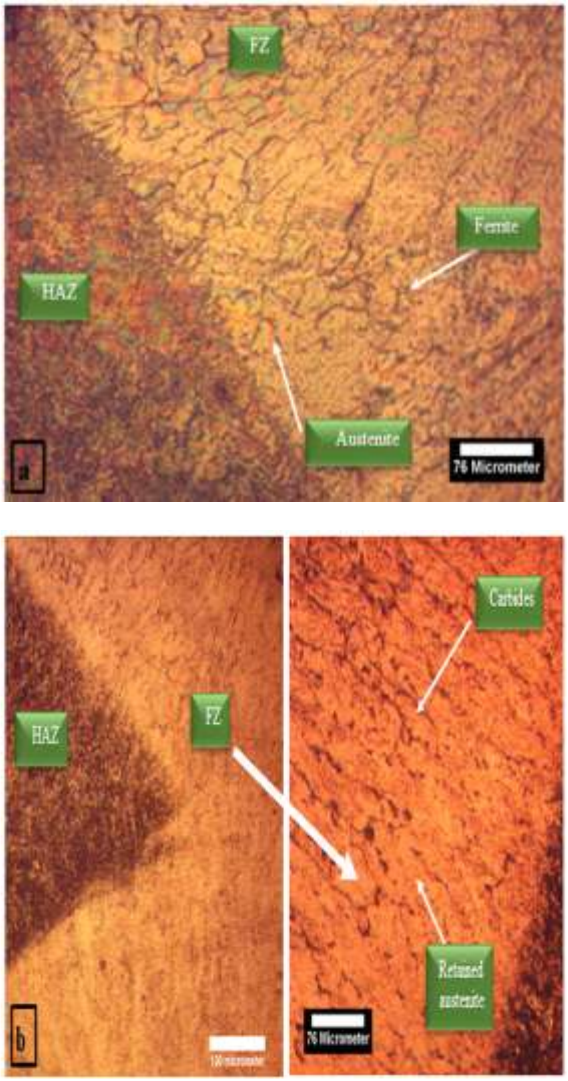


Figure4. A) Liquid-solid interface with HAZ, for AISI 420 MSS/ ER 309L after austenizing and tempering (a) at 200°C, (b) at 500°C.

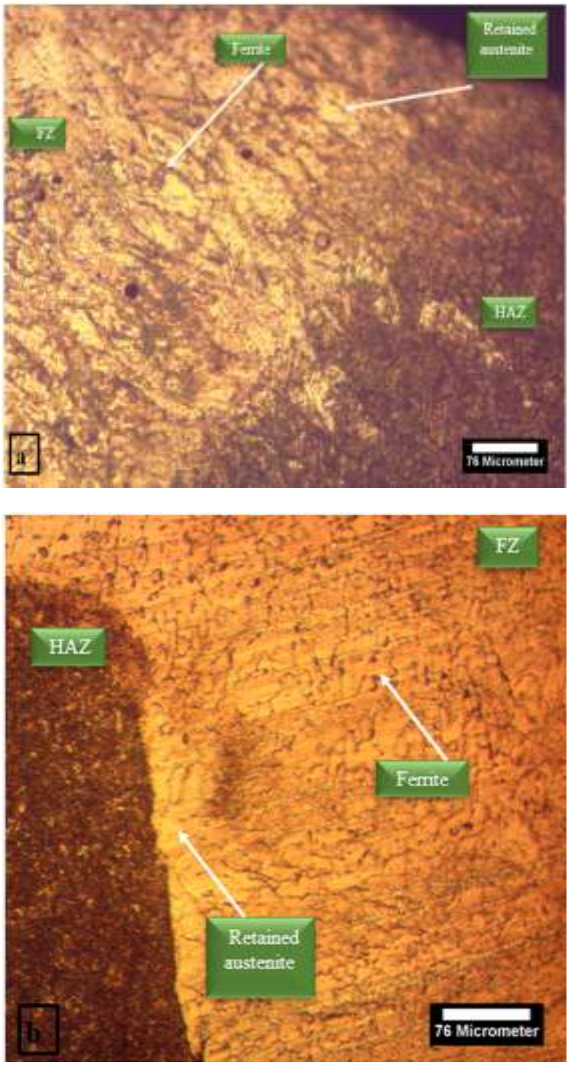
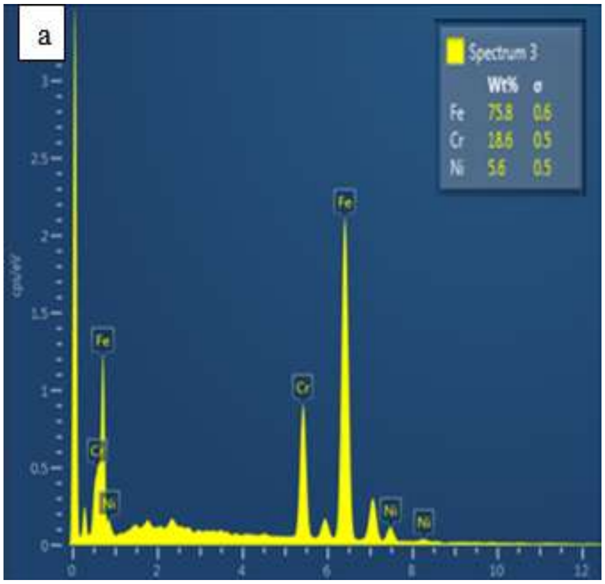


Figure 5a,b. Weld zone and HAZ for AISI 420 MSS/ER 309L after cryogenic treatment and tempering at (a) 200°C ,(b) at 500°C



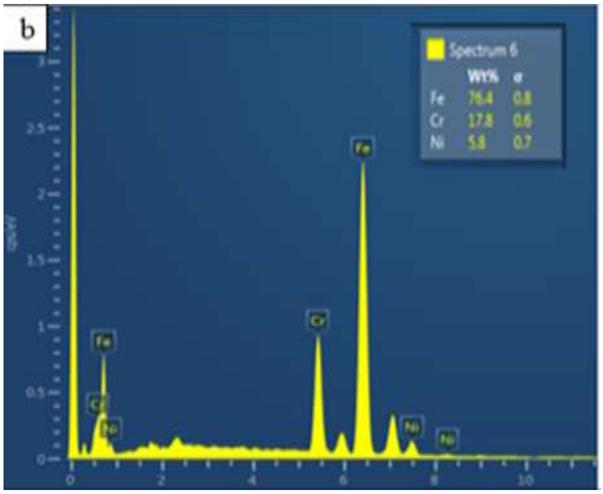


Figure 6. EDS analysis for FZ of specimens welded by ER309L (a) Refers to optimum CHT, tempered at 200 °C (b) Refers to optimum DCT, tempered at 500 °C.

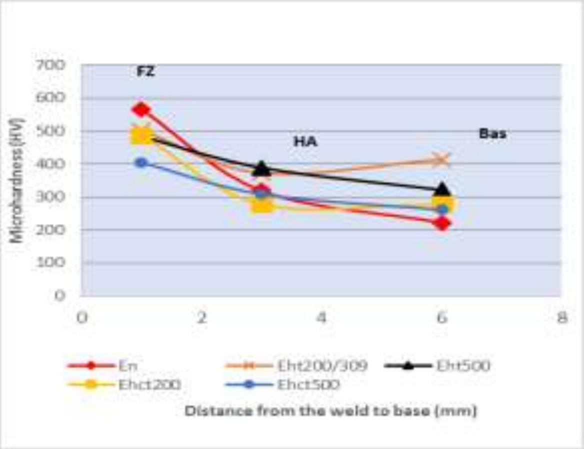


Figure 7. The micro-hardness variation across weldement of 420 MSS/ ER 309L after different PWT.

Table 2. Tensile properties of AISI 420 MSS/ER 309L after different post welding treatments

Material	Tensile strengths (MPa)	Yield strengths (MPa)	Elongation %
En	557	300	40
Eht200	997	800	12
Eht500	860	580	21
Ehct200	696	445	20
Ehct500	677	470	27

References

[1] A. Khazaei and A. Mollaahmadi,. “Rapid Tempering of Martensitic Stainless Steel AISI420: Microstructure, Mechanical and Corrosion Properties”. Journal of Materials Engineering and Performance, 2017

[2] G. Prieto, J. Ipiña and W. Tuckart. “Cryogenic Treatments on AISI 420 Stainless Steel: Microstructure and mechanical properties”. Materials Science and Engineering, Vol.605, PP.236-243, 2014.

[3] G. Prieto, W. Tuckart and J. Ipina. “Influence of a Cryogenic Treatment on the Fracture Toughness of an AISI 420 Martenstic”. Vol .51, No.4, PP. 591,2016.

[4]A. Isfahany, H. Saghafian and G. Borhani. “The Effect of Heat Treatment on Mechanical Properties and Corrosion Behavior of AISI420 Martensitic Stainless Steel”. Journal of Alloys and Compounds, Vol.509,No.9, PP.3931–3936, 2011.

[5] J. Jalal. “Fatigue life estimation of ferritic austenitic stainless steel welded joint. PhD. thesis, Department of Mechanical Engineering, Sinhgad College of Engi-neering, 2014.

[6] K. Hicken, D. Campbell, J. Daumeyer, B. Marburger , J. Marburger and B. Young. “Gas Tungsten Arc Welding”, Dan TN, 2009.

[7] Johnpaul, O. Daniel, S. Paul and O. “Effect of Heat Treatment on the Microstructure and Mechanical Properties of a Welded AISI 410 Martensitic Stainless Steel”. Vol. 3, Issue 4, April 2016

[8] D. Nadig, P. Shivakumar, S. Anoop, K. Chinmay, P. Divine, and H.Harsha. “Effects of Cryogenic Treatment on the Wear Properties of Brake Discs”. IOP Con-ference Series: Materials Science and Engineering, Ma-terials Science and Engineering. Vol.171, 2017.

[9] P. Hedstrom. “Deformation Induced Martensitic Transformation of Metastable Stainless Steel AISI 301”. Lulea University of Technology Department of Applied Physics and Mechanical Engineering Division of Engineering Materials, 2005.

[10] Outokumpu stainless AB. “Hand Book of Stainless Steel”, Outokumpu Oyi, Sweden, 2013.

[11] A. padhiha, R. Lesley and P. Rangel. “Stainless Steels Heat Treatment (Chapter 12). Steel Heat Treatment Handbook”. Second Edition. PP.695-739, 2007.

[12] V. Macro and C. Andrea. “Stainless Steels”, Lucefin S.p.A. 1-25040 Italy, 2014.

[13] C. Scheuera, R. Fragaa, R. Cardosoa, S. Brunattoa ,“Effects of Heat Treatment Conditions on Microstructure and Mechanical Properties of AISI 420 steel” 1º CBECIMAT - Congresso Brasileiro de Engenharia e Ciência dos Materiais 09 a 13, Cuiabá, MT, Brasil, 2014.

[14] M. Alwash, “The Effects of Heat Treating Process Parameters on the Hardness of a Martensitic Stainless Steel”. BSC thesis, In Mechanical Engineering.

[15] O. Hussein. “Investigation of Microstructural and Chemical Analysis of Turbine Blades Type 410 Stainless Steel Fusion Welded by Different Filler Metal Alloys”. PhD. thesis, Department of Materials and engineering University of Technology, 2017.