IRAQI Academic Scientific Journals
العراقية المجلات الاكاديمية العلمية

Al-Kut University College Journal
K. U. C. J.

ISSN (E) : 2616 - 7808 I ISSN (P) : 2414 - 7419

Vol. 6 Issue 1 2021

Welding Procedures of Steam Turbine Blades by Using ER 310L Austenitic Filler Wire

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Abstract

In the present work it has been investigated the repair of LP-blades steam turbine made of AISI 410 martensitic stainless steels (MSS) by GTAW welding, the repair welding carried out by using ER 310L as consumable filler wire. PWHT was carried out at 1100^{o}C for 1h. The structure-property relationships of the weldments were established based on the current modes employed by utilizing combined techniques of optical microscopy, line/point and EDS analysis. Results showed that Micro-hardness along the base and HAZ regions increased after PWHT as compared to in state of as-welded. After welding process, microstructure photographs of weld-metal region revealed two phase the vermicular δ-Ferrite and γ-austenite matrix. HAZ region consisted of tempered lath martensite with carbides. Line/Point analysis revealed the direction of segregation, whereas chromium was increased in core and depleted in boundary, while nickel was depleted in core and increased in boundary, this support the δ – ferrite was primarily solidified.

Keywords : Steam Turbine, LP (Low Pressure blades), Gas Tungsten Aric Welding, Repair welding, PWHT (Post Welding Heat Treatment), martensitic stainless steels.

إجراءات اللحام لريش التوربينات البخارية باستخدام سلك الحشو الاوستيناتي

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الخلاصة

في العمل الحالي، تم التحقيق في إصلاح التوربينات البخارية ذات الريش LP المصنوعة من الفولاذ المقاوم للصدأ (AISI 410 MSS) بواسطة لحام GTAW، وتم إجراء عملية اللحام باستخدام ER 310L كسلك حشو قابل للاستهلاك. تم تنفيذ PWHT عند 1100 درجة مئوية

لمدة ساعة واحدة. تم إنشاء علاقات التركيب والممتلكات الخاصة باللحام بناءً على الأوضاع الحالية المستخدمة من خلال استخدام مجموعة تقنيات للفحص المجهري البصري والخط / النقطة وتحليل EDS. أظهرت النتائج أن الصلابة الدقيقة على طول القاعدة ومناطق HAZ زادت بعد PWHT مقارنة بحالة اللحام. بعد عملية اللحام، كشفت صور البنية المجهرية لمنطقة معدن اللحام مرحلتين من مصفوفة δ-Ferrite و γ- austenite. تتكون منطقة HAZ من مارتينسيات مقسى بالكربيدات. كشف تحليل الخط / النقطة عن اتجاه الفصل، بينما تم زيادة الكروم في اللب واستنفاد في الحدود، بينما استنفد النيكل في اللب وزاد في الحدود، فإن هذا الدعم δ - الفريت تم ترسيخه بشكل أساسي.

الكلمات الرئيسية : توربينات بخارية، ريش الضغط المنخفض LP، لحام التنغستن الغازي، لحام الإصلاح، PWHT (المعالجة الحرارية بعد اللحام)، الفولاذ المقاوم للصدأ مارتينسيتي

1. Introduction

Recently, Low pressure blades of steam turbines are found to be susceptible to failure more than the other types (i.e., intermediate pressure (IP) and high pressure (HP) blades). Almost 50% of blades failure is related to fatigue and corrosion (cracking and fatigue corrosion types). Almost 50% of blades failure is related to fatigue and corrosion (cracking and fatigue corrosion types) [Ziegler D, 2013]. [Bhaduri et. al, 2001] investigated the developed of welding repair procedure on cracked blades steam turbine was made from MSS (martensitic stainless steel) by using TIG (Tungsten Inert Gas) welding process with consumable filler wire as ER 410 MSS and ER 316L austenitic filler wires. Results showed that employing ER 410 filler wire with preheating and PWHT processes is appropriate to weld MSS blades turbine. [Divya et. al, 2011] investigated the details in-situ weld repair of cracked shrouds of turbine and characterization the weld joint. Crack shrouds of the 3rd stage of a Low-Pressure turbine was in-situ repaired by removing the cracked pieces of the shroud that made of AISI 414 martensitic stainless steel (SS) and welding using gas tungsten arc welding with ER 410NiMo consumable wire. Micro-hardness result showed weld-metal region in state as welded and after heat treated was reduced from 400-260 VHN with applied load 500g. [Arivarasu et. al, 2015] investigated dissimilar welding joint between AISI 304L (ASS) and low alloyed AISI 4340 aeronautical steel that welded joint by CC (continuous current) and PC (pulsed current) GTAW techniques, using two types of consumables filler metal as ER309L and ERNiCr-3. optical microstructure results of the weldments joined by CCGTAW with 2 consumable filler metals was showed weld-metal was revealed coarser microstructure contained columnar dendrites with appearances of secondary phase (s) at the interface of AISI 4340 side. The aim of this research is investigation the developing procedure of repair welding to repair blades of trubine by using filler metal type ER 310L. welding procedure to repair turbine blades by using ER 310L filler metal. Also, studied the microstructure and the chemical composition along the weldment in state of as-welded and after PWHT.

2- Materials and Experimental Procedure

Base metal used in this research is LP blades of a steam turbine made from AISI 410 MSS. ER 310L austenitic filler metal is candidate and employed, chemical composition for 410MSS and ER310L is represented in Table 1.

Table 1:- Chemical Composition of Base Metal and Filler Alloys.

Base/Filler metal	Chemical Composition (% by Weight)				
	C%	Cr%	Ni%	Mo%	Mn%
	Si%	Fe%	Creq	Nieq	Creq/Nieq
AISI 410	0.127	11.94	0.2	0.0109	0.755
	0.38	B	----	-----	----
ER 310L	1.34	25.72	20.41	----	1.78
	0.52	50.06	26.5	22.2	1.19

Cr eq & Ni eq estimated from Shaeffler-Delong diagram assuming N=0.03wt%.

The blades were cutted by the spark discharge machine (EDM) to the pair's symmetry (each piece of pair's has dimensioned approximately (25mm*100mm). Followed by it is achieved standard V-Butt configurations (single V-groove having a root face of 2 mm, size land of 1 mm and included angle of 70°) was worked on these pair's. Multi-pass welding was performed through TIG welding machine (type/ ESAB LRT 160) and V-butt welding joint process was depended on the skill of welder; figure (1) showed specimens after welding.

Figure 1: Specimen after Welding.

The parameters of welding joint were fixed: - Main Supply 70-80 V/Hz, Current Range 130 A and Gas Flow Rate 6 L/min-1. When welding process was completed, the samples were cute by Wire-Cut EDM (type/ Smart DEM), to small specimens with dimension (50 * 10 * 10) mm, as shown in figure (2).

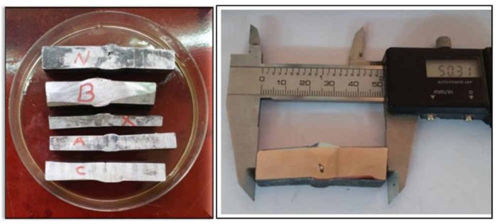


Figure 2: specimen after Cutting.

After cutting process, each sectioned specimen was subjected to PWHT (Post Weld Heat Treatment) in order to obtained best mechanical properties and some stress relief. PWHT method was conducted at 1100 ^{o}C. PWHT was carried out by using furnace (type/ Carbolite 1200). The holding time for PWHT was 1hr and cooling rate 30 C^{o}/min. The furnace was switched off and cross-section specimens were placed in to slowly cool to room temperature in order to prevent high-temperature oxidation of the joint.

2-1 Microstructure and Micro-hardness Testes

After metallography procedure, microstructure and micro hardness along weldments studied. Optical microscope with 5 mega pixel CCD camera into image pro software with the magnification of 5, 10, and 20X used to examine samples after grinding and polishing processes.

The Vickers micro hardness test (HVS-1000) with diamond indenter was conducted along weldment, with load of 1Kg and duration time 15 seconds. Samples were prepared in accordance with to ASTM E3-11 standard [2011].

2-2 Line/Point with EDS analysis

Electron probe micro-analyzer (EPMA), Houses a JEOL 8200 Superprobe EPMA device at

Microprobe Laboratory in the Department of Earth Sciences at the University of Dalhousie in Canada Country was used to complete these tests. Specimen's dimension (50 * 10 * 10) mm were prepared by grinding and polishing, and then making set of points along weldments across (base, HAZ and weld-metal regions), each of these points have been analyzed.

3- Results and discussion: -

3-1 Microstructure Test Results:

I. weldment AISI 410/ER 310L before PWHT:-

ER 310 weld-metal zone was found consisted of two-phase austenite dendrite (light etching) with inter-dendritic δ-ferrite (dark etching) between the primary and secondary dendrite arms, as shown in figure (3).

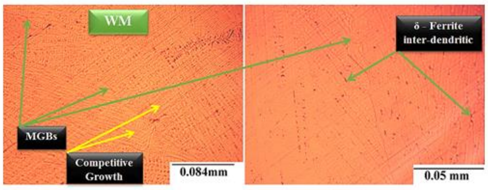


Figure 3: Weld-Metal Microstructure in state (As-Welded).

Concentration profile of ER 310 stainless steel was found consisted of 50.06% Fe, 25.72% Cr and 20.41% Ni by weight as mentioned in Table 1. Depending on Cr-Ni content 25.72/20.41, primary γ- austenite crystals are initially precipitated from the liquid and δ -Ferrite precipitated from three-phase sector (L + γ + δ) to Presence Cr enrichment crystal as inter-dendritic. During further cooling, γ crystals are maintained as an austenitic structure down to ambient temperature with a small amount of residual delta ferrite. The solidification mode was found to be austenitic- ferritic (AF) with moderate cooling rate and Cr:Ni ratio equal 1.19%, When Cr:Ni ratio was less 1.48%, this is mean no further transformation.

Microstructure at ER 310 weld-metal studies clearly inferred the formation of migrated grain boundaries (MGBs) at GTA weld zones, as shown in figure (3). Configuration of crystal in weld-metal zone was revealed columnar dendrite at the center toward opposite direction of flow rate. Far from the interface (fusion line), competitive was attributed to the growth of grains dendrite at different direction. Easy growth direction is <100> in FCC and BCC materials, however, the growth can occur at different direction due to presence of different phase (A+F). Liquid-solid interface and HAZ affected zone, as shown in figure (4). Liquid-solid interface was represented plane line and a crystal was first growing cellular and then is change over into directed dendrites along interface due to high cooling rate. While HAZ AISI 410 MSS was appeared tampered lath martensite with carbides.

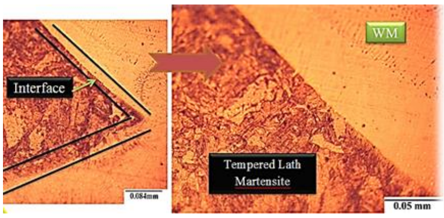


Figure 4:- Solid-Liquid Interface and HAZ Zone of 410 MSS/ER 310L (As-Welded).

II. weldment AISI 410/ER 310L after 1100°C/1h:-

At heat treatment (1100°C/1h), the full weld-metal zone was found consisted of columnar dendritic austenite phase, as shown in figure (5).

At heat treatment (1100°C/1h), the full weld-metal zone was found consisted of columnar dendritic austenite phase, as shown in figure (5). This may belong to the dissolution of all phase's residual δ-ferrite phase and carbides at (1100°C) and homogenous weld-metal zone structure formed. According to (Erich Folkhard [55]), austenitic steels always preferred to be subjected to a solution annealing treatment between (1050-1100°C) at which phases including carbide $M_{23}C_6$, sigma phase and delta ferrite were completely dissolved, and the annealing process produces a homogenous fully austenitic structure.

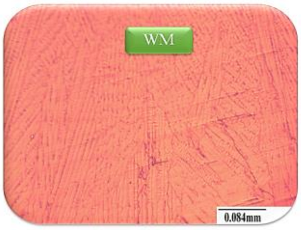


Figure 5: Weld-Metal Zone for AISI 410 MSS/ ER 309L after PWHT 1100°C/1h.

Figure (6) illustrates the Liquid-solid interface and HAZ microstructure. Liquid-solid interface was appeared clearly between the γ-iron weld-metal and (AISI 410 MSS) HAZ region, which is consisted of tempered martensite (α-Ferrite matrix with carbides), as shown in figure (6).

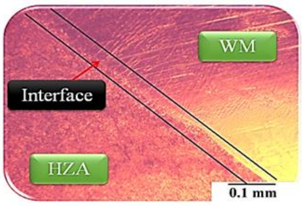
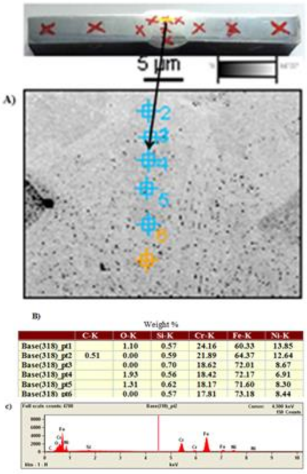


Figure 6:- A) Liquid-Solid Interface with HAZ Affected Zone for AISI 410 MSS/ ER 309L after PWHT 1100°C/1h.

3-2 Line/Point and EDS Analysis Results:

I. weldment AISI 410/ER 310L before PWHT:-

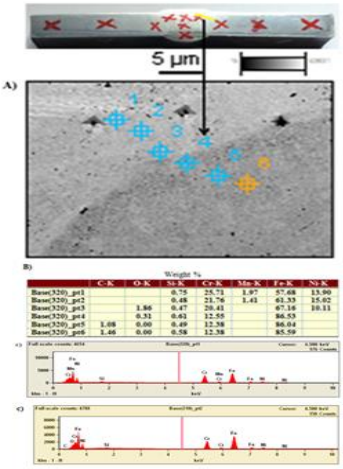
Line/point analysis confirmed with EDS results was showed chemical composition along ER 310 weld-metal zone center and weld boundary, as shown in figure (7) and (8). As can be noted from figure 7 (A and B), line/point analysis were appeared austenite phase at center of weld zone as represented in point (Pt1 and Pt2) enricher by nickel, whereas Cr content was found 24.16%, 21.89% and Ni content was equal 13.85%, 12.64%, respectively. While residual delta ferrite was appeared at point (Pt3, Pt4, Pt5 and Pt6) with enriched of chromium and depletion of nickel.



Weight %

	C-K	O-K	Si-K	Cr-K	Fe-K	Ni-K
Base(318)_pt1		1.10	0.57	24.16	60.33	13.85
Base(318)_pt2	0.51	0.00	0.59	21.89	64.37	12.64
Base(318)_pt3		0.00	0.70	18.62	72.01	8.67
Base(318)_pt4		1.93	0.56	18.42	72.17	6.91
Base(318)_pt5		1.31	0.62	18.17	71.60	8.30
Base(318)_pt6		0.00	0.57	17.81	73.18	8.44

Figure 7: A) Line Analysis B) Point Analysis C) EDS Analysis at Weld-Metal Zone for Weldment AISI 410MSS/ ER 310L (As-Welded).



Weight %

	C-K	O-K	Si-K	Cr-K	Mn-K	Fe-K	Ni-K
Base(320)_pt1			0.75	25.71	1.97	57.68	13.90
Base(320)_pt2			0.48	21.76	1.43	61.33	15.02
Base(320)_pt3		1.86	0.47	20.41		67.16	10.11
Base(320)_pt4		0.31	0.61	12.55		86.53	
Base(320)_pt5	1.08	0.00	0.49	12.38		86.04	
Base(320)_pt6	1.46	0.00	0.58	12.38		85.59	

Figure 8:- A) Line Analysis B) Point Analysis C) EDS Analysis at Interface for Weldment AISI AISI 410MSS/ ER 310L (As-Welded).

Also, austenite phase was existed at the beginning of weld boundary at point (Pt1, Pt2 and Pt3), as shown in figure 8 (A and B). EDS analysis results in figure 8 (C) showed appeared (Cr-Mn) together at one peak due to improvement hot cracking resistance along ER 310 weld-metal region.

Line/point analysis at HAZ showed; the presence of Fe, Cr and C elements richly along HAZ, as shown in figure (9). Average C content along HAZ was 2.5%. Excess carbon may precipitate in the form of chromium-iron carbides, mainly as M23C6, and in rarely as M7C3 or M6C. M23C6 were agglomerated at liquid-solid interface and precipitated as coarse or finer particles at the grain boundaries and within the grain areas.

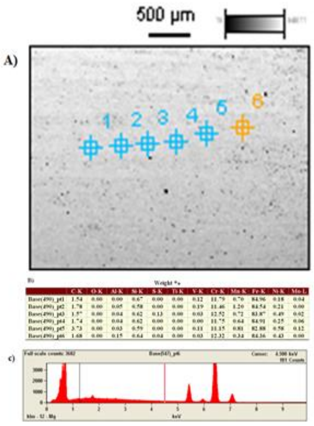
II. weldment AISI 410/ER 310L after 1100°C/1h:-

Line/point analysis and (EDS) analysis results showed the chemical composition of weld-metal zone, as shown in figure (10). These results appeared along the γ-iron weld zone. (Cr) content was found (23.95%, 23.47%, 21.70%, 23.09%, 22.55% and 23.00%), respectively. (Ni) content was found (14.17%, 13.58%, 13.04%, 14.06%, 14.42% and 13.92%). This supported existence of γ-iron phase along the weld-metal zone. In addition, presences of elements stabilized γ-phase and extended γ –loop, such as (C and Mn) in average value (1.74% and 1.58%), respectively. As mentioned previously,

(C) was across the liquid-solid interface toward the weld-metal zone with subsequent cooling some carbon may again precipitate as carbides in weld-metal zone. Figure (11) revealed the line/point analysis and (EDS) analysis for (HAZ) region after this heat treatment. These results showed the presence of high carbon content along the (HAZ) toward weld-metal zone. The average (C) content was found (2 %) at (HAZ) region, i.e., increased carbides precipitated with (Cr or Fe) or mixed carbides. Also, it was noted presence of other elements as (Si, Ni, Mo, V, Ti, S and P), this chemical composition was similar to chemical composition in state of as welded.

3-3 Micro-hardness Test Results:

Typical micro-hardness profiles across weldment 410 MSS/ ER 310L before PWHT (as-welded) and after PWHT 1100°C/1h were showed in figure (12). Results showed variation in micro hardness profile before and after the heat treatment depending on dilution from the base metal and weld-metal zone. Moreover, the average hardness of the HAZ and weld-metal regions was increased from HV 459.6, 159.8 in state as-welded to HV 472.5, 164.6 after PWHT 1100°C/1h respectively. Finally, the hardness results showed increment along HAZ region in state as welded due to carbon aggregated at interface and increased again after heat treatment due to more carbides formed above 500°C.



Weight %

	C-K	O-K	Al-K	Si-K	S-K	Ti-K	V-K	Cr-K	Mn-K	Fe-K	Ni-K	Mo-L
Base(490)_pt1	1.54	0.00	0.00	0.67	0.00	0.00	0.12	11.79	0.70	84.96	0.18	0.04
Base(490)_pt2	1.78	0.00	0.05	0.58	0.00	0.00	0.19	11.46	1.20	84.54	0.21	0.00
Base(490)_pt3	[illegible]	0.00	0.04	0.62	0.13	0.00	0.03	12.52	0.72	[illegible]	0.49	0.02
Base(490)_pt4	1.74	0.00	0.04	0.62	0.00	0.00	0.00	11.75	0.64	84.91	0.25	0.06
Base(490)_pt5	3.73	0.00	0.03	0.59	0.00	0.00	0.11	11.15	0.81	82.88	0.58	0.12
Base(490)_pt6	1.48	0.00	0.15	0.64	0.04	0.00	0.03	12.32	0.34	84.16	0.43	0.00

Figure (9): A) Line Analysis B) Point Analysis C) EDS Analysis at HAZ Region for Weldment AISI 410MSS/ ER 310L (As-Welded).

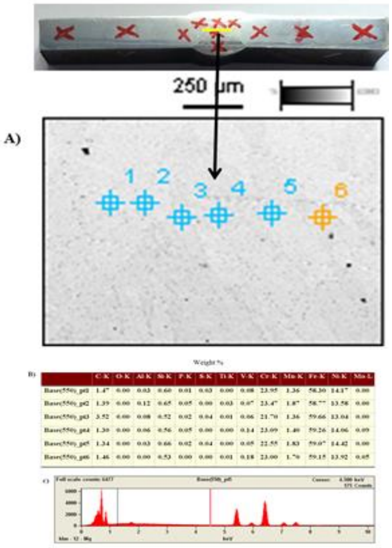


Figure (10): A) Line Analysis B) Point Analysis C) EDS Analysis at Weld-Metal Region for AISI 410MSS/ ER 310L after PWHT 1100°C/1h.

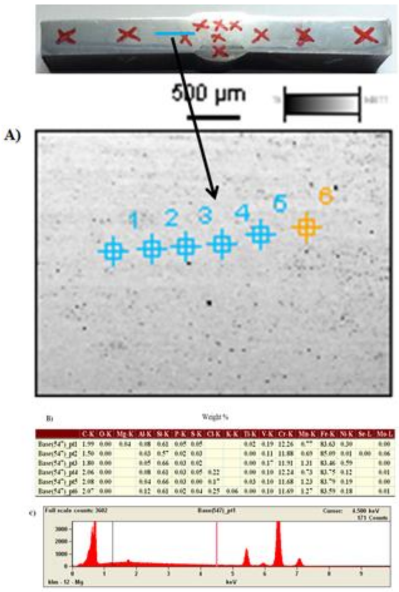


Figure 11: A) Line Analysis B) Point Analysis C) EDS Analysis at HAZ Regions Weldment AISI 410MSS/ ER 310L after PWHT 1100°C/1h.

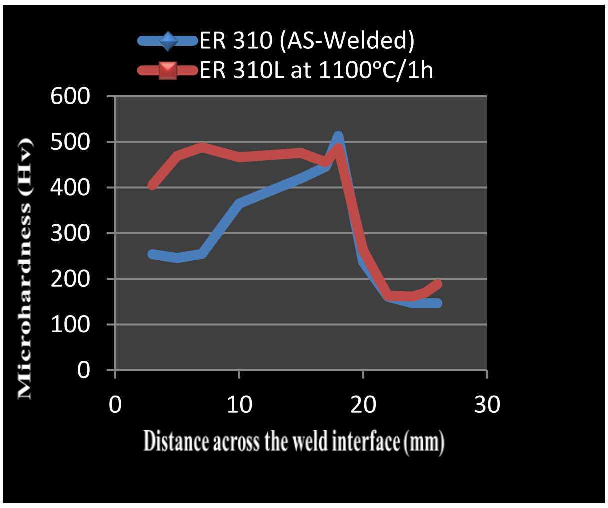


Figure12: Micro-hardness Variation across the 410 MSS/ ER 310L before PWHT (as welded) and after PWHT 1100°C/1h.

4- Conclusions

1) Sound welds of 410 MSS blade steam turbine could be obtained from GTA welding process using ER310L filler wires: -
2) ER 310 weld-metal enriched by Ni, resulted γ-austenite is primarily solidified. When Cr:Ni ratio less 1.48%, this is mean no further transformation and solidification mode AF.
3) Direction of segregation indicated to primarily phase.
4) MGBs (migrate grain boundaries) are prevalent in the weld zones on employing ER310L.
5) Increased hardness along base and HAZ region in state PWHT 1100°C/1h than at HAZ region in state as welded.
6) Large amounts from carbon elements aggregated at HAZ region close to interface to form carbides.

Acknowledgement

This work did not fund by any government institution.

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