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Comparative study of tube to tubesheet welding qualification on heat exchanger

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Abstract

Plant turnarounds are one of the most critical events in the Saudi Arabian oil and gas industries. Shutdowns have the potential to affect the plant's cash flow and objectives either in a constructive nor a bad way. A heat exchanger is an essential equipment for some procedures in the oil and gas refineries plant and it will decide the plant's shutdown span. In a heat exchanger, welded tube to tubesheet joint is a basic factor which requires a different qualification. In this paper, tube to tubesheet welding for various material combination (carbon steel-stainless steel, stainless steel-stainless steel, and alloy steel-alloy steel) is qualified. According to American Society of Mechanical Engineers (ASME) Section IX QW-193 mock up qualification is done and QW-193.1 to QW-193.1.3 (visual test, liquid penetrant test and macro etching test) likewise is followed and lab tested for acceptance criteria. Ten model welds are needed to determine the eligibility of each procedure according to the required standard and totally 60 models (every 20) tried to rate this 3 procedure qualification record and welder qualification test record (PQR / WQTR). Qualification of the sheet from tube to tube follows all needed variables referred to in QW-288. This study proposes the improved minimum and maximum value for current (I), voltage (V), and travel speed (mm/min) required for above said materials qualifications. Further discourse is made over the heat input (KJ/mm), after effects of minimum leak path all things considered (Macro etching test), and classifies the range qualified against utilized base material for better understanding according to QW-288 essential variables.

Keywords: Heat exchanger, Welded tube-tubesheet joints, Carbon steel, Stainless steel, Alloy steel, Visual test, Liquid penetrant test, Macro etching test

Introduction

Nowadays, the world is completely based on oil and gas; organized assignments are requisite parts of refining process [1]. Changes are required to maintain, renovate, or facilities of recondition generally every four years or so. Recovery activities need efficient labor and apparatus for some weeks. It is generally measured in shifts. Due to closure and response time, the facilities can be examined, so their execution time can be expanded if extra problems are marked [2, 3]. Expanding response activities can cause shortages of fuel, price increase, or both. It could cause strain as another supplier might increase to satisfy demands, and changes that become closure may be catastrophic for regional supply. Recovery(Turnaround) activities consists of preventative equipment

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care, corrective general failure repair, strip-downs, replacement of complete and maintenance or overhaul. Unlike changes, stops are not always described [4]. Frequently, it contributes to natural gas or another reagent which is necessary for the production of gasoline is missing; refineries will simply stop. These contributions may be obtained if resources of natural are scarce, or if prices are ease too large, as an outcome of another [5–7]. Shutdowns and changes may happen as accidents of natural disasters, terrorist threats, or political turn oil happen. Interruptions are third type of closing activity that is most-often overlooked. Dissimilar shutdowns, interruptions may not happen as attempt to secure apparatus or personnel. It occurs when power supplies are interrupted, apparatus breaks down, or conveyance do not reach [8–10]. They also tend to be much shorter in duration. Objective of all types of interruption must reach a return to process of normal time, within the budget, without damaging the staff, and least possible work as unplanned. In addition, objectives may consist of future plan that must have goal to expand the period among closures, and establish how to provide short and specific maintenance periods. Closure consists of capacity to influence the future of financial and commitments of plant in a positive or negative way [11]. Heat interchange is an apparatus of crucial as many processes in oil and gas refinery plant and may establish the duration of closure of plant [12]. In heat exchanger, welded joints of tube-to-tube-sheet are a critical factor that needs the rate of separation [13].

One of the most analytic welds in tube-to-tube condensers, generators of steam, wide variant shells, and exchangers of heat pipe are used in energy, oil, and industry process of chemical. Honesty of these welds is needed to enhance reliability and process to secure apparatus as well as plant. Therefore, a control of effectual quality is needed to weld various materials to the range in diameter as 10 to 30 mm and in thicknesses of 1mm to some millimeters. But tube-to-tube-sheet (TTS) welding configurations are rarely utilized to weld. It consists of geometries which are not susceptible to nondestructive volumetric examination [14, 15]. In particular, radiographic test (RT) needs access of two-sides to place source and film, rewardingly that is generally not considered [16–19]. An x-ray can be done in an exceptional case where spikes are eliminated from tube sheet and preparation of butt weld is performed. Therefore, it is only practical if diameter and tubes of pitch is appropriate. Because of this, all known codes are grant compromise and it cannot insist as volumetric non-destructive examination (NDE). It specifies as liquid penetrating test (LPT) and leak test [20].

Literature review

T. Huang et al. [21] have introduced tube-to-tube welding generators of steam to consider the design of feature, materials, and manufacturing that provide solutions to weld store which has tolerated impact as inner damage because of loose parts. After analyzing three welding designs, recessed design types were embraced. Wang et al. [22] has suggested that the fixed-tube vertical exchanger did not work as chemical plant, and exchanger of heat tubes leaked too. To discover the mechanism of failure of the tubes, research series were carried out that included verification, examination of visual, evaluation of chemical composition, metallographic, the composition of scale layer, and examination of fluid task. Holes as well as cracks were seen at the end of the tube that welded to sheet as top. To classify the corrosion of pitting and cracking stress of stainless steel was genuine. A. Bouzid et al. [23] has introduced the characteristics of elasto-plastic tubes and environmental tubes are subjected to the expansion of hydraulic changes as imitated tube-to-tube sheet connection utilized finite element method (FEM) as numerical. Expansion of neighboring tube to get the sequence order of expansion and the organization of ligament consists of significant influence on residual contact pressure

Joshi et al. [24] have explained that Dhruva is a 100 MW reactor and consists of heavy water in refrigerant as primary and demineralized water as secondary. It consists of three vertical shell and heat tube exchanger as a system primary refrigerant. Heat exchanger has a construction that has heavy water on one side of the tube and light demineralized water on the other side of the housing. Based on identification of leak, heat exchangers were removed for repairs that could need the replacement of the cover gasket seals. The end caps of the exchanger heat plate were screwed with housing to double tongue and groove gasket that has ring as inner gasket and outer ring gasket to implement sealing. Yang et al. [25] have suggested that a spirally wound exchanger of heat did not work due to the reliability test in power plant of nuclear and an unusual rupture of tubes as heat transfer was obtained as inspection. To resolve the impact, macroscopic series as well as evaluation techniques of microscopic were carried out, and evaluation of finite element was utilized to evaluate distribution stress of heat transfer tubes as fault.

Senthil Kumaran et al. [26] have introduced a friction welding technology in tube to tube with support of positions as external tool. In addition, a tube of SA213 as well as SA387 plate was contrasted using single interference methods of fit. In addition, strength of the contrasted portion was evaluated with and without the help of block as retention. Consequently, optimization methods of the analytics such as genetic algorithm, variant evaluation, and design of orthogonal matrix Taguchi L9 were implemented in forecast of optimal binding force. In addition, parameters of input consist of projection of tube (mm), rotation speed of tool (rpm), and depth of cut (mm). In addition, strength of tensile was enhanced as an output parameter. In addition, the size of grain distribution such as weld zone and presence of base metal was scaled via the microscope of optics due to linear interception technique of American Society of Testing and Materials (ASTM). A novel method of integrated utilization system as engineering was developed by Barros et al. [27]. It was partially due to the use of MIVES (Integrated Value Model for Sustainable Evaluation, or Integrated Value Model for Sustainability evaluation, in translation). Effectiveness was evaluated based on the method in shell and tube heat exchanger. This method was evaluated earlier as a case study in bibliography of existing was examined, in this method to variant objective. The internal diameter of housing, the external diameter of the tube, and the deflector spacing were employed to execute [28, 29].

Design of tube to tubesheet welding

There are many Shell and tube heat exchangers that are commonly found in all the Saudi Aramco Plants, SABIC, and its plants of affiliates in Kingdom of Saudi Arabia. Heat exchanger is utilized to transfer thermal energy among at least two fluids, particles and strong fluids, surfaces and strong fluids at different temperature levels [30]. The basic component of heat exchanger tubes provides the transfer of heat surface by fluid flowing inside the tube and another flowing fluid through the outside of the tubes. Tubes are held instead of being inserted into the holes of tube sheet. Whether expanded in

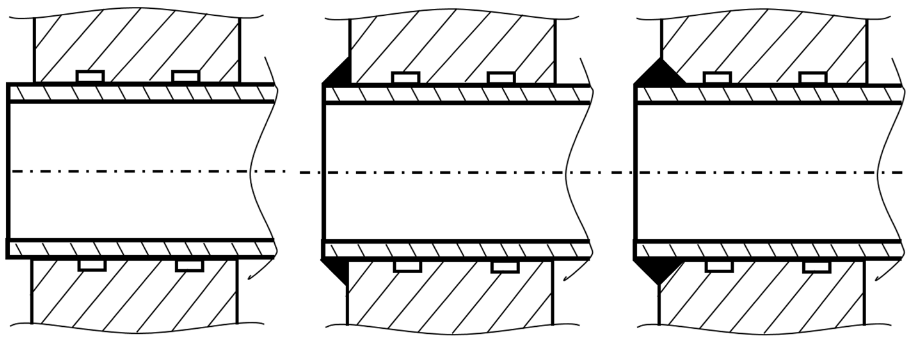

Fig. 1 Tube-to-Tubesheet welds. **a** Expanded TTS joint. **b** Seal welded TTS joint. **c** Strength welded TTS joint

grooves cut in the holes or welded sheet of tube protrudes from surface. Major fault of the exchanger of heat is corrosion of tubes and the jacket, blocking tubes, and failure of joints of tube to tube sheet. In design, exchanger of the heat is most essential part of tube in tube welding. It is useful for petrochemical, power generation, pharmaceutical, food processing industries, and power generation [31, 32].

To design the structure of tube-to-tube welds, three approaches are established. They are expanded TTS joint, seal welded TTS joint, and strength welded TTS joint. Figure 1 outlines three methods of welds from tube to tube sheet. First one is that expanded TTS is a process of expanding a tube to fully plastic state into contact with hole that creates residual interface pressure between the tube and tubesheet. Second, seal weld is used to support an expanded tube to tubesheet joint to ensure leak tightness. The tube normally projects beyond the face of the tubesheet 1/8″. So, when the tube is welded, it melts and fuses to the tubesheet. It is a single pass weld. The tube hole in the tubesheet is not beveled for a seal weld. Third, strength weld is provided "to carry longitudinal tube loads," and it also provides additional leak tightness. The procedure is essentially the same as a seal weld, except the tube hole in the tubesheet is beveled (as per drawing) to allow filler metal to be deposited. Generally, this is a 2-pass weld. Most commonly used joints was strength welded TTS joint. Consider the weld smoother outline, resistance, and induced corrosion/erosion of flow weld and materials of tube may decrease, when plant is shut down, we need to reduce the amount of residual radioactive corrosion products in system of primary, thus mitigating shutdown dose rates to workers. Primary and secondary pressure, temperature of reactor coolant is produced by welding the tube to the tube in service conditions. Under pressure and thermal load, restricted deformation is caused by the inclination of Tubesheet. Secondary stress is residual stress which does not induce the additional stress variations.

By taking into account of FEM analysis, the restricted deformation includes the lower head, Tubesheet, and shell connected to Tubesheet. In this model, the welding is assembled in a shape of triangle to pitch of 25 mm, hole pattern is 600, thickness of tube sheet is 50 mm, thickness of tube is 2.11mm, projection of tube is 3 mm, diameter of tube hole is 19.30mm, +0.05/−0.1mm, and ligament is 5.7 mm. The weld with triangular shape is depicted in Fig. 2.

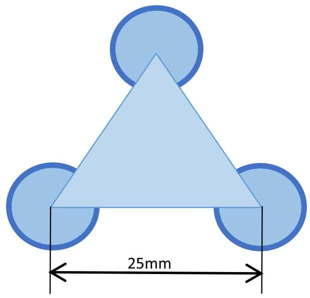

Fig. 2 Weld with triangular shape

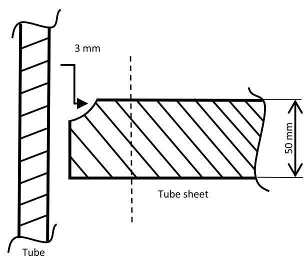

Fig. 3 Tube sheet groove design

From the model of lower assembly, the deformation is implemented and welding model as a constraint condition of forced deformation at every instant, at the same time pressure primary side and secondary side and final cover loads are generated by the pressure discrepancy among 1st loop and 2nd loop and thermal loads. In order to estimate the weld, three paths are chosen and placed at one of the sides in the tube and the other at tube sheet side and the third one in the middle. Considering the possible discontinuities and weld quality of other root weaknesses, a fatigue elimination factor is utilized to require a weld as partial penetration. The outline of testing tubesheet groove design is represented in Fig. 3. On evaluating the theoretical aspects of structures and materials prior, we now turn to the consideration of practical procedure as manufacturing that is needed to reach the desired welding performance. To meet the size of minimum, qualification test of welding procedure is carried out prior the production welding, as every section of at least 10 test welds is verified to micrograph consideration.

Novel processes of welding were introduced, in a way to implement laser welding that consists of many benefits such as productivity increasing and quality welds. Gas tungsten arc welding (GTAW) is still the mostly utilized welding process. Orbital GTAW is an ideal option to make welds with excellent through-wall properties. Therefore, GTAW was orbital without classification system of filler for filler materials. Prior to welding, 100% of visual test (hereinafter referred to as VT) was implemented. During welding, most product welding test coupons are needed to denote the welds of product and evaluate the strength of welding machine and reliability of procedure as welding. After welding, non-destructive tests are implemented, which consist of 100% liquid penetrant test (hereinafter referred to as PT) and macro test. Finally, after all the procedures of manufacturing, macro test is implemented, that is the final test to be implemented so that the heat exchanger can be accepted.

Table 1 Specifications, criteria, and P.no of base material

Criteria	Material	P.no vs. P.no	Tubesheet vs. Tube specifications
CS vs. SS	SA266 Gr.2 vs. SA312 316L	1 vs. 8	50-mm thick plate vs. 19.05 mm OD × 2.11 mm thick × 150 mm length
SS vs. SS	SA36+316L vs. SA312 316L	8 vs. 8	50 mm (6 mm Clad) thick plate vs. 19.05 mm OD ×2.11 mm thick × 150 mm length
AS vs. AS	SB564 800H vs. SB163 UNS8810	45 vs. 45	50-mm thick plate vs. 19.05 mm OD ×2.11 mm thick × 150 mm length

Selection of base material and filler metal

In this section, selection of the base material and filler metal is explained. Here, P. no of tube material to GTAW welding tube is carried out for 3 different combinations of carbon steel (CS)-stainless steel (SS), stainless steel (SS)-stainless steel (SS), and alloy steel (AS)-alloy steel (AS). P numbers are metals of basic group for complete rating list found in (QW / QB-422). F-Numbers are filler metals often known as "weld metal" limits of each other is defined in (QW-432). SFA number is a universal classification system for filler materials. These filler metals are required to be qualified separately for both qualifications of Welding Procedure Specification (WPS) and welder's performance. Nowadays in order to avoid the internal corrosion in industries, they are upgrading their existing heat exchangers tubes to SS or AS. Here, the tube sheet and tube material are selected based on P no of material that is inspected according to the standard of American Society of Mechanical Engineers (ASME) that manages the design and construction of boilers and pressure vessels. ASME functions as accreditation body and authorizes independent third parties as verification, testing, and certification agencies to inspect and secure compliance with Boiler Pressure Vessel Code (BPVC). Tube sheet material and tube material is selected based on P no of material which is inspected as per ASME Section II Part A and Part B. Table 1 depicts the specifications, criteria, and P no of base material. MTC's (Material Test Certificate) Heat number of plates was verified and transferred to test pcs plates accordingly. For tube inspection, the following parameters inspected and found acceptable [33].

- MTC's Heat number verification
- Manufacturing process
- Heat treatment
- Surface condition
- Chemical composition,
- Mechanical tests like flattening test, flaring test or flange test, hardness test, hydrostatic test, or non-destructive electric test
- Product marking
- PMI test/ grain size/ tensile strength/ yield strength/ and % of elongation (If req)

Filler metal was selected and it was based on ASME Sec II Part C as shown in Table 1 and based on chemical composition of base (Test) materials. Welding process will be GTAW. MTC of filler material was verified and found acceptable. Table 2 shows the P.no, F.no, and S.F.A no of filler metal [33].

Table 2 P.no, F.no, and S.F.A no of filler metal

P.no vs. P.no	S.F.A.no	F.no	Filler metal
1 vs. 8	5.9	43	ER Ni Cr-3 (1.6 mm Dia)
8 vs. 8	5.9	6	ER 316L (1.6 mm Dia)
45 vs. 45	5.14	45	ER Ni Cr-3 (1.6 mm Dia)

Experiment

The qualification of tube to tubesheet requires minimum 10 joints [33]. The step by step procedure to be conducted is explained in the following:

- Step 1: Tube is to tack with Tubesheet.
- Step 2: As per preliminary WPS, carryout first pass welding. All the values are noted by third party inspector.
- Step 3: Carry out visual inspection and penetrant testing.
- Step 4: As per preliminary WPS, carry out first pass welding.
- Step 5: Carry out visual inspection and penetrant testing.
- Step 6: After that, cleaning process and sent it to the lab.
- Step 7: Machining and macro etching
- Step 8: Preparation of result and WQTR card issuance

Table 3 delineates the process parameters for P no.1 vs. P no.8.Welding process involved would be GTAW process. Filler material will be ERNiCR-3 and diameter 1.6 mm. Current type polarity will be a DCEN. Same welders will be used throughout the welding under the supervision on third party inspectors. RP denotes the root pass and HP denotes the hot pass. Since two welders are used and each carryout 5 tubes, travel speed varies with welder's skill and it was noted down in the report for each tube welding by stopwatch.

$$\begin{aligned} \text{Heat input} &= (60 \times \text{Amps} \times \text{Volts})/(1000 \times \text{Travel speed}) \\ &= (60 \times 97.5 \times 9.15)/(1000 \times 74) \\ &= 0.7233\ \text{KJ/mm} \end{aligned} \tag{1}$$

Above heat input value was for tube no. 1 from the root pass welding which is shown in Table 3 already. Like all the tubes, both root and hot passes were calculated accordingly. Therefore, the average heat input for first tube in root pass welding is 0.7233 KJ/mm. As per the requirement, same is to be calculated for minimum or maximum heat input if required.

Results and discussion

Mechanical analysis result

Ten mock up welds have been sectioned through center of the tube for macro examination [33]. Forty exposed surface (refer to Fig. 4) has been smoothened and etched with $C_2H_40_2$+HNO_3 (acetic acid+ nitric acid) to give a clear definition of the weld and heat affected zone. Using a magnification of 12.5×, the exposed cross section of the weld shows no cracking, complete fusion of the weld deposit into the tube sheet and tube wall

Table 3 Process parameters for P no.1 vs. P no.8

Tube no	Weld layer	Current (Amp)	Voltage (volts)	Travel speed (mm/min)	Avg heat input KJ/mm
Tube 1	RP	97–98	8.8–9.5	74	0.7233
	HP	100–101	9.6–10.2	64	0.932
Tube 2	RP	96–97	9.0–9.6	75	0.717
	HP	100–101	9.2–9.7	72	0.787
Tube 3	RP	96–97	8.8–9.2	70	0.744
	HP	100–101	9.8–10.8	70	0.887
Tube 4	RP	96–97	8.8–9.5	74	0.715
	HP	99–100	9.5–10.2	57	1.036
Tube 5	RP	96–97	8.8–9.5	74	0.715
	HP	99–100	9.5–10.2	57	1.036
Tube 6	RP	95–97	8.5–9.4	79	0.655
	HP	100–101	9–10	67	0.855
Tube 7	RP	96–97	8.6–9.4	55	0.947
	HP	101–102	9.2–10	83	0.660
Tube 8	RP	97–98	9.2–10.2	52	1.09
	HP	101–102	9–9.8	81	0.706
Tube 9	RP	96–97	9–9.8	55	0.989
	HP	100–101	9.5–10.2	68	0.873
Tube 10	RP	96–97	9–9.8	55	0.989
	HP	100–101	9.5–10.2	68	0.873

face, complete penetration of the weld deposit, no porosity, and minimum leak path. Figure 4 shows macro details of P no.1-8 and same is to be followed for P no 8-8 and P no 45-45. Each process need 40 exposed surface and total of 120 tubes surface went macro examination.

Minimum leak path (MLP)

It is the distance from the root of the weld to the surface nearest the root. MLP must be equal that is required by the design or by the construction code or client requirement. For the strength weld joint MPL is the minimum distance required by a fluid from root side of the weld to get leaked from face side, i.e., tube sheet while designing the heat exchanger, critical and potential leak path of the fluid is tube to tube sheet joint. Hence, tube-to-tube sheet joint design is considered as the most important factor. side. The minimum leak path purely depends on tube thickness. Typically, minimal leak path is 2/3 of tube thickness. However, the design or fabrication code is stringent than the 2/3 in the thickness of the tube. Hence, the design or fabrication code shall be considered. The minimum leak path is 1.40mm which is in the acceptable criteria. The calculation is done as follows:

$$\text{Minimum leak path} = 2/3(2.11\ \text{mm}) = 1.40\ \text{mm} \tag{2}$$

CS-SS,SS-SS, and AS-AS tube to tube sheet minimum leak path value for all the 30 tubes was acceptable as all the value found more than 1.4 mm as shown in Table 4.

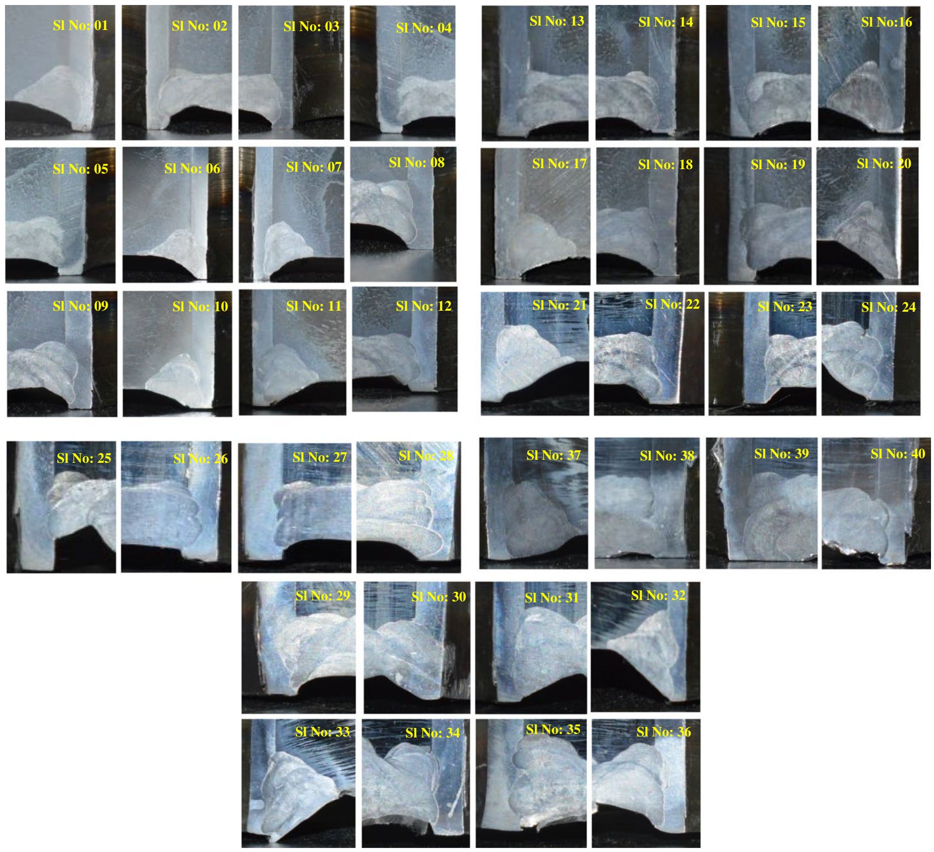

Fig. 4 Mechanical analysis (macro examination) for P no.1-8

Table 4 shows minimum leak path macro result for 3 different combinations of carbon steel (CS) to stainless steel (SS), stainless steel (SS) to stainless steel (SS), and alloy steel (AS) to steel alloy (AS). If any macro failed in any one of the tube, it will be mandatory to redo the test. If this PQR clears automatically welder is also qualified for WQTR issued along with PQR [33].

Table 5 depicts the minimum and maximum values of process parameters. The process parameters are material, weld layer, process, filler metal class and diameter (Dia) of filler metal, current type, current polarity, current amps, range of voltage, and speed travel. Record of actual range qualified is shown in Table 6. Figure 5 shows average value for CS-SS, SS-SS, AS-AS root pass TTS welding from the minimal and maximal value from Table 5. Figure 6 shows average value for CS-SS, SS-SS, AS-AS hot pass TTS welding from the minimal and maximal value from Table 5.

This result provides the technical basis for the qualification of welding in tube to tube sheet exchanger of heat as per ASME Sec IX is studied for different combination of materials [33]. As per required process parameter (essential variables), values are accepted after visual inspection, penetrant testing, and macro etching are checked. Value of minimal and maximal current for CS-SS TTS welding is 96–102 A. Value of minimal and maximal current for SS-SS TTS welding is 99–104A. Value of minimal and maximal current for AS-AS TTS welding is 84–87 A. Value of minimal and

Table 4 Minimum leak path

S.no	MLP for P no. 1-8	MLP for P no. 8-8	MLP for P no. 45-45	S.no	MLP for P no. 1-8	MLP for P no. 8-8	MLP for P no. 45-45
1	4.02	2.6	4.31	21	3.90	3.7	3.37
2	4.20	3	3.18	22	3.99	4.1	4.43
3	4.16	3.3	3.95	23	4.15	3.6	4.45
4	3.90	3.5	4.19	24	4.20	4	3.91
5	3.85	3.4	4.32	25	3.65	3.6	4.72
6	4.19	3.6	4.52	26	3.98	3.8	4.24
7	4.35	4	4.11	27	4.20	2.8	4.64
8	4.39	4.1	4.10	28	4.00	2.9	4.62
9	4.03	3.4	3.99	29	3.98	3.1	5.54
10	4.11	4	3.87	30	4.25	2.9	4.86
11	4.00	3.7	4.29	31	4.20	2.7	4.88
12	4.12	3.9	4.32	32	4.25	3.0	4.92
13	4.40	3.4	4.76	33	4.30	3.1	4.52
14	4.41	4	4.17	34	4.35	3.9	5.58
15	4.43	3	4.61	35	4.22	3.7	4.94
16	4.28	3.4	4.36	36	4.27	3.3	4.83
17	4.20	3.5	4.30	37	4.06	2.9	4.51
18	4.35	3.9	4.32	38	4.23	2.9	5.75
19	3.90	3	4.63	39	3.75	3.0	4.58
20	4.13	3.9	3.74	40	4.23	3.9	4.95

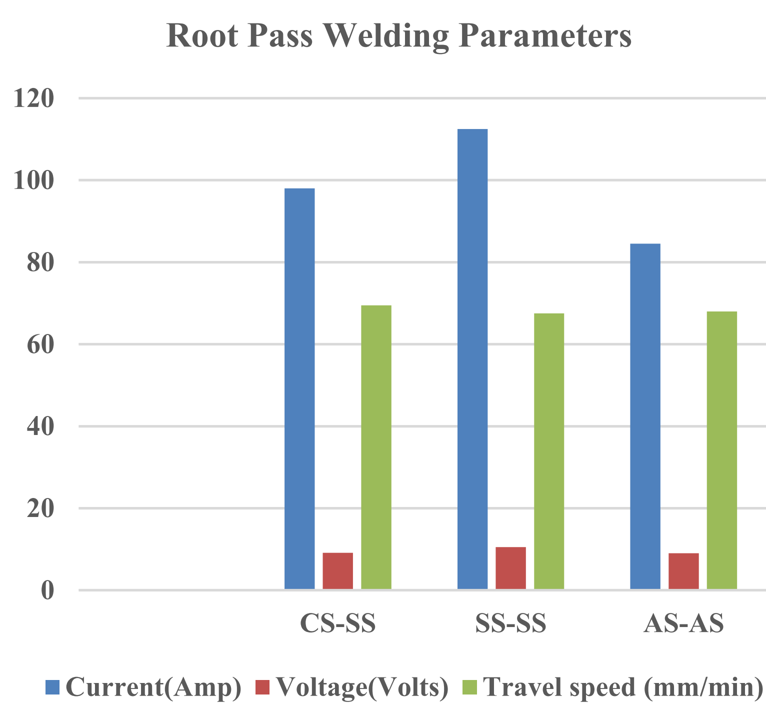

Fig. 5 Root pass welding parameter

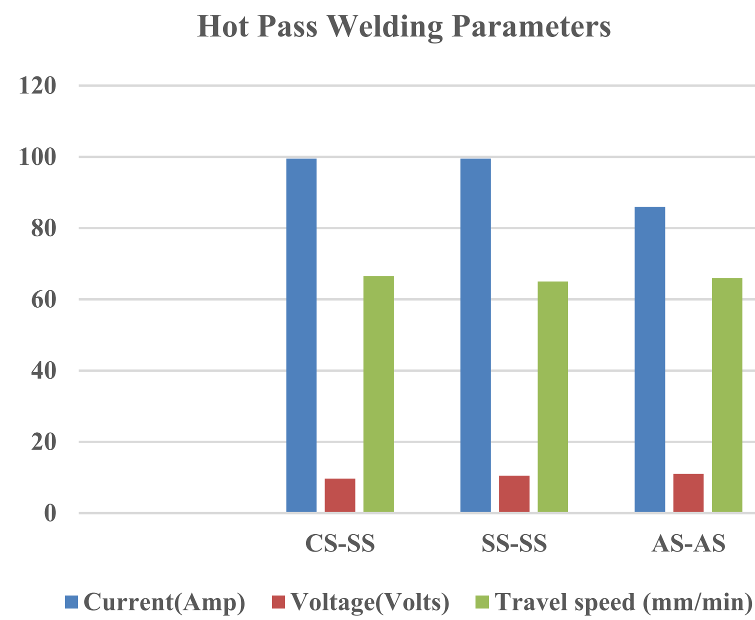

Fig. 6 Hot pass welding parameter

Table 5 Minimum and maximum values of process parameters

S.no	Material	Weld layer	Filler metal	Current (Amp)	Voltage (volts)	Travel speed (mm/min)
1	CS to SS	RP	ER Ni Cr-3	96–100	8.5–9.8	65-–74
		HP	ER Ni Cr-3	97–102	8.6–10.8	55–78
2	SS to SS	RP	ER 316L	99–124	9–12	60–75
		HP	ER 316L	95–104	9–12	60–70
3	AS to AS	RP	ER Ni Cr–3	84–85	8–10	67–69
		HP	ER Ni Cr-3	85–87	10–12	64–68

maximal voltage for CS-SS TTS welding is 8.5–10.8 V. Value of minimal and maximal voltage for SS-SS TTS welding is 9–12 V. Value of minimal and maximal voltage for AS-AS TTS welding is 8–12 V. Travel speed and heat input are based on welder speed per tube. Based on lab results and reports, there is no significant change in voltage value in tube to tube sheet welding for different material. Also a low current is required in AS-AS tube to tube sheet welding compared to others CS-SS and SS-SS tube to tube sheet welding. Minimum leak path never be 2/3 rd of wall thickness as per existing requirements. But as per report, value is at least equal to tube thickness or more. Mostly we get double the wall thick of tube (4.22 mm) or 1.5 times of wall thick of tube (3.16 mm).

Table 6 Record of actual values

Variable	Used in qualification	Range qualified	Variable	Used in qualification	Range qualified
Specification	SA 36 to SA 312 TP 316L	-	F-number	F.No.43	-
P-Number	P.No-1 to P.No-8	P.No-1 to P.No-8	Filler metal/Electrode diameter	1.6 mm	-
Welding process	GTAW	GTAW	Deposited thickness	4.2 mm	-
Type (manual, semi auto, auto)	Manual	Manual	Welding position	5G+5F	5G+5F
Backing (Yes/No) and type	Yes, metal	With backing only	Welding progression	Uphill	Uphill
Tube diameter	Ø19.05 mm	Ø17.145 mm and over	Multiple or single pass	Multiple	Multiple
Tube thickness	2.11 mm	1.9 to 2.32 mm	Gas shielding (GTAW)	Argon	Argon
Ligament size	5.7 mm	Above 5.13 mm	Current level (1st pass)	96 Amps	86.4 Amps to 105.6 Amps
AWS specification	SFA 5.14	-	Current level (2nd pass)	100 Amps	90.0 Amps to 110 Amps
AWS classification	ER Ni Cr-3 (INFO, only)	-	Current/Polarity (GTAW)	DCEN	DCEN
A-number	None	-			

Conclusions

Technical basis for welding qualification in tube to tube sheet exchanger of heat as per ASME Section IX is studied for different combination of materials which is proposed in this paper. Based on the requirement, the essential variable values are accepted after visual inspection, penetrant testing, and macro etching. Consequently, the value of minimal and maximal current and voltage for carbon steel (CS)-stainless steel (SS), stainless steel (SS)-stainless steel (SS), and alloy steel (AS)-alloy steel (AS) tube to tube sheet welding is accomplished. Furthermore, based on the welder speed per tube, the travel speed and heat input is estimated. By observing the lab reports, there is no change in the tube sheet welding voltage value for various materials. Finally, we conclude that the low current is required in AS-AS tube to tube sheet welding when comparing with CS-SS and SS-SS tube to tube sheet welding. We can carry out same research by changing the diameter of tube or changing the size of the filler metal or changing the welding process and to compare it. Also we can carry out the same material with different design, configuration like changing the pitch from triangular to square pitch. It will be necessary to carry out with post weld heat treatment (PWHT) or without PWHT satisfy as industry needs. Also some design requirements need tube to tube sheet welding expansion before welding or after welding. Based on above minimum leak path value change can be analyzed further.

Abbreviations

ASME American Society of Mechanical Engineers
ASTM American Society of Testing and materials
BPVC Boiler Pressure Vessel Code
FEM Finite Element Method
WPS Welding Procedure Specification
PQR Procedure Qualification Record

WQTR	Welding Qualification Test Record
TTS	Tube to Tubesheet Welding
GTAW	Gas Tungsten Arc Welding
MTC	Material test Certificate
RP	Root Pass
HP	Hot Pass
LPT/PT	Liquid Penetrant Testing
VT	Visual Testing
RT	Radiographic Testing
CS	Carbon Steel
SS	Stainless steel
AS	Alloy Steel
MLP	Minimum Leak Path
PWHT	Post Weld Heat Treatment
I	Current
V	Voltage
MW	Mega Watt
RPM	Rotation Per Minute

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Not applicable

Authors' contributions
MFS: experiment design, material selection, welding result interpretation, NDT works. Also he provided ideas and guidance on the manuscript. FTM: material arrangement (purchasing), welding machine arrangements, welders' coordination, macro etch analysis, and drawing preparation. AS: standards follow-up, draft paper preparation, Latex prep work, literature review, and third party inspector arrangement. All authors edited the manuscript and provided some references. All authors reviewed the results and approved the final version of the manuscript.

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Availability of data and materials
All presented data are available under any request.

Declarations

Competing interests
The authors declare that they have no competing interests.

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