International Journal of Modern Manufacturing Technologies
ISSN 2067–3604, Vol. XVI, No. 1 / 2024
https://doi.org/ 10.54684/ijmmt.2024.16.1.108

PREPARATION OF COMPONENTS FOR ORBITAL WELDING OF TITANIUM TUBES WITH TITANIUM CLAD STEEL SIEVE BOTTOM

Mateusz Przybyła[1], Agnieszka Rzeźnikiewicz[2], Jacek Górka[2]

[1]Famet S.A., Kędzierzyn Koźle, Poland
[2]Silesian University of Technology, Mechanical Engineering Faculty, Department of Welding Engineering, Konarskiego 18a, 44-100 Gliwice, Poland

Corresponding author: Agnieszka Rzeźnikiewicz, agnieszka.rzeznikiewicz@polsl.pl

Abstract: The article presents the method of preparing the tube sheet of a heat exchanger made of B265 Grade 1 titanium-clad steel with B338 grade 2 titanium tubes allowing for the qualification of the TIG (Tungsten Inert Gas) orbital welding technology. A test plate was made of A516M Grade 485 unalloyed steel clad with B265 Grade 1 titanium using the explosive method. The 300 x 300 mm plate consisted of a layer of 60 mm thick non alloy steel and 5 mm titanium clad. It had 20 holes drilled in a triangular arrangement, into tubes with a diameter of 34.93 mm made of B338 Grade 2 titanium with a thickness of 0.7 mm were welded. In order to obtain mechanical restraint inside the holes in the test plates, the titanium tubes were rolled out. For rolling, a five-roller was used, equipped with a retaining collar which allows the tube to move freely during rolling. The tests carried out showed that the proposed technology for preparing tube – sieve bottom elements allow for the preparation of a test plate for the qualification of welding technology. The test plate made in accordance with the technological assumptions met all the requirements necessary to qualify the technology for welding tubes with tube plates. Both in the case of non-destructive testing and macrographic testing, there were no problems with compliance with the PN-EN ISO 15614-8:2005 standard.

Key words TIG welding, titanium, plated steel, sieve bottom, welding of tubes to tube – plate joints

1. INTRODUCTION

Shell and tube exchangers currently constitute more than half of the number of devices of this type used in industrial installations, [1-10]. Due to the medium responsible for receiving heat, there are some limitations when it comes to the use of materials used for tubes located inside the exchanger. This is related to corrosion resistance because for example when seawater or water rich in sulphides and chlorides flow inside tubes, it is necessary to use titanium alloys. Titanium alloys are characterized by many physical and chemical advantages. Some of them are its lightness, good mechanical properties, resistance to electrochemical corrosion, biocompatibility. Because of this advantages titanium alloys are a perfect choice when designing structures exposed to considerable loads or operated in aggressive corrosion environments. Titanium and titanium alloys has become vital in many industries such as civil and military applications in fields as vast as in energy, transport, water treatment, and transport of corrosive liquids and gases, [6-17].
In each type of shell and tube heat exchanger the tubes should be connected to the tube plate (tubes are fixed freely, they are not connected with bulkheads). The technologies used to connect tubes with tube sheets include welding, rolling, adhesive bonding or explosive welding, [12-20].
The PN EN ISO 15614 standard *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 8: Welding of tubes to tube-plate joints* specifies requirements for the qualification of automatic arc welding technology of metal joints of tubes with tube-plates using technology test, [21]. This applies to both load bearing joints and those welded only for sealing purposes.
According to the ISO standard welding technological instructions should include the following data, [22]:
- welding method or methods (if more than one method is used to obtain a complete joint);
- technical conditions of test plate (plate thickness, cladding thickness);
- technical conditions of tube delivery (outer diameter, wall thickness);
- scale type and distance between tubes;
- joint geometry, hole size;
- welding position;

• cleaning and degreasing methods;
• type of the welding consumables;
• electrode diameter;
• minimum preheating temperature (it is also possible to indicate the interpass temperature in the case of welding in more than one pass);
• welding speed.

The main issue to qualifying welding technology is the appropriate preparation of tube – sieve bottom.

The purpose of the research was to develop a method for preparing the sieve bottom of a heat exchanger explosion-clad with titanium and titanium tubes allowing for the qualification of the TIG orbital welding technology.

2. EXPERIMENTS PREPARATION

The aim of the work was to develop a method for preparing the sieve bottom of a heat exchanger made of A516M grade 485 (P256GH) explosion-clad with titanium B256 grade 1 and titanium tubes made of titanium B338 Grade 2 allowing for the qualification of the TIG orbital welding technology. The chemical composition of the tested materials are presented in Tables 1 and 2.

Table 1. Chemical composition of the A516M Grade 485

Chemical composition %			
C	Mn	Si	Al
0.1 – 0.2	1.05	0.6	0.02
S	Cr		
0.03	0.3		

Table 2. Chemical composition of the titanium grade 1 and titanium grade 2

Chemical composition %					
	C	Fe	H	N	O
Ti Grade 1	≤ 0.1	≤ 0.2	≤ 0.015	≤ 0.03	≤ 0.18
Ti Grade 2	≤ 0.1	≤ 0.3	≤ 0.15	≤ 0.03	≤ 0.25

A test plate was made of A516M Grade 485 steel clad with titanium B265 Grade 1 using the explosive method, Figure 1. The test plate consisted of a 60 mm thick unalloyed steel layer and 5 mm thick titanium clad, Figure 2. It had 20 holes drilled in triangular arrangement, into which tubes with a diameter 34.93 mm were welded. The tubes are made of titanium B338 grade 2. The titanium tubes were cut into 100 mm long sections. Their end was degreased, similarly to the test plate with its holes. The tubes were measured using a three-point bore gauge. The measurement results are presented in table 3.

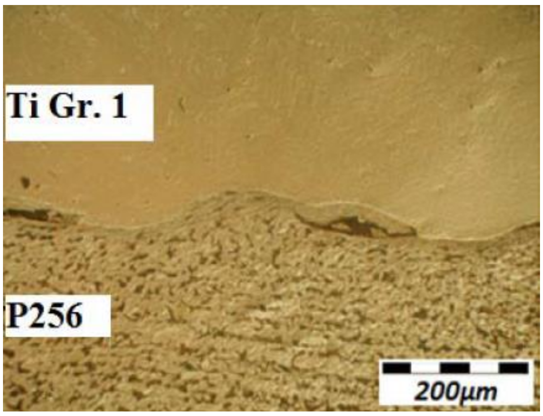

Fig. 1. A view of the titanium-clad plate

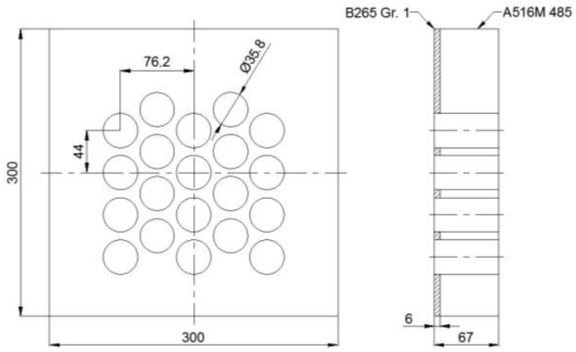

Fig. 2. Diagram of the test tube plate

Table 3. Results of hole measurements in a test plate before welding process

No of the hole	1	2	3	4	5
Diameter [mm]	35.399	35.400	35.403	35.403	35.404
No of the hole	6	7	8	9	10
Diameter [mm]	35.404	35.399	35.398	35.402	35.402
No of the hole	11	12	13	14	15
Diameter [mm]	35.402	35.403	35.403	35.401	35.402
No of the hole	16	17	18	19	20
Diameter [mm]	35.403	35.403	35.403	35.405	35.404

In order to obtain mechanical fixation inside the holes of the test plate, after measuring the diameter of the holes, the titanium tubes were rolled out. The tool used for rolling is a five-roller equipped with an interlocking collar, which allows the tube to move freely during rolling, Figure 3.

Table 4. Measurements report of final tubes expanding

Hole no.	Real dimension			
	DB	2S	Di	Ha
1	35.399	1.40	34.111	16
2	35.400	1.40	34.106	15
3	35.403	1.40	34.097	13
4	35.403	1.40	34.088	11
5	35.404	1.40	34.085	12
6	35.404	1.40	34.112	16
7	35.399	1.40	34.093	14
8	35.398	1.40	34.102	14
9	35.402	1.40	34.090	13
10	35.402	1.40	34.081	11
11	35.402	1.40	34.091	13
12	35.403	1.40	34.082	11
13	35.403	1.40	34.080	11
14	35.401	1.40	34.082	12
15	35.402	1.40	34.085	12
16	35.403	1.40	34.079	11
17	35.403	1.40	34.080	11
18	35.403	1.40	34077	11
19	35.405	1.40	34.077	10
20	35.404	1.40	34.083	11
	Theoretical dimensions			
	Ha min	Diameter min	Ha max	Diameter max
1-20	12%	33.964	22%	34.234

where: DB represents the tube hole of test plate of sieve bottom; S is a real thickness of the wall of the tube; Di means inside diameter of tube after expanding and Ha the expanding degree.

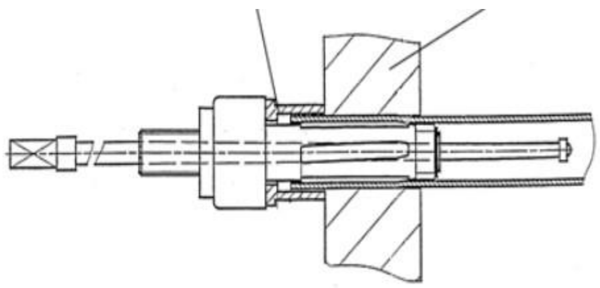

Fig. 3. Diagram of the tube reeling machine with the tube in one of the hole in the test plate

The degree of the tube expanding obtained as a result of the process was between 10% and 16%. After tube expanding the internal diameters of the tubes were measured. As a result of tube expanding, each tube protruded beyond the sieve on the clad side by approximately 3 mm. It required facing the ends of the tubes using a special facing head, Figure 4. After this treatment, the burrs formed after processing were removed by brushing. The tube may protrude from the sieve maximum 0.3 mm. A diagram of a properly prepared tube for the welding process is shown on Figure 5. The measurement report of final tubes expanding is in Table 4. All diameters of the holes, expanding degrees are in ranges given in standards.

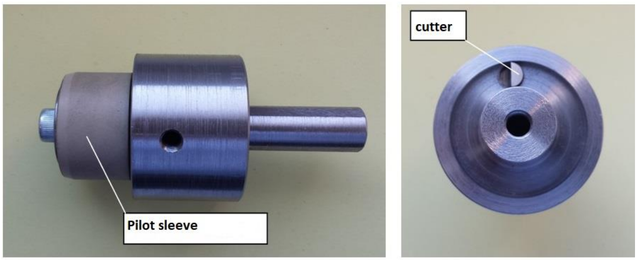

Fig. 4. A view of the facing head

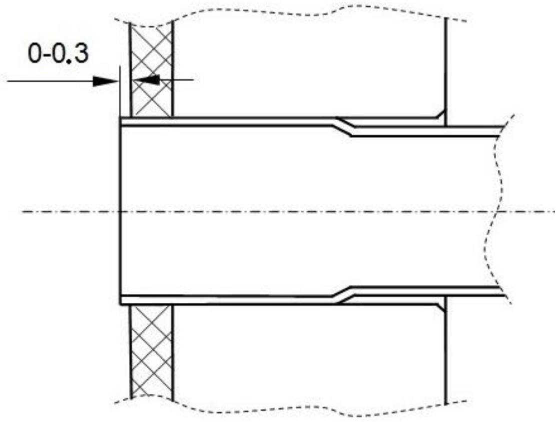

Fig. 5. Diagram of a properly prepared tube for the welding process

The welding process was carried out on a TIG orbital welding device. Joints were made in accordance with a previously adopted technology and parameters. Parameters used for the welding process: welding current – 55A, welding speed – 20 cm/min, arc voltage – 9.0 V. The direct current was set with negative polarity. Linear welding energy was 0.41 kJ/cm. A tungsten electrode with a diameter of 1.6 mm and a sharpening angle of 30^0 was used. Shielding gas outflow rate (99.998% pure argon) – 30 l/min.

3. RESULTS AND DISCUSSION

Visual tests and penetrant tests of the welded test plates did not show any welding defects coming to the surface, Figures 6 and 7.

Fig. 6. A view of the test plate

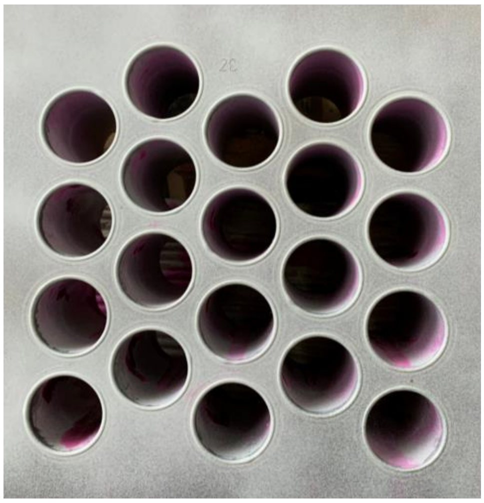

Fig. 7. A view of the test plate after penetrant testing

Also, radiography tests and macroscopic examinations did not show any welding non conformities in the area of the weld and HAZ, Figure 8.

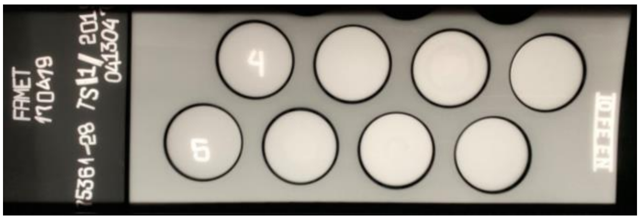

Fig. 8. A view of the test plate after RT examination of the fourth and fifth row of joints

The PN-EN ISO 15614-8 standard in point 7.2.5 macroscopic tests, specifies what the joint dimension “a” should be. This dimension should be the equal to the radius of the largest circle that is completely inscribed in the weld and whose center is at the lowest point of the root. The size of the dimension must meet the condition a ≥ 0.9 t, where t is the tube wall thickness, Figure 9.
While taking photos of the sections using a light microscope, the size of “a” dimension was measured. The values obtained did not exceed 0.63 mm (for a tube with a wall thickness t = 0.7 mm, the dimension of 0.9 t is 0.63 mm). Macroscopic tests have shown that the weld in terms of geometry meets the requirements of the PN EN ISO 15614-8 standard, Figure 10.

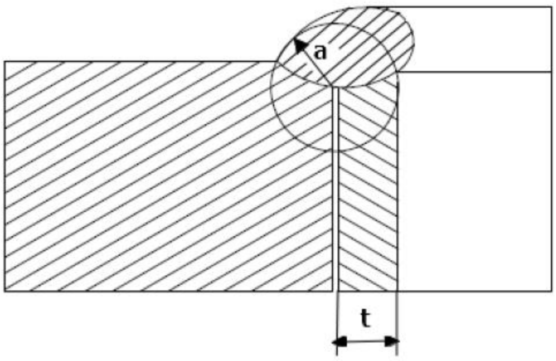

Fig. 9. Diagram showing how to designate “a” joint dimension

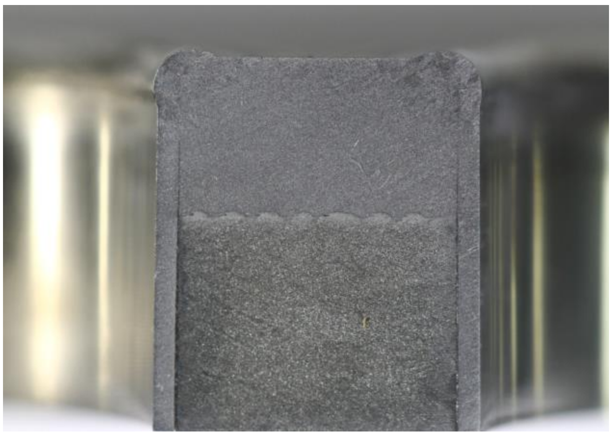

Fig. 10. A view of the macrostructure of the welded joint

The weld consists of a large grain of α phase and α’ phase (titanium martensite), inside which twins can be observed. The grains are large enough that one grain is included both of the weld root and of the weld face. This phenomenon is related to the formation of large grains during the crystallization of the weld metal. The dark horizontal line is the result of existence of a gap between the tube and the sieve plate, Figure 11.

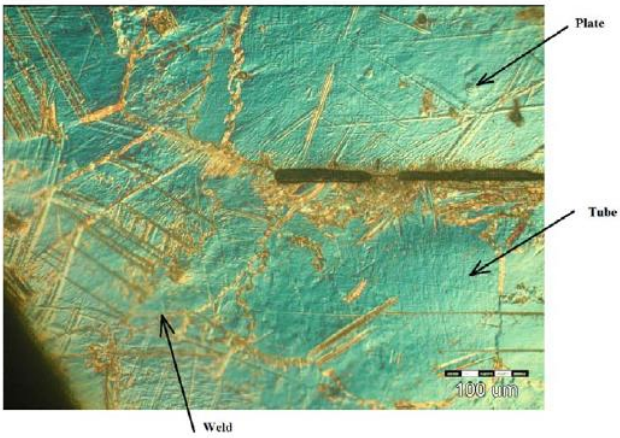

Fig. 11. Microstructure of a weld made in the properly gas-shielded welding process; Nomarski contrast

4. CONCLUSIONS

Previous research conducted by the Authors [21] showed that in order to ensure the appropriate quality of the connection of titanium tubes with the sieve plate, continuous control of the welding process is necessary. During the industrial process, defects may occur due to insufficient protective gas shielding, incorrect positioning of the tungsten electrode, too high electrode movement speed resulting from an incorrectly set welding program as well as too high current during welding process.

Based on the TIG orbital welding test of the sieve bottom of a heat exchanger made of A516M grade 485 (P256GH) explosion-clad with titanium B256 grade 1 and titanium tubes made of titanium B338 grade 2, the following conclusions can be drawn:

- the developed technology for preparing tube – sieve bottom elements allow for the preparation of a test plate for the qualification of welding technology,
- the test plate made in accordance with the technological assumptions met all requirements necessary to qualify the technology for welding tubes with sieve plate,
- non-destructive tests and macrographic test did not reveal the existence of any problems with compliance with the PN EN ISO 15614-8 standard,
- preparing the joint before welding process by cleaning of impurities from the future weld area significantly reduces the welding imperfections.

Conflicts of Interest: There is no conflict of interest.

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Received: April 12th, 2024 / Accepted: June 15th, 2024 / Paper available online: June 20, 2024 © International Journal of Modern Manufacturing Technologies.