QUALIFICATION PROCESS FOR MICRO PLASMA WELDING OF TUBE-TO-TUBULAR PLATE JOINTS IN LOW-CARBON AUSTENITIC STEEL

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Abstract: *Micro plasma welding is a specialized arc welding process that demands high precision and control, making it particularly suitable for thin-walled components and small-scale assemblies. In accordance with international and national standards, welding is classified as a special process, requiring stringent measures to ensure consistent and repeatable outcomes. Given the critical nature of micro plasma welding—especially in applications where dimensional accuracy and metallurgical integrity are paramount—both the welding technology and the personnel performing the welding must be properly qualified. The qualification of a micro plasma welding process entails rigorous assessment and documentation, considering factors such as joint configuration, welding parameters, base material type, and the specific characteristics of the welded connection. This paper presents the key quality requirements and procedural steps necessary for the qualification of a micro plasma welding process applied to a tube-to-tubular plate joint, using a low-carbon austenitic stainless steel as the base material.*

Keywords*:* Microplasma, Quality, Welded Structures, Non-Destructive Testing.

1. INTRODUCTION

Plasma arc welding was introduced to the industry in 1964 to enhance control over the arc, particularly at low current levels. Since then, it has maintained its relevance by offering precise arc control, high weld quality, and extended electrode life, making it ideal for both manual and automated applications [1].

Micro plasma welding is a fusion welding process in which energy transfer occurs through heating with a constricted electric arc, which burns between an electrode and the workpiece or between an electrode and a constriction nozzle [2]. Welding protection is ensured by an inert gas or a gas mixture. Welding can be performed with or without filler material. The process is like TIG welding, with the distinction that the plasma arc is constricted, either mechanically or electromagnetically. As a result, the temperature of the plasma arc column is significantly higher than that of the TIG arc [3].

Plasma welding is widely employed in various joining processes, from miniature component welding to seam welding and high-volume production.

A specific variant, pulsed current micro plasma arc welding (MPAW), involves alternating the welding current between peak and background values at a predetermined frequency. The peak current ensures adequate penetration and bead profile, while the background current maintains arc stability [4]. This pulsing technique effectively concentrates arc energy to create a series of overlapping weld nuggets. Compared to conventional constant current welding, pulsed MPAW leads to lower overall heat input, resulting in narrower heat-affected zones (HAZ), refined microstructures in the fusion zone, and reduced distortion and residual stresses. Additional benefits include better bead contour and improved tolerance to thermal variations [5].

The controlled heat input significantly reduces the formation of sensitized zones, which are prone to chromium carbide precipitation and subsequent intergranular corrosion. By concentrating the arc energy, pulsed MPAW ensures better penetration control and narrower fusion zones, which is especially beneficial in thin-gauge stainless steel components. The refined microstructure and reduced heat-affected zone (HAZ) contribute to maintaining the mechanical strength and ductility of the weld, while minimizing residual stresses. Additionally, the process promotes a cleaner weld appearance with minimal spatter and oxidation, reducing the need for post-weld finishing [6].

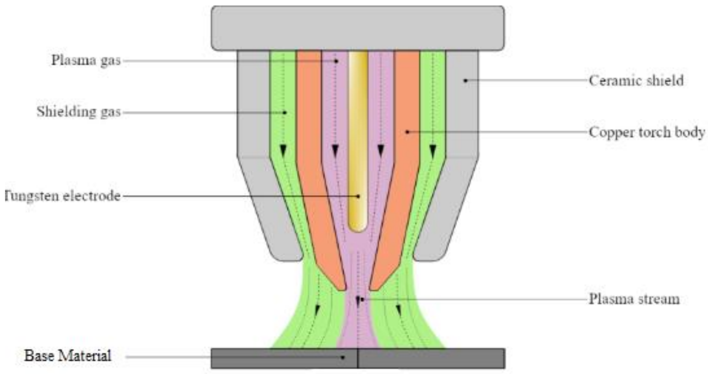

Fig.1. Schematic of microplasma arc welding [7]

These advantages are particularly important in the fabrication of components exposed to demanding conditions. Austenitic chromium-nickel stainless steels, such as X2CrNi19-11, are commonly used in such applications due to their excellent resistance to heat and corrosion. One notable example is the use of X2CrNi19-11 stainless steel in the energy industry, specifically in the production of stator bars for cooling systems [1-3]. These stator bars are crucial components in power generation equipment, where they are exposed to high thermal and mechanical stresses. In this application, thin sheets of 304L steel are precisely welded to form the stator bars, requiring accurate longitudinal welding along the seams - a process that is ideally suited for micro plasma welding due to its precision and ability to control heat input effectively.

Due to the high electrical conductivity required in stator bars, maintaining metallurgical purity and preventing weld inclusions is essential. The low contamination risk associated with micro plasma welding, combined with its ability to produce smooth, continuous welds with uniform microstructures, makes it highly advantageous in this context. In addition, the low dilution rates achieved during the process help preserve the corrosion-resistant properties of the base material, preventing premature degradation when exposed to cooling fluids and operational stressors.

As power generation technologies evolve toward higher efficiency and reliability, the demand for welding techniques that ensure durability, thermal performance, and dimensional precision continues to grow. Pulsed MPAW, when applied to stainless steel stator bars, offers a compelling solution that aligns with these performance criteria, making it an indispensable tool in modern energy system manufacturing [1,4,5].

2. MATERIALS AND METHODS

The present paper aims to present the qualification process of the micro plasma welding procedure for joint of the pipe-to-tubular plate type, in accordance with ISO 15614-8: 2016 [8].

The base material used is X2CrNi19-11, an austenitic stainless steel commonly used in the manufacturing of products for the food industry, the nuclear industry, and pressure vessels.

The chemical composition and properties of the base and filler material (W 19 12 3L) are presented in Table 1 and Table 2.

Table 1. Chemical composition of the base and filler materials in wt.%.

Materials	C	Si	Mn	Ni	P	S	Cr	N	Mo
X2CrNi19-11	max. 0.03	max. 1	max. 2	10 … 12	max. 0.045	max. 0.015	18 .. 20	max. 0.11	-
W 19 12 3L	0.02	0.45	1.4	12.5	max. 0.025	max. 0.02	19	-	2.8

Table 2. Mechanical properties of the materials used.

Materials	Hardness (HB 30)	Yield Strength (MPa)	Tensile Strength (MPa)	Impact Energy KV at 20 °C (J)	Elongation (%)
X2CrNi19-11	215	≥180	460…680	≥60	≥35
W 19 12 3L	215	≥180	460…680	≥47	≥30

The filler material, commercially known as INERTROD 316L, produced by Oerlikon, was used for creating the welded joints. The metal rod used was W 19 12 3L, classified according to EN 14343:2017 [10], with a nominal diameter of 1.00 mm.

For welding the tubes to the tube-plate with the micro plasma process, the joints were prepared as in the figure 2, where MB1 represents the tube and MB2 represents the tube-plate. The components were laser cut and mechanically grinded to ensure the offset of 0.3-0.6 mm of the tubes to the welding plate required in the figure 2.

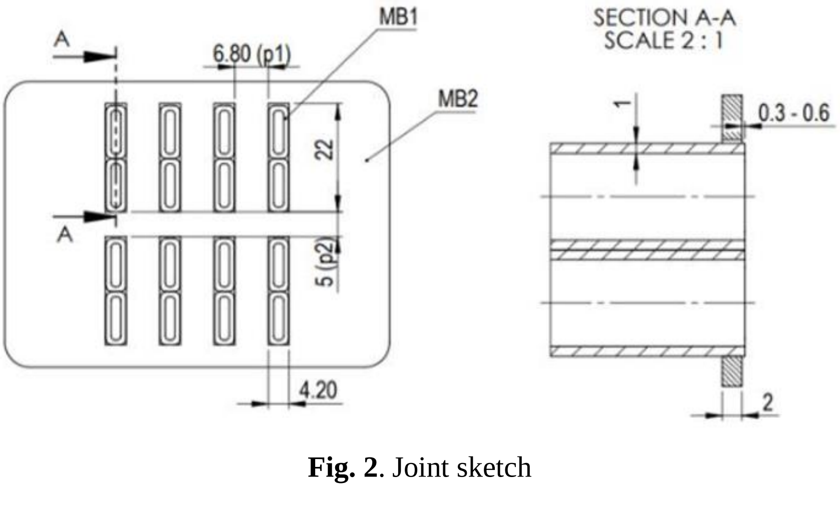

Fig. 2. Joint sketch

After the mechanical processing of the joints, the components were fixed in devices and welded with the welding power source PLASMAFIX 51, shown in Figure 3, manufactured by Lincoln Electric (Dearborn, Michigan, USA). The technical specifications of the power source are presented in Table 3 [11]. The welding parameters used for qualifying the welding procedure are shown in Table 4.

Table 3. The technical specifications of the power source

Supply Voltage [V]	230
Welding Current [A] at 100% duty cycle	0.08…50
Pulsation [Hz]	0.1…10000
Pilot arc pre-flow gas	5…25
Pilot arc post-flow gas [s]	0…25
Slope-out 1 time [s]	0 … 99.9
Slope-out 2 time [s]	0 … 99.9

Fig. 3. PLASMAFIX51 welding power source [11]

Table 4. Welding regime parameters used for welding procedure qualification

Welding current	18 (pulse base), 21 A (pulse peak)
Arc voltage	21…22 V
Welding speed	19 cm/min
Type of current	Pulsed current, direct polarity

According to the EN ISO 15614-8:2016 [8] standard, to evaluate the quality of the welded joint and implicitly the, a series of non-destructive and destructive testing methods were applied, as specified in Table 5.

Considering that in this study a tube with a major side diameter of 10.8 mm is analysed, with a base material from group 8 [12], a thickness of 1 mm, and a tubular steel plate from group 8 [12] with a thickness of 2 mm, the following destructive and non-destructive testing methods are applicable to the welded joint presented in this paper [8]:

- Visual examination
- Liquid penetrant examination
- Radiographic examination
- Macroscopic examination, 7 specimens.

Table 5. Examination and testing of the test pieces

Tube Arrangement in the Tube Plate	Number of Welds and Type of Test	Extend of testing
Square arrangement	— For outer diameter < 40 mm (12 pipe ends) — For outer diameter ≥ 40 mm (nine pipe ends) — Visual examination — Liquid penetrant examination — Radiographic examination — Macroscopic examination	 100% 100% 100% Seven specimens (Ø < 40 mm) Six specimens (Ø ≥ 40 mm)

3. RESULTS AND DISCUSSIONS

The qualification test consisted of welding 12 rectangular pipes arranged in a square pattern, measuring 10.8 × 4 mm with a wall thickness of 1 mm, onto a 2 mm thick tubular plate, as shown in Figure 4.

Fig. 4. The welded joints

The welding process was monitored throughout its entire duration. Following the visual inspection of the sample according to EN ISO 17637:2016 [13], no imperfections exceeding the limits defined in EN ISO 5817 [14], Level B were detected. The types of imperfections evaluated included: cracks, crater cracks, surface pores, burn-through on the pipe wall, and metal overflow greater than 0.5 mm.

Liquid penetrant testing was performed on the welded sample. No non-conformities were detected. According to EN ISO 3452-1 [15], no defects were identified during the liquid penetrant examination that would lead to the sample being rejected.

Radiographic testing was conducted on the welded sample. No non-conformities were identified.

According to EN ISO 17636-1 [16], no imperfections exceeding the allowable limits defined by EN ISO 5817 [15], Level B were found. The inspected imperfections included: cracks, crater cracks, elongated pores, vermicular pores, pore clusters, solid inclusions, and lack of fusion.

The macroscopic examination was also declared acceptable (Figure 5), as the penetration criterion of 0.9 mm (i.e., 90% of the 1 mm pipe wall thickness) was met.

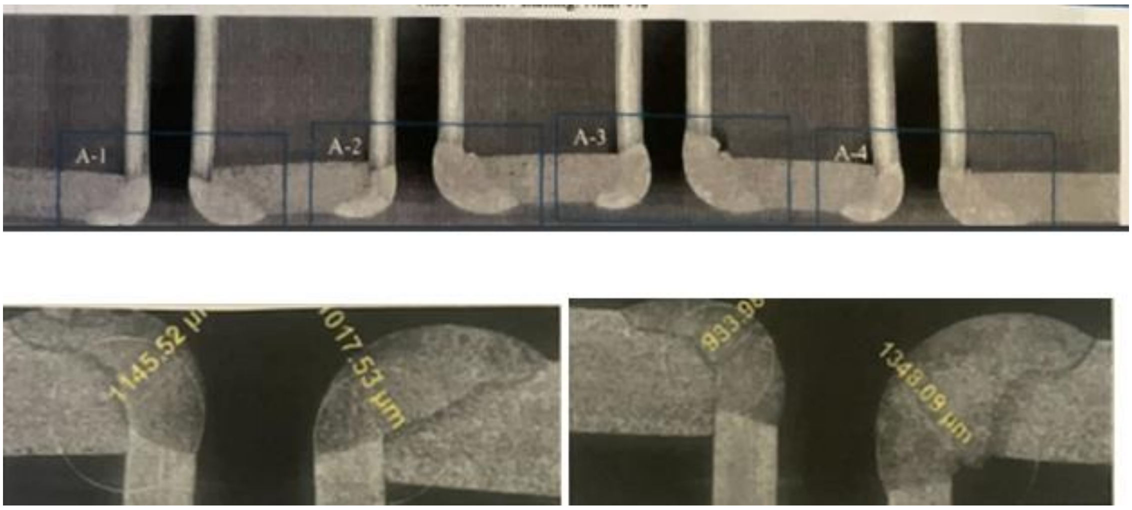

Fig. 5. Macrographic analysis of the welded joints

Figure 5 presents the macrographic analyses that demonstrate this result. The weld penetration was between 933 and 1145 μm.

Therefore, the sample complies with the requirements of EN ISO 15614-8:2016 [8], as specified in paragraph 8.2.5, Table 4.

4. CONCLUSIONS

- The welding process is a complex operation that must be verified and qualified before actual production begins.
- The welding procedure qualification was carried out in accordance with the quality requirements outlined in SR EN ISO 15614-8:2016.
- To verify the conformity of the welded samples, both non-destructive tests (visual inspection, liquid penetrant testing, and radiographic testing) and destructive testing (macroscopic examination) were performed.
- Following the examinations, no imperfections were found that would lead to the rejection of the samples, and thus the welding procedure was qualified and approved for use in production.
- The qualification process demonstrated the effectiveness and reliability of the pulsed micro plasma arc welding technique for joining tubular components with tight tolerances.
- The results confirmed the mechanical and metallurgical soundness of the welds, with full penetration and minimal discontinuities.
- The applied inspection methods ensured compliance with the most stringent acceptance

criteria (Level B of SR EN ISO 5817).

- Therefore, this procedure can be confidently applied in high-demand industrial sectors, including energy and nuclear applications, where weld integrity is critical.

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