

M. STOLECKI*, H. BIJOK**, Ł. KOWAL**, J. ADAMIEC*[#]

LASER WELDING OF FINNED TUBES MADE OF AUSTENITIC STEELS

SPAWANIE LASEROWE RUR OŻEBROWANYCH ZE STALI AUSTENICZNYCH

This paper describes the technology of welding of finned tubes made of the X5CrNi1810 (1.4301) austenitic steel, developed at Energoinstal SA, allowing one to get high quality joints that meet the requirements of the classification societies (PN-EN 15614), and at the same time to significantly reduce the manufacturing costs. The authors described an automatic technological line equipped with a Trumph disc laser and a tube production technological process. To assess the quality of the joints, one performed metallographic examinations, hardness measurements and a technological attempt to rupture the fin. Analysis of the results proved that the laser-welded finned tubes were performed correctly and that the welded joints had shown no imperfections.

Keywords: laser welding, finned tubes, austenitic steels, the power industry

W pracy przedstawiono technologię spawania rur ożebrowanych ze stali austenicznej X5CrNi1810 (1.4301), opacowaną w firmie Energoinstal SA zapewniającą uzyskanie wysokiej jakości połączeń spełniających wymagania towarzystw kwalifikacyjnych (PN-EN 15614), przy istotnym obniżeniu kosztów wytwarzania. Opisano automatyczną linię technologiczną wyposażoną w laser dyskowy firmy Trumph oraz proces technologiczny produkcji rur. Do oceny jakości złączy spawanych wykonano badania metalograficzne, pomiary twardości oraz technologiczną próbę odrywania żebra. Na podstawie analizy wyników stwierdzono, że rury ożebrowane spawane laserowo są wykonane prawidłowo, a w złączach spawanych nie ujawniono niezgodności.

1. Introduction

The need to reduce emissions from large power units formulated in the European Directive 2001/80/EC requires the construction of new flue gas desulphurisation systems, modernization of the existing units and construction of new units with supercritical parameters [1].

In the process of construction of power units with supercritical parameters one has to take into account the fact that the operating temperature and pressure are higher than those for sub-critical parameters, which in turn requires the application of materials with increased high-temperature creep resistance and heat resistance, such as austenitic steels [2,3].

Tubular heat exchangers constitute an important element of the boiler part of modern power units. Finned tubes with continuous or serrated fins, depending on the operating parameters of the working medium and the flue gas, can be used as heaters, economizers or superheaters. These tubes considerably increase the heat exchange surfaces, enabling one to fully optimize the boiler heating surfaces and thus to reduce the boiler dimensions and weight.

Nowadays finned tubes are usually made in the process of automatic welding in an active gas shield, using a consumable electrode (MAG). The particular elements are joined by a fillet weld or a butt weld done under the fin. The first method is characterized by low productivity, whereas the second one does not guarantee the required quality of the welded joint. While designing components for the power industry, one tends to apply on an increasingly more frequent basis, apart from new materials, new technological solutions, such as laser or hybrid welding [4,5]. The application of laser equipment for welding has many advantages. It also leads to a decrease in its prices, with a simultaneous increase in its reliability, as well as the power and the quality of the emitted beam [6].

The company Energoinstal SA attempted to weld finned tubes made of austenitic steels, using an innovative station for automatic laser welding. The station is made up of a TRUDISK 8002 laser disc of the Trumph company, with a system dividing the laser beam into two optical fibers, a system turning and feeding the tubes during the welding process, and an automatic painting system. The diagram of the welding system is shown in Figure 1

* SILESIA UNIVERSITY OF TECHNOLOGY, FACULTY OF MATERIALS ENGINEERING AND METALLURGY, 8 KRASINSKIEGO STR., 40-019 KATOWICE, POLAND

** ENERGOINSTAL S.A., 188 D. ROZDZIENSKIEGO AV., 40-203 KATOWICE, POLAND

[#] Corresponding author: janusz.adamiec@polsl.pl

TABLE 1

Chemical composition and properties of the material of the tube and steel used in the tests

Element [%]	C	Cr	Ni	Si	Mn	N	S	P
tube Ø 32x2	0.019	18.4	10.25	0.52	1.26	0.041	0.003	0.037
strip 15 x 1	0.05	18.1	8.1	0.43	1.44	0.049	0.002	0.032
EN 10216-5	0.07	17.0 -19.0	8.0 -10.5	≤ 1.0	≤ 2.0	≤ 0.11	0.015	0.040
Mechanical properties		Rp ₀₂ min. [MPa]		Rp ₀₁ min. [MPa]		R _m [MPa]		A ₅ [%]
tube Ø 32x2		280		308		542		55
strip 15 x 1		290		323		640		56
EN 10216-5		195		230		500÷700		40-35

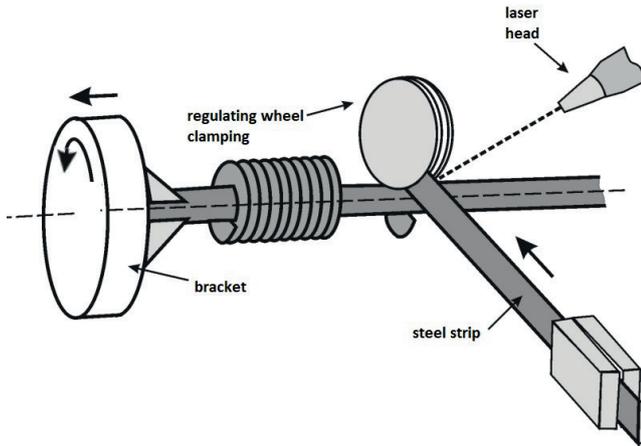


Fig. 1. General diagram of the welding system

The TRUDISK 8002 laser has been equipped with two 30-meter long optical fibers, which, combined with two welding heads, allows one to weld alternatively at each line of the station. Such a system maximizes the usage of the laser. When the welding process is in progress at line 1, another tube is being prepared at line 2. Thanks to the applied transport system, the tubes are moved with a linear speed of up to 5 m/min (Figure 2). The length of the welded tubes ranges from 3 to 24 m, while the beads are maintained in the range from 50 to 250 mm. The welding head positioning system is an important factor enabling one to weld finned tubes with rotational speeds exceeding 100 rpm (fig.3).



Fig. 2. General view of the station for the welding of finned tubes in the company Energoinstal SA

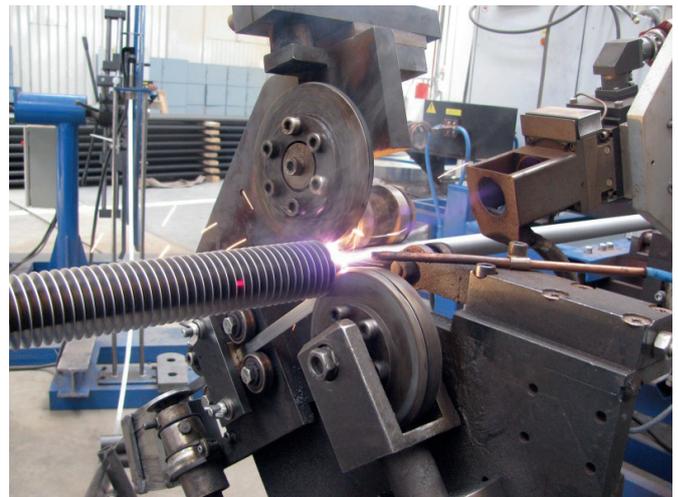


Fig. 3. View of the operating station for the welding of finned tubes in the company Energoinstal SA

The company Energoinstal SA has designed a triaxial system with a flexible adjustment in each axis, which enables one to precisely adjust the position of the laser head, to automatically tack the strip before the beginning of the welding process and to automatically cut the strip with the laser beam after the end of the welding process. To heat the tubes before the welding, one has designed a tube induction heating system, which, compared to the gas heating system, allows one to fully adjust and control the preheating temperature. This system is integrated with the entire line and allows one to heat tubes of ϕ 44.5 in diameter and with 5 mm-thick walls to the temperature of 300°C, with the linear speed of the feed of 5m/min. The advantage of the proposed solution, compared to the presently used one, is that it can be applied to a highly efficient welding process for finned tubes made of austenitic steels.

2. The test material and manufacturing technology

In the tests one used a finned tube measuring ϕ 32 x 2 mm, made of austenitic steels in the X5CrNi18-10 (1.4301, TP 304) grade, according to EN 10216-5:2004/ASTM A312M-12 and a strip measuring 15 x 1 mm, made of the same steel, manufactured in accordance with EN 10028-7/ASTM A240M-11. The chemical composition and the mechanical properties of the test material are shown in table 1.

The welding was performed at an automatic line for laser welding of finned tubes, developed in the company Energoinstal S.A. (Fig. 3). One made a finned tube with a continuous fin, with a distance of 6.25 mm between the fins. The welding parameters are presented in Table. 2. Figure 4 shows the macrostructure of the tube-fin joint made with a laser beam of the power of 2.8 kW.

TABLE 2
Parameters of the welding of finned tubes made of austenitic steel X5CrNi18-10

beam power [kW]	revolutions [n/min]	peripheral speed [m/s]	feed [mm]	number of fins [1/m]
2.8	40	0.067	5.8	160

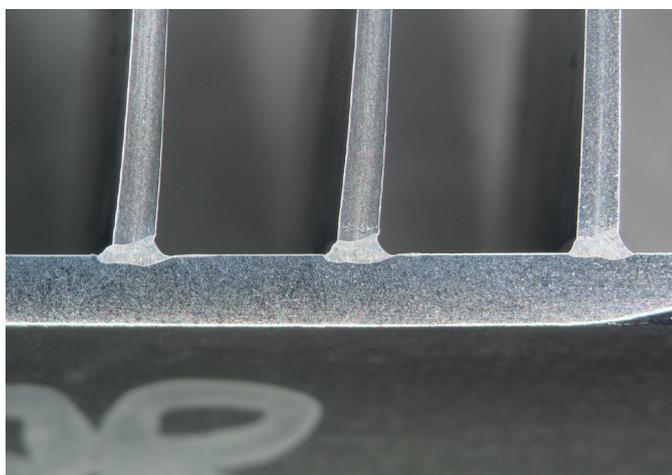


Fig. 4. Macrostructure of the tube-fin joint, power of the beam 2.8 kW

3. Test results and their analysis

The test scope included metallographic examination of the joint structure with the application of a light microscope in the bright field technique, and with a scanning electron microscope in the secondary electron technique. Microanalysis of the EDS chemical composition at the weld fusion line was also performed. The structural tests were complemented by the Vickers hardness test (HV10) and by the technological attempt to rupture the fin.

3.1 Metallographic examinations

The metallographic examinations were performed on samples cut parallel to the axis of the tube, so that the tube would cover at least three fins. The sample was then ground and polished to prepare the metallographic specimen. The joint structure was revealed in the process of electrolytic etching. The metallographic examination was performed with the application of Olympus GX71 light microscope at magnifications from 50x to 500x, and with the application of SEM Hitachi S-4200 scanning microscope at magnifications up to 2000x. Examples of the joint structures are shown in Figure 5

Analysis of the metallographic examination results revealed three typical areas characteristic of welded joints made of austenitic steels (Fig. 5c). It was found that both the tube and the fin were made of polygonal austenite grains (Fig. 5a, d). On the fusion line one can see a clear zone of incomplete fusion, in which one can observe partial melting of the grains of the solid solution and epitaxial crystallization of the fusion weld crystals.

In this zone one also found single partial meltings of the boundaries of the grains of the native material, especially from the side of the tube. The fusion weld area consists of elongated austenite grains, which build up in the direction of the heat abstraction during the welding process (Fig. 5b, 5d). One found no cracks, blisters or other structural imperfections, which allows one to classify the joint into the “B” level quality according to PN-EN ISO 13919.

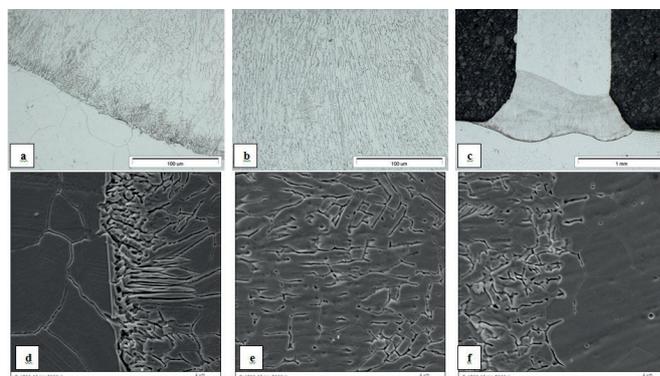


Fig. 5. Structure of the laser welded joint of the finned tube, made of austenitic steel XCrNi8-10: a) fusion line from the side of the tube, b) structure of the fusion weld, c) structure of the joint, d) fusion line from the side of the tube e) structure of the fusion weld f) fusion weld from the side of the fin

3.2 Microanalysis of the EDS chemical composition

Microanalysis of the EDS chemical composition was performed by means of a Noran detector and Voyager microanalyzer, with the application of a scanning electron microscope. One analysed the distribution of elements on a line passing through the entire joint (Fig. 6a) and through the infusion line from the side of the tube (Fig. 6b).

The measurement results shown in Figure 6 prove a high homogeneity of the chemical composition of the fusion weld. One found no significant differences in the chemical composition of the fusion weld, the HAZ and the base material

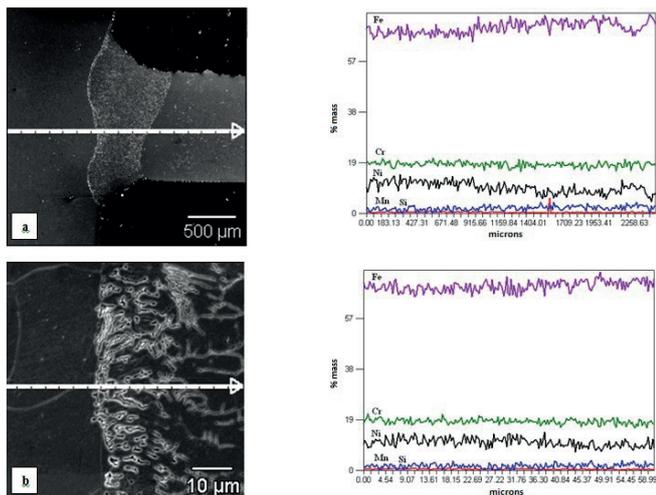


Fig. 6. Test areas and results of the linear distribution of the chemical composition

3.3 Hardness measurement and the rupture test

The analyses were complemented by the Vickers hardness test at a load of 9.8 N (HV10) and by the technological attempt to rupture the fin in the static tensile test. The hardness test results are shown in Figure 7. Figure 8 shows sample places in which the tube-fin laser joint has been ruptured.

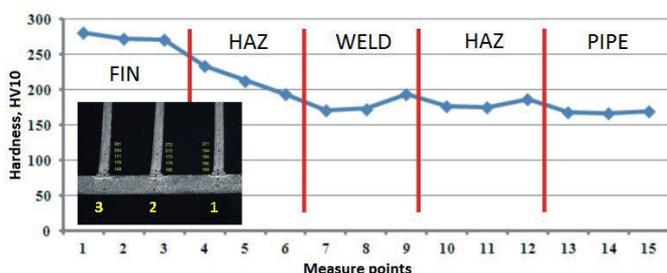


Fig. 7. Hardness distribution in the joint

Analysis of the hardness distribution results did not show any cure in the joint (Fig. 7). It was found that the hardness of the fin was at the level of 275 HV. The average hardness in the HAZ from the side of the fin amounted to 213 HV, in the fusion weld and in the HAZ from the side of the fin - to 179 HV. The hardness of the native material of the tube was 167 HV (Fig. 7).

The company Energoinstal SA performed a technological static tensile test on the tube-fin joint (rupture of the fin) to confirm the strength of the joint. One tested fragments of a single connection of the tube with one fin, cut from the production tube. The tensile test was performed with the application of a Cometech strength testing machine in grips allowing one to fix the tube and the fin section perpendicularly. Examples of the sample before the test are shown in Figure 8a. Figure 8b shows samples after the test. It was found that in all tested joints, the rupture occurred outside the joint, which indicates that the strength of the joint is greater than the strength of the fin. Thus, the tube-fin laser joint meets the structural requirements.

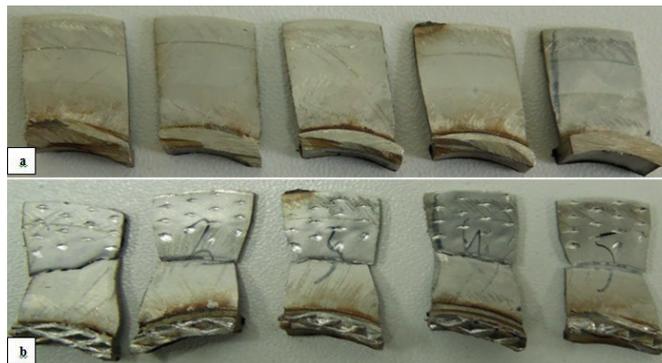


Fig. 8. Results of the technological tensile test of the tube-fin joint: a) test samples cut from a finned tube, b) place of joint rupture - rupture outside the joint

4. Conclusions

The authors prepared guidelines for the laser welding of finned tubes made of austenitic steel of the X5CrNi18-10 grade. The tests were performed at an automatic line of the company ENERGOINSTAL SA, equipped with a Triumph laser disc of the power of 8 kW (Figure 1-3). Based on the visual and macro-structural test results, one found that the joint was continuous over the entire length of the tube and had a full joint penetration and a normal shape (Fig. 4). Microstructure of the native material consists of polygonal austenite grains (Fig. 5a, d). On the fusion line one revealed a zone of incomplete melting, with a typical small partial meltings of the boundaries of the austenite grains, especially from the side of the tube (Fig. 5d). In this zone one can see fusion weld crystals crystallizing epitaxially on the partially melted grains (Fig. 5e). Linear analysis of the distribution of elements made with the EDS method indicates a high homogeneity of the chemical composition of the fusion weld. The hardness measurements showed no cure of the material of the joint (the maximum hardness did not exceed 281 HV). The technological tensile test (rupture of the fin) results confirm good parameters of the made joints. In all cases the samples were ruptured in the fin material, outside the joint.

The obtained results show that the joints meet the requirements of the “B” level quality according to PN-EN ISO 13919, which can constitute a basis for qualifying the welding technique according to the PN EN ISO 15614-11 standard.

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