CONTRIBUTIONS TO ROBOTIC GAS TUNGSTEN ARC WELDING OF A HEAT EXCHANGER ASSEMBLY USED AS A PART OF AN ELECTRICALLY DRIVEN CENTRIFUGAL AIR COMPRESSOR CCAE 15-300

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ABSTRACT: In order to weld the copper pipe components of a heat exchanger assembly for a centrifugal air compressor CCAE 15-300, experiments were performed on a test piece. In order to establish the welding parameters, a test piece was manufactured, identical in terms of quality and dimensions, with the heat exchanger assembly. The aim of the paper is to develop a software program for an 8-axis robotic welding system, with CLOOS CST FLEX S laser sensor and WIG AC / DC GLW 500 welding source and to establish the optimal welding parameters. The robotic software system will be implemented in its control console having the objective to weld the test piece. Furthermore, the operating technique used to program the robotic system is presented so that it can weld the ends of the copper pipes to the heat exchanger assembly within the test piece used. After the welding of the test piece is performed, the analysis of macro and microscopy is presented on the paper and was performed using a piece cut on the direction of the holes adjacent to the pipe that was extracted from the test piece.

KEYWORDS: **robotic system. heat exchanger assembly, test piece, centrifugal air compressor, welding parameters**

1. INTRODUCTION

Within the production issues which highly requested the execution of the heat exchanger assembly, component of an industrial centrifugal air compressor (CCAE), it was found that with the current soldering technology only 12 pieces per year can be executed.

An analysis of the decisional factors has led to the necessity of changing the technology of the heat exchanger and identifying a new solution: GTAW welding.

The new technology for the related heat exchanger assembly of the centrifugal air compressor CCAE, which consists in replacing the soldering with the GTAW welding, has been determined by technical and economic considerations.

In the aftermath by replacing of the soldering with the welding, the execution time of the final product decrease by 25%, and the costs of manufacturing decrease by 15%.

The main difference between the two processes, the soldering and the GTAW welding, is the usage of the additional material in the case of soldering, unlike in the case of the GTAW welding, where there is a lack of additional material.[1]

The advantage of using a soldering installation is represented by the low cost of its usage, unlike operating a welding installation. Another advantage in the training and certification of the operator executing the soldering consists in the costs and preparation time being reduced rather than instructing and certifying the welder. By modifying the technology used for the heat exchanger, the production capacity and the possibility of honouring the orders of the institute has increased to 15 pieces per year.

Modifying the manufacture technology of the heat exchanger assembly, after a technical and economic analysis, did not reassure the total coverage of the demanded orders.

The only solution that could solve the created issue was the implementation of a robotic GTAW process.

Within the robotic GTAW, the new technological process of manufacture a heat exchanger assembly has implied the manufacture of a test piece.

With this new technological approach, the production capability and the possibility of honouring the orders have increased by 45 pieces per year.

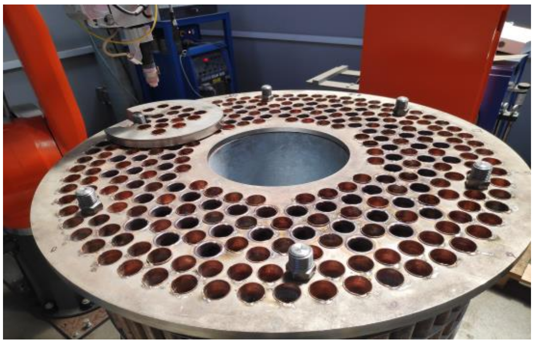

Figure 1. GTAW robotic system along with the heat exchanger assembly and the test piece on it

2. OVERVIEW OF THE ROBOTIC GTAW TECHNOLOGY OF COPPER PIPE HEADS AS PART OF A TEST PIECE OF THE HEAT EXCHANGER ASSEMBLY

The system operating technique of the robotic GTAW with the CLOOS CST FLEX S laser sensor and WIG AC / DC GLW 500 welding source is being used for programming the robotic system so that it may perform the welding of the ends of copper pipes of the heat exchanger assembly test piece.

In order for the test piece to be performed, there have been used 20 copper pipes which were fixed by tack welding inside of a structure which serves as a support for the pipes but also to mimic the heat exchanger assembly. The test piece, which is an identical copy of the heat exchanger assembly, is represented in figure 2.

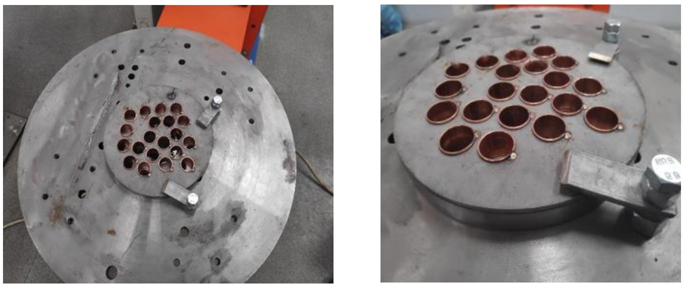

Figure 2. The test piece used for performing the GTAW welding of the copper pipes with the robotic system

For the robotic system to reach the copper pipe having the reference number 9 with its welding gun, there will be two intermediate points predefined: point number 10 and point number 20. Each defined point is saved in the memory of the robotic system console so that the position of the robot will be registered [2]. The intermediary point number 10 is represented in figure 3 through the final position of the robotic system before saving the point into the console.

In order to define the rest of the necessary points for the execution of the program, the welding gun of the robotic system will be centered on the hole of the copper pipe. The welding gun will be positioned above the copper pipe, in the center and so, the point resulted will be saved as point number 30.

Figure 3. Setting up the intermediary point 10 for the robotic GTAW system

Through setting up the welding gun of the robotic system in the center of the copper pipe, the cartesian coordinates obtained will be used in order to identify the remaining points.[3] Thus, starting from the center, the welding gun of the robotic system will move to the left (west) on the Ox axis, until the top of the wolfram electrode arrives at the edge of the copper pipe. After that, the welding gun tilts 60º and is fixed with a sheet spacer with a thickness of 1 mm between the top of the electrode and the edge of the copper pipe. At the end of the positioning of the welding gun, the spacer is removed and the obtained position will be saved into the robotic system console as point number 40. In figure 4, the setting up of point number 40 is being exemplified.

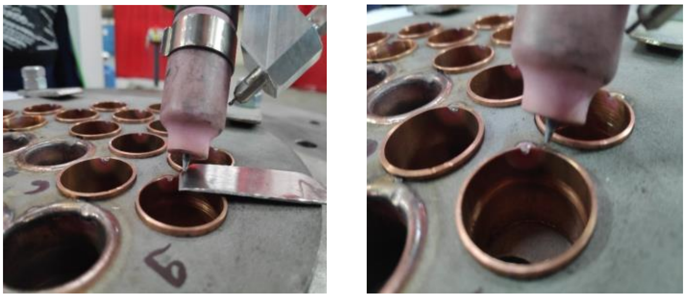

Figure 4. Setting up the point number 40 for the GTAW robotic system

After registering point number 40, point number 30 is called from the memory of the console and the welding gun will come back to the center of the copper pipe. Starting from the center, the welding gun of the robotic system will go upwards (to north) on the Oy axis, proceeding forward identically as done for the point number 40. Likewise, point number 50 will be saved.

The process described previously will be repeated, thus saving point number 60 and point number 70 through moving the welding gun from the center of the copper pipe to the east on the Ox axis and to the south on the Oy axis.

Keeping in mind the fact that the positioning of the welding gun in five points is necessary for each individual copper pipe, a 3D printed piece has been conceived, serving as a helper for centering and positioning. This piece has to be inserted in each copper pipe hole of the test piece, serving the purpose of facilitating the five points identification. In the research progress, it has been designed and executed three pieces for the welding gun centering and positioning, made out of plastic, in three colours.

The blue piece has the same outer diameter with the outer diameter of the pipe. The red piece has an outer diameter bigger with 2 mm than the outer diameter of the pipe. The yellow piece has an outer diameter with 3 mm bigger than the outer diameter of the pipe.

Figure 5. The 3D printed piece made of plastic

During the tests, there have been concluded that considering the project requirements, the best suited piece for centering and positioning of the top of the electrode is the red piece.

3. IMPLEMENTING THE SOFTWARE PROGRAM INTO THE GTAW ROBOTIC SYSTEM CONSOLE

For the welding process between the copper pipe and the test piece of the heat exchanger there must be defined seven points into the robotic system software program.

The developed software program for welding of the copper pipes to the heat exchanger test piece is composed of 11 code lines. The code implementation into the robotic system console is represented in figure 6.

```
[illegible]
EXTERNAL PROC SYN1 FROM MASTER
MAIN
CALL SYN1
GP (10,20,30)
$ ('LN1')
GP (40)
ARC (40,50,60)
ARC (60,70,40)
GP (30,20,10)
END
```

Figure 6. The console developed software program for welding each copper pipe to the test piece

The GP( ) function, or “Go Point”, positions the robotic system to a defined point or points by the software program found in the parenthesis of the command. Thus, when the program calls the GP(10, 20, 30) line, the robotic system will travel a trajectory to the three intermediate defined points, point 10, point 20 and point 30.

The command line GP(40) sets the initial position of the robotic system so that the welding gun will start to weld from that point through the entire length of the circle of the copper pipe.

The length of the circle is divided in two arc lengths. Through the ARC(40, 50, 60) instruction, the welding gun of the robotic system will weld the first arc length defined by the point number 40, point number 50 and point number 60 located to the west from the center of the copper pipe on the Ox axis, to the north from the circle on the Oy axis and respectively to the east from the circle center of copper pipe on Ox axis.

The second arc length is defined by the ARC(60, 70, 40) instruction, through which the welding gun has continuity to weld, going further on the arc length of the copper pipe from point number 60 to point number 70 situated to the south of the circle center on the Oy axis. The welding gun completes the circle of the copper pipe after returning from point number 70 to the point number 40 and finishes the welding process. At the end, the robotic system will retreat into the intermediate points defined in order: point 30, point 20 and then point 10. The retreat of the robotic system is implemented into the software program through the GP(30, 20, 10) instruction.

Through executing the “$ (‘LN1’)” command line, a list of predefined parameters is being called by the software program. In this list, the values of all the parameters are configured so that the robot system can weld the copper pipe to the test piece.

Also, beside the LN1 list, the start and the end lists are defined. The start list is LS1, in which the initial values of the welding parameters from the starting of the process are defined. Throughout these parameters, there are the speed of the welding Vsud=15 cm/min, the oscillation frequency Fpend=2,84 Hz, the pulse rate Fpuls=5 Hz, the base current Ibaza=125 A, the pulse current Ipuls=100 A and the speed of the addition wire Vsarma=0 cm/min. The end list is LE1.

4. EXPERIMENTAL RESULTS

After defining the robotic system seven points and ending the implementation of the software program code lines, the cold testing without tripping of the electric arc is the next objective to be achieved [4]. Lastly, robotic system GTAW welding is the final objective.

The phase of the cold testing involves line by line program execution and keeping track of the conformities from the robotic system final position. Depending on the obtained results after the cold testing, the software program can be improved by adding new code lines or modifying the points that have been previously defined.

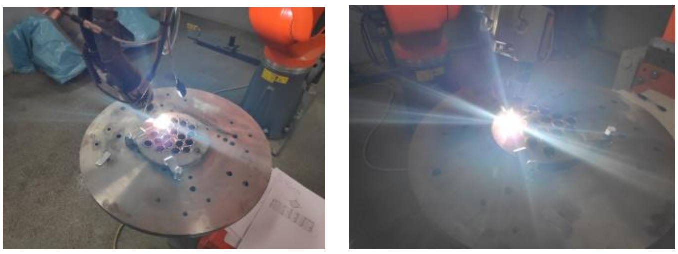

Figure 7. Robotic system welding between the copper pipe and the heat exchanger test piece, performed after the cold testing

4.1 Welding the first three test piece specimens

For determining the robotic welding optimal parameters, firstly there have been used manual welding parameters on the test piece.

Figure 8. Result of the test piece heat exchanger welding for the reference 1 copper pipe

For the reference 1 test specimen of the LN1 software program list, the welding parameter defined values are:

- Welding speed Vsud=15 cm/min;
- Oscillation frequency Fpend=0,25 Hz;
- Pulse rate Fpuls=0 Hz;
- Base current Ibaza=120 A;
- Pulse current Ipuls=100 A;
- Addition wire speed Vsarma=0 cm/min.

After a visual inspection of the reference 1 test specimen, it was concluded a complete melting on the copper pipe circumference. Since the welding speed was not high enough, the width of the copper ring melting area was irregular, thus highlighting the pipe fastening tack weld on the plate due to its non-inclusion in the molten welded cord.

Figure 9. Result of the test piece heat exchanger welding for the copper pipe with reference 2

There were only two different welding parameters defined within the LN1 list of the robotic system software program for the test specimen with reference 2:

- Welding speed Vsud=12 cm/min;
- Base current Ibaza=140 A.

After the specimen visual inspection, it was concluded the complete melting on the pipe circumference. Since the base current value was too high and the welding speed was too slow, there is a noticeable irregular weld enlargement. It was found the fastening tack weld inclusion into the weld.

Figure 10. Result of the test piece heat exchanger welding for the reference 4 copper pipe

For the reference 4 test specimen, there were only two different welding parameters defined within the LN1 list of the robotic system software program:

- Welding speed Vsud=18 cm/min;
- Base current Ibaza=130 A.

After the visual inspection of the reference 4 test specimen, it was concluded the complete pipe circumference melting. Because the welding speed was too fast, it was concluded that the width of the welding area is way too small, thus resulting in the non-inclusion of the fastening tack weld.

4.2 Optimal welding parameters for the reference 9 test specimen obtained from previous results

For the test pipe with reference 9, the LN1 list welding parameter defined values are:

- welding speed Vsud=15 cm/min;
- oscillation frequency Fpend=0,25 Hz;
- pulse rate Fpuls=0 Hz;
- base current Ibaza=125 A;
- pulse current Ipuls=100 A;
- speed of the addition wire Vsarma=0 cm/min.

After the test specimen visual inspection with reference 9, it was concluded the copper pipe circumference complete welding. The width of the weld is acceptable and uniform on the entire pipe outline, being able to include the fastening tack weld.

The welding necessity without the additional material has been confirmed, melting being performed only of the elevation material related to the copper pipe.

Figure 11. Robotic welding of the reference 9 copper pipe within the heat exchanger test piece

5. ELECTRONIC MACRO AND MICROSCOPY ANALYSIS

Keeping track of the welding results, the three adjacent copper pipes with reference 9 have been welded to confirm the process repeatability and there have not been nonconformities reported. [5]

The visual inspection found that the welds geometrical form repeatability on the copper pipe entire circumferences. At the welds dimensional inspection, which have a width of 3 ÷ 4 mm, it was concluded that the welds are uniform on the copper pipe entire contours, with a reinforcement of 0,5 ÷ 1 mm.

For obtaining the necessary electronic analysis specimen, it was first extracted a piece which was cut from the test piece with a 1 mm thickness flex disk in the direction of the adjacent reference 9 pipe holes.

As seen in figure 12, the test piece cut component presents six different sections of the welded joints between the copper pipes and the stainless steel plate.

Figure 12. Cutting of the heat exchanger test piece

5.1 The metallographic analysis using an optic microscope on the two samples taken

After cutting the component previously resulted at a 90° on the reference 9 copper pipe direction it has resulted two sample pieces noted with 1 and 2, as seen in figure 13.

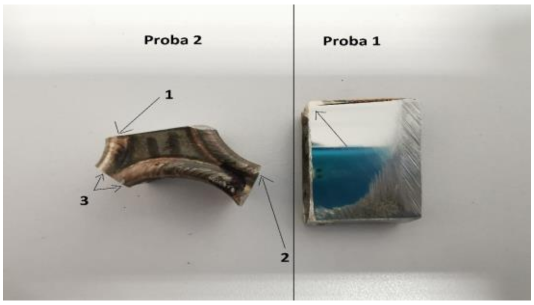

Figure 13. Points on the two samples onto which the microscopic analysis will be performed

The two samples have been prepared for the metallographic analysis as so:

- sample 1 in the indicated area;
- sample 2 in the marked areas 1, 2 and 3.

The jointing analysis at a 50X magnification confirms the complete melting of the copper pipe end and the partial melting of the tubular steel plate, after which resulting a composite area including re-hardened material from the two components, obtaining a flawless surface which offers a good jointing resistance without creating tension points that can lead to the jointing or copper pipe deterioration.

Figure 14. The point 1 analysis on the sample 1 and the sample 2 performed with the optic microscope at a 50X magnification

Following the jointing analysis at a 200X amplification factor it can be better noted the resulted composite on the tubular plate surface, as well as in the melted and re-hardened area at the pipe end. In the diffusion area between the two components there are no major flaws that may cause the jointing cracking, just small isolated inclusions which are unable to influence the jointing quality.

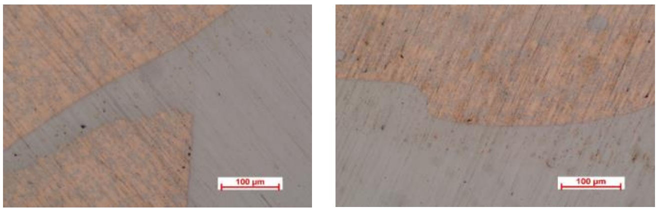

Figure 15. The point 1 analysis on the sample 1 and sample 2 performed with the optic microscope at a 200X magnification

The point 2 jointing analysis at a 50X magnification confirms the appearance of distinct dimensions metal drops resulted from the previous welding which do not influence the jointing quality.

Following the jointing analysis of the two re-hardened layers separation area it can be observed the lack of flaws which may influence its quality.

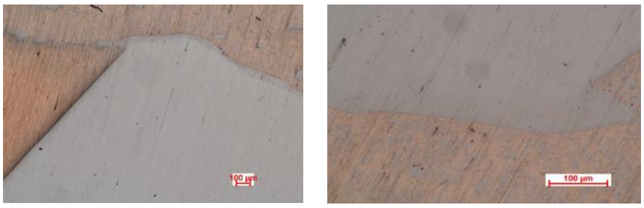

Figure 16. The point 2 analysis on the sample 2 performed with the optic microscopic at a 50X and 200X magnification

Same as in jointing point 1, at the 200X magnification in figure 16 it is noted the resulted solid solution good quality as well as the lack of flaws at the re-hardened areas and at the two areas association limit.

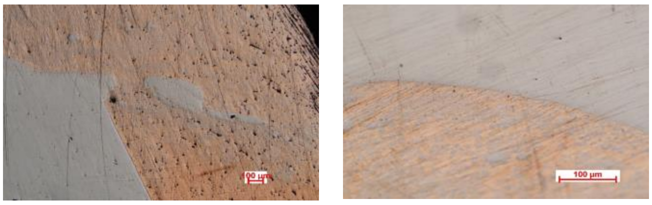

Figure 17. The point 3 analysis of the sample 2 performed with the optic microscope at a 50X and 200X magnifications

As for figure 17, at the 50X magnification, it is noted just a slight raise in the solidification area porosity from the re-melted copper pipe. This phenomenon is associated with the reduced re-hardened area in the tubular plate, but without affecting the jointing quality.

At a 200X magnification, it is noted the joining associated more with the copper pipe melting and less with the tubular plate melting, this being highlighted by a reinforced area developing which contains more of the steel alloy. Furthermore, as observed at a 200X amplification factor, this case does not lead to the jointing quality reduction, neither does it lead to transition area flaws between the two materials.

After the jointing analysis, it is concluded a good quality and a repeatability of the process. Despite the reduced distance between the two joints, they can still influence each other, keeping the resulting quality of the jointing at the same level without needing to worry about the jointing placement.

5.2 The SEM analysis

The micro-structural and micro-compositional examinations were performed using an electronic microscope with FEI INSPECT F scanning, field broadcasting and Energy Dispersive Analysis System (EDS). The examination was performed on the metallographic probes.

Within the SEM analysis, the probe is analyzed at 80X magnification and 160X respectively, as presented in figure 18.

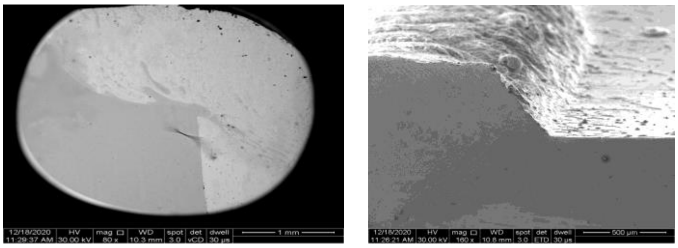

Figure 18. SEM sample analysis at 80X magnification and 160X respectively

In the next step of the SEM analysis, the sample is analyzed at a 700X magnification and a 1400X magnification respectively, at the under-layer interface/ diffusion area/welding, as presented in figure 19.

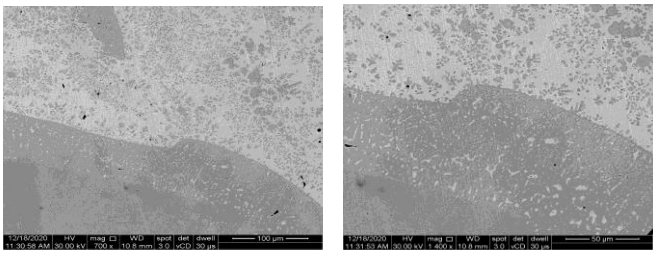

Figure 19. SEM sample analysis at 700X magnification and 1400X respectively

5.3 The EDS analysis

As for figure 20, it is presented the Energy-Dispersive X-Ray Spectroscopy (EDS) of the welding cord area. Based on this spectre, the analyzed sample chemical composition was determined.

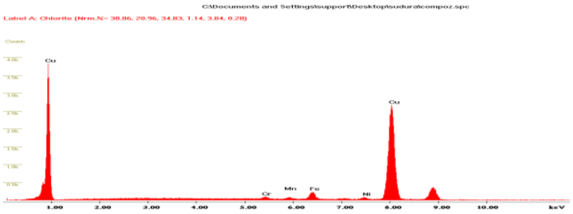

Figure 20. EDS analysis for the welding cord area

6. CONCLUSIONS

Designing new technology for developing the heat exchanger assembly of a CCAE industrial centrifugal air compressor which replaces the soldering process with the robotic GTAW has been determined by technical and economic considerations.

The robotic GTAW technology without additional material assumes that each pipe should be positioned by tack welding with the addition of 2 mm to each end.

As for the robotic GTAW, the implementation of a software program for the robot console is necessary, as well as a programmer involvement.

The 576 copper pipes solders at both ends have a bigger number of reworks, unlike the case of robotic GTAW.

7. ACKNOWLEDGEMENTS

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