Research regarding strip cladding of heat-resistant SA 387 Gr.11Cl.2 steel type

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Abstract. The continuous development of industrial processes in the petrochemical field requires the use of materials with anticorrosive properties, able to withstand working conditions at high temperatures but also in highly corrosive environments. The basic materials with anticorrosive properties have a high cost price which leads to the need to find alternative manufacturing solutions. In such situations, the use of bimetal plates or the option of welding cladding with an anticorrosive layer of the base material is used. The paper analyses the possibility of strip cladding using the submerged arc welding process of a reactor made of SA 387Gr11Cl.2 basic material, a heat-resistant alloy steel. To achieve the deposition of the appropriate anticorrosive layer (stainless steel type AISI 347) it was necessary to use a buffer layer made of austenitic stainless-steel type 309L. In order to eliminate the internal tensions appeared after the cladding process, the sample was subjected to a stress relieving heat treatment. After the heat treatment, the sample was subjected to non-destructive examinations (visual and penetrant testing) but also to destructive examinations specific to the approval tests of cladding technology (Metallographic tests, Vickers hardness test, bend test, ferrite number, chemical composition). Metallographic tests of cross-sectional phase structures were carried out in macroscopic and microscopic terms. In the area of the deposited material can be observed a typical austenitic casting structure resulting from the use of a high linear energy, specific to the automatic submerged arc welding. Following the performance of hardness measurements made in the characteristic areas of the deposition, it can be seen that there was a slight increase in the values obtained in the heat affected zone, without exceeding the prescribed values for the materials used. Following the analysis of the results obtained from the specific examinations and tests to the plated samples, it can be seen that they are within the limits prescribed by the standards in force regarding the approval of the cladding technology used.

1. Introduction
Modern industrial processes require the use of high values of technological parameters (temperature, pressure, etc.) as well as different working environments, some of which are highly corrosive. Erosion, high temperature, high pressure, vibrations during operation can cause corrosion of materials, leaks and working failure of products [1-4]. In order to meet the technological requirements, materials with high mechanical properties and high thicknesses are needed (in order to meet the requirements of high pressure) but also materials with anticorrosive properties, in contact with the working environment.

Taking into account the high cost price in the case of using materials with anticorrosive properties, the solution chosen in such cases is to use bimetal plates obtained by roll bonding, in the case of shell
components manufacturing. For elliptic head manufacturing, taking into account the drawing process used, the bimetal plates is not accepted. In such cases, after drawing the base material, the anticorrosive layer is deposited with the help of cladding processes. Thus, cladding can be done using welding cladding procedures (laser welding, submerged arc welding, explosive welding, gas tungsten arc welding, etc.). The welding cladding process is a demanding process that requires a series of tests to obtain the desired quality of deposition [5-8].

The corrosion properties of the layers deposited by welding are given by the alloying elements contained by the filler materials. Taking into account the fact that the deposition is made on base material type C-Mn steel or low alloy steel base material, the resulting dilution must be as small as possible [9-13]. Table 1 presents the values of the dilution coefficient obtained in the case of using different welding processes [2]. In the case of submerged arc welding (SAW) the mechanical properties of the deposited layer depend on the properties of the chosen wire/flux combination but also on the dilution of the welding process [14,15].

Table 1. Dilution percentage for different welding processes [2].

| Welding process                        | Typical dilution (%) |
|----------------------------------------|----------------------|
| Shielded metal arc welding (SMAW)      | 25-30                |
| Flux cored arc welding (FCAW)          | 20-25                |
| Submerged arc welding (SAW), wire      | 25-35                |
| Submerged arc welding (SAW), strip: 60 × 0.5 mm | 18-20            |
| Electroslag welding (ESW), strip: 60 × 0.5 mm | 7-12              |

The main objective of the paper was to present the necessary steps to qualify the welding technology of the base material SA 387 Grade 11 Class 2 (a heat-resistant alloy steel) with a layer of steel with anticorrosive properties type AISI 347 (stainless steel) using the SAW welding method with strip electrode. The cladding is necessary for the deposition of the anticorrosive layer of an elliptical head from the component of a pressure vessel reactor.

2. Experimental data
The base material used for the reactor manufacturing was SA 387Gr11C1.2 steel. Corrosion protection of shell plates was achieved by using bimetal plates (SA 387Gr11C1.2 and AISI 347) manufactured by roll bonding. For the ellipsoidal heads, the welding option with SOUDOTAPE 347 strip electrode was chosen (60x0.5mm). To achieve the deposition it was necessary to use a buffer layer made of austenitic stainless steel type SOUDOTAPE 309L (60x0.5mm). The flux used for both types of band electrode was RECORD INT 109. The chemical composition as well as the mechanical properties of the materials used for cladding, according to the standards in force, are presented in table 2 and table 3 [14-16].

Table 2. Chemical composition of basic materials and filler material [14-16].

| Weight Percent |
|----------------|
| Materials      | C     | Si    | Mn    | P     | S      | Cr    | Mo    | Ni    |
| SA387Gr11CL2   | 0.04-0.17 | 0.5-0.8 | 0.4-0.65 | 0.025 | 0.025 | 1.0-1.5 | 0.4-0.7 | -     |
| SUDOTAPE 309L  | 0.013 | 0.4 | 1.69 | 0.016 | 0.001 | 23.7 | 0.1 | 13.6 |
| SUDOTAPE 347   | 0.010 | 0.41 | 1.70 | 0.017 | 0.001 | 19.7 | 0.07 | 10.5 |
Table 3. Mechanical properties of base materials and filler material [14-16].

| Materials      | Yield Strength (MPa) | Tensile Strength (MPa) | Elongation (%) |
|----------------|----------------------|------------------------|----------------|
| SA387Gr11CL2   | 310                  | 515-690                | 18             |
| SOUDOTAPE 309L | 365                  | 580                    | 38             |
| SOUDOTAPE 347  | 470                  | 640                    | 35             |

For the qualification of the welding cladding procedure, the sample made of the basic material SA387Gr11CL2, with dimensions 30x300x400 mm, was mechanically cleaned in order to remove the dust, oil, rust and other foreign particles and preheated to a preheating temperature of 150 °C, according to the preliminary specification of the welding procedure (figure 1).

Figure 1. Metal plate subjected to the: a) mechanical cleaning process; b) preheating process.

After cleaning the sample and performing the preheating, the layers were deposited with the two types of tape electrode, using the technological parameters indicated in table 4. The thickness of the deposited layers must be at least 6 mm.

Table 4. The parameters used in the experiments.

| No..crt. Parameter | Value          | SOUDOTAPE 309L | SOUDOTAPE 347 |
|--------------------|----------------|----------------|---------------|
| 1 Welding current [A] | 680-730       | 650-700        |
| 2 Arc voltage [V]   | 29-30          | 29-30          |
| 3 Filler material [mm] | 60x0.5         | 60x0.5         |
| 4 Travel speed [cm/min] | 15            | 16             |
| 5 Flux type         | RECORD INT 109 | RECORD INT 109 |
3. Results
After finishing the cladding process (figure 2), the samples were subjected to non-destructive testing (visual, penetrant and ultrasound testing – figure 3) [17-19]. After performing the examinations, no imperfections were detected, the piece being subjected to a heat treatment of stress relieving in order to minimize residual stresses in the structure. The heat treatment was performed with the following parameters: heating temperature 650-680 °C, heating rate maximum 60 °C/h, cooling rate maximum 60 °C/h, holding time 240 minutes. After the completion of the heat treatment, the piece was subjected to non-destructive and destructive examinations specific to cladding samples.

In order to visualize the geometric characteristics and the structure of the welding deposition areas, the sample was cut, cleaned, degreased and subjected to the metallographic preparation process (grinding, polishing, washing, drying and etching. For a detailed analysis of the plated sample, two specimens were taken, one cut perpendicular to the cladding direction and the second parallel to the cladding direction (figure 4) [20]. Metallographic images were taken using the Olympus GX51 optical microscope. The magnification used for image capture was 10x for macrographs and x 100 for micrographic images. Following the analysis of the metallographic samples, it was found that the layer deposited in two passes has a thickness between 6.5 and 7.5 mm.

Chemical analysis of the deposited material was done at a distance of 3 mm from the top of the sample. The values of the resulting chemical composition are presented in table 5.

| Materials       | C   | Si  | Mn  | P   | S   | Cr  | Mo  | Ni  |
|-----------------|-----|-----|-----|-----|-----|-----|-----|-----|
| Deposit material| 0.023 | 0.682 | 1.45 | <0.005 | 0.0015 | 19.0 | 0.364 | 9.77 |

Following the analysis of the values presented in table 5, it can be seen that they differ from the values of the filler material. The values obtained depend on the dilution of the welding process but also on the number of layers deposited.
From the analysis of the micrographic images it can be observed that the structure of the basic material is a ferrito-perlitic one, with plastic deformation strings and small metallic inclusions (figure 5(a)). The heated affected zone (HAZ) has a ferritic-pearlitic with bainite structure grain size 2-3 and normalizing grain size 10. In the area of the deposited material a typical austenitic casting structure can be observed.

Following the analysis of the results of the additional destructive tests (side bend, ferrite content, Vickers hardness test HV10) necessary for the qualification of the welding cladding technology, the sample was declared compliant in relation to the specific test standards and a procedure qualification record and a welding procedure specification were issued, necessary for use in technology developed in production. Figure 6 presents images during welding cladding an elliptic head of the reactor made from the SA 387 Grade 11 Class 2 base material. The cladding was made using the parameters of certified technology.
4. Conclusions

The use of welding cladding technologies combines the advantages offered by different classes of materials to meet the ever-increasing demands of industrial technological processes. In this case, the high mechanical properties of the non-alloy material are doubled by the anticorrosive properties of the stainless material.

The dilution of the welding process significantly influences the mechanical properties of the deposited layer. In order to obtain properties as close as possible to those of the filler material, it is recommended to use a dilution as small as possible or to deposit several layers of material.

Considering the nature of the cladding process used, it can be seen that the structure of the material deposited by cladding is a typical austenitic casting. It is recommended to use a low linear energy to avoid overheating of the material and to reduce the risk of excessive growth of grains in the HAZ.

5. References

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