RESEARCH ON WELDING OF STAINLESS STEEL VACUUM CHAMBER COMPONENTS

Boiko, I.; Filipov, A.

Abstract: The goal of this paper is to examine the TIG (Tungsten Inert Gas) welding process for joining of components of vacuum chamber. During welding and cold working the martensitic structure can occur as well as δ-ferrite, both structures are magnetic. This possible structural transformation is one of the significant problems in welding technology elaboration for joining of components of vacuum chamber. A complete investigation from the choice of material of vacuum chamber, design of welds to experimental testing of TIG welding of the elements of vacuum chamber has been performed.
Key words: vacuum chamber, welding, stainless steel, ferrite content

1. INTRODUCTION

Nowadays for manufacturing of the thin and nano layers on the surface of different materials some deposition methods in the vacuum are used. Generally, deposition of the layer occurs in the vacuum. In magnetron sputtering technique, which is able to coat any workpiece with a wide range of materials (any solid metal or alloy and a variety of compounds) a vacuum of less than one ten millionth of an atmosphere must be achieved [1]. The working principle of magnetron sputtering deposition techniques is following: the substrate is placed into a vacuum chamber and a small amount of the coating material is vaporized into the chamber (Fig. 1). The molecules or atoms of vapour condense onto the substrate, forming (ideally) a uniform coating of controllable thickness and properties [2].

The deposition process is strongly dependent on magnetic field and plasma parameters such as ion flux, plasma potential, electron temperature and density [3]. Within other process parameters the magnetic field strength and uniformity during deposition have a significant influence on coating properties. Each deviation from the optimal regime leads to rejects. Some deviation could be caused, for example, by deflection of magnetic field due to presence of magnetic structures in welding seams of vacuum chamber. This paper is devoted to examination of the TIG (Tungsten Inert Gas) welding process for joining of components of vacuum chamber taking into account prevention of formation of possible magnetic structures in the welds.

2. EXPERIMENTAL

2.1 Materials

According to application different materials for elements of vacuum
equipment can be used: stainless steel, aluminum alloy, mild steel, titanium and other.
The material used for the manufacturing of the vacuum chambers must have magnetic permeability of $\mu_{rel} < 1.005$. Grain size and amount of impurities are strictly regulated [4]. To achieve these materials must generally be as follows [5,6]:

- Vacuum chamber walls: austenitic stainless steel sheet/tubes grade AISI 316 LN (another possible materials are 304, 304L, 316 and 316L);
- Vacuum chamber flanges/blanking flanges: AISI 316LN Electro-slag Remelted (ESR) forgings;
- Cooling water pipe fittings: stainless steel AISI 316.

Type X2CrNiMo17-12-2 (AISI 316L) stainless steel is suited for vacuum vessel construction because of its machining characteristics, excellent corrosion resistance and overall cost effectiveness. Based on the magnetic measurements of sample materials X2CrNiMo17-12-2 stainless steel underwent no significant changes in magnetic permeability throughout the fabrication processes [7,8]. Without cold working, X2CrNiMo17-12-2 had very low permeability (less than 1.005). Thus, stainless steel X2CrNiMo17-12-2 is recommended for use where low magnetic permeability is requires. The chemical composition of steel X2CrNiMo17-12-2 is shown in Table 1.

<table>
<thead>
<tr>
<th>Chemical element</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content, %</td>
<td>max</td>
<td>max</td>
<td>max</td>
<td>max</td>
<td>max</td>
</tr>
<tr>
<td></td>
<td>0.030</td>
<td>2.0</td>
<td>0.045</td>
<td>0.030</td>
<td>1.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chemical element</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content, %</td>
<td>16.0–18.0</td>
<td>10.0–14.0</td>
<td>2.0–3.0</td>
<td>max 0.5</td>
</tr>
</tbody>
</table>

Table 1. Chemical composition of stainless steel X2CrNiMo17-12-2 (AISI 316L) (%)

But during stainless steel X2CrNiMo17-12-2 welding the martensitic structure can occur as well as $\delta$- ferrite, both structures are magnetic. This possible structural transformation is one of the problems in welding technology elaboration. Hence the possibility to use these steel for welded vacuum chamber elements have to be proved.

### 2.2 Weld joint design

When designing or constructing a vacuum system, the following points need to be observed [9]:

- Full penetration welds should be utilized wherever possible to avoid pockets where volumes of gas or contaminants can be trapped;
- Utilize single pass welds if possible to avoid trapped volumes that could be generated with multi-pass welds;
- Welds should always be made on the vacuum side of the joint;
- If for structural reasons double welds are required, allow for an easy path to flow gas from the joint. This could be in the form of a machined hole between the two welds, or a discontinuous weld on the non-vacuum side.

Correct and incorrect practices of weld butt joints commonly used in vacuum chamber construction are shown in Figure 2.

![Fig. 2. Examples of the correct and incorrect butt weld joint’s design for the vacuum chamber](image-url)
2.3 Methods

Different welding methods are used for stainless steel welding depending on the materials and customers’ requirements: Plasma arc welding, Laser welding, Resistance welding, TIG welding, Electron beam welding etc. TIG welding and electron beam welding are the common welding processes for joining of the elements of vacuum chamber. The energy density of electron beam welding is much higher and leads to less chamber deformations compared to TIG welding. Usually all longitudinal vacuum chamber welds are done with electron beam. But cheaper and easier is TIG welding process: manual or automated orbital welding [10].

There are some common recommendations for welding of the elements of vacuum chamber:

- The high purity inert gas (Ar - Argon) should be used;
- Ar purging gas flow should be used until the part has cooled down to 60°C;
- All parts to be welded must be cleaned prior to welding. Any later brushing or other finish work on the welds is prohibited.

The vacuum chambers must be manufactured so as to have extremely low leak (the leak rate must be lower, for example, than \(1.10^{-10}\) mbar.l/s) and outgassing rate and, due to the potential inconvenience of a failure in service, exhibit a high degree of reliability. These requirements mean that the welding processes must be correctly determined and then controlled during production [6]. So, it is obligatory, that the quality of the weld must be according to the ISO standard ISO 5817, quality level B: Stringent.

Taking into account mentioned issues the preliminary welding procedures specification (pWPS) was elaborated. For example, the main TIG welding parameters for stainless steel X2CrNiMo17-12-2 (AISI 316L) welding in the case of butt joint (material thickness is 5,4 mm) are given in Table 2. The weld preparation details and welding sequence are given in Figure 3.

<table>
<thead>
<tr>
<th>Welding parameters</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shielding and backing gas</td>
<td>Ar (99.999%)</td>
</tr>
<tr>
<td>Arc current</td>
<td>80…100 A</td>
</tr>
<tr>
<td>Arc voltage</td>
<td>10…14 V</td>
</tr>
<tr>
<td>Ar purging gas flow:</td>
<td></td>
</tr>
<tr>
<td>Shielding</td>
<td>10…14 l/min</td>
</tr>
<tr>
<td>Backing</td>
<td>8 …10 l/min</td>
</tr>
<tr>
<td>Post flow time</td>
<td>30 sec</td>
</tr>
<tr>
<td>Tungsten electrode</td>
<td>2,4 mm</td>
</tr>
</tbody>
</table>

Table 2. TIG welding parameters

Fig. 3. Sketch of weld preparation details (joint design) and welding sequence of the pipe with outside \(\varnothing88.9\) mm and thickness 5,4 mm TIG welding: 1 – 1\(^{st}\) run, 2 – 2\(^{nd}\) run

Filler metal was chosen on purpose of control of the amount of ferrite in the weld metal using Schaeffler-DeLong diagram. Predicted Ferrite Number (FN), using filler material LVS EN ISO 14343 –A-W 19 12 3 LSi was 7 FN (approx. 7% ferrite).

After welding the different types of testing we made: visual test, penetration test and measurement of Ferrite Number. The Ferrite Number after welding was measured using a Feritscope FMP30 (Helmut Fischer GmbH, Germany).
The Feritscope FMP30 measures the ferrite content in austenitic and duplex steel according to the magnetic induction method: a magnetic field generated by a coil begins to interact with the magnetic portions of the specimen. The changes in the magnetic field induce a voltage proportional to the ferrite content in a second coil, which is then evaluated [11].

3. RESULTS AND DISCUSSION

Since the optimal conditions were used the high quality of welds was achieved. It is confirmed by results of visual and penetration testing. The view of welds is given in Figure 4, but penetration view of the weld is shown on the Figure 5.

It is shown that welds are of good performance full penetration. Ferrite Number measurements after welding are the follows (mean value): 8 FN. Obtained value non-significantly differs from predicted FN. This difference can be explained by the fact, that using Feritscope FMP30 all magnetizable structure sections are measured i.e., in addition to δ-ferrite also strain-induced martensite, for example, or other ferritic phases [11]. It is well known that the δ-ferrite contents in the austenitic stainless steel welds should be controlled in the range of 3…12 vol.% to prevent hot cracking, reducing of corrosion resistance and weld metal toughness [12]. On the other hand in work [13] for the determination of the ferrite rate the method of measure of the relative magnetic permeability of the weld was used. It was revealed, that the increasing value of welds’ relative permeability is due to an increasing in the rate of ferrite. Since an optimum condition can be attained for ferrite contents between 3 and 8 vol. % in the weld deposit [14], especially for vacuum components [15], which assure required low magnetic permeability, we can conclude, that stainless steel X2CrNiMo17-12-2 is the acceptable material for vacuum chamber elements to be welded.

4. CONCLUSION

A complete investigation from the choice of material of vacuum chamber, design of
welds to test for the TIG welding of the elements of vacuum chamber has been performed. Elaborated preliminary welding procedure specification (pWPS) for stainless steel TIG welding has provided the high quality welds. It was proved that stainless steel X2CrNiMo17-12-2 (AISI 316L) is acceptable material for vacuum chamber with satisfying weldability and magnetic permeability after welding.

5. REFERENCES

2. DCL Vacuum Coating Corporation: http://www.dclvacuum.com (15.10.2011.)
15. 304 vs. 316 Stainless Steel, MKS, HPS Products: www.mksinst.com (08.01.2012).

6. ACKNOWLEDGEMENTS

This work has been supported by the European Social Fund within the Project 2009/0201/1DP/1.1.1.2.0/09/APIA/VIAA/112 “Nanotechnological research of the mechanical element surface and internal structure in mechanical engineering”.

7. ADDITIONAL DATA ABOUT AUTHOR

Dr. Irina Boiko
RTU, Institute of Mechanical Engineering
Ezemalas 6k-426, LV-1006, Riga, Latvia
Phone: 371+67089701,
Fax: 371+67089739,
E-mail: irinaboyko@inbox.lv