Studies and Experimental Research on Correlation Thermal Field with Mechanical Properties of Cryogenic Steels Welded Joints with MIG Procedure

Bormambet Melat, Cazacu Mihăiță
Faculty of Maritime, Industrial and Mechanical Engineering, Ovidius University of Constanta, Romania
melat@univ-ovidius.ro

Abstract. The paper presents the analysis and experimental research that is performed to correlate the welding procedure with hardness in HAZ (Heat Affected Zone) and toughness of welded joints of austenitic stainless steel X6CrNiTi18-10, used to build cryogenic tanks to liquid nitrogen storage. For this were welded a sample by MIG welding process. In a first step it was estimated the hardness of HAZ with a soft computer, and then it was made a testing to its experimental verification welding procedure. The results showed that the welding procedures developed and implemented resulted in obtaining the HAZ hardness almost equal to those of basic material. This shows that the HAZ properties are unaffected and a good weldability of austenitic stainless steel. In a second step the toughness were measured at room temperature and work temperature, -196°C.

1. Introduction
To ensure the safety of large-scale structures exposed to cryogenic temperatures it is very important to evaluate the mechanical properties of materials, including welded structure. It is also very important to determine the condition of the material at low temperatures to assess the safe life of cryogenic installations.

Welding processes acting on the material pieces by the energy brought sharply localized and suddenly. Energy density must be large enough to offset losses due to thermal contraction and to accumulate in the welding joint. Energy level of the base metal increases in that place, resulting in physical and chemical reactions: dilatations, contractions, structural transformation, a gas absorption, oxidations, reductions, formation and decomposition of precipitated and/or intermetallic phases. The phenomena described are conducted in a relatively small volume, surrounding the seam, called the heat-affected zone HAZ.

2. Experimental studies
To achieve experimental sample has been used, as basic material is a steel X6CrNiTi18-10 austenitic steel structure recommended in the manufacture of vessels for transporting liquid nitrogen. Chemical analysis of steel is shown in table 1.

| C  | Si  | Mn  | Cr   | Ni  | Mo  | Cu  | Ti  | Nb  | Al  | W  | V  | Co  |
|----|-----|-----|------|-----|-----|-----|-----|-----|-----|----|----|-----|
| 0,034 | 0,69 | 1,70 | 18,55 | 9,41 | 0,28 | 0,35 | 0,0018 | 0,049 | 0,068 | 0,085 | 0,061 | 0,24 |
For analysis and experimental work it was used an sample welded with MIG procedure (figure 1). For welding the sample was used a wire/gas protection T19.9LR M (C) 3/Ar (AWS/ASME classification) and the parameters presents in table 2.

| Row | Wire diameter, (mm) | Amperage, (A) | Arc voltage, (V) | Welding speed, (cm/s) | Input energy, (J/cm) |
|-----|---------------------|--------------|----------------|----------------------|---------------------|
| 1   | 1.2                 | 120          | 20             | 0.381                | 6000                |
| 2-8 | 1.6                 | 340          | 30             | 1.75                 | 6000                |

As studies in terms of welding field shall be supplemented the study appears to welding heat and cooling time calculation especially since it is an important factor in welding.

In figure 2 shows the evolution of thermal field in welding for studied case.

### 2. Calculation of Welding Thermal History

Using the relations of thermal field one could lead to developments in space to weld temperature experimental evidence (fig. 3). Thus, using the Mathcad calculation, the following results were obtained for the temperature reached at different points material (T_i) that field lines corresponding thermal field.
Fig. 3. Thermal field in welding with linear energy of 6 kJ/cm

Temperature value Ti is regarded as material points of a side of heat source. Using software to estimate the maximum allowable hardness in the welded joint area was obtained estimated HAZ hardness 331.4HV5 for MIG welding (fig. 4).

Fig. 4. Predicted HAZ hardness – MIG welding

To check the influence of welding procedures there were designed two specimen extracted from samples that were made hardness measurements (HV30). Hardness was measured in base material (BM), heat affected zone (HAZ) and weld (W) using Vickers method with 29.42 daN load (30 kgf). In order to measure hardness was performed macroscopic analysis of specimens for evidence of welded joint zones (BM, HAZ, W).
Point position has been determined Vickers hardness is shown in figure 5.

![Hardness measure points position (BM, HAZ, W)](image)

**Fig. 5.** Hardness measure points position (BM, HAZ, W)

In table 3, respectively figure 6, are shows HV30 hardness values measured in three zones of welded joints characteristic.

### Table 3. Vickers hardness HV30 (MIG welded joint)

| Row | Zone |  |  |  |
|-----|------|---|---|---|
|     | Left |   | Right |   |
| I   | W    | 0 | 212 | - |
|     |      | 1 | 198 | 1  | 200 |
|     | HAZ  | 2 | 202 | 2  | 205 |
|     | BM   | 3 | 189 | 3  | 193 |
| II  | W    | 0 | 220 | - |
|     |      | 1 | 211 | 1  | 208 |
|     | HAZ  | 2 | 203 | 2  | 200 |
|     | BM   | 3 | 185 | 3  | 190 |
| III | W    | 0 | 208 | - |
|     |      | 1 | 203 | 1  | 206 |
|     | HAZ  | 2 | 203 | 2  | 201 |
|     | BM   | 3 | 192 | 3  | 189 |

![HV30 hardness variation along the MIG welded joint](image)

**Fig. 6.** HV30 hardness variation along the MIG welded joint
Having in view the fact that the studied steel is designed for work at temperatures below 0°C, respectively -196°C, attempts were made and the tenacity, by bending shock Charpy V specimens, at room temperature and the work temperature. Table 4 shows the results of impact bend test.

| Test temperature, (°C) | Average rupture energy, (J) | KCV resilience, (J/cm²) |
|------------------------|-----------------------------|------------------------|
| +20                    | 93.33                       | 166.66                 |
| -196                   | 40.00                       | 50.00                  |

3. Conclusions
Analysis and experimental measurements made the following conclusions:

- the hardness values obtained in HAZ is very similar to the hardness of base material, which shows that the welding system developed and applied welding, namely linear energy introduced, does not affect the characteristics of HAZ, steel presented a behaviour that is very good at welding;
- use of software to estimate the hardness enable the correct development of welding procedures prior to actual implementation of welded joints;
- the introduction of welding conditions could check also during cooling tΔ5 which is of particular importance in assessing the anticipated zone hardness and structure of, with opportunities to influence the processes taking place through proper modification of process parameters.
- were obtained a very good values of toughness, at ambient temperature and working temperature, so the steel allow practical use in industry giving safe operating.

Microscopic analysis of the joints (fig. 7) highlights the following:

- the welding structure is looking dendritic solidification. Structural constituents: austenite and δ ferrite. It also notes the presence of Cr carbide precipitates;
- in HAZ, the structure is affected by heating a small thickness; heating and rapid cooling led to fragmentation of the initial austenite crystals;
- the basic material structure consists of polyhedral crystals of austenite with numerous macle bands, δ ferrite and Cr carbide precipitates at the boundary grains. The grain size is 4-6, according to ISO 643:1993 classifications.

![Fig. 7. Macro and microstructure of test. Attack: aqua regia. 200:1](image_url)
References
[1] ANGHEL I.: Sudarea oțelurilor aliate, Editura Tehnică, București, 1993
[2] ANGHELEA H., POPOVICI V.: Sudarea în mediu de gaze protectoare, Editura Tehnică, București, 1982
[3] BURCĂ M., NEGOIȚESCU S.: Sudarea MIG/MAG, Editura Sudura, Timișoara, 2004
[4] CHENG X.N., DAI Q.X., WAND A.D.: Effect of temperature and alloying elements on impact toughness of cryogenic austenitic steel, Meter Scientific Eng. A, 2001
[5] DAI Q.X., WANG A.D., CHENG X.N.: Effect of temperature and alloying elements on strength of cryogenic austenitic steel, Meter Scientific Eng. A, 2001
[6] Scurtu, I.C., Manufacturing and design of the offshore structure Froude scale model related to basin restrictions, (2015) IOP Conference Series: Materials Science and Engineering, 95 (1), art. no. 012068, DOI: 10.1088/1757-899X/95/1/012068
[7] FAIRCHILD D.P.: Fracture toughness testing of weld heat-affected zones in structural steel. Fatigue and Fracture Testing of Weldments, ASTM STP 1058, American Society for Testing and Materials, 1990
[8] FOLKWARD E.: Welding metalurgy of stainless steels, Springer Verlag, Wien, 1988
[9] MICLOŞI V.: Oţeluri înalt aliate (inoxidabile), Q-Akademia, București, 2001
[10] MARSHAL P.: Austenitic stainless steels microstructure and properties, Elsevier, London, 1984