Influence of marine corrosion on the roughness of MAG welded joint surfaces

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Abstract. The study presents in the first part the behavior of the EH 36 steel with the thickness of 10 mm to MAG mechanized welding of butt-welded joints from the naval field, destructive and non-destructive testing for all welded samples. Furthermore, corrosion of the marine environment is analyzed by the electrochemical method. The study is completed with the corrosion influence on the roughness of the welded joints surfaces and conclusions.

1. Introduction

Steels for shipbuilding and offshore structures are low carbon steels, with good weldability, designed for high productivity processes of welded structures, which meet the conditions imposed by classification societies. In the early 1980s, in addition to normal-strength naval steels, the High Strength Low Alloy (HSLA) steels, which allow the production of narrower welded naval structures, were introduced to the same mechanical stresses. According to the rules of Lloyd’s Register (LR), naval steels are classified as follows [1, 2]:

- with normal strength (Rp0.2 min. 265 MPa): AH 27S, DH 27S, EH 27S, and PH 27S steels;
- high strength (Rp0.2 min. 315 MPa): AH 32, DH 32, EH 32, and PH 32 steels (Rp0.2 min. 315 MPa); AH 36, DH 36, EH 36, and PH 36 steels (Rp0.2 min. 355 MPa); AH 40, DH 40, EH 40, and PH 40 steels (Rp0.2 min. 390 MPa), and EH 47 steel (Rp0.2 min. 460 MPa).

For the butt-welded joint of the steel plates from the naval field, in all welding positions, the welding process in fusible electrode gas environments is the most commonly used (MAG welding 135 and 136). Depending on the volume of work and the deadlines imposed, the decision will be made regarding the degree of mechanization necessary to ensure optimum welding productivity [3].

The experimental research presented in this study is structured in three directions: the welding behavior of the EH 36 naval steel with the thickness of 10 mm; the corrosion behavior by the electrochemical method of the base material and the welded joints; the influence of the marine corrosion on the roughness of the base material and welded joints surfaces. This research was carried out in three research units within "Dunarea de Jos" University of Galati, Faculty of Engineering, Center for Advanced Research in Welding (SUDAV), Competences Center: Interfaces-Tribocorrosion and Electrochemical Systems (CC-ITES), and the Center for Research Technological Engineering in Machine Construction (ITCM).
2. Experimental program

2.1. Welding materials and equipment

In the experimental program, the following were used [3]:
- eight EH 36 naval steel sheets with 500x150x10 mm dimensions;
- metal-cored wire E70C-6MH4 according to AWS A5.18 and rutile flux-cored wire E81T1-Ni1MJH4 according to AWS A5.29, with diameters of 1.2 mm;
- Corgon 18: 82% Ar + 18% CO₂ (M21) shielding gas mixture;
- flat ceramic backing with concave channel (channel width 9 mm and channel depth 1.3 mm);
- four stands for MAG-M mechanized welding in PA/1G, PC/2G, PF/3G, and PE/4G positions.

The stands were equipped with the universal welding source Phoenix 405 Progress pulse MM TDM and the welding tractor K-BUG 5102.

2.2. Welding of samples

Within the experimental program, four butt-welding samples were welded in the positions involved in the construction and assembly of naval sections. The root layers were made with metal-cored wire E70C-6MH4 and RootArc transfer. The filling and final layers were made with rutile flux-cored wire E81T1-Ni1MJH4 and ForceArc transfer. The layers were deposited with pendulum and stationary on the edges (except for the final layer PC/2G welded sample made of three rows without pendulum). The samples were made on flat ceramic backing with concave channel.

The plates for the EH 36 naval steel samples, with dimensions of 500x150x10 mm, were processed with air plasma, according to Figure 1 (a - positions PA/1G, PF/3G, PE/4G; b - position PC/2G).

![Figure 1](image_url). The preparation of the plates for welding [3].

During the mechanized welding some of the technological parameters were kept constant [3]: DC⁺, reverse polarity; stationary time at the edges, \( t_{\text{sm}} = 0.2 \text{ ms} \); gas protection flow, \( Q_G = 18 \text{ l/min} \); gas flow time before starting the welding process, \( t_{\text{bw}} = 5 \text{ s} \); gas flow time after ending the welding process, \( t_{\text{aw}} = 5 \text{ s} \), and the sample-nozzle distance, \( h_{\text{sn}} = 15 \text{ mm} \) [3]. Table 1 centralizes the welding process variables which were applied in the experimental program.

| Layer type | Welding position | Parameters of welding regimes* |
|------------|------------------|-------------------------------|
|            | \( v_e \), [m/min] | \( I_e \), [A] | \( U_e \), [V] | \( v_r \), [cm/min] | \( v_p \), [cm/min] | \( L_p \), [mm] | \( v_{\text{ws}} \), [cm/min] | \( E_l \), [KJ/mm] |
| Root       | 4.5              | 183                          | 26.5                         | 25                         | 80                         | 6                         | 10                         | 0.065                      |
| Final      | 11               | 302                          | 31                           | 30                         | 80                         | 8                         | 13.7                        | 0.091                      |

*Table 1. Welding process variables applied in the experimental program [3].
|          | Root | 2.7 | 103 | 13.8 | 17 | 60 | 6 | 8 | 0.024 |
|----------|------|-----|-----|-------|----|----|---|---|-------|
| Filling  | 5.4  | 158 | 18.9| 27    | 60 | 8  | 14.3| 0.028|
| Final    | 6    | 167 | 18.9| 60    | 10 | 15.5| 0.027|

|          | Root | 2.7 | 103 | 13.8 | 17 | 60 | 6 | 8.13 | 0.023 |
|----------|------|-----|-----|-------|----|----|----|-------|-------|
| Filling I| 5.4  | 158 | 18.9| 27    | 60 | 8  | 14.3| 0.028|
| Filling II| 6   | 167 | 18.9| 30    | 60 | 10 | 15.5| 0.027|
| Final    | 6    | 167 | 18.9| 27    | 60 | 12 | 16.7| 0.025|

|          | Root | 5.9 | 170 | 18.9 | 60 | -  | -  | 60 | 0.071 |
|----------|------|-----|-----|-------|----|----|----|-----|-------|
| Filling  | 8    | 220 | 25.3| 60    | -  | -  | -  | 60  | 0.012 |
| Final    | 6    | 167 | 18.9| 60    | -  | -  | -  | 60  | 0.007 |

|          | Root | 5.5 | 160 | 18.9 | 92 | -  | -  | 92  | 0.004 |

Note: *v e* - advance speed of the welding wire; *I w* - welding current; *U a* - arc voltage; *v t* - speed of the welding tractor; *v p* - pendulum speed; *L p* - pendulum width; *v w* - welding speed; *E l* - linear energy.

Figure 2 presents aspects during the welding of the four butt-welded samples: a - position PA; b - position PF; c - position PE, and d - position PC.

3. Non-destructive and destructive testing

3.1. Non-destructive testing

According to the rules of Lloyd’s Register (LR), the butt-welded joints samples have been subjected to non-destructive, visual (100%), and radiographic (100%) testing. Following the non-destructive inspections, all four welded samples were of good quality (admitted), without surface and interior defects [1, 3].
3.2. Destructive testing
All four samples welded to each other had dimensions of 500x300 mm, and from each sample the following specimens were taken [1, 3]:
- one specimen for the macroscopic and microscopic examination and the Vickers HV1 microhardness test;
- four specimens for testing at the front transverse bending (two with the compressed root and two with the extended root), at an angle of 180°, on a 40 mm diameter thorn;
- two flat specimens with the calibrated portion for cross-tensile testing;
- nine specimens for the bending test by shock on Charpy V-shaped test tubes, at a temperature of -20°C: three with a notch in the center of the weld; three with the notch on the fusion line, and three with the notch in the thermomechanically influenced area, at a distance of 2 mm from the fusion line.

The good results of the mechanical laboratory tests, and the macroscopic and microscopic analyzes, make possible the application of the welding technologies for the high strength EH 36 naval steel with the thickness of 10 mm in the convenient PA position and in the difficult positions (PF, PE, and PC).

4. Corrosion behavior by electrochemical method
The experimental program regarding the corrosion behavior of the base material and the welded joints in natural seawater was conducted with the electrochemical working equipment consisting of: potentiostat / galvanostat PGZ 100, the electrochemical cell, and the computer for data acquisition.

In the electrochemical cell, containing 200 ml of Black Sea water, the three electrodes were arranged, the working electrode (cathode), the auxiliary electrode (anode) Pt-Rd, and the reference electrode. The method of sampling the working electrodes from the specimens previously subjected to mechanical bending tests with the compressed root is shown in figure 3.

![Figure 3. Sampling for the corrosion behavior analysis [4].](image1)

The resulting data were interpreted with the help of the VoltaMaster software 4. From the corrosion behavior of the base material and the welded joints in natural seawater, it can be observed that the corrosion speeds decrease with the exposure time, the lowest corrosion rate had the base material BM, and the corrosion speeds of the welded joints are different, depending on the welding regimes used [4].

5. The influence of marine corrosion on the surface’s roughness
Experimental research on the influence of marine corrosion on the surface’s roughness was performed using the SJ210 Mitutoyo roughness meter and SJ-Comunication-Tool analysis software.

![Figure 4. Determination of the depths of the asperities on the surfaces.](image2)
The determinations were made on a distance of 4 mm, with a speed of 0.5 μm/s on the surfaces of the five specimens, before and after conducting the behavior analyzes on corrosion (Figure 4: a - for the specimen taken from the base material BM, and b - for samples taken from butt-welded joints PA, PF, PE, and PC).

In the case of the base material, the depths of the asperities on the surfaces were determined in three areas, the base, the middle, and the upper part of the specimen taken on the thickness of the base material BM.

For the welded joints, the determinations were also made in three zones, corresponding to the root layer 1, the filling layer 2, and the final layer 3, in the joint between the welding components (PA, PF, PE, and PC samples).

In figures 5-7, the evolutions of the asperities’ depths on the surfaces, before and after conducting the corrosion behavior analyzes, for a determination in the base material (BM) sample, and a determination related to the final layers are presented, in direct contact with the seawater (PA, PF, PE, and PC samples).

![Figure 5](image1.png)  ![Figure 6](image2.png)

**Figure 5.** The evolutions of the depths of asperities for the BM sample.  
**Figure 6.** The evolutions of the depths of asperities for the PA sample.

With the SJ-Communication-Tool analysis software, the Ra roughness could also be determined. Figure 10 shows the average Ra values, before and after completing the corrosion behavior analyzes.

From figures 5...8, it is observed that both depths of the asperities on the surfaces, as well as the average roughnesses Ra of the surfaces, after the completion of the corrosion behavior analyzes by the electrochemical method, are higher, due to the corrosive action of the natural seawater [5, 6, 7].
6. Conclusions
The good results of the mechanical laboratory tests, and the macroscopic and microscopic analyzes, make possible the application of the welding technologies for the high strength EH 36 naval steel with the thickness of 10 mm in the convenient PA position and in the difficult positions (PF, PE, and PC).

After completing the behavioral analyzes on corrosion (the corrosion behavior of the base material and the welded joints in natural seawater) the roughness and the average roughness Ra of the test surfaces, were higher, due to the corrosive action of the seawater.

7. References
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