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INFLUENCE OF ROLLING DIRECTION IN CALCULATION OF RESIDUAL STRESS BY USING DCP METHOD IN NAVAL WELDED SHEETS

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Abstract. *Rolling processes introduce residual stress due to uneven plastic deformation, in which stress distribution at the sheet are of compressive nature on the surface and tractive in the center line. Residual stress are important for welded components structural integrity. In order to determine residual stress in welded joins of naval sheets from MAG process with different rolling direction, a displacements of coordinated points method was used, which preliminary results have shown a good correlation with the results obtained by traditional X-ray diffraction method. Average difference between the mapped points' centers of the welded sheets with welding bead in rolling direction was of 0.007 mm in X direction and 0.011 mm in Y, and average residual stress was of 63.303 MPa. Average difference of the centers in transverse direction was of -0.015 mm in x and -0.011 mm in y, and average residual stress was of 141.360 MPa. This difference is explained by Bauschinger effect (1886), in which anisotropy is explained by pre-deformation.*

Keywords: *residual stress, anisotropy, Bauschinger effect, Rolling process.*

1. INTRODUCTION

Residual stresses are significantly important in welded joints' structural integrity, as in large naval panels for example, which may present amplified defects due to the huge mechanical stress to which are subjected. These residual stresses produce big distortions, committing the panels integrity, as much as their assembly. In order to stablish residual stresses values in welded joints, a displacements of coordinated points (DCP) method was used. It's preliminary results have shown a good correlation with results obtained from traditional X-ray diffraction method. This is a quick, safe and low cost method.

The DCP method consists of measuring the extension of previously mapped points' displacements by using a coordinate measurement machine (CMM). Using these values and the material's modulus of elasticity and Poisson's ratio, residual stresses can be calculated and compared with DR-X measured values. It was, however, observed that anisotropy's effects of welded sheets were of importance, thus, significantly changing the results.

2. EXPERIMENTAL PROCEDURE

Four sheets with dimentions of 70 x 200 mm were welded two by two, having the weld bead both in the rolling direction, and cross direction. A MAG welding process was used with a semiautomatic machine (Fig. 2).

Figure 1. Semiautomatic MAG machine

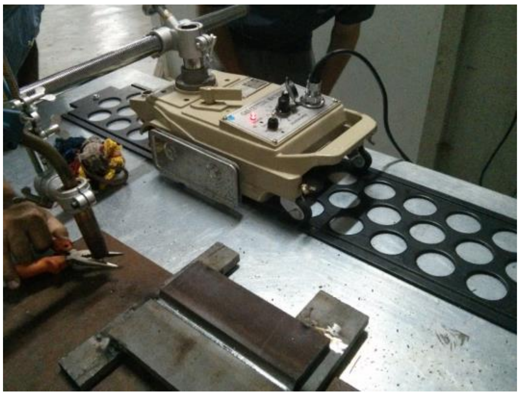


Figure 2. Cart

An AWS ER70S-6 wire with 1,2mm diameter was used having an Ar-25%Co_2 as shielding gas. The welding was performed in sheets with bevel angle of 25^o and an opening at the root of 2mm. To simulate the naval panels welding, it was necessary to lock the sheets' ends with welding. Then, the pairs were aligned with the torch cart for the root pass, and 4 later passes for filling and 1 underneath, for stiffening. During the welding were used an average voltage of 18,96V, current of 212,8A, welding speed of 3,485mm/s, with welding transfer efficiency of 80%, obtaining an average heat input per pass of 0,9kJ/mm. After each pass, slag was removed by using a steel brush.

2.1 Displacement of Coordinated Points

The method (Siqueira Filho, 2012) consists in drilling 2mm height holes with a 2,5mm diameter drill bit (Fig.3), and then, mapping the coordinates (X,Y) of its centers in a coordinate measurement machine (CMM) with computerized numerical control.

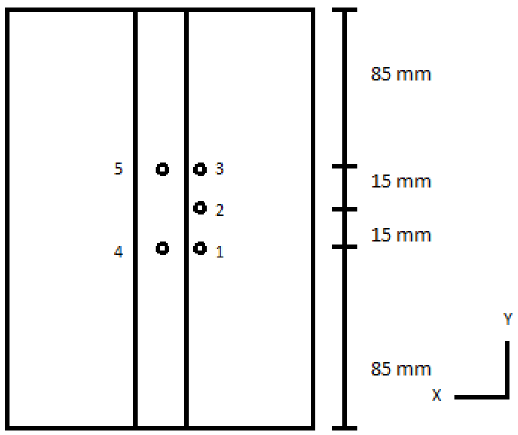


Figure 3. Distribution of points in welded sheet.

After this step, the steel is submitted to an annealing heat treatment at 680ºC for 30 min, in order to stress-relieve it. At the end of it, the mapped points will have been dislocated due to the material's yielding and were mapped again. According to the principle of coordinate measurement, that has the objective of determining dimentional parameters through coordinated points measurement over the surface of some piece and mathematically process it (Rolim, 2003), making it possible to calculate the strains through Eq. 1 in both length and crosswise direction.

$$\varepsilon = \frac{\Delta L}{L_0} \tag{1}$$

ε: deformation;
ΔL: distance variation of coordinated points;
L_0: distance between the point and sheet's center.

With coordinated points measured from before and after heat treatment, the welding strains can be found from Eq. 2 e 3 (Okumura, 1982):

$$\sigma_x = \frac{E}{1-\upsilon^2}(\varepsilon_x + \upsilon\varepsilon_y) \tag{2}$$

$$\sigma_y = \frac{E}{1-\upsilon^2}(\varepsilon_y + \upsilon\varepsilon_x) \tag{3}$$

σ_x: lengthwise residual stress – welding direction (Pa);
σ_y: crosswise residual stress – normal to welding direction (Pa);
ε_x: deformation in welding line;
ε_y: deformation normal to welding line;
υ: Poisson's ratio.

According to Okumura (1982), residual stress values σ_x and σ_y are obtained by measuring ε_x and ε_y, which are residual deformations in the points where it is wanted to know the residual stresses. To calculate it, data from a similar carbon steel with modulus of elasticity of 207.000 MPa and Poisson's ratio of 0,3 was used.

3. RESULTS

3.1 Method DCP

The center of mapped points from welded sheets with weld bead in rolling direction (sheet 1) and transverse to rolling direction (sheet 2), before and after heat treatment.

In sheet 1, all the points moved within Y's positive direction, however, points 1, 2 and 3 had a decreasement in the distance between them, thus showing the region is of compression. The other two points over the weld bead moved within Y's negative direction, and the distance between them has increased, resulting in a region of traction. (tab.1).

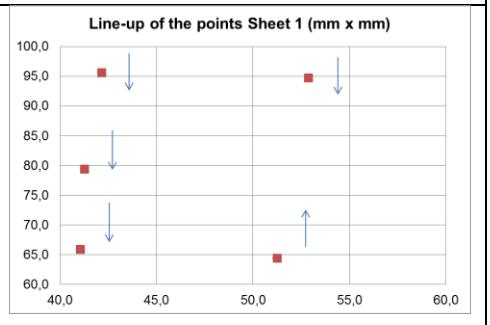
Table 1. Relative distance between two points of sheet 1.

Relation between points	Yi (mm)	Yf (mm)
2-1	13.462	13.461
3-2	16.269	16.264
3-1	29.731	29.729
5-4	30.355	30.339

For sheet 1, tensions calculated within X, Y, and residual stresses are displayed in tab. 2.

Table 2. Displacements of the points, directional tensions and residual stresses of the sheet 1.

SHEET 1					
Points	Xi-Xf	Yi-Yf	σx (MPa)	σy (MPa)	σresidual (MPa)
HAZ					
1	-0.014	-0.022	-118.010	-125.672	122.021
2	-0.004	-0.007	-35.016	-41.070	38.403
3	-0.001	-0.003	-11.873	-15.187	13.831
MZ					
4	0.016	0.020	129.616	121.028	125.542
5	-0.002	-0.003	-15.894	-17.957	17.020



In sheet 2, points 2 and 3 came closer to 1, showing the region to be of compression. The other two points over the weld bead have dislocated within Y's negative direction, and the distance between the points has decreased, resulting in a region of compression (tab.3). However, by analyzing the picture taken of sheet 5 it was able to observe the measurements of the weld bead points were done in different passes, showing the points have dislocated in the opposite direction the welding was executed.

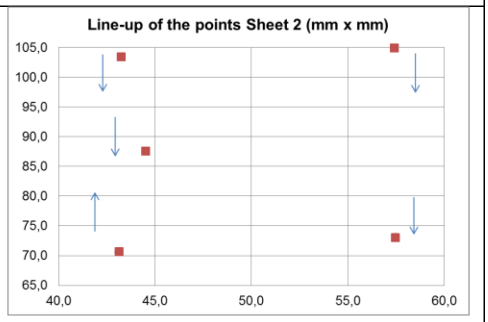
Table 3. Relative distance between two points of sheet 1.

Relation between points	Yi (mm)	Yf (mm)
5-4	31.892	31.874

For sheet 5, tensions calculated within X, Y, and residual stresses are displayed in tab. 4.

Table 4. Displacements of the points, directional tensions and residual stresses of the sheet 1.

SHEET 2					
Points	Xi-Xf	Yi-Yf	σx (MPa)	σy (MPa)	σresidual (MPa)
HAZ					
1	0.016	0.026	138.211	148.825	143.812
2	-0.006	-0.015	-62.807	-82.556	74.667
3	-0.004	-0.008	-37.157	-44.114	41.080
MZ					
4	-0.024	-0.030	-196.840	-184.956	191.175
5	-0.026	-0.048	-237.569	-271.236	256.068



3.2 Tensile Test

From tensile testing of test specimen of 0° e 90° of the sheet's rolling direction, tensile strength values were obtained. These are displayed in Tab. 5.

Table 5. Test specimen mechanical properties results.

Test specimen	Tensile strenth (MPa)	Back stress
1	368,9	24,7
2	381,6	
3	348,9	
4	353,9	
5	380,7	
6	375,3	

For test specimen taken by the rolling direction, tensile strength's average was of 354,6MPa, and for those transverse to the rolling direction, it was of 379.3MPa. This results in an increase of back stress of 24.7 MPa.

3.3 Relation between residual stresses

In order to relate residual stresses in welded sheets transverse to rolling direction, the back stress, found in tensile testing, is summed to residual stresses from sheets welded by rolling direction. Tab. 6 displays two sheets, which were welded by rolling direction, in relation to transverse ones.

Table 1. Relation between residual stresses.

SHEET 1	residual σL	σT=σL+σR	Sheet 5	residual σT
1	122,021	146,721	1	143,812
2	38,403	63,103	2	74,667
3	13,831	38,531	3	41,080
4	125,542	150,242	4	191,175
5	17,020	41,720	5	256,068

Results have shown a good relation between residual stresses in both rolling directions. However, on the weld bead region there was no such relation.

4. CONCLUSIONS

DCP method has shown capable of calculating residual stresses and it's nature in a simple, accessible way.

The correlation between calculated residual stresses in different rolling directions was observed by summing the back stress imposed to the material previously by the rolling process. The results have shown the back stress has influence in calculating residual stress of sheets welded transverse to the rolling direction. However, on the weld bead region requires further studies to identify such relations.

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