INFLUENCE OF WELDING PARAMETERS IN CALCULATION OF RESIDUAL STRESS BY USING DCP METHOD IN NAVAL WELDED SHEETS

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Abstract. *Residual stress classify commonly as the internal stress that remain in the material, even when no longer under influence of mechanical and thermal stresses. In welding, residual stresses are introduced by the high temperature gradient due to uneven heating and cooling. Heat flux in welding affects phase changing, becoming the great responsible for residual stress existence. By changing welding parameters in a MAG process, it changes current, voltage, joint aspects and therefore, heat input. In order to study the influence of welding parameters in residual stress, a displacement of coordinated points method was used. Sheets that dealt with higher heat input presented higher residual stresses values as well.*

Keywords: *residual stress, welding parameters, displacement of coordinated points, naval welded sheets.*

1. INTRODUCTION

Residual stresses are often classified as the internal tensions which remain in the material, mechanical elements and finished product, even when no longer under mechanical or thermal influences, or, as defined by Macherauch & Kloos

(1987), "self-balanced tensions existing in the materials in the absence of external load, displacement or temperature gradients". They can be harmful for such material's performance a component's life cycle.

In welding, residual stresses are introduced from the elevated temperature gradient due to heating and uneven cooling, and the three main sources to producing them are cooling contraction, intense surface cooling and phase changing. Since we are working with a heat treatable steel, it is possible to say that heat flow during welding affects phase changing, modifying such microstructure and the affected area's properties, thus being the great responsible for the existence of residual stresses and distortions.

By switching welding parameters, such as welding speed, spacing, bevel angle, amount of passes, it changes arc's current, voltage, bead aspects and heat input's value, which may be calculated by the following Eq. (1).

$$Heat\ input\left(\frac{kJ}{mm}\right) = \frac{Arc\ voltage\ x\ Current\ x\ 60}{Welding\ speed\left(\frac{mm}{min}\right) x\ 1000} \times Efficiency \tag{1}$$

When heat input varies, heat flow changes, becoming the greatest responsible in modifying values of residual stress. According to Zinn (2002), heat input is an important characteristic, because like preheat and interpass temperature, it influences the cooling rate, which affects the mechanical properties and metallurgical structure of the weld and HAZ, and, in consequence, affects the residual stress distribution in the weldments.

The determination of residual stresses may be performed by various experimental procedures, such as techniques based on blind bore, X-ray diffraction, which may involve non-destructive or destructive procedures (Calle, 2004). In order to study the welding parameters influence in residual stresses, a displacement of coordinated points (DCP) method was used, which consists of measuring the extension of previously mapped displacement points by using a coordinate measurement machine (CMM). With these values and the material's modulus of elasticity and Poisson's ratio, residual stress can be calculated.

2. EXPERIMENTAL PROCEDURE

Five pairs of 70 x 200mm sheets were welded using different welding parameters. For the weld process, a semiautomatic MAG machine was used (Fig. 1) along with a gas cutting machine, adapted to translate the torch (Fig. 2).

Figure 1. Semiautomatic MAG machine

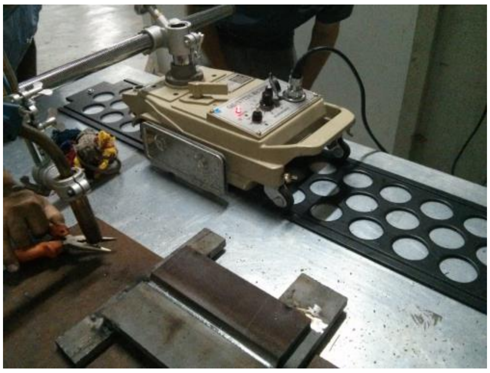

Figure 2. Gas cutting machine

An AWS ER70S-6 wire with 1,2mm diameter was used. The welding was performed in sheets with butt joints and bevel angles of 25º and root height 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 gas cutting machine for the root pass, and the later passes for filling. After each pass, slag was removed by using a steel brush. The following welding parameters were changed in order to study the effects: welding speed, root opening, amount of passes and bevel angle, along with current and tension. This reflects in the heat input.

Table 1. Sheets and theirs welding parameters

Parameters	Sheet 1	Sheet 2	Sheet 3	Sheet 4	Sheet 5
Welding speed (mm/s)	3,5	5,4	3,5	1,0	8,1
Root opening (mm)	0	0	1,2	0	0
Amount of passes	5	5	5	8	6
Bevel angle (°)	25	25	25	25	35
Welding power (W)	4257	3861	4463	3897	3723

2.1 Displacement of Coordinated Points

The method used to measure residual tensions is the DCP method, developed by Siqueira Filho (2013), which consists in observing the punctual sheet's displacements. In order to do so, five 2mm height holes were drilled with a 2,5mm diameter drill bit, as shown in Figure 3, and then, mapping the coordinates (X,Y) of its centers in a coordinate measurement machine (CMM) with computerized numerical control.

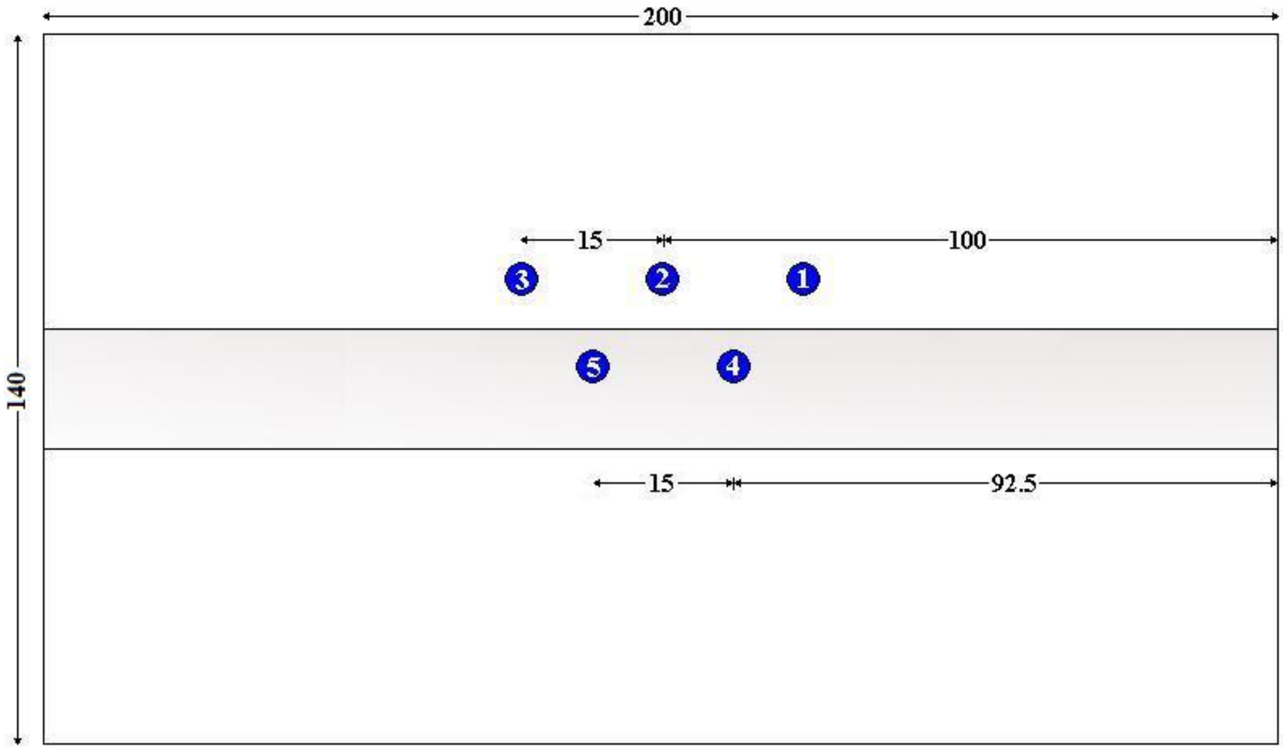

Figure 3. Distribution of points in welded sheet.

After this step, the steel is submitted to an annealing heat treatment at 680ºC for 30 min, in order to stress-relieve it. The mechanical methods to stress relieving can be effective; however, according to Modenesi (2001), the most used method is currently the annealing heat treatment, also known as stress relieving heat treatment (SRHT). In this, sheets or parts of them are heated to high temperatures, while still below material's phase changing critical temperature for a period of time, and then cooling in rates below 150°C/h, covering the main operational steps of stress relieving (Kwofie, 2009).

At the end of it, the mapped points have been dislocated due to the material's yielding and were mapped again, according to the principle of coordinate measurement, which has the objective of determining dimensional parameters through coordinated points measurement over the surface of some piece and mathematically process it (Rolim, 2003). This makes 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 point measured before and after heat treatment, the welding strains can be found from Eq. 2 e 3, as done by Okumura (2002):

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

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

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.

Still, according to Okumura (2002), 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 desired 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

The five sheets presented the following values of heat input by pass, differences of coordinates dislocation, stress in X and Y axis and residual stresses, as shown in Tables 2-6 below.

Table 2. Stresses length and crosswise of the weld bead and residual stress for sheet 1.

Sheet 1	Average Heat Input (kJ/mm)	Xi-Xf (mm)	Yi-Yf (mm)	σx (MPa)	σy (MPa)	σresidual (MPa)
1	979,1	0,001	0,001	7±4	8±4	8±5
2		-0,008	-0,017	-75±4	-92±4	85±5
3		-0,010	-0,026	-100±6	-137±6	123±9
4		0,025	0,034	209±29	202±29	206±42
5		-0,004	-0,007	-33±1	-38±1	35±1

In sheet 2, welding speed was changed from 3,5 to 5,4mm/s. The residual stresses in the welded sheet were of compressive nature as shown in table below.

Table 3. Stresses length and crosswise of the weld bead and residual stress for sheet 1.

Sheet 2	Average Heat Input (kJ/mm)	Xi-Xf (mm)	Yi-Yf (mm)	σx (MPa)	σy (MPa)	σresidual (MPa)
1	574,5	-0,007	-0,011	-61±2	-64±2	63±3
2		-0,006	-0,012	-57±3	-66±3	62±4
3		0,001	0,002	6±4	8±4	7±5
4		0,084	0,107	-695±72	-652±72	674±100
5		-0,003	-0,006	-30±5	-34±5	32±7

In sheet 3, root opening was changed from 0 to 1,2mm. The residual stresses in the welded sheet were of compressive nature as shown in table below.

Table 4. Stresses length and crosswise of the weld bead and residual stress for sheet 2.

Sheet 3	Average Heat Input (kJ/mm)	Xi-Xf (mm)	Yi-Yf (mm)	σx (MPa)	σy (MPa)	σresidual (MPa)
1	1130,6	-0,004	-0,006	-32±8	-36±8	35±11
2		0,013	0,028	121±9	154±9	141±12
3		0,024	0,063	243±3	333±3	299±4
4		0,017	0,024	143±1	141±1	142±1
5		0,017	0,034	156±7	188±7	174±10

In sheet 4, the amount of passes were changed from 5 to 8 passes. The residual stresses in the welded sheet were of compressive nature as shown in table below.

Table 5. Stresses length and crosswise of the weld bead and residual stress for sheet 3.

Sheet 4	Average Heat Input (kJ/mm)	Xi-Xf (mm)	Yi-Yf (mm)	σx (MPa)	σy (MPa)	σresidual (MPa)
1	2929,3	-0,008	-0,012	-69±5	-70±5	70±7
2		-0,011	-0,019	-96±7	-109±7	103±9
3		-0,005	-0,010	-43±13	-55±13	50±18
4		-0,013	-0,016	-104±12	-98±12	101±17
5		-0,006	-0,011	-52±1	-62±1	57±1

In sheet 5, the bevel angle was increased from 25 to 35°. The residual stresses in the welded sheet were of compressive nature as shown in table below.

Table 6. Stresses length and crosswise of the weld bead and residual stress for sheet 4.

Sheet 5	Average Heat Input (kJ/mm)	Xi-Xf (mm)	Yi-Yf (mm)	σx (MPa)	σy (MPa)	σresidual (MPa)
1	369,4	-0,014	-0,022	-118±11	-126±11	122±15
2		-0,004	-0,007	-35±16	-41±16	38±23
3		-0,001	-0,003	-12±10	-15±10	14±11
4		0,016	0,020	130±2	121±2	126±2
5		-0,002	-0,003	-16±1	-18±1	17±2

By analyzing sheets 1 and 2, when welding speed was increased, it is possible to say that reducing heat input in sheet 2 reduced the residual stress due to a smaller extension of HAZ. This has shown to be true, for average residual stress in HAZ has decreased from 73 MPa to 44 MPa.

Heat input has been slightly increased in sheet 3 in comparison to sheet 1, raising the average of the residual stress in HAZ to 158 MPa. The root opening increment could have part in explaining the residual stress raise as well, and it will be reviewed in the next steps of this study.

In sheet 4, a raising in the number of passes has not influenced the heat input as much as the consequence of increasing of welding speed in this proportion. Nevertheless, average residual stress in HAZ is similar to sheet 1 (74 MPa).

In recent studies, Siqueira Filho et al (2013) has shown that increasing the bevel angle of 25° to 35° increases the residual stresses in the joint due to the greater volume of weld metal. However, in sheet 5, due to the increased speed, heat input is reduced, resulting in a reduction in residual stresses of HAZ to 58 MPa.

Weld bead region's behavior within the welding process was not under full control, so this region still presents difficulties to be analyzed and requires an improvement in methodology.

4. CONCLUSIONS

By varying welding parameters, different welding bead's shape and size were obtained. A relation between HAZ zone size and welding speed and power was stablished, however, this relation only does not explain the results observed to the residual stresses values.

For residual stresses it is coherent to watch for heat input, which unlike the power itself, considers, beyond voltage and current, welding speed and process efficiency. Further studies will be made in order to stablish comparisons while setting heat input's value in order to prevent mixed sources of residual stress. Weld bead region's results have shown to be difficult to analyze due to the process not being fully under control in this region. However, in HAZ this value is of great importance, since with higher values of heat input, we have higher values of residual stress.

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