Methodology for measurement of residual stresses in welded joints by the technique of pulse-echo ultrasound

A. Ballesteros-Hinojosa[1], J.J. Ruíz- Mondragón[1], J. Acevedo-Dávila[1] and F. Macias-Lopez[1], Corporación Mexicana de Investigación en Materiales (COMIMSA). Calle Ciencia y Tecnología No 790 Fraccionamiento Saltillo 400, Saltillo, Coahuila, México, C.P. 25290.

Abstract

The objective of this investigation is establish a methodology for residual stresses evaluation. Electrode of use submarine (UW-CS-1) and API 5L X65 steel were employed for welding development in situ to 10 and 15 meter on depth.

Residual stress measurements by ultrasound (UT) were correlated by X-ray diffraction (XRD), showing similar results between the two techniques, as well as the tendency to increase the residual stress level as increases the weld depth.

Keywords: underwater welding, residual stresses, ultrasonic method.

E-mail: aballesteros@comimsa.com

1 Introduction

The wet process manual arc welding (MMAW, for its acronym in English) acts directly in contact with the water from the environment affecting mainly the solidification time of wet welds in compared to registered in welds dry[3, 4, 5]. Deriving from these changes, exist deterioration greater of the mechanical properties and a failure susceptibility greater of the joint[1, 2, 5, 6; 7]. Therefore, is this main reason of why this type of welding can be only provisionally applied during repair works[7].

Most research in underwater welding has been focused on improving the mechanical properties based primarily of filler metal used for this type of joints [6-13]. However, the measurement and evaluation of residual stress should be considered with the same importance, since the presence of high levels of stresses can mitigate severely the mechanical properties of the joint[14].

Finding by several researchers[14, 15] that the generation of residual stresses in welded joints is primarily due to non-uniform plastic deformations promoted by phase transformations and thermal gradients. Presenting such conditions with more severity in underwater environments[5, 15].

This research focuses primarily on developing a measurement methodology applied and extrapolated to measure residual stresses in welds underwater by the ultrasound method and validated by the method of X-ray diffraction

2 Experimental Development

2.1 Materials

Figure 1 shows the preparation made in welded joints. Plates were extracted with dimensions of 200 X 100 mm of a steel pipe of API 5L X65 305.4 mm diameter and 6.35 mm thick, with a butt joint in V bevel in a 45°

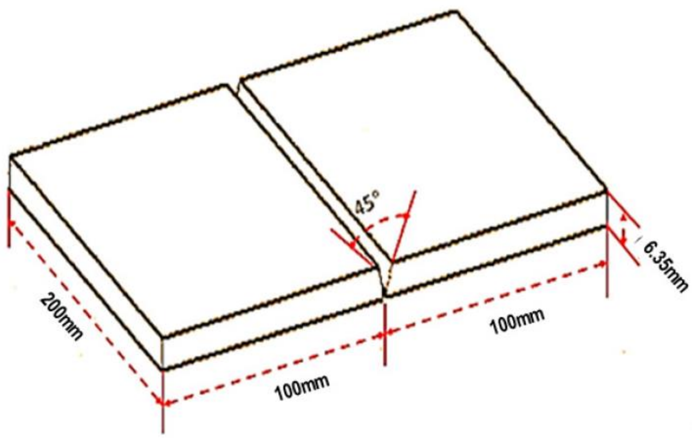

Figure 1 Coupons used for V groove welds wet

Electrodes of the trademark Broco Underwater UW-CS-1 AWS E70XX of 3.2 mm (1/8 in) were used as filler metal with a polarity direct current electrode positive (DCEP), a welding speed of 1270 to 1016 mm/min and amperage 190A constant. Keeping as only variable the depth of welding in 10 and 15 m depth on sea

Figure 2 shows the weld deposits on the specimen, four samples for each depth were developed using the above parameters.

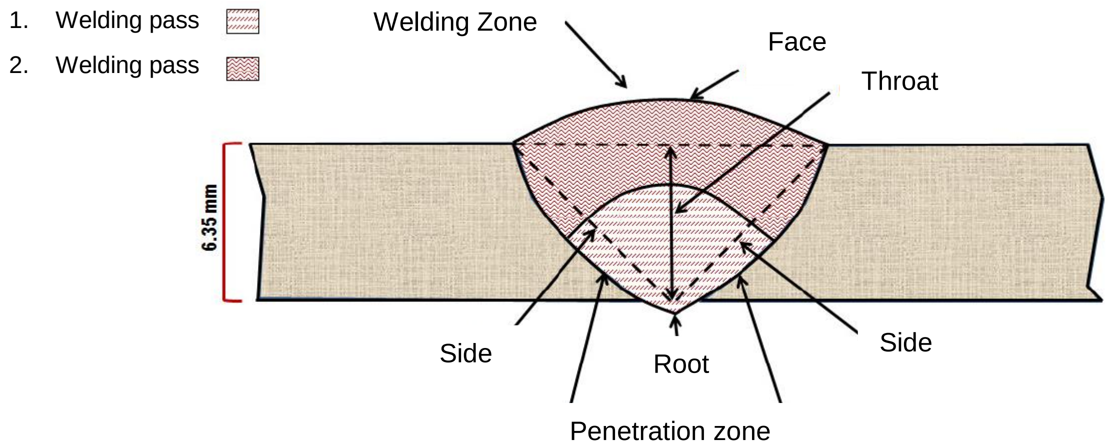

Figure 2 Scheme of welds made at 10 and 15 m on depth under sea

The welded specimens were cut transverse to the weld bead to give a final dimension 4 x 4 mm (thickness, width) and were prepared metallographic with 5% of nital and an analysis of residual stress by X-ray diffraction (XRD) and ultrasonic were used.

The XRD measurements were performed to 1.3 mm under the surface in an angle of 90° with a frequency of 3 mm for an average six measurements per specimen. While for UT, an average 10 measurements to 1.5 mm of the surface were employed. In both cases went tested the three zones of the weld.

2.2 Measurement of residual stresses

2.2.1 X-Ray Diffraction

The evaluation of residual stress by X-ray diffraction (XRD) was performed based on Bragg's law, using a equip XTRESS 3000, measuring an average of six points per test at a distance of 1.3 mm from the transverse surface in an angle of 90° and with a collimator aperture size of 1 mm. The separation between each measurement was 3 mm in a straight line by the three zones of the weld. Table 1 shows the parameters used by the team of DRX.

Table 1 XRD Parameters

Parameter	Values	Unit
Radiation (CrKa)	156.4	Grades
Collimator size	1	mm
Distance Collimator	9.75	mm
Direction	90	Grades
Voltage	30	Kv
Current	5	mA
Young´s Modulus	211000	MPa
Poisson’s Ration	0.3	---

2.2.2 Ultrasonic

The evaluation of residual stress by ultrasound was based on the acoustic-elastic effect or what is the same in the variation of the speed of propagation of the acoustic wave as a function of the mechanical stresses in the material.

For this was used a equip model OmniScan OMNI-M-type PA1664PRM, in Pulse-Echo mode, using one type K-PEN pencil high resolution as transducer.

Table 2 shows the parameters used by the ultrasound equipment during the execution of the various tests.

We were performance an average of ten measurements per specimen by UT, covering the three areas of welding (Metal base, heat affected zone and weld).

The Acoustic-elastic constant was obtained by heating of a steel plate of measure 50 X 40 X 6.35 mm (length, width, thickness) of 21 at 110°C using a equip Thermolyne Cimarec.

Table 2 UT Parameters

Parameter	Values	Unit
Transducer diameter	3.175	mm
beam delay	9.3	µs
Range	5	µs
Frequency	7.5	MHz
Velocity	57.658	mm/s
Pulse width	66.6	ns

3 Results

Figure 3 shows the average values of the residual stresses measured by XRD in the specimens welded to 10 and 15 meters underwater have tensile stresses higher in the heat-affected zone for both as welded specimens 10 as to 15 meters.

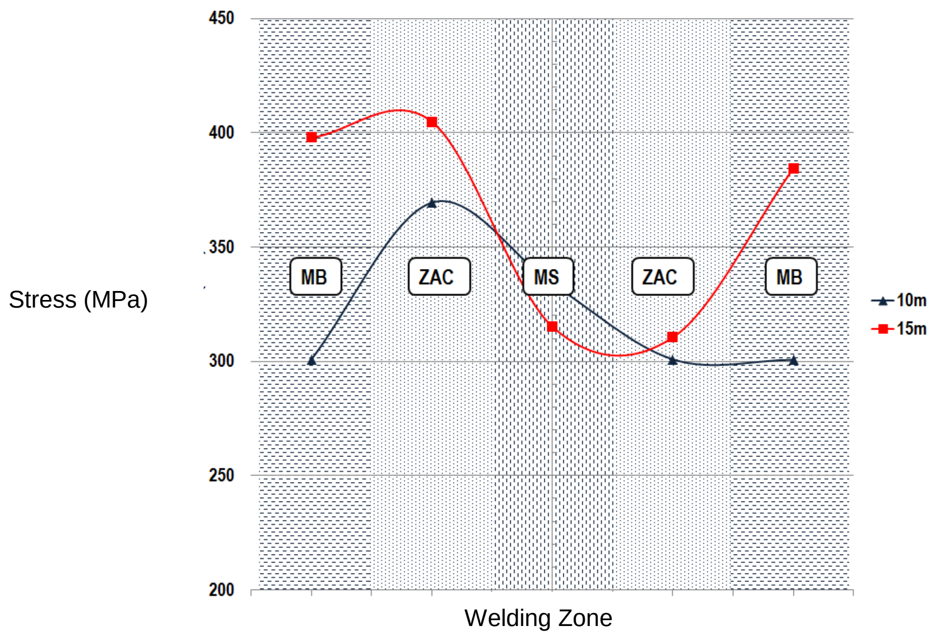

Figure 3. Residual stress measurement by XRD in underwater wet welding

Furthermore, one can see that there is a significant discrepancy between the two HAZ, attributed primarily to the interface weld-HAZ, where concentrates the higher tensile stress as a result of internal forces the material by solidification of weld metal. Therefore it is established that the measurements performed on the left side of the graph corresponds to a point closer to the interface weld-HAZ measurements made, for other part is estimated that right side were closest of the base metal.

Another important point discussed is that the residual stress value measured in the HAZ of welds made at 15 m depth represents be slightly higher than that obtained in the welded specimens to 10 meters deep.

Table 3 shows the values obtained from the speed change in according to temperature change, with your corresponding thermal stress. Observed that as the thermal stress increases, decreases the speed ultrasonic.

Table 3 Speed and stress data according to temperature change

Temperature(°C)	Velocity (mm/μs)	Stress (MPa)
21	56.93	0
60	53.69	98.28
70	50.80	123.48
80	48.56	148.68
90	44.62	173.88
110	42.06	224.28

Through to linear regression of the plot values of Table 3 was obtained the relationship between the variables ΔV/V0 and thermal stress, represented this way the acoustic-elastic constant of the test material, as seen in Figure 4.

By obtaining the acoustic-elastic constant of the material we proceeded to calculate residual stresses, in based on flight time.

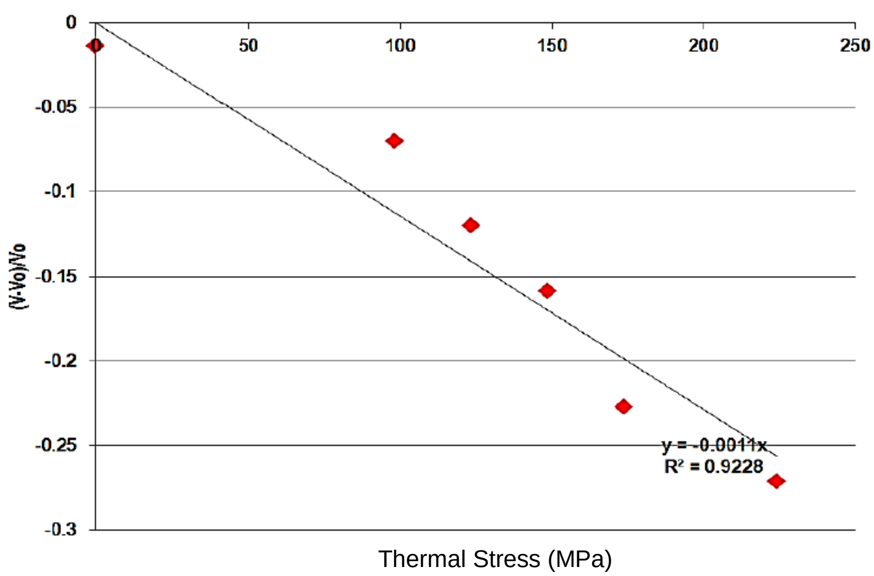

Figure 4 Relationship between the change in acoustic wave velocity and thermal stress.

In Figure 5 are recorded the signals obtained in display A-Scan, which plots the signal frequency on function to time. The flight time is obtained through difference between the first and second echo generated in the work piece.

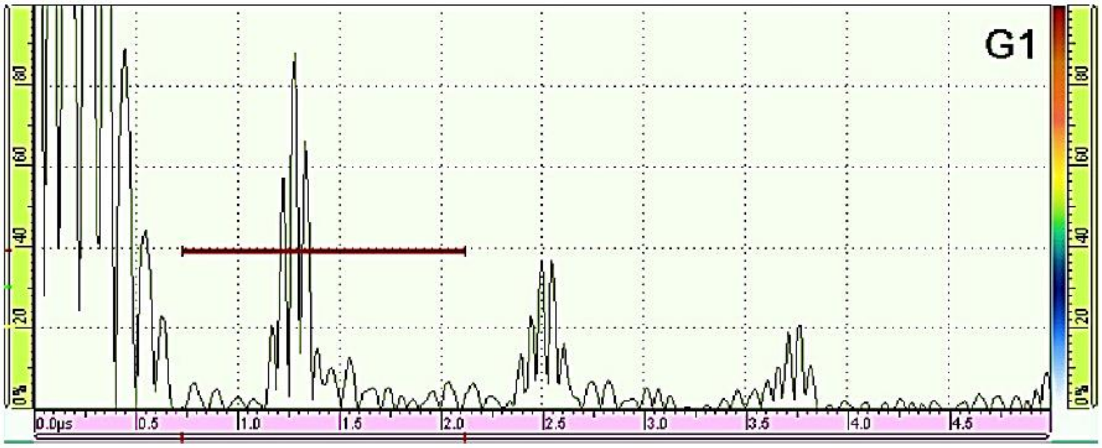

Figure 5 A-Scan display showing the ultrasonic signals obtained from the workpiece

Figure 6 shows the results obtained by UT for the residual stresses in the welded specimens to 10 and 15 meters deep. We observed in the three zones on the welding, tensile stresses. The higher value is obtained in the HAZ while at compare the two depths of welding were recorded a slightly more high stress in the tests to 15 meter depth.

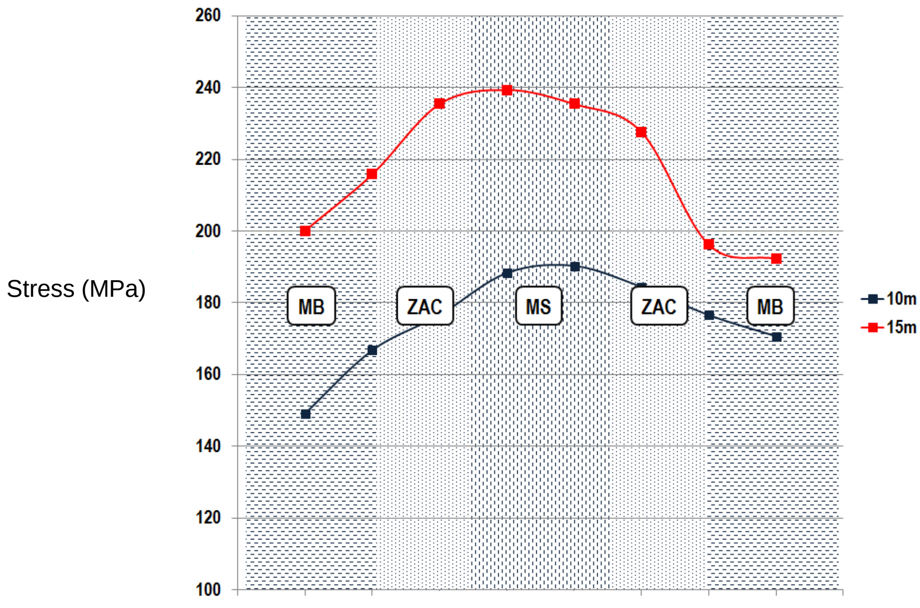

Figure 6 Measurement of residual stresses by wet underwater welding for UT

In Figure 7 are plotted the mean measured values of residual stresses by XRD and UT. We observed a similar trend between the two techniques on behavior of residual stress distribution in the three areas of welding.

Likewise the XRD values are greater than those recorded by the technique of UT attributing these differences to following points:

- The differences in directionality generated for residual stress, is because the UT technique obtained the sum of residual stresses through the full thickness of the part, thus complicating its comparison with other measuring method[17].

- The thickness plays an important role, since in thin walls, the sound can be remain after having stopped emitting the beam onto the work piece, thereby changing the shape of the ultrasonic wave and overestimating the value of effort measured[18].

Figure 7 show that the values obtained for XRD as UT are below the yield stress and the failure API 5L X65 steel. Besides, the welds made at 15 meters depth provide an effort slightly larger than to 10 meters deep, regardless of the measurement technique.

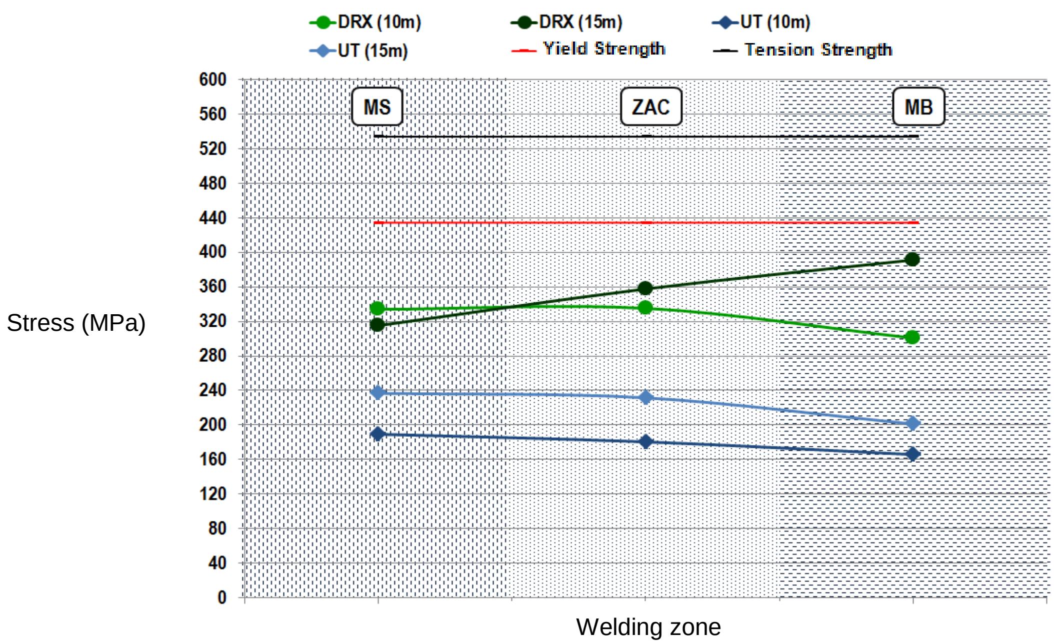

Figure 7. Comparing the average residual stress distribution measured by XRD and UT

4 Conclusions

DRX techniques and UT are similar in the distribution of residual stresses along the weld and your discrepancies on magnitudes are attributed to the limitations for each method, to the direction in which the strain was measured and the calibration each team.

The residual stress value found in the three weld zones remains below the yield stress a 27 and 45% and similar form for failure stress with a 38 and 53% according to measurements made with DRX and UT respectively.

The welding depth have not significant an effect on the generation of residual stresses, however the magnitudes of the welded specimens to 15 meters deep were slightly high to the stresses generated in the specimens welded to 10 meters depth, regardless of the measurement technique. This suggests that there is a tendency to increase of value the residual stresses generated as welding depth increases under the sea.

The technique of UT proves to be a viable tool for measuring residual stresses in underwater environments besides requiring a minimum preparation of the surface examination and using water as means coupling of ultrasonic waves, with a decreasing in the probability of error on rough surfaces and inspecting parts more fast and economical compared with others techniques of measurement of residual stresses.

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