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Vasile Cojocaru, Viorel Constantin Campian, Calin-Octavian Miclosina

Experimental Analysis of Residual Stresses in Samples of Austenitic Stainless Steel Welded on Martensitic Stainless Steel Used for Kaplan Blades Repairs

Residual stresses occur in materials as a result of mechanical processes: welding, machining, grinding etc. If residual stresses reach high values they can accelerate the occurrence of cracks and erosion of material. An experimental research was made in order to study the occurrence of residual stresses in the repaired areas of hydraulic turbine components damaged by cavitation erosion. An austenitic stainless steel was welded in various layer thicknesses on a martensitic stainless steel base. The residual stresses were determined using the hole drilling strain gage method.

***Keywords**: residual stresses, austenitic stainless steel, martensitic stainless steel, cavitation erosion, Kaplan turbine*

1. Introduction

Residual stresses occur in materials as a result of mechanical processes: welding, machining, grinding etc. If the residual stresses reach high values they can accelerate the occurrence of cracks and erosion of material.

The cavitation erosion is a main cause of damages in Kaplan hydro turbines runner blades. The repairs of turbine components with eroded areas are usually made by welding. The thickness of welded coatings depends on the depth of cavitation caverns.

A experimental research was made in order to study the link between the weld thickness and the occurrence of residual stresses at the repairs made on the Kaplan turbine runner blades affected by cavitation erosion. Three samples with 7 mm (sample 1), 10 mm (sample 2) and 15 mm (sample 3) weld thickness were manufactured [1,2]. The base material was a martensitic stainless steel 1.4313, EN 10088-2 (runner blades material), with 20.155 Cr equivalent and 5.035 Ni equivalent on Schaeffler diagram. The filler material was an austenitic stainless steel with 19.99 Cr equivalent and 18.64 Ni equivalent on Schaeffler diagram. A similar investigation was made using the same filler material applied on an austenitic-ferrite stainless steel. The work procedure and the results were presented in [3].

2. Measurement of residual stresses

The Hole Drilling Strain Gage method [4,5] was used for the measurement of residual stresses. The method (standardized in ASTM E837 - 08e1 [6]) consist in the multistep drilling of a blind hole in the center of a strain gage rosette applied on the tested material. Readings are made for each step on three or six direction. In this research strain gage rosettes with three elements (RE rosette) were used.

Two measurements were made on each sample, first on the top surface of the welding and second, in the cross section of the sample (the heat affected zone HAZ- figure 1).

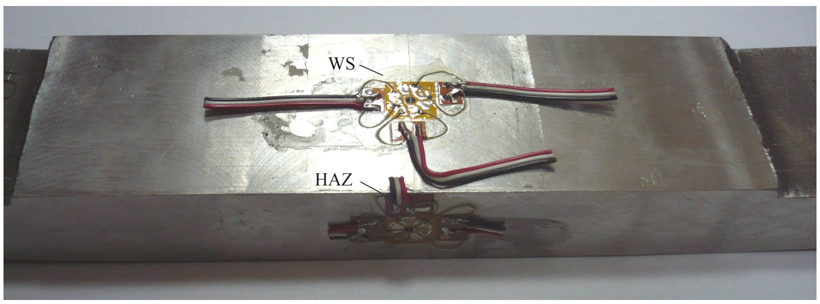

Figure 1. The strain gauges set-up for residual stresses measurements: on welding surface (WS) and in the heat affected zone (HAZ)

The residual stresses $\sigma_{\max}$ and $\sigma_{\min}$ were calculated from the measured strains ε_1, ε_2 and ε_3 using [7]:

$$\sigma_{\max,\min} = \frac{\varepsilon_1 + \varepsilon_3}{4A} \mp \frac{\sqrt{(\varepsilon_3 - \varepsilon_1)^2 + (\varepsilon_1 + \varepsilon_3 - 2\varepsilon_2)^2}}{4B} \quad (1)$$

The coefficients A and B depend on the material characteristics, the holes diameter D_0 and the rosette diameter D:

$$A = -\frac{a(1+\upsilon)}{2E} \quad (2)$$

$$B = -\frac{b}{2E} \quad (3)$$

Where:

E – Young's modulus;

υ – Poisson's ratio;

a, b – coefficients depending of D_0/D ratio. For this study the coefficients *a* and *b* were determined from ASTM E837 experimental diagrams.

The results are represented in the diagrams residual stresses, $\sigma_{max}, \sigma_{min}$ [MPa] – hole depth, z [mm] (figures 2 to 7).

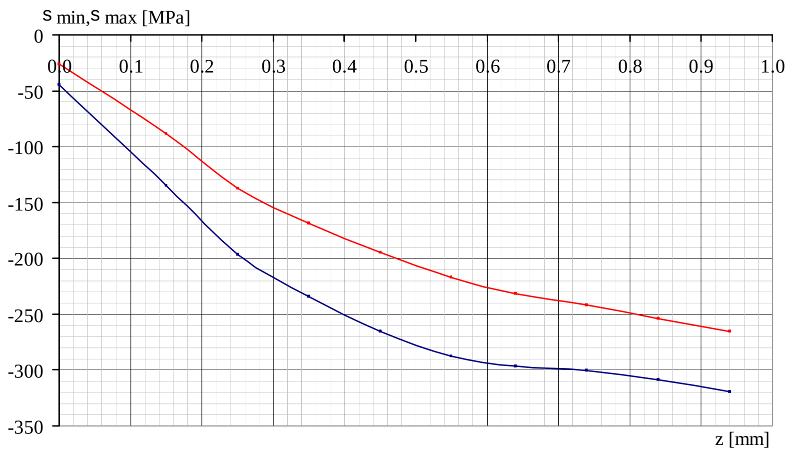

Figure 2. Sample 1 - Residual stresses measured on welding surface

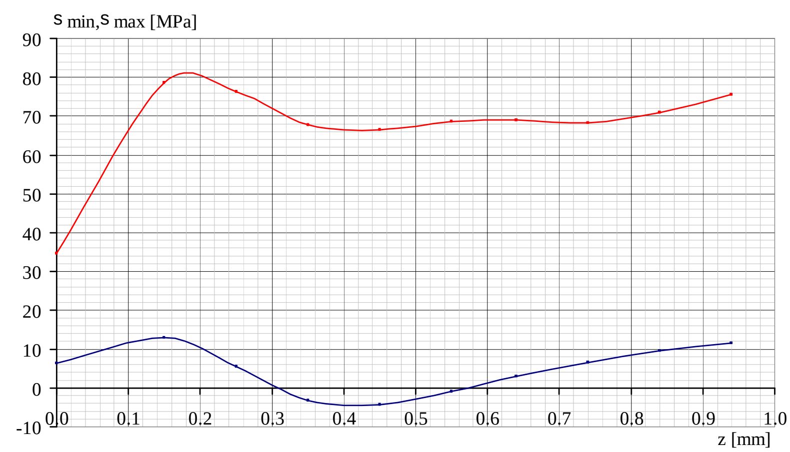

Figure 3. Sample 1 - Residual stresses measured on heat affected zone (HAZ)

The yield strength for the base material provided by the material manufacturer was Rp0.2 = 650 MPa. For the filler material Rp0.2 = 268 MPa.

Residual stresses σ_{max} and σ_{min} measured on the welding surface had negatives values for all three samples. The maximal values for σ_{min} were: -319.5 MPa (sample 1), -259 MPa (sample 2) and -285.6 MPa (sample 3). The maximal values for σ_{max} were: -265 MPa (sample 1), -178 MPa (sample 2) and -246 MPa (sample 3).

Residual stresses measured on the heat affected zone had positive values for sample 1 and negative values for samples 2 and 3. The maximal were smaller compared with the values measured on the welding surface: 78 MPa (σ_{max}, sample 1), -157.5 MPa (σ_{min}, sample 2) and -114.5 MPa (σ_{min}, sample 3).

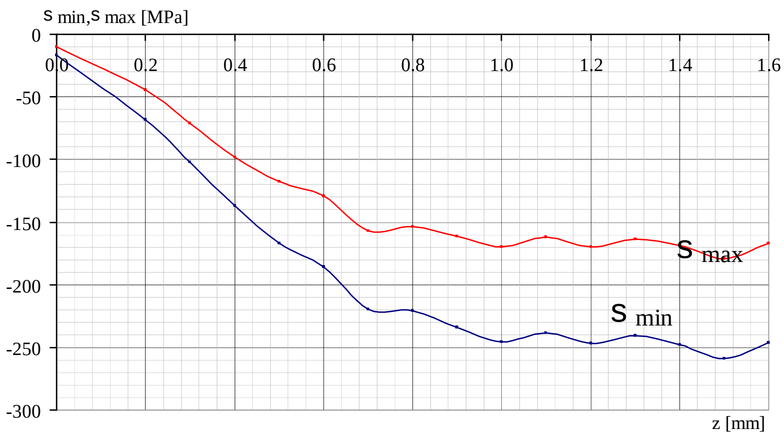

Figure 4. Sample 2 - Residual stresses measured on welding surface

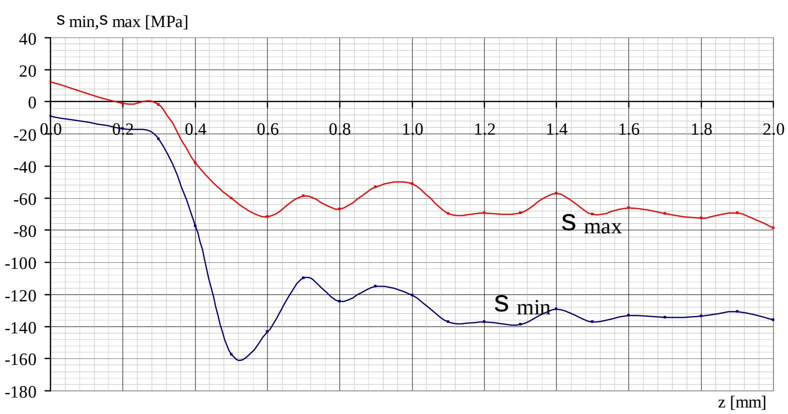

Figure 5. Sample 2 - Residual stresses measured on heat affected zone (HAZ)

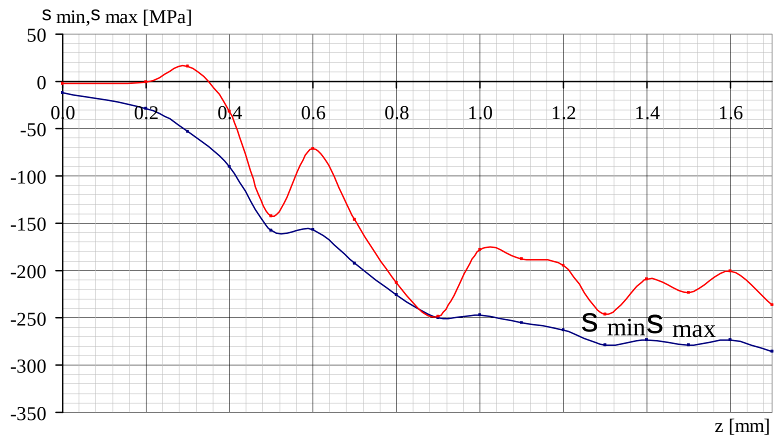

Figure 6. Sample 3 - Residual stresses measured on welding surface

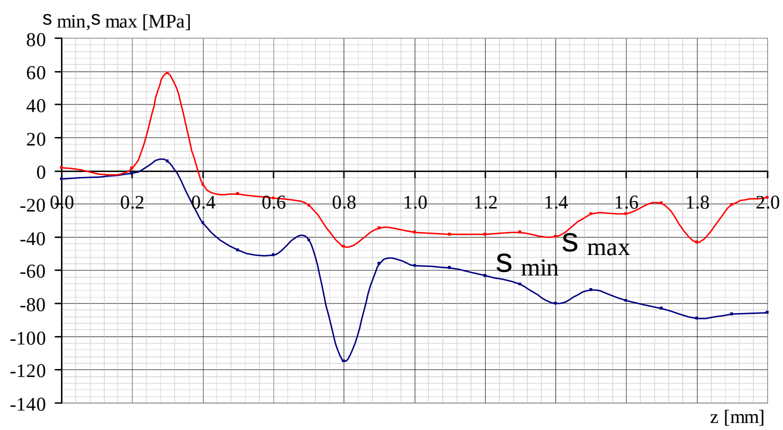

Figure 7. Sample 3 - Residual stresses measured on heat affected zone (HAZ)

4. Conclusion

The residual stresses measured on three welded samples with different weld thicknesses show that:

- for all the three samples values are high and can affect the endurance of the mechanical components;
- the values measured on the welding surface are higher than the values measured on the heat affected zone. The highest values were obtained for the samples 1 (7 mm weld) and 3 (15mm weld).

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Addresses:

- Eng. Vasile Cojocaru, PhD. Student, "Eftimie Murgu" University of Reşiţa, Center for Research in Hydraulics, Automation and Thermal Processes, P-ţa Traian Vuia, nr.1-4, 320085, Reşiţa, v.cojocaru@uem.ro
- Prof. Dr. Eng. Viorel Constantin Campian, "Eftimie Murgu" University of Reşiţa, Center for Research in Hydraulics, Automation and Thermal Processes, P-ţa Traian Vuia, nr.1-4, 320085, Reşiţa, v.campian@uem.ro
- Lect. Dr. Eng. Calin-Octavian Miclosina, "Eftimie Murgu" University of Reşiţa, Center for Research in Hydraulics, Automation and Thermal Processes, P-ţa Traian Vuia, nr. 1-4, 320085, Reşiţa, c.miclosina@uem.ro