RESIDUAL STRESSES ANALYSIS IN TIG DRESSED WELDED JOINTS

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Abstract. Fatigue strength of welded joints is significantly influenced by the presence of residual stresses due to welding, of flaws and notch sharpness at the weld toe. Compressive residual stresses enhance the fatigue behavior of the structure, while tensile ones impair it. TIG dressing at the weld toe is frequently used to remove flaws to lessen the notch sharpness at the weld toe and to introduce compressive residual stresses. This paper presents a 2D finite element model to predict the residual stresses generated in a TIG dressing at the weld toe of a T joint. The welded T joints are made in St 52-3 steel and are obtained by covered electrode process. The analysis was developed with the *Marc* finite element code. The modeled stress field is compared with some measurements of residual stresses obtained using X-ray diffraction and the strain gauges technique.

Resumo. A presença de tensões residuais numa estrutura influencia o seu comportamento. Tensões residuais de compressão melhoram o comportamento è fadiga da estrutura enquanto que as tensões de tracção pioram prejudicam o seu desempenho. As tensões residuais provocadas pela soldadura, a presença de fendas e a severidade da concentração de tensões são factores importantes que influenciam de forma determinante a resistência à fadiga de juntas soldadas. A técnica de refusão TIG do pé do cordão de soldadura é frequentemente utilizada com o objectivo de reparar as fendas e diminuir o efeito de concentração de tensões no pé do cordão. Esta comunicação apresenta um modelo bidimensional de elementos finitos para determinação das tensões residuais, geradas pelo processo de refusão TIG no pé do cordão de uma junta soldada em T. As juntas são fabricadas em aço St 52-3 e são obtidas por soldadura com eléctrodo revestido. O modelo é desenvolvido sobre o código de elementos finitos comercial *Marc*. O campo de tensões residuais modelado é comparado com alguns valores experimentais de tensão, obtidos usando as técnicas de difracção de raios-X e a técnica do furo usando uma roseta de extensómetros.

1. INTRODUCTION

The presence of flaws and the stress concentration at the weld toe are very important factors affecting the fatigue strength of welded joints. TIG dressing is an important post weld technique used to improve the fatigue strength in such joints [1 and 2]. This treatment is also used as a rehabilitation technique in cracked welds [3].

The behaviour of welded joints under static or dynamic loading is also strongly influenced by the residual stress field induced by the welding process.

The knowledge of residual stresses is important in understanding the role they play in creating fatigue and other fracture problems.

The high tensile residual stresses induced by welding are responsible for the independency of the fatigue strength on the applied mean stress [4]. The residual stress field induced by TIG dressing in post weld treatment decrease the effective mean stress [5] and improve the fatigue behaviour of welded joints.

Conventional design methods use empirical techniques to assess the welded induced stresses and to evaluate his effects on the structural integrity of welded structures.

To improve the accuracy of these methods, simulations can be performed. To reduce these processes costs, over the pasts two decades, experimental simulations are gradually changed to the numerical ones. In these numerical simulations, the finite element method is frequently used to predict distortion and residual stresses due to welding.

This paper presents a two-step thermo mechanical finite element analysis for predicting the residual stress field, induced by TIG dressing at the weld toe of a T joint. A 2D transient non-linear thermal analysis is fallowed by a 2D small deformation quasi-static elastoplastic one.

2 MATERIALS AND EXPERIMENTAL PROCEDURE

The base material used in this study was a medium strength steel, St 52-3 DIN 17100, in the form of plates with 12.5mm thickness, and the chemical composition presented in table 1. The welds were made by covered electrode process. Chemical composition of the weld metal is presented in table 2.

Table 1. Chemical composition of the steel St52-3 (percentage in weight).

C	Si	Mn	Cr	Mo	Ni	Ti
0.131	0.413	1.44	0.063	0.024	0.034	0.009

Al	V	Cu	Co	Nb	P	S
0.029	0.043	0.018	0.013	0.005	0.011	0.005

Table 2 Chemical composition of the weld material (percentage in weight).

C	Si	Mn	Cr	Ni	Mo	P	S
0.08	0.45	1.28	0.50	1.87	0.37	0.017	0.01

The mechanical properties of the base material, at room temperature, were obtained using a tension specimen with 8mm diameter according with Portuguese standard NP EN 10 002-1. The tests were carried out in a servo-hydraulic Instron machine. The load rate was constant and the strain was measured using a strain gauge with 50 mm length mounted directly on the specimen. The machine software calculated the strain and stress.

The mechanical properties of the parent material at high temperature were obtained using a tension specimen with 6mm diameter according with Portuguese standard NP EN 10 002-5. The tests were carried out also in the servo-hydraulic Instron machine coupling a furnance and using a axial quartz gauge, model Instron-A1387-1023, directly coupled in the specimen. The machine software calculated the strain and stress.

The results obtained in these tension tests were used together with others published for similar materials [6 to 8] to model the thermo mechanical behaviour of the parent material.

The welding T specimens were produced from main plates with 12.5 mm thickness and low penetration fillet welded with equal thickness attachment. From this plate were cut specimens with 70mm width and 270mm length. The weld leg length had a medium value of 9mm.

Post weld treatment and rehabilitation of weldments with fatigue cracks at the weld toe were performed by TIG dressing technique, using the parameters indicated in table 3

Table 3 TIG dressing parameters.

Current intensity	110A
Tension DC	19V
Linear rate	1.08mm/s
Argon flux	

The hole-drilling strain gauge method is used to obtain some measures of the residual stresses at the surface of the specimens in the proximity of the weld toe. With the same objective there are performed some measures using the X-ray diffraction method. More details of the performed experiments can be obtained in [3].

3. WELDING SIMULATION

The simulation was performed in a Personal Computer with a Pentium II processor and the Windows NT system using a numerical model based in the finite element code *Marc*.

To minimize the computing cost the analysis was done in the plane normal to welding direction as shown in the Fig.-1. The heat flow in the welding direction is neglected. This simplification is reasonable when the arc speed is high.

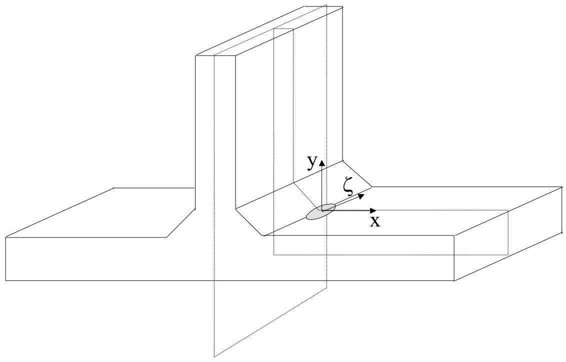


Fig.1- Plane and coordinate system used for finite element model.

Two-dimensional models on the plane perpendicular to the welding direction produce good residual stress approximations for continuous welds [6 to 13].

If the influence of the deformation on the heat flow and microstructure is considered despicable the analysis can be performed in two steps: The thermal analysis is followed by the mechanical analysis. The thermal dilatation drives the deformation.

The influence of phase transformations in the mechanical analysis is not considered in this study. This simplification was successful used in [6 and 8].

As shown in Fig.-1, symmetry conditions are assumed in the middle vertical plane.

3.1 Thermal Analysis

In the middle plane perpendicular to the welding a two-dimensional transient non-linear heat flow finite element analysis is performed. Fig.-2 shows the used model, consisting of 828 nodes and 766 elements.

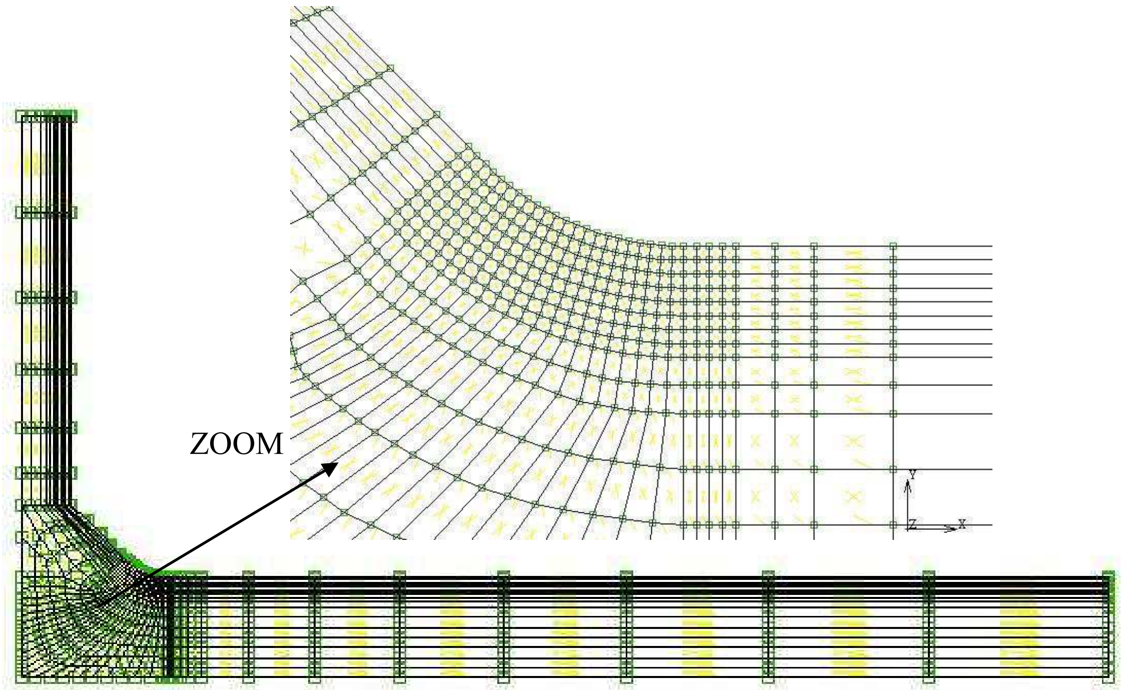
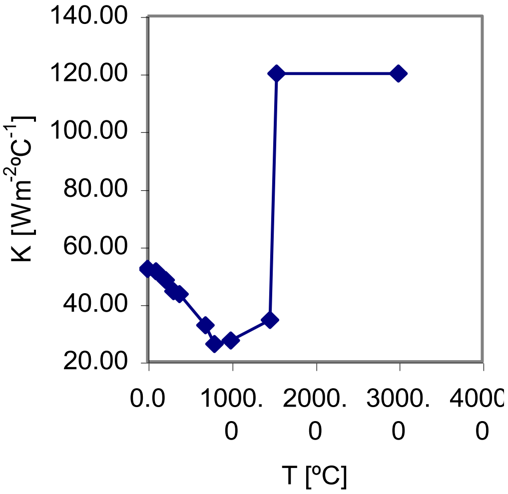


Fig.2- Used mesh in the finite element analysis.



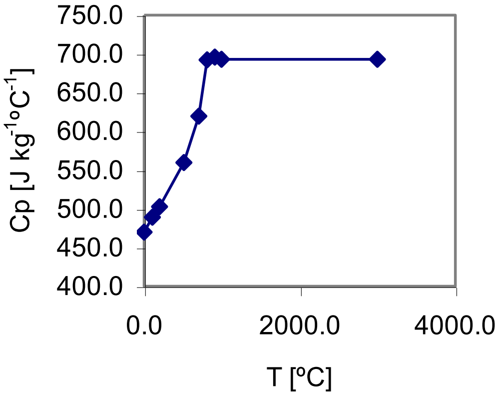


Fig.-3 Thermal conductivity and specific heat.

The *Marc element type 39* is used. He's a four-node, isoparametric, heat transfer quadrilateral, linear element. This element uses bilinear interpolation functions, the thermal gradients tend to be constant throughout the element.

Adiabatic boundary conditions are considered in the symmetry plane. In all the others surfaces convective-radiative conditions are used [10].

For the convective and radiative boundary conditions, a combined heat transfer coefficient is calculated using the relationship, from [14]:

$$h=24.1\times10^{-4}\varepsilon T^{1.61}$$

T [ºC]
h [$Wm^{-2o}C^{-1}$]

where ε is the emissivity of the surface of the body. From [15] a value of 0.9 is assumed for ε.

The thermal properties presented in fig.-3 for the temperature dependent thermal conductivity, K, and the specific heat, Cp, were used.

To take account the influence of convection, caused by the fluid flow in the weld pool, the thermal conductivity is artificially increased for temperatures above the melting point.

A latent heat of fusion of 247 $kJkg^{-1o}C^{-1}$ at the melting point to be released and a density of 7860 kgm^{-3} were assumed.

The heat generated by the welding process was inputted using the *double ellipsoid heat source model*. In the ellipsoid model a Gaussian distribution of the power density in an ellipsoid with centre at point (0,0,0) and semi-axes a, b and c, parallel to the coordinate axes x, y, ξ, as indicated in Fig.1, was considered.

With this model, the temperature gradient in the front of the heat source was not as steep as expected, and in the rear the gradient was steeper than expected. To overcome this limitation in the *double ellipsoid heat source model,* two semi-ellipsoidal sources are combined as shown in Fig.-4.

The power density distribution in this model is done by

$$q(x,y,z,t)=\frac{6\sqrt{3}f\,Q}{abc\,\pi\sqrt{\pi}}\,e^{-3x^2/a^2}\,e^{-3y^2/b^2}\,e^{-3[z+v(\tau-t)]/c^2}$$

where:
Q=ηVI
η efficiency of the weld process
v=Arc speed
τ is a lag factor to define the position of source at t=0.

$$\xi=z+v(\tau-t)$$

For the frontal semi-ellipsoid
f=0.6
$c=c_1=a$
For the rear semi-ellipsoid
f=1.4
$c=c_2=4a$

Adaptable solution to the two dimensional model was performed.

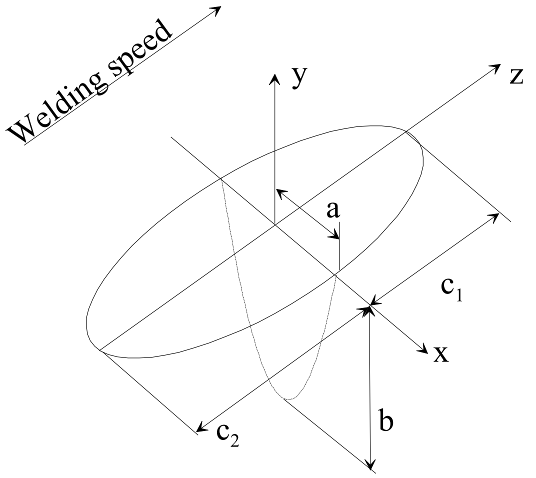


Fig.-4 Geometry of a double ellipsoid heat source.

3.2 Mechanical Analysis

In the middle plane perpendicular to the welding, there is performed a two-dimensional generalized plane strain quasi-static finite element analysis.

The *Marc element type 11* was used. He's a four-node, isoparametric, plane strain quadrilateral, and linear element. This element uses bilinear interpolation functions; the strains tend to be constant throughout the element. The mesh was similar to that used for the thermal analysis, consisting of 829 nodes and 766 elements.

In the symmetry plane, horizontal displacement restriction was performed. In the lower right node a spring, with despicable stiffness, is added, in order to restrict the vertical movement. The material was modelled as elasto-plastic, with a rate independent von Mises plasticity, using a combined hardening rule.

The temperature-dependent mechanical properties are presented in Fig.-5. These properties are obtained for similar materials [6 to 8], and pondered in order to correlate the properties obtained in the material tests referred in section 2. The results of these experiments are presented in [3].

The loading was performed by imposing graduate the deformation field originated by the temperature field obtained in the preceding thermal analysis.

4. RESULTS AND DISCUTION

4.1 Thermal Analysis

The fusion boundary position predicted by the finite element model is in good agreement with the experimental data as shown in Fig.-6. The smaller width obtained for the welding pool (65% of the real one) is also reported in others investigations [10] with similar modelling of the heat generated by the welding process.

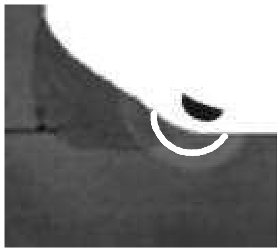


Fig.-6 Experimental and predicted fusion zone.

The temperature profile obtained for the meddle point of the welding pool, and for a point in the boundary of the fusion zone, are presented in Fig.-7. Fig.-8 presents the obtained temperature field, near the weld zone for the higher temperatures.

4.2 Mechanical Analysis

The longitudinal residual stress field, obtained near the weld zone, is illustrated in Fig.-9. At the weld region, compressive residual stresses are observed. At zones remote do the weld, tensile stresses are developed equilibrating the compressive ones of the weld zone.

Surface residual stresses measurements are obtained in the weld zone. Two techniques were used to obtain these stresses: the X-ray diffraction and the blind hole drilling method. These results are presented in Fig.-10 against the computed residual stresses using the finite element method.

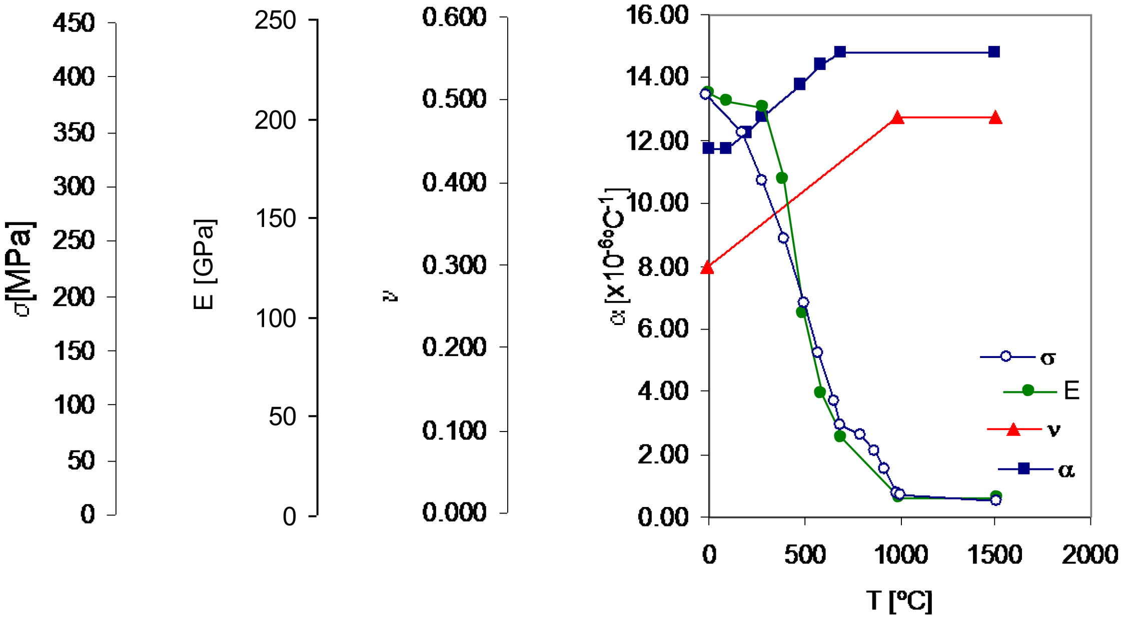


Fig.-5 Variation of mechanical properties with temperature.

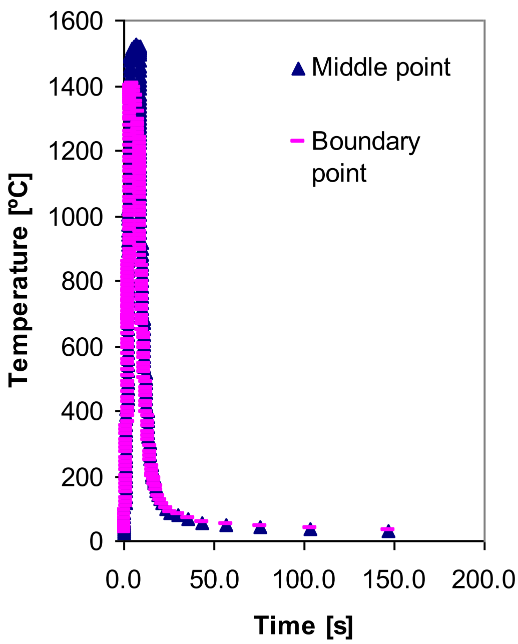


Fig.-7 Temperature history.

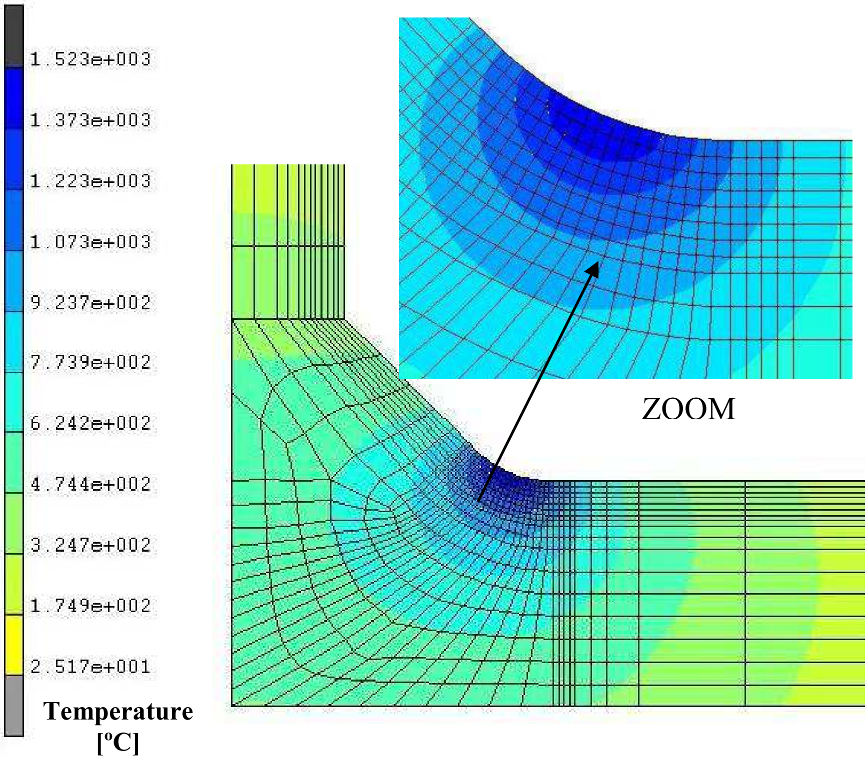


Fig.-8 Higher predicted temperature field.

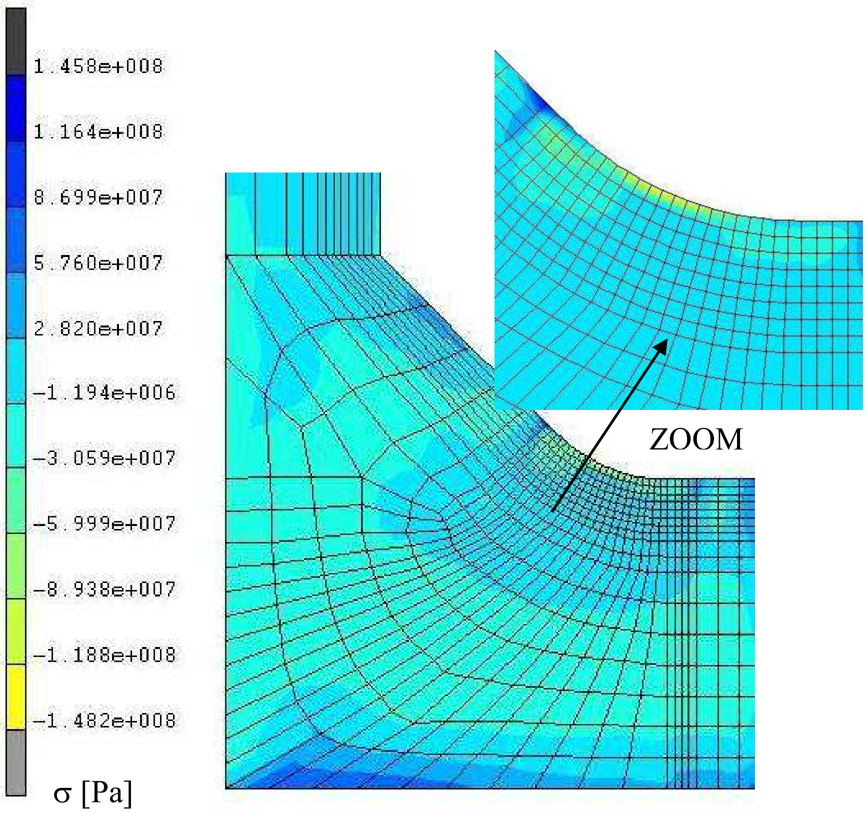


Fig.-9 Predicted residual stress field.

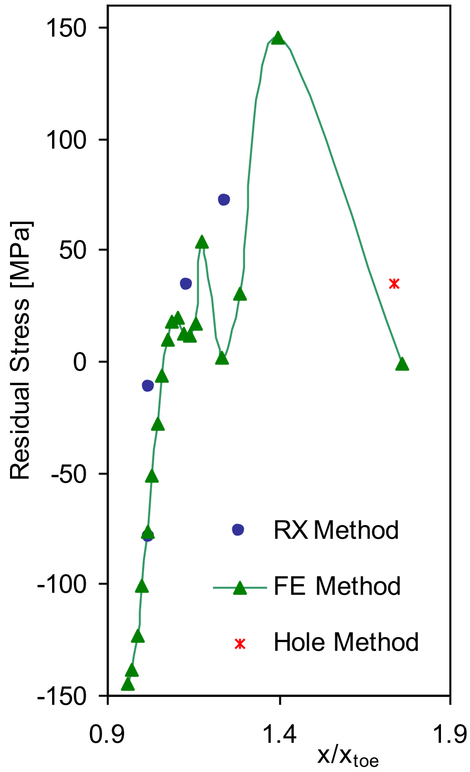


Fig.-10 Correlation of longitudinal residual stresses on bottom surface.

Considering the error inherent to the experimental measures, there are a very good agreement between the experimental stresses and the computed ones.

5. CONCLUSIONS

- A two-step thermo mechanical finite element analysis was applied to predict residual stress field, induced by TIG dressing at the weld toe of a T joint using a 2D transient non-linear thermal analysis fallowed by a 2D small deformation quasi-static elastoplastic one.
- Predicted and experimental surface residual stresses obtained by the X-ray diffraction and the blind hole drilling method were compared and a very good agreement was obtained.
- The method is being applied to other situations and other refusion techniques such as plasma dressing.

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