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WELDING RESIDUAL STRESSES MIGRATION EFFECT

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Abstract. *Welding is one of the main technology operations used in all steps of ship's manufacture. Emergence of distortions in the ship structure during construction is inevitable because of welding residual stresses and geometric imperfections related to cutting of the steel pieces and their union in the blocks. Correction of the dimension disagreements in the ship's blocks during their assembly involves, among other procedures, new welding operations named repair welding, that introduce new residual stresses in components of the ship structure. This paper presents an experimental study of the behavior of residual stresses due to welding for butt-jointed steel plates and repair welding for the plates. The residual stresses were monitored using the X-ray diffraction method. The experimental results show continuous process of welding stress redistribution over a relatively short length of time, with a significant difference between initial and final distributions, two weeks after welding. The observed stress redistribution trend was characterized by a reduction in and a uniformity of the values of maximum shear stresses and decrease of its concentration factor.*

Keywords: *welding residual stresses, butt weld, repair weld, X-ray diffraction.*

1. INTRODUCTION

One of the first technology operations in shipbuilding consists of the manufacture of naval plates through butt-joint weld. The emergence of geometric distortions on the plates is related to the welding residual stresses. This phenomenon is undesirable for subsequent use in the manufacture and assembly of sub-blocks. Correction of dimensional disagreements on ship blocks during their assembly involves, among others things, new welding operations named repair welds, which in turn add others new residual stresses on the ship structure. Since this operation is an emergency in manufacturing, repair welds become standard operations in the maintenance of ships.

The repair weld is an operation that is not expected in the original ship design, and it is made in the final step of the manufacturing process. The knowledge about the distribution of residual stresses induced is important for the shipbuilding industry. Unfortunately until now this has not been duly studied, and this explains the lack of technique and equipment for measuring welding residual stresses in shipyards, and the deficiency of practical experience in experimental analysis of residual stresses.

Sources of welding residual stresses differ in some aspects: contraction in cooling regions differently heated and plasticized during the welding operation, the stronger superficial cooling and the phase transformation. Therefore, the status of welding residual stress is of a complex nature (Macherauch E. and Wohlfahrt H., 1977.). Even though it is a simple weld structure, there are a lot of factors that influence the welding residual distribution. Some of them are the residual stresses in the material before welding, base material properties and deposited material, weld elements' geometrical restrictions applied while welding, the welding process applied, the preparation of the parts to be welded, the conditions and sequences of welding passes, residuals stresses from post-welding operations or from the cooling process. Recent studies show, for example, that welding residual stresses depend tightly on the application procedure of constraints during the welding operation, especially the time of fixation, removal and its geometry (Schenk T. *et al.*, 2009.).

In addition to the traditional methods used for experimental stress analysis through different destructive and non-destructive tests, with the computational progress, a large number of numerical simulations emerged in this area (Korsunsky A. *et al*., 2007, Paradowska A. M., *et al*., 2009, Deng D. and Murakawa H., 2008.). However, several authors recognize that there is always some disagreement when the results of numerical simulation are compared with experimental results (Korsunsky A. *et al*., 2007 and Aloraier A., *et al*., 2010). It is noted that the authors of the experimental work on welding stress measurements do not specify the period of time from the end of the welding process and the cooling until the time of the measurements. On the other hand, the results of numerical simulation of the welding stresses are always related to the time of cooling the plate and removing the welding restrictions. Thus, the authors compared the experimental measures with the numerical simulation results and assumed that probably the welding stresses' distribution do not change after the end of the welding process.

Recently, in our work, it was reported the effect of redistribution of welding residual stresses within a short time in a technological point of view. See reference (Estefen, S., *et al*., 2011, Estefen S., *et al.*, 2012 and Estefen, S., *et al*., 2013). This effect consists of a decay of the stresses effective value in time (von Mises stress) in an area close to the weld bead. Microstructural analysis held out the possibility of the stress relaxation to be a consequence of material failure. At this paper we continue the study of this phenomenon by monitoring daily the welding residual stresses, followed by vertical displacement measurement on the welded plates' surfaces. Furthermore we performed an experimental study of the residual stress distribution on the weld repair, used in the manufacture and maintenance of ships. The aim is to solve two questions: first, where the location of the critic points (with the maximum and minimum values) of the welding stresses is and, in this case, if the location of these points has similar characteristics to the weld repair with hole not cast studied yet, (Gurova, T. and Leontiev, A., 2009, Gurova, T., *et al.*, 2008 and Vieira, D. L. *et al*., 2008.); second, prove or discard, in the case of the repair weld, the effect of welding stresses migration, observed in the butt welding (Estefen S., *et al*., 2012, Estefen, S., *et al*., 2013, Gurova, T., *et al.*, 2012, Gurova, T., *et al*., 2011).

2. EXPERIMENTAL PROCEDURE, EQUIPAMENT AND SOFTWARE

It was used in the tests carbon steel DH-36. Two plates of size 1200 x 500 x 19 mm, angle chamfer 20º, were attached along its long side in butt-jointed welding using "flux-cored arc welding" (FCAW) E71T-1 1.2mm diameter. It has been performed seven welding passes with 180A current (DC +), voltage 28.2 V, with wire feed speed of 6.1 m / min, using argon gas protection with 13L/min flow. During the welding process, the plates were fixed on a jig table along the perimeter. The restrictions imposed while welding were removed on the next day.

For the repair tests it was chosen AWS A5.20 steel plate with 10 mm of thickness used in shipbuilding, and the specimen with a square format (400 x 400mm), with a rectangular hole cast size 190mm x 20mm, located in the center of the plate.

The weld repair process was performed using FCAW with cored wire in MIG machine - 408-T ESAB. For the wire, it was used E71T-1C diameter 1.2 mm and CO2 shielding gas. The welding was carried out with ceramic backing. It was emplyed one root pass and two passes followed by finish bead. For the first three passes the voltage and wire speed were 25.5 V and 176 m/min, respectively, for the finish bead voltage was 25.5 V and speed 168 /min.

The absolute values of residual stresses were measured with a portable x-ray equipment - RAYSTRESS that uses the double exposure method. The displacements of the plates' surfaces were measured with the equipment FARO ARM with software for data acquisition. The FARO ARM is an articulated portable arm from which the measurement values are obtained through end tip contact of the arm with the surface of the plate. The data of the geometric points positioned on the plate surface is collected by the arm and plotted in a three-dimensional cloud points, using the software FARO CAM2 MEASURE. To import the cloud points obtained by the distortions of the plates after the welding it was used the computational package: MATLAB. The position of the surface was defined using a fitting curve to second degree polynomial by the method of least squares, using the tool SFTOOLS - surface fitting tools.

The residual stress measurements made by X-ray method were made at points located in the middle of the plate, in a perpendicular line to the weld bead on the front surface. The distance between the four measurement points (1, 2, 3 and 4) in the base metal was chosen within a variable pitch of 50, 100 and 150 mm, respectively. The measurements were also made in the deposited metal (MS point), heat-affected zone (HAZ point) and the base metal near the weld bead (point MB), all located on the same line.

The distance between HAZ point and MB point and the distance between MB and point 1 is 10 mm. At each point the stresses were measured in the parallel direction to the weld bead (longitudinal stress σ_L), in the perpendicular direction to the weld bead (transverse stress, σ_T), and in the diagonal direction between the σ_L and σ_T (stress σ_{45}).

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The residual stress measurements by X-ray method in test samples were made to fix the front surface at points located in the middle of the test specimen in a perpendicular line to the weld bead surface (direction A) and in the weld bead continuation to the outside of the specimen (direction B), Fig 1.

The electrolytic polish with 0.2 mm in depth was applied in the measuring points to ensure the absence of mechanical stresses induced on the plate surface while the manufacturing process, and to identify the location and boundaries of the HAZ. For X-ray analysis it was used diffracted plane {211} ferrite. Elastic constants were obtained from reference (11). We used the X-ray beam session with 0.5 x 6 mm.

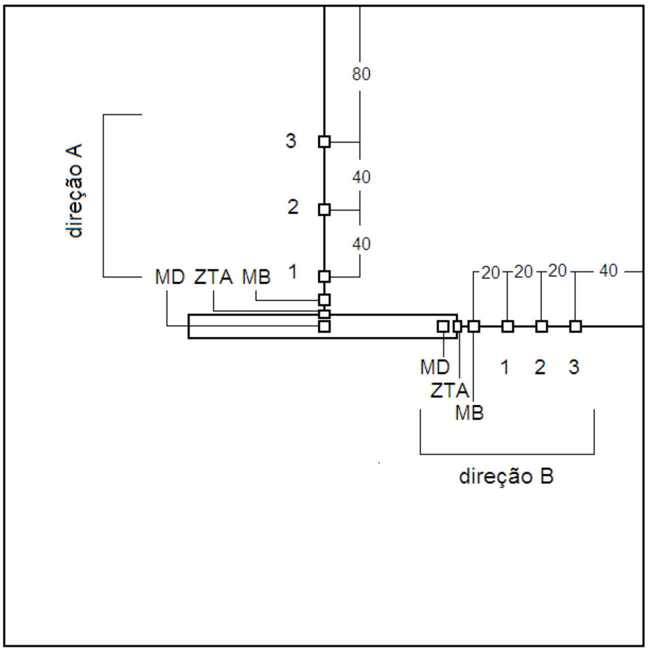

Figure 1. The location of the measurement points of the welding residual stress related to the repair welding

For each direction A and B, measurements were made at three points of the metal base (1, 2 and 3) located as in the figure and also at the deposited metal (DM point), HAZ and base metal close to the weld bead (BM point). At each of these points the stresses were measured in the parallel direction to the weld bead (longitudinal stress σ_L), in the perpendicular direction to the weld (transverse stress σ_T) and in the diagonal direction between them (σ_{45}). Measurements by the method of X-ray for the repair specimens were performed at the same day (initial results), and two weeks later (final result).

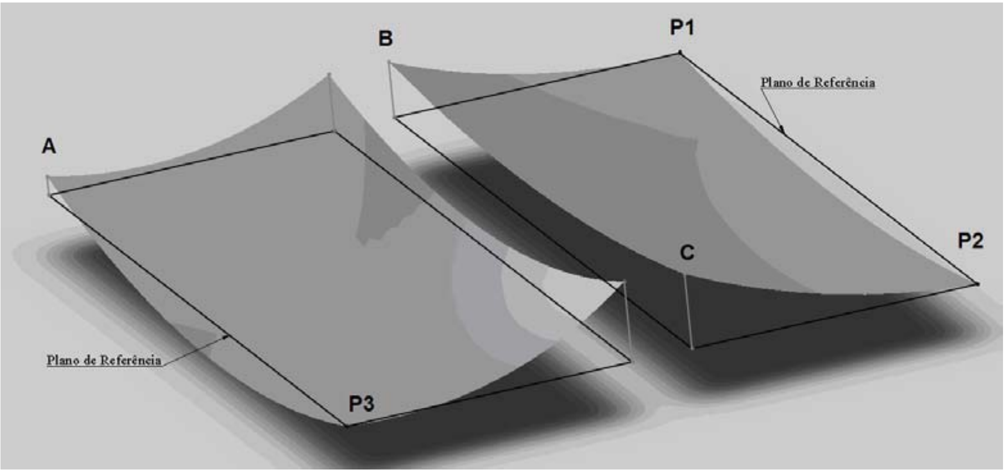

Figure 2. The reference plan and the control point positions A, B and C

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3. EXPERIMENTAL RESULTS

Observing the vertical displacements of the plate's surface, it was chosen a reference plane for the points P1, P2 and P3 as shown in Figure 2, and it was also calculated the distance of the control points A, B and C to the plan. Figure 4 shows vertical displacement measurements of points A, B and C of the welded plate, relative to their measured values after removing the restrictions (first monitoring day) for four consecutive days, and (2^{o}, 3^{o}, 4^{o} and the fifth days).

Variations of these values were observed for all five days, with a magnitude of up to 4mm and subsequent reduction of these variations in time.

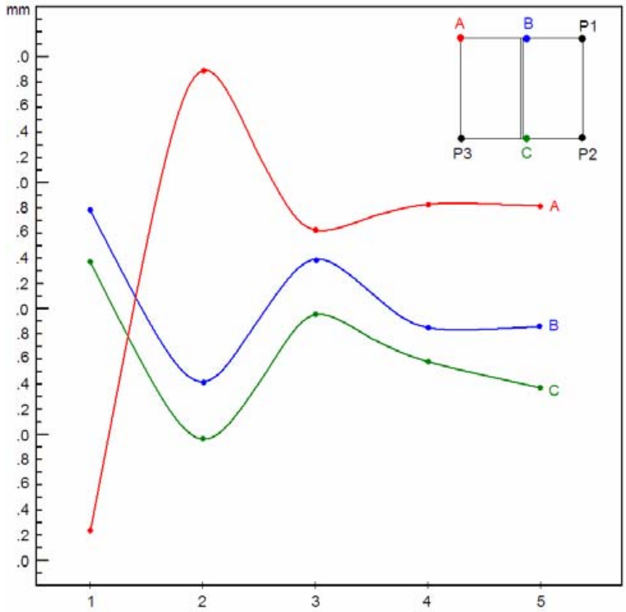

Figure 3. Vertical displacements of points A, B and C of the front surface of the welded plates for five days mo nitoring

We understand that displacement of the welded plates is a consequence of the redistribution process of welding residual stresses, which was observed based on the results of mapping and measuring the stresses shown below.

Measurements by the method of X-ray on the welded plates was performed during the first five days from the next day welded, when they were removed from the welding restrictions, with a 24 hour interval and then using X-ray method after 12 and 30 days.

From the three absolute values of the stresses σ_L, σ_T and σ_{45} measured in the weld metal, HAZ, base metal near the bead and points 1, 2 and 3 by the method of X-ray diffraction were calculated values of the principal stresses and, subsequently, the maximum value of the shear stress at these points.

In Figures 5 and 6 have been presented the measurement results of the absolute values in the form of maximum shear stress. The final state of the stresses measured in the direction A is characterized by a greater uniform distribution of the maximum shear stress, with their smaller absolute values, when compared with the same immediately after welding data. Similar behavior of welding residual stress was observed, previously, in the case of butt weld, (Estefen S., *et al.*,2012, Estefen, S., *et al.*, 2013, Gurova, T., *et al.*, *2012* and Gurova, T., Estefen, S., Leontiev, A., 2012). In direction B, it was observed a change in the position of the maximum and minimum values of the maximum shear stress, with a decrease of the absolute values of the maximum shear stress accompanied by a maximum and minimum displacement in the welding direction.

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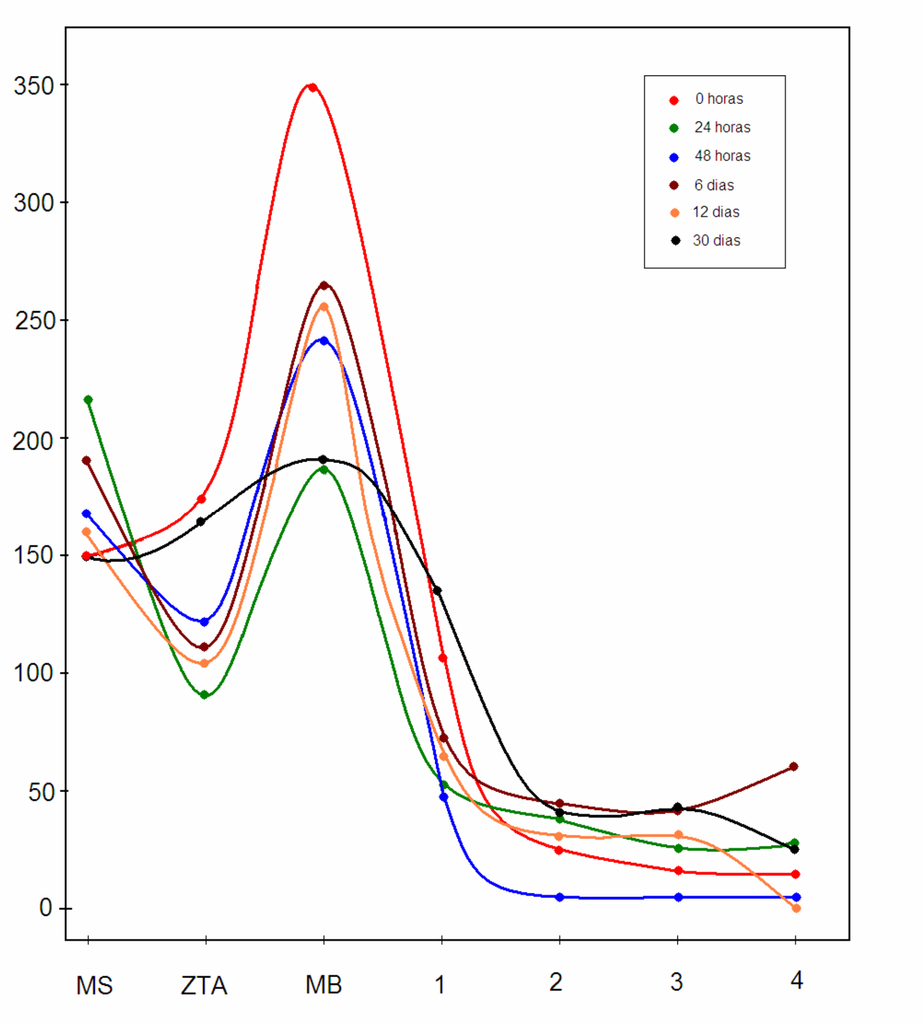

Figure 4. Vertical displacements of points A, B and C of the front surface for the welded plates for five days monitoring

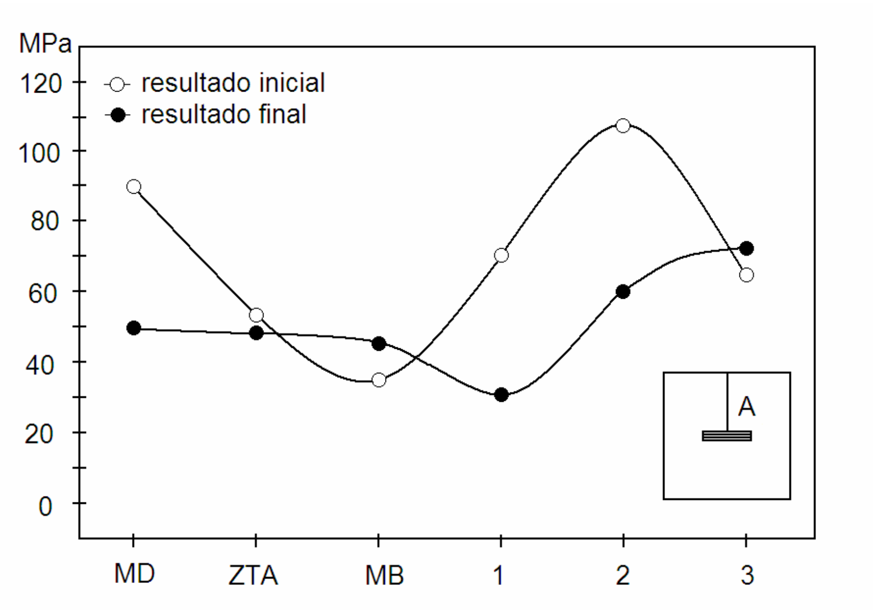

Figure 5. Direction A. Initial and finals values of maximum shear stress

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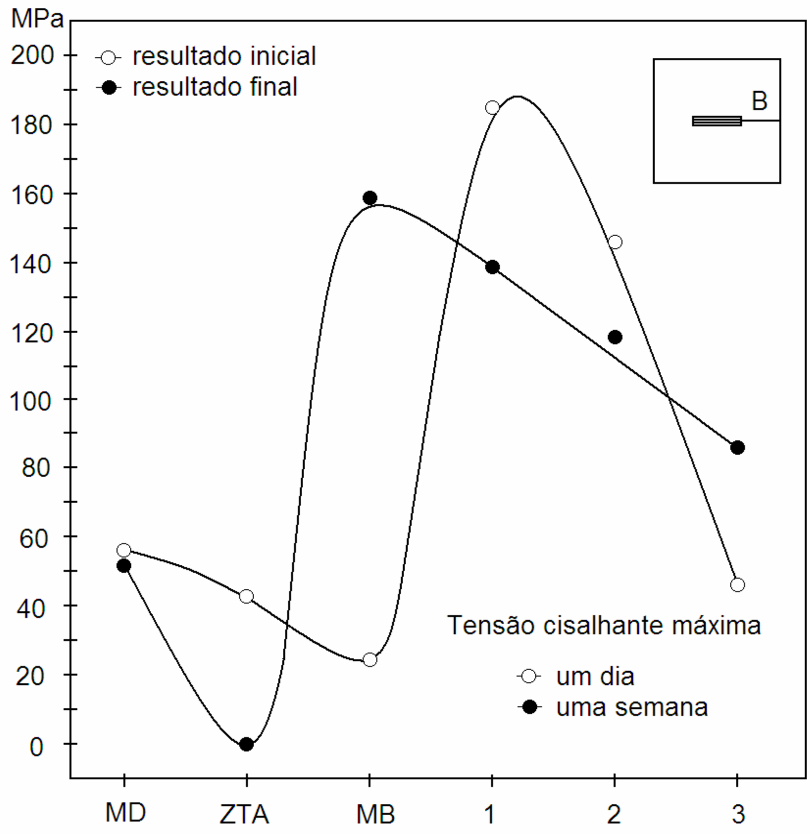

Figure 6. Direction B. Initial and finals values of maximum shear stress

The experimental results show that the distribution of the welding stresses values in the repair welding case varies significantly within a period of two weeks from the moment of welding. It is a fact not previously reported in the literature. We call this phenomenon as the migration effect of welding stresses.

4. CONCLUSIONS

1. The experimental results of the vertical displacements' measurements of the butt welded plates' surface show a variation in time of these values, explicitly within five days after the removal of welding restrictions.
2. The final residual stress state is characterized by more uniform distribution of the maximum shear stress and in absolute values smaller compared to the same data after removing the restrictions welding.
3. Final state of the stresses in the transverse direction to the bead weld repair is characterized by a more uniform distribution of the maximum shear stress, with their absolute values and values of the von Mises stresses lower when compared with the same immediately after welding results. Similar behavior of welding residual stresses was observed previously in the case of butt weld.
4. In the longitudinal direction of the repair welding was observed a change in the position of the maximum and minimum values of the maximum shear stress and von Mises stress with a decrease of the absolute values of the maximum shear stress.
5. The variation observed on the residual stresses and vertical displacements of the welded surface after the welding process indicates the necessity to specify the experimental results in a period of time between the execution of the welding operation and measurement.
6. To obtain results with applicability in numerical simulation of welding processes, the phenomenon of stresses evolution after welding process execution should be included in numerical models.
7. It was observed a redistribution effect of welding stresses after completion the welding process. This can contribute significantly to understand the processes related to welding residual stresses, help adjust the computer models and interpretation of data from numerical simulation of welding stresses.
8. Probably, the stabilization period of the state of welding stress and its ultimate distribution depends on the type of welding process and the welding conditions, as well as geometry, material, size and locations of the pieces to be

repaired. Studies on the relationship between these parameters and the minimum time required to stabilize the state of stresses for each welding technique are matters of great concern to be addressed in future research.

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6. REFERENCES

Aloraier A., Al-Mazrouee A., Price J. W. H., Shehata T., 2010. "Weld Repair Practices Without Post Weld Heat Treatment for Ferritic Alloys and their Consequences on Residual Stresses: A review", *Int J Pressure Vessels and Piping,* Vol. 87, p. 127-33

Deng D., Murakawa H., 2008. "*Prediction of Welding Distortion and Residual Stress in a Thin Plate Butt-Welded Joint*", *Comput Mater Sci,* Vol. 43, p. 353-65

Estefen S., Gurova T., Werneck D. S., Leontiev A.,2012. "Welding Stress Relaxation Effect in Butt-Jointed Steel Plates", *Marine Structures*, Vol. 29, p. 211-25.

Estefen, S., Gurova, T., Leontiev, A., 2013. "Redistribution of the Residual Welding Stresses". Marine Systems & Ocean Technology. In publication

Estefen, S., Gurova, T., Werneck, D. S., Leontiev, A., 2011. "Efeito de Redistribuição das Tensões Residuais de Soldagem". In *Proceedings of* the Conferência sobre Tecnologia de Equipamentos, Porto de Galinhas – Ipojuca ABEND 2011

Gurova, T., Estefen, S., Leontiev, A., 2012. "Redistribuição das Tensões Residuais de Soldagem", In *Proceedings of the NAVTEC 2012. "Conferência Internacional em Tecnologias Naval e Offshore: Ciência e Inovação*" , Rio Grande – RS.

Gurova, T. , Leontiev, A., 2009. "Novas Técnicas de Mapeamento das Tensões Mecânicas". In *Proceedings of the– Congresso Nacional de Ensaios Não Destrutivos e Inspeção- Salvador and 10ª COTEQ – Conferência sobre Tecnologia de Equipamentos XXVII CONAEND,* São Paulo, Brasil.

Gurova, T., Leontiev, A., Monin, V., Silva, B. M., Vieira, D. L., 2008. "Nova Técnica de Avaliação do Estado das Tensões de Soldagem". In *Proceedings of the Congresso Nacional de Ensaios Não Destrutivos e Inspeção & Conferencia Internacional sobre Evaluación de Integridad y Extensión de Vida de Equipos Industriales CONAEND&IEV 2008,* São Paulo, Brasil

Gurova, T., Estefen, S., Leontiev, A., *2012*. "Controle Dimensional e Monitoramento das Tensões Residuais na Fase de Sub-Montagem Durante a Fabricação de Navios". In *Proceedings of the Congresso Nacional de Ensaios Não Destrutivos e Inspeção*, São Paulo - SP.

Korsunsky A. M., Regino G. M., Nowell D., 2007."Variational Eigenstrain Analysis of Residual Stresses in a Welded Plate", *Journal of Solids Structures*, Vol. 44, p. 4574-91.

Lienert U., Walls P., Ibrahim R., 2009. "Residual Stress Distribution in Steel Butt Welds Measured Using Neutron and Synchrotron Diffraction"

Macherauch E., Wohlfahrt H., 1977. "Residual Stress in Welded Construction and Their Effects: *An international conference*"- London, Cambridge, Welding Institute.

Schenk T., Richardson I. M., Kraska M., Ohnimus S., 2009. "A Study on the Influence of Clamping on Welding Distortion", *Computer Material Science* , Vol. 45, p. 999–1005.

Paradowska A. M., Price J. W. H., Finlayson T. R., 2009. "Residual Stress Distribution in Steel Butt Welds Measured Using Neutron and Synchrotron Diffraction", J Phys: Condens Matter, Vol. , p.

Vieira, D. L., Silva, B. M., Gurova, T., Leontiev,A., 2008. "Mapping of Residual Stress State in Steel Plates after Welding Using Magnetic and X-ray Diffraction Techniques", In *Proceedings of* the12th International Workshop on New Approaches to High-Tech: Nano-Design, Technologies, Computer Simulation", NDTCS-2008

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