Evaluation of mechanical vibration effect on the residual stresses levels in steel welded joints using an Interface Matlab based on Norm API 579

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ABSTRACT
Nowadays with the high growth of petrochemical welding technology a great development due to high manufacturing offshore structures, storage tanks of petroleum, boilers and pressure vessels for refining plants have been done. Due to various metallurgical changes and restrictions to contraction and expansion undergone by materials when subjected to welding thermal cycle , internal stresses are generated in welded joint which are nominated residual stresses. It is generally undesirable because it can lead to several problems, such as cracks, cold stress fracture, stress corrosion, among others. Although several studies involving residual stresses have been developed in recent years, few information about the variation of the residual stresses level in welded joints when subjected to stress relief treatment by mechanical vibration have been done. Likewise, there are few information related to the comparison between the degree of efficiency by using the post-weld heat treatment and those treatment. Therefore, the goal of this work was to apply the relieve residual stresses treatment by mechanical vibration in steel welded joints used in oil industry, and compare the results with those obtained by post heat treatment and evaluate the efficiency level of this technique In addition, this works also hope to contribute for a better understanding of this technique and to find which parameters have a greater influence on the results.

Keywords: Welded joints, API 579, Residual Stress, Treatment for vibration

1. INTRODUCTION

Nowadays with the high growth of the petrochemical industry world of welding technology a tremendous development due to high manufacturing offshore structures, storage of petroleum, boilers and pressure vessels for refining plants tanks have been done. In the industry, processing and storage of many products are made larger or smaller than the atmospheric pressure. Thus, employees are sealed and resistant containers to withstand pressures in your body, as well as temperatures that go beyond the environment. These devices, called "pressure vessels", by generally subject to operating pressure and/or elevated temperatures are considered high risk equipment, because they contain large amount of energy stored inside.

The design and construction of pressure vessels (Fig. 1) involves a lot of special care and requires knowledge of standards and suitable for every type of application materials. As failures in pressure vessels can lead to catastrophic consequences with loss lives, it can be considered a highly dangerous equipment.

Figure 1: Examples of tanks and pressure vessels [1]

One of the major problems that lead to accidents caused by pressure vessels is correlated with disabilities during the design or manufacturing process. One of its major causes is the appearance of residual stresses often induced due to the welding process during the construction of the equipment. However, their presence is neglected, leading them to rupture in service due to the combination of it with variable loads and pressures during their operation. The welding is widely used in the construction or repair of pressure vessels and piping industrial and in many cases it is used wrongly in the maintenance and repair causing many accidents due to changes caused by thermomechanical process.

Given that the generation of residual stresses are intrinsic to the thermal cycle generated by any welding process characteristics, it is not possible to avoid them, and their presence is usually undesirable because it is associated with many metallurgical problems. Then it becomes essential to know ways to reduce it both before and after execution of the welding process.

There are many post-weld treatments aiming to relive these residual stresses formed during the thermal cycle of welding. Among those treatment there is the vibrations technique also called VSR (Vibration Stress Relief) which use the mechanical vibrations in order to reduce the residual stresses. It is a vibratory resonance-based method, in which the parts are subjected to low frequency vibrations for a short period of time. The treatment by mechanical vibration has been used for over 20 years in many parts of the world [2], with satisfactory and proven energy-saving results, appearing as an option to heat treatments, by presenting a lower cost of energy and hours, maintaining the mechanical properties of the unchanged components.

The practical results of the treatment of stress relieving by vibration have been proven in companies here in Brazil, but its credibility in the academic and industrial media is still questioned. This is due to the fact that normative institutions have not yet included this technology, probably due to lack of scientific evidence to base the practical results achieved [2]. Although the study of residual stresses has drawn the attention of many researchers in recent years, given their direct action on major metallurgical problems related to welding, little is known about the characteristics of the treatment for RSV and its advantages as a process and with respect to other control processes post-weld stress.

Therefore, in view of the deficiency that exists in scientific knowledge of the mechanical vibration treatment to relieve residual stresses this work was developed. With the results obtained in this work we can get wider and deeper knowledgment about the degree of reduction in levels of residual stresses induced by processes of manual or automatic welding, using the RSV treatment, and compare it with the conventional thermal treatments [3, 4, 5, 6].

2. EXPERIMENTAL PROCEDURE

2.1 WELDING JOINTS

To perform the welding of the samples it was necessary to define the welding process and parameters. In this work the Metal Inert Gas (MIG) welding process was used. The welding parameters are presented at Table 1. These welding process and parameters are the same used by Teske [7]. Figure 2 illustrates one of the eight welded joints used in the search.

2.2 RESIDUAL STRESS EVALUATION

The technique used for the residual stress analysis was by X ray diffractometry using the $\sin^2ø$ method, with ø values of 0°, 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40° and 45° [9].

Two measurements of residual stresses were performed: one after welding and other after finished mechanical vibration treatment. In both cases measurements for transverse and longitudinal stresses along the weld bead were done.

For transverse stresses two horizontal lines spaced from 10 mm with 7 points (measurement) from the weld bead center spaced 5 mm from each other were done as it is showed in Fig. 3a.

For the longitudinal strains two lines parallel to the weld bead with 7 points (measurement) distanced 2 mm from each other were done. One from 5 mm and the other from 15 mm to the fusion line as it is showed in Fig. 3b.

2.2.1 Treatment by mechanical vibration

Before the treatment is carried out tests with the objective of obtain the natural frequencies of the structure were made. The experimental modal analysis to select the frequencies range for treatment was performed in two steps (Fig. 4).

First tests with impact hammer with the purpose of identifying the first natural frequencies of the beams provided cantilever were done. In the second part of the experimental analysis tests with the pneumatic driver coupled to the free end of the beam in order to adjust the frequency in which the treatments were performed. It was done by vibration which would be achieved by controlling the pressures of work.

Table 1: Parameters used for the welding of joints

Voltage (V)	34,0
Wire Speed (m/s)	0,1417
DBCP (m)	0,016
Gás Flow (m^3/s)	0,00023
Welding Speed (m/s)	0,0067
Average Current (A)	220

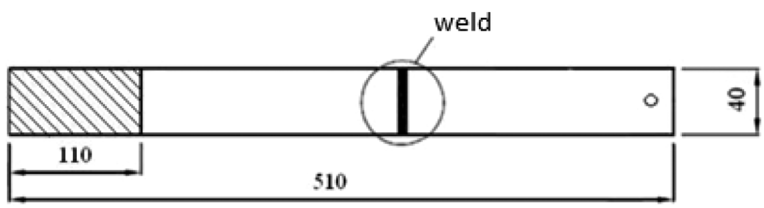

Figure 2: Illustration of the dimensions of the beam and the weld

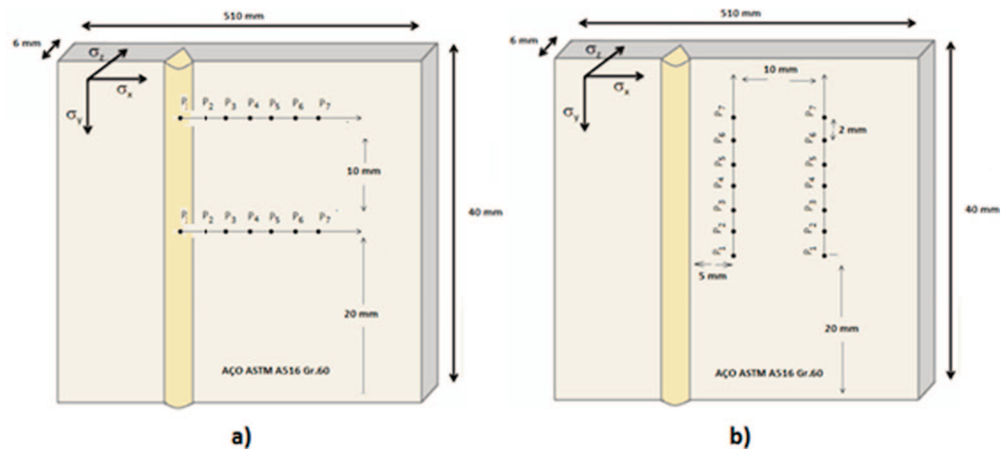

Figure 3: a) Lines for measuring transverse stresses; b) Lines for measuring longitudinal stresses

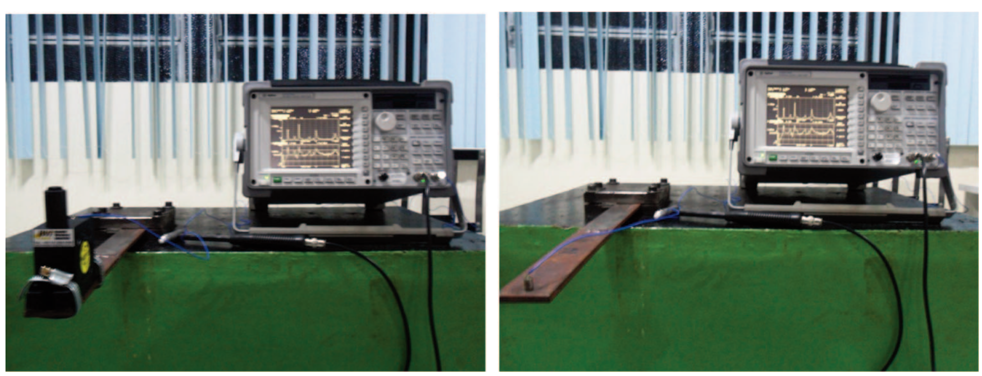

Figure 4: Setup of experimental modal analysis on samples with and without the vibration exciter

For vibration application a pneumatic mechanical vibration exciter type industrial vibrator (NCR 10 model) was connected to an air compressor with a capacity of maximum pressure of 10 bar. The air leaves the compressor and passes straight through a set of air filter and pressure gauge in order to remove impurities from the air and adjust the working pressure.

Following the manufacturer's specifications for operation of the equipment and within what was possible to maintain stable pressure in terms of period of time two treatments pressures (2 bar and 4 bar) were chosen. Figure 5 shows the experimental setup for conducting the treatment by vibration.

2.2.2 Graphical interface

To assist the calculation of the stresses of the standard and to compare the results the comparison a GUI in Matlab platform, as shown in Fig. 6, was created. The interface was built using the equations of the standard API 579 concerning cylindrical pressure vessels as a basis for their algorithm.

Figure 5: a) Experimental setup for conducting treatment by vibration; b) Detail of the pneumatic vibrator

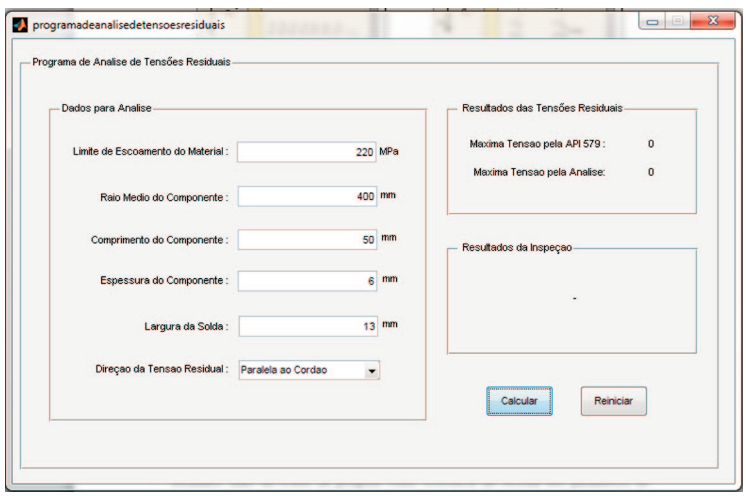

Figure 6: Graphical interface built in Matlab platform

The equations already has a voltage reduction factor (Rf) which depends on the factor called pressure test (Tp). This reduction factor is expressed in the equation because all pressure vessel after the end of its construction phase, undergoes a pressure test for safety parameters that determine whether the pressure vessel will be able to work in those pressures. However this voltage reduction factor was not considered in the development of our algorithm because our samples were not subjected to post-weld pressure test.

The interface consists of three regions. The first region, named "Data for Analysis" (Fig. 7a), corresponding to the area of the interface where the main input parameters for the calculation of the stresses of API standard will be inserted. The second interface region is named "Results of Residual Stresses" (Fig. 7b) which is expressed at maximum stress of the welded joint and the standard. Finally we have the area named "Inspection Results" (Fig. 7c) where the interface shows the user if the weld passed or not the conditions proposed by the API standard [10].

It also generates once finalized all calculations, a graph (Fig. 8) containing the stresses obtained by the equations of the standard strains and obtained the samples, in order to make a comparison between these results.

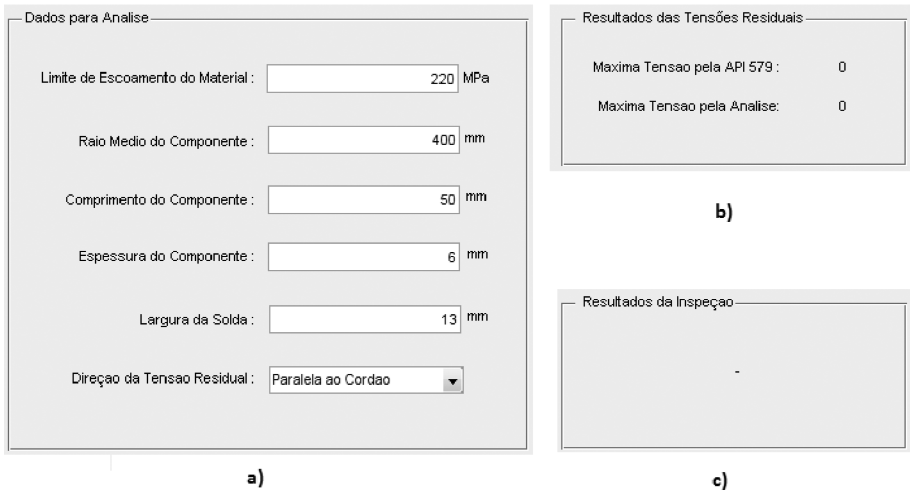

Figure 7: Graphical interface built in Matlab platform

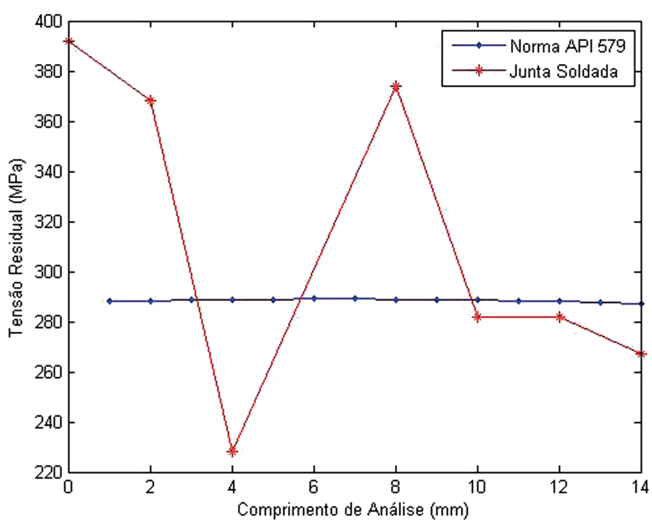

Figure 8: Graph of residual stress by graphical interface

3. RESULTS AND DISCUSSION

Done all the weld bead in the joints, it was evaluated the remaining stress due to weld thermal cycle before treatment (BT). The results for the transverse and longitudinal stress are summarized in Tables 2 and 3.

We can observe that before treatment all the transverse and longitudinal stresses values were higher than 300 MPa. One factor that has been calculated and found in Tables 2 and 3 is the coefficient of variation (CV). The coefficient of variation is a measure of dispersion used to estimate the precision of the experiments. It is expressed as a percentage standard deviation of the mean.

The coefficients of variation are classified in the literature as low if it is less than 10%, medium when between 10 and 20%, high if between 20 and 30% and very high, if greater

Table 2: Transversal residual stress in the welded joints (BT)

Joints	Transverse 1 (MPa)	CV	Transverse 1 (MPa)	CV
Joint 1	279,57	0,13	297	0,09
Joint 2	372	0,14	314,86	0,2
Joint 3	335,29	0,23	307,86	0,15
Joint 4	316,57	0,21	306,14	0,19
Joint 5	296,71	0,14	292	0,15
Joint 6	410,71	0,13	288,71	0,17
Joint 7	323,43	0,15	249,71	0,12
Joint 8	391,14	0,13	304,43	0,18

Table 3: Longitudinal residual stress in the welded joints (BT)

Joints	Longitudinal 1(MPa)	CV	Longitudinal 1(MPa)	CV
Joint 1	357,14	0,12	334,86	0,13
Joint 2	321,29	0,16	334,43	0,21
Joint 3	352,29	0,17	328,71	0,12
Joint 4	337,57	0,1	316,71	0,12
Joint 5	332,86	0,13	330,71	0,15
Joint 6	340,14	0,14	343	0,18
Joint 7	324,29	0,13	341,57	0,11
Joint 8	340	0,2	363,86	0,2

than 30% [9]. We can observe by the data obtained in both tables that the values are very precise given that all CV's, except for the joint 3, had medium values.

Then, with the help of the graphical user interface, it was possible to compare the levels of the sample residual stress with those established by standard. Figures 9 and 10 show the transverse and longitudinal stresses for the first 4 samples. The figures allows us to clearly see that all the transverse and longitudinal residual stresses of the samples were above the limits stipulated by the standard (288.85 MPa for transversal and 284.13 MPa for the longitudinal stress).

Afterwards the sample were submitted to stress relief by mechanical vibration methods. This treatment was done taking into account two factors: time and pressure. Both the time and pressure factor were done with two levels: 20 minutes and 40 minutes and 2 bar and 4 bar. Both factors were permuted making two sample for each pair of factors, to know which factors have greater influence on the stress reduction during the treatment.

Tables 4 and 5 show the results obtained for the post-treatment (PT) residual stresses.

It can be observed that there was a significant reduction in residual stresses values after the treatment, all of them much below than 300 MPa. The values of CVs show that the measurements were very precise. Analyzing the tables it can be noted that the variation of time and pressure factor were not decisive in change the values.

Figures 11 and 12 show the transverse and longitudinal stresses for the first 4 samples. It can be clearly that that all transverse and longitudinal residual stresses of the samples were below the limits stipulated by the standard for both measurement conditions.

Due to the heterogeneity of the set of values of residual stresses after both treatments when compared to the API standard it was necessary to evaluate the results also in percentage as it is showed in Table 6 to analyze the efficiency of the treatments. For this

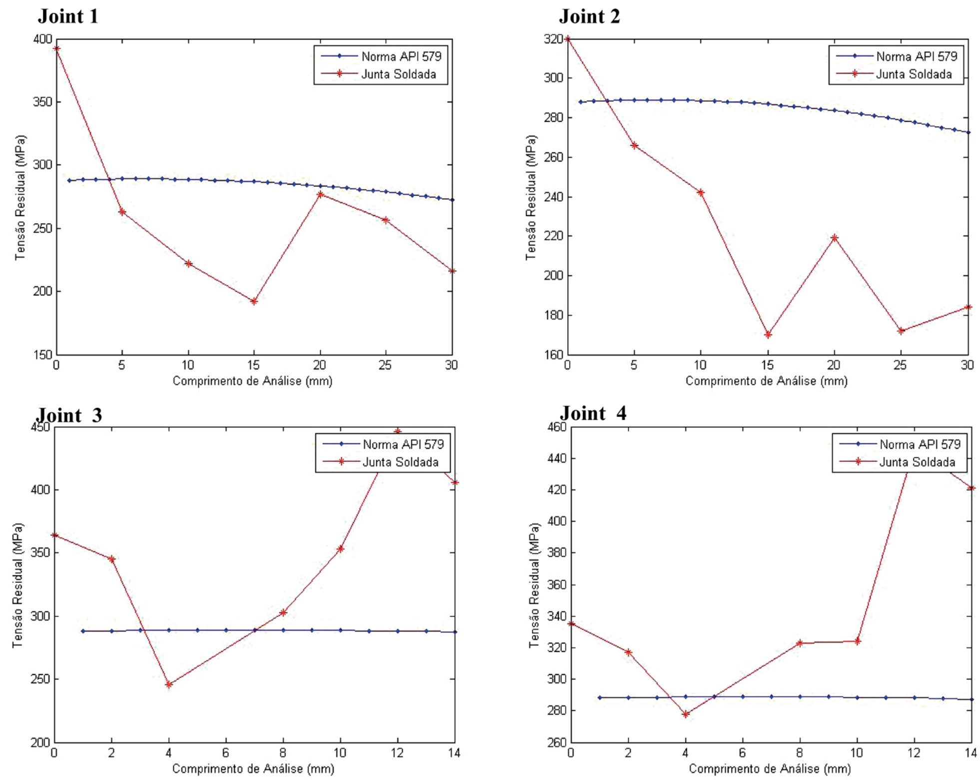

Figure 9: Transversal residual stress generated by the graphic interface (BT)

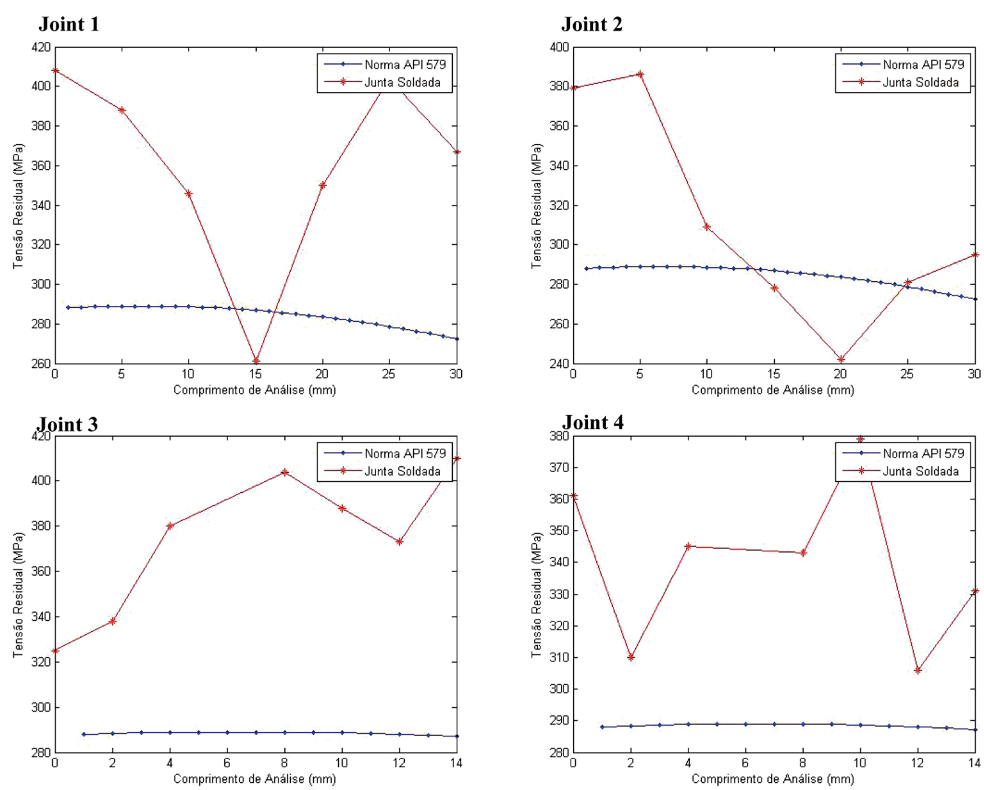

Figure 10: Longitudinal residual stress generated by the graphic interface (BT)

Table 4: Transversal residual stress values after the treatment by mechanical vibration

Joints	Transverse 1 (MPa)	CV	Transverse 1 (MPa)	CV
Joint 1	145,29	0,22	131,54	0,19
Joint 2	147,77	0,1	139,56	0,2
Joint 3	115,7	0,15	153,64	0,14
Joint 4	107	0,15	143,92	0,14
Joint 5	145,71	0,18	163,71	0,17
Joint 6	134	0,08	158,7	0,11
Joint 7	157,35	0,2	114,2	0,17
Joint 8	163,15	0,22	108,56	0,24

Table 5: Longitudinal residual stress values after the treatment by mechanical vibration

Joints	Longitudinal 1(MPa)	CV	Longitudinal 1(MPa)	CV
Joint 1	150	0,2	169,86	0,17
Joint 2	144,57	0,19	171,71	0,08
Joint 3	144,57	0,2	161	0,08
Joint 4	144,43	0,2	154	0,21
Joint 5	130,86	0,18	153	0,12
Joint 6	133	0,2	151,29	0,17
Joint 7	147,45	0,22	139,14	0,11
Joint 8	146,29	0,16	145,29	0,12

one factor nominated R_{API} was created to to define the percentage of reduction with respect to the norm given by:

$$R_{API} = \frac{TR_{API} - TR_{pós}}{TR_{API}}$$

where:

TR_{API} = Residual stresses generated by the standard;

$TR_{Pós}$ = Residual stresses of the sample after the treatment.

Table 6: Percentual of residual stress reduction (R_{API}) in relation to the API standard

	Transverse (%)		Longitudinal (%)	
Joints	**Line 2**	**Line 2**	**Line 1**	**Line 2**
Joint 1	46,56	51,61	42,3	37,12
Joint 2	45,68	48,66	44,47	36,43
Joint 3	57,44	43,48	45,37	40,4
Joint 4	60,64	47,06	46,53	42,99
Joint 5	46,4	39,78	51,56	43,36
Joint 6	50,71	41,62	50,76	43,99
Joint 7	42,12	57,99	45,42	48,49
Joint 8	39,99	60	45,85	46,21

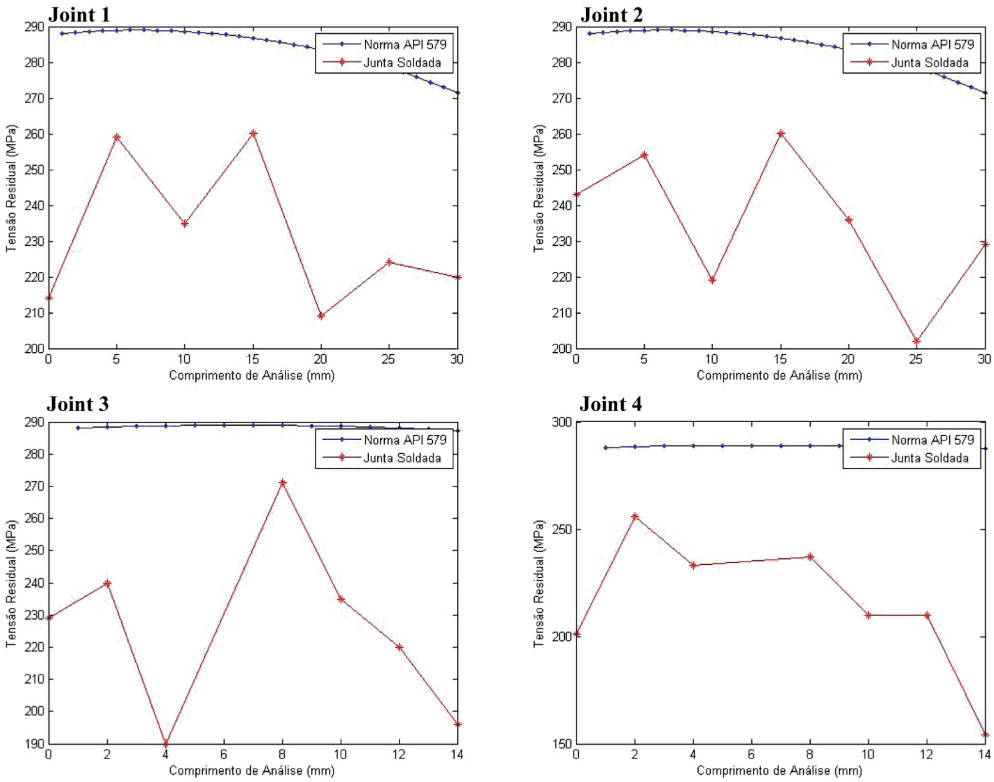

Figure 11: Transversal residual stress generated by the graphic interface (PT)

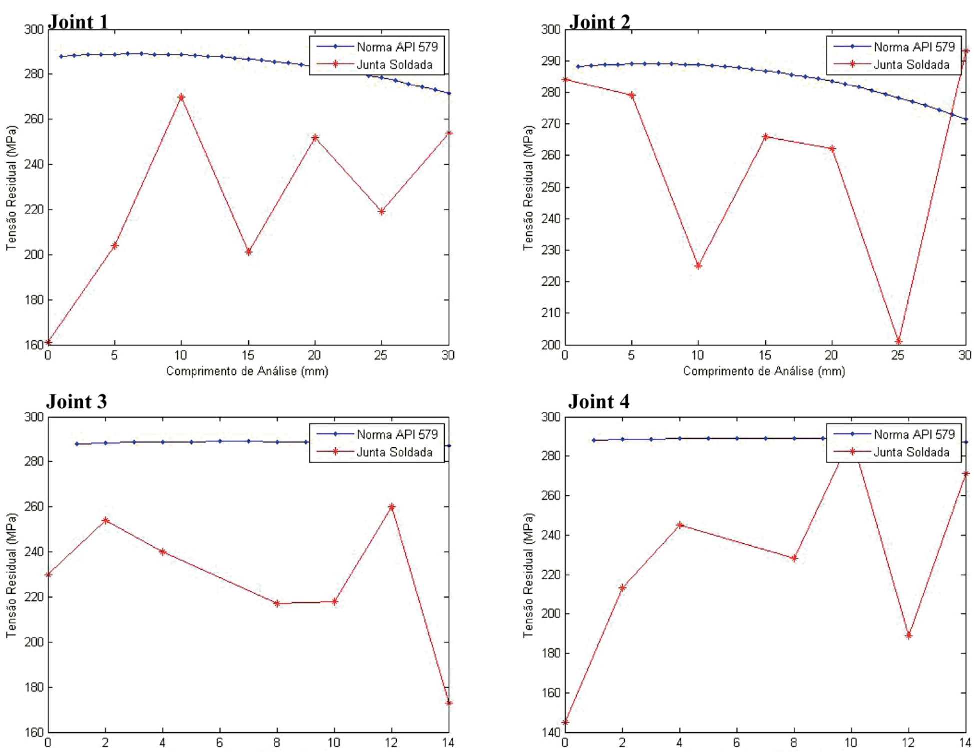

Figure 12: Longitudinal residual stress generated by the graphic interface (PT)

It can see by in the Table 6 that the vibration treatment is always maintained with percentage reductions between 40 and 60%, which shows that the vibration treatment can be considered a very effective.

4. CONCLUSIONS

The present study aimed to evaluate the efficacy of treatment for residual stress relief by mechanical vibration welded joints in steel allows the following conclusions:

- The effect of mechanical vibration treatment in relieving residual stress was present in steel studied and was significant in both transverse and longitudinal directions of the weld;
- We have achieved excellent levels of reduction of residual stresses in both directions, with a maximum of 60,64% for transverse tension and a maximum of 50,76% in the longitudinal direction;
- Treatment by vibrations ceased all levels of residual stresses within the limits set by the standard API 579 demonstrating effectiveness in meeting the requirements of the standard.

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