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Experimental Investigation of Vibration Stress Relief of A106 Steel Pipe T-Welded Fittings

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ABSTRACT

This research examines the use of vibratory treatments to reduce residual stresses in small welded parts. In this experimental investigation, a post weld vibration treatment was applied to T- A106 steel pipe fitting specimens to study the effect of the treatment on the residual stress and the hardness of the material. The vibratory stress relief treatment was carried out at different vibration frequency. The results have demonstrated that post-weld vibratory stress relief of small size fittings is possible and residual stress may be relieved, and the treatment may be an alternative method for heat treatment especially when unchange in dimensions and material stability are required.

Keywords: Vibratory stress relief, Residual stresses, Welded pipe fitting, Heat treatment, Hardness test.

دراسة عملية لازالة اجهادات وصلات الانابيب لفولاذ A106 المنتجة باللحام باستخدام الاهتزازات

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الخلاصة

يهدف البحث الحالي الى دراسة استخدام الاهتزازات لازالة الاجهادات المتبقية في الاجزاء الصغيرة المعدنية المنتجة باللحام. طبقت هذه التقنية لازالة الاجهادات المتولدة في وصلات الانابيب لفولاذ A106 نوع T المنتجة باللحام ودراسة تاثيرها على مستوى الصلابة والاجهادات المتبقية .

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اجريت معاملة ازالة الاجهادات بالاهتزازات عند ترددات مختلفة واثبتت النتائج انه من الممكن تطبيق هذه التقنية على وصلات الانابيب صغيرة الحجم ويمكن ازالة الاجهادات المتبقية بنسبة مقبولة وكذلك يمكن اعتمادها كبديل عن ازالة الاجهادات بالمعاملة الحرارية خاصة عندما تكون هناك حاجة ضرورية للمحافظة على استقرارية المادة وابعاد المنتج.

1. INTRODUCTION

Welding processes inevitably induce a state of residual stress into materials and products. They pose series of problems, in terms of dimensional stability, corrosion cracking, reduced fatigue life, and structural integrity. The conventional way to relieve the residual stresses is by post-weld heat treatment (PWHT). It is an effective process, but it suffers from several disadvantages such as the cost of treatment of equipment and energy is high; the growth of oxide scale on the surface implies the need for subsequent finishing processes to remove the scale; in some metals, PWHT is unable to relieve the residual stresses. The use of vibration to modify residual welding stress has been reported, but as yet the process has not received a detailed investigation.

Recently more extensive works (experimentally and numerically) were achieved to find out whether the method can be used systematically to relieve residual stresses of weldments. The estimation of residual stresses becomes a crucial concern to provide a safe working environment to these structures involving the development of residual stress due to welding process, **Palve**, and **Kshirsagar**, **2015**.

In a related work, **Patil**, **et al.**, **2017** summarized the methods used to measure the residual stresses in a body subjected to external forces or temperature gradient. Among the methods mentioned in their work are stress relation technique, slitting method, x-ray diffraction, and vibratory stress relief method. The decision on which method is the most effective way to be used in stress relief of a part mainly depends on how much savings can be made in the cost and time of the used method. Besides, the consideration of changes in material properties and crystalline structure should be taken into account in selecting the proper method for stress relief.

As the literature declared that; among the factors, those affect the corrosion behavior of the materials are the residual stresses. **Kim, et al**., **2015** studied the effect of residual stress on stress corrosion crack amongst three different parameters: susceptible material, corrosive environment, and residual stress. It was explained that residual stress becomes a critical factor for stress corrosion crack when it is difficult to improve the material corrosive of the components and their environment under operating conditions. In their study, stress corrosion cracks are artificially produced on STS 304 pipe itself by control of residual welding stress, and they are used the instrumented indentation technique and 3D FEM analysis (using ANSYS 12) to evaluate the residual stress values in the gas tungsten arc welding process (GTAW) area. They found that the stress corrosion crack was quickly generated and could be reproduced, and it could be controlled by welding residual stress.

An attempt was made by **Munsi**, **et al**., **2001** to investigate whether the vibratory method could be used systematically to relieve residual stresses in welded joints. Two forms of treatment were investigated with vibratory stress relief (VSR): 'during-welding' treatment and 'post-weld' treatment. Also, they investigated the effect of vibratory stress on the crystallographic orientation and change in the hardness of the weldments due to VSR treatment. They found that the residual stresses were decreased in response to vibration whether it was applied during welding or after welding and the applied stress influenced the grain growth process in the weld.

Various methods are seen from published works on studying the stress relief from the welded parts. Some methods utilized software other than experiments. For instance, simulation using ANSYS used by **Palve**, and **Kshirsagar**, **2015** to compute the residual stress induced in welded steel pipes. The simulation results compared to experimental results measured by x-ray technique. Both hoop and axial residual stresses were measured.

Yang et al. 2005, investigated the mechanisms and vibration parameters of frequency and amplitude of the stress relief process by vibration. They studied the resonant and non-resonant vibrations. A finite element model using ANSYS was developed for this purpose. The study used a weld cantilever bar for stress relief after the welding process taking the effect of three parameters which are vibration amplitude, vibration frequency and vibration time. The results showed that for non-resonant vibration the reduction of stress mainly depended on amplitude while for the resonant type the reduction depended on vibration frequency. Also it was found that there was no considerable effect of time on the stress reduction process.

Kalpana et al., 2017, stated that the reduction of welding quality happened during the normal welding processes as a result of the produced residual stresses. Among the recently used methods to avoid such defects is the vibratory assisted welding process. Through the mentioned process it was noted that the mechanical properties of the weldment were improved.

The effects of residual stresses of multiple welding repairs of the pipeline on the corrosion cracking behavior were evaluated by **Contreras, et al**., **2015**. As a result of multiple welding repairs of X52 pipelines, residual stresses were produced which affect the behavior of stress corrosion cracking of these pipes. The microstructure of the welding repairs was carried out using scanning electron microscopy. The results showed that the failure occurred in two areas: the base metal and heat affected zone interface.

The current study is aimed to show that the vibratory stress relief of small size fittings is possible and residual stress may be relieved. Thus, an experimental investigation was carried out by using a post weld vibratory stress relief method. Specimens of T weldment pipe fitting were used, and different vibration frequency is applied. The study investigated the change in the hardness of the weldments due to VSR treatment and compared with a hardness of the heat-treated specimen.

2. EXPERIMENTAL WORK

2.1 Test Specimens and Material Properties

The T- fitting specimens were made from seamless A106 low carbon steel pipe, of equal length of 104 mm and a diameter of 50 mm with a thickness of 3 mm. Carbon and other alloying elements of the pipe material are shown in **Table 1**.

Table 1. Alloying elements of the specimen material.

C wt %	Mn wt %	P wt %	S wt %	Si wt %	V wt %	T wt %
0.24	1.40	0.025	0.015	0.45	0.1	0.04

The web and flange pipes of the T fitting were joined by manual metal arc welding process (MMAW) using an electrode of E6010 type with a single pass. The welding process parameters are kept constant during the welding process of all specimens. The welding processes of five T-fitting specimens are carried out by qualified welders under a qualified welding procedure at Carbon Wza Company for General Trade Providing and Transporting Oil Products /LTD according to their standard manufacturer's. The dimensions and shape of the specimen are shown in **Fig. 1**. The distance x represents the line over which the parallel lines of residual stress measurement are distributed. The mechanical properties of the specimen material were determined by a tensile test, where the yield stress is determined to be 300 MPa and ultimate tensile strength of 460 MPa.

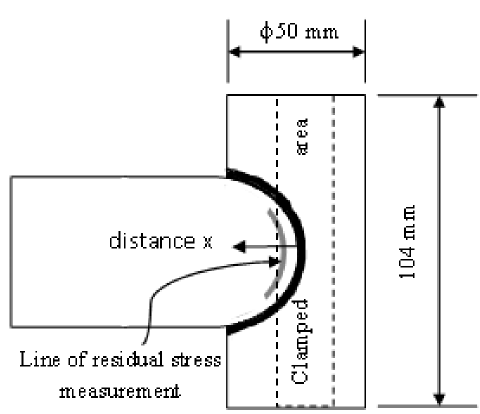

Figure 1. T-pipe fitting test specimen.

2.2 Experimental Procedure

The experimental set-up for the present experimental investigation is shown in **Fig. 2**. A vibration shaker of a mechanical actuated type was used to apply vibration to the test specimens. The frequency of vibration is controlled via frequency controller, and the amplitude of vibration is measured by an accelerometer magnetically fixed to the shaker table and integrated with the vibration meter. The T-fittings specimen is firmly secured to the shaking table by a special fixture designed for this purpose. The specimen is clamped look like a cantilever beam with excitation amplitude applied at the fixed end of the specimen. The frequency is increased gradually until the resonant or nonresonant conditions are satisfied. In each test, the amplitude of vibration is recorded, and the frequency was kept constant during each test.

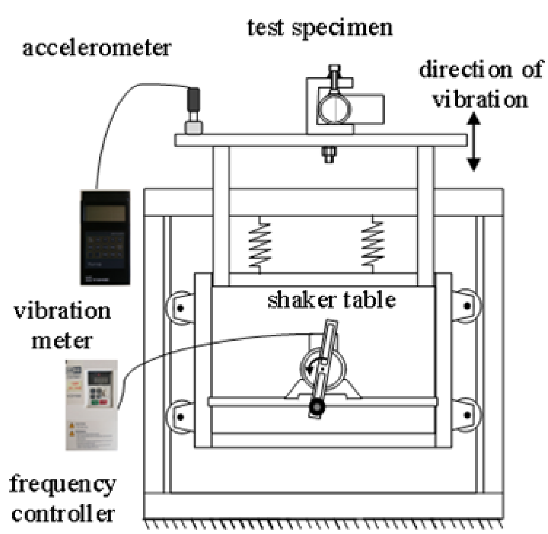

Figure. 2. Experimental setup and test specimen.

Five T pipe -fitting specimens were used in the present study. One of the specimens was kept as a control specimen (as received), and the second specimen was used for post weld heat treatment. The three remaining specimens were used for post weld vibratory treated to relieve the residual stresses. In this test, the specimens were vibrated at different frequencies, and the changes in the residual stresses due to treatments were investigated. Investigation of the residual stresses was carried out at a line parallel to the weld line. The details of the results are described in the subsequent sections.

2.3 Heat Treatment

The heat treatment was carried out in a furnace of the Metallurgical Laboratory. The heat treatment was conducted according to standards related to heat treatment using Iron-Iron carbide phase diagram for selecting the required PWHT temperature. The heating routine was carried out as follows. Firstly, the heat treated specimen was soaked at 300 ºC for one hour; then the temperature was raised until the soaking temperature of 450 ºC was achieved and it was still for one hour soaking time. Finally, the temperature was raised again until 600 º C temperatures was reached and the specimen was soaked at this temperature for two hours. Then, the oven was switched off and allowed to cool with the specimen in it.

3. RESULTS AND DISCUSSION

3.1 Post Weld Vibration Test

The post weld vibration test was carried out for three specimens. The test was carried out at different frequency and amplitude but the vibration time was kept constant for all tested specimens. The frequency of vibration, measured amplitudes, and time of post weld vibration treatment was shown in **Table 2**.

Table 2. Post welds vibration test data.

Sample	Frequency (Hz)	Amplitude (mm)	Time (min)	FR
TS3	4.7	7.51	10	1.09
TS4	5.8	6.23	10	1.35
TS5	13	1.99	10	3.02

where: FR represents the ratio of excitation frequency to the natural system frequency.

3.2 Investigation of Hardness

The hardness of the as-received specimen, heat treated specimen, and specimens subjected to post weld vibration was measured. The hardness measurements were carried out by employing a Brinell Hardness Test. The residual stresses measurement was made in three points located at the line of residual stress measurement 5 mm away from the weld line. In each measurement, the average of these three reading points was considered. The hardness measurements of the test specimens are shown in **Table 3**.

Table 3. Hardness (HB) of test specimens.

Sample No.	As received TS1	Heat treated TS2	Post weld vibrated specimens		
			TS3	TS4	TS5
Hardness (HB)	166	141	155	157	162
Δ (%)	-----	15.1	-----	-----	-----

Where Δ represents the percentage reduction in hardness calculated as follows:

$$\Delta(\%) = \frac{\text{as recived hardness} - \text{post weld vibration hardness}}{\text{as recived hardness}}$$

Fig.3 shows the effect of frequency ratio FR (applied vibration frequency) on the percentage reduction in hardness (Δ) of post weld vibrated treatment. The result indicates that the amount of removed residual stress near the resonant vibration is greater than that at over resonant vibration. This change in hardness of weldment results due to grain refinement occurred in the high-heat, and high amplitude vibrated specimens, which occurs in post-weld vibration treatment.

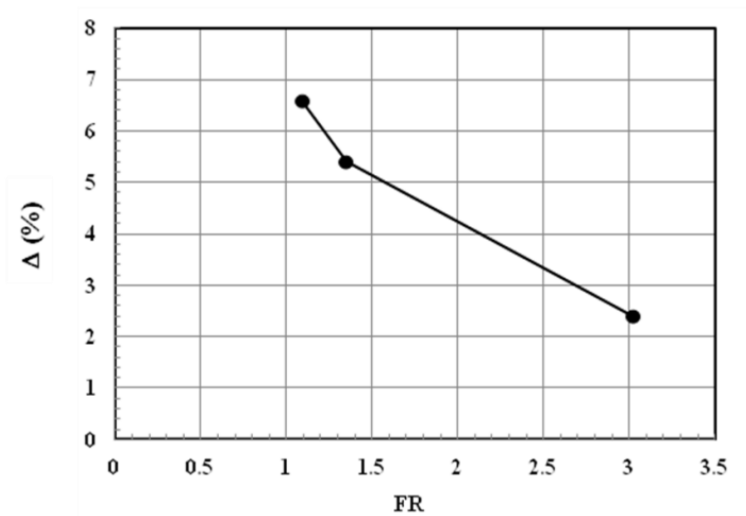

Figure 3. Variation of percentage reduction ratio (Δ) with frequency ratio (FR).

Also, it can be seen that with 23.6% increase in FR, compared with near-resonant ratio, there is an 18.18% decrease in Δ, and 176.6% increase in FR, results in 63.6% decrease in Δ. Accordingly, it means that very careful attention should be given to the proper selection of the applied frequency in post-weld vibration treatment. In other words, the proper selection of applied frequency results in saving of the cost and time, and the frequency may represent the key control in vibration stress relief treatment.

Fig. 4 shows the variation of the hardness of post weld vibrated test specimens with the distance x over which the parallel lines of measurements are distributed for different frequency ratio. It will be seen that the hardness level parallel to the weld line was found to be less with the application of a low frequency of vibration (FR=1.03), while, with the increase of vibration frequency the hardness level was found to be larger. However, beyond a certain level of vibration frequency, there is no more reduction in hardness may be occurred. This may be attributed to the fact that the amount of removed residual stress near resonant frequency (high vibration amplitude) is greater than that removed at over resonant frequency.

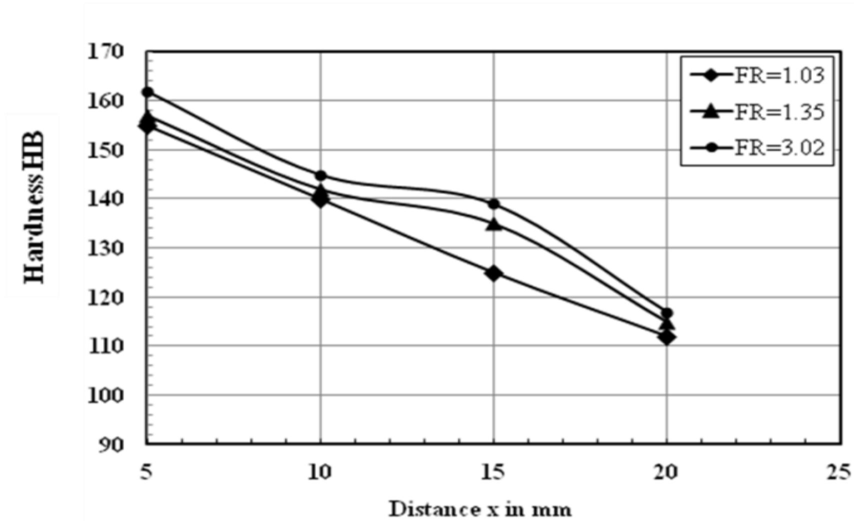

Figure 4. Variation of the hardness with distance x for different values of frequency ratio (FR).

Fig. 5 shows a comparison between heat treatment and post weld vibration treatment. The comparison revealed that the heat treatment is the effective method in reliving of residual stress of welded pipe fittings. Also, the results show the effectiveness of the post weld vibration process in reliving of residual stresses for small size pipe fittings when it is known that max Δ of vibratory stress relief is equal approximately half that of the heat treatment. Consequently, it may provide a practicable alterative solution of heat treatment irrespective of the size of the treated parts and especially when there is no need to re-crystallization of the material structure and no change in the part dimensions after treatment.

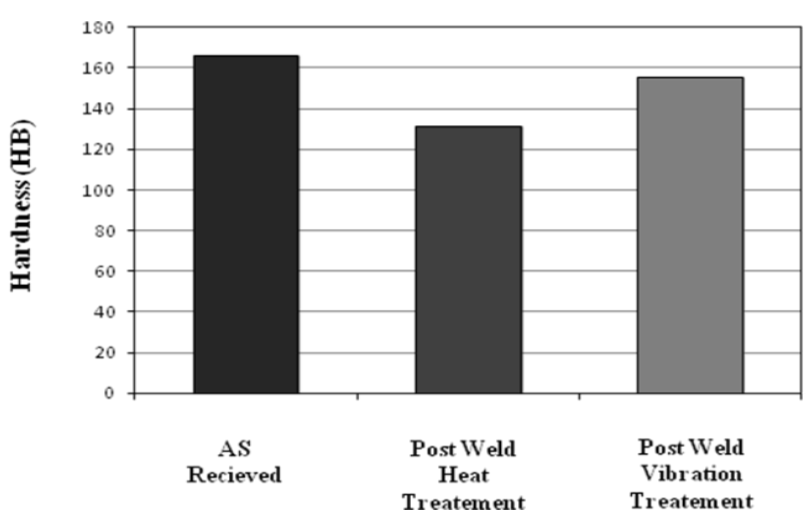

Figure 5. Comparison between different stress relief treatments.

Finally, whatever the amount of removed residual stresses by post weld vibration treatment of pipe fittings, this process results in enhancement of the corrosion properties of the fittings when these parts are used in the transportation of an aggressive media in a corrosive environment, and this may be agreed with that declared by **Kim, et al**., **2015**.

4. CONCLUSIONS

From this investigation the following conclusions are made:

(1) Post-weld vibratory stress relief of small size fittings is possible and residual stress might be relieved.

(2) Stress relief at the resonant frequency is greater than that at over resonant one.

(3) The hardness level of lines parallel to the weld line is affected by vibration frequency.

(4) Vibratory treatments of small sizes parts may be an alternative for heat treatment especially when unchanged in dimensions are required.

(5) Although the results regarding heat treatment are better, the vibratory treatment has many advantages particularly in terms of surface oxidation and re-crystallization of the structure.

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