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Stress Relief and Material Properties Improvement Through Vibration VS. Common Thermal Method

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ABSTRACT

The goal of this study is investigating reduction of residual stresses from welding carbon steel plates through vibration stress relief method vs. thermal method. In order to carry out the required experimental tests, carbon steel plates were welded together under specific conditions as samples. Some of the samples were vibration stress relieved, some were thermal stress relieved while the rest remained without any stress relief operation.
Several destructive and non-destructive tests were performed on all the stress relieved and non-relieved specimens and the data obtained from these tests were compared in order to reach the optimum vibration effect on stress relieved welded joints. The results attained for vibration method indicated an acceptable amount of reduction of residual stresses in the joints. In addition, some improvements in mechanical properties achieved vibration stress relief method were used.

Keywords: Stress Releasing; Vibration; Thermal; Mechanical Properties

1 INTRODUCTION

SOME heat or mechanical operations such as welding, casting, machining etc. used in fabrication processes cause residual stresses in work pieces. These residual stresses can be damaging, have undesired influences on functions and lead to twists, cracks and damage of the parts. Thermal stress relieving, having its shortcomings and limitations, is a common practice for minimizing residual stresses. Another method is vibration stress relieving in which, in addition to reduction of residual stresses with less energy consumption and pollution compared to the common thermal practice, mechanical properties are also improved.

Since 1943, experimental methods such as vibration and annealing combined with vibration, have been proposed for facilitating stress relieving and stabilizing welded steel and cast iron structures [1]. Years later, techniques were developed for analyzing distribution of residual stresses and measuring stress in cantilever beams [2]. Furthermore, the influence of vibration in resonant and sub-resonant frequencies on longitudinal residual stresses was studied [3]. There are several ways for measuring the amount of residual stress reduction, some of which used in the analyses carried out for measuring reduction of residual stress in vibration method were residual strain measurement using drilling holes in work pieces and measuring the changes in their dimensions [4] and X-ray Diffraction Technique [5]. Modeling is a suitable practice in the analytical investigation of practical researches. An analytical model was employed in the investigation of residual stress reduction via vibration [6]. Both resonant and non-resonant vibration can relieve residual stresses in welded structures by creating plastic deformation around the weld area. For the non-

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resonant vibration, the stress reduction strongly depends on the vibration amplitude. For the resonant vibration, the vibration frequency is the key for stress relief [7].

2 EXPERIMENTAL PROCEDURE

In situations when performing stress relief operations via thermal method involves various problems, vibration stress relieving method seems to be a suitable substitute. To do the required tests, a vibration producing machine was constructed and some test plates were prepared as samples.

2.1 Manufacture of vibration producing equipment

A vibration producer was constructed for vibration generation by using an electric motor and a non-centric disk as shown in Fig.1. The following parts are employed in the manufacture of this equipment:

- One-phase 1250 rpm electric motor.
- Steel disk 8mm thick, 100 mm dia. eccentrically attached to electric motor.
- Drive, comprised of a panel and a control handle used for controlling motor's revolution.
- Two strong bearings for protecting the shaft of the motor

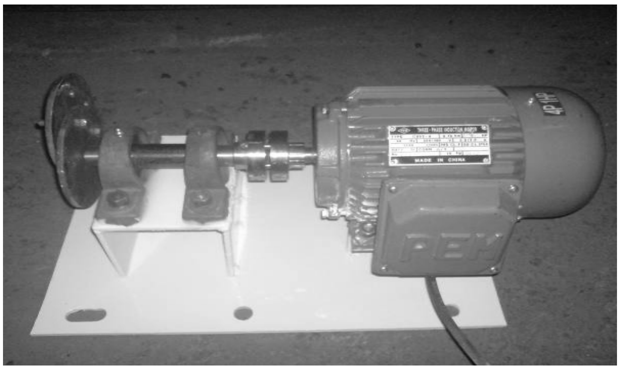

Fig.1
Vibration generating equipment.

2.2 Test Plate Preparation

To carry out the tests three pairs of carbon steel (A516-Gr.70) test plates 32 mm long, 22 mm wide, and 12 mm thick were prepared.

After assembling the samples, they were welded to each other according to the instructions offered for this type of material (Welding Procedure Specification) as below:

At first E-7018 electrode was used for the root pass and next passes. Considering the fact that the heat input on the samples in SAW (submerged are welding) is higher than SMAW(shielded metal are welding) and thus more residual stresses are produced, after welding of initial passes using SMAW the next passes were welded using SAW. EA1 welding wire and OP122 flask were used in SAW welding process. After welding was done from one side, defective welds were removed from the other side with graphite electrode using Arc-Air Gouging method. The process was then completed by the other side.

2.3 Vibration Stress relieving

To accomplish vibration stress relieving operations, No.03 was fixed and anchored to the chassis using 4 bolts & nuts. The sample was vibrated for 15 minutes 3 times at 10 minutes intervals.

2.4 Thermal Stress Relieving

Sample No.02 was stress relieved using thermal stress relief method. The stress relieving operation was carried out in a stress relief furnace equipped with gas-fueled burner. The thermocouples at several places in the furnace determine the temperature and record it at different times and adjust it using a burner turn on-turn off automation system.

The thermal stress relieving operation was carried out as per the requirements of ASME standard based on which the temperature was increased to 425C° with an optional temperature increase rate and a further temperature increase to 600C° with a 190C° temperature increase rate per hour. The sample was kept in 610C° ±10C° for 60 minutes. The temperature was then lowered to 425C° with a 210C° per hour temperature decrease rate and cooled from 425C° to environment temperature with an optional temperature decrease rate. The stress relieving operation lasted 154 minutes.

3 EXAMINATIONS AND RESULTS

3.1 Hardness Test

Various industries and standards such as PD5500/EN ISO15614-1 propose hardness test for checking and approval of thermal stress relief operations, since any decline in hardness on the surface of material after vibration stress relief operation is an evidence of the reduction of residual stresses.

3.1.1 Primary Hardness Test

After welding process and before any stress relieving, samples were cleaned and prepared for primary hardness test. The hardness test of Brinell Factor was carried out on 3 areas of weld, HAZ (heat affected zone) and base metal the result of which are shown in Table 1.

3.1.2 Final Hardness Test

After vibration and thermal stress relieving, the samples were prepared and brought under hardness tests on the areas of weld section, HAZ and base metal, the average results of which in 3 hardness tests for each area are shown in Table 2.

The comparison of the results in Table 1 .and Table 2 .shows a surface hardness reduction in each of the 3 areas (weld section, base metal and HAZ) which is an indication of the drop in residual stresses and validity of vibration stress relieving operations.

Table 1
Average Brinell values obtained in 3 hardness tests done.

Sample's No.	Weld	HAZ	Base Metal
01	142	160	141
02	159	156	142
03	154	155	138

Table 2
Average Brinell values obtained in 3 hardness tests done after stress relieving.

Sample's No.	*Weld*	*HAZ*	*Base Metal*
02	*130*	*133*	*118*
03	*130*	*132*	*119*

3.2 Impact Test

In order to obtain more precise results samples were impact tested in stress relieved and unrelieved states .To do this, grooves were cut on weld areas of the samples and the temperature was further lowered to - 28C° with the help of solid co2 (dry ice). The results obtained in impact tests of carbon steel samples are presented in Table 3.

The impact test results obtained for the weld areas of carbon steel samples indicate that both thermal and vibration stress relieving of samples increase resistance to hitting in low temperatures.

Table 3
Impact tests results of weld area obtained in Jules values.

Sample's No	First Test	Second Test	Third Test	Average
01	62	34	50	49
02	60	60	152	91
03	128	82	54	88

3.3 Tensile Test

A common problem occurring during thermal stress relieving is drop in yield stress. Therefore, tensile strength tests were carried out on samples the results of which are shown in Table 4.

The closeness of results in tensile strength tests for carbon steel samples is an approval of the fact that no yield stress reduction occurs during vibration stress relieving process.

Table 4
Values of tensile strength (MPa) for carbon steel samples.

Sample's No	First Test	Second Test	Average
01	429.1	395.6	412
02	396.3	382.6	389
03	448.94	431.36	440

3.4 Side Bending Test

Work piece fatigue is of great concern in vibration stress relieving operations. To prevent this, although all mechanical tests carried out in this regard had been acceptable, side bending test was also carried out for more certainty. To do this, four samples were cut from test plates encompassing the entire weld section, base metal and HAZ.

The samples side by side were simultaneously brought under side bending test the results of which showed no fractured samples or samples cracked more than the allowable standard limit.

3.5 Metallography

For each test plate a sample was prepared for the analysis of molecular structure, and using a microscope, images were taken from HAZ, weld and base metal areas 500 times actual size as per Figs. 2 to 10.

As pointed out earlier, the temperature required for thermal stress relieving method is 600C° in which no changes occur to steel crystal structure, however, phases' pointed boundaries are expected to become rather round. In some spots the grains disintegrate into smaller pieces, furthermore, more noticeable in vibration stress relieving process.

- The images provided for samples with no stress relieving operations show that the grain structures are generally pointed and angled indicating the formation of near martensitic and hard phases.
- The images provided for thermal stress relieved samples show that the phases formed are rather regular with corners/angles slightly pointed.
- In the images provided for vibration stress relieved samples, the phases' boundaries are clearly shown to have become regular, of smaller sizes and of corners\angles less pointed.

Considering the images obtained in the samples' metallography process we can see that in the stress relieved samples, grain boundaries are changed and number of pointed corners and stress concentration locations are reduced.

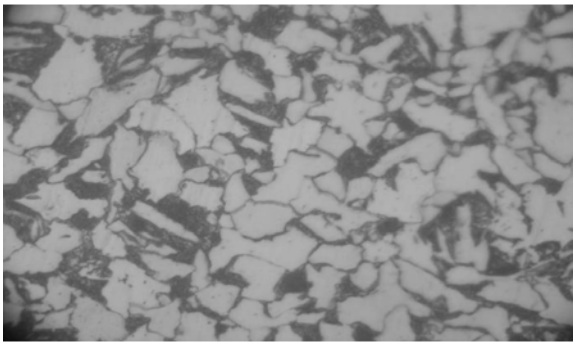

Fig.2
HAZ area of non-stress relieved sample.

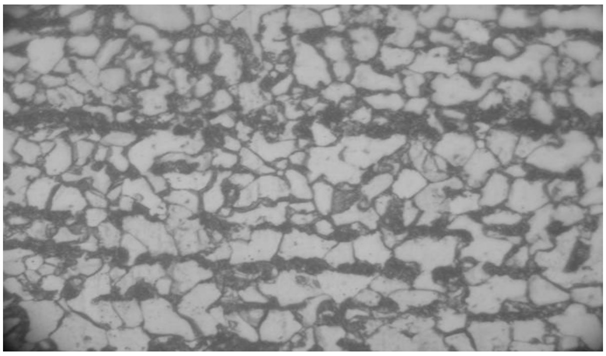

Fig.3
HAZ area of vibration stress relieved sample.

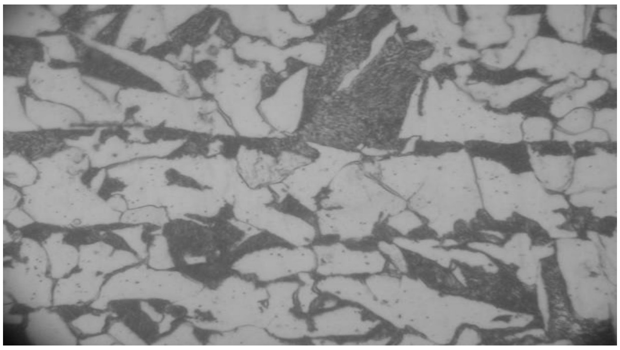

Fig.4
HAZ area of thermal stress relieved sample.

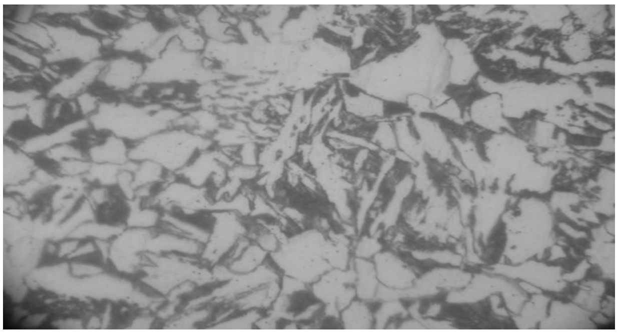

Fig.5
Base metal area of non-stress relieved sample.

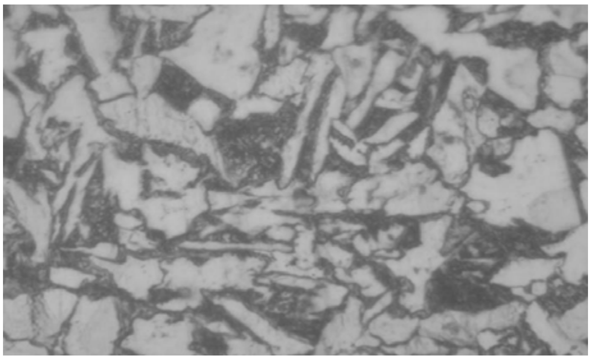

Fig.6
Base metal area of vibration stress relieved sample.

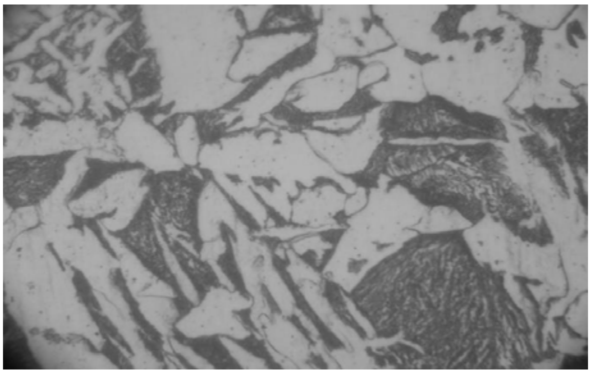

Fig.7
Base metal area of thermal stress relieved sample.

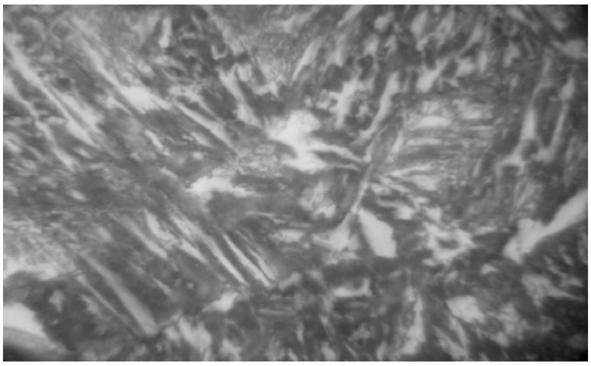

Fig.8
Weld area of non-stress relieved sample.

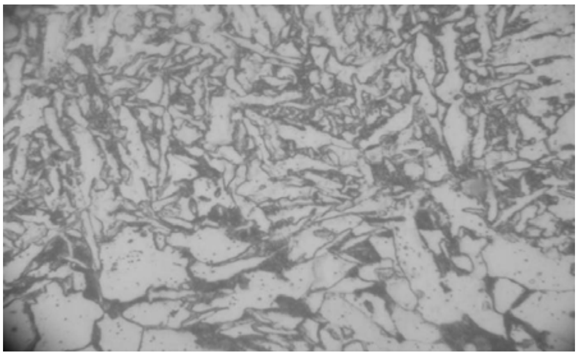

Fig.9
Weld area of vibration stress relieved sample.

4 CONCLUSIONS

- From the results of hardness test and analysis of the values obtained for thermal and vibration samples, the soundness of vibration stress relieving can be approved.
- The results of impact test show the increase of carbon steel samples resistance to hitting in low temperatures by vibration stress relieving.
- Tensile strength test results show that thermal stress relieving reduces yield strength, not existing in vibration method.
- The images obtained in metallography show molecular structure similarities of thermal and vibration stress relieving in different weld areas.
- Side bending test results indicate that there is no worry for work piece fatigue in vibration stress relieving.

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