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INFLUENCE OF VIBRATIONS ON RESIDUAL STRESSES DISTRIBUTION IN WELDED JOINTS

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This paper presents research experience related to implementation of vibrations on residual stress relief with the equipment for treatment by vibration method. The paper provides explanation of effects achieved by vibration method when implemented during welding, and elaborates advantages and disadvantages of that method applied after welding process. In order to present effects of vibration on solid structures, there was experimental analysis performed and compared with heat treatment.

Key words: welding, vibrations, residual stress, heat treatment

INTRODUCTION

Welding is one of common method applied in production of large massive structures. It can cause residual stresses within a structure. Residual stresses can be useful but also harmful. Useful stresses are for example the compressive stresses induced by some forms of surface treatment of cyclically loaded parts that leads to prolongation of service life. The consequence of the negative effect of residual stress (usually tensile) is creation of cracks, stress corrosion and reduction of fatigue strength, fracture resistance, etc. [1]

Therefore, such structures require residual stress relief to be performed by heat treatment or some other method.

Heat treatment process does not change only the structure and other properties of parts but also significantly affects their shape, dimensions, stress state, etc. [2].

Vibrations method, which is considered as alternative to heat treatment has also influence on reduction of residual stresses [3].

The method of vibration is still not widely used in industrial production because of two main reasons, one being insufficient research into this process, and the other reason is difficulty to assess effectiveness of this method in comparison to heat treatment.

The vibratory stress relief process uses controlled and monitored vibration to cause dynamic loading, this dynamic loading combined with the internal load from residual stresses, enables plastic flow to occur. Flexure is a key requirement of the process. [4]

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If a structure is large, or if it is long or has an open space, it may be necessary to apply the method in several spots. This method is suitable for processing of structures that weigh up to ten tons. It is also possible to use the method on structures that are heavier than ten tons in two consecutive 15 minute periods, without causing any damage on them. While implementing the method, it is necessary to follow two rules: [3,5]

a) Setting up of a workpiece in the best way possible, isolation from floor or solid structure, leaving it free to vibrate.
b) Force inducer (inductor) should be directly connected to the workpiece in order to transfer entire energy of vibration on the product.

Recommended implementation of the method of vibrations is: before rough processing, before final processing, before heat treatment, before cutting, before quality control, before initial usage of service components, as preventive maintenance of service parts, during welding, after repair welding and always before distortion and/or cracking.

Materials that are not suitable for method of vibration are: [6]

- cold-formed steel, including cold-rolled steel plates, sheet metal, and parts difficult to uplift,
- edges of heat treated plates,
- copper and copper alloys.

EQUIPMENT FOR TREATMENT OF RESIDUAL STRESS RELIEF BY VIBRATIONS

A device for residual stress relief by vibrations usually consists of the following: console, force inducer (inductor), adjuster and stop key, clamps, probe, rubber isolation pad, AC input cable, computer cable, computer, printer and program disk. All elements required for implementation of vibration treatment are shown in Figure 1.

Figure 1 Equipment for residual stress relief by vibration [6]

Number of locations of force inducers (inductors) depend on the scope of a particular force inducer (inductor). They are positioned in a central location foreseen for a specific force inducer (inductor), and in case of larger dimensions than those for which specific force inducer (inductor) is made, there is a need to used more inductors for processing of the workpiece in question. Cylinders and large diameters of the ring can have greater volume than length. In such cases, volume should be considered as length when installing force inducer. Vibrational energy works most effective when directed parallel to the rotational plane of force inducer motor. Thus, the base of force inducer should be directed along the longest dimension of a processed workpiece, which can be seen in the Figure 2.

Monitoring of relaxation process follows after installation of force inducer. Upon completion of the process there is post-processing analysis of data obtained from measuring devices. Upon installation of vibrational stress relief device, it is necessary to determine resonant frequency, as presented in Figure 3, and to set up values for 1/3 lower of resonant curve height for material class „A“, while „B“ and „C“ values shall fluctuate from 1/3 – 1/2 below resonant frequency value.

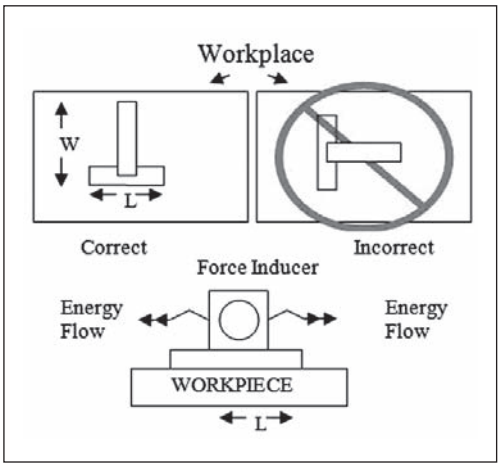

Figure 2 Correct orientation of force inducer base [6]

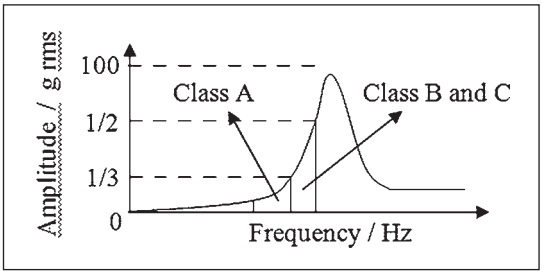

Figure 3 Values of frequency for material class „A“, „B“ and „C“ [6]

After setting up of required frequencies, the workpiece is subjected to these frequencies for 10 - 60 minutes, and then the frequencies are reduced for re-setting and determining of resonant frequency. In the automatic mode, the second scanning is performed automatically. As proceeding, the material is again held loaded under frequencies for 5 - 15 minutes and values are again measured to determine the resonant frequency. The workpiece relief is carried out until the difference between the values of resonant frequencies between two intervals decreases below 1 Hz.

EXPERIMENTAL ANALYSIS OF VIBRATION METHOD

The process of vibrating is performed by the METALAX 2700-CC vibration stress relief device, designed as user-friendly, portable and adaptable for the most workplaces. Since the structure on which the relief was done was rigid, it was necessary to perform relief at several spots, and for this purpose the force inducer (inductor) was positioned in two places.

The Figure 4 presents two positions of force inducer (inductors), and treatment by vibrations.

The workpiece was isolated by high-density rubber pads, placed under each angle.

The probe was positioned at a distance of 1 m from the inducer, which was used for reading of frequencies. In order to complete the vibration successfully, data on the structure (dimensions, weight, type of material) were entered in the software, and then the value of eccentric weight was also set up. Vibration process was implemented as long as the difference of resonant frequency drops below the value of 1 Hz. In the first case (First position of force inducer (inductor)) presents in the Figure

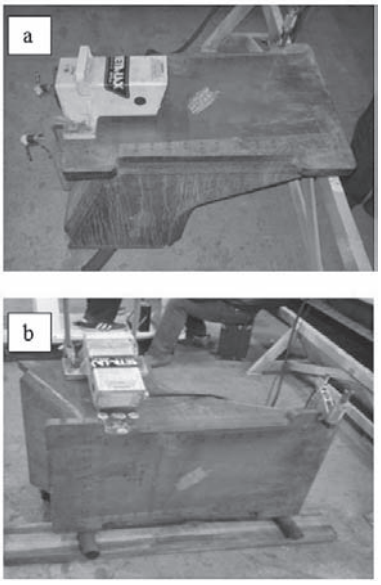

Figure 4 Setting up of inductor: a) First position of force inducer (inductor), b) Second position of force inducer (inductor)

4, it was necessary to perform three cycles of relief, while in the second case (Second position of force inducer (inductor)) presents in the Figure 4, when the values of the resonant frequencies were lowered, there were two cycles of 10 minutes required to lower the difference between resonant frequencies below 1 Hz, to reach the value of 0,7 Hz. Structure subjected to vibration method is constructed of low-carbon steel St 52-3 N. Based on the results obtained within vibration treatments, it can be concluded that force inducer (inductor) in the first position affected the reduction of resonance frequencies, since the values in the second position were 70,1 Hz which was for 9,3 Hz lower than in the first position.

The method of magnetic permeability was used to measure the difference of residual stresses in order to determine real action of vibration method on the respective type of structure.

Directional effective permeability technique is a magnetic technique which uses the magnetic anisotropy to measure the stress present in a magnetic material. [7]

Measurements were performed on the entire structure before and after vibration process and after heat treatment.

Measurement was performed at all areas (Area I, Area II, Area III) previously mentioned, and as presented in the Figure 5.

While performing the experiment, attention was directed towards the order and direction of welding, as well as towards direction of magnetic measurements implementation method. This was necessary for analysis of obtained results. Average of residual stresses in the entire construction were within acceptable values below the yield point, about 60 % lower. But in some parts of the structure are observed value of the residual stresses that are 34 % lower than the yield point. Such places are marked as critical, and it is necessary to solve the problem. The problem can be solved in several ways:

1. to apply proper method and technology of welding,
2. to apply vibration method to reduce residual stresses in a structure,
3. to apply heat treatment.

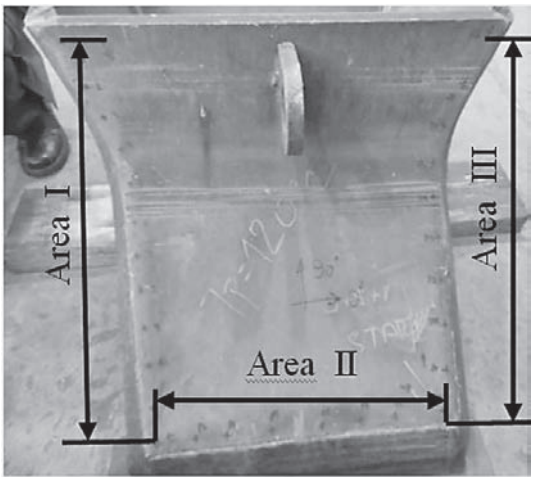

Figure 5 Marking of workpiece before measurement

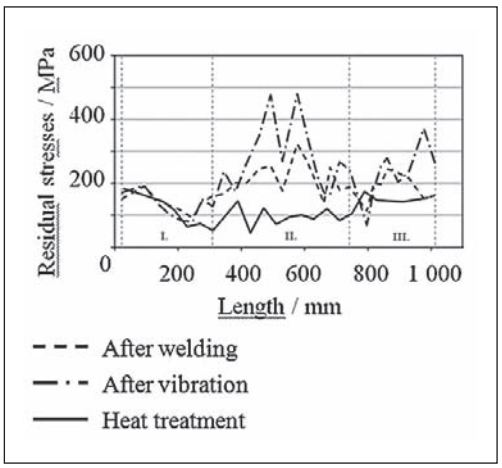

Figure 6 Comparison of results of implemented methods of residual stress relief

Results of application of vibration method on welded structure indicated that residual stress was effective. The decline or increase in stress was represented in dependence of how vibrations and impact of force inducer (inductor) reflected on the structure. Average value of the residual stresses in the entire construction after vibration was for 7,89 % higher than the value before vibrations. However, in some parts of the structure who are most influenced by force inducer (inductor), there was significant decrease of these stresses, even up to 43 %. Application of vibration method on solid structures requires more experimental research and more extensive studies.

The process of vibrating parts and completed structures may or may not relieve stresses, but it increases confidence in the stability of the shaken part. [8]

In comparison to the initial state, heat treatment results in about 37 % lower value of average of residual stresses in the entire construction. In the area II, as of the diagram in the Figure 6, with measured maximum residual stresses, influence of heat treatment resulted in the greatest reduction of the residual stresses.

PREVIOUS RESEARCH INTO APPLICATION OF VIBRATION METHOD

Previous research into vibration methods published in scientific journals elaborates approaches to the studies into that method applied during welding. The vibration stress relief device is placed on a workpiece and then in the process of welding preheating temperatures can be reduced. Values of eccentric weight are set for 20 – 40 % lower than the values of residual stress relief after welding. Method of stress relief by vibrations during welding can be applied in all alloys and it usually results in finer and more uniform grain welds (Figure 7), in improved ductility, longer service life, less distortion contraction, less cracks in the heat affected zone, and in faster welding.

There is a positive effect of vibration during welding on impact toughness. Vibration stabilizes microstruc-

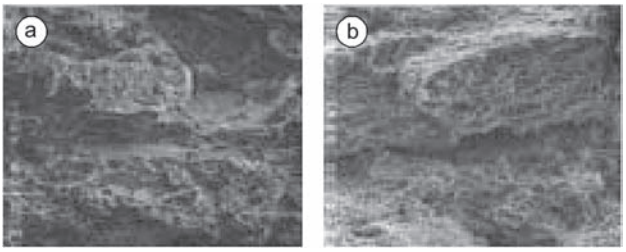

Figure 7 Fracture appeatance of as-welded samples, SEM, 540x: a) un-vibrated during welding, b) vibrated during welding [9]

tures to become more resistant to heat affects that could minimize impact toughness. [9] Since the method can be applied in the process of welding, researches into such application of vibration proved that slight vibration during welding had significant impact on the weld itself. Slight vibrations cause the weld metal to remain "liquid" for a few seconds longer, which enables the entire weld to be more balanced. The method provides two immediate benefits: there is less distortion of the weld, and a welder is enabled to reduce 3 – 15 % welding current and to increase welding speed of up to 25 % in order to achieve the highest quality of the weld. Some of the benefits of vibration method are reflected in lowered costs of processing, less time needed for processing, service life is prolonged, occurrence of cold cracks is lowered, porosity of welds is lowered, and there are no restrictions in method application as far as size and weight are concerned. The greatest influence of the vibration method can be seen in those structures with different size of sides.

CONCLUSION

Influence of vibrations on residual stresses was experimentally elaborated. Upon obtained results, it was concluded that application of vibration method can reduce residual stress in specific structure areas in dependence on the position of force inducer (inductor). Since metallurgical action on the structure is negligible if compared to the heat treatment, more correct redistribution of stresses in the structure should be achieved by a proper choice of force inducer (inductor) position, and by increasing the number of treatments. According to some studies, the main objective and effect of vibration is to improve dimensional stability by selective reduction of intensity of the very stresses that cause the biggest problems. Dimensional stability can be assessed during exploitation or during processing.

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