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Improvement of Mechanical Welding Properties by using Induced Harmonic Vibration

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Abstract: The enhancement of the welding mechanical properties and the quality of the fusion metal is considered recently by using vibration during welding. In this study, the effect of induced harmonic vibration during welding is employed to improve the welding mechanical properties and to reach the best shape of welding line on the surface. The harmonic vibration method is examined experimentally by using four values of mechanical frequency during welding on the ductility, tensile strength and the homogeneity of the welding line. The frequencies were specified according to the natural frequency of the plate. Five simply supported rectangular plates are supported on the supporting stand and welded using a manual arc-welding machine. The experimental results show that the vibration applied during welding generally improved the bend property of the welding line, as well as the tensile strength has been improved distinctively at the resonance case when compared with that one welded without vibration. The morphology of the fillet metal after welding and for each value of frequency show an enhancement in the distribution of the fusion fillet metal, with gradually disappearing of the micro crack that may shown inside the metal with increasing the mechanical frequency. A comparison between the properties of welding without vibration and welding with vibration is discussed.

Key words: Welding micro crack, natural frequency, vibratory weld conditioning, mechanical properties, bending and tensile, welding morphology

INTRODUCTION

Vibration is the study of the repetitive motion of objects relative to the stationary frame of reference or nominal position. Vibration can be harmful and must sometimes be avoided while on other occasions it can be extremely useful and beneficial (Inman, 1994). The vibration of structures has many applications and in the vibration field, plates are one of these structures that are constructed under several applications for several research fields. The plate is considered as a two dimensional beam and the modelling of these 2D systems is more challenging and involves more boundary conditions (Virgin, 2007). The welding process is also conducted on plates as an important research area. The quality of welding is very important in the modern industries which mean best welding shape and performance with strongest mechanical properties for the weld itself (Robbins, 2004), so recently many studies have been done to identify the best welding properties by employing vibration as an enhancement factor for the mechanical properties of the welds. Most of the methods are focused on use the beneficial of vibration in reducing the residual stress and distortion that occurred due to the thermal cycles of the welding process (Qinghua *et al*., 2008). The heat source causes highly non-uniform temperature distribution across the joint and in the parent metal. Therefore, the thermal expansion and contraction during heating and subsequent cooling, as well as material plastic deformation at elevated temperatures, result in inevitable distortions in the joint and parent metal, may cause early failure of the structure (Kang *et al*., 2008). These thermal expansions and contraction can lead to increase the growth rate of the fatigue crack of the fillet metal (Barsoum and Barsoum, 2009). Since, microstructure study in the weld determine the properties of welding metal and are important area of interest for limiting the size of the micro crack (Zhang *et al*., 2008).

Various vibratory welding techniques have been employed in different application in industry which provided varying levels of success (Qinghua *et al*., 2008). Harmonic vibration, random vibration, specific vibration amplitude vibratory weld conditioning, vibratory stress relieving (Qinghua *et al*., 2008; Aoki *et al*., 2005, 2007) that all of them are employed for enhancing welding properties and to reduce as much as can the residual stress and distortion. The vibration during welding is a new welding technology that enables the piecework improved the

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welding properties and relieve the stress in the base metal after welding (Xu *et al*., 2007).

This study describes an experimental work on employing induced vibration frequency during welding and studies its effect on the welding, especially for the homogeneity of the welding line and also for the improvement of the mechanical properties such as ductility and the tensile strength of the welds.

MATERIALS AND METHODS

This research project was conducted from 1/1/2010 to 1/5/2010.

Two different welding procedures are done experimentally, normal welding without using vibration and welding with vibration. The specimens that welded without vibration were made entirety to be as a reference for comparison. The material used in this experiment was hot rolled steel (milled steel) JIS G 3101 SS400, for general used, for example, boiler pipes, Chequer plate, structural steel, storage tanks and many other industrial applications. Mild steel is the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications. Table 1 and 2 show the mechanical properties and the chemical component of JIS G 3101 SS400, respectively.

The dimension of the plate is 400 mm×200 mm×6 mm; the quantity that was used is 10 pieces. Each piece of plate was cut into two parts and the edge of the cutting was formed into a skewed shape with angle 30° longitudinally; the purpose of the angle is to be a place for the fillet welding material and to visualize the shape of it later. Before welding is started the plate is cleaned thereby removing the spots of corrosion by using a simple steel broom.

The plate is simply supported from two edges and it's supported on to supported stand by bolts as shown in Fig. 1. The specimens are shaken by a small shaker connected to the power amplifier, which is connected to the data acquisition. The frequency that provided during welding was specified by using the LMS test lab software manually.

The specimens were welded using manual arc welding machine. The voltage of welding is 220 V and current is 150 A. The welding was performed through one pass along the Vee grove. Velocity of welding was 0.6 mm sec^{-1}. The natural frequency of the specimen was measured experimentally by four accelerometers and the results analyzed by the LMS test lab. That is equal to 4.6 Hz. In order to examine the effect of the excitation frequency on the improvement of the homogeneity and the mechanical properties of the fillet metal, excitation frequency were chosen as 3, 5, 10 and 100 Hz. The amplitudes of the excitation were fixed by the voltage indicated at the amplifier of the shaker. For comparison the improvement, some specimens were welded without vibrational load.

Table 1: Mechanical properties of JIS G 3101 SS400

Yield (N mm^{-2})	Tensile (N mm^{-2})	Elongation (%)
354	426	35

Table 2: Chemical component of JIS G 3101 SS400

x 100%		x 1000%		
C	Si	Mn	P	S
4	15	75	13	9

Fig. 1: The plate holder and the shaker for the experimental

RESULTS AND DISCUSSION

Three tests were performed to notify the improvement of each value of frequency, the tests were bending and tensile test as well as SEM test.

Bending test: The bending test is an important test to ensure the ductility of welded parts and to make certain that the weld and the base metal are properly fused; as well as to ensure that the weld metal and the heat affected zone have appropriate mechanical properties. Five types of specimens were prepared according to the (ASTM E190-92, 2003) standard. The specimens were

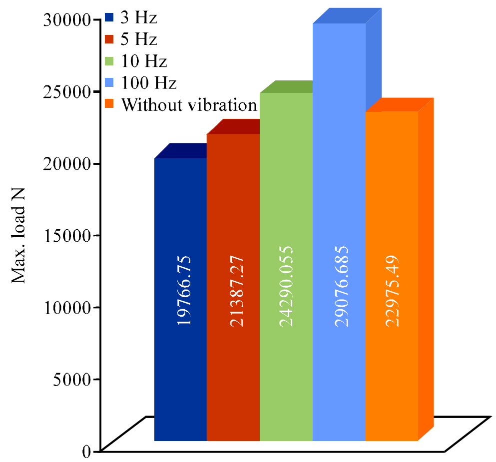

Fig. 2: Maximum loads for bend test

Table 3: Geometry of the specimen

Geometry	Values (mm)
Thickness	6
Width	38
Length	150

prepared from the work pieces directly and taken with their length perpendicular to the weld line. Four specimens were prepared from the welding with vibration and the last specimen was prepared from welding without vibration. Table 3 shows the dimension of the specimen.

The obtained results show that the specimens have excellent bend properties. Moreover, the specimens have no visible crack, especially for the specimens welded with vibration, the maximum load was found to be for the one welded with vibration. Figure 2 shows the maximum load for both specimens, welded with and without vibration and for each frequency.

From Fig. 2, the maximum load was found to be at 100 Hz, which is 29.076 kN and is higher than the welding without vibration, which was equal to 22.975 kN. The next improvement was at 10 Hz, which gave a maximum load of 24.29 kN.

The 3 Hz was provided a maximum load and bend properties less than the load of welding without vibration. The reason being that is the low frequency at 3 Hz grown the grains of the welds metal in random directions with re-distribute them randomly, The large stress generated from welding at the cooling stage beside the expansion coefficient are different from the weld and the base metal led to increase the stresses at these area and causes in ductility less than 10 and 100 Hz. In further, the heat transfer rate at 3 Hz is less than 10 and 100 Hz so the average of generated stress at 3 Hz is higher than 10 and 100 Hz and causes a less ductility (Qinghua *et al*., 2008). Thus, it is obvious that the bend properties and the maximum load were obtained at 100 and 10 Hz, which means that the vibration can increase the ductility of the bead by shaking the melting fillet metal and re-distributing it with the base metal. In addition, the reason for the effect of 10 and 100 Hz on the welding is that the frequencies above the natural frequency make the deposition of the liquid of the melting fillet metal in the phase transform to be mixed well with the melting base metal. Figure 3 shows the transverse face bend test; the results show a good deposit of the fillet metal and the bending occurs on the welding itself.

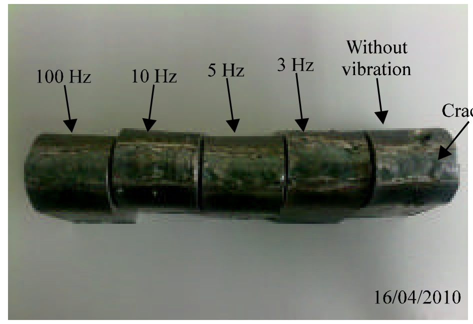

Fig. 3: Specimens after bending test

Fig. 4: The 3 mm crack in the specimen welded without vibration

Only in the specimen welded without vibration appeared with a crack of around 3 mm Fig. 4. This crack can be still qualified according to the ASTM standard, so the adoption of vibration during welding can improve the bend property.

Tensile test: The tensile test provides and indicates the maximum of a stress-strain curve, which is indicated by the necking occurring in the specimen. Five types of specimen were prepared according to the American welding society (AWS, 2000). The specimens were prepared from the work pieces directly and taken with their length perpendicular to the weld line. Four

Fig. 5: The tensile specimen

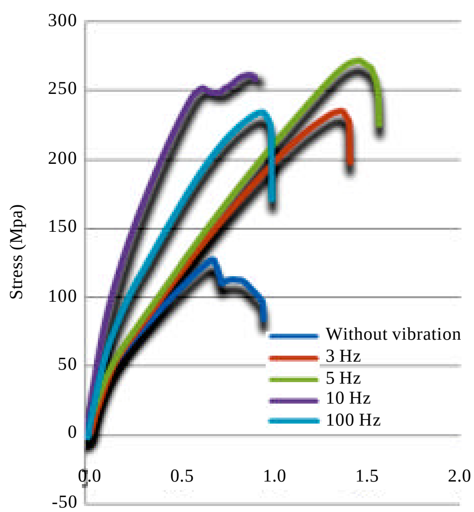

Fig. 6: Tensile test for the specimens welded with vibration and without vibration

specimens were prepared from the welding with vibration and the last specimen was prepared from welding without vibration. The test was carried out at room temperature (25°C) with a loading speed of 0.1 mm sec^{-1}; Fig. 5 shows the geometry of the specimens.

The test results show an increase in the tensile stress with an increase in the frequency by comparing it with the welding without vibration. The maximum tensile strength is 272 Mpa for all the specimens welded with 5 Hz, which is at the natural frequency of the specimen, as shown in Fig. 6. Also, the other value of frequencies resulted in an improvement in the tensile strength that was better than welding without vibration. The welds was one pass on the plate surface and the value of tensile strength is less than the value of tensile properties that found by Yang *et al*. (2008) and Lathabai *et al*. (2001) because the welding that done by them is two pass with different welding condition. The improvement in tensile strength is 50%, by comparing with welding without vibration, which also indicates an acceptable estimation for the effect of vibration on improving the welding strength.

Scanning electronic microscopy (SEM): This test was done in order to examine the homogeneity of the welding line and how much the effect of increasing vibration frequency on the distribution resulted in a consequent improvement in the internal structure of the fillet metal. The thicknesses of the specimens were 2-3 mm according to the requirement of the instrument. Figure 7 shows the distribution of the fillet metal without using vibration during welding, the cracks and few holes are clearly appeared on the fillet metal, which they happened due to the high welding temperature that was generated to fuse the metal and also for the unlikely melting of the initial solid grain that penetrates with the molten liquid as impurities.

Due to the vibration during welding, a change in the micro crack that appears in the microstructure was observed, that changed with the changing the frequency value. In Fig. 8a the microstructure of the fillet metal in the case of welding with 3 Hz is shown. The cracks became less and the distribution becomes more uniform than in welding without vibration. Therefore, the effect of the low frequency is observed and provides the first step for more uniform and good distribution of the fillet metal for frequencies higher than 3 Hz because the energy of vibration that applied to the weldments agitates the weld pool and affects the direction of solidification. The white spot which appeared like a small stone resulted from storing the sample with the adhesive tape stuck on the surface of the sample. Figure 8b-d show welding with frequencies 5, 10 and 100, respectively, the improvement in the distribution of the fillet metal was clearly shown by the increased deposition and the distribution of the solidified liquid of the fillet metal, Increasing the vibration frequency vibrates the liquid metal, which contributes to the rate of heat transfer and the removal of liquid superheat that is generated from the welding heat and from the effect of increasing the temperature of the base metal during the cooling mode of the fillet metal (Qinghua *et al*., 2008). When, 100 Hz was applied during the welding of the two pieces of plate, the welding or the fusion metal occurs in fine distribution. As shown in Fig. 8d, some impurities were suspended on the surface because of storage. Also in the Figure, we can see some inhomogeneous heights have been distributed on the surface. These heights were generated because of the effect of the high frequency of 100 Hz during the soldification, which led to a fine distribution of the liquefied metal. Furthermore, this high frequency resulted in volatility of some superheated liquid on the other part of the fusion metal. The cracks that generated because of the high temperature of welding have been almost removed. The 100 Hz provides a good indication that the high frequency can affect the welding metal, this is because all the energy of vibration is delivered to the work piece and then to the welds metal which work on agitating the weld pool and influencing the distribution of the solidification. However, this value of frequency (100 Hz) reduced or could remove all the cracks by making fine distribution of the fillet metal because of vibration.

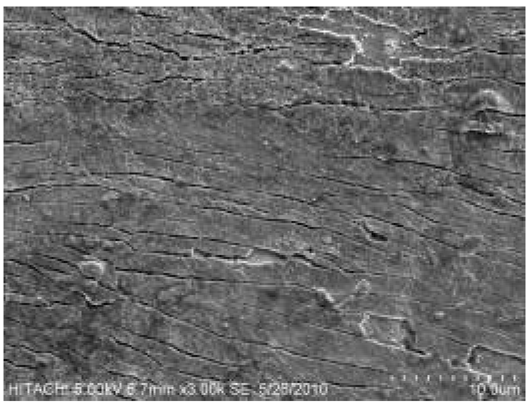

Fig. 7: Microstructure of the fillet metal in the case of welding without vibration

Most research that done for this kind of test is shown how the crack appear on the fillet metal surface because of the high temperature of welding and how is the distribution of it. Zhang *et al.* (2008) found the micro structural characteristics of the welds by using such test with a zooming of 25 and 100 μm to study the surface properties. Also, Qinghua *et al.* (2008) used this test to examine the effect of vibration on the fracture of the welds, the magnification that used by the same study is 10 μm which is provide a good vision for the welds surface. Matsuoka and Imai (2009), Backman *et al.* (1990), Matsuokaa and Imai (2009) and Kumaresh Babu and Natarajan (2008) characterised the morphology of the welds for different welding conditions to show the interfacing between the welding type and the condition of welding on the micro structure of the fillet metal. In the current study the same approach used for measuring the microstructure but with a new condition for welding which is the variation of frequency on the microcrack of the fillet metal. Also the magnification is chosen to provide a best vision for the crack and as shown in Fig. 8.

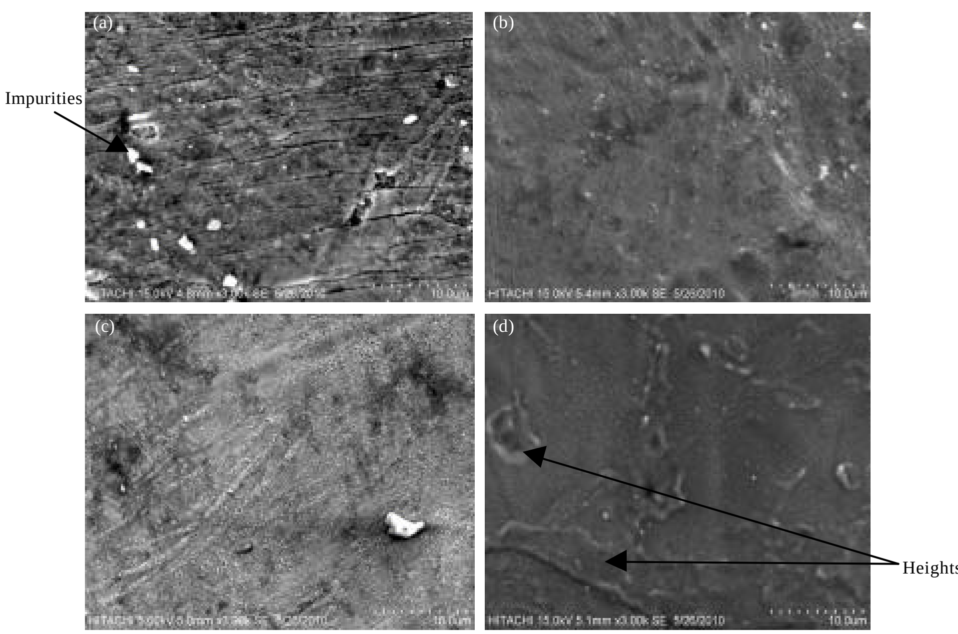

Fig. 8: Microstructure of the fillet metal in the case of welding with vibration at (a) 3 Hz, (b) 5 Hz, (c) 10 Hz and (d) 100 Hz

CONCLUSIONS

The induced vibration during welding plays an important role in improving the mechanical properties of the welding line. The ductility has been increased for the fillet metal due to the effect of induced vibration. The maximum load that tested for the welds was obtained at 100 Hz, whereas the applied frequency during welding with value of 3, 5 and 10 Hz resulted in a good maximum load and not in a big different with the 100 Hz, so that provide an indicator of whenever the frequency increased the ductility of welds also increased.

All the specimens welded with vibration resulted in bend properties did not have any crack while the tested specimens that welded without using vibration are resulted in a crack with 3 mm in length. In another hand the tensile strength is improved for all the specimens that welded with vibration compared with the specimens welded without vibration.

The macro crack that resulted as a detrimental effect of welding is obviously reduced by using vibration. The maximum cracks are shown at the case of welding without using vibration which occurred due to high welding temperature that required fusing the fillet metal. Thus cracks are reduced clearly in the case of welding with 3 Hz which also resulted in crack but less than welding without vibration.

At 5 Hz the cracks propagation are mostly removed, then at 10 Hz the crack can be said it's totally disappeared. This reduction in the crack propagation was belongs to the effect of vibration, in another word all the energy of vibration are transferred to the work piece which transmitted after word to the fillet metal. This energy worked on re-fine and re-distribution the solidification of the fillet metal. However, the 100 Hz resulted in a better homogeneity of welding due to the high vibration energy.

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REFERENCES

ASTM E190-92, 2003. Standard test method for guided bend test for the ductility of welds. ASTM International, Wast Conshohocken, PA, USA.

AWS, 2000. B4.0M Standard methods for mechanical testing of welds. Lejeune Road, Miami, FL 33126 United State of America.

Aoki, S., T. Nishimura and T. Hiroi, 2005. Reduction method for residual stress of welded joint using random vibration. Nucl. Eng. Design, 235: 1441-1445.

Aoki, S., T. Nishimura, T. Hiroi and S. Hirai, 2007. Reduction method for residual stress of welded joint using harmonic vibrational load. Nucl. Eng. Design, 237: 206-212.

Backman, A., B.O. Gustavsson and L.E. Svensson, 1990. Welding consumables for the 1990s. Materialsand Des., 11: 291-300.

Barsoum, Z. and I. Barsoum, 2009. Residual stress effects on fatigue life of welded structures using LEFM. Eng. Failure Anal., 16: 449-467.

Inman, D.J., 1994. Engineering Vibration. Prentice Hall, Englewood Cliffs, New Jersey.

Kang, H.T., Y.L. Lee and X.J. Sun, 2008. Effects of residual stress and heat treatment on fatigue strength of weldments. Mater. Sci. Eng., 497: 37-43.

Kumaresh Babu, S.P. and S. Natarajan, 2008. Influence of heat input on high temperature weldment corrosion in submerged arc welded power plant carbon steel. Mat. Des., 29: 1036-1042.

Lathabai, S., B.L. Jarvis and K.J. Barton, 2001. Comparison of keyhole and conventional gas tungsten arc welds in commercially pure titanium. Mat. Sci. Eng. A, 299: 81-93.

Matsuoka, S.I. and H. Imai, 2009. Direct welding of different metals used ultrasonic vibration. J. Mat. Process. Technol., 209: 954-960.

Qinghua, L., C. Ligong and N. Chunzhen, 2008. Effect of vibratory weld conditioning on welded valve properties. Mech. Mater., 40: 565-574.

Robbins, M.E., 2004. Topics in Vibratory Stress Relief of Weldment. University of Hartford, Hartford, USA., pp: 66.

Virgin, L.N., 2007. Vibration of Axially Loaded Structures. Cambridge University Press, New York.

Xu, J., L. Chen and C. Ni, 2007. Effect of vibratory weld conditioning on the residual stresses and distortion in multipass girth-butt welded pipes. Int. J. Pressure Vessels Piping, 84: 298-303.

Yang, Z.Z., W. Tian, Q.R. Ma, Y.L. Li, J.K. Li and J.Z. Gao, 2008. Mechanical properties of longitudinal submerged arc welded steel pipes used for gas pipeline of offshore oil. Acta Metallurgica Sinica, (Engl. Lett.), 21: 85-93.

Zhang, Z.D., L.M. Liu, Y. Shen and L. Wang, 2008. Mechanical properties and microstructures of a magnesium alloy gas tungsten arc welded with a cadmium chloride flux. Mater. Characterization, 59: 40-46.