EFFECT OF IN-SITU VIBRATION ON THE PROPERITES OF A-GRADE STEEL SMA WELDMENT

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ABSTRACT

Effect of in-situ vibration on the properties of A-grade steel SMA weldment has been investigated. Welding was performed on the steel fixed at the experimental jig under the mechanical vibration of a given frequency. The applied frequency varied from 39 to 43.5 Hz (harmonic frequency). For weldments formed under the vibration with a sub-harmonic frequency, both the columnar width of the weld metal and the prior austenite grain size of the HAZ near the fusion line clearly decreased. This indicates that the vibration increase the cooling rate after welding. Vibration effect was also found at the weld metal formed at the center region of the weldment. The weld metal showed finer microstructure both in columnar zone and in equiaxed zone with thinner grain boundary ferrite. However mechanical properties of the weld metal did not exactly follow the microstructural changes developed under the vibration. The weld metal formed under the vibration revealed higher yield and tensile strength but lower ductility and impact toughness, compared with the conventional weld metal.

KEYWORDS

In-situ vibration, vibration frequency, SMAW, mechanical properties, microstructure

1. Introduction

Welding is the most important joining technique in the fabrication of steel structures. However some inherent problems of the welding, such as remarkable microstructural changes and formation of residual stresses at the weldment, still need to be solved. It is therefore very important to control these problems during or after welding for the safety of weldment.

Vibratory stress relieving technique is a method for reducing residual stresses of the weldment by means of cyclic loading treatments. Although many researchers have cast doubts on its effectiveness, research on this technique with sub-harmonic vibration frequency has still been carried out [1]. This is due to the fact that vibratory stress relieving technique could eliminate the disadvantages of thermal stress relieving technique and is applicable to the structures regardless of its size and may be applied at any point during the manufacturing. In particular, Wu [2,3] reported that vibration also affected solidification of the weld pool and thus refined the weld metal microstructure in addition to the reduction of residual stresses.

In this study, effect of in-situ vibration on the properties of carbon steel weldment has been investigated in order to evaluate the its validity. The properties of interest are the microstructures and mechanical properties such as strength, ductility and toughness of the weld metal. SMA welding was performed on the steel fixed at the experimental jig under the mechanical vibration of a given frequency. The applied frequency varied from 39 to 43.5 Hz, which was selected based on the harmonic frequency of the weldment including the experimental jig.

2. Experimental procedures

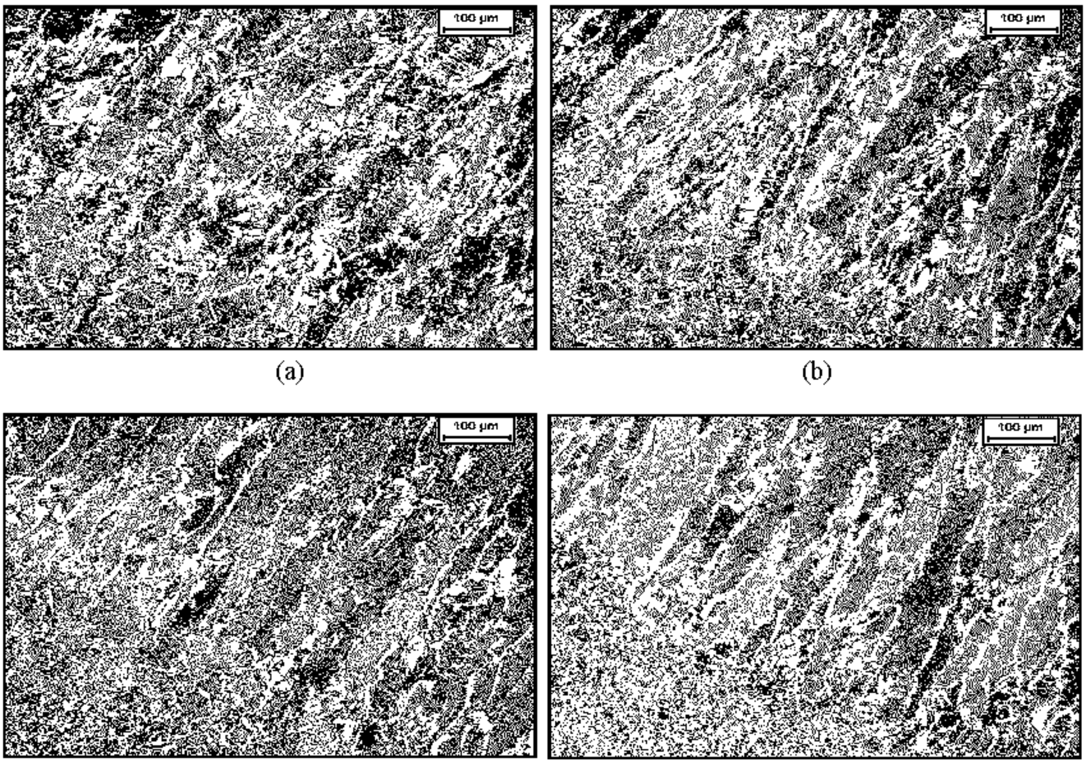
An in-situ mechanical vibration system was made for the study, which consists of mechanical vibration apparatus, an experimental jig (basal plate, 1.5m x 1m x 80mm) and a rubber pad. Mechanical vibration apparatus also consists of rotary vibrator, programmable logic controller, sense and analyzer. The experimental jig was made in order to fix mechanical vibration apparatus and test piece on it. More importantly, it increases the mass of the system so that we could reduce the harmonic frequency of the system below 50Hz. The rubber pad acts as a damper during welding with the vibration. Before welding, the harmonic frequency of the vibration system was evaluated by a simple impact test and it was 43.5Hz. Based on this value, the applied frequency was changed from 39 to 43.5 Hz during welding.

SMA welding was carried out with a 22 mm thick A-grade steel using E7016 electrode. The heat input applied was about 20 - 25kJ/cm under 210 Amp. and 28 V. For all weld metal test, 20^{o} V-groove with the root gap of 16mm was used and total 14 passes were made. Microstructural analysis, hardness measurement, all weld metal tensile test and charpy impact test were followed to evaluate the effect of in-situ vibration on the properties of the weldment.

3. Results and Discussion

3.1 Microstructure near the fusion

Fig.1 shows the variation of microstructures near the fusion line as a function of vibration frequency. For the conventional weld metal, microstructure consists of grain boundary ferrite, side plate ferrite and acicular ferrite as shown in Fig.1 (a). For the weld metal formed under the vibration with a sub-harmonic frequency, some features are found as shown in Fig.1 (b), (c) and (d). First, the amount and thickness of grain boundary ferrite is clearly reduced and thus the width of columnar structure is very narrow. Second, the formation of side plate ferrite is suppressed. To quantitatively evaluate the microstructural change particularly columnar width as a function of vibration frequency, an image analyzer was used. As shown in Fig.2 (a), the columnar width of the weld metal formed under the vibration generally is thinner than that of the conventional weld metal. This feature is eminent at the weld metal formed under the vibration with a sub-harmonic frequency. For a 39Hz, the columnar width of the weld metal is only about half of that of the conventional weld metal. Due to the finer microstructure developed by the vibration, hardness value of the weld metal also increases as shown in Fig.2 (b). Effect of vibration frequency on HAZ microstructure near the fusion line is similar to that observed in the weld metal. This is attributed to the epitaxial growth characteristics of the weldment.



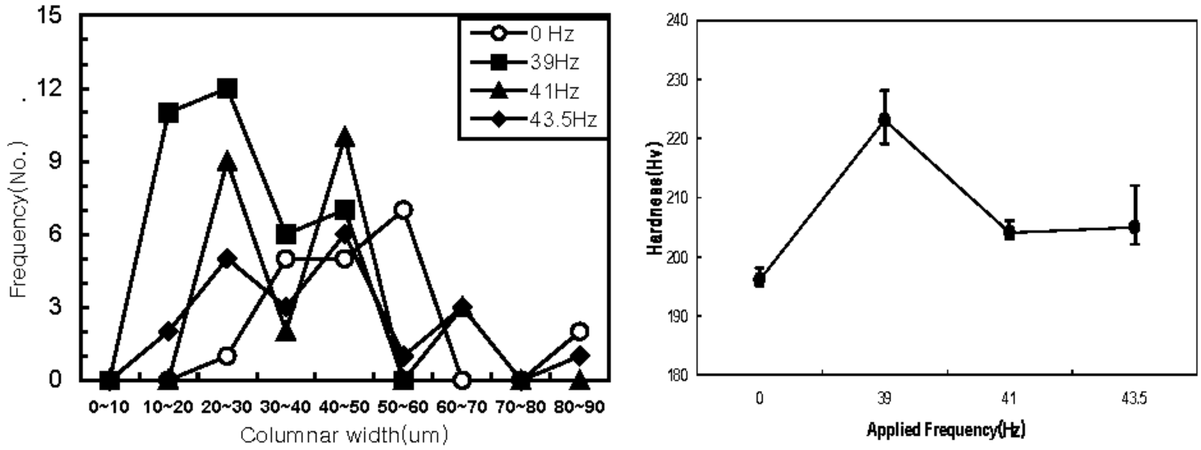
(a) (b)

(c) (d)

Fig.1 Microstructures near the fusion line formed different vibration frequency :
(a) 0 Hz, (b) 39 Hz, (c) 41 Hz and (d) 43.5 Hz

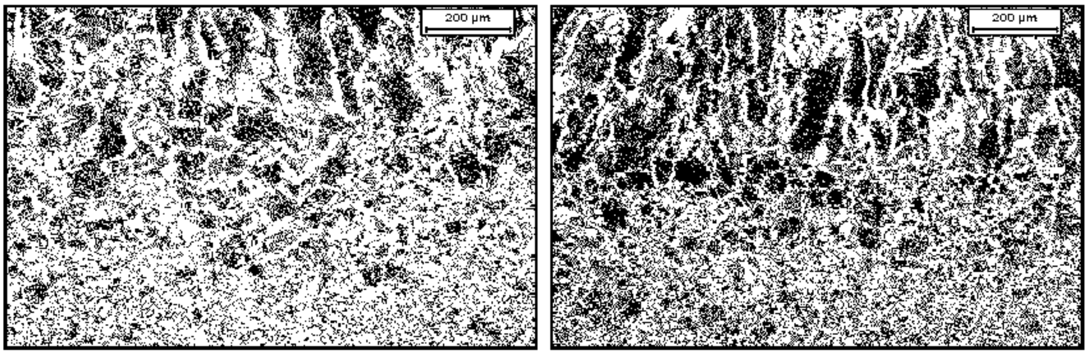
3.2 Microstructure at the center region of the weldment

Weld metal at the center region of the multi-pass weldment consists of columnar microstructure zone and equiaxed microstructure zone formed by reheating as shown in Fig.3. Comparing with the weld metals formed under the vibration, the conventional weld metal has wider equiaxed zone, bigger grain size and thicker grain boundary ferrite and columnar width as shown in Fig.3. It is quite similar to that observed in Fig.1 and is also much finer than the conventional weld metal and no significant effect at a sub-harmonic frequency is found. The size of columnar width and thickness of grain boundary ferrite fully depends on the cooling rate after welding. It is therefore deduced that application of the vibration can increase the cooling rate of the weldment by stirring the weld pool.

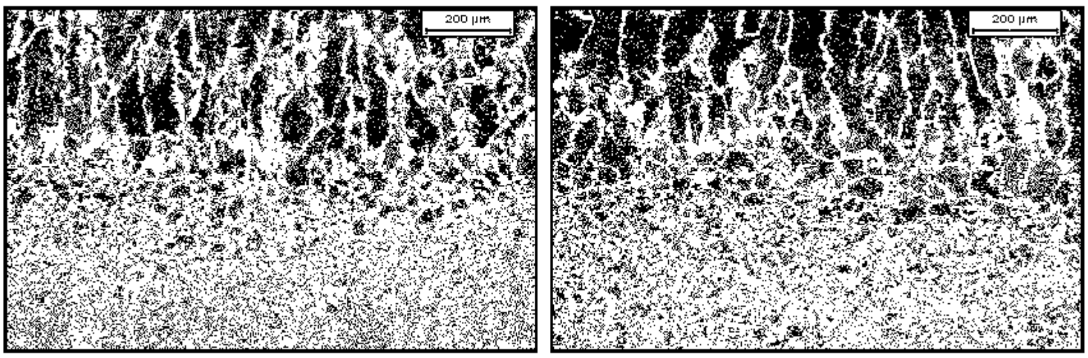


(a) (b)

Fig.2 Variation of microstructure and hardness value of the weld metal near the fusion line with the vibration frequency applied : (a) Columnar width and (b) Hardness value



(a) (b)



(c) (d)

Fig.3 Microstructures at the center region of the weldment formed different vibration frequency : (a) 0 Hz, (b) 39 Hz, (c) 41 Hz and (d) 43.5 Hz

3.3 Mechanical properties of the weld metal

Hardness measurement, tensile test and charpy impact test were performed to evaluate the effect of in-situ vibration on the mechanical properties of the weld metal. Fig.4 (a) shows the hardness distributions of the SMA weldment as a function of the vibration frequency applied, which were measured at a quarter location of the thickness from the bottom of the weldment. Hardness values of the weld metal are clearly higher than those of the conventional weld metal. This is directly attributed to the finer microstructure developed by the vibration as shown in Fig.3. In order to evaluate tensile properties of the weld metal, all weld metal tensile specimen was made. Fig.4 (b) and (c) shows the effect of vibration on the tensile properties of the weld metal. As expected from the hardness distributions, the weld metals formed under the vibration have higher yield and tensile strength than the conventional weld metal. Yield strength of the weld metal increases in a linear manner but its tensile strength is almost constant with an increase in the vibration frequency applied. Elongation and reduction of area of the weld metal decrease with an increase in the vibration frequency applied. This tendency is also found in the variation of charpy impact toughness of the weld metal with the vibration frequency applied as shown in Fig.4 (d). Toughness values of the weld metals formed under the vibration are generally lower than that of the conventional weld metal, although they has finer microstructure. It is very difficult to understand the reduction of ductility and toughness of the weld metals due to the vibration in terms of optical microstructure. Further detail microstructural analysis is necessary to clear this problem.

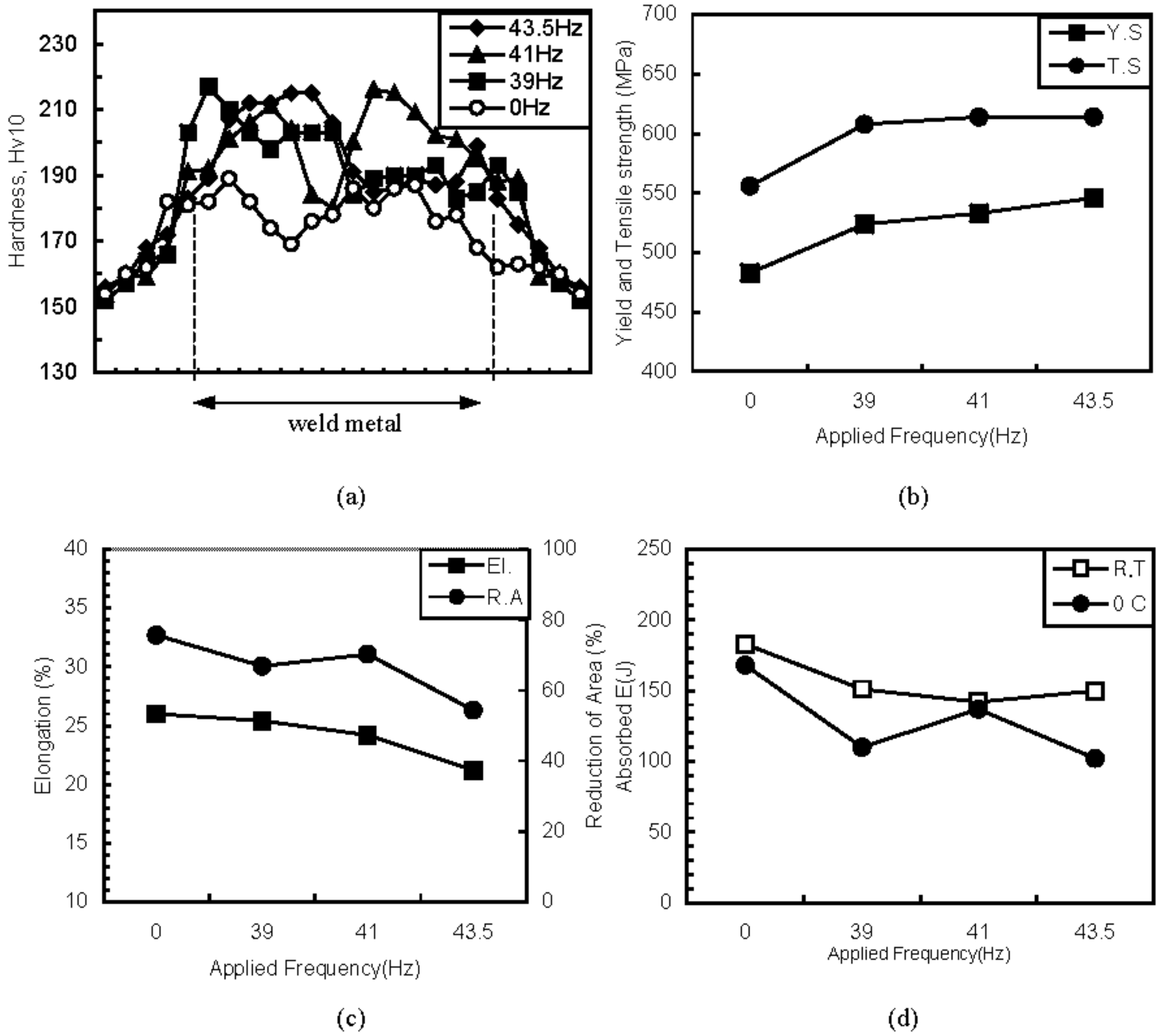


Fig.4 Effect of vibration on the mechanical properties of the weld metal as a function of the vibration frequency applied : (a) Hardness distribution, (b) Yield & Tensile strength, (c) Elongation & Reduction of area and (d) Charpy impact toughness

4. Conclusion

Effect of in-situ vibration on the properties of A-grade steel SMA weldment has been investigated. The applied frequency varied from 39 to 43.5 Hz. The results obtained are summarized as follows;

1) The weldment formed under the vibration particularly with a sub-harmonic frequency showed narrower columnar width with thin grain boundary ferrite at the weld metal and smaller prior austenite grain size of the HAZ near the fusion line, compared with the conventional weld metal.
2) The weld metal formed under the vibration revealed higher yield and tensile strength but lower ductility and impact toughness, compared with the conventional weld metal.

References

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