INVESTIGATION ON THE EFFECT OF VIBRATIONS ON COOLING BEHAVIOR AND MECHANICAL PROPERTIES OF SMAW BUTT WELDED JOINTS

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In the present investigation, a vibratory setup have been designed which is capable to stir the molten weld pool before it solidifies, during Shielded metal arc welding (SMAW) process. To make a comparative study, two sets of specimen were prepared, first set of specimen were welded under conventional condition and another was in vibratory welding condition. The UTS of vibratory welded joints improved by 80 MPa compared to that of the conventional welded joints. The yield strength and percentage elongation has been increased by 78% and 49% respectively. Steeper cooling curves has been found for the vibratory welding process.

Keywords: Vibration welding, Cooling curve, Hardness, Tensile strength, SMAW

1. Introduction

Properties of weld metals are greatly influenced by type of microstructure and grain size. Fine grained materials normally have higher strength and are more ductile than similar coarse grained materials. It is often intended to achieve fine grain structure in the weld bead because such structure leads to reduced susceptibility of the weld metal to solidification cracking during welding and fine grain helps to improve mechanical properties like ductility and toughness of weld metal. The faster the cooling rate during welding operations more fine grain structures are obtained and the hardness is increased [1]. The application of vibration in the field of welding has been introduced from a very long time. Number of researchers has shown their work on the vibratory welding to improve the mechanical properties. The vibratory welding process is a technique in which an external vibratory setup vibrates in the whole welding process and affects the welding solidification which improves the quality of microstructure. The vibrations accelerate the movement of atoms and phase fluctuations. The forced vibration during welding also affects the super cooling temperature, which is extremely

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important during the formations of new nucleation [2]. The high heat removal rate helps to prevent the new grains from re-melting.

In fusion welding operations due to non-uniform heating and cooling behavior, stress has been developed in weld specimen this stress is well known as residual stress. Vibratory welding technique transfers the external stress in the weld pool which opposes the residual stresses. Basically, the vibration during welding vibrates the molten weld pool and helps to increase the heat transfer rate and reduce the super cooling temperature. Vibrations provide higher weld pool velocity causes the higher cooling rate during solidification [3]. The vibration technique is useful to control the distortion and to reduce the residual stress. Its main purpose is to refine the grain structure, control the residual stress and reduce the distortion [4-9]. Vibratory welding has lots of advantages as compare to the various heat treatment processes; it consumes less energy, having high efficiency, no pollution, low cost and easy to use in operations [10-12].The utilization of vibrations during welding operations eliminates the unmixed zone formed between weld zone and base metal [13].There are various methods to use the vibration technique during welding operations. Table 1 shows a brief discussion on the use of various vibratory welding techniques used by the researchers.

To the best of our knowledge, it has been found from the literature review that no work exists on the use of induced auxiliary mechanical vibrations in the weld pool when it is in molten state, for achieving better mechanical properties. Researchers have trampled down on vibrating as a choice for the base metal or filler metal, nevertheless no area has been declared publicly on inducing the auxiliary mechanical vibrations to the molten weld zone during welding operation which probably could be due to the reason that in the arc welding process the size of weld pool is small and hence the solidification rate is additionally high.

2. Experimental Details

The present work has tried to investigate the effect of inducing auxiliary vibration into the weld pool during welding and hence has thus been aimed to understand the fundamental role of vibration in controlling the weld pool cooling rate and hence mechanical properties. Mild steel plates (200mm×50mm×6mm) were welded by Shielded metal arc welding (SMAW) process, under the two sets of conditions. In first condition specimens were welded using conventional technique which means weld specimen were prepared without introducing vibrations during SMAW process. The second set of experiment was conducted under the vibratory condition in which 300 Hz of vibrations has been transferred in the molten metal of the weld pool during SMAW process. A comparative study between conventional and vibratory welding was investigated. Two sets of samples were prepared, one was welded under the vibratory condition at 300 Hz of frequency and another set was prepared under the conventional condition (no application vibration) to serve as a source for comparison. The 300 Hz is the resonance frequency generated by the vibratory setup used in the present investigation. Each set of experiment contains three welded specimen. The welding parameters are same in both of the conditions which mentioned in table 2. Figure 1 shows the block diagram and actual photograph of work piece.

Fig. 1. Block diagram of joint design and Base metal Positioning

Table 1

Vibratory welding techniques

S. No	Vibratory Techniques	Frequency produces	Process	Reference
1	Electromagnetic	0-40 Hz	GTAW	[6]
2	Vibratory Table	80-400 Hz	SMAW	[2]
3	Electromagnetic	50 Hz	Casting Process	[7]
4	Vibratory Table	58 Hz	GTAW	[8]
5	Vibratory Table	25 Hz	MIG	[9]
6	Vibratory Table	2.5 Hz	MIG	[10]
7	Vibratory Table	-	SAW	[14]
8	Ultrasonic	20kHz	SMAW	[13]
9	Vibratory Table	54-59 rps	SAW	[3]
10	Vibratory Table	54-59 rps	SAW	[12]
11	Electromagnetic	-	GTAW	[16]
12	Ultrasound	50 kHz	PAW	[15]
13	Vibratory Table	100-3000Hz	GTAW	[17]
14	Vibratory Table	-	SMAW	[18]
15	Wave guide	20kHz	MIG &TIG	[19]
16	Vibratory Table	375 Hz	GTAW	[20]
17	Vibratory Table	150-350 Hz	TIG	[21]
18	Horn Plus tool	429 Hz	FSW	[22]
19	Vibratory Table	60.9 Hz	TIG	[23]
20	Vibratory Table	15kHz	TIG	[24]
21	*A new concept of vibratory setup has been designed ,80-300Hz, SMAW Process PW**			

Note: - SMAW: - Shielded metal arc welding; MIG: - Metal inert gas; GTAW: - Gas tungsten arc welding; SAW: - Submerged arc welding; TIG: - Tungsten inert gas; PAW: - Plasma arc welding; PW*: - Present work

Table 2

Welding variables and process parameters

	Conventional Condition	Vibratory condition
Current (Amp)	110	110
Welding Speed (cm/min)	15	15
Frequency (Hz)	Not introduced	50
Material :- Mild steel plate (200mm×50×6mm)	Filler Rod (Electrode):- E3106	

2.1 Vibratory welding technique

With the aim to improve the mechanical properties of the butt welded joint vibratory setup has been designed and developed. Since the solidification rate of the weld pool is quick, so such an arrangement has been proposed that vibratory setup stir the molten weld puddle before it solidifies. The schematic block diagram of the present experimental setup is depicted in figure 1 and 2. Vibratory setup is assembled with a thorium- zirconium –tungsten alloy rod having diameter of 3 mm, an Eccentric rotation mass (ERM) motor, a regulator which controls the frequency of the ERM, pieces of glasses mounted on the rod which prevents the ERM motor from high heat, a holder used to grab the setup during welding [25].

As shown in figure 2 and 3 the one end of the rod is merged into the molten weld pool. ERM motor is mounted on thorium- zirconium –tungsten alloy rod the other end of the rod is fixed with a non conducting holder, used to grab it by the welder. The vibratory setup constantly moves in the same direction and having the same speed as that of welding speed maintained by the welder. It has been done in the manner that the vibratory tip is inserted into the weld pool and is made to keep contact with it while maintaining a constant speed along with the welding arc while welding process takes place. So this case resembles the quasi-stationary state where the observer finds that at any instant of time across the entire weld length the vibratory tip is submerged in the weld pool.

2.2.Temperature Measurement

The temperature measurement was conducted using K-Type thermocouples. K type thermocouples are the most general type of thermocouple which contains the combination of chromel and alumel materials. The measuring range of thermocouple was from -200˚C to 1400˚C. In the present experimentation, 3 thermocouples were used. Each thermocouple was connected to the digital meter which records temperature at the same time and at same position. These three thermocouples were fixed in opposite direction of the weld surface. First thermocouple was fixed at the centre of the weld bead, second was 4 mm apart from the previous one and last was 4 mm apart from the previous thermocouple. A schematic diagram of location and positioning of thermocouples is depicted in figure 4.

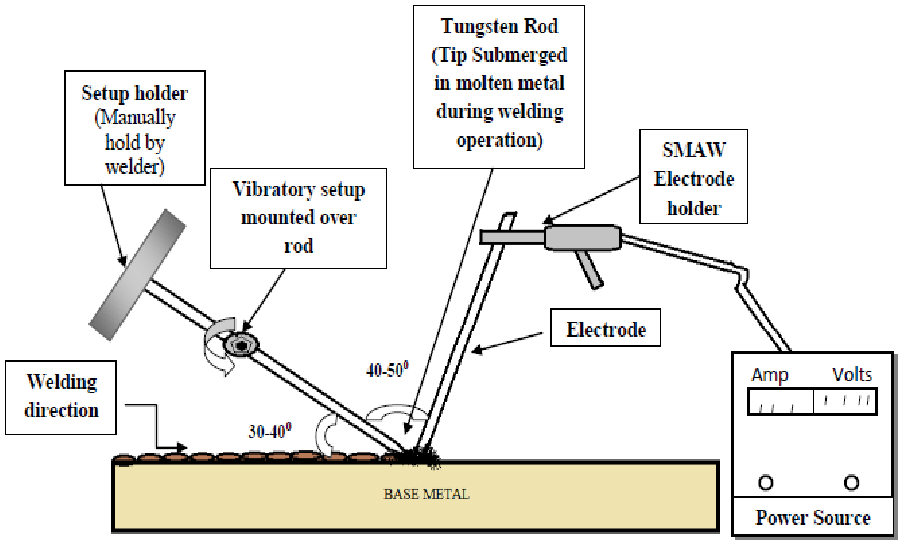

Fig. 2. Schematic Block Diagram of vibration setup

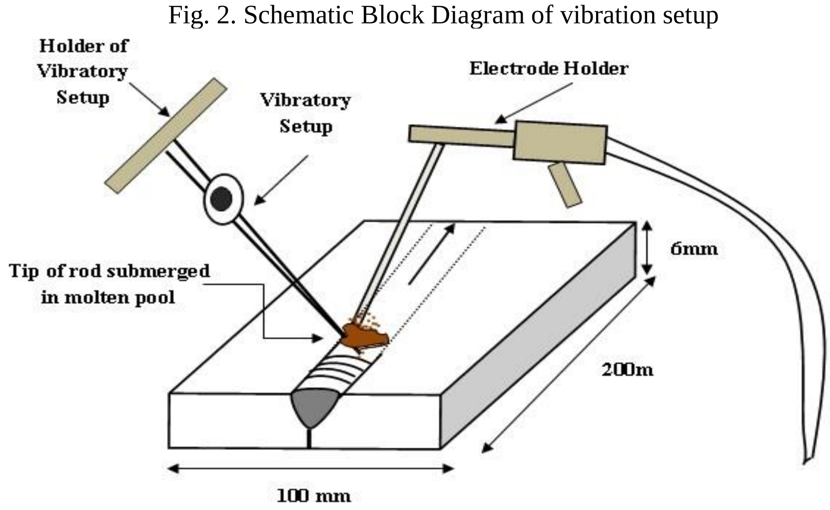

Fig. 3. Top view of vibratory setup

2.3 Mechanical testing

For the micro-hardness test, the specimens were polished using emery papers of various grades that successfully removed corrosion, scratches and oxide layers from the surface of the specimens. The Vickers hardness test was performed on the polished surface of the welded specimen using a load of 500 gm and a dwell time of 20 sec. The hardness value was measured along the center line; each point was measured three times to inquire about its average value. Three transverse tensile specimens were machined out from each of the weld pad and prepared according to the ASTM E8 with the help of wire electrical discharge machine. The test was carried out on a 100 KN servo-hydraulic universal testing machine (UTM)

(INSTRON 8501). The displacement rate was 0.5 mm/min (Figure 5). The elongation was measured with the extensometer (Instron make) GL-50 mm. This test of the welded joints facilitated the recording of the UTS, yield strength, percentage elongation, and stress-strain curve diagram.

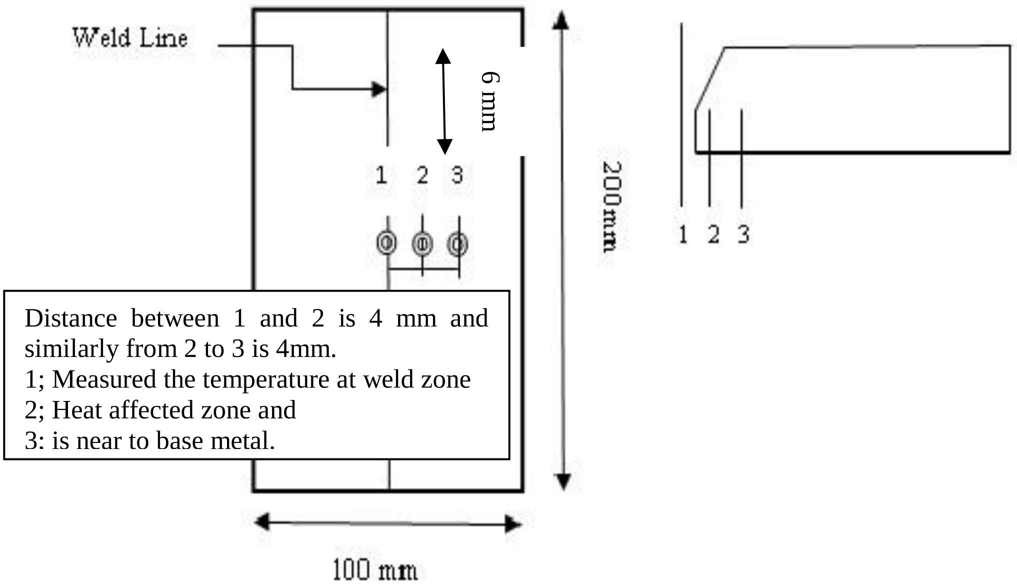

Fig.4. Location of thermocouples throughout weld specimen

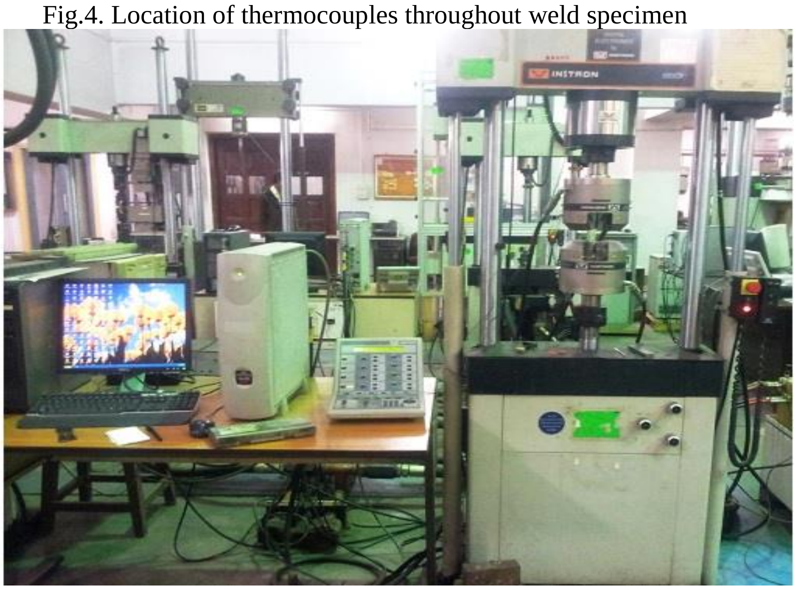

Fig.5. Ultimate Tensile Machine (INSTRON 8501)

3. Results and discussion

Micro-hardness tests were performed across different zones of weldments. The average of three readings at each point of micro hardness results has been recorded. Figure 6 (a - b) is the hardness and the cooling curve of the weld zone. Cooling curve of weld zone (WZ) (figure 6. b) depicts that due to the application of vibrations faster the heat transfer rate takes place and cooling rate is increased with respect to the conventional process. Figure 6 (c-d) shows the hardness property and cooling curve of the heat affected zone (HAZ). The cooling temperature has been recorded from thermocouple 2. And similarly figure 6 (e-f) shows the hardness and cooling behavior of base metal for both conventional and vibratory conditions.

Examining the micro-hardness results it reveals that by inducing the vibrations of 300 Hz, the hardness values increased from 232.12 to 282 VHN in WZ, 210 to 233.4 VHN in HAZ and 193 to 200 VHZ in BM as compared to conventional weld joints. The cooling curve of the particular zone shows the interesting results. The imposed vibration stir the molten weld pool due to which the heat transfer rate from the weld zone and HAZ has been increased as shown in figure 6 (b) and 6 (d). The heat transfer rate is almost same for the base metal in both of the conditions (figure 6 (f)). The imposed vibrations into the molten weld pool restrict the growth of the new grains; these grains could not achieve its original dendrites length. Few grains get fragmented due to these external applied vibrations, the fragmented dendrites act as a new nucleation sites and helps in formation of new grains. This mechanism increases the number of grains and reduces the grain size, and resulting fine grain structures have been formed. The external vibration increased the energy fluctuations and flow of heat transfer from the weld pool, which resulted in the faster cooling of the weld pool and prevent the new nucleus from re-melting [1,3]. The high heat transfer and large formation of new grains improved the mechanical properties of weld structure.

After investigating of cooling curve and hardness properties, tensile properties were analyzed. For every condition three specimens were prepared and the average value of Ultimate tensile strength, yield strength and percentage elongation were recorded. The results of the tensile tests shown in figure 7; yield strength shows an increase of 61 MPa (From 219 to 280 MPa) and UTS value also showed an increase of 80 MPa (From 340 to 420 MPa). Ductility, which was measured in the form of percentage elongation, increased almost twice in value from 5.71 to 12.9%. This increase in the value of UTS and yield strength of welded joints (vibratory weld specimen) attributed to the favorable micro-structural changes that impeded grain growth, resulting in relatively shorter dendrites in the weld pool.

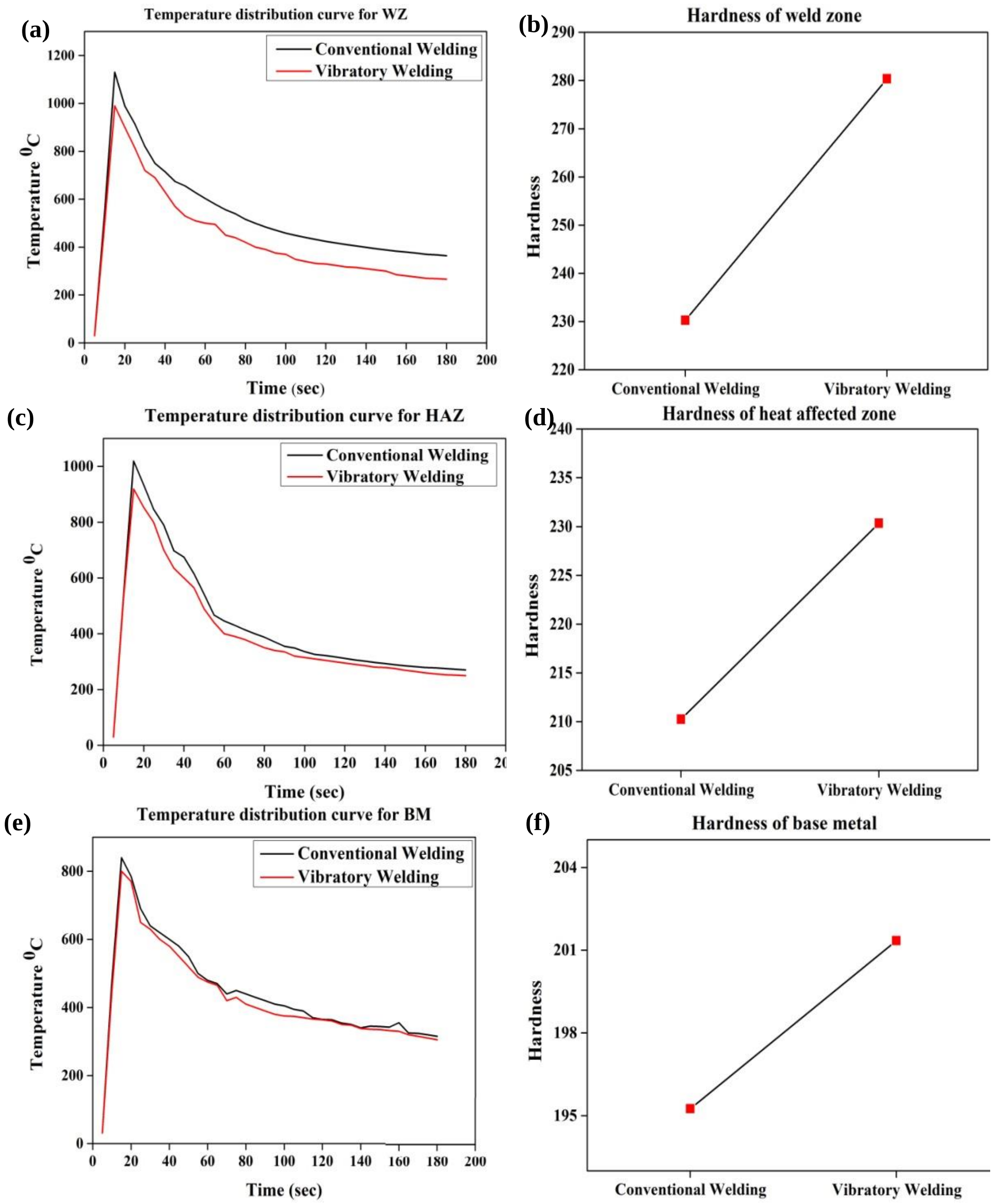

Fig. 6. Hardness properties and cooling curve for various zone of weld joint

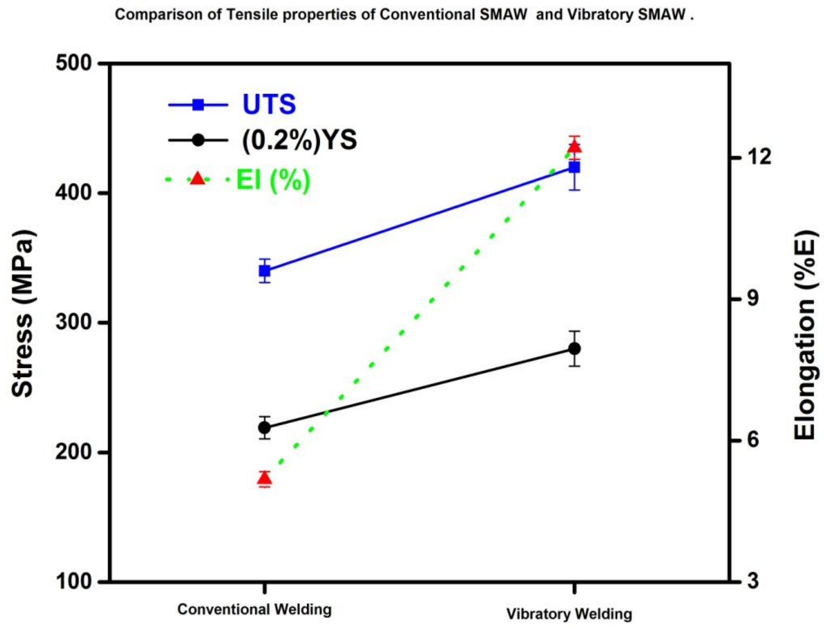

Fig.7. Tensile graph for welded specimen

4. Conclusions

The current work as shown that application of vibration into the weld-pools successfully enhances the mechanical properties of weld joints. Thus the present research attempt provided an alternative for grain refinement of weldments.

The auxiliary vibrations induced into the weld pool resulted in increased micro hardness of the weld metal which indicates the orientation of the crystal and refinement of grains took place. Cooling behavior of vibratory welding shows the faster heat transfer as compare to the conventional process.

The Yield Strength increased by 78% and tensile strength of the welded joint increased by 80% due to transformation of 300 Hz of vibration into the weldpool when it was in liquid state. The ductility of welded joint also improved. The total percentage of elongation gets twice by using the vibrations.

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