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Development of Vibratory Welding Technique and Tensile Properties Investigation of Shielded Metal Arc Welded Joints

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Abstract

Objectives: In the present article, the effect of inducing auxiliary vibration into the weld pool during welding has been investigated and the work has been aimed to understand the fundamental role of vibration in controlling the weld pool microstructure and mechanical properties. **Methods/ Statistical Analysis:** Shielded Metal Arc Welding (SMAW) process, which is one of the most widely process, has been used for preparation of weld specimen. In present study a new concept of vibratory setup has been designed which stir the molten metal of the weld-pool before it solidifies during the welding operation. The vibratory setup is capable to produce a resonance frequency of 300 Hz with maximum amplitude of 0.5 mm. **Findings:** To study the effect of vibration on mechanical properties of the weld joints tensile test and microhardness test has been conducted. The test result shows the improvement in microhardness properties and the Ultimate tensile strength increases by 80 MPa. The yield strength and percentage elongation of vibratory welded joints also get increased as compare to the welded joints prepared using conventional welding operation. Present investigation propose that inducing auxiliary vibrations into the weld pool results into grain refinement of the weld zone which is attributed not mainly to dendrite fragmentation but impeding of the dendritic growth. The microstructure study of vibratory welded joints shows the small size of grains as compare to the conventional welded joints. **Application/Improvement:** Based upon the results obtained the present experimentation provides an alternative vibratory welding mechanism for enhancement of mechanical properties by shaking the weldpool only during welding operation.

Keywords: Auxiliary Vibrations, Frequency, SMAW Process, Tensile Properties, Vibratory Welding Technique

1. Introduction

Fusion welding process are widely used in many fabrication purposes which are very important for the field of engineering like aerospace, automotives, ship buildings etc[1] . 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[2,3]. 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. There are various mechanisms to produce the fine structures some of them are inoculation, arc oscillation, arc pulsation and also the generation of vibrating the welding torch, or vibrating the work piece, etc[4-7]. Vibratory welding mechanism transfer energy into the weld-pool during the welding operations which disturb the solidification process of the molten weld pool. From last few decades various vibratory techniques were developed to control the solidification behavior of weld joints. Amongst the various vibratory welding mechanisms a Vibratory table has been used by various authors to vibrate the base plate at certain range of frequencies. The application of electromagnetic field, ultra sound and ultrasonic vibrator also been used by the researchers to improve the weld qualities. A brief discussion of various

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vibratory techniques designed by various researches has been comparatively mentioned in Table 1.

From literature review we found that no work has been reported on the use of inducing auxiliary mechanical vibrations into the weld pool for achieving better mechanical properties which probably could be due to the reason that in arc welding process the size of weld pool is small and hence solidification rate is too high[8-10].

So on the basis of research gap, following objectives have been decided:-

1. Design and development of a setup for inducing auxiliary mechanical vibrations into the weld pool during welding.
2. To study the effect of auxiliary mechanical vibrations on the mechanical properties of butt welded joints using SMAW process.

Table 1. Vibratory welding techniques used by researchers

S. No	Material Used	Vibratory Technique	Frequency produced	Process
1	MS	Vibratory Table[5]	80-400 Hz	SMAW
2	Nickel Alloy(690)	Vibratory Table[7]	58 Hz	GTAW
3	MS	Vibratory Table[8]	25 Hz	MIG
4	AISI 310	Electromagnetic[9]	0-40 Hz	GTAW
5	AL-6XN	Ultrasonic[10]	20kHz	SMAW
6	304-SS	Vibratory Table[12]	375 Hz	GTAW
7	Al Alloy (1085,2214)	Electromagnetic[14]	50 Hz	Casting Process
8	A-105	Vibratory Table[15]	54-59 rps	SAW
9	Al alloy	Vibratory Table[16]	100-3000Hz	GTAW
10	304-SS	Vibratory Table[17]	150-350 Hz	TIG
11	D6AC,D406A	Vibratory Table[18]	2.5 Hz	MIG
12	Niomol 490K	Vibratory Table[19]	-	SAW
13	Super alloy 800	Electromagnetic[20]	-	GTAW
14	MS	Vibratory Table[21]	-	SMAW
15	Al alloy	Wave guide[22]	20kHz	MIG &TIG
16	AISI 304	Horn Plus tool[23]	429 Hz	FSW
17	AZ31 Mg alloy	Vibratory Table[24]	15kHz	TIG
18	*MS (PW)*	*Vibration transfers into the molten weldpool during welding operation.*	*0-300Hz*	*SMAW*

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.

Solidification of welding states that, to start the nucleation process it is very essential to reach at the super cooling temperature[11-13]. Once the nucleation grows up, the dendrites propagate in opposite direction of heat flow and an epitaxial grain growth of the weld structure take place. The vibration produced by the vibratory techniques breaks the growing grains and forms a new nucleation site, if the new born nucleus sustained than it propagates in the form of grains[14-18]. The imposed vibrations increases the number of nucleation sites by fragmenting the growing dendrites which results in large number of grains and the fine structures obtained. The sustainability of the new nucleus depends upon the way of cooling of the weld pool or we can say the temperature gradient of the weld-pool, it is very essential to reach at super-cooling temperature[18-21]. The weld pool convection during vibratory welding operation increase cooling rate of the molten metal resulting the formation of large number of new nucleation sites and competitive growth of the growinggrains[21,22]. Principle of solidification states that high cooling rate forms fine grain structure. Alloys with a fine-grain-structure, associated with superior mechanical properties, are the ultimate goal of a solidification process[23,24]. So in the present investigation a vibratory setup has been designed which transfers energy in form of vibration into the molten weld-pool and tried to disturb the solidification behavior of the SMAW welded joints.

2. Design of Vibratory Welding Technique and Experimental Details

The main work of the vibratory setup is to transfer the vibration in weld-pool during the welding operation before the solidification of the molten weld pool. The vibratory setup is assembled with an Eccentric rotation mass (ERM) motor, 9 Volt rechargeable batteries as a power source, the thorium- zirconium-tungsten alloy rod, and non conducting holder, small pieces of ceramic bricks and a glass. The working principle of ERM motor is based upon the rotation of unbalanced mass. An offset weight, attached with a shaft, when rotates produced vibrations. Further the ERM motor has been fastened with a 3 mm diameter of thorium- zirconium-tungsten alloy rod; this rod has ability to sustain at very high temperature. The one side of the rod is assembled with a non conducting holder to grab the setup by the welder during welding operation. The vibrations generated by the ERM motor transfer to the molten pool through the thorium- zirconium-tungsten alloy rod during SMAW welding operation. The other tip of the rod, tapered and coated with ceramic foil, submerged into the molten weld pool. The solidification time of welding process is quick so it has been made possible to stir the molten metal before it becomes a complete solidifies mass in the present work. It has been done in the manner that the vibratory tip is inserted into the molten 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. Figure 1 shows the schematic diagram of vibratory setup.

The present vibratory setup generates maximum vibrations of 300 Hz and having amplitude of 0.5 mm. The manufacturing cost of the present vibratory setup is inexpensive and the equipments are easily available in market. So in comparison to the electromagnetic, ultrasonic and ultrasound vibratory welding process the present setup is very economical and showing a great enhancement in mechanical properties.

The base metal used in the present experimentation is Mild steel plates of size 200 × 100 × 6mm. Figure 2 shows the block diagram and actual photograph of work piece. 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 performed on a 100 KN servo-hydraulic universal testing machine (UTM) (INSTRON 8501). The displacement rate was 0.5 mm/min (Figure 3).

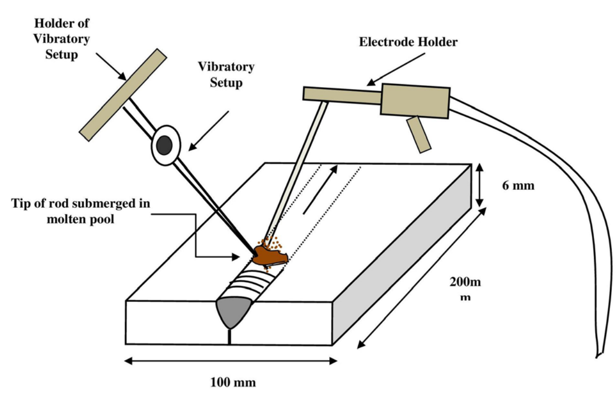

Figure 1. Schematic block diagram of vibratory welding technique.

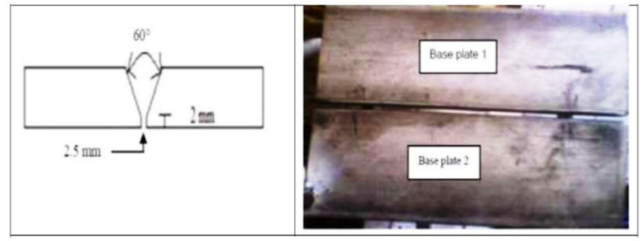

Figure 2. Joint design and base metal positioning.

Figure 3. Ultimate tensile machine (instron 8501).

The elongation is measured with the extensometer (Instron make) GL-50 mm. For micro-hardness testing the specimens were prepared using standard procedures like belt grinding, polishing using successively fine grades of emery up to 1500 grit size. This helped in removing coarse and fine oxide layers as well as scratches on the surfaces that were to be metallographically analyzed. Micro-hardness tester (Make: Omnitech, Capacity: 1000grams) was used to measure micro-hardness at various zones of interest in different weldments. A load of 500 grams and a dwell time of 20 seconds were used for these studies.

3. Result and Discussion

The efficiency of the vibratory setup developed and used in the present work was found to be satisfactory in terms of giving better weld quality. No observable defects were found in the weld seams, as all the weld beads were uniform and geometrical consistent as well as free from any surface porosity, blow holes, excessive spatter etc. Figure 4 is presenting the weld bead joints welded by conventional welding and vibratory welding process. Since we had took care about all the constraints like neat and clean rust free specimen, the flux coated electrode was free from any type of moisture, a proper weld structure was maintained etc. In the mean while stirring of the weld pool helps to release of the dissolve gases from the molten metal resulting, weld bead was free from porosity and blow holes type of defects. Another benefit of stirring was floating the inclusions to slag with imposed vibration from the molten metal weld pool, as a result the weld structure was uniform and defect free.

Submerged flux does not exert any significant influence on the results of the present work as the role of flux is only to provide adequate shielding envelop to the weld pool from atmospheric contamination. Imposed vibrations helps to drift the various impurities to the slag and speed up the convection of melt in the weld pool and hence, bubbles and impurities are come out through the slag and make a defect free weld bead.

3.1 Effect of Vibrations on Microhardness

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.

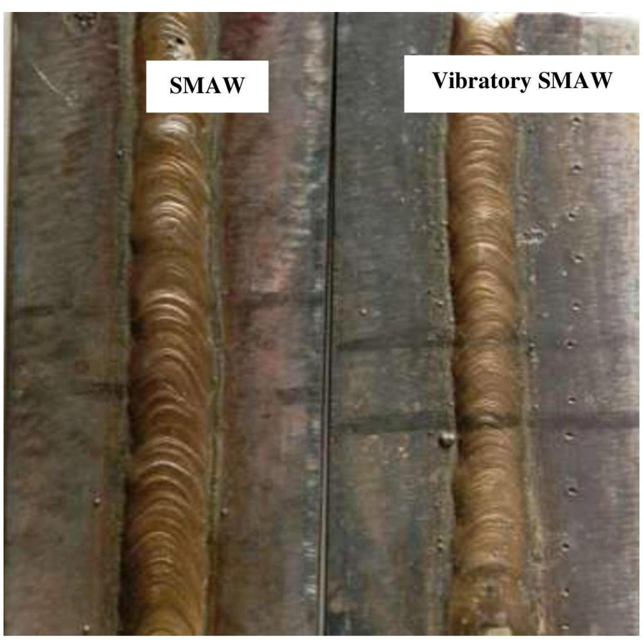

Figure 4. Actual image of weld bead laid on ms base plate.

Figure 5 shows that microhardness values increased in almost all the areas where the vibrations came in action. A disturbance created during the solidification process of weld joints leads to the fragmentation of growing grains, resulting in the formation of fine structures. Due to the vibrations, the growing grains could not reach their original dendritic lengths, i.e., the length observed in the absence of a vibratory setup. The faster cooling of the vibratory welded joints increases the hardness values of the weld bead[25,26].

3.2 Effect of Vibration on Tensile Properties

Tensile test specimens were prepared from the conventional and vibratory welded work pieces. In the case of conventionally welded tensile specimen, the fracture occurred near the heat-affected zone (HAZ). Whereas, during vibratory welding, the fracture point is located in the base metal, indicating that the strength of the weld bead increases after the application of vibration compared to the conventional process. The results of the tensile tests shown in Figure 6, yield strength shows an increase of 61 MPa (From 219 to 280 MPa) and UTS value also showed an improvement of 80 MPa (From 340 to 420 MPa) due to the application of vibratory welding technique. 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 microstructural changes that impeded grain growth, resulting in relatively shorter grains in the weld pool. [Figure 5][Figure 6]

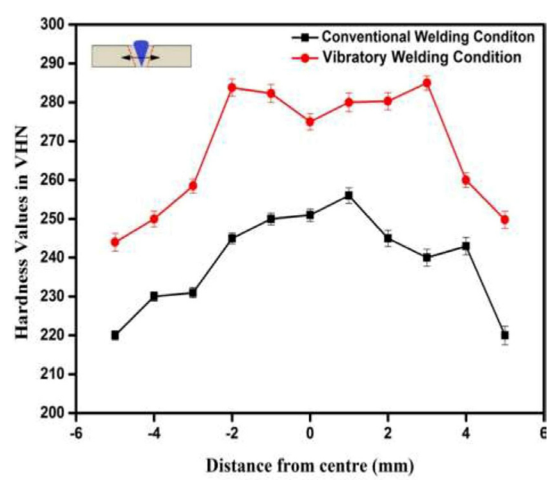

Figure 5. Hardness plot for welded joint.

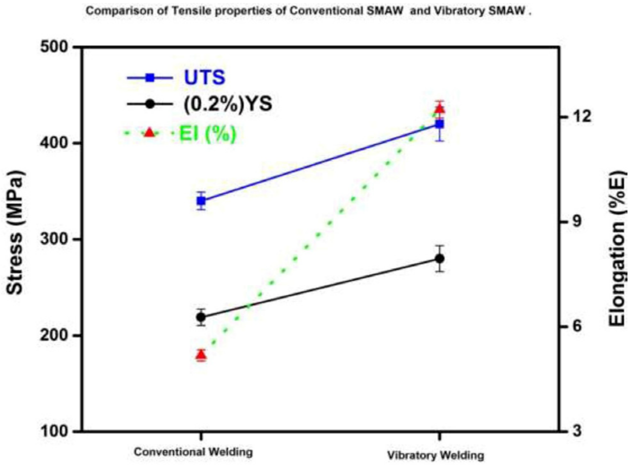

Figure 6. Tensile graph for welded joints.

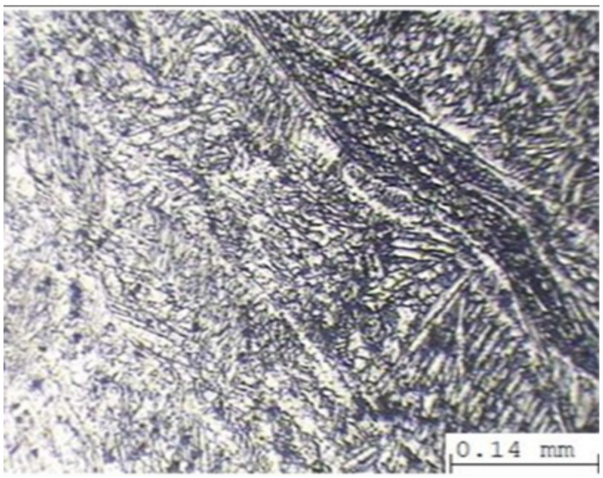

Figure 7. Photomicrograph (100 X) of conventional SMAW process welded joint.

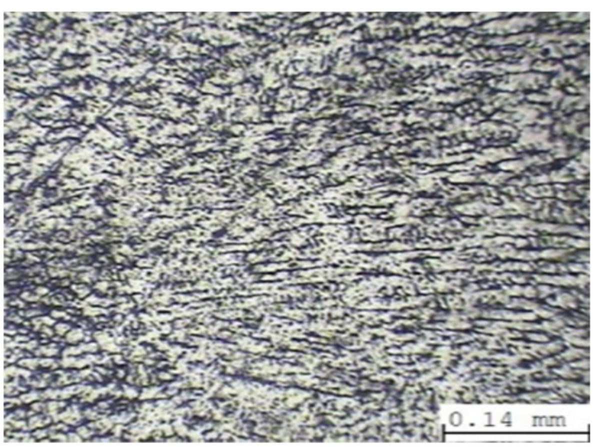

Figure 8. Photomicrograph (100 X) of Vibratory SMAW process welded joint.

3.3 Microstructral Studies

Metallographic studies on different specimens were conducted and photomicrographs of various zones of interest were captured with a CCD camera equipped with Image analyzer software. These micrographs for different weldments and macrosections/weld profiles cross sections (for butt welded joints) are presented in Figure 7& 8.

The welded specimens prepared by vibrating welding conditions, showing variation in the microstructure of the weld metal with respect to the microstructure of conventionally welded specimen. The reason for the occurrence of these changes was primarily due to the reason that the dendrites of the weld metal while solidifying experienced a hindered growth i.e. an opposing force generated due to auxiliary mechanical vibrations induced into the weld pool, did not allow these dendrites to grow to their fullest extent as these would have grown in the absence of any such disturbance. Figure 7showing the photomicrograph of weld bead prepared under the conventional welding condition which shows the large non-uniform growing grains where as on other side (Figure 8)the weld bead prepared under the vibratory condition has small and large number of grains which are uniform in nature.[Figure 7] [Figure 8]

4. Conclusion

This study discussed the application of vibrator welding technique during the SMAW process of butt welded joint. From the analysis of the results, following can be concluded:

1. It has been shown in this work that vibration applied into the weldpool can be successfully enhanced the mechanical properties of welded joints. Thus the present research attempt provided an alternative for grain refinement of weldments.
2. The Yield Strength increased by 27% and tensile strength of the welded joint increased by 23% 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.
3. The auxiliary vibrations induced into the weld pool resulted in increased micro hardness of the weld metal which indicates the orientation of the new crystals and refinement of grains took place.

4. The grain refinement has been found in the welded structures which were welded during vibratory conditions. Microstructure studies of the welded joints have revealed that due to auxiliary stirring of the weld pool using a vibratory tip, steeper thermal gradients are established that lead to a condition where grain coarsening is relatively less.

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