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# INFLUENCE OF WELD POOL VIBRATION ON IMPACT STRENGTH AND METALLURGICAL PROPERTIES OF AISI 304L BUTT WELDED JOINT

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## ABSTRACT

*Effect of simultaneous weld pool vibrations during the gas tungsten arc welding process on the impact strength and micro hardness of butt welded joints have been studied. AISI 304L SS material was selected for the present study. A set up for imparting continuous and constant frequency and amplitude vibrations to the weld pool was designed and fabricated. Comparative study of the welded joints both under the influence of weld pool vibrations and without weld pool vibrations (conventional) was conducted. Charpy impact test and micro hardness test were conducted. Microstructural studies reveal that relatively fine grained structures have been obtained in the joints welded under the influence of weld pool vibrations. The improvement of impact strength of the joint welded at low input current due to weld pool vibration is of 11.9%, and the improvement in impact strength of the joint welded at high input current is of 6.5%. Similar trend is observed in the micro hardness values ($HV_{0.5}$). Increment of 8.5 % in micro hardness value was achieved by applying vibration to the conventional welding fabricated at low input current and increment of 7.5 % in micro hardness value was achieved by applying vibration to the conventional welding process fabricated at high input current.*

***Key Words: Weld Pool Vibrations, Charpy Test, Micro Hardness Test, Microstructure, Grain Refinement***

## I. INTRODUCTION

Coarse grained microstructure in the welded joint can be one of the possible reasons for the degradation in the mechanical strength of the weld joint [1-13]. The reason for deterioration in the mechanical strength may be due to the fact that the movement of dislocation in the crystal structure in case of coarse grain is much easier as compared to fine grained structure. In case of fine grained structure the movement of dislocation is restricted by more number of grain boundaries and higher dislocation density present in it. This can make it more difficult for the dislocations to move and for the metal to deform. The result is more resistance offered by the joint thus higher strength. This may be the reason that fine grained metal is therefore stronger than a coarse grained metal [5].As welding is such a process where the metal is heated close enough to melting point, converted to molten state and thereafter simultaneously cooling to room temperature, there arise the possibility

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for the development of residual stresses in the welded joint. This could also be another reason to degrade the mechanical properties of the weldments [9]. Various techniques for grain refining in weld metal have been studied by the researchers, such as ultrasonic weld-pool vibration [1-3], mechanical vibration [5, 6, and 9], electromagnetic weld-pool vibration [16], and arc oscillation [8]. Moreover this can turn to be an advantageous technique to obtain finer grain structure as it is non-pollutant process, low cost and simplified equipment and ease of use compared to other techniques [5]. GTAW (Gas Tungsten Arc Welding) has been selected for the welding of specimens. A comparative study has been carried out to discuss the significance of weld pool vibrations over conventional GTAW process. The process parameters for the experimentation were selected on the basis of bead on plate pilot experimentation conducted. Bead geometry studies and weld spatter were the main response parameters for finalization of the input parameters for the present study.

## II. EXPERIMENTATION

### 2.1 Base and filler material combination

AISI SS 304L stainless steel was cut into $150mm \times 50mm \times 6\ mm$ specimens whichwere used for present study. Single V groove design with groove angle of $60°$ and root gap of $2mm$ was used in the present study. SS 308L stainless steel filler rod was selected for joining the specimens by GTAW process. Table 1 and Table 2 show the chemical composition of base material and filler rod material respectively.

**Table 1: Chemical composition of base material (SS 304L) used for the present work**

| C% | Mn% | P% | S% | Si% | Ni% | Cr% | Mo% | Fe% |
|---|---|---|---|---|---|---|---|---|
| 0.027 | 1.27 | 0.03 | 0.140 | 0.433 | 8.07 | 18.09 | 0.2 | Balance |

**Table 2: Chemical composition of filler rod (SS 308L) used for the present work**

| C% | Mn% | P% | S% | Si% | Ni% | Cr% | Fe% |
|---|---|---|---|---|---|---|---|
| 0.024 | 1.32 | 0.03 | 0.009 | 0.58 | 9.51 | 19.94 | Balance |

### 2.2 Base metal preparation

Before welding all the edges were thoroughly cleaned with rough emery paper and hand grinder so as to remove any source of contamination like rust, scales, dust, oil, moisture etc. Inclusion of foreign particles results in degrading the strength of welds and forms discontinuity of weld. So the cleaning of edges of plates to be welded is must before performing the welding operation.

### 2.3 Weld pool vibration

A vibrating motor of $1200\ rpm$ is used to produce vibration to the welding base so as to develop weld pool vibration. Constant vibration frequency and amplitude of vibration has been used in the present study. Working table or vibrating welding base vibrated at a frequency of 17Hz during welding, which resulted in oscillating the weld pool in liquid state. Figure 1 shows the schematic view of the vibrating work table used in the study.

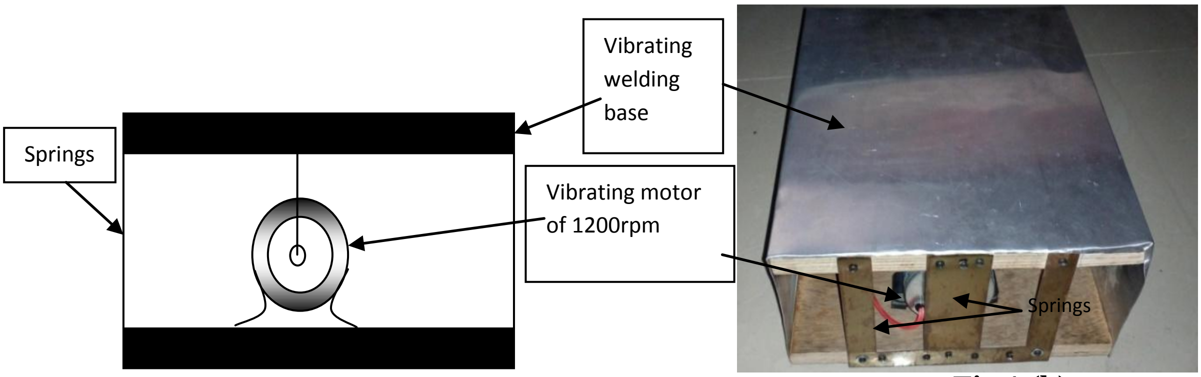


**Fig.1 (a)** **Fig.1 (b)**

**Fig. 1: (A)Schemataic View Of The Vibrating Table Used In The Present Study. (B) Actual Setup Used In The Present Study**

### 2.4 Welding of Plates

GTAW welding process was used to weld the plates in the present work. DC rectifier type power source with straight polarity was used in the experimentation. Tungsten electrode of $2.4\ mm$ diameter was used in the welding process. Filler metal AISI 308L of $2.5\ mm$diameter was used. Shielding gas used was argon with gas flow rate of$13\frac{litre}{min}$. Welding was performed manually and speed of welding was maintained at$2.5\frac{mm}{s}$ throughout the welding of all the plates. Only welding current was varied [14] and all other parameters were kept constant for welding of all plates with and without vibrations of welding base. Table 3 gives the welding conditions used in the experimental work. Root was given to weld without using any filler, later first and second pass of weld to fill the groove was used with filler rod feeding externally by the welder manually for each joint of weld. Due care and precautions were exercised during welding. Whereas all necessary precautions like pre-cleaning of the groove edges and inter pass cleaning between consecutive weld passes were followed to avoid contamination of any sort, thus ensuring defect free welds. Inter pass temperature was maintained according to the standards.

**Table 3: Welding parameters used for the experiment**

| **Welding input current** | **Type of pass** | **Welding current (A)** | **Welding speed (mm/s)** | **Gas flow rate (L/min)** |
|---|---|---|---|---|
| Low | Root pass | 100 | 2.5 | 13 |
| | First pass | 120 | 2.5 | 13 |
| | Second pass | 120 | 2.5 | 13 |
| High | Root pass | 100 | 2.5 | 13 |
| | First pass | 150 | 2.5 | 13 |
| | Second pass | 150 | 2.5 | 13 |

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The plates were welded with and without vibration of the welding base with two heat input levels respectively. Scheme of experimentation is as shown in the Table 4.

**Table 4: Sampling categorization**

| Sample No. | Welding condition | Input current (A) |
|---|---|---|
| 1 | Without vibration | 120 |
| 2 | | 150 |
| 3 | With vibration | 120 |
| 4 | | 150 |

## 2.5 Specimen Sampling

Specimens for impact test, micro hardness test and microstructural studies were sampled out from the welded plates as shown in the Figure 2. The specimens sampled out are according to ASTM standards for testing. Samples were cut from the welded plates using wire-cut EDM.

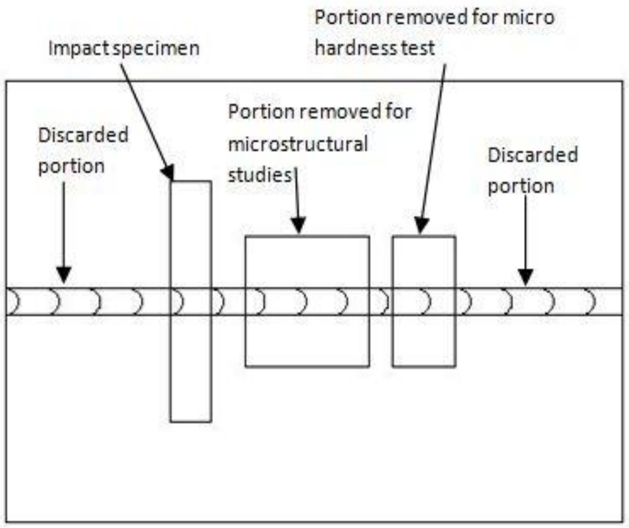



**Figure 2: Schematic illustration of specimen sampling from welded plates**

## 2.6 Charpy impact testing

Charpy impact test specimens were sampled out from each welded plate as shown schematically in the Fig.2. Dimensions of the sample were according to ASTM E23 standards. Specifications of dimensions for the charpy impact test specimen are shown in the Fig.3. Standard specimen size for impact testing is 55mm x 10mm x 10mm, but thickness of plate used in present study is of 6mm. A nonstandard criterion was employed in order to compare the degree of parts welded trough [5]. V-notch is provided on the specimen as shown in the figure with the notch angle of 45° to a depth of 2 mm. Test was conducted on "pendulum impact tester" 300 joules.

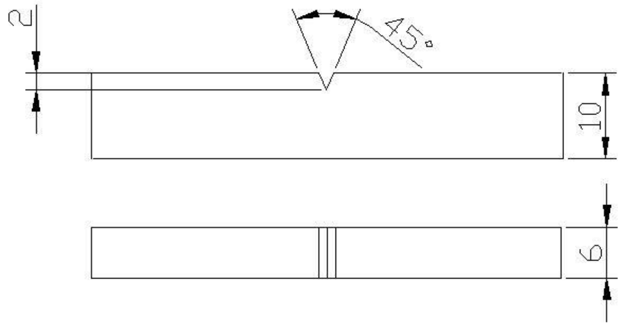



**Fig.3. Specifications of Charpy Test Specimen Used In Present Work**

### 2.7 Micro hardness test

The micro hardness values of each joint were measured using Vickers Hardness Tester with loading of 500 gm weight for 20 seconds dwell time on the cross section of the each specimen. Measurement of hardness values on the cross sectional surface of the specimen were made at perpendicular to the plate and also along the parallel direction of the plate. The test was conducted to find the difference in hardness values under the application of vibration to the conventional GTA welding process.

### 2.8 Microstructure analysis

In order to observe microstructural changes that take place during welding, corresponding to each input current value and vibration conditions, the specimens were sampled out as shown in the sampling of specimen's diagram Figure 2.Sample for microstructure analysis was polished with emery papers of various sizes viz. 100, 200, 400, 600, 800, 1000, 1200, 1500, 2000, 2500, 3000 and finally with diamond paste on the velvet cloth lapping to get the scratch less shiny mirror finish for microstructure studies. Following the polishing procedure specimens were etched using "Aqua regia" (hydrochloric acid and nitric acid in ratio 3:1) solution for 1minute. Microstructure of weld metal of different welding combinations viewed and captured using optical microscope coupled with an image analyzing software.

## III. RESULTS AND DISCUSSION

### 3.1 Impact Test

Charpy impact strength of the all the welded joints were tested by sampling the specimen across the weld joint and were evaluated. This pendulum strikes the specimen and fractures it. Strength required to fracture the joint gives the impact strength of the joint. Here a comparative study was made for the impact strength of joints which were welded at various combinations of process parameters. In each condition of input current and the vibration condition, the corresponding impact strength is mentioned in the Table 5.

**Table 5: Charpy Impact Test Results Obtained in the Study At Various Parameters of Welding**

| Sample no | Input current | | Impact strength(J) |
|---|---|---|---|
| 1 | Low | Without vibration | 143 |
| 2 | High | | 138 |
| 3 | Low | With vibration | 160 |
| 4 | High | | 147 |

It is observed that the charpy impact strength of joint welded at low heat input current and simultaneous vibration of welding base gave the best result among all the specimens. The joint welded at low heat input current gives the best impact strength of than compared to the one that welded with high input current. Fig.4 shows the graphical representation of variation in impact strength possessed by various joints. The improvement of impact strength of the joint welded at low input current due to weld pool vibration is of 11.9%, and the improvement in impact strength of the joint welded at high input current is of 6.5%. Weld pool vibration definitely improves the impact strength of the joint, which can affect the practical use of the welded joint.

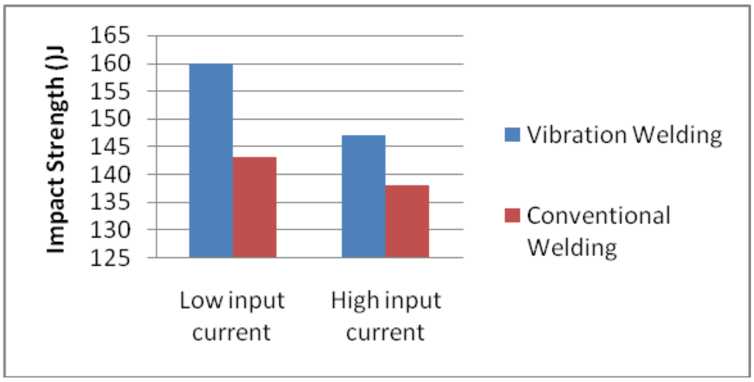



**Figure 4: Graphical Representation of Variation In Impact Strength Of Joint At Various Combinations Of Process Parameters**

### 3.2 Microhardness

Microhardness values taken in two directions i.e. perpendicular to the plate on the weld cross section and along the parallel direction of the plate on the weld cross section as shown in the Fig. 5 and Fig. 6 respectively

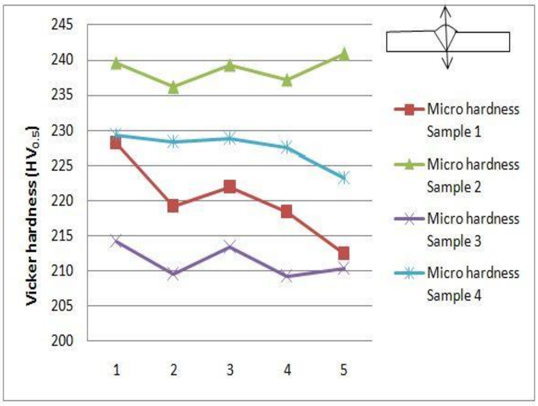



**Fig. 5: Micro hardness values of various samples taken in the direction perpendicular to the plate**

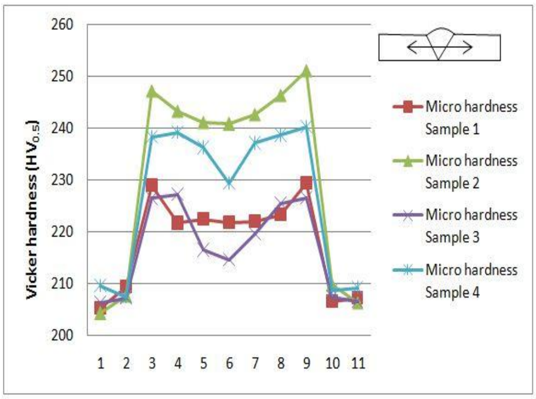



**Fig. 6: Micro hardness values of various samples taken in the direction parallel to the plate**

As it is observed the maximum micro hardness values obtained in the joint are at fusion boundary zone (FBZ) in all the joints because of presence of partially unmelted grains at FBZ [14]. The average value of micro hardness for each sample from the Fig 6 i.e. for the surface perpendicular to the plate is shown in the Table 6. It is observed that the welded joint fabricated with low input current by possesses high hardness values compared to the joint fabricated at high input current. Vibration welded joint has the better hardness value as compared to the conventionally welded joint to the corresponding input current values. Increment of 8.5 % in micro hardness value was achieved by applying vibration to the conventional welding fabricated at low input current and increment of 7.5 % in micro hardness value was achieved by applying vibration to the conventional welding process fabricated at high input current. Fig.7 shows the graphical representation of variation in micro hardness value of various joints.

**Table 6: Average micro hardness number of samples taken perpendicular to plate**

| Sample no | Input current | | Average micro hardness ($VH_{0.5}$) |
|---|---|---|---|
| 1 | Low | Without vibration | 220.2 |
| 2 | High | | 211.4 |
| 3 | Low | With vibration | 239.3 |
| 4 | High | | 227.4 |

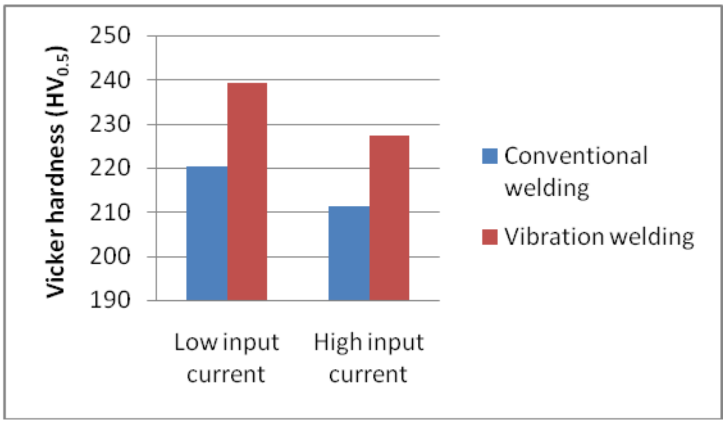
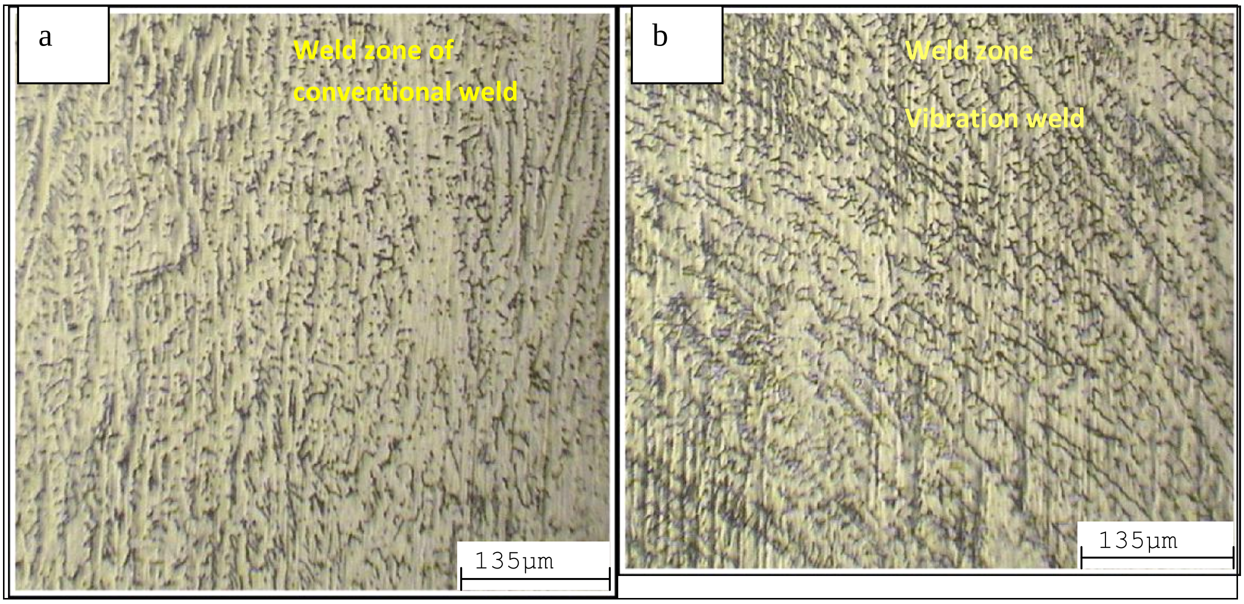



**Fig.7 Shows the Graphical Representation of Variation In Micro Hardness At Various Combinations of Process Parameters**

### 3.3. Microstructural Studies

Microstructure of weld metal was captured at 100X magnification, images of which are shown below. Figure 8 (a) & (b) shows the microstructure of weld metal which was deposited at low heat input by conventional and vibration welding respectively. Figure 8 (c) & (d) shows the microstructure of weld metal which was deposited by conventional and vibration welding respectively. From the microstructure of different weld metal, it was observed that fine grain structure is observed at low heat input value. Vibration welding results in equiaxed and fine grain structure. The fine and equiaxed grain structure was observed in metal joint which is welded at low heat input current and with simultaneous vibration of welding base.



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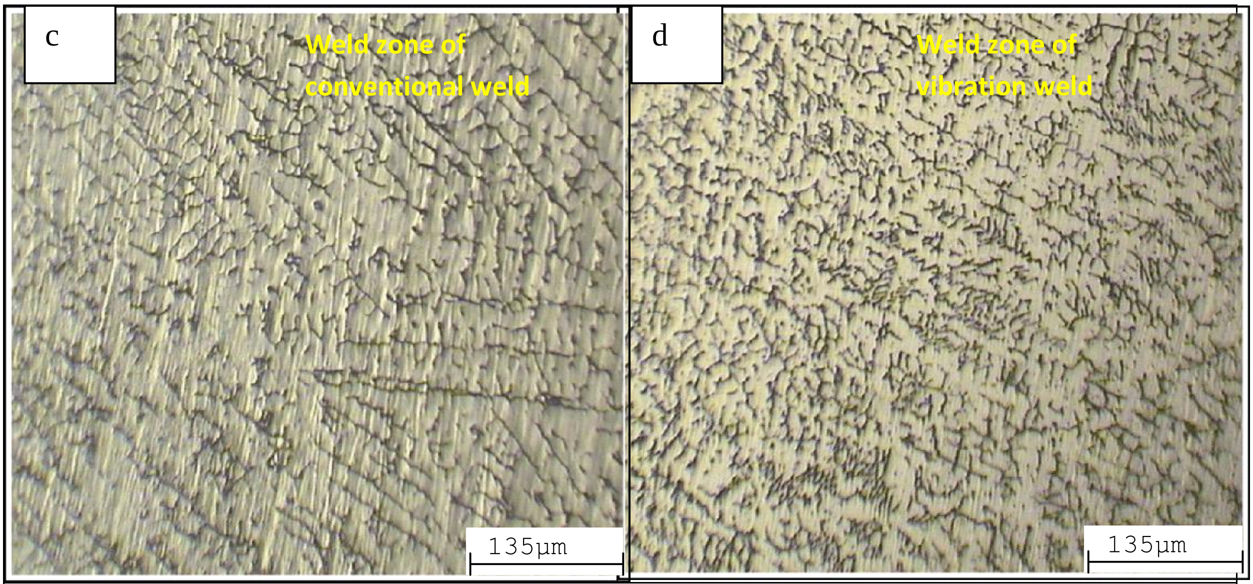


**Figure 8: Microstructure of weld metal at 100X magnification (a) low input current with conventional welding (b) low heat input current weld with vibration welding (c) high heat current with conventional welding (d) high heat input current weld with vibration welding**

## IV. CONCLUSIONS

Weld pool vibration has shown significant effect on the mechanical and microstructural behaviour of welded joint when compared to the joint which was welded without weld pool vibrations. Following conclusions can be drawn from the facts studied during present study:

- Adequate joint strength was exhibited by all the joints which shows that welding of 6mm thick plate of AISI 304L SS welded by GTAW process offering good quality weld to the fabricator.
- Impact strength of the joint which was welded with low current input value and simultaneous vibration welding observed to be significantly high as compared to the joints without weld pool vibrations or high input current. This indicates the better endurance of the material under impact loading for the joint when welded with vibrations and at low input current.
- It was also observed that the microstructure of the weld metal is fine and equiaxed in case of welding under vibration and thus better mechanical properties of the joint are observed.

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