

# A Study of Mechanical Properties of Vibration Assisted Arc Welding Joint

Mahmudul H. Pavel, Nuruzzaman Rakib, Mohammad A. Habib, Ahmed Y. Sanin, and Asif Salman

**Abstract**—Welding is one of the major aspects of manufacturing as well as mechanical engineering. The strength of the metal joint depends on the type of welding used. Quality of metal joining strength can be improved with a few changes in the regular welding process. A few factors that improve metal joining strength during the arc welding process had been studied in this paper. Research in welding process shows that Vibration can improve mechanical properties of the joining section. However, welding joint quality varies with different ranges of parameters in different conditions. To analyze those ranges of parameters in some selected conditions, a study has been performed in this paper. Some input parameters like vibration amplitude, vibration frequency, welding speed and electrode angle are selected to analyze the variation in the welded joint. For analyzing the results, output parameters –bending strength and dilution rate are calculated. It has been found that if all input parameters are kept in a selected range then output parameters –bending strength, the percentage of dilution increases than the regular case. Finally, it can be shown that Bending strength and percentage of dilution of a metal joint assisted with vibration shows the better result than without vibration.

**Index Terms**—Vibration Assisted Welding; Vibration Amplitude; Vibration Frequency; Welding Speed; Electrode Angle; Bending Strength; Dilution Rate.

## I. INTRODUCTION

Welding is an ancient art which has been in use since the Bronze Age. It produces a secure, strong joint that is stronger than other methods of bonding metals. Welders ply their trade in a number of different industries, including construction, mining, oil, and automotive, to name a few. Filler material is typically added to strengthen the joint. Welding is a dependable, efficient and economical method for permanently joining similar metals. In arc welding, vibration can be applied either during or after the process. When applied after welding, it is generally termed as vibration stress relief, which is a stress relieving method in which controlled vibrations are being applied on welded pieces after welding. Continuing the search for higher productivity, researchers are now putting their effort to develop the process of arc welding during vibration, i.e. vibration assisted welding (VAW), which can cut most of

the expenses related to post weld vibrations or heat treatments. Production lead time can be considerably reduced due to the parallel processing of vibration and welding. Moreover, VAW leads to improved microstructure [1] and better mechanical properties [2]. There are different modes in which vibration is applied to the workpiece such as longitudinal, transverse, vertical and random vibrations. In their oldest available paper, Tewari and Shanker [3] reported the effect of longitudinal vibration on mechanical properties such as yield strength, ultimate tensile strength and hardness. They reported that significant enhancement of mechanical properties was observed within the range of 80–400 Hz for frequency and 5–30 mm for amplitude. In another investigation, breaking strength, ultimate tensile strength (UTS) and yield strength of specimen made under longitudinal vibratory conditions registered an improvement of [4]–[5] and 2% respectively [6]. Electromagnetic stirring of molten pool was found to be favoring the grain refinement in gas tungsten arc (GTA) welds of thin sheet made of aluminum alloys [7]. The electromagnetic stirring apparatus had a magnetic coil with a ferrous core at the center. The coil was fixed under the specimen and in line with the axis of welding torch. The mode of metal transfer has a lot of influence on the quality of welds. Pulsed current Gas Metal Arc Welding (GMAW) is a way to achieve controlled metal transfer. An analytical model was developed for explaining the droplet oscillation and detachment process in pulsed current GMAW [8] - [9]. The oscillation of arc welding was proved to be another method of generating agitations in weld pool. A two-dimensional mathematical model was developed to study the effect of electromagnetically oscillated arc on the microstructure and temperature distribution of bead on plate welds on thin tantalum sheets made through GTA Welding [10]. The ultrasonically vibrated welding electrode could produce more arc pressure in TIG welding [11]. The electrode vibrated axially, and the vibrations were passed on to weld pool through arc plasma. The ultrasonic vibrations created using an ultrasonic generator was transmitted to welding torch through a mechanical coupling and bead on plate welding was carried out on stainless steel pieces.

Though many studies have been done to find out the variation of results between vibration assisted welding and regular welding without vibration, but since today, very few Vibration-assisted welding experiments have been done using ranges of different parameters. Here, some input parameters like vibration amplitude, vibration frequency, welding speed and electrode angle are selected to analyze the variation in the welded joint. For analyzing the results, output parameters – bending strength and dilution are selected. In this study, the main purpose is to analyze the

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Published on March 21, 2018.

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changes of mechanical properties like bending strength and percentage of dilution of the joining section of the metals with the addition of vibration on the metal joining point during arc welding process.

## II. EXPERIMENTAL SETUP AND METHODOLOGY

### A. Concept and setup

First, a wooden frame of the experiment has been made. This wooden frame includes a large table over which all the accessories like base table, a large wooden plate for vertically up and down movement, nylon rack and pinion, pulley, and motors are attached.

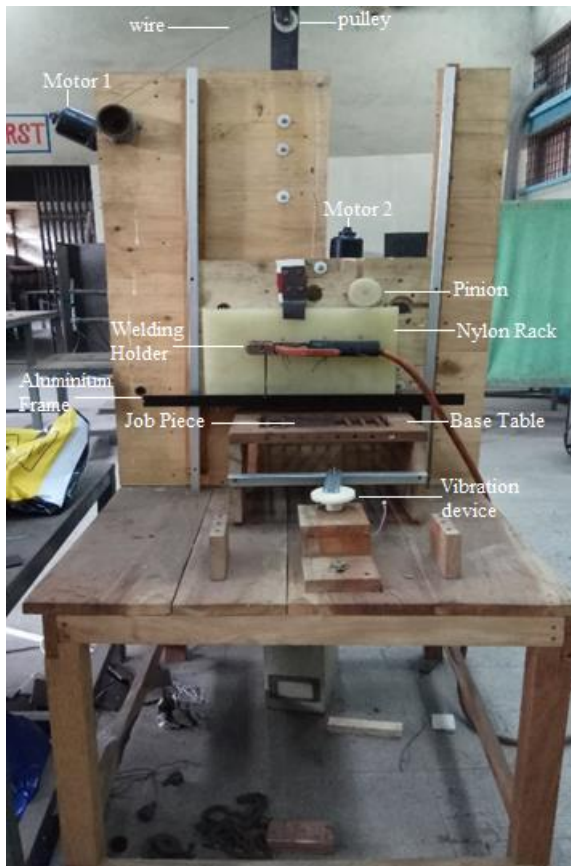


Fig. 1. Experimental setup

On the wooden plate, there is a pulley and the pulley is controlled by a dc 12V motor. By this connection, that wooden plate can move upward and downward. On that plate, there is a pinion made of Nylon. A Nylon rack is set on an aluminum frame which is connected to the wooden frame. Rack and pinion have meshed together, that is why this connection can move back and forth. On that nylon rack, welding holder is connected. The vertical wooden plate has space in front of it, where the small wooden base table is kept. This wooden base table has a square hole where metallic rods are placed. At that place, job piece will be kept for the experiment. The Metallic rods are placed over there because earthing point should be maintained for welding. The sidewall of the small base table is connected with two springs with the main table. The small base table has four wheels and those wheels can roll on two rail lines. One vibration device is established in front of that small base plate. This arrangement allows the base table and the job piece to vibrate in back and forth direction. The system

is made fully automatic by using an Arduino micro-controller and relay circuits to neutralize the effect of experimental error. The experimental setup and vibration system are shown in Fig. 1 and Fig. 2.

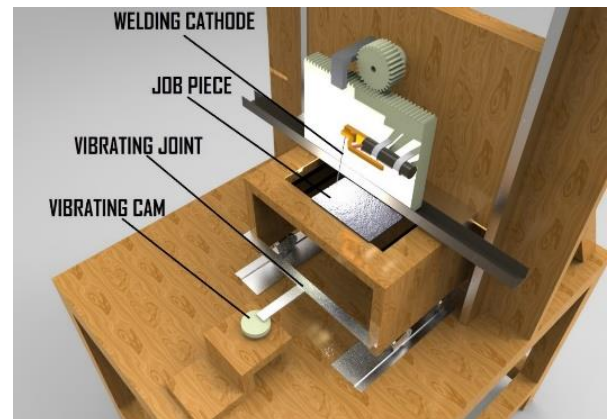


Fig. 2. Vibration system of the experiment designed by CAD software

### B. Methodology

This experiment of the welding process is done to analyze the change of the mechanical properties of welding joining point. At first, it has been selected that which of the parameters have the great effect on the joining point of welded materials. Those selected input parameters are Vibration amplitude, Vibration frequency, Welding speed and Electrode angle. Experimental design is widely used for controlling the effects of parameters in many processes. Its usage decreases the number of experiments, using time and material resources. A full factorial design requires at least three levels per variable to estimate the coefficients of the quadratic terms in the response model. Thus for the four independent variables, 81 experiments plus replications would have to be conducted which is reduced by the Central Composite Design Software (CCD). For all parameters, five levels of data using CCD is used (Table I). Total thirty experiments are conducted, where 24 of them are non-center points and 6 of them are center points.

TABLE I: PROCESS PARAMETERS WITH THEIR VALUES AT DIFFERENT LEVELS

Parameters		Levels				
		$-\sqrt{2}$	-1	0	+1	$+\sqrt{2}$
Vibration						
amplitude	$V_A$	12.9	15.0	20.0	25.0	27.1
( $\mu\text{m}$ )						
Vibration						
Frequency	$V_F$	79.29	100.0	150.0	200.0	220.7
(Hz)						
Welding						
speed	$W_S$	1.4	2.0	3.5	5.0	5.6
(mm/sec)						
Electrode						
Angle ( $^\circ$ )	$E_A$	11.9	15.0	22.5	30.0	33.1

To compare the vibration results with non-vibration welding, 10 separate experiments are conducted (Table II). After completing the welding process, workpieces are taken

to analyze for the changing of the mechanical properties of the joining point. With the help of a Universal testing machine, every specimen is tested and bending strength is noted down. Dilution calculation is one of the difficult parts of this experiment. Because this small amount of area cannot be easily calculated. For this calculation, another software “ImageJ” has been used. After taking the picture of all specimens, those are imported in this software one by one and calculated the percentage of dilution in the welded area.

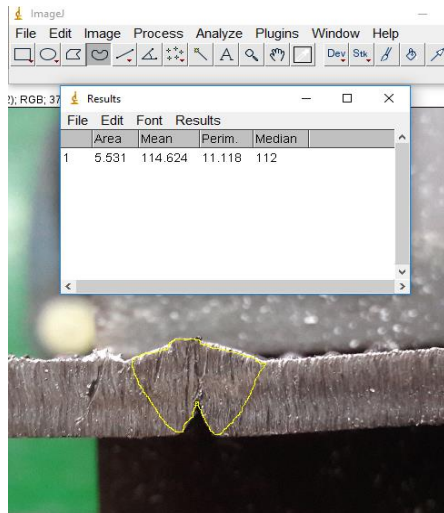


Fig. 3. Interface of “ImageJ” software (sample No. 2)

Mild steel bars are used as the workpiece. For these experiments, 2.5 mm filler rod is used. All the experiments are repeated five times to get an average data. The average bending strength and percentage dilution rate for different conditions are given in Table II (without vibration) and Table III (with vibration).

TABLE II: EXPERIMENTAL RESULTS FOR WITHOUT VIBRATION OR OSCILLATION

N o.	Input parameters				Output parameters (Experimental)	
	V <sub>A</sub>	V <sub>F</sub>	W <sub>S</sub>	E <sub>A</sub>	Bending strength (HRC)	Dilution (%)
1	0	0	1.4	15.0	15.0	26
2	0	0	2	15.0	14.0	24
3	0	0	3.5	15.0	12.0	21
4	0	0	5	15.0	10.0	19
5	0	0	5.6	15.0	9.0	18
6	0	0	2	11.9	16.0	25
7	0	0	2	15.0	14.0	24
8	0	0	2	22.5	11.0	22
9	0	0	2	30.0	9.0	20
10	0	0	2	33.1	8.0	19

TABLE III: EXPERIMENTAL RESULTS FOR WITH VIBRATION OR OSCILLATION

N o.	Input parameters				Output parameters (Experimental)	
	V <sub>A</sub>	V <sub>F</sub>	W <sub>S</sub>	E <sub>A</sub>	Bending Strength	Dilution (%)
1	15.0	100.0	2.0	15.0	13.20	34.0
2	25.0	100.0	2.0	15.0	17.90	35.0
3	15.0	200.0	2.0	15.0	17.80	38.0
4	25.0	200.0	2.0	15.0	22.50	41.0
5	15.0	100.0	5.0	15.0	8.60	26.0
6	25.0	100.0	5.0	15.0	13.50	23.0
7	15.0	200.0	5.0	15.0	13.20	30.0
8	25.0	200.0	5.0	15.0	17.90	31.0
9	15.0	100.0	2.0	30.0	8.60	22.0
10	25.0	100.0	2.0	30.0	13.20	21.0
11	15.0	200.0	2.0	30.0	13.40	32.0
12	25.0	200.0	2.0	30.0	18.00	29.0
13	15.0	100.0	5.0	30.0	4.00	10.0
14	25.0	100.0	5.0	30.0	8.80	14.0
15	15.0	200.0	5.0	30.0	8.60	22.0
16	25.0	200.0	5.0	30.0	13.00	23.0
17	12.9	150.0	3.5	22.5	8.60	19.0
18	27.1	150.0	3.5	22.5	13.3	21.0
19	20.0	79.29	3.5	22.5	8.6	23.0
20	20.0	220.7	3.5	22.5	17.8	39.0
21	20.0	150.0	1.4	22.5	17.5	42.0
22	20.0	150.0	5.6	22.5	8.60	17.0
23	20.0	150.0	3.5	11.9	13.40	32.0
24	20.0	150.0	3.5	33.1	8.6	23.0
25	20.0	150.0	3.5	22.5	13.20	29.0
26	20.0	150.0	3.5	22.5	13.10	30.0
27	20.0	150.0	3.5	22.5	13.30	31.0
28	20.0	150.0	3.5	22.5	13.00	30.0
29	20.0	150.0	3.5	22.5	13.40	31.0
30	20.0	150.0	3.5	22.5	34.20	29.0

### C. Mathematical Model

For developing the mathematical model, first, the fitness function for the output parameters are calculated. To find out the fitness function the natural log transformation is selected and quadratic type equation is used for this case. By using these conditions, the ANOVA (analysis of variance) for response surface quadratic model shows significant behavior and for lack of fit, it shows non-significant behavior. This proves that the fitness equation is working within the reasonable range. Using Design Expert 7.00 software, ANOVA output and model equation is found for every output Parameters-Bending strength, Dilution rate.

The model (Eq. 1 and 2) as suggested for the Bending strength and Dilution percentage by the fit and summary tests is shown below:

$$\ln(\text{Bending Strength}) = 2.83267 + .021641 \times V_A + 3.58006 \times 10^{-3} \times V_F - .24062 \times W_D - .049555 \times E_A - 1.81305 \times 10^{-4} \times V_A V_F + 5.78903 \times 10^{-3} \times V_A W_D + 1.05134 \times 10^{-3} \times V_A E_A + 4.87406 \times 10^{-4} \times V_F W_D + 1.11842 \times 10^{-4} \times V_F E_A - 3.89770 \times 10^{-3} \times W_D E_A \quad (1)$$

$$\ln(\text{Dilution}) = 2.55566 + .24876 \times V_A - 7.82848 \times 10^{-3} \times V_F - 0.17037 \times W_D - .047886 \times E_A - 3.53875 \times 10^{-5} \times V_A V_F + 2.75915 \times 10^{-3} \times V_A W_D + 3.68005 \times 10^{-4} \times V_A E_A + 6.32976 \times 10^{-4} \times V_F W_D + 2.11886 \times 10^{-4} \times V_F E_A - 3.31292 \times 10^{-3} \times W_D E_A - 6.43646 \times 10^{-3} \times V_A^2 + 1.66453 \times 10^{-5} \times V_F^2 - 6.85794 \times 10^{-3} \times W_D^2 - 1.39441 \times 10^{-4} \times E_A^2 \dots \dots \quad (2)$$

Using the model equation equations, the output Parameters-Bending strength & percentage dilution rate is calculated and compared with the experimental output values and percentage of error is calculated. For bending strength, only experiment no 18 & 23 have a percentage of error more than 10%. For dilution rate experiment no- {5, 12, 13, and 22} have a percentage of error more than 10%. Except that all the percentage of error was less than 8%.

### III. RESULTS AND DISCUSSION

Generating the model equation, graphical representation is done to analyze the effect of input parameters on output.

#### A. Effect of Vibrational Amplitude

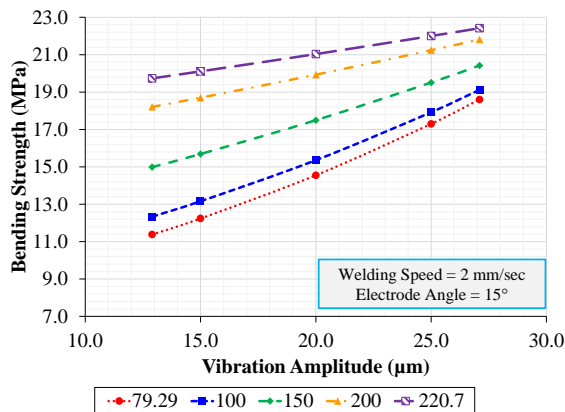


Fig. 4. Effect of vibration amplitude for different vibration frequency on bending strength

Fig. 4 shows bending strength curves are increasing with the increment of amplitude with different frequency. The increase of amplitude provides more penetration to the joining point because it helps the molten metal to enter into the lower depth of the joint. Bending strength varies with penetration quality. If penetration is high then bending strength is high and if it is low then so as bending strength. Fig. 5 (a) shows lower amplitude and frequency provides less penetration wherein Fig. 5 (b), high amplitude with high frequency provide almost complete penetration and stronger joint.

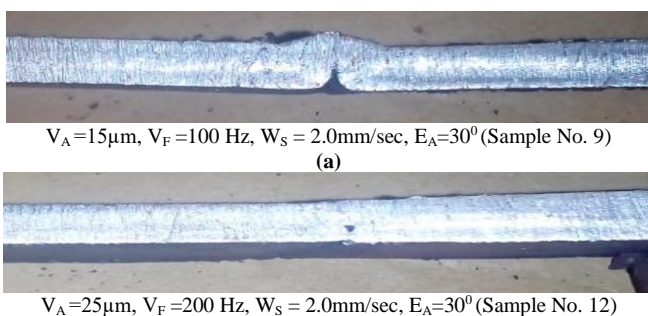


Fig. 5. Higher penetration with the change of amplitude in welding (a) less penetration (b) complete penetration

Fig. 6 shows that at first dilution increases but after a certain point, it goes down but it can easily say that within 20-25μm amplitude with high frequency it provides better result.

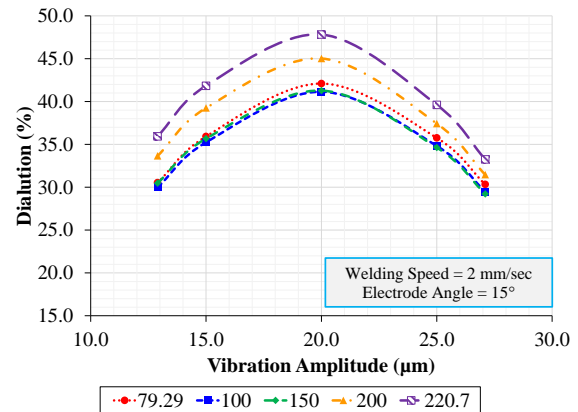


Fig. 6. Effect of vibration amplitude for different vibration frequency on Dilution

Fig. 7(a) shows low amplitude gives lower dilution percentage but Fig. 7 (b) indicates with high frequency high amplitude provides higher dilution percentage.

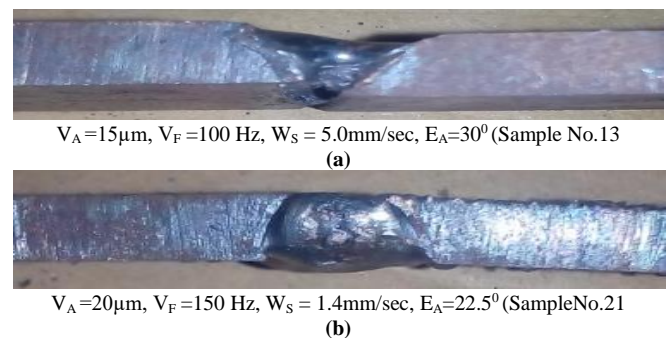


Fig. 7. Change of dilution with the variation of vibration amplitude (a) less dilution (b) more dilution

#### B. Effect of Vibration Frequency

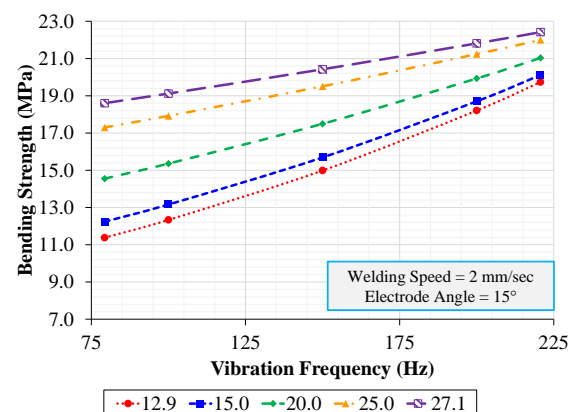


Fig. 8. Effect of vibration frequency for different vibration amplitude on bending strength

Fig. 8 also shows that frequency has a very significant role to improve the bending strength of the joining point.

Here bending strength increases with the increase of frequency. For getting more bending strength, it is necessary to increase the penetration of molten metal in joining point. Frequency helps to increase the penetration of molten metal. In Fig. 9(a), low frequency with less amplitude provides lower penetration than the high frequency with high amplitude shown in Fig. 9(b).

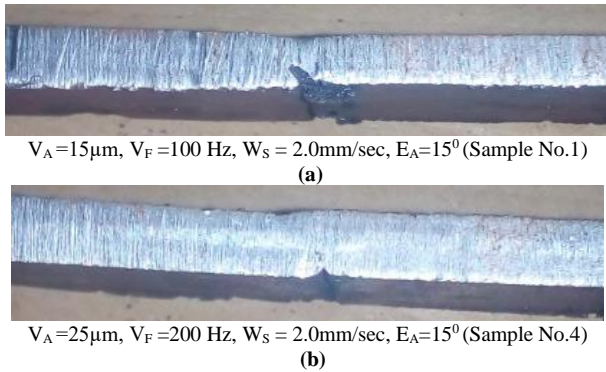


Fig. 9. Higher penetration in welding joint with the variation of frequency (a) low penetration (b) higher penetration

Fig. 10 also shows dilution of the joining point is also increasing with frequency and amplitude because having less porosity and more penetration, now molten metal can dilute more area of the job piece and create a strong bond.

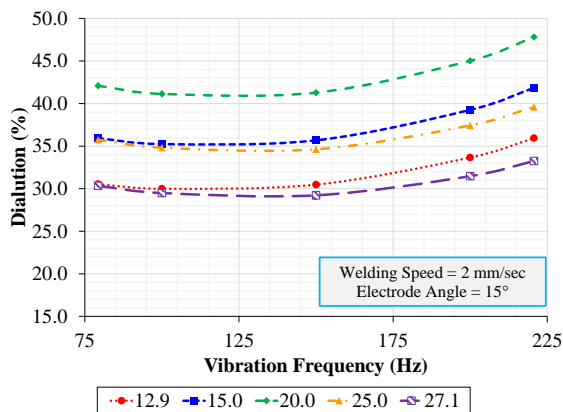


Fig. 10. Effect of vibration frequency for different vibration amplitude on Dilution

Dilution is lower with low frequency and amplitude shown in Fig. 11(a) but higher with high frequency and amplitude shown in Fig. 11(b).

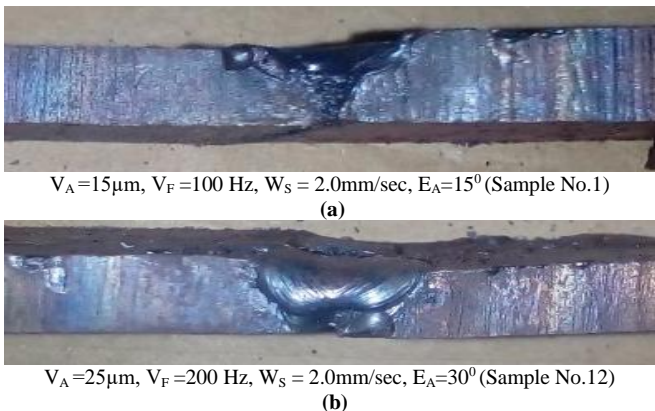


Fig. 11. Change of dilution with the variation of vibration frequency (a) low dilution percentage (b) high dilution percentage

### C. Effect of Welding Speed

Fig. 12 shows different colored lines of bending strength is decreasing with the increase of welding speed because molten metal does not get enough time to penetrate the joint. The Black colored line shows the changing without oscillation.

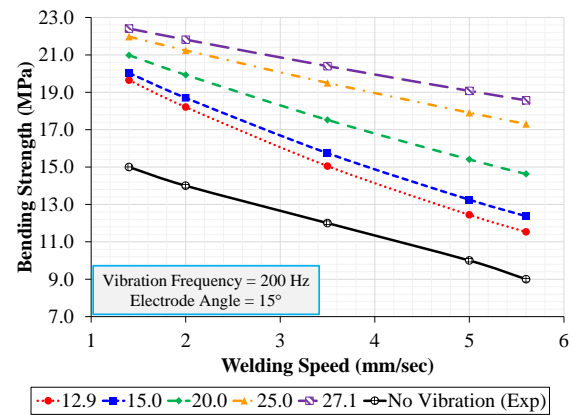


Fig. 12. Effect of welding speed for different vibration frequency on bending strength

Fig. 13(a) shows incomplete penetration due to high welding speed. On the other hand, Fig. 13(b) shows complete penetration due to less welding speed. Fig. 13(c) shows no oscillation gives less penetration at the welding joint.

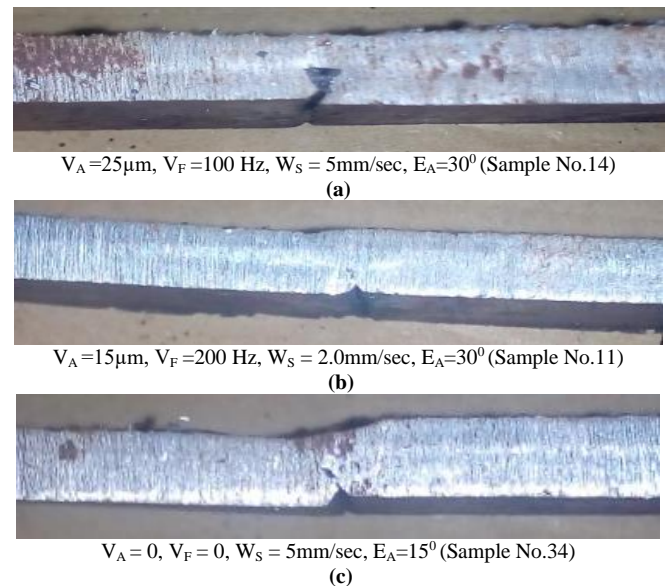


Fig. 13. Change of penetration with welding speed (a) less penetration (b) high penetration (c) less penetration (no oscillation).

Fig. 14 shows less welding speed with high frequency and amplitude gives more dilution cause for higher penetration and less porosity in the joining point, more hot metal enters and it dilutes more area than without oscillation. Therefore, joining becomes stronger than normal welding process. Fig. 15 (a) shows lower dilution because of higher welding speed, which is gradually turned into higher dilution with less welding speed shown in Fig. 15(b). In Fig. 15(c), it shows dilution percentage is very low when the welding process is without oscillation.

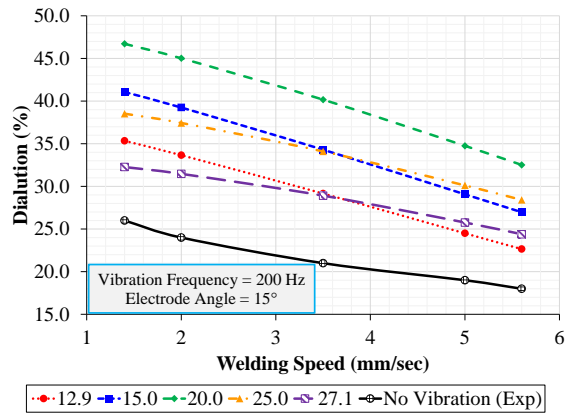


Fig. 14. Effect of welding speed for different vibration frequency on Dilution

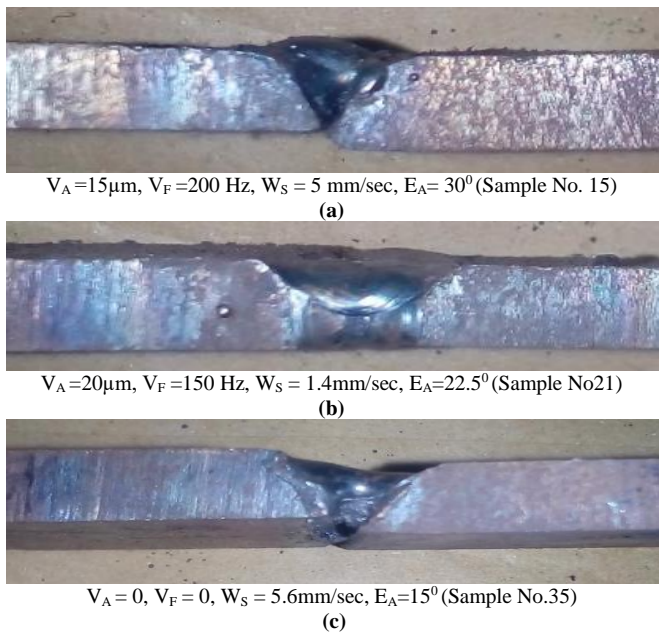


Fig. 15. Change of dilution with the variation of welding speed (a) lower dilution (b) higher dilution (c) lower dilution (no oscillation).

#### D. Effect of Electrode Angle

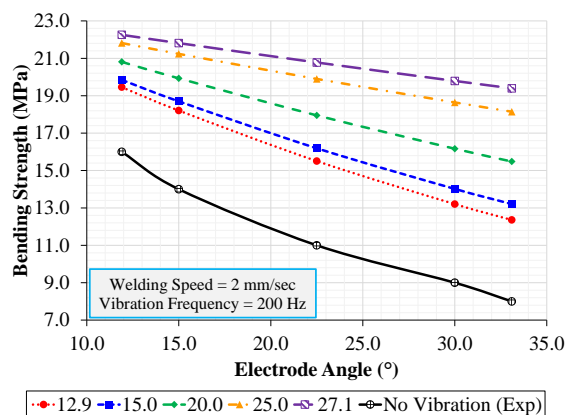


Fig. 16. Effect of electrode angle for different vibration frequency on bending strength

Fig. 16 represent that with high frequency and high amplitude, less electrode angle provides greater penetration in joining point. Because more metal is entering and metal is getting enough space to reach the lower point of the joint. Therefore, penetration increases, so the bending strength of this joint becomes high.

Fig. 17 (a) shows high electrode angle with low amplitude and frequency decreases bending strength but less electrode angle with high amplitude and frequency increases bending strength shown in Fig. 17(b). Fig. 17(c) shows the incomplete penetration when the welding process is without oscillation.

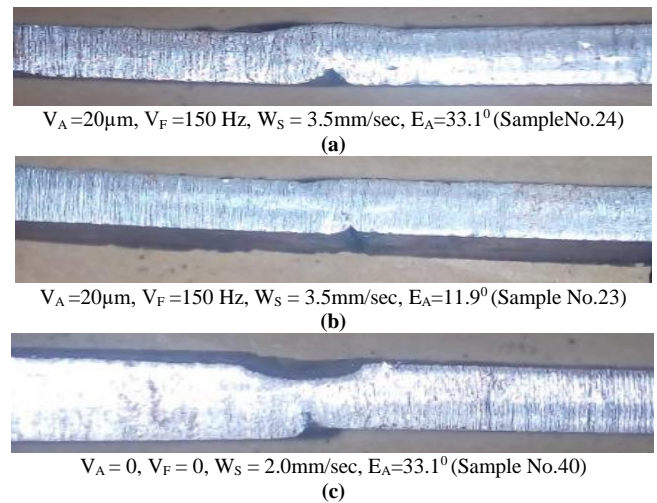


Fig. 17. Penetration change with electrode angle (a) less penetration (b) high penetration (c) less penetration (no oscillation).

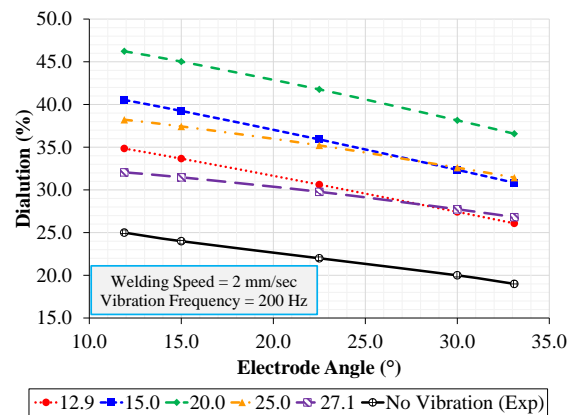


Fig. 18. Effect of electrode angle for different vibration frequency on Dilution

Fig. 18 shows less electrode angle with high frequency, Amplitude and less welding speed gives more dilution cause for higher penetration and less porosity in the joining point, amount of hot metal increases into the joining point and so it can dilute more area than high electrode angle with oscillation. Fig. 19(a) shows welding with high electrode angle dilutes less area than welding with less electrode angle shown in Fig. 19 (b). In Fig. 19(c), it shows dilution percentage is very low when the welding process is without oscillation.



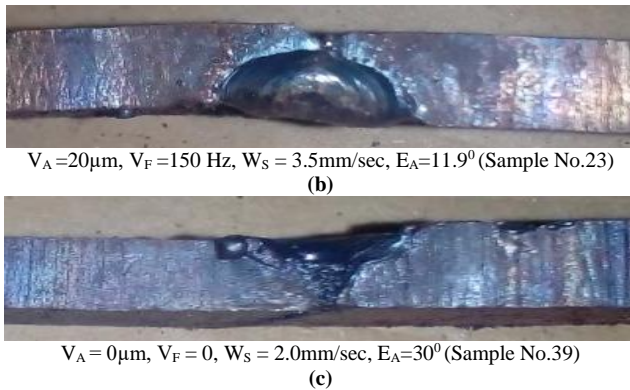


Fig. 19. Change of dilution with the variation of electrode angle (a) lower dilution (b) higher dilution (c) lower dilution (no oscillation)

#### IV. CONCLUSION

From the above discussion, it can be easily said that the input parameters- Amplitude, Frequency, Welding speed, Electrode angle have a very significant effect on welding process. It can be concluded that

- Input and output parameters shows that Bending Strength of a welded joint increases with the increase of amplitude & frequency but it decreases due to increase of Welding speed and Electrode angle.
- Vibration amplitude, frequency, welding speed and electrode angle control penetration level in the welded joint. These control input parameters in some specific ranges help to get complete penetration in joining the section, which provides the better joint than regular cases.
- Less welding speed, less electrode angle with high frequency and amplitude gives more dilution in the metal joint as for higher penetration and less porosity in the joining point, more hot metal enters and it dilutes more area than without oscillation.

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