Evaluation of Micro Hardness of Rotational Arc Welded HSLA Steel Specimens at Different Speeds & Vibrational Frequencies

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Abstract:

Metal Inert Gas welding (MIG) is a type of welding categorized under the domain of Arc welding which is used for adjoining ferrous and non-ferrous metals. Gas metal arc welding is a versatile process because of high deposition rates, ease of welding in all positions, requirement of less operator skill and adaptability to weld almost all metals which produces leak proof joint. A Traditional gas metal arc welding process is modified to a Rotational Arc Welding (RAW) by changing motion of the welding torch, where the electrode wire rotates at a rated speed in its own axis and propels the molten fluid into the walls of joints. Two similar HSLA steel specimens were welded by RAW process by using wire spool electrode and CO_2 as a shielding gas, at different rotational speeds of welding torch and by vibrating the work table at different vibrational frequencies. An enhanced properties were noticed especially upon micro hardness due to variations in weld bead geometry and refinement of grain boundaries, fine grain structures over weld region and HAZ of the samples are noticed.

Keywords: Rotational Arc Welding, P22 Steels, Vibrational Frequencies, Micro Hardness.

I. INTRODUCTION

Metal Inert Gas welding (MIG) is a form of Welding which is used for joining ferrous and non-ferrous metals. In which, an arc is formed between a consumable metal electrode and the work piece in an inert gas atmosphere [1]. The coiled electrode wire is fed by drive rolls at constant rate as filler material. The shielding gases commonly used are helium, argon, carbon dioxide and their mixtures. Rotational Arc Welding is a modified form of MIG welding, where the spool wire rotates among its central axis and due to the action of centrifugal force the molten metal droplets across the arc creating a consistent weld bead [2]. In order to meet the industrial requirement of high strength construction grade materials, High Strength Low Alloy Steels (HSLA) were developed that replaces low carbon steel. HSLA have improved mechanical properties such as “High strength-to-weight ratio, Toughness, Ductility, Weldability, Good Fatigue Resistance, Corrosion Resistance and Good Formability.” This fulfils the basic requirement of oil and gas pipe lines, storage tank, bridges, offshore structures, and automotive industry [4]. The objective of the vibratory setup is to transfer the vibration to weld-pool during the welding operation before the solidification of the molten metal in the weld pool. Vibratory welding technique is the process of transferring the vibrations into the molten weld pool through various modes of vibratory setup [3].

II. MATERIALS & EXPERIMENTAL SETUP

ASTM A335 Gr 22 or P22 grade steel (High Strength Low Alloy Steels) is used in this current study is certified and supplied by UTTAM Value Steels limited, Mumbai, Maharashtra in the form of flat plates of thickness 6 mm. The plates were sectioned into (300 x 60 x 6 mm) using hand cutter to prepare welding specimens using RAW process. The chemical composition (wt %) and properties of P22 grade steel material is given in the Table 1.

Table 1 Chemical Composition of P22 Grade Steel (wt%)

Element	C	Mn	Si	P	S	Cr	Mo	Fe
wt%	0.095	0.455	0.5	0.025	0.025	1.9	0.87	96.13

Table 2 Mechanical Properties of P22 Grade Steel

Parameter	Value
Tensile Strength	415 MPa
Yield Strength	205 MPa
Hardness	185 VHN
Toughness	64 J
Poisson's Ratio	0.33

To prepare butt joints upon rotational arc welding apparatus, a consumable steel electrode (Er70S6) solid filler wire of 0.8 mm diameter is used and its chemical composition (wt %) is given in the Table 3. The specimens were edge prepared with Single-V groove for sequence of weld passes (root pass and cover pass), before undergoing welding operation the edges were thoroughly cleaned to avoid any traces of contaminates. To minimize the effects of thermal distortions, to maintain groove geometry i.e., root gap throughout the joint the plates were tacked at ends of the specimen.

Table 3 Chemical Composition of Er70S6 Filler Wire (wt%)

Element	C	Si	Cu	Mn	S	V	Mo	Cr	Fe
wt%	0.105	0.975	0.3	1.625	0.025	0.35	0.035	0.045	96.54

The RAW machine consists of base support structure which holds base plates, corner supports, all these individual components which are assembled through welding to provide a rigid structure as a base support. The lead screws are inserted in the corner supports with the help of bearings. The two lead screws are supported by rod bearings. A support bar is placed over the lead screws and on which the mounting plates are placed with help of nuts. The bearing casing along with the centre coupling is placed in between the mounting plates. The welding nozzle is assembled through the centre coupling of the mounting plate. A driver and driven sprocket are assembled along with the chain drive for the rotation of the nozzle, where the rotation is be given by the motor placed in a motor hub. Two number of motors are used to provide the horizonal motion and welding torch rotation respectively. The sprockets are provided with chain mechanism at the end of the lead screws which gives the horizontal motion to the mounted assembly. Bolts and nuts are used as screwed fasteners which can be tightened to hold the mounting plates clearance and to clamp the workpieces firmly. Springs are used to provide cushioning effect at the work piece. A wire feed motor is used to give continuous spool wire as feed to the welding torch.

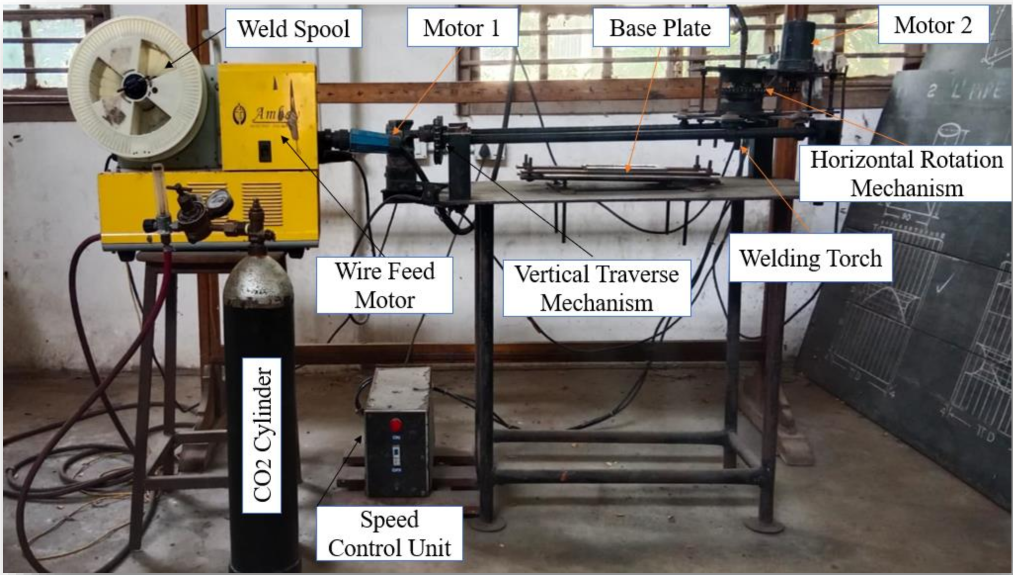

Figure 1 Typical Rotational Arc Welding Apparatus

Gases like CO2, Argon, Helium, etc., can be used as shielding gas to avoid the spattering of weld. The rate of gas flow is measured in Lit/min by a gas flow meter. A hose connects a regulating device to the gas solenoid contained in the wire drive. A typical rotational arc welding machine is shown in Figure 1.

III. METHODOLOGY

The two work pieces at a time were fixed on the table in a flat position. The welding torch would be allowed to move over the joint at uniform speed by striking the arc in the inert gas environment. The distance between the contact tip and work piece was maintained at 13 mm to 15 mm, the welding torch is at 90º, the welding conditions are shown in Table 4.

Table 4 Welding Conditions

Parameter	Value
Material	P22 Gr. High Strength Low Alloy steel
Filler Wire	Er 70 S6 Solid wire
Electrode diameter (mm)	0.8mm of Wire dia.
Polarity	DCRP
Shielding Gas	CO_2
Welding Arc Voltage (V)	22

The following sequence of steps are to be followed, P22 steel Specimens where edges should be prepared for butt joint are clamped to the base along with the surface level of the table rigidly without any loose connections with fixtures. The connections of the MIG welding setup, earth connection, wire feed mechanism, speed control unit and specimens are carefully verified and power is turned on. A tack welding should be done at the ends of the samples to avoid the irregularities due to thermal distortions.

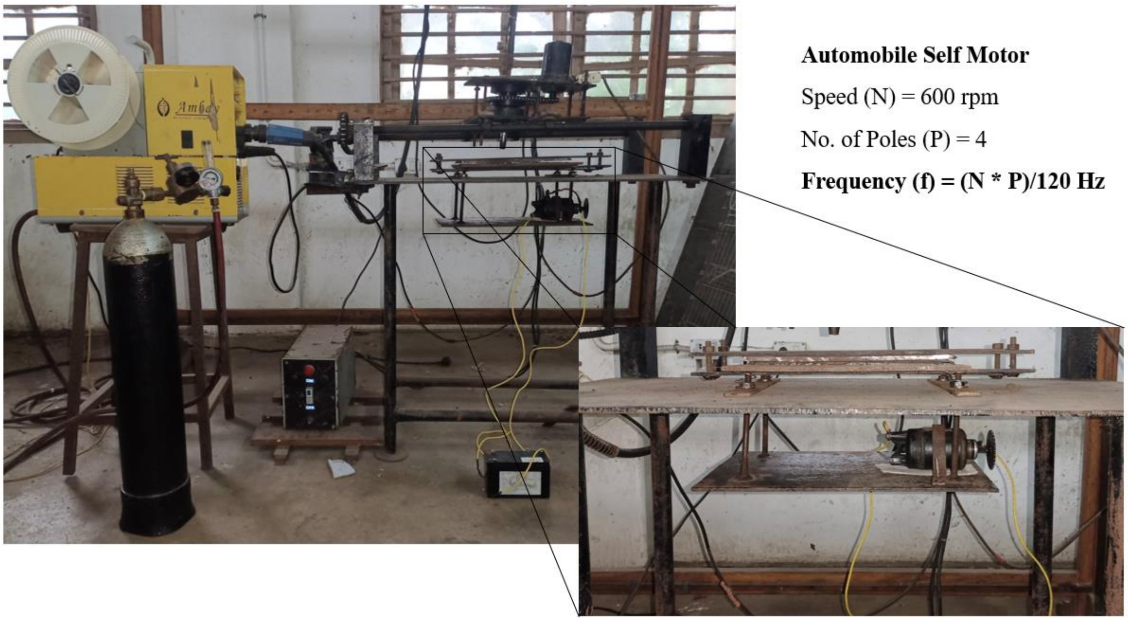

Figure 2 Rotational Arc Welding Apparatus with Vibrational Setup

Initially, without inducing any vibrations a set of specimens were welded using rotational arc welding by varying its rotational speeds (i.e., 90 (S1), 120 (S2), 150 (S3), 180(S4) rpm) under ideal conditions to make comparisons. Then by varying the frequency of vibrations (i.e., 0, 15 (F1), 30 (F2) Hz), welding is done to different sets of specimens at different rotational speeds. The vibration is introduced into the base plate by using vibro-motor setup as shown in Figure 2. Unclamp the specimens carefully and remove the slags, spatters etc., using chipping hammer and wire brush. The above procedure is repeated for all 12 samples in the experimentation phase. A root pass followed with capping pass at the should be maintained at a welding current, voltage and welding speed as tabulated in Table 5.

Table 5 Weld parameters for Root and Capping Pass

Welding Pass	Current (Amps)	Voltage (V)	Speed (m/min)
Root Pass	90-110	22-24	0.25
Capping Pass	120-140	22-24	0.25

Micro Hardness Test:

Hardness is a property of material, exhibiting the resistance to plastic deformation under a constant compression loading. Hardness test is performed upon the micro-Vickers hardness testing apparatus according to ASTM E-384 standard which specifies a load range indentation using a diamond indenter, the resulting indentation is measured upon its diagonals and converted in to a hardness number which is referred to Vickers Hardness Number (VHN). The most used indenters are of square base diamond pyramid type with an apical angle of 136º, so it is called as Knoop which means a narrow rhombus shaped indenter. Typical Micro Vickers Hardness Tester is shown in Figure 3.

Figure 3 Micro Vickers Hardness Apparatus

The result for Vickers or Knoop micro hardness is reported in terms of Kg/cm^2 which is relatively expressed as applied load per square terms of the diagonal of the indentation acquired from the test. Following ASTM E3 standards, the sample from the welded joints is considered which is defect/ void free and sectioned into required dimensions. The samples were sectioned using hand cutting machine, as per the dimensions. Later the specimens should be grinded in order to avoid sharpen edges using grinding wheel. The specimens must be thoroughly cleaned and the surface should be flat along the cross-section at both sides of the specimen. The sample utilized for the evaluating micro hardness is shown in Figure 4 along with a measuring rule. The specimens must be thoroughly cleaned and the surface should be from defects or voids along the cross-section.

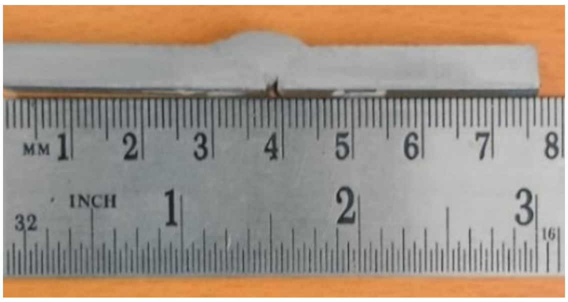

Figure 4 Sample for Micro Hardness

To locate the indentation upon the specimens, they should be thoroughly polished to attain a mirror finish upon a sequence of grit papers (i.e., 80, 180, 220, 320, 400, 600, 800,

1000) using double disc polishing machine, following with velvet cloth polishing using abrasive Al_2O_3 for a smooth finish. The measurement of hardness is made on the polished surface of weld zone, heat affected zone (HAZ) and base material by means of diamond shape indentation.

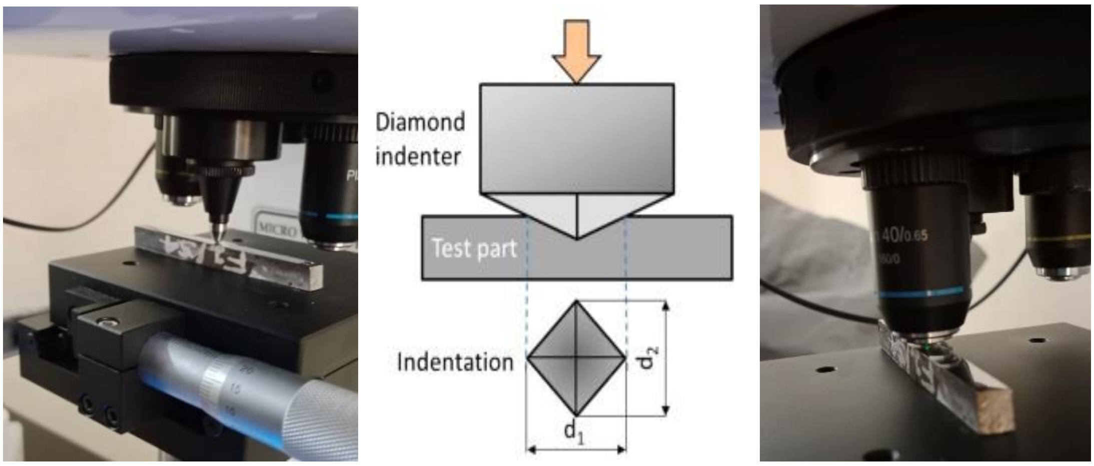

Figure 5 Applying 0.5 kg load and locating the indentation

Firstly, the indentation is made on the required location at a load of 500 grams for a dwell period of 8 seconds as shown in Figure 5. Over a selected region at least three impressions must be noted and the same procedure should be followed for all the regions for considerations over the uniform intervals in the linear transverse direction. The hardness values of the specimens at various regions must be tabulated for further interpretation.

IV. RESULTS & DISCUSSION

Micro Vicker's hardness test results depend on the applied load, dwelling duration, and indention dimensions. Hence, for this test, 0.5 Kgf was applied for 8 sec to indent on the P22 Gr. HSLA steel welded joint specimens. Once the Vickers indenter made a pit on the specimen in a form of the diamond shape pyramid, the cross hairs of micro-Vickers's instrument lens were adjusted to the both edges of diagonals. The readings were taken on the weldment, heat affected zone (HAZ) and base metal upon three measuring points and average of these three readings were considered at each point are tabulated and plotted. Hardness for the specimens upon the cross section with varying rotational speeds is tabulated in Table 6.

Table 6 Hardness for welded specimens at varying rotational speeds

Specimen Id	Rotational Speed (rpm)	BM	HAZ	WZ	HAZ	BM
		-4	-2	0	2	4
P22/S1	90	176.4	190.66	181.58	190.3	177.3
P22/S2	120	177.3	193.09	184.58	191.15	176.8
P22/S3	150	177.1	196.66	186.23	195.12	178.1
P22/S4	180	179.4	197.76	191.24	197.64	179.4

where the microstructure showed the evidence of equisized coarse grain's structure upon the base material having less hardness of 176 VHN however, in HAZ is more and dementia is found in WZ respectively with fine grain size of binate structure where the hardness is improved then BM, the graphical representation is shown in Figure 6.

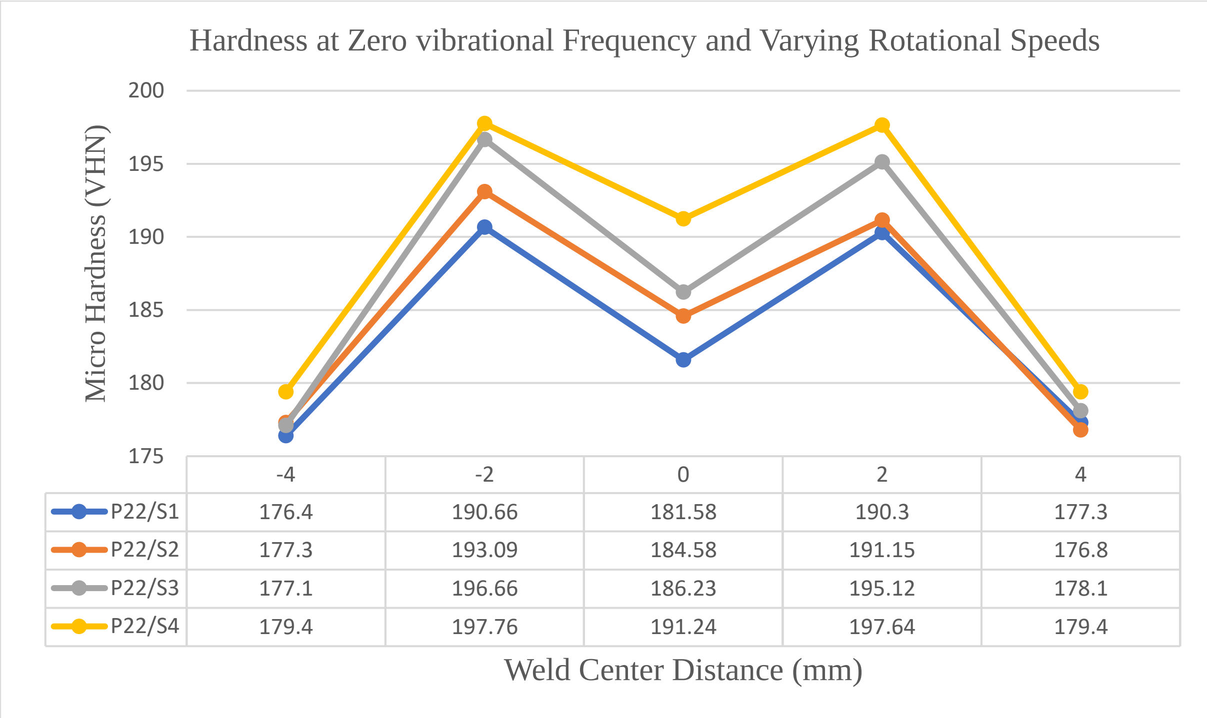

Figure 6 Hardness at Zero vibrational Frequency and Varying Rotational Speeds

While introducing the vibrations of 15 Hz frequency into the welding process at varying rotational speeds an improved hardness number is noticed and all the readings measured from the weld centre were tabulated in Table 7.

Table 7 Hardness at 15 Hz frequency & varying rotational speeds

Specimen Id	Rotational Speed (rpm)	BM	HAZ	WZ	HAZ	BM
		-4	-2	0	2	4
P22/F1/S1	90	177.5	193.94	187.25	194.51	175.3
P22/F1/S2	120	179.4	197.3	190.24	196.67	176.1
P22/F1/S3	150	177.6	195.66	193.9	199.28	176.8
P22/F1/S4	180	176.4	200.97	193.8	203.74	177.5

The hardness at weld region was improved from 187.25 VHN to 193.8 HNV while increasing the rotational speed from 90 rpm to 180 rpm at 15 Hz vibrational frequency, the hardness of the HAZ is also improved from 193.94 VHN to 200.97 HNV at -2 mm distance from the weld centre whereas 194.51 VHN to 203.74 HNV at 2 mm distance from the weld centre due to refined grains evolved during welding process, the graphical representation is shown in Figure 7.

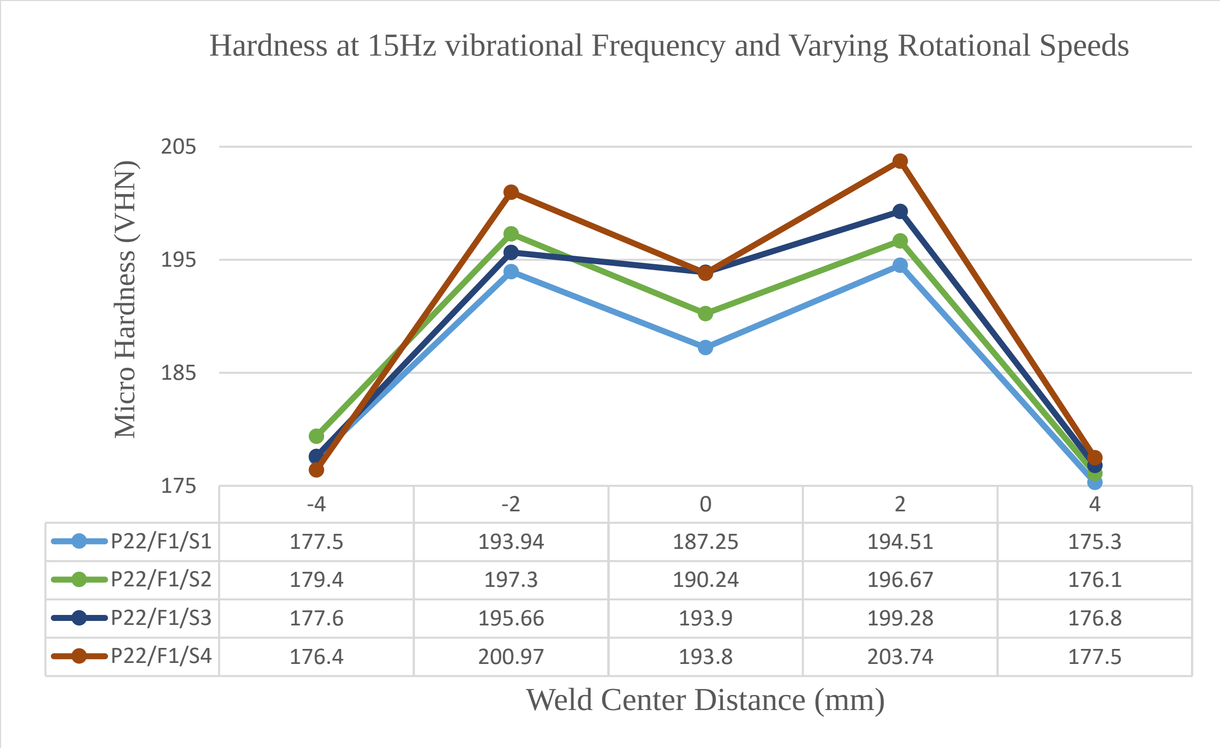

Figure 7 Hardness at 15Hz vibrational Frequency and Varying Rotational Speeds

While increasing the vibrational frequency to 30 Hz at different rotational speed the similar trend is noted but with an improved hardness number. The readings were tabulated in Table 8.

Table 8 Hardness at 30 Hz frequency & varying rotational speeds

Specimen Id	Rotational Speed (rpm)	BM	HAZ	WZ	HAZ	BM
		-4	**-2**	**0**	**2**	**4**
P22/F2/S1	90	176.5	198.13	189.4	201.09	178.6
P22/F2/S2	120	179.1	201.46	191.5	203.35	176.5
P22/F2/S3	150	177.3	202.22	195.1	202.98	180.4
P22/F2/S4	180	176.4	206.05	196.9	204.13	179.4

The hardness at weld region was improved from 189.4 VHN to 196.9 HNV while increasing the rotational speed from 90 rpm to 180 rpm at 15 Hz vibrational frequency, the hardness of the HAZ is also improved due to high heat transfer interaction and immediate air cooling from 198.13 VHN to 206.05 HNV at -2 mm distance from the weld centre whereas 201.09 VHN to 204.13 HNV at 2 mm distance from the weld centre due to refined grains evolved during welding process, the graphical representation is shown in Figure 8.

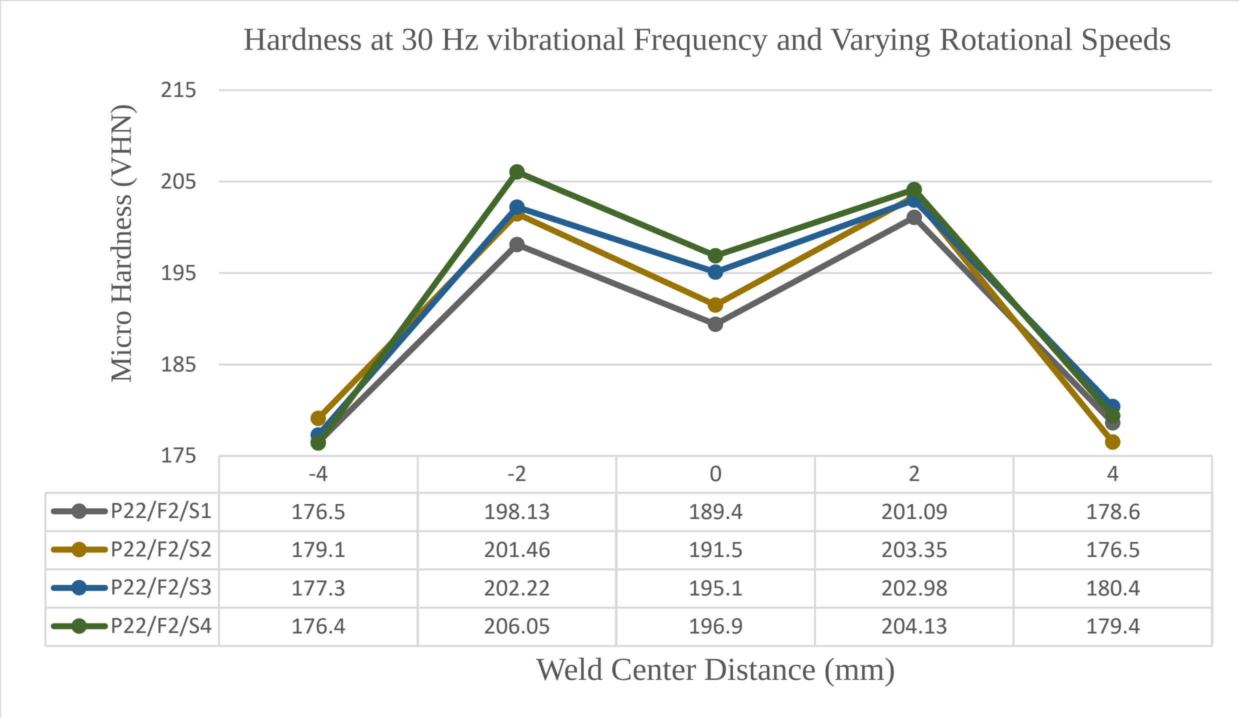

Figure 8 Hardness at 30 Hz vibrational Frequency and Varying Rotational Speeds

The hardness at weld region over various rotational speed and vibrational frequencies are plotted in the Figure 9, which shows that with increase in these input process parameters the thermal interaction enhances the grain structure and exhibits more hardness and the density of Allotriomorphic Ferrite grains was also decreases which are studied in metallurgical studies. The hardness more than base material but less than the Heat affected region.

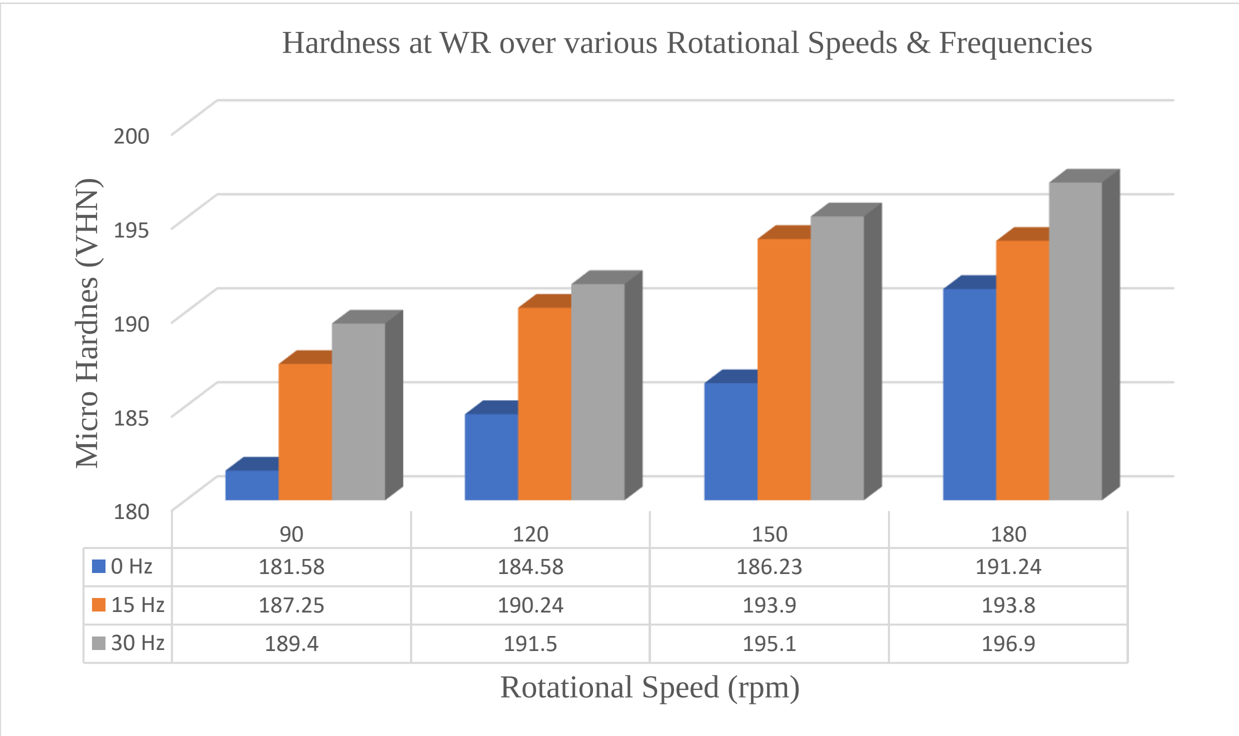

Figure 9 Hardness at WR over various Rotational Speeds & Frequencies

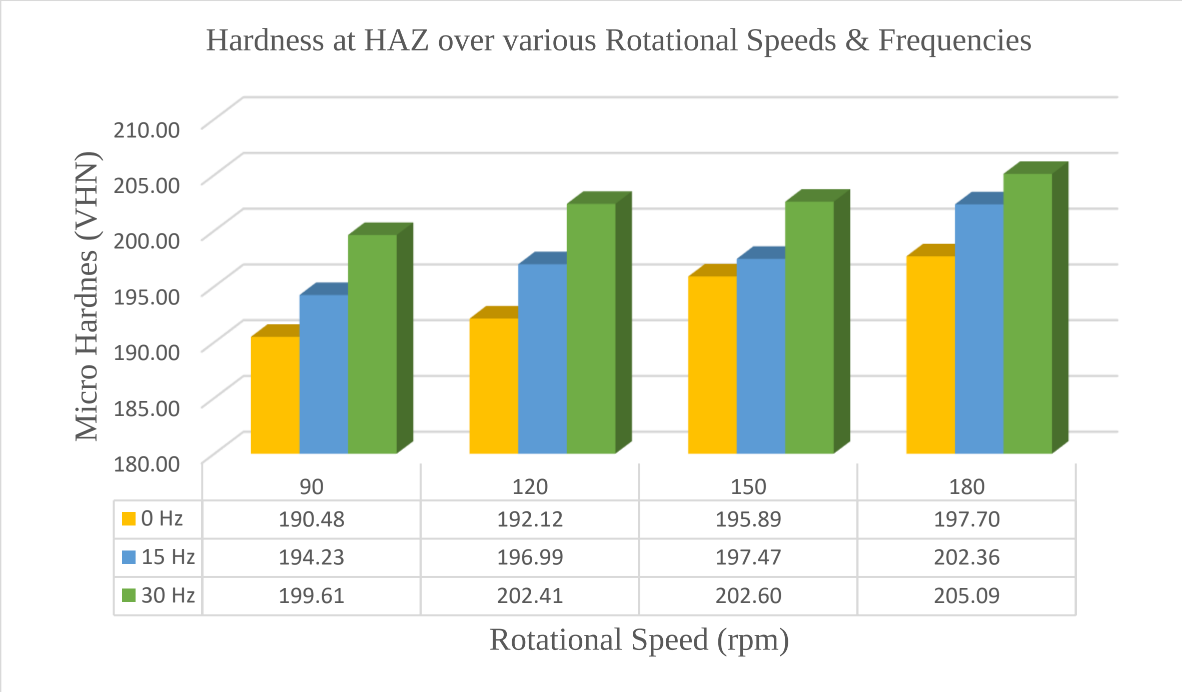

Figure 10 Hardness at HAZ over various Rotational Speeds & Frequencies

Similarly, the hardness at HAZ over various rotational speed and vibrational frequencies are plotted in the Figure 10, which shows that with increase in these input process parameters the thermal interaction enhances the grain structure and exhibits more hardness. The hardness more than base material and WR.

V. CONCLUSIONS

Vibrations in welding process can be employed to improve the mechanical characteristics, weld penetrations and reduces the density of residual stresses etc., torch rotational speed and base plate vibrational frequency are major factor considered for the study. An improved hardness from 189.4 VHN to 196.9 HNV while increasing the rotational speed from 90 rpm to 180 rpm at 15 Hz vibrational frequency Due to formation of fine structure in the WR and HAZ the hardness has been improved with 195 VHN and 205.6 VHN respectively at 180 rpm rotational speed and 30 Hz frequency when compared to weld region and the base metal. It can be concluded that a moderate increase in both the parameters i.e., torch rotation speed (with in a range of 140 rpm to 190 rpm) and base plate vibrations (15 Hz) in case of MIG welding) could effectively improve the hardness of the welded joint, VWC could avoid post welding operations with a minimal welding defects.

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