Hardness Analysis of P11 Alloy Steel Welded in Rotational Arc Welding at Different Torch Inclinations

Venkata Dasaradha Rama Voota[1], Vara prasad Vemu[2]
Jawaharlal Nehru Technological University, Kakinada, India.
Department of Mechanical Engineering
vvdrama.1@gmail.com[1], varaprasadv@jntucek.ac.in[2]

Abstract:

Rotational arc welding is similar to the Metal Inert Gas (MIG) Welding, the main difference is the torch is allowed to rotate at a specified speed so that the weld penetration would be more and the weld strength is comparatively high. The rotating torch is also inclined at different angles. Rotating the torch at different speeds and inclining the torch will result variable mechanical properties in the weld bead. P11 high strength low alloy steel which is used in pipeline applications is to be welded with ER-70S-6 filler wire and CO2 is used as shielding gas. The main objective of this work is to investigate the mechanical properties of the P11 alloy steel which is welded at different speeds and different inclinations using rotational arc welding process.

Key words: Rotational arc welding, Metal Inert Gas (MIG) Welding, P11 high strength low alloy steel, ER70S-6 filler wire and CO2 Shielding gas.

I. INTRODUCTION

Welding is a process of joining two similar or dissimilar materials permanently by using heat, pressure, or both. This process is mostly used for making permanent joints. In the welding sector, Mig welding is a widespread variety of welding process. The molten droplets near the tip of the welding wire are transported into the weld pool by the combination of active forces such as gravity, surface tension, electromagnetic force, viscous drag force, and arc pressure during the welding process. In rotational welding technique, the wire's motion was enhanced not only to feed downward but also to rotate along its central axis. The arc is rotated constantly at a specified speed during welding in an arc rotation mechanism system, which results in a flat and wide weld bead due to the centrifugal force of the revolving arc, and the penetration profile may also be improved. In some cases, inert gas or shielding gas may be used. Use of shielding gas in welding improves the quality of the weld bead by protecting it from the environmental changes. Depending on the substance of the workpiece, shielding gases such as argon, helium, nitrogen, carbon dioxide, hydrogen, and their mixes are utilized. These gases are utilized to keep the atmosphere away from the heat-affected zone and molten metal. Additionally, these gases regulate arc characteristics, metal transfer method, weld bead, and penetration profile, tendency for undercutting, cleaning behavior, and welding speed. Numerous sectors, including those in the automotive, building, general fabrication, pipeline, offshore, aerospace, shipbuilding, clad overlay, and storage tanks, use the rotation arc welding method. Because of improved sidewall fusion, rotating arc welding allows for deep narrow groove welding. The machine is as shown in Fig 1.1.

Fig.1.1 Rotational Arc Welding Machine

II.MATERIAL CHARACTERISTICS

2.1 Base material:

The material used for the present work is a type of high strength low alloy steel which is designated as ASTM A335 Gr.11, simply known as P11 steel. The steel alloy comprises 1.25% chromium and 0.5% molybdenum, thus the designation is given as1 1/4 Cr- 1/2 Mo. The Chromium has high thermal strength, enhanced oxidation resistance, and increases tensile strength, yield strength, and hardness at room temperature. Molybdenum increases the strength, elastic limit, wear resistance, toughness characteristics, and hardenability of P11 material. Molybdenum is essential for improving high temperature creep strength and enhancing the material's corrosion resistance. Due to the ferrimagnetic characteristics of iron, a few steel alloys in A335 P11 pipes can be used in applications where their reactions to magnetism are important. This includes transformers and electric motors. P11 is also a popular grade for many different applications such as: Spacecraft, Turbine blades of jet engines and nuclear reactors. [1]. The chemical composition of the P11 material tested and certified by UTTAM Value Steels Limited, Mumbai, Maharashtra as in following Table 1.

Table 1. Element composition

C	Mn	P	S	Si	Cr	Mo	Fe
0.14%	0.60%	0.012%	0.005%	0.75%	1.37%	0.50%	96.6%

2.2 Filler material:

The filler metal in the form of an electrode wire was employed to complete the joint. Due to the opposite polarities, an arc is produced when the electrode approaches the workpieces. In the heat of the arc, the electrode wire melts and fills the weld groove along the base metal. As a result, the electrode wire is a consumable that works as a filler in addition to creating and sustaining the arc throughout the welding process. The filler wire selection must be compatible with the base metal so that property changes are not so high to minimize flaws once the weld settles. In the current project, a ER70S-6 wire spool with a diameter of 0.8 mm is employed as the filler material. The composition of the filler material used in this welding is shown in Table 2 in percentages.[2]

Table 2. Element composition of filler material

C	Mn	Si	P	S	Ni	Cr	Mo	V	Cu	Fe
0.08	1.45	0.98	0.025	0.035	0.15	0.15	0.15	0.03	0.50	96.45

III. METHODOLOGY

3.1 Groove preparation:

The material in the form of large plates is cut into the dimensions of 30cm X 5cm X 0.6cm. then Surfaces of the workpieces were properly cleaned before welding to remove dirt and oil by using a grinding machine. Welding grooves include V-shaped grooves, U-shaped grooves, Double V, Double U, J, and Double J grooves. For a strong welding joint, edge preparation is essential when combining thick plates. It is usually desirable to have a smaller volume of groove size. A smaller groove volume results in reduced HAZ and better mechanical characteristics. Because of the ease of edge preparation, single V groove may be employed in the majority of circumstances. The edge preparation includes grinding the edge of working plate at 30 degrees so that two edges will form a V groove.

3.2 Torch Inclination:

The rotating torch in the rotational arc welding machine was provided with some special attachment to get the torch inclination. There washers were used to make the whole torch setup to be inclined. Each washer of 2mm thickness provides an inclination of 2 degrees, so that 2 and 4 washers are used as shown in fig. to obtain an inclination of 4° and 8° respectively. The rotating torch in the rotational arc welding machine was provided with some special attachment to get the torch inclination [3]. There washers were used to make the whole torch setup to be inclined. Number of washers of 1mm and 2mm thickness are used as shown in Fig.3.1 to obtain an inclination of 3° and 6° respectively.

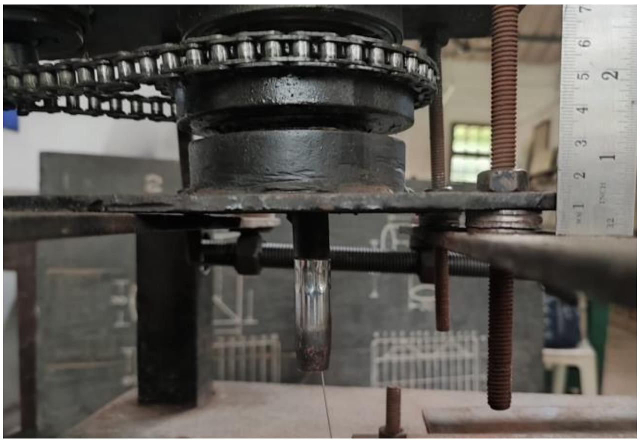


Fig.3.1. Inclination attachment

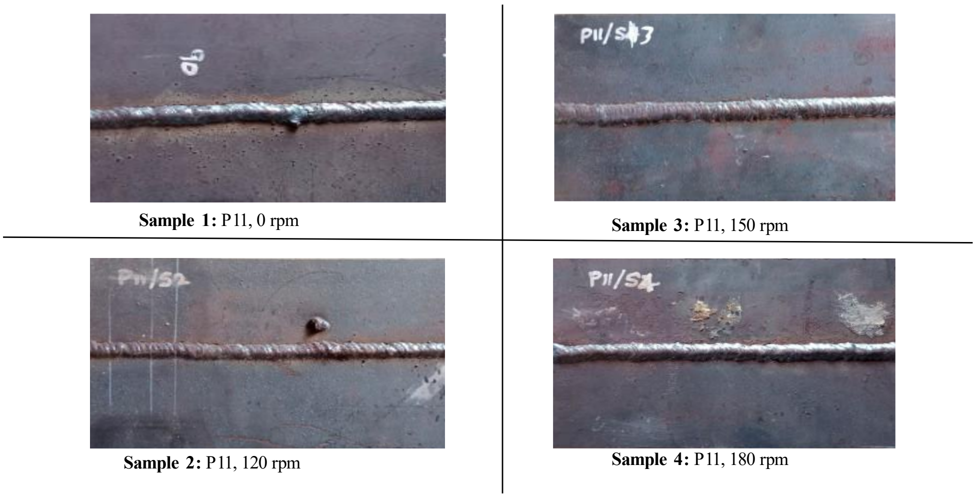
The use of washers made the height of one side of the welding torch setup mounting plate is increased by 10mm whi1ch will gives an inclination to the torch.

The height raised 10mm becomes the opposite side to the angle and the 100mm of mounting plate becomes the adjacent side of the angle. By using Trigonometric formulae, the value of that particular angle can be measured by using Tangent rule.

Here the angle is 6° for a washer's raised height of 10mm so that a 5mm of raise will gives the 3° of inclination. The mounting base plate of the welding torch and the welding torch are perpendicular to each other and the inclination obtained by washers to the mounting base plate is same as the welding torch inclination. Whenever the base gets inclined at 6° with the help of washers, it will give raise to the same inclination of 6° to the welding torch. both the work angle and torch angle are proportional [4].

3.3 Welding Process:

The two workpieces that are to be welded are placed on the work table and fixed in a flat position. Arc is generated between the electrode wire and the workpiece so that the filler material joins the two workpieces. The electrode wire at the weld pool, as well as the weld pool itself, are shielded from environmental contamination by shielding gas (CO_2) pumped onto the weld zone. The torch is rotated at different speeds such as 120rpm, 150rpm, 180rpm to get different weld beads. These are to be compared with the weld bead that is produced without rotating the welding torch. Also, the same procedure is carried out at different angles of 4° and 8° to investigate the weld bead mechanical properties.



Sample 1: P11, 0 rpm

Sample 3: P11, 150 rpm

Sample 2: P11, 120 rpm

Sample 4: P11, 180 rpm

Fig.3.2 Welded specimens without torch inclination

The specimens welded at different rotational speeds and without any inclination of torch are shown in the Fig.3.2. Next, the torch is inclined at 3° by using inclination attachment as discussed in the before topics, the welded specimens are shown in Fig.3.3.

Finally, the inclination of the torch is increased to 6° by increasing the washer's height and the welding is carried out. The welded specimens at 6° of inclination are as shown in Fig.3.4.

Sample 5: P11, 3°, 0 rpm

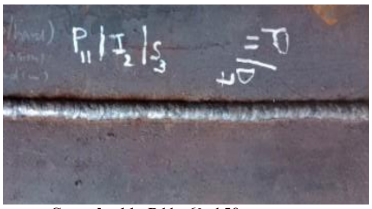
Sample 7: P11, 3°, 150 rpm

Sample 6: P11, 3°, 120 rpm

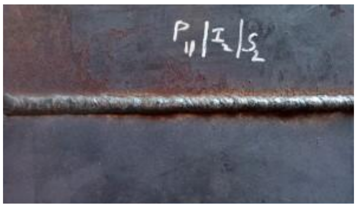
Sample 8: P11, 3°, 180 rpm

Fig.3.3 Welded specimens with 3° torch inclination

Sample 9: P11, 6°, 0 rpm



Sample 11: P11, 6°, 150 rpm



Sample 10: P11,6°, 120 rpm

Sample 12: P11, 6°, 180 rpm

Fig.3.4 Welded specimens with 6° torch inclination

3.4 Hardness test:

Micro Vickers is a hardness test for all solid materials, including metallic materials. The Vickers Hardness (HV) of a material is measured by measuring the diagonal lengths of an indentation left by introducing a diamond pyramid indenter with a particular force. In order to evaluate the hardness, the diagonals of the impression are optically measured. When using the Micro Vickers hardness testing method, it is usually necessary to prepare the surface of the specimen to be tested. So, the surface is grinded and polished to obtain a mirror finish by using disc polishing machine. We also used alumina powder along with red velvet cloth to get smooth surface finish. Firstly, the specimen is placed in the micro-Vickers hardness testing machine and induced a load of 0.5kgf into the specimen using the diamond indenter in it. After the application of load the diagonals of the rhombus shaped indenter are measured using the optical attachment in the machine. From these diagonal values, the hardness value is displayed on the digital display of the Micro Vickers hardness testing machine.

IV. RESULTS & DISCUSSIONS

The hardness is evaluated at three positions such as Base material (BM), Heat affected zone (HAZ) and the Weld region (WR). The hardness values of the specimens welded at different speeds without inclining the torch are shown in Table.4.1.

Table.4.1: Hardness values at 0° inclination

Rotational speed (rpm)	BM	HAZ	WR	HAZ	BM
	-6	-3	0	3	6
0	201.7	207.1	211.53	206.7	200.77
120	199.2	212.17	217.83	211.33	198.33
150	201	213.47	218.07	213.07	199.7
180	198.73	214.03	219.93	213.33	200.17

The hardness is improved in HAZ region from 206HV to 214HV. While the hardness at weld region is gradually increases on increasing the rotational speed of the torch from 211HV to 219HV. The hardness values at various regions is plotted in a graphical representation showing the effect of rotational speed on hardness values in Fig.4.1.

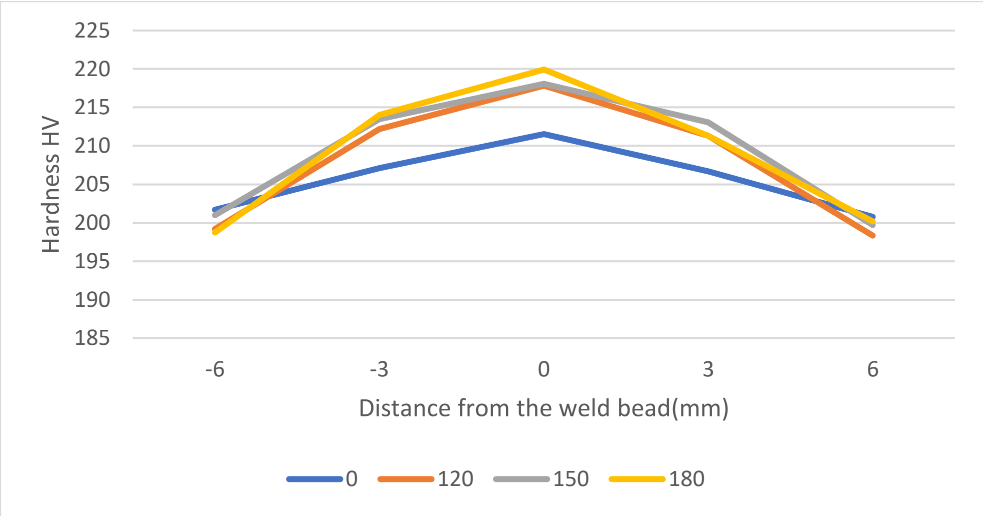


Fig.4.1. Graphical representation of hardness for specimens without inclination

The Table.4.2. shows the values of hardness for specimens welded at 3° of welding torch inclination and different weld speeds.

Table.4.2: Hardness values at 3° inclination

Rotational speed (rpm)	BM	HAZ	WZ	HAZ	BM
	-6	-3	0	3	6
0	199.7	210.7	212.87	209.93	201.2
120	200.17	212.93	218.13	212.97	198.37
150	200.77	214.5	219.5	214.7	199.67
180	201.7	216.43	221.13	216.9	200.17

The hardness value at the HAZ is improved from 210HV to 216HV as 3mm distance from the weld. The hardness at the weld region is improved when compared to the previous specimens welded at 0° inclination of torch. The hardness values at various regions is plotted in a graphical representation showing the effect of rotational speed on hardness values in Fig.4.2.

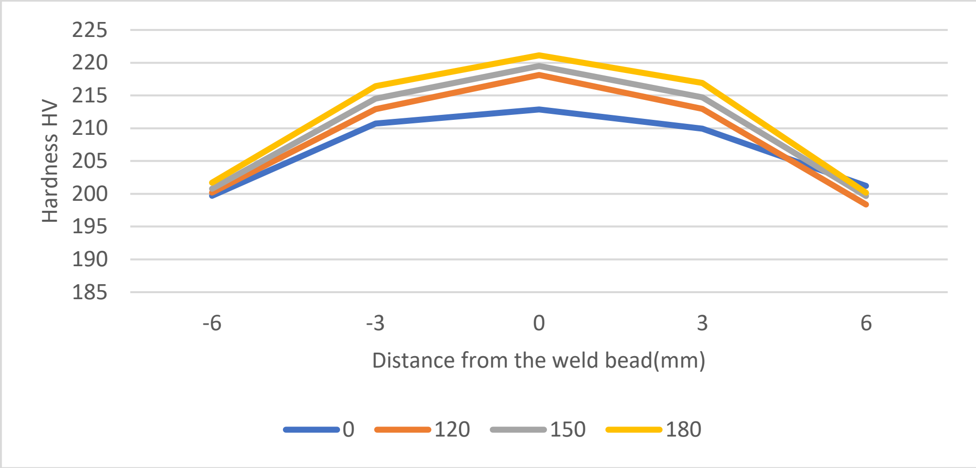


Fig.4.2. Graphical representation of hardness for specimens with 3° of inclination

The hardness values for specimens welded at 6° of torch inclination and different rotational speeds are tabulated as in Table.4.3. It is represented in the graph as in Fig.4.3.

Table.4.3: Hardness values at 6° inclination

Rotational speed (rpm)	**BM**	**HAZ**	**WZ**	**HAZ**	**BM**
	-6	-3	0	3	6
0	199.7	212.1	215.87	211.33	200.77
120	201	213.83	219.8	212.97	198.53
150	201.33	216.27	223.6	215.83	199.7
180	201.7	217.43	225.13	217.23	200.5

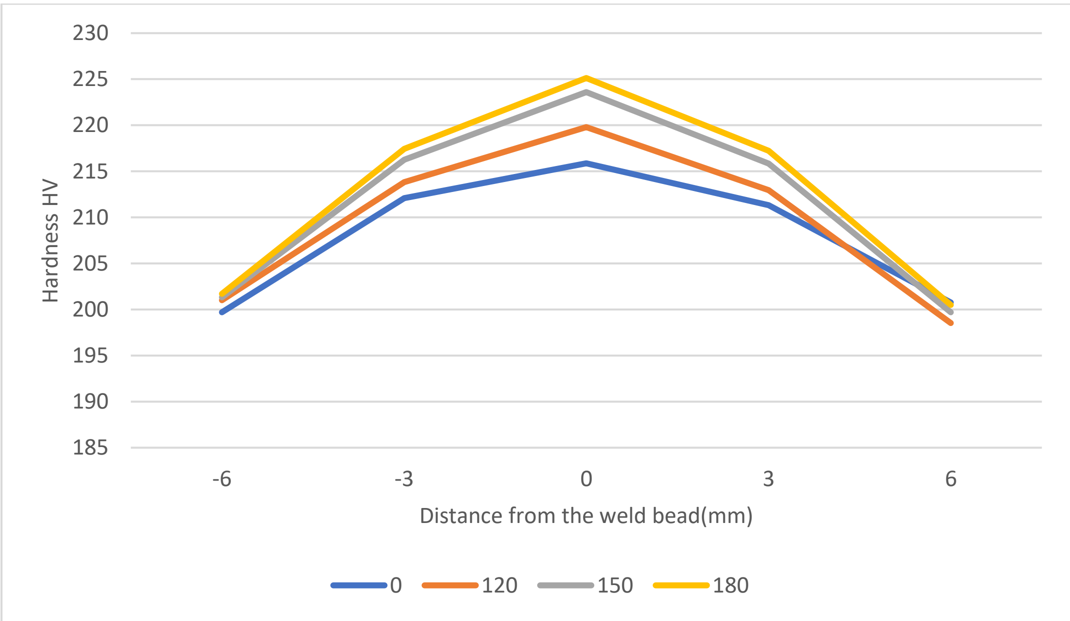
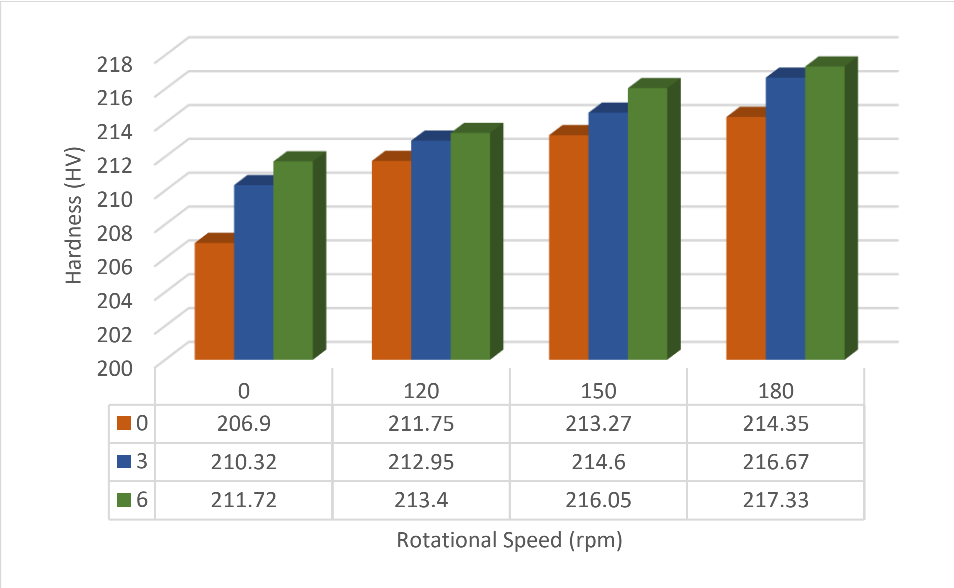


Fig.4.3. Graphical representation of hardness for specimens with 6° of inclination

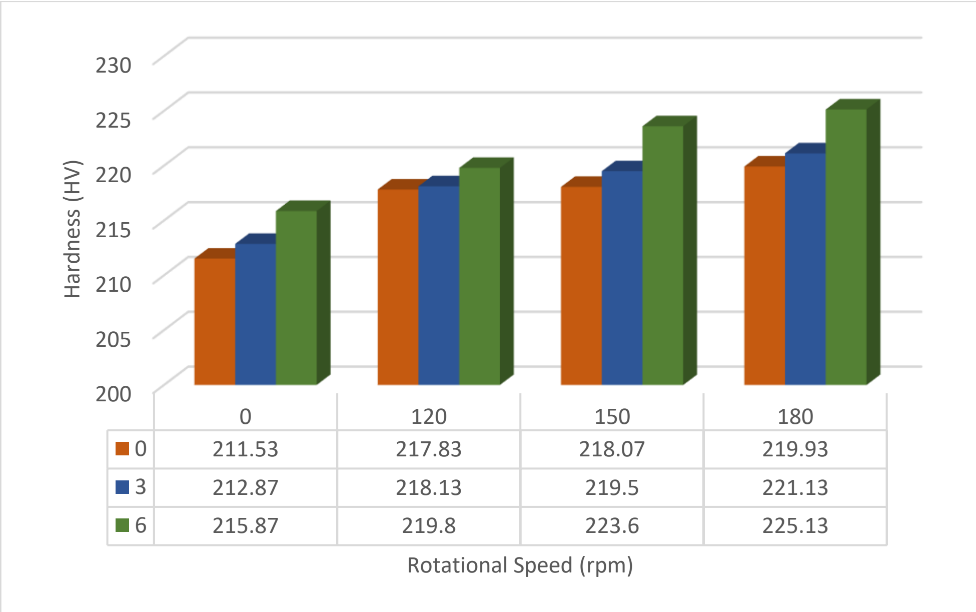
While increasing the inclination angle from 0 to 6 degrees, the hardness value has been improved from 206.9 HV to 217.33 HV with respective to rotational speed from 0 to 180 rpm. It is shown in the bar graph in Fig.4.4. The higher hardness was measured at HAZ than base metal indicating that the strengthening had occurred due to welding process. It was also supported by precipitation of Cr-rich carbides and sensitization of the grain boundary in this region.

While increasing the inclination angle from zero to 8 degrees, the hardness value has been improved from 211.53 VHN to 225.13 VHN with respect to rotational speed from 0 to 180 rpm. The comparison of hardness at the weld region is represented as bar chart in Fig.4.5.



	0	120	150	180
0	206.9	211.75	213.27	214.35
3	210.32	212.95	214.6	216.67
6	211.72	213.4	216.05	217.33

Fig.4.4. Hardness values at HAZ for various rotational speeds and inclination angles



	0	120	150	180
0	211.53	217.83	218.07	219.93
3	212.87	218.13	219.5	221.13
6	215.87	219.8	223.6	225.13

Fig.4.5. Hardness at Weld Region for various rotational speeds and inclination angles

CONCLUSIONS:

The hardness of the material is improved in both the HAZ and weld regions. Due to this the material can bear more tensile load and bending load on it. The Vickers hardness at the normal welding situations that is without inclination and without torch rotation is 206.9HV and 211.53HV at HAZ and weld regions respectively. These are improved to 217.33HV and 225.13HV at 6° and 180rpm. So that an increase of 5.04% hardness in HAZ and 6.42% of increased Vickers hardness in weld region is obtained.

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