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Experimental Investigation For Process Parameter Optimization Of Rotating Arc Welding Of A106 Pipe

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Abstract:
Rotating Arc Welding (RAW) is a solid-state welding technology that uses a high-speed rotating arc to provide heating effect to form a weld. When compared to other standard welding procedures for pipe welding, this method takes less time and consumes less electricity. This study was conducted to investigate the joining of ASTM A106 grade B steel pipes using RAW method. The experiments were carried out by using a custom-designed and developed RAW welding setup. The trials involved changing the process parameters and understanding their impact on the joint strength and hardness in order to determine their optimal range. The key parameters considered in this study were welding current, upsetting pressure, and welding time. It is observed that the welding current has a considerable influence on the mechanical properties of the welds. A higher welding current of 220A resulted in a lower tensile strength but higher hardness when compared to welding current of 190A. The optimal tensile strength was obtained with a welding current of 190 A, at an arc rotation time of 30 s and an upsetting pressure of 6 MPa.

Keywords: RAW welding, MIAB welding, magnetic field, A106 Pipe material

1. Introduction

Rotating Arc Welding, also known as Magnetically Impelled Arc Butt (MIAB) welding, is a specialized pressure welding process for joining pipes and tubes. When a rotating electric arc heats the pipe faces to red hot state, pressure is applied to upset them and produce a welded junction. The Fig.1 depicts a schematic of the pipes to be welded

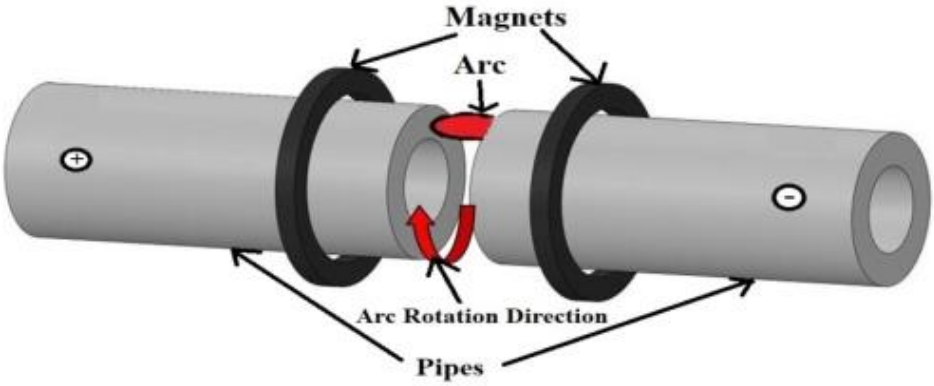


Figure.1: Rotating Arc Welding Process.

The rotation of the arc is caused by the electromagnetic field produced by the magnetic system and the welding current. The arc spins at speeds of 200 m/s or higher which is proportional to the supplied current. The RAW process eliminates the need of both the electrode and the shielding gas, resulting in a sound weld joint thereby making it one of the most successful welding techniques. The flash developed on the pipe's surface is removed by grinding operation.

The RAW process was invented in Europe in the 1950's and various advances were made to explore the benefits of this welding process, which was later labeled as industry-friendly welding technology. Since the 1980s, this approach has been used in the automotive industry to manufacture hollow components such as pneumatic springs, shock absorbers, brake rods, economizer coils, boiler heat exchangers, and so on. [1–3,5].

When compared to other solid-state welding methods, this approach has numerous advantages, including no component rotation, no need of surface preparation, filler metal, or shielding gas, little material loss, lower energy input, cost efficiency, faster weld cycle and reliability. This welding process consists of four major stages: current flow in pipes, arc initiation and stability, stable arc rotation, and upsetting [3]. These stages are as follows:

1. **Stage I**

The pipes are clamped and brought together so that they are in contact with each other and the current flows through them.

2. **Stage II**

The pipes are then retracted which produces a rotating arc in the gap. This rotating arc will be produced only when there is a minimum gap of 2 mm in the presence of the applied current [4].

3. **Stage III**

The arc rotation gets stabilized after a specific time and produces heating effect on the pipe surfaces. Through the literature survey[3,4], it is known that the arc rotation is due to the interaction of the current and the magnetic field which causes the arc to move along the faying surface and in zigzag fashion [5]. This heating causes the temperature to rise in the weld region and the pipe material at the periphery reaches a plastic state.

4. Stage IV

Subsequent to the plastic state, the two pipes are forged together due to the application of an upsetting pressure. The arc disappears as the pipes are brought together for forging. The impurities having lower melting point temperature get excluded out of the joint and forms weld bead. This expelled impurity is deposited on the weld face in form of a flash and referred as reinforcement [2,3].

Initially, the arc velocity grows linearly [7] as it passes from the inner diameter to the outside diameter of the pipe. As the time passes, the arc achieves a stable speed on the faying surface, resulting in an appearance of spinning ring. Heating of the pipe's periphery is carried out until it causes localized melting, after which a quick jump of spark causes the arc to become unstable. This is because the molten material creates a bridge between the pipes. This instability in the rotation of arc [1-3,5,8] causes arc quenching. Because of the localized heating and melting, the microstructure and grain boundaries of the material reorganize, affecting the mechanical characteristics of the surface. At this juncture, the pipes are forged together using upsetting pressure to create an effective welded junction.

The major limitation of this welding technique is the thickness of the pipe, which is limited to around 10mm and has restricted the adaptability of this process in the manufacturing industry. This limitation has led to the research about the feasibility of this technique and for further design, development of MIAB welding setup for welding pipes with larger thicknesses. This process can be applied only for ferrous materials because the external magnetic field is considered as the basis of arc rotation. The magnetic field distribution relies on the gap between the pipes and the position of the magnets [9,10].

The movement of the arc from inner to outer surface frequently may lead to non-uniform heating which effects the quality of weld [14,15]. So, the design of the electromagnetic system in the MIAB system is crucial as magnetic flux density affects the arc rotation. The magnetic flux density relies on the current, the gap between the pipes, the position of the coil and the relative permeability of the material to be welded [16]. A high arc rotation speed is required in this technique to avoid fluctuation in temperature during every rotation cycle. The radial magnetic flux density is directly proportional to the linear arc speed [15]. During arc initiation, it is observed that the arc is pushed towards inner diameter (ID) which is due to the effect of magnetic blow which creates stronger magnetic field around outer diameter (OD)[17].

The speed of arc rotation mainly depends on the intensity of arcing current and the intensity of magnetic field[18]. For pipes with larger thickness, the speed of arc is slow at inner region compared to that of outer region which deteriorates the quality of weld [13,14]. In order to achieve excellent weld quality, the frequency of arc rotation must be higher to avoid immediate solidification of the soften metal. This high-speed revolving arc raises the temperature, resulting in extensive metal evaporation [3]. The metal evaporation creates a barrier that inhibits the oxidation of plasticized metal surfaces.

The literature survey reveals that in the past research, there was no systematic study of the process parameters and their effect on the welded joint. The researchers performed random trials and experiments as per the requirement so there was a need for a study, which could explores the significance of the process parameters [19].

A systematic parametric study for this technique was performed on A106 Grade B steel pipes with outer diameter of 48.1mm and thickness as 5.08mm. The process parameters used were welding current as 160A, arc rotation time ranging from 20sec to 30sec and the upsetting pressure between 4MPa to 6MPa. During the initial phase, the trial were conducted with large time gaps as the setup required reconfiguration. It was observed that when the trials were conducted in quick succession of time at welding current of 160A, the results so obtained differed from those of initial trials[20]. This difference was attributed to the unstable operation of the transformer which was drawing higher currents due to frequent switching actions.

So far, In their work contains both the experimental and simulation results for steel pipes & tubes of various grades, having an outer periphery greater than 40 mm which find application in industry. The automobile industries have been using conventional techniques of welding like flash butt welding or induction pressure welding for fabrication of the parts. This welding technique, in the past research had met the fabrication requirements to a large extent compared to above techniques. Moreover, RAW is an advanced joining technique but its standards for different applications are yet to be established. Apart from the issues discussed in the literature, there are several technical challenges, which remains unsolved. In this work, a parametric study of the factors influencing the RAW was carried out during which experiments were performed to weld the steel pipes of ASTM A106 Grade B to achieve better weld characteristics.

This study presents experimental results for rotating arc welding and destructive evaluation of ASTM A106 Grade B steel pipes with the stated requirements. The welding was performed on a newly fabricated RAW setup that was specifically designed for welding metal pipes with an outside diameter of 1.5 inches and different schedule thicknesses. The data generated served as the foundation for the parametric study of this process.

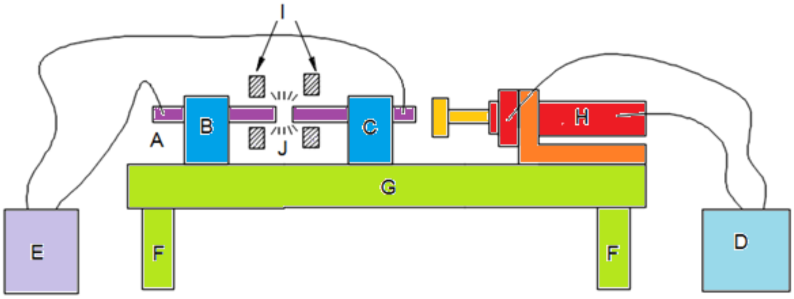
2. Experimentation

Material of the pipe: The material used in this work is ASTM A106 Grade B steel in the form of pipes with outside diameter of 48.1mm and a thickness of 5.08mm. The chemical composition of the pipe material is given below in Table 1.

Table 1: Chemical composition (wt. %) of ASTM A106 Grade B Steel

Material	C	Mn	S	P	Si	Cr	Ni	Mo	V	Cu
ASTM A106 Grade B	0.21	0.60	0.01	0.015	0.27	0.057	0.014	0.007	0.001	0.017

Experimental Setup: The Rotating Arc Welding (RAW) setup shown in Fig.2 was custom-designed and fabricated, using which the experiments were performed to investigate the effect of process parameters on the quality of the weld joint produced.



A-Steel Pipes, B&C- Pipe Holding Block, D&H-Hydraulic Setup, E-Power Supply, F-Lathe Machine Legs, G- Lathe Bed, I-Magnets, J-Arc Gap.

Figure 2: RAW Fabricated Setup

Experimentation and Parameters: The process variables associated with the experiments include welding currents of 190 A and 220 A, upsetting pressures of 4 MPa, 5 MPa, 6 MPa, and arc rotation times of 20s, 25s and 30s. The experiments were conducted as per the full factorial design. Following the successful trials and experiments, the produced welded joints were visually inspected before being tested for mechanical properties such as tensile strength of the joint in the weld region and micro hardness at the joint interface.

3. Results and Discussions

Visual Inspection of the Weld Samples: The RAW of pipes with different parameter settings resulted in sound weldments, though the joints exhibited differences in reinforcement height, HAZ breadth, and bead formation. Every combination of pressure and duration of arc rotation produced a consistent bead. The weldments were visually inspected and confirmed to be adequately reinforced.

Tensile & Hardness Test of the Weld Sample: During welding, the microstructure of the faying surfaces varies as the temperature gradient increases over time which leads to deformation during upsetting. The samples for conducting tensile test were obtained from welded pipes by using wire-cut Electric Discharge Machining (EDM), in accordance with ASTM E8 standard represented in Fig.3. The hardness of the joint was determined at the welded zone, on the Vickers hardness tester using a diamond-type indenter.

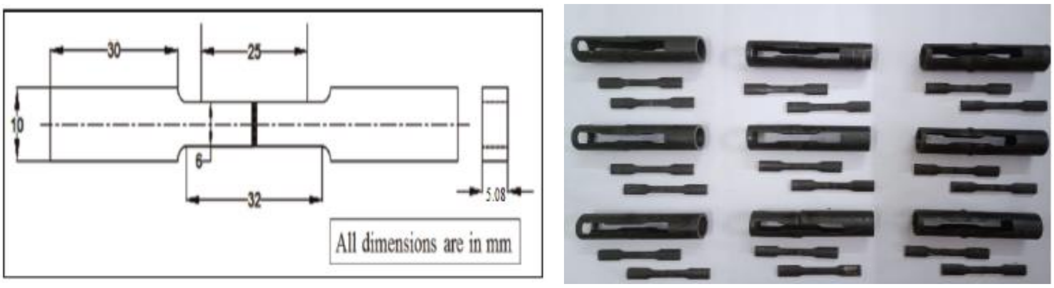


Figure 3: Tensile test samples obtained from the welded pipes

Contour plots of Tensile Strength and Hardness vs Pressure, Time for 190A & 220A: The contour plots shown in Fig. 4, represent the relationship between welding parameters i.e. welding current as 190 A, arc rotation time (20-30 sec), and upsetting pressure (4-6 MPa) and the resulting mechanical properties of the weld samples. It is observed that with an increase in arc rotation time and upsetting pressure, there is a slight increase in both ultimate tensile strength and hardness. This suggests that longer arc rotation times and higher upsetting pressure contribute to improved mechanical properties. The average tensile strength of joint ranges from 393.17 MPa to 398.43 MPa while hardness varies from 165.33 HV to 170.67 HV, when the pressure increases from 4 MPa to 6 MPa and rotating time increases from 20 s to 30 s.

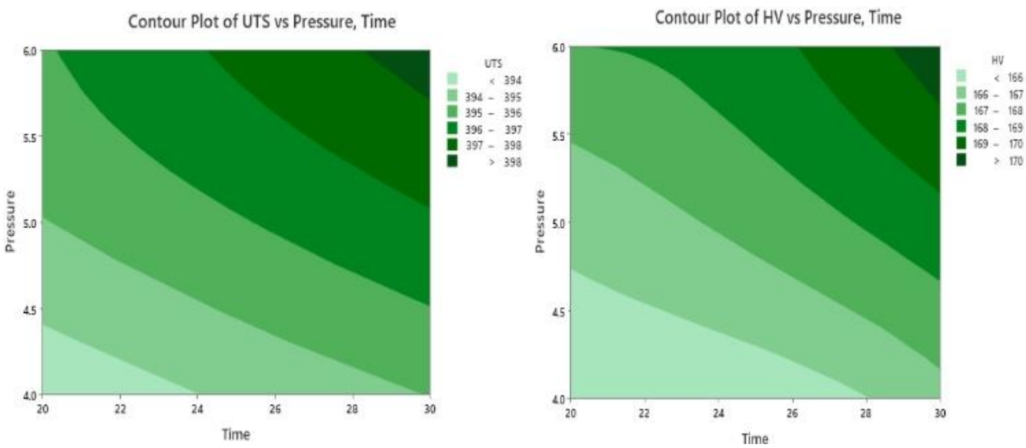


Figure 4: Contour plot of Tensile strength & Hardness vs Pressure, time for 190 A current

The contour plots shown in Fig. 5 represent the relationship between welding parameters i.e. welding current as 220 A, arc rotation time (20-30 s), and upsetting pressure (4-6 MPa) and the resulting mechanical properties of the welded samples. The plot represents that with an increase in arc rotation time and upsetting pressure, there is a slight increase in both ultimate tensile strength and hardness. This suggests that longer arc rotation times and higher upsetting pressure contribute to improved mechanical properties. In this case, the tensile strength of welded samples ranges from 392.21 MPa to 396.86 MPa while the hardness value ranges from 171.67 HV to 177.33 HV, when the pressure increases from 4 MPa to 6 MPa and rotating time increases from 20 s to 30 s.

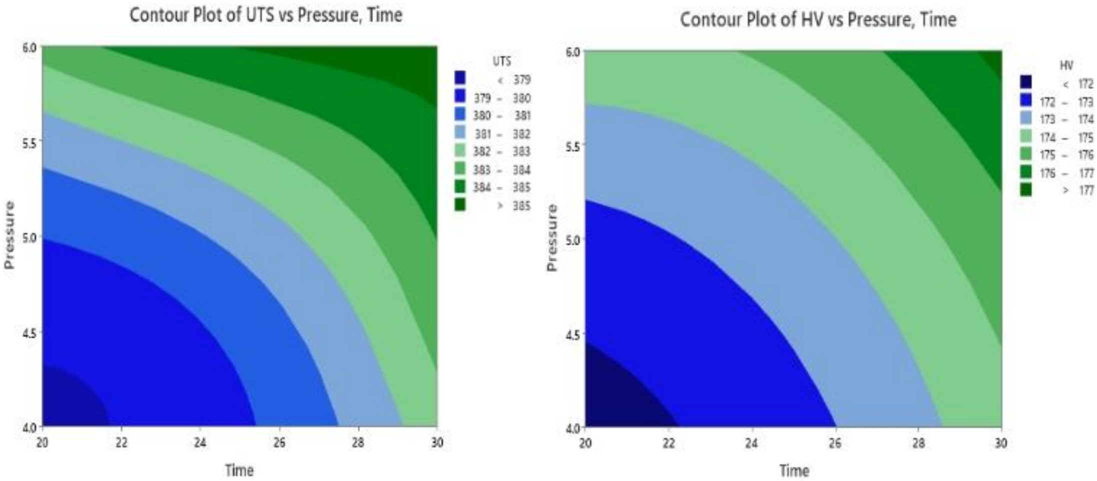


Figure 5: Contour plot of Tensile strength & Hardness vs Pressure, time at 220 A current

Graphs of Tensile Strength and Hardness vs Pressure, time for 190 A & 220 A: The bar graphs shown in Fig. 6 & 7 represent the comparison between the parameter with respect to tensile strength and hardness. It can be observed that the welding current has a considerable influence on the mechanical properties of the welds. A higher welding current (220 A) results in a slightly lower tensile strength but higher hardness than that of the lower welding current (190 A). This could be attributed to the fact that an increased heat input due to higher welding current results in a wider heat-affected zone (HAZ) and various microstructural alterations. Increasing the arc rotation time improves tensile strength and hardness. The higher upsetting pressure and longer arc rotation time produce the optimum mechanical characteristics. The maximum tensile strength and hardness are attained with at arc rotation time of 30 s and 6 MPa upsetting pressure.

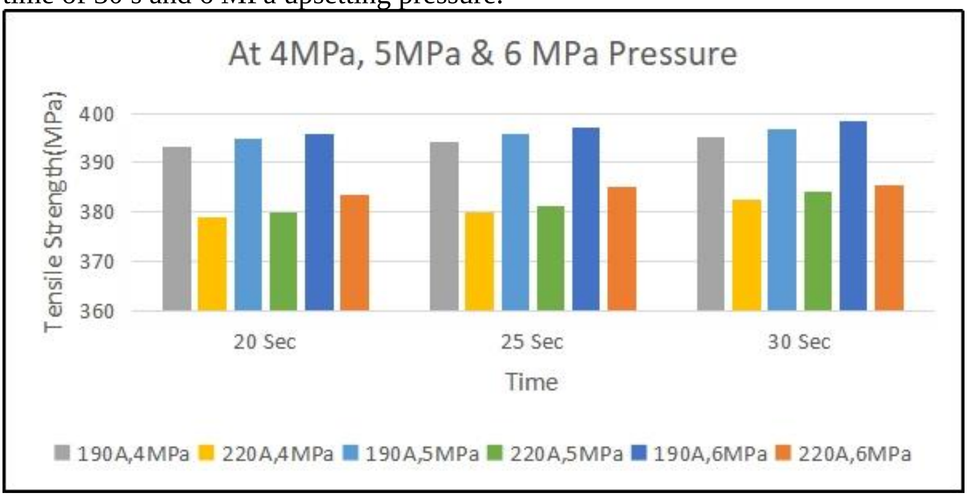


Figure 6: Ultimate tensile strength vs Pressure, time at 190 A & 220 A

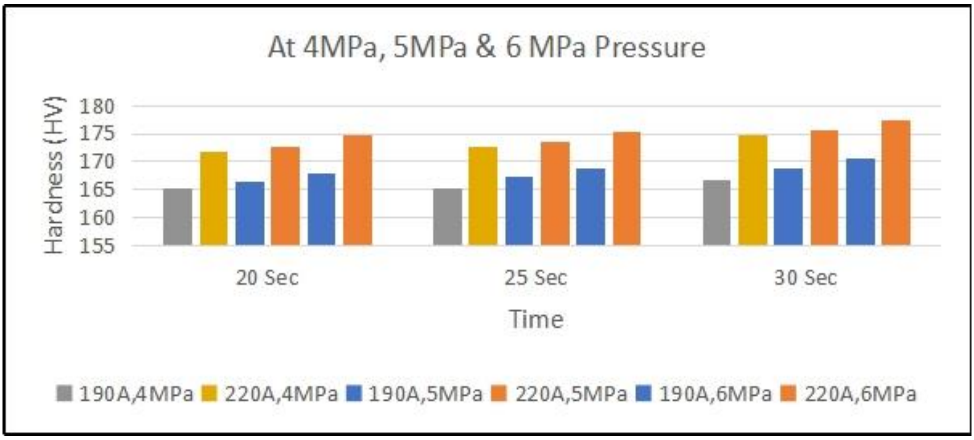


Figure 7: Hardness vs Pressure, time at 190 A & 220 A

Signal to Noise(S/N) Ratio:

Table 2: Response Table for S/N Ratios for Tensile Strength & Hardness at 190A

Larger is better						
Level	Time	Pressure		Level	Time	Pressure
1	51.92	51.91		1	44.43	44.39
2	51.95	51.95		2	44.46	44.48
3	51.97	51.98		3	44.54	44.56
Delta	0.05	0.07		Delta	0.11	0.17
Rank	2	1		Rank	2	1

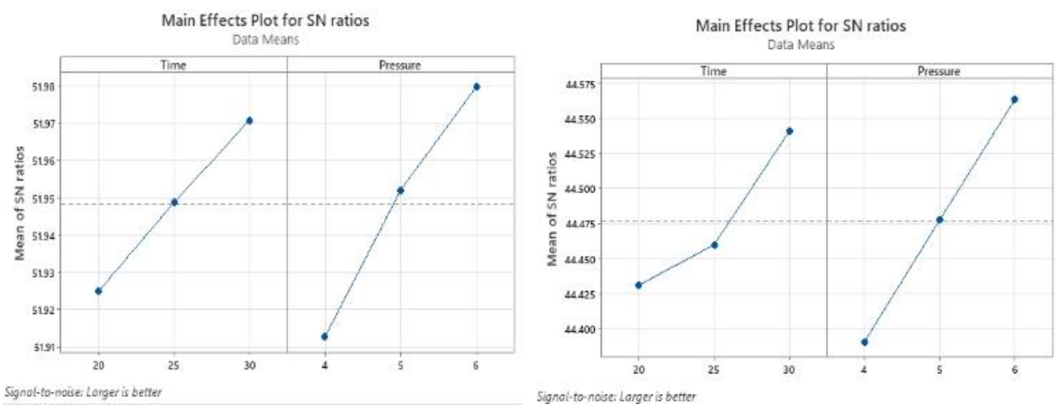


Figure 8: Main Effects Plot for SN ratio for Tensile Strength & Hardness at 190A

The Fig. 8 depicts an S/N ratio study of tensile strength & hardness. The tensile strength increases with the change in arc rotation time and upsetting pressure although not significantly. The higher tensile strength & the higher hardness (S/N) ratio as the larger-the-better could be achieved with the combined settings of A3, B3, i.e., at an arc rotation time of 30 s and at an upsetting pressure of 6 MPa.

Regression Analysis: The regression equation relating the ultimate tensile strength & hardness versus upsetting pressure, arc rotation time at 190 A welding current are given below.

Time		Time	
20	UTS = 387.030+ 1.5300 Pressure	20	HV = 158.212+ 1.668 Pressure
25	UTS = 388.113+ 1.5300 Pressure	25	HV = 158.768+ 1.668 Pressure
30	UTS = 389.120+ 1.5300 Pressure	30	HV = 160.328+ 1.668 Pressure

Probability Plot: The Probability plot of tensile strength at welding current of 190 A is shown in Fig. 9.

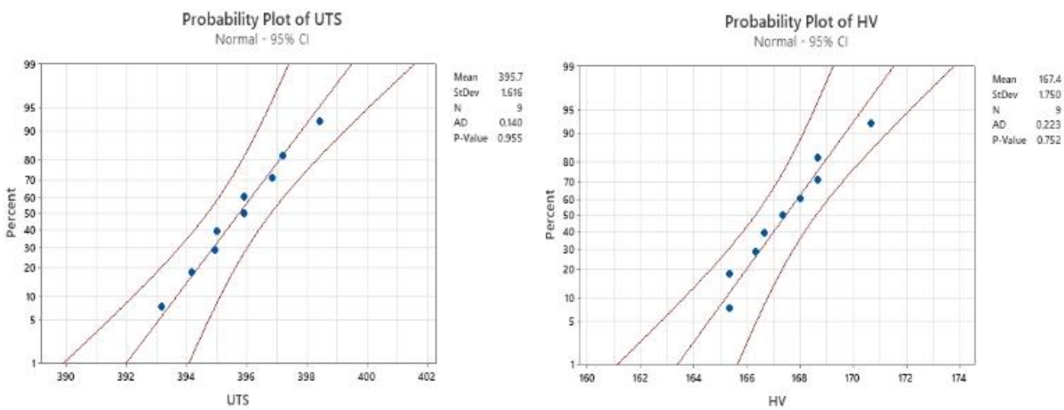


Figure 9: Probability plot of Tensile strength & Hardness at 190 A

These plots show the distribution of tensile strength values and associated probability. As each tensile strength value has the same probability, the distribution is uniform, implying that all tensile strength values are equally likely to occur. This also indicates that there is no particular trend or bias towards specific tensile strength values thus emphasizing the distribution's consistency in this dataset.

Conclusions:

The selection of proper combination of the welding parameters is crucial for obtaining the desired mechanical properties of weld joints. It was observed from the investigation that,

1. The welding current is the most significant parameter that influences the mechanical properties of the welded joints produced by RAW process.
2. A welding current of 190 A resulted in a joint with a maximum tensile strength of 398.43 MPa and a hardness of 170.67 HV whereas when the welding current was increased to 220A, the joint so obtained had a tensile strength of 385.48 MPa with a hardness of 177.33 HV.
3. An increase in the arc rotation time improves the tensile strength and hardness of the joint.
4. A higher upsetting pressure and a longer arc rotation time produces excellent mechanical characteristics in terms of tensile strength and hardness.
5. The maximum tensile strength (398.43 MPa) and hardness (177.33 HV) were obtained with a maximum arc rotation time of 30 s and an upsetting pressure of 6 MPa.
6. For the applications requiring higher tensile strength, a welding current of 190 A, arc rotation time of 30 s, and an upsetting pressure of 6 MPa are recommended.
7. For the applications requiring higher hardness, a welding current of 220 A, arc rotation time of 30 s, and an upsetting pressure of 6 MPa are recommended.

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