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Optimization of Process Parameters for Cu90Ni10 Alloy Processed by Wire Arc Additive Manufacturing (WAAM) Using an L9 Orthogonal Array

Jyothi Padmaja Koduru[1],*, T. Vijaya Kumar[2], Kedar Mallik Mantrala[3], G. Murali[4]

Abstract

Wire Arc Additive Manufacturing (WAAM) has gained significant attention in recent years as a promising technique for producing complex metallic components. This study focuses on the processing of Cu90Ni10 alloy using WAAM and employs an L9 orthogonal array to optimize the mechanical properties of the resulting components. Cu90Ni10 alloy is known for its excellent corrosion resistance and electrical conductivity, making it a critical material in various industries, including aerospace and electronics. In this research, a systematic approach based on the L9 orthogonal array is utilized to investigate and optimize the key process parameters of WAAM, such as welding current, Robot/travel speed, Gas flow rate, Distance between tip and nozzle to achieve desired mechanical properties in the Cu90Ni10 alloy. The L9 orthogonal array is a statistical design of experiments (DOE) method that enables efficient experimentation with a minimal number of trials, making it a cost-effective and time-saving approach for process optimization. The mechanical properties under consideration include tensile strength, hardness, and impact energy. By systematically varying the process parameters according to the L9 orthogonal array design, a comprehensive dataset is generated. The findings of this study contribute to the advancement of Cu90Ni10 alloy processing via WAAM, enabling the production of components with enhanced mechanical performance. This research aligns with the ongoing efforts to explore innovative manufacturing techniques for high-performance materials, ultimately driving advancements in various industrial sectors.

Keywords: Copper-Nickel alloy, WAAM, Process parameters, Optimization, L9 orthogonal array, Mechanical properties.

***Author for Correspondence**
Jyothi Padmaja Koduru

[1]Research Scholar, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Green Fields, Vaddeswaram, Guntur, Andhra Pradesh, India
[2]Associate Professor, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Green Fields, Vaddeswaram, Guntur, Andhra Pradesh, India
[3]Professor, Department of Mechanical Engineering, Vasiredyy Venkatadri Institute of Technology, Nambur(V), Peda Kakani (Md)Guntur District, Andhra Pradesh, INDIA.
[4]Professor, Department of Mechanical Engineering, Koneru Lakshmaiah Education Foundation, Green Fields, Vaddeswaram, Guntur, Andhra Pradesh, India

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INTRODUCTION

Additive Manufacturing (AM) is defined as “the process of joining materials to make components directly from 3D CAD data, the parts are made layer by layer in successive layers by adding build material, as opposed to subtractive manufacturing methodologies, such as traditional machining [1]. It is also known as 3D printing, has revolutionized the way metallic components are designed and fabricated. The development and advancement of Additive Manufacturing System (AMS) technology has enabled the manufacturing of unimaginable complex forms [2]. Among the various additive manufacturing techniques, Wire Arc Additive Manufacturing (WAAM) has emerged as a versatile and cost-effective method for producing complex metal parts. WAAM utilizes an electric arc to melt a continuously fed wire, which is then deposited layer by layer to build up the desired object. This process offers distinct advantages, including the ability to fabricate large-scale components, excellent material utilization, and the potential for high deposition rates.

One of the intriguing applications of WAAM lies in the processing of Cu90Ni10 alloy, a material renowned for its exceptional corrosion resistance and electrical conductivity. This alloy finds wide-ranging applications in industries such as aerospace, electronics, and power generation, where its unique combination of properties is highly desirable. However, the mechanical properties of Cu90Ni10 alloy, particularly its tensile strength and hardness, can be influenced significantly by the processing parameters employed during WAAM.

The optimization of process parameters is one important aspect of enhancing the quality of welds [3–4]. It is possible to improve the welds' mechanical properties and performance characteristics by determining the best combination of parameters. Traditional trial-and-error methods for parameter optimization can be time-consuming and costly. In this context, the application of statistical design of experiments (DOE) offers an efficient and systematic approach to understand the intricate relationship between process parameters and the resulting mechanical properties.

Objective

This study aims to improve the process parameters for welding copper-nickel alloy in a 1.2-millimeter-diameter spool [5–6]. Welding current, robot/travel speed, gas flow rate, and the distance between the tip and nozzle are the primary process parameters that can be improved. The Table 1 exhibits the sample L9 orthogonal array structure. Utilizing the L9 orthogonal array, the study aims to identify the essential process parameters that have a significant impact on weld quality. The primary objective is to find the optimal combination of interaction boundaries for the copper-nickel composite welds' best mechanical and execution properties [7].

Material Considered

Cu90Ni10, often referred to as 90–10 copper-nickel, is an alloy composed of 90% copper (Cu) and 10% nickel (Ni). This alloy is part of the copper-nickel family and is known for its excellent resistance to corrosion, particularly in marine and seawater environments. This was considered in a wire spool format of 1.2 mm diameter. The Table 2 and Table 3 give the Nominal composition and the various fabrication properties of the Cu90Ni10 alloy.

The *Nominal Composition of 90/10* Copper-Nickel alloy: Cu90Ni10 is considered as below.

Experimental Setup

The project's main theme is to find the mechanical properties and compare the results with the results that have been achieved [8].

Table 1. The sample L9 orthogonal array structure.

Experiment	A	B	C	D
Sample 1	1	1	1	1
Sample 2	1	2	2	2
Sample 3	1	3	3	3
Sample 4	2	1	2	3
Sample 5	2	2	3	1
Sample 6	2	3	1	2
Sample 7	3	1	3	2
Sample 8	3	2	1	3
Sample 9	3	3	2	1

Nb: A, B, C, D are known as process parameters (PP)

Table 2. Chemical Composition of Copper-Nickel alloy

Material	**Carbon (C)**	**Copper (Cu)**	**Iron (Fe)**	**Lead (Pb)**	**Manganese (Mn)**	**Nickel (Ni)**	**Phosphorous (P)**	**Sulfur (S)**	**Zinc (Zn)**
Percentage	< 0.050 %	85.6 to 90 %	1 to 1.8 %	< 0.020 %	<1%	9 to 11 %	below 0.020 %	below 0.020 %	below 0.50 %
Selected wire for experimentation		88.5%	1.30%		0.70%	9.50%			

Table 3. Fabrication Properties of Copper-Nickel alloy

Property Considered	**Value or Range of the alloy**	
Casting temperature	1225°C to 1300°C	2235°F to 2370°F
Annealing temperature	700°C to 825°C	1290°F to 1515°F
Stress relieving temp	275°C to 400°C	525°F to 750°F
Hot processing temp	825°C to 950°C	1560°F to 1740°F
Hot formability	Suitable	
Cold formability	Outstanding	
Cold reduction in annealed	80%	
Machining rate (free cutting brass-100)	20	
Soldering	Outstanding	
Brazing	Suitable	
Oxy acetylene welding	Not preferred	
Carbon arc welding	Not preferred	
Gas shielded arc welding	Outstanding	
Coated metal arc welding	Suitable	
Resistance welding	Suitable	
Butt welding	Suitable	

Ensuring that all safety protocols and guidelines are followed, the below Figure 1 describes the General structure of a sensor based robotic arc welding system which shows the path followed to make the desired nine samples by using robot welding machine. The work piece was set up in a wire spool format with 1.2 mm diameter and the work piece to be welded in the correct position and orientation. A CNC program was included to program the robot's movements to specify he welding parameters, such as voltage, amperage, and wire feed speed, based on the material and welding process being used. Now we will initiate the welding process through automated control. Multiple line deposition was done using the alloy. The Figure 2 illustrates us about the complete Materials and Equipment Setup Diagram which monitors the welding process for any issues, such as irregularities in the arc or weld quality and to achieve the final sample work pieces for testing. Inspect the welded joints periodically to ensure they meet the desired quality standards. Make any necessary adjustments to the welding parameters or robot program to maintain weld quality. Once welding is complete, shut down the welding machine and robot and detailed records of the welding parameters are maintained.

METHODOLOGY

In this section, we will go into great detail about how the L9 orthogonal array was used to improve the welding process parameters for copper-nickel alloy. This study aims to figure out the best combination of process parameters for the welded copper-nickel alloy's desired mechanical properties and performance characteristics.

Specific Process Parameters

The following process parameters are specifically taken into consideration for optimization in this study:

(a) *Welding current:* How much current that is provided during the welding system, which affects the attributes of combination and intensity input.

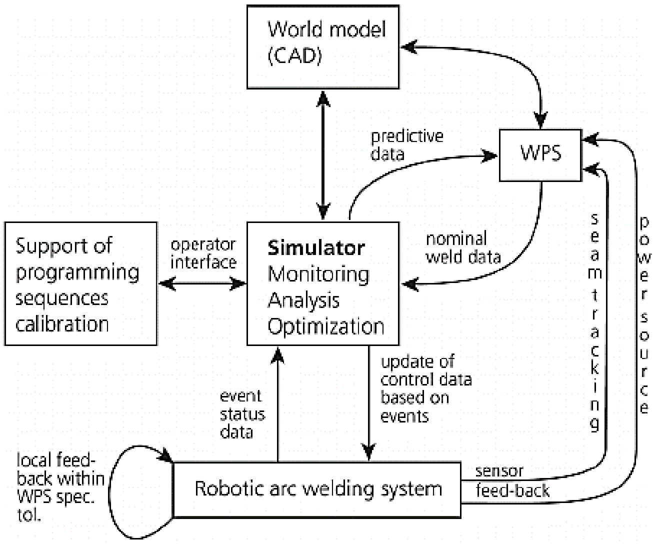

Figure 1. General-structure-of-a-sensor-based-robotic-arc-welding-system.

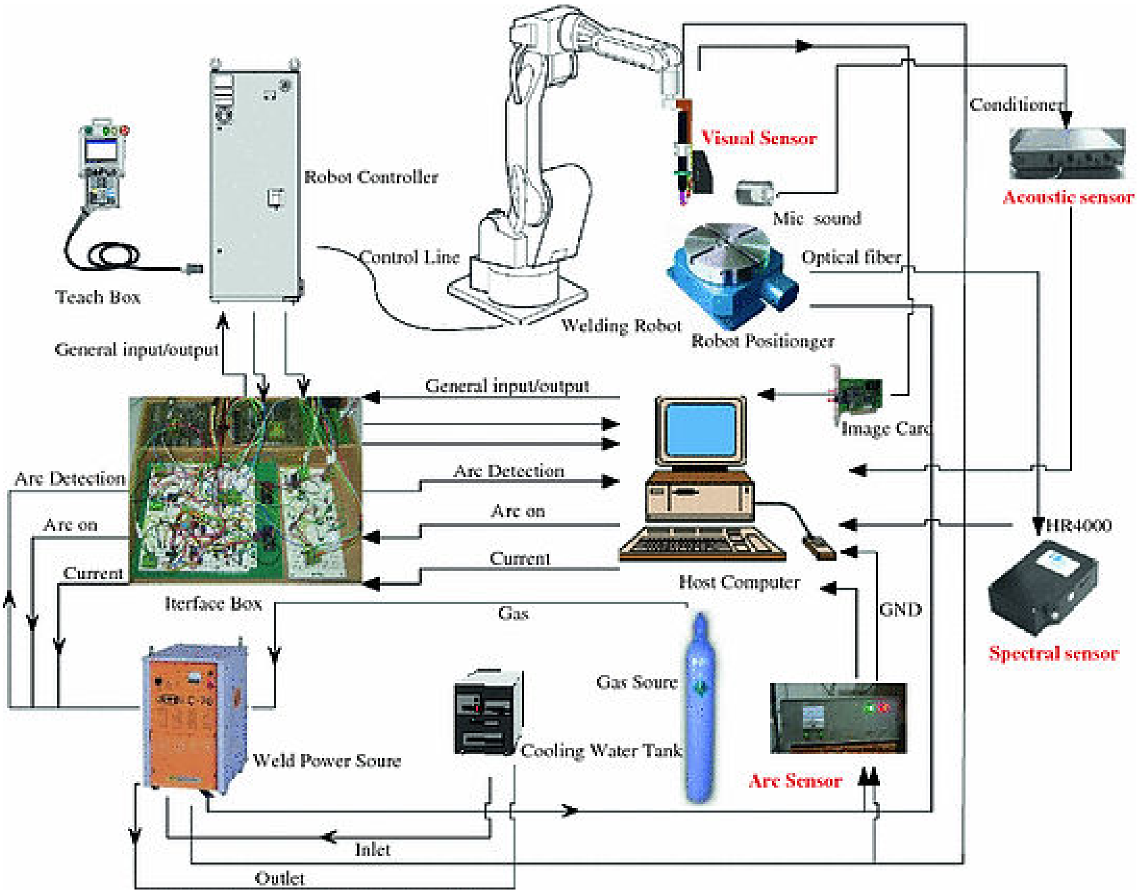

Figure 2. Materials and Equipment Setup Diagram.

(b) *Robot/Travel speed*: The heat distribution and shape of the weld bead are affected by the speed at which the travel mechanism or welding robot moves during the welding process.

(c) *Gas flow rate:* The rate at which shielding gas is delivered to the welding zone influences how well the molten metal is protected from contamination from the air.

(d) *Distance between tip and nozzle:* The distance between the welding tip and the spout, which impacts the protecting gas inclusion and bend dependability.

Experimental Design

The process parameter levels that each experiment represents are defined by the L9 orthogonal array. The L9 orthogonal array makes sure that the parameter space is thoroughly and methodically explored [7]. The levels for each cycle boundary are resolved in view of the qualities 1, 2, and 3 determined in the exhibit. The impacts of different blends of interaction boundaries on the weld quality and execution attributes of the copper-nickel amalgam can be accessed via doing these analyses.

Measurement Techniques and Data Collection

Most often the components or machine parts are subjected to impact or sudden loading in industries [9]. Initially specimen is to be made with 10 mm × 10 mm × 25 mm dimension; notch should be made at exact center [10]. The pendulum is kept at maximum position and tested the impact without specimen to find the initial impact from scale provided, which might cause due to friction in machine. Several tests are performed to evaluate the outcomes of different parameter combinations.

The tests include:

(a) *Tensile test:* Measures the mechanical strength and flexibility of the welded copper-nickel combination.

Equation: $T = F/A$

- T: Tensile strength of the welded copper-nickel alloy
- F: Maximum load applied during the tensile test
- A: Cross-sectional area of the weld specimen

(b) *Hardness test:* Determines the weld's hardness, which is related to its resistance to wear and deformation.

Equation: $H = F/D$

- H: Hardness of the weld
- F: Applied force during the hardness test
- D: Indentation diameter or depth

(c) *Impact test:* Evaluates the weld's ability to withstand sudden forces or shocks.

Equation: $E = (mgh) / A$

- E: Energy absorbed by the weld upon impact
- m: Mass of the impact hammer
- g: Acceleration due to gravity
- h: Height of the drop
- A: Cross-sectional area of the weld specimen
- T: Exposure time

RESULTS AND ANALYSIS

The objective of this analysis is to figure out the best combination of process parameters for the welded copper-nickel alloy's desired mechanical and performance properties. The best collaboration limits for improving weld quality and achieving the ideal microstructure, strength, and disintegration resistance will be revealed by the audit's findings [11–13]

Presentation of Results

Considered nine different samples of same material Copper-Nickel Cu-Ni 90/10 Alloy (UNS

C70600) were considered in different shapes such as rounded shape and in rectangular bar shapes and various tests such as tensile test, hardness test, influence test, pressure test, and consumption test are introduced. Each sample is verified against certain tests and all the data is tabulated in the form of a table as output results and diagrams, or outlines are utilized to really show the information and give a reasonable portrayal of the outcomes. The Table 4 shows the readings of the Weld Quality or Performance Measures of the alloy used in testing.

Analysis of Results

Any significant findings, patterns, or trends are carefully examined in light of the findings. The relationships that exist between the process parameters and the outcomes that have been observed can be evaluated using statistical analysis methods like the analysis of variance (ANOVA) or regression analysis. The welded copper-nickel alloy's various mechanical properties and characteristics are examined in relation to each process parameter. In Figure 3 the Weld Quality or Performance Measures in Bar Graph are calibrated with the attained results.

Table 4. Weld Quality or Performance Measures.

Cu90Ni10	Welding current	Travel speed	Gas flow rate	Tip distance	Tensile Strength	Hardness	Impact Energy
	Amp.	m/min.	ml/min.	mm	MPA	HRC	J
Sample 1	35	1	20	8	450	55	25
Sample 2	35	1.25	40	10	480	58	28
Sample 3	35	1.5	60	12	430	52	23
Sample 4	40	1	40	12	460	57	26
Sample 5	40	1.25	60	8	470	56	27
Sample 6	40	1.5	20	10	440	53	24
Sample 7	45	1	60	10	445	54	25
Sample 8	45	1.25	20	12	475	59	27
Sample 9	45	1.5	40	8	455	56	26

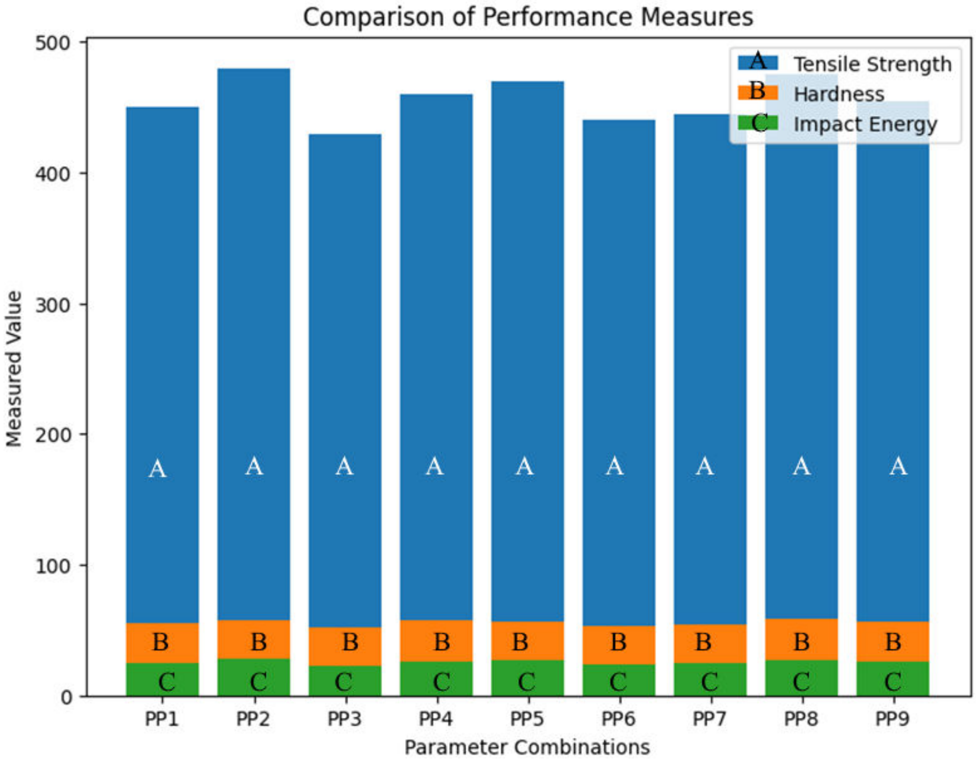

Figure 3. Weld Quality or Performance Measures in Bar Graph.

Comparison and Identification of Optimal Settings

Based on the desired mechanical properties and performance characteristics, the optimal settings are identified and their performance is compared. We can determine which combinations of welding current, robot/travel speed, gas flow rate, and tip-to-nozzle distance improve weld quality, strength, hardness, impact resistance, corrosion resistance, and desired microstructure by analyzing the results.

In Figure 4 the Weld Quality or Performance Measures in Line Graph are calibrated with the attained results.

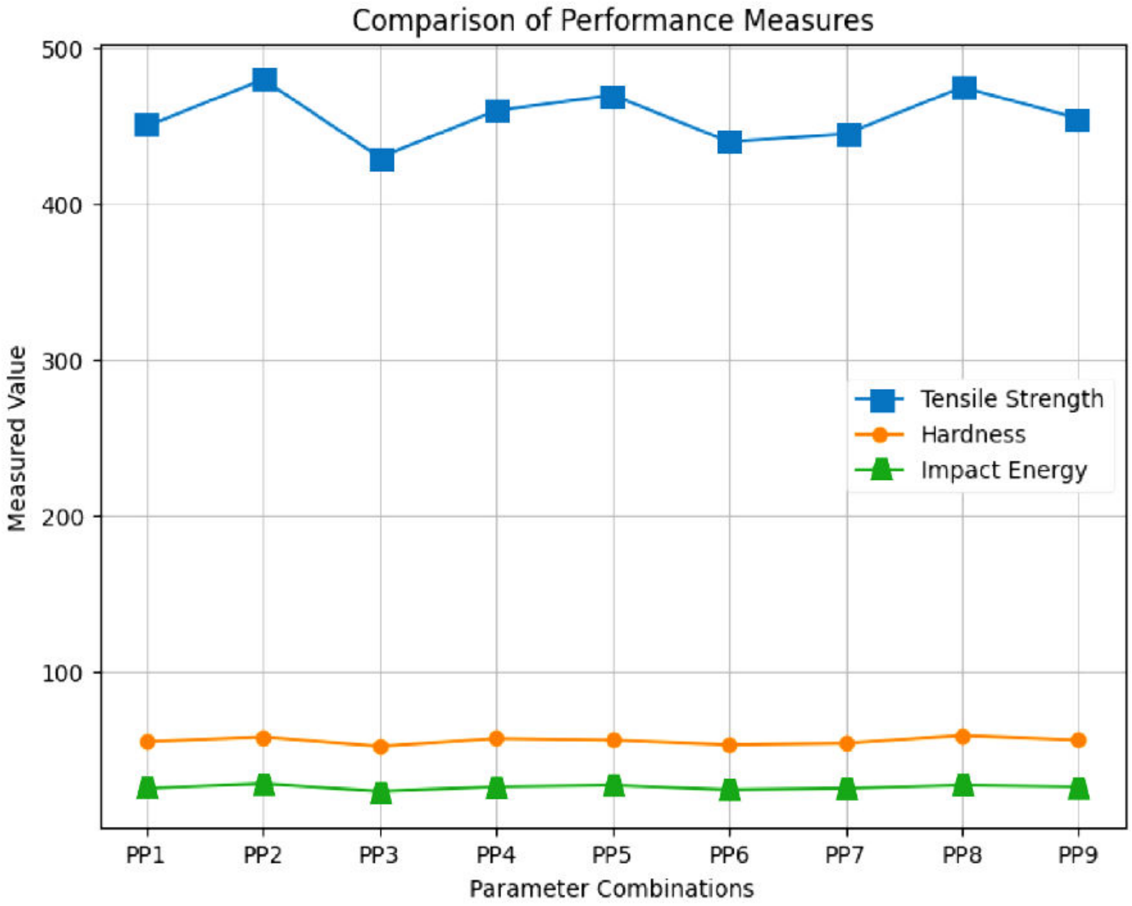

Figure 4. Weld Quality or Performance Measures in Line Graph.

Discussion of Limitations and Sources of Uncertainty

Any limits or wellsprings of vulnerability in the outcomes are examined. Variations in experimental conditions, sample preparation, and measurement methods are examples of this. Perceiving and tending to these restrictions give experiences into the dependability and generalizability of the discoveries.

We gain valuable insight into the ideal process parameters for achieving the desired outcomes in copper-nickel alloy welding by presenting the results and conducting a comprehensive analysis. The findings contribute to the development of copper-nickel alloy welding techniques and offer industry professionals and those working in copper-nickel alloy welding applications with useful advice, resulting in improved welding practices and superior product performance.

In Figure 5 the Performance Measures for the parameters considered and measured values are reported in Bar graph and in Figure 6 they are represented in a line graph.

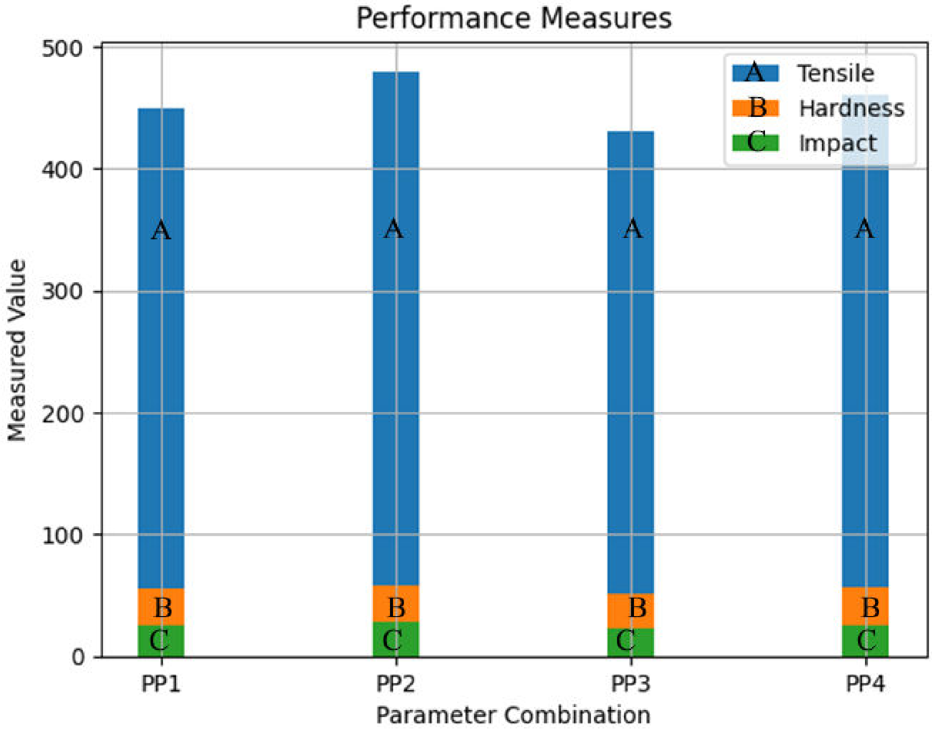

Figure 5. Performance Measures-Bar Graph.

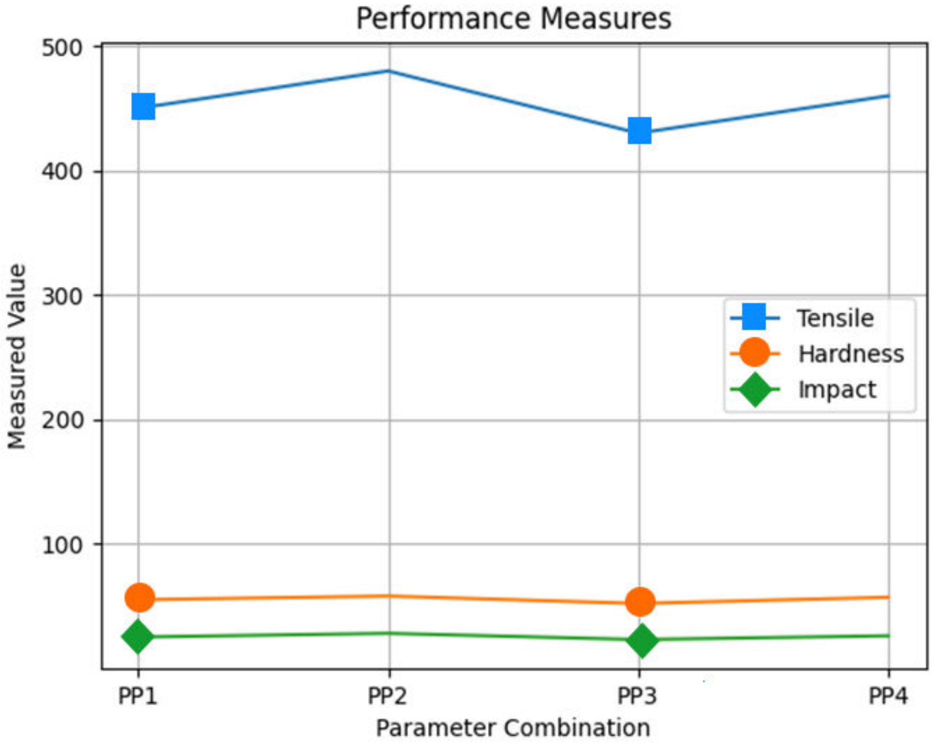

Figure 6. Performance Measures-Line Graph.

DISCUSSION

The implications and significance of the results obtained from optimizing process parameters for copper-nickel alloy welding with the L9 orthogonal array are discussed in this section. In addition, we provide insight into the broader implications for the welding industry and compare the findings to the study's goals.

Implications of the Results

For the welding of copper-nickel alloys, this study's identified optimized process parameters have significant implications. The results shed light on the parameters that have a significant impact on the performance characteristics of the welded joints in terms of achieving the desired microstructure, improved strength, impact resistance, corrosion resistance, and weld quality. These optimized parameters can be utilized by industries that use copper-nickel alloy welding to enhance their welding procedures, resulting in improved product performance.

Significance of the Findings

This study's findings contribute to the development of copper-nickel alloy welding methods. The study addresses the difficulties and issues associated with welding these alloys, which are widely used in a variety of industries, by optimizing the process parameters. The upgraded mechanical properties and execution attributes accomplished through the enhancement interaction can prompt better dependability, strength, and generally speaking item quality. This is especially important in situations where copper-nickel alloy welds are subjected to high stress or harsh environments.

Alignment with Objectives:

This study successfully achieved its objectives, which were to improve the process parameters for welding copper-nickel alloy in spool form. The L9 symmetrical exhibit gave a precise and complete investigation of the boundary space, taking into consideration the recognizable proof of key cycle boundaries that fundamentally impact the nature of the welds. Through a series of tests and analysis of the results, the best combination of process parameters has been identified in accordance with the study's objectives.

Broader Implications

This study's optimized process parameters have wider repercussions for the welding industry. The examination results offer important experiences into the elements that impact weld quality, strength, hardness, influence obstruction, erosion opposition, and microstructure. These insights are applicable not only to welding copper-nickel alloys but also to other welding processes or alloys that are similar. The results of the study can be used as a basis for future efforts to improve welding methods and optimize process parameters for a wide range of materials and applications.

CONCLUSION

All in all, this concentrate effectively improved the cycle boundaries for welding copper-nickel combination in spool structure utilizing the L9 symmetrical cluster. The study found the best combination of welding current, robot/travel speed, gas flow rate, and the distance between the tip and nozzle by evaluating the results of various parameter combinations in a series of tests. Weld quality was improved, as was strength, hardness, impact resistance, corrosion resistance, and the desired microstructure thanks to the optimized process parameters.

The findings of this study contribute to the advancement of welding techniques for Copper-Nickel composites and offer important insights to businesses and professionals involved in the welding applications of copper-nickel compound. Welding techniques can be improved and product performance enhanced by utilizing the optimized process parameters.

The findings of the study also have wider repercussions for the welding industry and will serve as a guide for future research into how to optimize process parameters for a variety of materials and applications.

By and large, this study improves how we might interpret the ideal cycle boundaries for copper-nickel composite welding and exhibits the viability of the L9 symmetrical cluster in accomplishing wanted weld quality and execution attributes. The discoveries prepare for further developed welding works on, prompting upgraded item execution and headways in the field of welding innovation.

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