SINGLE RESPONSE OPTIMIZATION PROCESS FOR ENHANCING IMPACT STRENGTH OF MILD STEEL WELDMENT USING TAGUCHI METHOD

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CERTIFICATION

This is to certify that the research reported here was carried out by **OSEMENE SAMUEL** with matriculation number **PG/ENG1918220** in the Department of Production Engineering, University of Benin, Benin City.

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DEDICATION

This research work is dedicated to Almighty God whose divine protection made it possible for me to undertake and complete it.

ACKNOWLEDGEMENTS

I am grateful to the Department, for giving me the opportunity to carry out this research study.

In the course of this research work some persons make very salient contributions and I wish to use this medium to appreciate their efforts, but first of all thanks be to God Almighty who spared my life in the frequent and numerous journeys in pursuance of this degree. I also want to thank Him for the wisdom, strength and grace to undertake this programme.

I sincerely acknowledge the effort and support of my project supervisor, Prof. J.I. Achebo and my co-supervisor Dr. F Uwoghiren. in the success of this project. I appreciate his guidance and attention which were not withheld in the course of the project. May the good Lord bless him and his family?

I acknowledge the efforts of HOD Prof. R.O. Edokpia and all my lecturers and classmates whose efforts and criticism proved immensely helpful in the success of the project and to my friends, I say thank you for your encouragements.

ABSRTACT

Process parameters have been known to determine the quality of weldments in welding operations. Therefore the process parameters have to be manipulated to determine the desirable quality of the weldment. In doing this, the Taguchi method was applied to optimize these process parameters. The response obtained from the welding operation was the Impact strength of the weldments. From using the Taguchi method, it was derived that the optimum process parameters is A_3,B_1,C_3. The analysis of variance was computed to determine the level of contribution of each of the process parameter to the quality level of the weldment.

It was investigated that voltage contributed most having a total of 14.42% of the quality level of the weldment, followed by the welding current, with a value of 7.94% and gas flow rate being the least with a contribution of 2.04%. A confirmation test was carried out to validate the inference that A_3,B_1,C_3 is the optimum process parameters. The signal to noise ratio of the existing process parameters of A_2 B_3, C_1 was determined to be 40.3997dB, whereas, the optimum welding process has a signal to noise ratio of 42.8796 dB. This shows that there is an improvement of 2.4799 dB of the optimum process parameters over the existing one. The Impact Energy of the weldment produced by the welding operation made by using the optimum process parameters has 12 J more than the Impact Energy obtained from the weldment made by using the existing process parameters.

In this study, the Taguchi method was useful in improving the quality of weldment made by applying the optimum process parameters obtained.

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CHAPTER ONE
INTRODUCTION

1.1 Preamble

Daniyan et al (2019) were of the opinion that the welding process is a fast, reliable, and economical way of joining different materials together during manufacturing processes. The authors also said that the main requirements of modern welded structures are the safety, fitness for production, integrity, strength, and economy. Pipavat et al (2014) wrote that the American Welding Society (AWS) defines weld as “A localized coalescence of metals or non-metals produced either by heating the materials to suitable temperature, with or without application of pressure, or by pressure alone, and with or without the use of filler material.” Indian Standard IS: 812-1957 defines the weld as “a union between two pieces of a metal at faces rendered plastic or liquid by heat or by pressure, or both. Filler metal may be used to affect the union”.

Omprakasam et al (2022) said that modern fabrication industries join metallic materials through melting the base materials with the addition of filler materials. Welding has been a high-quality and cost-effective method for producing strong joints in several applications. Many conventional joining processes are used in the fabrication sectors. Among them, the tungsten inert gas (TIG) welding process was one of the popular conventional welding processes, primarily employed in the automobile, oil, gas pipeline, and container manufacturing sectors (Balaram and

Chennakeshava, 2018). Gupta and Kamboj (2016) wrote that Welding is a manufacturing process of creating a permanent joint obtained by the fusion of the surface of the parts to be joined or welded together, with or without the application of pressure and a filler material. The materials to be joined may be similar or dissimilar to each other. The heat required for the fusion of the material may be obtained by burning of gas or by an electric arc. The weld property depends on the various welding parameters like current, voltage, speed, position etc.

In this research work, the Taguchi method was used to optimize the welding process parameters. Gupta and Kamboj (2016) wrote that Taguchi Method was developed by Genichi Taguchi. The overall objective of Taguchi method is to produce high quality product at low cost for the manufacturers. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied. Instead of having to test all possible combinations, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect the product quality with a minimum amount of experimentation, thus saving time and resources. Taguchi method is basically used to optimize welding parameters for single weld property, it do not work well in case of multiple weld property. Pipavat et al (2014) wrote that optimization of process parameters is the key step in the Taguchi method for achieving high quality without increasing cost. This is because optimization of process parameters can improve quality characteristics and the optimal process parameters obtained from the Taguchi method are insensitive to the variation of environmental conditions and other noise factors. Basically, classical process parameter design is complex and not easy to use. A large number of experiments have to be carried out when the number of process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with a small number of experiments only. A loss function is then defined to calculate the deviation between the experimental value and the desired value. Taguchi recommends the use of the loss function to measure the deviation of the quality characteristic from the desired value. The value of the loss function is further transformed into signal-to-noise (S/N) ratio.

In this study, the Taguchi method was used to optimize welding process parameters which include the welding current, welding voltage and Gas Flow Rate. These parameters are said to have significant impact on the quality of the welded joint.

1.2 History of Welding

The Bible mentions Tubal Cain, “forged all types of tools from bronze and iron.” He may have been one of the first to join metals with the forging process. His flame was an open hearth into which he placed the metals to be heated to the forging temperature. (Of interest, in forge welding the material does not melt. It becomes very soft at temperatures several hundred degrees lower. The most recent innovative joining process, Friction Stir Welding_also does not melt the base metal-it just becomes soft and plastic!)

In 1892 Morehead and Wilson accidentally discovered how to make acetylene. It was found that combining acetylene with oxygen produced the hottest flame temperature-5720 degrees F. Since this is well above the melting point of most metals the oxyacetylene welding process soon developed.

In 1881 a Russian inventor, Benardos demonstrated the carbon electrode welding process. An arc was formed between essentially a moderately consumable carbon electrode and the work. A rod was added to provide needed extra metal.

In 1904 Oscar Kjellberg in Sweden, who started ESAB, invented and patented the covered electrode. This electric welding process made excellent quality, strong welds very fast.

A significant invention was defined in a patent by Alexander, filed in December 1924 (Patent Number 1,746,207) for what came to be known as the Atomic Hydrogen Welding Process. It looks like MIG welding but hydrogen is used as the shielding gas which also provides extra heat as it bums with the surround the arc.

A major innovation was described in a patent (US Patent number 2,043,960)_that defines the Submerged Arc Process invented by Jones, Kennedy and Rothemiund. This patent was filed in October 1935 and assigned to Union Carbide Corporation. The Specification states, Page 4, Column 2, Lines 4 through 7 that the application was in part a continuation of applications Serial Numbers 657,836 and 705,893 filed in February 1933 and January 1934. The following was excerpted from an article written by Bob Irving in The Welding Journal “The importance of welding was emphasized early in the war when President Roosevelt sent a letter to Prime Minister Winston Churchill, who is said to have read it aloud to the members of Britain’s House of Commons. The letter read in part, “Here there has been developed a welding technique (referring to Submerged Arc Welding) which enables us to construct standard merchant ships with a speed unequaled in the history of merchant shipping.”

Russell Meredith working at Northrop Aircraft Company in 1939-1941 invented the TIG process. This new process was called “Heliarc” as it used an electric arc to melt the base material and helium to shield the molten puddle. Mr. Jack Northrop’s dream was to build a magnesium airframe a lighter, faster warplanes and his welding group invented the process and developed the first TIG torches. The patents were sold to the Linde Division of Union Carbide who developed a number of torches for different applications and sold them under the brand name Heliarc. Linde also developed procedures for using Argon which was more readily available and less expensive than Helium.

In a January 1990 Welding Journal article Gus Manz interviewed one of the key inventors of the MIG process (US Patent Number 2,504868- January 1949), Glen

Gibson._Mr. Gibson indicated he had observed the demonstration of a manual submerged arc process by Lincoln Electric and had the vision to define the process using and inert gas shield. He had been working on TIG welding in the Development Lab at Airco at the time. He indicates although he went on to be the owner of a very successful business; “the greatest single day in his life was the day Steve (Steve Sullivan worked with Glen at the Lab) and I cranked up the first (MIG) welding gun.”

On July 26, 1955 Robert Gage (my old boss) filed US Patent Number 2,806,124 for Plasma, entitled “Arc Torch and Process.” This was the first Plasma Torch and Process patent. It had 29 claims. One of the patent figures is shown on left. Although usable for welding it has gained wide acceptance as the process of choice for thermal cutting.

Bob Gage, photo right, was a brilliant Physicist and a great boss. Although tough, he always made you think, often with a critical statement such as; “Your solving a problem not know to exist using a method known not to work!” Bob managed the Welding R&D for the Linde Division of Union Carbide (in all US facilities) for many years.

1.3 Aim and Objectives of the Study

The aim of this study is to **o**ptimize welding parameters used in this study by applying the Taguchi optimization method.

The objectives are as follows:

1. to determine the ranges of the process parameters
2. to determine the matrix design of the experiment generated by the Taguchi orthogonal array;
3. to carrying out the experimental runs and determine the corresponding Impact Energy absorbed on each of the weldments;
4. to determine the weldments’ signal to noise ratio;
5. to determine the optimum input process parameters;
6. to calculate for the analysis of variance which would eventually determine the contribution of each of the input process parameters on the quality of the weldment
7. to conduct a confirmation test, to compare the quality performance of the weldment using the existing input parameters and the obtained optimum input parameters

1.4 Statement of the Problem

Welding involves the joining of parent metal joints to create a permanent structure which may be subjected to some loads. If the welded joints are not properly joined, the joint formed may fail over time and the welded structure may not be able to achieve its designed service life. Failures from welded joints have been studied and decisions reached shows that it could be catastrophic and can eventually lead to death in some instances. Some of the defects that could lead to weld failure are lack of fusion and incomplete penetration. These defects may not be discovered until the strength of the welded joint is investigated.

In this circumstance the reliable strength testing process that could be adopted was the impact energy. The impact energy reveals the extent to each the welded joint can absorb impact load. Microscopic examination of the impacted joint would show

1.5 Scope of the Study

The scope of this study covers the optimization of welding parameters using Taguchi method.

1.6 Limitations of the Study

The limitations are as follows:

1. There is dearth of literature in this area, and
2. conducting these experiments were very expensive

CHAPTER TWO
LITERATURE REVIEW

2.1 Welding Processes

Aditya Kumar et al. (2015) worked on the submerged arc welding and fuzzy logic. In submerged arc welding flux composition plays an important role in deciding the quality of weld. In a SiO2 based flux NiO, MnO and MgO are added in three different proportions. The Vickers hardness and impact strength of the weld was measured and the effect of each flux alloying element was investigated. For multi-objective optimization, a Fuzzy Logic model was proposed and optimal levels of NiO, MnO and MgO was obtained using a single multi-response performance index (MRPI).

Prasenjit Mondal et al. (2015) worked on the dissimilar metal weld joints. The dissimilar metal weld joints have been used as structural material for industrial applications and provides good combination of mechanical properties like corrosion, strength, resistance with lower cost. In this study stainless steel plate of AISI-304 has been welded with mild steel plate of IS: 1079 by Metal Inert Gas (MIG) welding processes. The tensile strength and hardness of dissimilar metal joints have investigated. The results are compared for different joints made by MIG welding processes and finally optimize the best combination of input parameters.

Manoj Raut et al. (2014) experimental study was based on an investigation of the effect and optimization of welding parameters on the tensile shear strength in the Resistance Spot Welding process. The experimental studies were conducted under varying electrode forces, welding currents, and welding times. The settings of welding parameters were determined by using the Taguchi experimental design of Orthogonal array L18 method. The combination of the optimum welding parameters have determined by using the analysis of Signal-to-Noise (S/N) ratio. The confirmation test performed clearly shows that it is possible to increase the tensile shear strength of the joint by the combination of the suitable welding parameters.

Ajit Khatter et al. (2013) worked on the welding process parameters in TIG welding. This paper proposes a method to decide optimal settings of the welding process parameters in TIG welding. Welding properties affecting parameters are like Tensile Strength, Impact Force, Hardness etc. Experiments are performed, based on the data collected from experimental value, the optimized parameters are calculated. By using Taguchi method and ANOVA analysis technique, optimized solution is obtained.

Nabi Mehri Khansari et al. (2013) used Friction Stir Welding (FSW) for joining aluminium alloys system. In order to decrease the count of experimental tests, Mamdani-Type Fuzzy implication has been applied. In this paper an intelligent relationship has been created between the input and output data i.e. between the forward and rotational speed as inputs and mechanical properties as output using fuzzy logic. The result indicated that by adopting and using an appropriate fuzzy method, both the number of experiments conducted and mechanical properties of welded FSW can be optimized. Fuzzy logic created a relationship between input and output data so that mechanical properties for an untested rotational speed can be estimated.

S.V. Sapkal et al. (2012) papers presents the influence of welding parameters like welding voltage, welding current and welding speed. Metal Inert Gas (MIG) welding process is an important component for many industrial operations. The welding parameters are the most important factors that affect the quality, cost and productivity of welding. A plan of experiments based on Taguchi technique is used to acquire the data. An orthogonal array, signal to noise (S/N) ratio and analysis of variance (ANOVA) are used to investigate the welding characteristics of MC C20 material and optimize the welding parameters (i.e. welding voltage, welding current and welding speed). At the last confirmation test is carried out to compare the predicted value with the experimental value that confirms its effectiveness in the analysis of penetration.

Joseph I. Achebo (2011) the strength value most desired in any welding process is an excellent Ultimate Tensile Strength (UTS) of the weld, compared with the parent metal. The optimization was achieved by employing the Taguchi Method. A step by step approach for applying the Taguchi Method is applied. The study shows that by using Taguchi Method successfully improved value is obtained on the existing process parameters, giving the industrial firm a more efficient welding protocol.

Claudio Morga et al. (2005) worked on the fuzzy if-the rules optimization. Evolutionary optimization of fuzzy if-then rules for the approximation in the area of research achieved much attention. A new possibility has been added by proposing a method for data driven reshaping or designing the uncertainty transitions for piecewise linear fuzzy sets representing the linguistic terms of the fuzzy rules. Method disclosed to optimize the shape of the sides of a piecewise linear linguistic terms. This method is based on fine tuning of the parameter which controls the sides of the linguistic terms. The shapes of the linguistic variable are controlled by both dilation and compression of shapes. The constrained optimization can be improved by changes in position and size of the core and support of the linguistic terms.

J. L. Lin et al. (2000) worked on optimizing electric discharge machining process based on Taguchi method with Fuzzy Logic. A Multi Response Performance Index (MRPI) is used to solve the electric discharge machining process with multiple performance characteristics index. The machining process parameters like workpiece polarity, duty factor, pulse-on time, open discharge voltage, discharge current and dielectric filed, are optimized with considerations of the multiple performance characteristics such as electrode wear ratio and material removal rate.

Experimental results presented, demonstrate this approach. Taguchi method has been concerned in optimizing single process parameter, handling multiple process parameters is done using fuzzy logic.

Y. S. Tarng et al. (1998) used the application of the Taguchi method to optimize submerged arc welding process. The Taguchi method helps to formulate the experimental layout, to analyze the effect of each welding parameters on welding performance. The Taguchi method is also used to predict the optimal setting for each welding parameter. As shown in this study the Taguchi method provides a very systematic and efficient methodology for determining optimal welding parameters with far less work than that would have been required for most optimization techniques. It has been shown that deposition rate and dilution can be significantly improved in the submerged arc welding process using the optimized welding parameters. The experiments were performed and based on the experimental results confirm the effectiveness of the approach. As a result, the performance characteristics such as dilution and deposition rate can be simultaneously considered and improved through this approach.

Yasuhiko Dote (1995) worked on fuzzy logic and its control. Fuzzy logic has been mostly used for control and measurement. Fuzzy membership functions are designed according to the requirements of the input and output terms. Further operations like and, or applied on the designed membership function to achieve the desired output.

The crisp inputs are fed to the fuzzifier on which rules are fired, the resultant produces fuzzy sets, the output is further fed to the defuzzifier where the fuzzy input are converted back to the crisp form. Work also has been done on the membership function and various operations are also performed on it.

N. Rajesh Jesudoss Hynes et al. (1994) their purpose of the work is to study the influence of process parameters of friction stud welding on joining of steel AA 6063 and AISI 1030. With the application of fuzzy logic, empirical models are developed for output response characteristics. Rotational speed, friction time and friction pressure are considered as the influential input process parameters. The values of Impact strength and axial shortening are predicted by fuzzy models and they are compared with the experimental data

2.2 Statistical Modelling and Optimization of TIG Welding Process Parameters Using Taguchi's Method

Modern fabrication industries join metallic materials through melting the base materials with the addition of filler materials. Welding has been a high-quality and cost-effective method for producing strong joints in several applications. Many conventional joining processes are used in the fabrication sectors. Among them, the tungsten inert gas (TIG) welding process was one of the popular conventional welding processes, primarily employed in the automobile, oil, gas pipeline, and container manufacturing sectors, Balaram et al. (2018). This TIG welding process was most commonly used in the joining of aluminium alloys. In comparison to aluminium alloys, aluminium AA5052 alloy possesses better weldability and excellent corrosion resistance to seawater and salt spray, making it ideal for marine applications, Sathishkumar, et al. (2021). The TIG welding process was preferred over other process for joining 5xxx alloys due to its ease and low cost, Shanavas et al. (2018). Denykui et al. (2018) revealed that applying different geometric shapes to a material changes its mechanical properties; they characterized the weld joints in terms of weld width, penetration depth, and reinforcement process profiles and found that the tensile strength was increased. Wan et al. (2021) attempted to modify the weld geometry through multi-pass welding with swing-improved TIG for aluminium AA 2219 alloys. It was observed that the joints with a tensile strength coefficient of 70 % and elongation over 4 % were acquired after weld geometry optimization. Aravind and Das (2020) investigated welding aluminium 7075 alloy and found that the maximum welding strength achieved by optimizing the process parameters (100 A current, 60 mm/min welding speed, and 17 lit/min gas flow rate) was 130.27 MPa. Samiuddin et al. (2020) investigated on the weldability of the Al-5083 alloy under the influence of different heat inputs (varied from 1 kJ/ mm to 2 kJ/mm) in the TIG welding process. Tensile strength 18.26 % of datum strength was lost after welding from base material were compared. Joseph and Muthukumaran (2016) investigated optimizing pulsed GTAW welding parameters for AISI 4135 powder metallurgy steel weld using a simulated and genetic algorithm and inferred that peak current of 80 A, base current of 35 A, welding speed 60 mm/min, and gas flow rate of 12 lit/min improved the tensile strength up to 685.31 MPa. Adalarasan and Santhanakumar (2015) performed welding experiments on 6061 aluminium alloy based on Taguchi orthogonal L9 array and employed grey relational analysis to study the significance of the welding parameters. Input parameters including arc voltage (17 V to 24 V), current (160 A to 180 A), welding speed (90 mm/min to 110 mm/min), and gas flow rate (9 lit/h to 14 lit/h) were varied to determine the mechanical characteristics; it was concluded that current has greater significance (47 %) over the mechanical properties followed by arc voltage (35 %). Kanakavalli et al. (2019) investigated the effect of welding current, voltage, speed, and bevel angle in joining two dissimilar metals; it was observed that characteristics like tensile strength up to 405.62 MPa and hardness up to 150.4 HV was enhanced for the optimal parameter values of 150 A, 16 V, 0.94 m/ min and 45°. Hazari et al. (2019) studied the fracture behaviour of AA6082 and AA8011 butt-sweated joint deformation during tensile tests. As the intensity of current increased, the ultimate tensile strength was improved from 90.25 MPa to 170.25 MPa remarkably with a considerable increase in its yield strength. Kumar and Sundarrajan (2009) approached Taguchi's technique to optimise pulsed TIG welding process parameters such as pulsed current (70 A to 80 A), base current (40 A to 50 A), welding speed

(210 mm/min to 230 mm/min), and pulse frequency (2 Hz to 4 Hz) of AA 5456 aluminium alloy welds for improvement of 10 % to 15 % in mechanical properties. Shunmugasundaram et al. (2020) performed friction stir welding on AA5052 with a Taguchi L9 orthogonal experimental array under the influence of tool rotational speed (650 rpm to 850 rpm), welding speed (20 mm/min to 40 mm/min), and tilt angle (1° to 2°). An optimized process parametric condition (tool rotational speed of 850 rpm, the welding speed of 20 mm/min, and the tilt angle of 2°) was found to obtain better mechanical properties in welded joints. ANOVA was performed to determine the percentage influence of the process parameters on the mechanical properties. Signal-to-noise (S/N) ratio analysis can be performed using the options such as smaller the better, nominal the better and larger the better , according to the desired response. The Taguchi method, Vora, et al. (2021), Srirangan, et al (2016), Kasirajan, et al (2020) and Sathish, et al (2021), allows the understanding of the influence of individual parameters on the materials' performance, i.e., microstructure and mechanical properties. The present study aims to weld the AA5052 alloy through the TIG welding process parameters using the Taguchi method. Process parameters such as current, voltage, and speed were varied during the welding process to study their significance on enhancing the reinforcement form factor (RFF), penetration shape factor (PSF) and hardness. Analysis of variance (ANOVA), S/N ratio analysis, and regression analysis were also performed.

2.3 Optimization of Welding Parameters by using Taguchi Method and Study of Fracture Mode Characterization of SS304H Welded by GMA Welding

Gas metal arc welding (GMAW) is an advanced version of electric arc welding in which no pressure is applied during the welding process and arc is created between a continuous copper coated wire and work piece Saadat et al (2009). This GMAW commonly used method for joining of steels structural, components for the automotive industry, Ghazvinlo et al (2010) and Ramazani et al (2014). Type 304/304L is the modern evolution of the original “18-8” austenitic stainless steel. It is very economical and versatile corrosion resistant stainless steel suitable for a wide range of general purpose applications.SS304H with a higher chromium and lower carbon content. Lower carbon contents minimize chromium carbide precipitation during welding and its susceptibility to intergranular corrosion.SS304H frequently was used in various industries such as Chemical and Petrochemical, Processing industries, pressure vessels, tanks, valves and pumps, heat exchangers, piping systems, flanges, fittings, Medical, Pharmaceutical Processing, Food, Beverage Processing and nuclear industries due to its excellent tensile strength, good weldability, and better corrosion resistance properties. Dinesh Mohan arya et al (2013) investigated process parameters for Metal Inert Gas welding and they reported that welding current is having maximum percentage contribution in experimental work. Nabendu Ghosh et al (2016) optimized the metal inert gas welding parameters, by Grey-Based Taguchi method and they reported in their result that current having the more significant effect than gas flow rate in influencing the strength of the welded joints. Vikas Chauhan and R. S. Jadoun (2015) studied the joining of two dissimilar metals SS304 and Low Carbon Steel by metal inert gas Welding (MIG) and they optimized the process parameter by using Taguchi Design Method and finally they informed that the effect of welding parameters on the ultimate tensile strength can be ranked in decreasing order as follows: voltage >speed > current. Abhishek Prakash et al (2016) determined the (welding) process parameters which influence the mechanical properties by using the Taguchi method and they produced a result that Welding Current has the greatest influence on Tensile and Hardness in the Weldability of welded joint followed by wire feed speed and arc voltage. S. M. Bayazid et al (2015) predicted welding parameters such as travel speed, rotational speed and plates position on microstructure and mechanical properties of Friction Stir Welded joint of two dissimilar Aluminum 6063 and 7075 alloys via Taguchi method and they reported that rotational speed, travel speed and plates position have 59, 30 and 7 % influence on tensile strength of welded joint respectively. Saurav Datta et al (2008) developed a multi-response problem to optimize parameters by combining to yield favorable bead geometry of submerged arc bead on-plate weldment and they coupled the Taguchi optimization method with Grey relation technique to evaluate the optimal parametric combination for deeper penetration, minimum bead height and depth HAZ of welded part. D Kalita and P. B Barua (2015) investigated the effect of the process parameters of Metal Inert Gas Welding such as welding current, arc voltage and shielding gas flow rate on tensile strength of welded joints by the Taguchi Optimization method and they concluded that welding voltage has significant effect, both on mean and variation of the Tensile strength of the weld having 87.019% and 85.398% contribution respectively, whereas welding current has significant effect on mean only (10.807% contribution) whereas Shielding gas flow rate has insignificant effect on the tensile strength of the welded joint. Therefore, in this research article, an attempt has to be made to optimize the process parameters of metal inert gas (MIG) welding. S R.Chikhale et al (2016) predicted the mechanical properties of Al Alloy 6061-T6 by metal inert gas welding and they consider the welding current, arc voltage and wire feed speed as welding parameters and finally they optimized the parameters by reporting that welding current has the most significant effect on the Tensile strength, depth of penetration and toughness of weld joint. Saadat Ali Rizvi et al (2016) optimized various welding process parameters by application of Taguchi method on MIG welding during welding of IS2062, and they mentioned in their research results that welding current and welding voltage have significant effect whereas gas flow rate has an insignificant effect on tensile strength of the weldment. Emmanuel O. Ogundimu et al (2018) studied the mechanical properties and microstructure of AISI

304 weldment, welded by MIG and TIG welded and they concluded that welding current has the most significant effect on weldment hardness and they also added that UTS is depended on welding parameters. WoeiShyan Lee et al (2003) studied the fracture behaviour of SS 304 welded and they analysed the fractography of failed samples and observed that weldments, all fail in a ductile manner as a result of an extensive localized shearing in the fusion zone and they also added that failure of the weldments initiates at the site of second-phase particles within the fusion zone. Uğur ÇALIGÜLÜ et al (2012) observed the tensile fracture of weldment and they concluded that after welding, it is seen that tensile strength values can be decreased depending on increasing the welding speed and this values can be increased depending on increasing the heat inputs, mainly in ductile fracture manner due to the fact that the ferritic stainless steel is a ductile steel. Anmol jeet Singh and Rutash Mittal (2017) applied the Taguchi technique to optimize the process parameters and the observed that a dimple pattern in the whole width of impact fracture specimen which confirms the ductile mode failure of the joints. Ýhsan Kirik and Niyazi Özdemýr (2015) examined the fracture mode of SS 304 weldment and mentioned that the tensile test mostly occurred on the AISI 1040 side, and especially ductile fractures in the form of quasi-cleavages were observed in the dimples. Ravindra V. Taiwade et al (2013) examined the fractured surface of tensile test of AISI 304 weldment and they observed that the AISI 304 SS failed due to ductile fracture. The

fractured surfaces of AISI 304 SS showed a wide range of dimple sizes of equiaxed type.

2.4 Grey-Based Taguchi Multi objective Optimization and Artificial Intelligence-Based Prediction of Dissimilar Gas Metal Arc Welding Process Performance

Welding techniques have been increasingly used in the automotive, aerospace, nuclear, vessel production, railway, and other manufacturing industries because of their simplicity, structural adaptability, and desired mechanical characteristics, Teng, et al (2001) and Derakhshan et al (2018). One of the most effective techniques for welding different materials is GMAW welding. Because of their low production costs and simplistic functionality, GMAW is used in a wide range of sectors. One of the capabilities of GMAW is the welding of certain dissimilar metals exclusively at less expense and without making the welding process more complicated. Moreover, dissimilar metal welding (DMW) has highlighted a lot of metallurgical challenges causing the formation of different intermetallic compounds, differences in metallic compositions, mechanical and thermal properties. Another prime factor that affects the efficiency of DMW is problems of corrosion, including the growth of brittle martensite Fuentes et al (2011) and Devaraj et al (2021), galvanic corrosion, oxidation, and hydrogen-induced cracking Davis (2006). Some of these complications are also inevitable when it comes to DMW of stainless steel to low alloy steel when improper process parameters are selected to perform the weld operation. These kinds of DMW have intensive application in the power production Shushan et al (2021), and petrochemical and construction industries Fuentes et al (2011) and Celik (1999). The maximizing demand for high-quality products has accelerated the development of modern automated industrial operations. Overall quality indices of a product are determined by the caliber of each sub-operation throughout the manufacturing phase, and welding is clearly a significant sub-process in certain instances. Dissimilar stainless steels were welded using GMAW and obtained the most contributing parameters among weld current, gas flow rate, and Z-distance Ghosh (2017). Ramarao et al. (2021), obtained a dissimilar joint from steel and stainless steel and optimized the input parameters based on impact strength. Weld irregularities and imperfections, which are the primary source of stress corrosion cracking causing erosive underwater equipment, particularly in the oil and gas industry, Dong et al. (2015).

The heat-recovery steam generators (HRSGs) are utilized in cycle power plants and coal-fired power systems, Rop et al. (2015) and the pressure vessels can use thin plates for building their walls, Dzierwa et al (2016). The American Society of Mechanical Engineers (ASME) guideline is used to manufacture HRSGs across European countries (ASME, 2021). These applications indicate that there is an obvious need for research related to thin plate welding. Generally, the mechanical characteristics might vary dramatically based on the heating and cooling circumstances, and also the structural as well as chemical characteristics of the test specimen Rodrigues et al (2014) and Easterling (2014). In this context, it is crucial to look at the effects of welding operation ultimate mechanical properties of the joint. Thus optimization of process parameters plays a crucial role in achieving weldment of desired strength, weld bead characters, Mohanty et al (2020), and defect-free joint, Zhao et al (2020). The key factors for achieving the desired integrity of the weldment, including hardness and strength, are the geometric features of the weld bead, like penetration depth (P), bead width (BW), bead height/reinforcement (R), and depth-to-width ratio (D/w), Esme et al (2009). The input variables that are used during the welding process mostly determine the weldment characteristics. As a result, the optimal selection of input parameters and a technique for evaluating the eventual weld geometry are the first phases in product design, Jeyaganesh et al (2021) and Tomków et al (2020). Moreover, the relationships of the output and input characteristics can sometimes be incompatible, causing an optimization technique much more difficult to solve. Multiobjective optimization is the terminology for a method that optimizes multiple responses at the same time. To address multiobjective functions, many techniques have been developed, with the weighted additive utility function approach combing multiobjective problems to single objective context are being widely utilized for weld situations, Vora et al (2021).

The fourth industrial revolution urges towards the upcoming era of production technologies, in which intellectual optimization and smart input will boost innovative technologies. Because of the growing demand for higher production rates, lower operating costs, and protracted quality, welding parameter prediction has become important. Meanwhile, because of the nonlinear nature of the multi-input process, selecting and implementing an appropriate and effective approach is critical to attaining better results, Mastanaiah et al (2018). As a result, machine learning techniques like ANN and ANFIS are required to predict the characteristics of the obtained joint. Numerous methods for predicting and optimizing processes such as the RSM technique, Taguchi method, artificial neural network (ANN), and adaptive neurofuzzy interface system (ANFIS) were outlined in the various literature with satisfactory results, Nwobi-Okoye, (2019), Yuan (2014) and Kochar (2019).

Hitherto, utilizing the most up-to-date predictive analytics methods and machine learning concepts can help to improve welding management and oversight Tuominen (2016). Such machine learning concepts may save substantial amounts of time, expense, and waste generation in the industry by reducing excessive experimentation. Weld techniques are across-the-board to the use of sophisticated algorithms to estimate and improve the geometry, structural properties, and mechanical characteristics of a joint before the actual welding of materials begins. By using the automated GMAW method, Xiong (2014) used ANN and regression analysis to determine the optimal weld parameters that affect the shape factors of the weld bead. They observed that the ANN outperformed the regression model because it can approximate nonlinear processes more effectively. However, for the performance analysis, these methods are frequently coupled using sophisticated adaptive optimization algorithms.

Some sophisticated investigations were conducted by Sreeraj and his research group. They developed an optimization model and a prediction model for characteristics such as bead geometry and Dilution percentage. The research proposed optimal input param-eters for obtaining minimum dilution and optimal bead geometry using particle swarm optimization, Sreeraj et al (2013) and ANN integrated with genetic algorithm, Sreeraj et al (2013).

The purpose of this article is to develop statistical optimization and machine learning prediction models for determining the optimum GMAW operating conditions, such as welding current (I), wire feed rate (F), welding speed (S), and contact tip to work distance (CTWD)(Z-dist.). Obtained results illustrate the role of the optimum weld bead geometry (BG) such as reinforcement, penetration, bead width including dilution percentage. Multiobjective optimization is conducted using the Grey-based Taguchi method. A comparative prediction model is developed using statistical regression analysis (RA), machine learning algorithms like ANN and ANFIS. This research is the first of its kind to perform statistical optimization and artificial intelligence-based prediction for thin dissimilar welding.

2.5 Prediction of Effects of Process Parameters to Study the Microstructure of TIG Welded Mild Steel Sheet by using Taguchi Method

Kohyama et al. (1992) studied he Microstructural changes in welded joints of 316 SS by dual-ion irradiation was analyzed in this study. They welded the specimens at three different parameters Current, Voltage, Flow Rate. The mechanical and corrosion property changes in welded joints under fusion environment should be very carefully evaluated. Ahmet Durgutlu (2004) studied the experimental investigation of the effect of hydrogen in argon as a shielding gas on TIG welding of Stainless Steel material by changing the parameters of Shielding gas. And it can be observed that increasing hydrogen content in the shielding gas reduces the mechanical properties. P. Liu et al. (2007) worked on microstructure characteristics in TIG welded joint of Mg/Al dissimilar materials with parameters of welding velocity, wire feed velocity. The structure close to the weld metal is columnar crystals, which grow into the weld metal. The Mg substrate close to the fusion zone was largely affected by the welding thermal cycle, and the crystals were small. The weld metal was mainly composed of dendrite crystal. M. Ahmad et al. (2007) Analyzed the microstructure and characterization of phases in TIG welded joints of Zircaloy-4 and Stainless Steel. Input process parameter range of voltage, current and Gas flow rate using the X-ray diffraction (XRD) technique. B.Y. Kang et al. (2009)

study the effect of alternate supply of shielding gases in austenite stainless steel GTA Welding on the material of Stainless Steel 304 by applying the both Conventional and Alternate method. The input parameters considered are Shielding gas, welding ampere and welding voltage

S. P. Gadewar et al. (2010) analyzed of the experimental investigations of weld characteristics for a single pass tig welding with SS304 with input parameters of Welding current (15-180 Amp), Shielding Gas Flow (1-18 LPM), Work Piece thickness (1-3mm) and applied the Regression analysis technique. Rui-Hua Zhang et al. (2011) study of the mechanism of penetration increase in A-TIG welding used the stainless steel materials plate with input parameters which are flux- Al2O3, Fe2 O3, SiO2, Cr2O3, TiO2, MnO, and B2O3 to find the result of penetration simulation by the PHOENICS software. C. Balaji et al. (2012) has studied on evaluation of mechanical properties of SS 316 L weldments using tungsten inert gas welding with stainless steel 316 L rod specimen which have dimensions of 25 mm diameter and 75 mm length and changed the input parameters range which are current (90,100,110 amp) bevel angle (60, 70, 800) gas volume (1.1, 0.9, 0.7 lpm) uses the Taguchi L-9 orthogonal array technique and they found the results. Dheeraj Singh et al. (2013) studied on parametric optimization of TIG process parameters using Taguchi and Grey Taguchi analysis. They used the Stainless Steel 304 grade plate with the process parameters Current (40-85A), Gas flow rate (5-20 lit./ min), Welding speed

(8-14m/min) and Gun angle (500 -800). And they applied the Taguchi method L16 orthogonal array for optimization the result. Cheng-HsienKuo et al. (2011) studied on the effect of activated TIG flux on performance of dissimilar welds between mild steel and stainless steel and they used the dissimilar plate with the process parameters which are different flux CaO, Fe2O3, Cr2O3, and SiO2. TIG welding with SiO2 powder can increase weld depth-to-width ratio, which indicates a high degree of energy concentration during welding process, and tends to reduce angular distortion of the weldment. Furthermore, the defects susceptibility of the welds can also be reduced. Sharma et al. (2019) used the TM and PROMETHEE (which widely used MCDM tool) technique to obtain an optimal setting of process parameters for single and multi-optimization resulting in an optimal value of the material removal rate and tool wear rate. Kumar and Mondal (2020) compared the results of experimental data on the electric discharge machining of AISI M2 steel by different optimization techniques such as TM, TOPSIS and gray relational analysis (GRA). Viswanathan et al. (2020) aimed to investigate the effective factors in turning of magnesium alloy with physical vapor deposition coated carbide insert in dry conditions. To identify the optimal parameters setting, a combination of principal component analysis (PCA) and GRA has been conducted. Liu et al. (2001) and, Land and Yeh (2008) used both TM and ANSYS which widely used numerical simulation software in order to optimize and design injection molded products. Asafa et al. (2013) presented integration of TM and artificial neural network (ANN) technique for the prediction of intrinsic stresses induced during plasma enhanced chemical vapor deposition of hydrogenated amorphous silicon thin films. From the literature review, it is found that welding of thin plated mild steel is a big challenge by TIG welding process. Again repeatability of welding depends on its control on welding processing parameters. In this work to perform welding of 3 mm MS plate, an automated TIG welding setup was made. Welding of the MS plate was done by changing the welding current, gas flow rate and diameter of filler rod to get a high strength joint. Effect of welding current, gas flow rate and diameter of filler rod were considered for radiographic test and liquid penetration test of weld joint, macrostructure of the heat affected zone and weld joint was analyzed.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

The Gas Metal Arc Welding (GMAW) was used to weld 10 mm mild steel plates. The input parameters used for this study are current, voltage and gas flow rate.

The welding machines (see Fig 3.1) contain the welding gun, shielding gas consisting of 100% argon. A 3.2mm consumable wire electrode of AWS classification ER70S-3 was used for the welding operation.

Figure 3.1: GMAW Welding Machine

3.1.1: History of Charpy impact Test

The Charpy impact test was invented in 1900 by Georges Augustin Albert Charpy (1865–1945), and it is regarded as one of the most commonly used test to evaluate the relative toughness of a material in a fast and economic way. The Charpy impact test measures the energy absorbed by a standard notched specimen while breaking under an impact load. This test continues to be used as an economical quality control method to determine the notch sensitivity and impact toughness of engineering materials such as metals, composites, ceramics, and polymers. The standard Charpy impact test specimen is of dimension 55 mm × 10 mm × 10 mm, having a notch machined across one of the larger dimensions. The Charpy impact test measures the energy absorbed by a standard notched specimen while breaking under an impact load. This test consists of striking a suitable specimen with a hammer on a pendulum arm while the specimen is held securely at each end. The hammer strikes opposite the notch. The energy absorbed by the specimen is determined precisely by measuring the decrease in motion of the pendulum arm. The important factors that affect the toughness of a material include low temperatures, high strain rates (by impact or pressurization), and stress concentrators such as notches, cracks, and voids.

3.1.2: Impact Strength Test

This test is used for quality tests of base and welded materials, it allows the assessment of the fracture behaviour under specified load conditions. A notched bending test specimen is broken by an impact with a hammer swing at a specified temperature.. The Charpy impact test, also known as the Charpy V-notch test, is a high strain-rate test that involves striking a standard notched specimen with a controlled weight pendulum swung from a set height. The impact test helps measure the amount of energy absorbed by the specimen during fracture.

3.1.3: Specimen Preparation

The size of the sample should be 55mm x 10mm x 10mm and should have a depth of 2mm notch at centre.

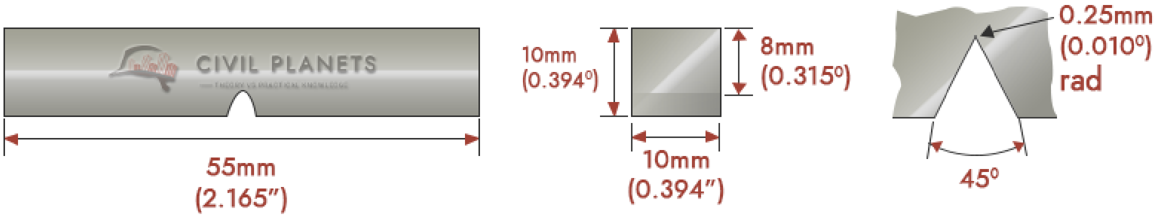

Figure 3.2: Illustrated V Notch Sample Preparation

- Lift the pendulum to its starting position. Then you have to check whether the test machine has been adjusted correctly.
- Initially, the Charpy machine has to be calibrated. To do this turn the dial gauge to the en value(highest value measurement) and release the pendulum without placing the specimen. The needle now goes to the starting value 0. Hence the Charpy machine is ready for the test.
- Now place the test specimen on the machine at the correct position by using the centring device.
- Then turn the dial gauge indicator needle downwards at the end value and release the pendulum.

- Now the pendulum swings down and cuts the specimen.
- Due to the energy absorption by the specimen, the pendulum does not attain the full height on the other side. Refer to the below pic.
- Using the dial gauge, we can measure the amount of energy absorbed by the specimen (in terms of Joules or Nm). Note down the value from the dial gauge.

3.1.4: Factors Affecting Charpy Impact Energy

- **Yield Strength** – High yield strength metal will absorb less impact energy.
- **Notch –** The shape and depth of the notch should be made accurately. The improper notch will show the error value of energy absorption.
- **Temperature –** The test should be executed at the 23°C +/- 5°C. Higher temperature affects the ductility

Figure 3.3: The Charpy impact tester

3.2 Methods

3.2.1: Steps Involved in Taguchi Method

The use of Taguchi's parameter design involves the following steps.

a. Identify the main function and its side effects.

b. Identify the noise factors, testing condition and quality characteristics.

c. Identify the objective function to be optimized.

d. Identify the control factors and their levels.

e. Select a suitable Orthogonal Array and construct the Matrix

f. Conduct the Matrix experiment.

g. Examine the data; predict the optimum control factor levels and its performance.
h. Conduct the verification/confirmation experiment.

CHAPTER FOUR

PRESENTATION AND DISCUSSION OF RESULTS

4.1 Results

Table 1 shows the orthogonal matrix layout and heat affected zones measurement results.

Table 4.1: Orthogonal Matrix Layout and Heat Affected Zones (HAZ) Measurements of corresponding Weldments

Experiment runs	*current* I	*voltage* V	*Gas flow rate* $L/\min$	Impact Energy J
1	160	18	13	125
2	160	19	14	85
3	160	20	15	106
4	170	18	15	121
5	170	19	13	110
6	170	20	14	96
7	180	18	14	127
8	180	19	15	118
9	180	20	13	116
$\sum$				1

Table 2 shows the range of process parameters

Table 4.2: Range of Process Parameters

Factors	*levels*		
	1	2	3
A. Voltage, V	18	19	20
B. Current, A	160	170	180
C. Gas Flow rate, Litre / min	13	14	15

Applying the larger the better methodology by using Eq.1

Signal to Noise ratio for the larger the better function is

$$\eta = -10\log_{10}(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y^2}) \quad (1)$$

Where, n is the sample size and y is the mean weld HAZ width in mm

For experiment 1,

$$\eta = -10\log_{10}(\frac{1}{1}\sum_{i=1}^{n}\frac{1}{125^2}) = 41.9382$$

For experiment 2,

$$\eta = -10\log_{10}(\frac{1}{1}\sum_{i=1}^{n}\frac{1}{85^2}) = 38.5387$$

For experiment 3,

$$\eta = -10\log_{10}(\frac{1}{1}\sum_{i=1}^{n}\frac{1}{106^2}) = 40.5061$$

For experiment 4,

$$\eta = -10\log_{10}(\frac{1}{1}\sum_{i=1}^{n}\frac{1}{121^2}) = 41.6558$$

For experiment 5,

$$\eta = -10\log_{10}(\frac{1}{1}\sum_{i=1}^{n}\frac{1}{110^2}) = 40.8281$$

For experiment 6,

$$\eta = -10\log_{10}(\frac{1}{1}\sum_{i=1}^{n}\frac{1}{96^2}) = 39.6457$$

For experiment 7,

$$\eta = -10\log_{10}(\frac{1}{1}\sum_{i=1}^{n}\frac{1}{127^2}) = 42.0761$$

For experiment 8,

$$\eta = -10\log_{10}(\frac{1}{1}\sum_{i=1}^{n}\frac{1}{118^2}) = 41.4375$$

For experiment 9,

$$\eta = -10\log_{10}(\frac{1}{1}\sum_{i=1}^{n}\frac{1}{116^2}) = 41.2889$$

The process parameter with the highest S/N ratio is regarded as the optimum. In this study, the highest S/N ratio is 42.0761 obtained from conducting experimental run 7.

The S/N ratio for the individual control factors as extracted from Table 1, are as calculated hereunder:

For Current

$$S_{v1} = \eta_1 + \eta_2 + \eta_3, S_{v2} = \eta_4 + \eta_5 + \eta_6, S_{v3} = \eta_7 + \eta_8 + \eta_9$$

Average S/N ratio for Current

$$\frac{S_{v1}}{3}; \frac{S_{v2}}{3}; and\ \frac{S_{v3}}{3}$$

$$Level\ 1: \frac{41.9382 + 38.5387 + 40.5061}{3} = 40.3277$$

$$Level\ 2: \frac{41.6558 + 40.8281 + 39.6457}{3} = 40.7099$$

$$Level\ 3: \frac{42.0761+41.4375+41.2889}{3} = 41.6008$$

For Voltage,

$$S_{c1} = \eta_1 + \eta_4 + \eta_7, S_{c2} = \eta_2 + \eta_5 + \eta_8, S_{c3} = \eta_3 + \eta_6 + \eta_9$$

Average S/N ratio for Voltage

$$\frac{S_{c1}}{3}; \frac{S_{c2}}{3}; and\ \frac{S_{c3}}{3}$$

$$Level\ 1: \frac{41.9382+41.6558+42.0761}{3} = 41.8900$$

$$Level\ 2: \frac{38.5387+40.8281+41.4375}{3} = 40.2681$$

$$Level\ 3: \frac{40.5061+39.6457+41.2889}{3} = 40.4802$$

For Gas Flow rate,

$$S_{w1} = \eta_1 + \eta_6 + \eta_9, S_{w8} = \eta_2 + \eta_4 + \eta_9, S_{w3} = \eta_3 + \eta_5 + \eta_7$$

Average S/N ratio for Gas Flow rate

$$\frac{S_{w1}}{3}; \frac{S_{w2}}{3}; and\ \frac{S_{w3}}{3}$$

$$Level\ 1: \frac{41.9382+39.6457+41.2889}{3} = 40.9576$$

$$Level\ 2: \frac{38.5387+41.6558+41.2889}{3} = 40.4945$$

$$Level\ 3: \frac{40.5061+40.8281+42.0761}{3} = 41.1368$$

The average S/N ratios for the process parameters are shown in Table 4.3

Table 4.3: Sum and Average S/N ratio for each Process Parameter

Level	A. Current	B. Voltage	C. Gas Flow rate	Total Average of S/N ratio
	Average of S/N ratio	Average of S/N ratio	Average of S/N ratio	40.8740
1	40.3277	41.8900∗	40.9576	
2	40.7099	40.2681	40.4945	
3	41.6008∗	40.4802	41.1368∗	

*signifies the optimum level based on the larger-the-better criterion. From Table 4.3, the optimum level corresponding to the highest S/N Ratio is **A_3-B_1-C_3**

4.1.1 Analysis of Variance (ANOVA)

Table 4.4 shows the analysis of variance tabulation

Table 4.4: Analysis of Variance (ANOVA)

Parameter	Process Parameter	Degree of Freedom	Sum of Squares	Variance	F-ratio	Contribution (%)
A	Voltage, V	2	1.5544	0.7772	0.1908	14.42
B	Current, A	2	0.8556	0.4278	0.1050	7.94
C	Gas flow rate, Litre/min	2	0.2197	0.1099	0.0270	2.04
Error		2	8.1482	4.0741	-	75.60
Total		8	10.7779	1.3472	-	100

Sum of square, $S_i^2 = \sum (y_i^2) - \frac{\left(\sum y_i\right)^2}{n}$ (1)

Where n is the number of test conducted (Achebo, 2012)

% Contribution = $\frac{S_i^2}{S_T^2} x\, 100\%$ (Achebo,2012) (2)

$Variance = \frac{Sum\ of\ Square}{Degree\ of\ Freedom}$ (Achebo,2012) (3)

F-ratio = $\frac{Variance_i}{Variance_{error}}$ (Achebo, 2012) (4)

Table 4.5: Calculation of Sum of Squares for Current Parameters

y_1	$= 40.3277$	y_1^2	$= 1626.3234$
y_2	$= 40.7099$	y_2^2	$= 1657.2960$
y_3	$= 41.6008$	y_3^2	$= 1730.6266$
$\sum y_i$	$= 122.6384$	$\sum \left(y_i^2\right)$	$= 5014.2460$
$\left(\sum y_i\right)^2$	$= 15040.1772$		

The sum of squares

$$S_i^2 = 5014.2460 - \frac{15040.1772}{3} = 0.8556$$

Table 4.6: Calculation of Sum of Squares for Voltage Parameters

y_1	$= 41.8900$	y_1^2	$= 1754.7721$
y_2	$= 40.2681$	y_2^2	$= 1621.5199$
y_3	$= 40.4802$	y_3^2	$= 1638.6466$
$\sum y_i$	$= 122.6383$	$\sum \left(y_i^2\right)$	$= 5014.9386$
$\left(\sum y_i\right)^2$	$= 15040.1526$		

The sum of squares

$$S_i^2 = 5014.9386 - \frac{15040.1526}{3} = 1.5544$$

Table 4.7: Calculation of Sum of Squares for Gas Flow rate Parameters

y_1	$= 40.9576$	y_1^2	$= 1677.5250$
y_2	$= 40.4945$	y_2^2	$= 1639.8045$
y_3	$= 41.1368$	y_3^2	$= 1692.2363$
$\sum y_i$	$= 122.5889$	$\sum\left(y_i^2\right)$	$= 5009.5658$
$\left(\sum y_i\right)^2$	$= 15028.0384$		

The sum of squares

$$S_i^2 = 5009.5658 - \frac{15028.0384}{3} = 0.2197$$

Table 4.8: Calculation of the Total Sum of Squares

Experimental Runs	S/N *Ratio* (y_i)	y_i^2
1	41.9382	1758.8126
2	38.5387	1485.2314
3	40.5061	1640.7441
4	41.6558	1735.2057
5	40.8281	1666.9337
6	39.6457	1571.7815
7	42.0761	1770.3982
8	41.4375	1717.0664
9	41.2889	1704.7733
$\sum y_i$	367.9151	$\sum\left(y_i^2\right) = 15050.9469$
$\left(\sum y_i\right)^2$	135361.5208	

The sum of squares

$$S_i^2 = 15050.9469 - \frac{135361.5208}{9} = 10.7779$$

4.1.2: Confirmation Test

Using $\eta = \eta_m + \sum_{i=1}^{n} \left(\bar{\eta} - \eta_m \right)$ (4)

Where η_m is the total mean of S/N ratio; $\bar{\eta}$ is the mean of S/N ratio at the optimal level and n is the number of main welding parameters.

The optimal parameters are A_3-B_1-C_3 and the corresponding S/N ratios are 41.6008, 41.8900 and 41.1368 respectively.

The total mean of S/N ratio, $\eta_m = 40.8740$

Therefore,

$$\eta_{opt} = 40.8740 + \left[\left(41.6008 - 40.8740\right) + \left(41.8900 - 40.8740\right) + \left(41.1368 - 40.8740\right) \right] = 42.8796$$

The existing process parameters in use for welding processes are A_2-B_3-C_1

Its S/N ratio is calculated as follows:

$$\eta_{ex} = 40.8740 + \left[\left(40.7099 - 40.8740\right) + \left(40.4802 - 40.8740\right) + \left(40.9576 - 40.8740\right) \right] = 40.3997$$

Table 9 shows the confirmation test results

Table 4.9: Confirmation Test Results

	Existing Process Parameters	Optimum Process Parameters	Improvement in S/N ratio and Impact Energy
Process Parameters	$A_2 - B_3 - C_1$	$A_3 - B_1 - C_3$	
Impact Energy (J)	115	127	12
S/N dB	40.3997	42.8796	2.4799

4.2 Discussion of Results

In this study, Taguchi optimization method was used to select the weldment with the best process parameters and Impact Energy

Table 4.1, contains the process parameters which include, the welding current, voltage and gas flow rate and the output parameters which is the Impact Energy. The Impact Energy is an expression of the extent to which the welded joint can absorb impact load and it is also an indication of the strength level of the welded joint.

A good parent metal is highly tightly packed with fine grained microstructure. When joined by wielding, as the arc heat increases and welding gas decreases, the solid filler metal transit into molten metal and fills the gap in-between the parent metal, the gas which tend to deracinate into the welding environment may not be sufficient to protect the environment from atmospheric air infiltration. However when sufficient air inter mixes with the molten metal, it may be trapped in the weldment. This is because molten metal cools very fast; therefore before the evacuation of the air from the molten metal as it is cooling very fast, air could be trapped.

Sufficient air that could oxidize the micro structural grains of the parent metal, transform these microstructures into macrostructures. macro-structural grains allow for metal indentation which lowers the quality of the weldment.

The above explanation expresses the reason why the higher the Impact Energy the better the quality of the weldment. In using the tagushi method to analyse the output parameter, the signal-to-noise ratio was used in this study.

Table 4.2 shows the project parameter alongside with their levels. The levels are divided into three parts, the low, medium and high. Applying the larger the better quality criteria, the signal to noise ratio of the output processes parameter was obtained. The higher the signal to noise ratio the better the quality characteristics of the weldment. In this sturdy, the weldment 7 has the highest signal to noise ratio of 42.0761. The signal to noise ratio of the individual input process parameter at the different levels were computed and averaged. The average values are recorded in Table 4.3.

From table 4.3, under each process parameter, the level with the highest signal to noise ratio is selected that is, for current 40.7099, for voltage 41.8900 and for gas flow rate 41.1368 were selected from the available values, the optimum process parameters becomes A_3,B_1,C_3.

The analysis of variance was computed to determine the level of contribution of each of the process parameter to the quality level of the weldment. Table 4.4 shows the computation process of analysis of variance. From table 4.4, it can be seen that voltage contributed most having a total of 14.42% of the quality level of the weldment, followed by the welding current, with a value of 7.94% and gas flow rate being the least with a contribution of 2.04%

A confirmation test was carried out to validate the inference that A_3, B_1, C_3 is the optimum process parameters. The signal to noise ratio of the existing process parameters of A_2 B_3, C_1 was determined to be 40.3997dB, whereas, the optimum welding process has a signal to noise ratio of 42.8796 dB. This shows that there is an improvement of 2.4799 dB the optimum process parameters has over the existing one. Also the Impact Energy of the weldment produced by the welding operation made by using the optimum process parameters has 12 J more than the Impact Energy obtained from the weldment made by using the existing process parameters.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The aim of this study is to determine the optimum welding parameters using the Tagushi method and this was clearly achieved.

The Taguchi method was able to develop new and improved welding process parameters used by the welders. The newly developed process parameters has a higher signal to noise ratio and higher Impact Energy than the ones produced by the existing process parameters.

Optimal process parameters are an important factor to be considered because it can be used to evaluate the quality of the weldment.

5.2 Recommendations

From the findings in this study, it is hereby recommended that;

i. The effect of input process parameters on the output process parameter should be investigated
ii. Other methods should be used to optimize the process parameters and compare the outcome with the values obtained in this study.
iii. More mechanical test, aside from the Impact Test should be done on the weldment produced by the optimum process parameters to further validate the status of the quality of the weldment.

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