The Scientific Temper (2023) Vol. 14 (2): 405-411 E-ISSN: 2231-6396, ISSN: 0976-8653
Doi: 10.58414/SCIENTIFICTEMPER.2023.14.2.26 https://scientifictemper.com/

ARTICLE TYPE

Satellite hardfacing of mild steel using robotic mig welding

Jonah*, Danush Kumar S M, Yugeshkrishnan M, Santhoshkumar K, Shahid Gaffa

Abstract

Hardfacing is carried out to enhance the hardness of the surface of a substrate by depositing a hard and wear resistance filler metal. It is more cost-effective to construct it out of regular steel and then coat the important layer of welded metal that can ensure the required hardness at the surface. A hardfacing system was developed by employing Robotic Gas Metal Arc Welding for the hardfacing of Stellite 21 on the Mild steel substrate. The various components of the hardfacing system and the detailed procedure of hardfacing, including programming the robot, setting the process parameters, conducting the experiments as per Taguchi L9 array and the measurement of hardness, were explained. Hardfacing trial 5 gave the maximum hardfacing deposit hardness of 499 Hv.

Keywords: Robotic, Corrosion, Hardfacing, Satellite, Mild Steel.

Introduction

Hardfacing is indeed a welding method in which a base metal is coated with a tougher or stronger substance. This is normally done with gas tungsten arc welding, oxyacetylene filler, or specialized MIG welding electrodes and is deposited to the base metal. Hardfacing can be used to improve a worn-down surface or boost a new item's wear resistance during manufacturing. Hardfacing by arc welding is a coating technique used to extend the life of parts and components before installation or as part of a maintenance program. Robotic Welding Technique is used to automate this operation. Robotic Metal Inert Gas (MIG) welding, also called as Robotic Gas Metal Arc Welding (GMAW), is a high deposition rate welding technique which includes a wire to be fed through a hot welding tip continuously. It's considered a semi-automated welding method. MIG welding is the most usual methods of welding in industrial applications, and it's a straightforward process to incorporate into a robot system. When robots are employed, MIG welding is more efficient than other forms of welding. MIG welding robots can work in any orientation, increasing the flexibility of the welding process.

Robotics and Automation Engineering PSG College of Technology Coimbatore, India

***Corresponding Author:** Jonah, Robotics and Automation Engineering PSG College of Technology Coimbatore, India, E-Mail: drnmurugan@gmail.com

How to cite this article: Jonah, Danush, K.S.M., Yugeshkrishnan, M., Santhoshkumar, K., Gaffa, S. (2023). Satellite hardfacing of mild steel using robotic mig welding. The Scientific Temper, **14**(2):405-411.

Doi: 10.58414/SCIENTIFICTEMPER.2023.14.2.26

Source of support: Nil

Conflict of interest: None.

Literature Survey

Stainless steel cladding is often utilized to give improved corrosion-resistant features in the petroleum, nuclear and marine sectors. The grade of components that are cladded is determined by the form and dilution of weld beads, both of which are influenced by process variables. The study on the cladding variables such as current and speed of welding and the nozzle-to-plate distance and its effects on the form of the weld bead were reported (Palani & Murugan, 2006).

Welding process variables have an impact over the performance of a welding connection. Numerical methods that can anticipate weld bead geometry and form connections must be developed so as to achieve the required mechanical features of welding (Marimuthu & Murugan, 2005).

Hardfacing is the process of applying a layer of a specific alloy to a surface in order to provide wear resistance. During deployment, wear has a considerable influence on metallic components, as well as cost. In terms of overcoming wear difficulties, the hardfacing approach has improved greatly in recent years. The gas tungsten arc welding (GTAW) process, for example, is mainly used in the valve industry for the deposition of Stellite 6, an alloy of cobalt-chromium, on low carbon steel (ASTM-A105) seat face of steam globe valves. Under conditions that generated severe metallic wear of the hardfacing alloy, the effect of critical factors on the Stellite-6 alloy's dry sliding wear resistance was studied (Shanmugam & Murugan, 2004).

Received: 15/04/2023 **Accepted:** 05/05/2023 **Published** : 30/06/2023

Hardfacing methods have advanced quickly and are currently used in a variety of sectors. The most significant distinction between welding and hardfacing is the dilution, which is the intermixing of filler and base materials. The dilution obtained significantly impacts the composition and qualities of hardfacing. Dilution control is critical in hardfacing, where minimal dilution is often desired. Welding process factors such as the welding current, open circuit voltage, travel speed, shielding gas, nozzle-to-work distance, welding position and gas flow rate are all properly selected to achieve the desired dilution.

Wear is the most essential factor in determining how long a hardfaced mechanical part can last. Wear causes metal plates to lose size and functionality, causing them to fail to fulfill their intended purpose. Abrasion, metallic (metal on metal) wear, heat, and corrosion are the most prevalent forms of wear. Rather than a single cause of wear, such as impact, most worn parts fail owing to a collection of wear modes, namely impact and abrasion (Mohan & Murugan, 2009; Balamurugan and Murugan, 2014)

Wear has an impact on the life of machine parts, and machine components are prone to fracture as a result of wear. Common wear mechanisms include abrasion, erosion, adhesion, impact, and corrosion. Hardfacing alloys, matrix materials, matrix hardening agents, erodent, temperature, and abrasion particles all affect wear resistance. The research work reported the wear behavior of hardfacing alloys to be deposited on ferrous and nickel-based alloys (Venkatesh et al., 2015).

The primary objective of the present research work was to explore and evaluate the best robotic MIG welding process parameters (gas flow rate, travel speed, welding current and nozzle to plate distance) to obtain the maximum hardness of Stellite 6 deposit hardfaced on the mild steel.

Methodology

Initially, the issue is recognized, and the project's goal is stated. Following that, other study articles on the subject were examined. The Welding process is then selected. The hardfacing process begins with the selection of the hardfacing material for the object to be hardfaced. Following the selection of the material, the processing parameters to be optimized are decided. The next step is to choose an optimization strategy for the processing parameters that have

been chosen. This is a critical stage since the optimization approach decides the number of samples that must be manufactured for optimization. The metal is then hardfaced with the optimal process parameters to achieve maximum deposit hardness. The Stellite 21 wire spool of 15 kgis shown in Figure1

Selection of Process and Materials

Gas Metal Arc Welding (Gmaw): An electric current is struck between the consumable electrode and the base metal to be welded. GMAW is a common welding technology for welding materials indoors in industries including construction, automobile production, manufacturing, and aerospace. Welders have it easier since the procedure is semi-automated or entirely automated, so they don't have to worry about errors on stops and starts.

Selection of Material: The cobalt-based Stellite metal family has a rich history of being among the most wear- and corrosion-resistant alloys on the market. It has a high level of mechanical wear resistance as well as remarkable corrosion resistance, particularly at high temperatures. The first Stellite version to be approved for use in Laser Powder Bed Fusion plates is Stellite 21. It is perfect for petrochemical and power-generation downhole flow control systems, valve trim, and applications involving erosion, cavitation, corrosion, and/or high temperatures.

Selection of Plate as Mild Steel: Low-carbon steel has been more typically utilized, and cost was a major consideration in selecting the material. ER70S-6 was chosen as the filler metal wire for wire arc additive manufacturing. This is a general-purpose welding wire for mild steel manufacturing. This recipe contains more deoxidizers than Stellite. Additionally, the deoxidizers improve moisture, resulting in a flatter bead shape and the potential to fly faster.

Selection of Process Parameters

The parameters to be optimized were welding current, welding speed, and gas flow rate. The following table shows the consequences of the various parameters.

Welding Current: The effect of current on welding can be summarised as follows, assuming all other factors remain constant: Controls the rate of heat generated, electrode melt off rate, and the rate of metal deposited.

Increased current may cause excessive melting ofelectrodes, more dilution, more residual stress and distortion.

Welding Speed: When all other variables are held constant, increasing the welding speed reduces the amount of heat input per unit of bead length, weld deposition and weld reinforcement because less filler metal is deposited. Distortion and residual stress are reduced. The potential of undercut and porosity increases as the weld solidifies faster. Uneven deposition may result from arc instability.

Gas Flow Rate (Constant): Assuming all other parameters remain constant, Weld depth and cross-sectional area can be affected by gas flow rate. The atmosphere can penetrate the arc if the flow rate is very low. Turbulence and wastage of shielding gas might occur if the flow rates are so high.

Nozzle to Plate Distance: Assuming all other parameters remain constant, the flow and heat transmission properties are determined by the distance between the nozzle and the plate.

Selection of Optimization method

Taguchi technique, Classical DOE, and Response Surface Methodology were evaluated to determine the best

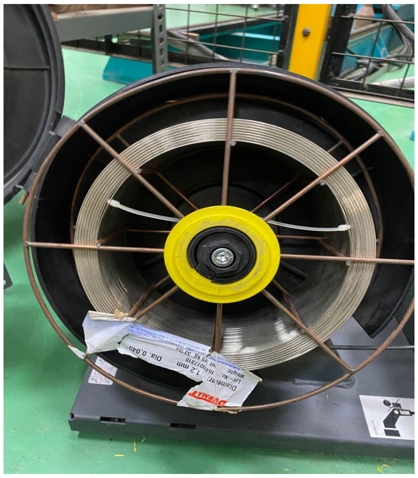

Figure 1: 1.2 mm Diameter Stellite 21 Filler

optimization strategy. The Taguchi approach was chosen since it was the least expensive. Taguchi techniques are simple to understand and use, as well as computationally.

Taguchi Method: The Taguchi methodology is a method for product optimization that comprises designing, running, and evaluating matrix experiment data to discover the ideal control factor values. Even if noise is present, the primary aim is to limit the performance variation to a minimum. The Taguchi technique combines a collection of inputs and decreases the number of input combinations required to complete an experiment. The Taguchi method uses a matrix representation of parameters, with each parameter having its own levels before being merged into a whole array of parameter combinations. The Taguchi technique can solve two sorts of issues: static or dynamic problems. Optimization requires determining the appropriate control factor measures for static issues to ensure the result is at the desired value. A signal input determines the output of the product to be optimised for dynamic challenges. The configuration process involves determining the best control factor values for transforming the incoming signal to the output signal.

L9 Orthogonal Array: An orthogonal array can be created, which reflects the input combinations that should be used in an experiment. The orthogonal array is a set of inputs that helps to decrease the number of trials in a study. Different quantities of orthogonal array structure are employed based on number of components and levels available. Because there were three sets of variables to be examined and nine specimens to be evaluated, a L9 orthogonal array was perfect for this experiment. A L9 orthogonal array is made up of nine different groups of three input combinations.

TABLE 1 Experimental Setup

The important components needed to conduct the experiment, as well as their varied specifications, are explained below, as these components have a significant impact on the process variables.

FANUC ARC Mate 100iC Welding Robot: The FANUC ARC Mate 100iC shown in Figure 2 is a 6-axis robot developed for continual movement activities such as cutting and welding. It can manage weights of up to 12 kg. The robot can route all of the necessary cables and wires via its own body. It comprises of a Fronius TPS 400i welder power source and an R-30iB controller.

Specifications: The FANUC Arc Mate 100iC is a 6- axis welding robot with great performance and dependability. The weld torch cable, gas lines, air lines, as well as other cables are all routed within the robotic manipulator for protection. This cuts down on setup time and ensures that cords don't interfere with one another. The 100iC robot can constantly sustain high speeds while managing up to 12 kg and its specifications are provided in Table 1. It features a slender wrist that allows it to fit into tight spaces in the workplace.

In the bot, there really are 2 kinds of coordinate systems: the Joint coordinate system and the Cartesian coordinate system. The Robot location is indicated using angular position in the Joint coordinate system, and joints can be moved individually. The coordinates in the Cartesian coordinate system also provide tool position and orientation and the ability to move the robot linearly or alter its orientation. The robot has a range of 1098 mm as a result of this. The robot may be positioned inverted and at an angle on the floor. In order to operate the robot securely, prescribed safety procedures must also be observed.

Controller: The R30iB from Fanuc is a small, power controller. Auxiliary arc control and force detection are completely supported. It can cut the robot's cycle time by as much as 15% while maintaining flawless mobility. It can operate up to four robots using up to 72 axes with pinpoint accuracy. It contains built-in features to prevent robots from colliding,

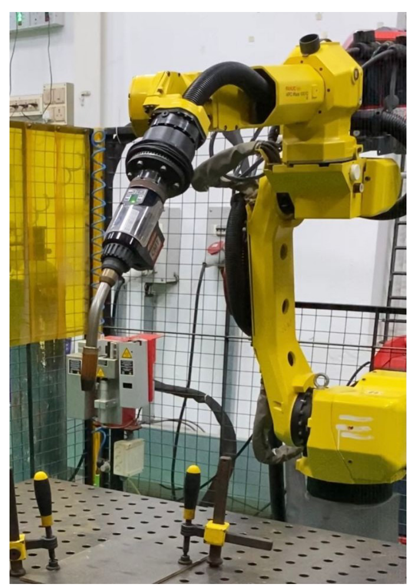

Figure 2: FANUC Arc Mate 100iC (arc tool)

Table 1: Specification of Fanuc Arc Mate 100ic

Robot	*FANUC Arc Mate 100iC*
Controller name	R30iB
No. of Axis	6 AXIS
Type	ARTICULATED
Mass of robot & DOF	130 kg & 6
Payload	12 kg

Figure 3: R30iB Controller

allowing for a higher robot density on the factory floor. It features unique vision hardware incorporated in, which enables for easy mistake proofing. With the embedded hardware, it also enables safety-rated speed and location monitoring. It features a safe PMC option that allows it to act as a Safety PLC without any additional hardware. Figure 3. depicts the Fanuc R30iB controller. The control should be used in a 0 to 45°C temperature range. The humidity level should be less than 75% RH, and the vibration level should be less than 0.5G. It features a 480 V three-phase power supply. It offers two 100 Base-TX/10 Base-T Ethernet connections, a USB port, and an RS-232 port, among other features. Device net, ProfNet, FL-Net, Ethernet I/O, Profibus DP slave master, and CC-Link are among the controller's remote I/O protocols (Slave). On the cabinet, there is a faulty reset, a cycle start button, and two LEDs showing fault and power status. The cabinet is equipped with a mode selector along with an emergency push button placed on it.

Teach Pendant: The teach pendant is a portable device for communicating with and configuring the robot. It features a touch screen and a toggle switch in the top left corner to deactivate or to activate it. The input keypad is the most important part of the touch pendant. It also comes with two active man switches to keep the user safe. When a user either lets go off the button or presses into it, the live man switch is triggered. Figure 4. depicts the teach pendant.

Programming the Robot: FANUC's unique program code, 'Karel,' is used to program the robot. The procedures involved in programming the robot are depicted in the flowchart in Figure 5. The following are the stages involved in programming crucial features like jogging the robot and instructing a joint. The many components involved in the robot's programming screen are shown in Figure 4 The following titles identify the individual program utilized in this project.

Figure 4: Teach pendant

Release E-Stops, activate TP, change Mode to T1, select low feed rate, hold dead man switch, move to position screen, then hold Shift + J1 or J2 to jog the robot. As illustrated in Figure 6, the program screen of the teach pendant is detailed with its characteristics.

To educate a point, use the Jog feed to control the robot to the required place, drag the pointer to the endpoint, and choose POINT from the standard motion command menu using the F1 key. Figure 7. depicts the screen and the button.

Preparing a program, position the cursor on the first line, activating the TP and pick T1, selecting "step" mode with override buttons, holding Dead man and pressing shift + FWD are the steps for testing a program.

Program Line Details: Figure 8. depicts the many components of a robot programming line. The motion format is the first. The most common motion formats are joint, linear, and circular, which are indicated by J, L, and C, respectively. Joint motion is also known as non-linear motion, and it is employed when all joints must move independently and continuously. The Joints move in a coordinated manner to move the tool tip in a straight path in linear action. When an arc motion is required, circular motion is utilized. A beginning point, a passing point, and an end point are all required. Because this format may only move equal to or less than the motion of a semicircle, a full circle motion must be split into two independent motions.

The position data format is next on the list. Finally, the feed rate may be provided in a variety of forms, as shown in the diagram. Finally, there are two options for the robot's placement path: Fine and Continuous. The robot can pause at some locations before reaching the end point in fine movement, and the robot goes from the beginning point to the finish point in a single motion in continuous route placement.

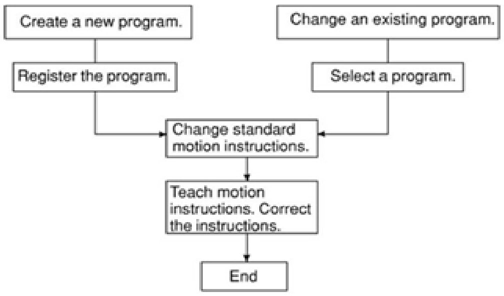

Figure 5: Programming flowchart

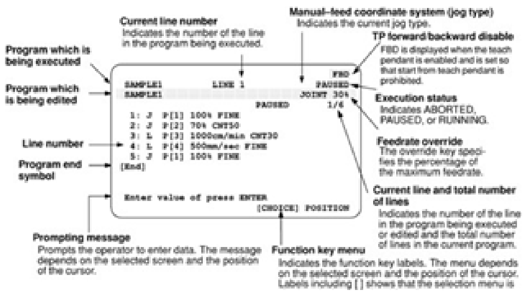

Figure 6: Use of the teach pendant for programming

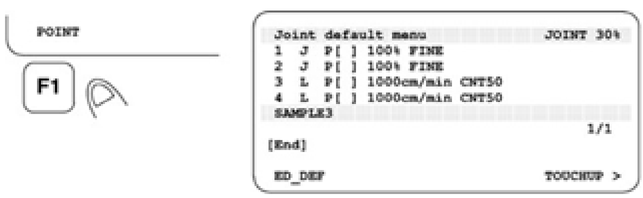

Figure 7: Teaching a point

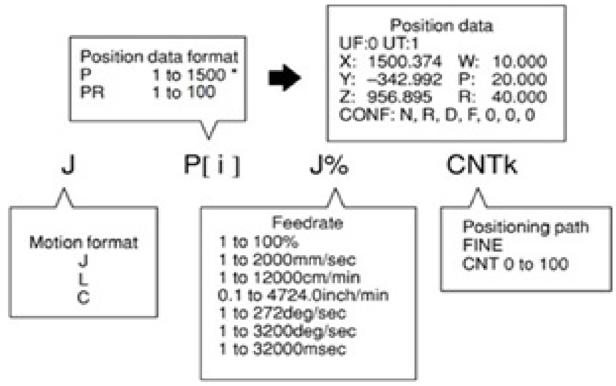

Figure 8: Program line details

Figure 9: Fronius TPS 400i

Gas Composition: The gas utilized was made up of 80 percent Argon and 20 percent Carbon dioxide. This is another process parameter that may be changed, but it was maintained constant for the sake of this experiment.

Power Source: The Fronius TPS 400i is a digitalized inverter power source shown in Figure 9. controlled by a microprocessor. It has a lot of possibilities for system additions, which gives it a lot of versatility. It has a digital signal processor that is linked to the power source's control and regulation unit. They collaborate to fully manage the welding process. The data is continually measured during welding and responds promptly to any changes. It employs a set of control algorithms to guarantee that the intended target state is maintained. As a result of all of this, good welds with great accuracy and repeatability are produced.

A USB port is used to connect flash drives, an adjusting dial with a turn/press function is used to set values, a touchscreen display is used to operate the power source, display values, and navigate the menu, a wire threading button is used to thread the wire electrode into the torch hose pack, and a gas-test button is used to set the required flow rate on the gas pressure regulator. It also has a primary switch for turning on and off the power supply, as well as an ethernet connection connector.

Experimentation

Taguchi Method

Non-linear effects were assessed using two or more tiers of parameters in the Taguchi technique. One of the most cost- effective strategies for parameter optimization is the Taguchi method. The selection of parameters is critical in this approach since the method's results are largely dependent on the parameters chosen. Multiple experiments are conducted with various parameter combinations. The outcomes of these trials, which were done using various parameter combinations, are recorded, and the final product is manufactured using this combination, which produces a favourable result. System design, design methodology of parameters, and tolerances design are the three steps of this procedure. The Taguchi Method consists of six steps: determining the main objective, selecting various control factors and their levels, selecting the orthogonal array, performing the matrix experiment, predicting the optimum value, and performing a verification experiment.

Identification of Main Objective: The goal of the present work is to optimize the settings in order to increase the hardness of the hardfacing deposit. This is accomplished by selecting the suitable parameters that determine the

Table 2: Parameters and their levels

Levels	*Welding current (A)*	*Welding speed (mm/s)*	*Nozzle to plate distance (mm/s)*
-1	200	5	15
0	225	6	18
1	250	7	21

hardness value and the grade of the model being produced.

Determining Various Control Factors and their Levels: The selection of levels is the next stage in the Taguchi technique. These values were established based on the nominal value of the parameters, which was discovered by consulting many literatures. The workable range of the parameters was determined using initial trial runs and are provided in the Table 2.

Selection of Orthogonal Array: Based on three factors of three levels, the Taguchi L9 array was selected consisting of the best 9 combinations of the three parameters provided as shown in Table 3

Perform Experiments (Robot Programming): A robot program was developed to weld a bead on the low carbon steel plate. This program is shown in Figure 10. and is explained in detail below

Line1: a random point P1 is selected, Line 2: the welding torch moves to the P2 point, where the weld deposition has to start with the speed of 100 mm/s, Line 3: the welding is enabled, which makes the robot to deposit weld on the plate, Line 4: the welding torch moves to the point P3 where the weld deposition has to end, Line 5: the welding is disabled, which stops the welding, and Line 6: the welding torch moves to a random position P4.

Setting of Parameters: The welding process parameters were set as discussed below.

Welding Current: The welding current was set by selecting the current parameter in the Fronius TPS 400i power source inverter. This is done by rotating the knob present in inverter power source as shown in Figure 11.

Welding Speed: The required welding speed was set by editing the speed in the robot program as shown in Figure 10. The Welding speed is given in the fourth line of the figure.

Table 3: Orthogonal taguchi L9 array

Trial No.	*Welding current (A)*	*Welding speed (mm/s)*	*Nozzle to plate distance (mm/s)*	*Hardness (HV 0.3)*
Trial 1	200	4	15	419
Trial 2	200	5	18	388
Trial 3	200	6	21	400
Trial 4	225	4	15	428
Trial 5	225	5	18	449
Trial 6	225	6	21	442
Trial 7	250	4	15	441
Trial 8	250	5	18	423
Trial 9	250	6	21	411

Nozzle to plate Distance: The nozzle to plate Distance was being adjusted using the Handheld Device by adjusting the Tip of the welding torch to the Ground shown in Figure 12.

Gas Flow Rate: The gas flow rate was changed using the flow vison MX 1.4.14 software as shown in Figure 13.

Welding: The program was fed to the robot through the teach pendant as shown in Figure 14. The steps involved in this process is discussed Previously. Gas flow rate was set as 20 SLPM Welding was performed by running the program through the teach pendant. All nine experiments were conducted as per the design matrix.

Hardfacing of Plates: The nine hardfacing trials are shown in Figs. 15-18. deposited based on the 9 process parameter combinations obtained from the L9 array.

These are the Stellite Hardfaced Trials in Mild steel with the Respective Parameters from Trail 1 to Trial 9. The next objective is to find the hardness of each weld. The welded beads were given for testing after the filing of the weld beads. This was done to ensure accurate Rockwell Hardness test "C" results. The Rockwell C scale uses a cone-shaped, diamond-tipped indenter with a 150 kg load. It is usually abbreviated HV (Vickers Hardness) and is presented in Table 3. From the table, the hardness of the hardfacing deposit of trial 5 is maximum. The optimization and its validation will be carried out further.

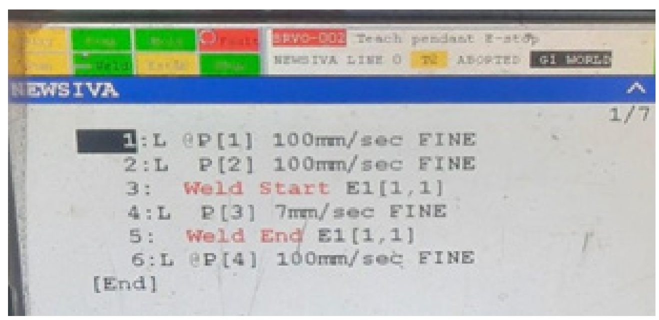

Figure 10: Program for robotic welding

Figure 11: Fronius TPS 400i power source

Figure 12: Adjusting the welding torch

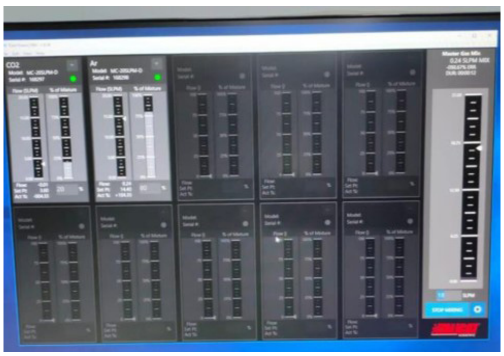

Figure 13: Flow Vison MX 1.4.14 Software

Figure 14: Welding process

Figure 15: Harfacing trials

Figure 16: Hardfacing trials 4,5 and 6

Figure 17: Hardfacing trials 7,8 and 9

Figure 18: Hardfacing Trials 1 to 9

Conclusion

The detailed procedure of Stellite 21 hardfacing of mild steel was explained, including the robotic MIG welding setup, writing the robotic programming, selecting the process parameters and Taguchi L9 array, setting the process parameters and depostingstellite 21 on mild steel and measuring the hardness of the deposits. The hardfacing trial 5 had a maximum hardness of 499 Hv.

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