M.tech (Production Engineering) Abhiraj kumar gupta 2023

OPTIMIZATION OF ROBO-MIG WELDING PARAMETERS FOR WELDING OF PROPELLER SHAFTS USING TAGUCHI DOE AND ANOVA

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

MASTER OF TECHNOLOGY
IN
PRODUCTION ENGINEERING

Submitted by

ABHIRAJ KUMAR GUPTA

2K21\PRD\01

Under the supervision of

PROF. VIPIN

DEPARTMENT OF MECHANICAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

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CANDIDATE'S DECLARATION

I, Abhiraj kumar gupta, Roll No. 2K21\PRD\01 student of M.Tech production Engineering, hereby declare that the project Dissertation titled "Optimization of Robo-mig welding parameters for welding of propeller shafts" which is submitted by me to the Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place : Delhi Abhiraj kumar gupta

Date:

DEPARTMENT OF MECHANICAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

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Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the project Dissertation titled "Optimization of Robo-mig welding parameters for welding of propeller shafts" which is submitted by Abhiraj kumar gupta, Roll No. 2K21\PRD\01 Department of Mechanical Engineering, Delhi Technological university, Delhi in partial fulfilment of the requirement for the award of the degree of Master of technology, is a record of the project work carried by our student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any degree or diploma to this university or elsewhere.

Place : Delhi PROF VIPIN

Date: SUPERVISOR

ABSTRACT

MIG Welding had been widely used in the industry since decades for welding purposes due to its higher weld deposition rate, Ease of use, weld quality and Longer pass welding capability. These all features of this welding process makes the process most prefered welding process for the welding of propeller/Drive shaft. MIG has been proven as the easiest of all the welding processes that uses arc. In automobile sector, its had been widely used. The process uses continuously fed electrode to form the weld bead and joint formation. The process becomes more robust and efficient when it is automated and robots are inherited with the welding process.

The usage and combination of robots with MIG Welding makes it robust but it needs to be optimized and process parameter like welding current, welding voltage, gas flow rate must be of such value that prevents any kind of weld defects to be formed over the weld bead. The most major issue that occurs while welding of propeller shafts is improper weld penetration and pin holes. The main aim of this research was to find the optimized value of all the weld parameters with the help of Taguchi design using minitab software and look for any other types of defects while welding and to rectify them and make the process as robust as possible.

Addition of automation in any process makes it free from human errors that may occur.As robots can perform repeatative tasks more efficiently we just have to teach them what they have to do and they have to do that. MIG welding when combined with the robot can perform welding at same point without any deviation in position and weld parameters like arc length. To maintain arc length to be constant in MIG welding is almost impossible for any human being which directly effects the weld quality and penetration.

An effort was undertaken to study the effects of using robotic arm for welding gun and effects of various process parameters over the weld bead. When non optimized parameters were used for the welding process there we have seen various defects in the final product.

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I would like to express my sincere gratitude to my advisor, Prof. Vipin, for their invaluable guidance and support throughout my master’s program. Their expertise and encouragement helped me to complete this research and write this thesis.

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CHAPTER 1 - INTRODUCTION

1.1 HISTORY

The history of joining metals can be traced back upto thousands of years. Earlier it can be traced from iron & bronze ages in middle east. Welding is a metal joining process that is utilized for joining of metals as well as thermoplastics by using heat as a medium to melt the metals and join them together. There are various forms of heat input for the welding processes like Arc, electric resistance, friction, gas etc. The use of these heat sources totally depends over the area of application and the type of metal to be welded. These all welding processes are capable of joining metals as well as non metals . The strength of joint formed by the welding process is sometimes more than the base metal which depends on the amount of fusion and the penetration of the welding. In previous few decades, welding is inherited with the automation to make the process more efficient and repeatability is enhanced. Robots can be taught to perform a task to perform a operation accurately and precisely. Therefore, they can be used to increase the accuracy of any process. In MIG welding, robots when added to the process makes it robust and the speed of process is enhanced too. Earlier when MIG was not inherited with the automation the process was not as much as fast as now when inherited with the robots.

The first technique that was used to join two pieces was brazing/Forging/Soldering and was founded by circain 3000 BC and it is used till today. Then after certain decades more types of welding techniques were invented and used. MIG welding comes under the category of arc welding that was founded by Benardows and Gkazewiski in 1865 and is used till date for joining purposes.

More welding techniques like gas welding, resistance welding were also developed with time and started using in various fields of automobile, aeronautics etc. as shown in Fig 1. Moreover, welding was not only used to join two pieces but also used for repair purposes like repairing of railway tracks with the help of thermite welding.

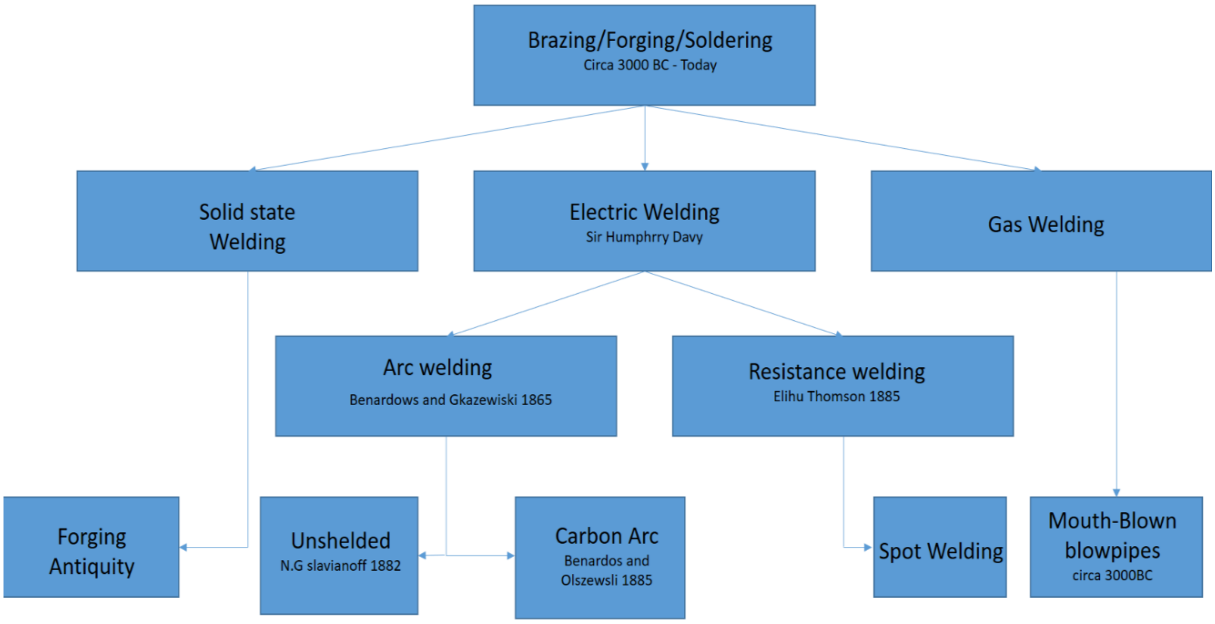


Figure 1 History of welding

1.2 BACKGROUND

In MIG process, a continuous wire is fed as an electrode which melts down and acts as the filler material for the weld pool. The wire is fed through a welding gun into the weld pool, and joining the two base metals. MIG is also known as GMAW. MIG electrodes do not have any additional coating of flux material therefore it needs external shielding for preventing the molten metal to get oxidized. So, externally shielding gas is fed to the weld pool. The shielding gas are the inert gases like Co2, N2, Argon that forms a shielding environment near the weld pool that prevents the atmospheric oxygen to reach the weld area. The continuously fed electrode is basically of same metal as the base metal.

The most commonly used welding process in the industry is metal inert gas (MIG) welding. In this process, an electrode is continuously used and a trigger regulating device is employed to control the wire feed and the wire bob. MIG welding is often used in manufacturing operations where high output rates are required, and there is a risk of arc or gas loss due to wind or air. While MIG welding has higher productivity than tungsten inert gas (TIG) welding, TIG welding produces cleaner welds as it produces less spatter than MIG welding. While some researchers have studied the effect of activated flux on TIG welding, little research has been conducted on MIG welding.

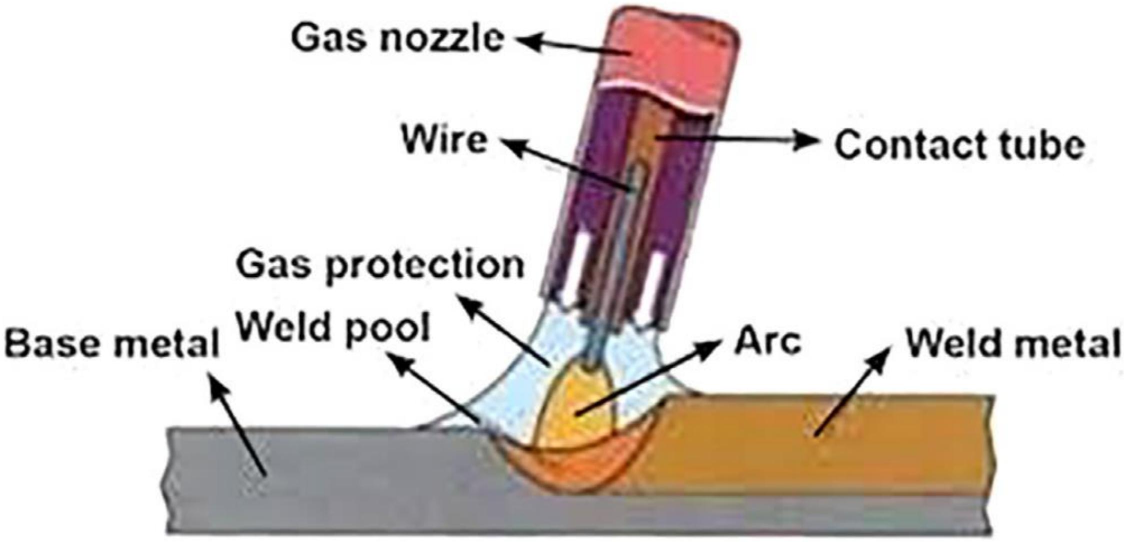


Figure 2 MIG Welding setup [1]

1.3 MIG Welding:

Gas metal arc welding (GMAW) has been available commercially for approximately six decades. The GMAW process involves establishing and maintaining an electrical arc between a base material and a wire electrode that is continuously fed. A shielding gas is continuously flowed around both the wire filler metal feeding in the weld pool and the weld pool itself to protect the molten weld pool from atmospheric conditions.

The heat of the electrical arc melts the base metal and the wire filler metal fed into the weld. Two variables are at play in the GMAW process: burn rate and feed rate. Burn rate refers to the rate at which the wire filler metal is melted or consumed by the thermal energy of the welding arc, while feed rate refers to the rate at which the wire filler metal is fed into the weld.

To maintain a stable welding arc, the burn rate and feed rate need to be equal. If the burn rate is higher than the feed rate, the wire filler metal would melt back to the contact tip, and if the feed rate is higher than the burn rate, the wire filler metal would feed into the molten weld pool, causing issues.

1.4 Robo-MIG Welding:

The project was done in the facility of where they have FANUC MIG welding robot. The MIG machine integrated wih robot is the advanced version of MIG welding. This type of MIG welding is getting famous day by day due to its various advantages over the convention MIG:

i) Faster than conventional

ii) Robust

iii) Precise

iv) Able to weld most complex areas

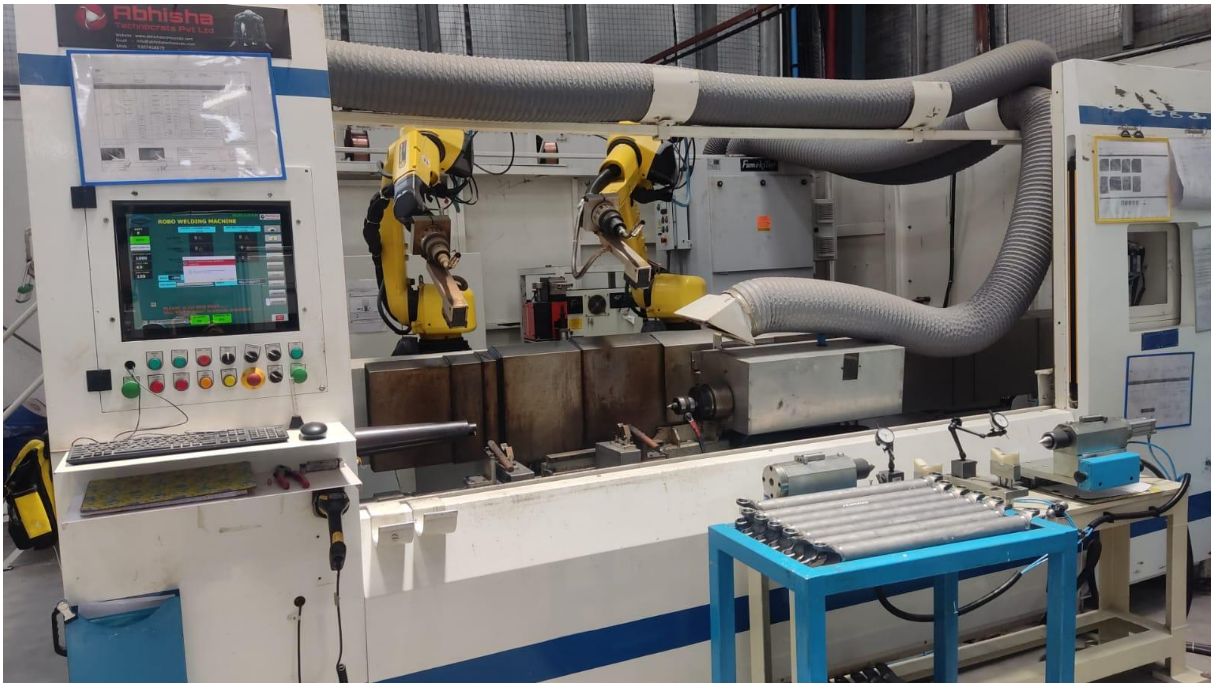


Figure 3 Robo MIG : FANUC ARCMate 100iD

CHAPTER 2 - LITERATURE SURVEY

2.1 LITERATURE REVIEW

S. No.	Author	Findings/Results
1	K.R. Madavi, B.F. Jogi, G.S. Lohar	In this study, MIG welding was studied with the application of two different types of fluxs which were magnesium carbonate and iron oxide and there effects were studied over the HAZ and weld penetration using Taguchi L9 arrays where three parameters with 3 levels were used current, Gas flow rate and the flux used. It was clearly found that MgCo3 flux shows highest UTS of the weld at 180 A and 10 lt per minutes of gas flow rate. When this data was studied for highest hardness it was found that the maximum hardness of the weld was found at 180 A, MgO flux and gas flow rate of 9.[1]
2	Harish K. Arya, Kulwant Singh, R. K. Saxena	The paper discussed about the effect of thickness of the base metal over the various product parameters of the weld bead like weld penetration and the bead with in submerged arc welding. Moreover, the paper concludes about the effect of various weld parameters like current, voltage,

		welding speed over the weld penetration and the weld bead. The results was analyzed using anova which showed that the weld penetration decreases with the increase in plate thickness due to increase in amount in heat loss in thickness direction of the weld and it increases with the increase in welding voltage and the current. And the weld bead width increases with the increase in arc voltage.[2]
3	Shahazad Ali a , Anant Prakash Agrawal a,⇑ , Naseem Ahamad b , Tribhuwan Singh c , Atif Wahid d	The paper investigates the effect of various welding parameters like Welding current, Welding voltage, Wire feed rate and welding speed over a MIG welding setup inherited with a kuka robot. It was found that using robot in welding process can make it much more efficient. And effect of these welding parameters was also studied over the tensile strength and ultimate tensile strength of the material. The study showed that the highest strength of material was found at the highest current and the higher wire feed rate. There was a major dip in tensile strength of the material with the decrease in welding current. That simply predicted that current optimization is the most major factor for the MIG welding.[3]

4	SP. Arunkumar a , C. Prabha b , Rajasekaran Saminathan c , Jabril A. Khamaj d , M. Viswanath e , C. Kevin Paul Ivan f , Ram Subbiah g,⇑ , P. Manoj Kumar h	The major concern of this paper is to improve the variables of the process by optimizing welding parameters like welding current, Voltage,and the bevel angle. The aim was to improve the impact strength of specimen which were A3387 steel alloy and stainless steel of SS316 alloy. In this study, optimization was done through Taguchi method using L9 orthogonal array. The combination of DOE that gave optimal solution was 20 V voltage of welding 140 A of current and 0 degrees of bevel angle. Observations were that there was a dip in impact strength for some time thereafter impact strength increased with the increasing voltage and moreover the impact strength was decreased with the increase in welding current. The end results showed that current was the most dominant factor in deciding the impact strength of the material.[4]
5	Nabendu Ghosh*a, Pradip Kumar Palb , Goutam Nandic	In this research, the X-ray radiography test and visual inspection was done over AISI 316L stainless steel to detect surface defects when it was welded under Various levels of currents, voltages, gas flow rates and nozzle to plate distance. The results were mainly focused to evaluate in terms of UTS, YS and the %age elongation.

		It was evident that there was spatters, improper penetration that was mainly caused by less current and instability of welding arc moreover it was also caused by poor gas supply. It was also observed that using Dirty environment also increased the spatters. It was also seen that when using CO2 as shielding gas spatters were more in comparison when argon was used for the shielding purpose it was to due to using CO2 increases arc energy but at the cost of arc instability. It was also seen that when faster arc travel speed was used there was lack of fusion at the roots and the wall were seen. When Optimum arc travel speed was used weld penetration was seen in the specification limit.[5]
6	Nabendu Ghosha , Ramesh Rudrapatib *, Pradip Kumar Palc , Gotam Nandic	The study was done in order to inspect and analyse the effects of weld parameters : Welding current, nozzle to plate distance and gas flow rate over the UTS and the % elongation in MIG welding process over AISI409 stainless steel material. For inspection purpose, X ray radiography and visual inspection method was choosen in order for the detection of defects either over the surface or the sub surface defects in the welded specimens. All the data that we got was analysed with the help of Taguchi methodology. The results predicted that:

		i) Porosity and blow holes were detected in the samples where faster arc travel speed and higher nozzle to plate distance was used ii) Undercuts were found in some samples where faster arc travel speed was used. iii) Lack of fusion was observed in the samples with lesser amount of current and faster arc speed. iv) It was also observed that on increasing the gas flow rate leaded to better bead geometry but after certain amount of increase there were blow holes seen in the bead. The possible cause of this is that on increasing the gas flow rate further increase the turbulence of the gas that cause unprotected environment for the weld bead.[6]
7	Sudhir Kumar a,⥣ , Rajender Singh b	In this research work, the experiments were done over AISI mild steel samples to study the effects process parameters such as current, voltage and the preheat temperature. Previously, none of the study was done over the effect of preheat temperature over the weld bead quality. The results were judged over the basis of UTS and % elongation. The results showed that the highest values of UTS and % elongation were found at 275 degree Celsius, current= 120A and Voltage= 25V. The results showed that i) 275 degree Celsius temperature is good for this grade of steel.

		ii) In comparison with all the factors current, voltage and the preheat temperature. Preheat temperature proved to be the most predominant factor affecting the tensile strength of the weld. iii) UTS and % elongation decreased when the preheat temperature was increased but on increasing the value of current it also increased. v) When X ray radiography tests were conducted it was concluded that higer voltage, moderate current, and the moderate preheat temperature produced the weld joints with least defects.[7]
8	K.R. Madavi, B.F. Jogi, G.S. Lohar	In the paper, the major focus was to study the affect of activated flux over the weld bead strength. Moreover, the study was orientated towards learning its effect over the weld penetration. From this study it was evident that MgCO3 flux gave the maximum tensile strength in comparison with Fe2o3, TiO3 and zinc powder. Iron oxide was rated second after the magnesium carbonate. i) Moreover, in this study weld penetration was studied at various wire feed rate and it was seen that penetration was poor at the lower feed rate (< 10 m/min). ii) The condition for perfecrt hardness was achieved at 180A, MgO flux, and gas flow rate of 9.

		iii) It was also proved that by using the MgO flux increased the UTS upto a level that its strength increased to a level more than the parent material. [8]
9	N. Rakesh a,⇑ , Ajay Mohan a , P. Navaf a , M.S. Harisankar a , Sreehari J. Nambiar a , M. Harikrishnan a , J.S. Devadathan a , K. Rameshkumar b	The paper was orientated towards the study of activated fluxes in welding and it effect over the weld penetration. The results showed that when zinc oxide or manganese oxide was used as the flux material in the process the penetration was increased upto 300%, the reason behind this was that by the usage of flux heat input was enhanced and there was an improvement in energy density. i) The phenomenon that was responsible for the enhancement of penetration of the weldment was the reversal of Marangoni effect. ii) When oxide fluxes were used they proved to increase penetration in the ferrous alloys. iii) When these fluxes were coated over the filler metal wire further increased the weld penetration. [9]
10	Deng-kui ZHANG1 ,Yue ZHAO1,2, Ming-ye DONG1 , Guo-qing WANG3 , Ai-ping WU1,2,4, Ji-guo SHAN1,2,	The paper studies about the effect of the weld penetration over the tensile properties of aluminum alloys using the TIG welding method. The study showed that the deeper the weld penetration is, more less the tensile strength of the

	Dan-yang MENG5 , Xian-li LIU6 , Jian-ling SONG5 , Zhong-ping ZHANG5	joint is. The reason behind this is that when more weld pemetration happens it causes more stress concentration over the area of weld toe and at that region there are more chances of cracking. Moreover if the weld penetration is lessor insufficient it may result in poor combination of the base metals and the joint will be failed easily. But if we increase the penetration rapidly it will result in overheating of the metal which can cause more HAZ and will lead to fracture failure. Keeping all the parameters constant when weld penetration was increased the tensile strength was decreased. Moreover it was seen that weld penetration was increased with increasing the current of welding, and decreasing the welding voltage. [10]
11	Yanling Xua,∗,1, Ziheng Wanga,b,1	The paper was basd on the study of various visual sensing devices that can be used in welding technologies for the improvement of the process. Like one of the study was about the visual sensing camera that was used for ensuring the weld shift during the mig welding. The visual sensing camera senses the position of the torch where the welding will take place and give feedback to the system for right or wrong weld position. [11]
12	Hao Cheng a,b , Liangang Zhou a , Qijun Li a , Dong	In this paper spatters were studied and how are they formed over the weld metal. The study was mainly

	Du b,c,**, Baohua Chang b,d,*	focused on the effect of different welding parameters over the formation of the spatters. The study showed that whenever low power and lesser speed parameters were used in the welding process the flow of molten metal inside the weld pool become unstable. In this case the key hole diameter shrinks that causes increase in the metal vapour eruptions and hence forms spatters with lesser size and higher velocity of eruption. Moreover, when high power and higher velocity parameters were used for the process a huge amount of vapour erupted from the weld pool of comparatively bigger size and lower flying speed. As well as, it was also known thar when the pressure of the metal vapour was higher it caused explosion from the backside of the pool and hence large amount of spatter was erupted from the backside of the weld. [12]
13	K. Devendranath Ramkumar n , B. Monoj Kumar, M. Gokul Krishnan, Sidarth Dev, Aman Jayesh Bhalodi, N. Arivazhagan, S. Narayanan	The study was based over the effect of using activated flex in TIG welding process over the weldability, mechanical properties and the microstructure of the process. Based on the trials it was concluded that the penetration increases with the increase in the welding current and the use of activated flux. When fluxs (siO2 & TiO2) were used in welding the hardness was found to be increased as compared to

		the base metal, this was due to the moderate cooling and the lesser heat input due to the higher energy density. It was also seen that after using of the fluxes the UTS was also enhanced and it was evident from the fact that under tensile loading the fracture occurred at the parent metal not at the joint. Impact toughness was also increased and was also due to the presence of the inclusion in the weld bead. [13]
14	Akhilesh Kumar Singh, Vidyut Dey, Ram Naresh Rai	The purpose of this study was to learn various techniques to improve the TIG welding in the area of the weld penetration. In this research, we got to know various new techniques in TIG welding to improve the weld penetration like ATIG, PCTIG, FBTIG. The weld penetration was increased upto 300% after the use of these methods. i) Flux when used in ATIG method makes the arc narrower over the molten weld pool and hence the weld bead width was reduced to almost half times and hence by this weld penetration was increased. ii) In FBTIG weld penetration also increases but with the increase in distance between the flux layers penetration also decreases. [14]

15	A. R. Deshmukha , G.Venkatachalamb*, Hemant Divekarc , M. R. Sarafd	The study was focused over the effect of weld penetration on the fatigue life of the weld joint. In this FEM method was used to estimate the joint under two test condition – Tensile loading and the bending loading. It was evident from the paper that welded components were less tolerant to the fatigue loading and it was due to two factors: i) Welded parts contains internal defects which acts as a point of the crack propagation. ii) Welding creates internal stresses at the joint. [15]

Table 1: Literature review

2.2 PROBLEM STATEMENT

The experiment was done to analyze the effect weld parameters which were current, Gas flow rate and the wire feed rate over the weld bead and the penetration. As the shaft with lesser penetration will be of lower strength as there may be chances of failure. Therefore, the weld penetration must be optimized. Here the work that needs to be done is to minimize these defects by optimizing all these parameters.

The problem is specifically modelled keeping in mind that when improper weld parameters is used during the welding there occurs many defects like :

1) Pin holes
2) Improper weld penetration
3) Half weld
4) Improper bead

2.3 RESEARCH OBJECTIVE

The main objective of this research work is to optimize the weld parameters listed below :

1) Welding current/voltage
2) Wire feed rate
3) Gas flow rate

All these parameters are manually controllable by the operator. So after getting values of optimized parameters they are input into the machine.

CHAPTER 3 – THEORETICAL STUDY

3.1 EFFECT OF VARIOUS WELD PARAMETERS OVER WELD PENETRATION

1) Welding current :

With the variation of welding current it is seen that deposition of weld metal is directly affected. The welding current and the wire feed rate is directly proportional i.e when one is decreased or increased the other parameter is automatically decreased or increased. This was studied by performing an experiment in which 5 welds were done by increasing the wire feed rate in each weld from experiment 1 to 5 and keeping all the other parameters constant. The DOE is shown below in Table.

Welding Current								
Weld ID Number	Target Welding Current (A)	Welder Settings			Data Acquisition			Heat Input (kJ/in)
		WFS (IPM)	Votlage (V)	Travel Speed (in/min)	WFS (IPM)	Voltage (V)	Current (A)	
1	100	150	24	15	151	24.5	111	10.88
2	150	250			252	24.7	162	16.01
3	175	325			331	24.8	193	19.15
4	200	400			462	24.9	212	21.12
5	250	615			618	25	254	25.40

Table 2 Welding current data [19]

In the table above we can clearly see that voltage, travel speed were fixed and the wire feed rate was varied as 100, 250, 325, 400, 615 IPM in experiment from 1 to 5.

From this experiment it was pretty clear that the current was increasing with the increase in wire feed rate. The current also affected the welding current profile. With the increase of current it was evident that penetration into the base metal was also increased.

Therefore, the way to increase the weld bead width & somehow penetration was to increase the welding current which was not directly possible. For that purpose we have to increase the wire feed rate.

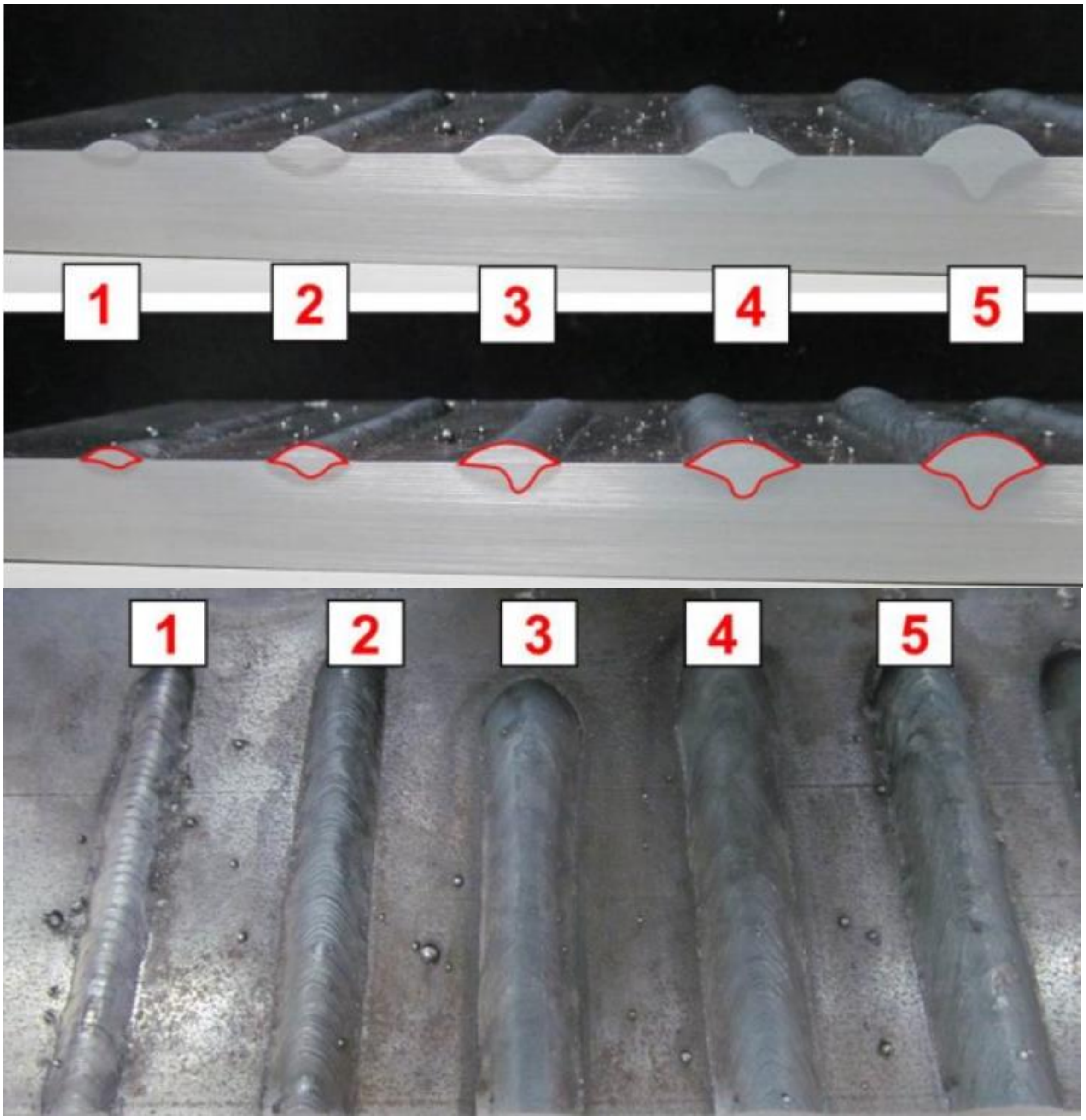


Figure 4 Weld profile at different current value

2) Welding Voltage:

The arc length is basically controlled by the welding voltage. Arc length is the distance between the wire filler material at the point of fusion to the weld pool. The relation of the voltage and the weld bead is that whenever the voltage is increased it is evident that weld bead is more flattened i.e width to depth ratio of the weld bead is increased with the increasing voltage. For this study, an experiment was performed. [20]

Welding Voltage								
Weld ID Number	Target Welding Voltage (v)	Welder Settings			Data Acquisition			Heat Input (kJ/in)
		WFS (ipm)	Votlage (v)	Travel Speed (ipm)	WFS (ipm)	Voltage (v)	Current (A)	
7	18	325	17.5	15	328	18	177	12.74
8	21		20.4		328	21.1	174	14.69
9	23		22		327	22.7	173	15.71
10	26		25.2		328	26	185	19.24
11	30		29.2		328	30.1	208	25.04

Table 3 Welding voltage data

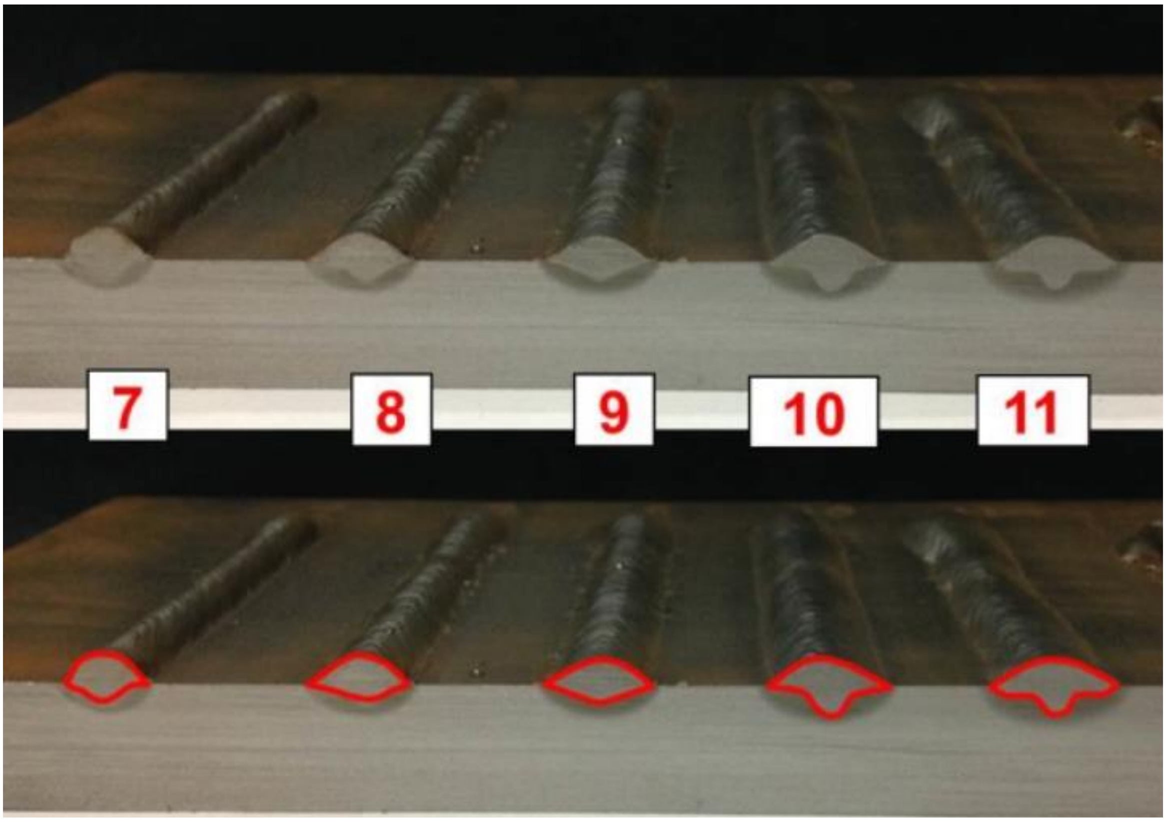


Figure 5 Weld profile at different welding voltage

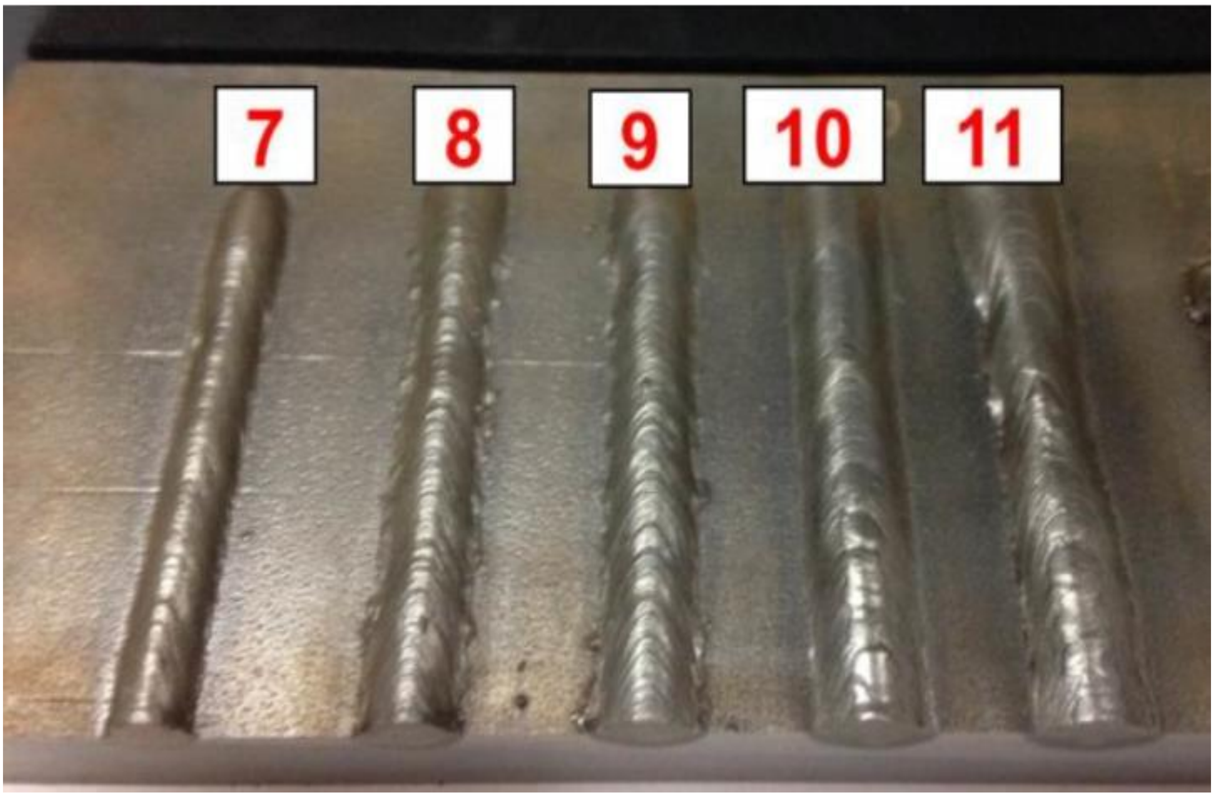


Figure 6 Weld bead profile at different voltage

3) Gas Flow Rate :

Shielding gas plays an important role in the geometry and quality of the weld bead. Shielding gas are basically the iner gases that are able to provide an inert atmosphere to the molten weld pool. Some examples of shielding gases are argon, Co2 etc. When an improper amount of shielding gas is provided over the weld pool, there are high chances of oxidation of motlen metal. Moreover, gases from the atmosphere can be entrapped into the molten pool that can cause various welding defects like blow holes, pinholes etc. to minimize this defects it is important to supply the proper amount of shielding gas around the molten pool.[22]

Here, we have studied the Robo-MIG welding process over the MIG welding machine which is automated with the help of a 6-axis robot Fanuc ARC Mate 100iD. The machine setup was done in DAIPL, Dharuhera plant which is leading manufacturer of propeller shaft and rear axles of Maruti eeco and maruti super carry. Here, my main concern was the drive shafts and to be specific I have choosen Y9T shaft which is a part of maruti eeco. The shaft was taken into consideration and studied for welding of the tube and tube yokes to form a semi assembled propeller shaft. The formation of drive shaft consists of total 10 processes:

i) **Tube pressup** : In this process, the tube yokes is pressed into the tube in press up and permanent marking machine. This machine basically indent QR code over the tube which consists of all the info like Vendor code, Date of manufacturing (Current date of working), Part ID, and part no. and then after that the ram presses the tube yokes into the tubes which is pneumatically controlled.

Figure 7 Tube yoke

Figure 8 Tube

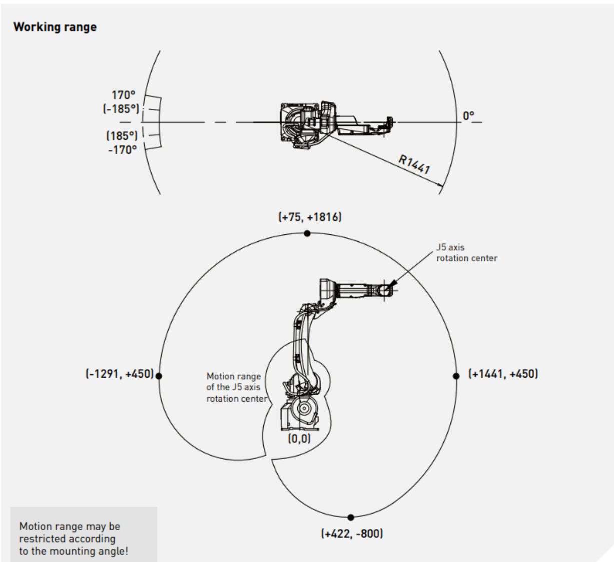
Figure 9 Tube & Tube yoke joint

Figure 10 Tube pressup machine

Figure 11 Knockdown machine

ii) **Knock down** : In this operation, After press up it is nessesary to do this operation as when tube yokes is pressed into the tube there due to some excess ram pressure tube get buldged or distorted. To avoid such kind of shafts to reach the customer the knock down operation is done. In which the run outs are checked with the help of the plunger dial, and the points where deviation is greater then the specified limit it is hammered at that point to reduce the run out and make the shaft's run out into the specified limit.

iii) **Robo-MIG Welding** : After completion of previous 2 processes, the tube and tube yokes joint is ready to be joined permanently with the help of Robo MIG welding. The welding process is semi-automated all the operator have to do is to put the shaft over the V-block fixture and push the start button, at a condition when all the parameters are set previously Like welding voltage, Wire Feed rate, and the Gas flow rate over both LH & RH robots.[16]. The working range of the robot is shown below in Fig. .The robot is taught its home position and the weld position and it have to continuously do the same work over the shafts over a period of time until we have to change the product parameters of the shaft.



Robot	ARC Mate 100*i*D
Robot footprint [mm]	343 x 343
Mounting position Floor	•
Mounting position Upside down	•
Mounting position Angle	•
Controller	**R-30*i*B Plus**
Open air cabinet	-
Mate cabinet	○
A-cabinet	•
B-cabinet	○
*i*Pendant Touch	•
Electrical connections	
Voltage 50/60Hz 3phase [V]	380-575
Voltage 50/60Hz 1phase [V]	-
Average power consumption [kW]	1
Integrated services	
Integrated signals on upper arm In/Out	1/1
Integrated air supply	1
Environment	
Acoustic noise level [dB]	< 70
Ambient temperature [° C]	0-45
Protection	
Body standard/optional	IP54
Wrist & J3 arm standard/optional	IP67

Figure 12 Working range of Fanuc ARC Mate 100iD

iv) **Sub Assembly**: At this station, 2 child parts are assembled which are flange yoke and slip yoke. Both of these parts are assembled with the UJ cross, bearing cup and locked with the help of circlip that prevents the joint to open. Each child part has 2 axis of rotation. And the UJ cross is torqued with the grease nipple that allows the joint to be filled with the grease for smooth movement and make the part safe from wear and tear. Each of this child part consist of 4 bearing, 1 UJ.

Figure 13 SubAssembly machine

Figure 14 Shaft sub Assy machine

v) **<u>Shaft Sub-Assembly</u>**: In this process, both side of shaft i.e tube yokes are assembled with flange yoke one side and another side is assembled with the slip yoke. Slip yoke is engaged with the gearbox side and the other side which is flange yoke has to be connected with the differential. In this assembly, bearing cups are inserted between each joint which makes it free to move along 2 axis of rotation and each joint is locked with the circlip. That means each shaft has 4 rotational joints made with total of 8 bearing cups. At this station both the child parts are assembled with the UJ Cross.

vi) **<u>Welch plug riveting & leak testing</u>**: In this process, slip yoke is riveted by the welch plug and tested if the joint is leak proof or not. The joint is made leak proof by the help of rubber O ring that is sandwiched between the slip yoke and the welch plug. The ram pressure is applied over the welch plug first after that riveting is done by a rotating plunger.

Figure 15 Welch plug riveting machine

vii) **<u>Flex effort correction</u>**: In this process, the effort for turning a joint is corrected according to the spec required with the help of hammer and a dowel pin. It is important to correct the flex effort as if it not corrected the shaft will fall down during the rotation and there will be issue in power transmission from the gearbox to the rear axle.

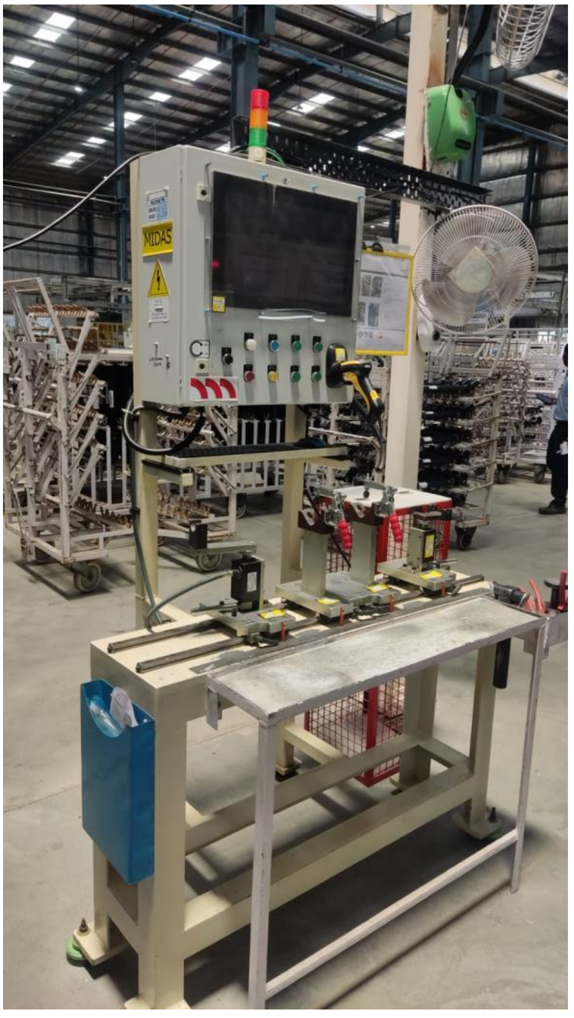


Figure 16 Flex effort machine

viii) **<u>Straightening</u>**: It is the process in which shaft is made straight by pressing the shaft at high run out points. Shaft is rotated on its axis and three LVDT sensors sense the high deviation points the ram presses the shaft at these high deviation points and made the shaft straight at high deviation points.

Figure 17 Straightening machine

ix) **Balancing**: Balancing is the last and the most important part of shaft assembly process. In this processs, shaft is rotated and high unbalance is calculated. And then weights are added to the opposite side of high unbalance points according the amount of unbalance weights shown over the machine display.

Figure 18 Balancing machine

x) **Painting**: This is the process that does not happen inside the plant. For this process the company has given work to another company name Kamal CED solutions that is located in maneser,Gurugram. After painting greasing is done in the joints and shaft is send for PDI and thereafter directly to the customer (MSIL).

Figure 19 Shaft after painting

Moreover, it was the demand of the customer (Maruti Suzuki India Ltd.) to make all of these processes robust and defect free. For this purpose, we have installed poka yokes over each and every station. So, that if any defect happens by mistake we will know about that or the poka yoke will itself not allow the defects to happen. These all poka yokes plays an important role in the final quality of the finished product. All the poka yokes at every station is listed below:

i) PERMANENT MARKING & TUBE PRESSUP

a) AIM : To prevent part of inappropriate B length to pass at next station

B length of shaft is defined as the length of the tube that needs to be pressed. If tube of incorrect B length is pressed there will be fitment error of that shaft between the gearbox and the axle. The correct length for the tube of Y9T model which is for maruti supercarry is 645+-1 mm.

For preventing this error to happen machine has a set length of pressing if that specified length shaft is not pressed, The machine will give alarm about the inappropriate length pressed and cycle will not be executed for the next part until the part is dumped into the rejection bin, which has a proximity sensor that gives feedback to the machine whether the

Figure 20 Rejection bin for pressup machine

part is dumped into the bin or not.

In such case, what we have to do is that we have to dump the part into the bin and then after start the another cycle.

b) AIM : If FDM graph does not pass through the set window

FDM graph plays an important role while pressing as it shows the variation of length or displacement of tube yokes inside the tube during pressing. If more than the required force is applied over the shaft, the shaft will bend and will become eccentric and therefore more amount of unbalance will be there in the shaft which will make the shaft to vibrate during the rotation during its operation and mae the system unstable and more amount of vibration will be there. For this purpose, we have set a window in the FDM graph of the machine, the the FDM graph must pass through this window i.e it must pass through left side of first rectangle and leaves through right side of the rectangle and it must enter the second rectangle from the bottom and exits the rectangle from the top, if this does not happen the machine will reject the part, as the is not correctly pressed.

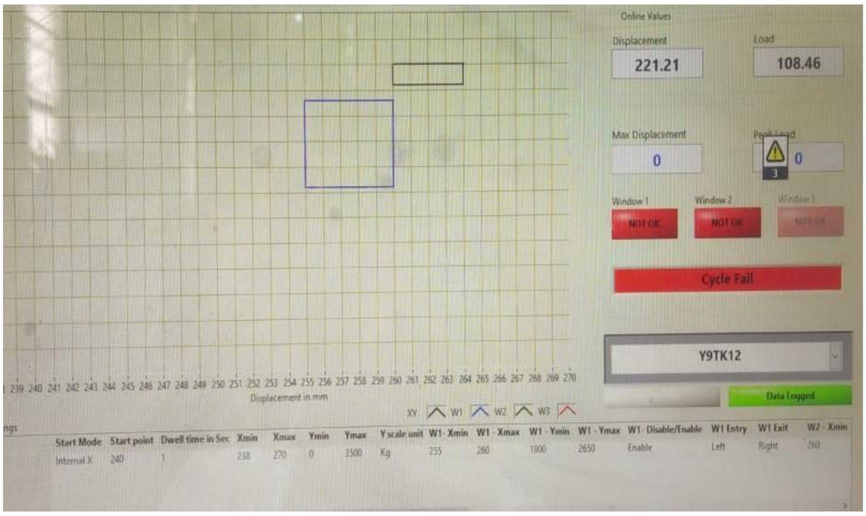


Figure 21 Set window for FDM graph

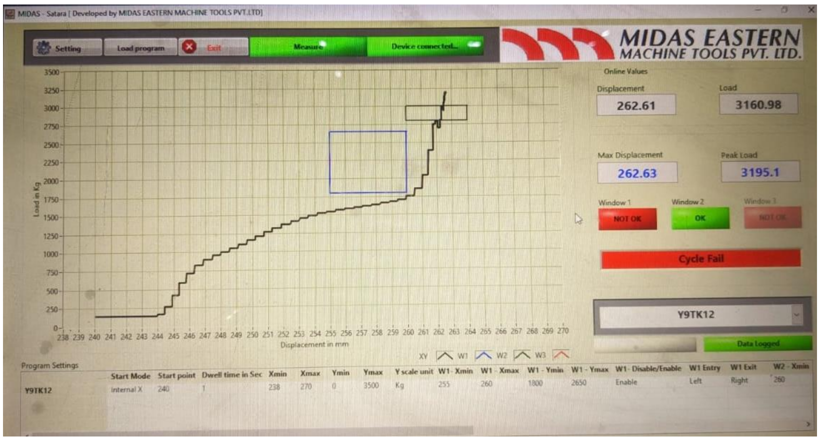


Figure 22 Graph passing out of set window/Rejected part

c) AIM: To prevent part with not readable QR code to be pressed

It is nessesary that part must be traceable at every stage during the production and after the production during its service. So if part without properly readable QR is passed there may be change that part may become untraceable and whenever it will be required to know the origin of the part, we will be unable to do so. Therefore, we have installed a poka yoke over the machine that if the part is not scanned by the machine the alarm will be given by the machine that QR not readable and we have to dump that part ino the bin. This poka yoke ensure the traceability of the drive shaft at every stage of its service and during the production.

Figure 23 Rejection bin

In this case, we directly dump the part into the rejection bin, that has proximity sensor. The machine will not execute the operation over the next part until the proximity sensor senses that the part is dumped into the rejection bin.

ii) ROBO-MIG WELDING

a) To prevent the same part to be scanned again

It is very important to ensure that same part must not be welded twice because of the operators mistake. For this purpose, the machine is installed with a program that gives alarm about to scan the new part, the part is already scanned and this program will not allow the machine to weld the new part until the old part is removed and the new part is scanned by the scanner integrated with machine. This program makes the process more robust.

Figure 24 Program display for not repeatition of same shaft to weld

In the above fig, we can clearly see the alarm that is showing to scan the new part, this part number is already processed.

b) If any of the process parameter (Current, Voltage, Gas flow) is out of the set range

In welding process, it is important to keep the process parameters to be in set range to avoid any kinds of defects and for this purpose there is program installed into the machine that gives alarm about the process parameters set out of the specified range. If the parameter found to be out of the set range the machine gives alarm and does not allow to execute the next operation until the process parameters is set in range manually.

Figure 25 Rejection bin for MIG welding

iii) GREASE NIPPLE TORQUING MACHINE

a) If set range of torque is not achieved by the machine

In this machine, there is a set range of torque defined by the machine for torqueing the grease nipple to the UJ cross It is important that this torque must be in specific limit. As if the Grease nipple is torqued less than the desired value there may be chances of grease leakage during the operation. But if the Grease nipple is torqued more than the desired value there may be chances that it may be broken under shear force. Therefore, a set limit is programmed to the machine for torqueing at exact amount of torque to avoid any kind of failure.

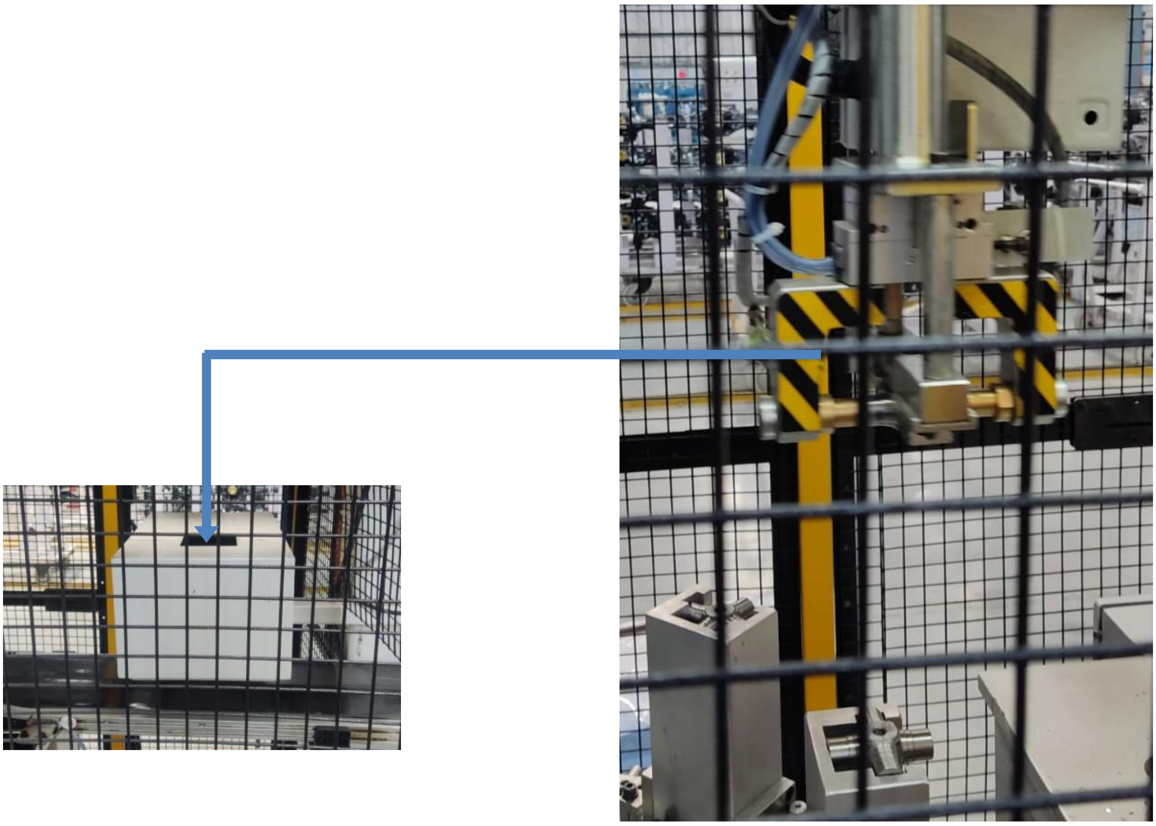


Figure 26 Rejection of incorrectly torqued UJ cross

In case of failure, in this process the rejected part is automatically picked up by the gantry system and rejected to the rejection bin. The system is totally automated.

b) If set range of angle is not achieved by the grease nipple after torqueing is completed

If set angle is not achieved after completion of the torqueing process, there may be issue that when grease is to be filled in the assembled product we will not able to access that area. Therefore, a set angle is provided for that over the machine system. And is that angle is somehow not achieved the machine is programmed in such a way it will be dumped to the rejection bin.

iv) WELCH PLUG ASSEMBLY & LEAK TESTING

a) If ‘O’ ring is missing

‘O’ ring is a important part of the slip yoke assembly. If during assembly somehow operator forgets to put the ‘O’ ring between the welch plug and the slip yoke there may be high chances of oil leakage from the slip yoke. Therefore, it was nessessary to install a system that avoids missing of O ring from the slip yoke assembly. For this purpose, a laser sensor is installed that

Figure 27 Poka yoke for O ring missing

senses the presence of O ring inside the slip yoke. If the O ring is not present inside the slip yoke, a alarm will be generated over the HMI screen that the O ring is missing and machine will not allow the operator to execute the operation.

In this condition, operator has to put the O ring below the machine or if he had already put the O ring just have to move the part a little such that sensor senses the O ring.

b) If air leak specification is not matched

The slip yoke when riveted passes through a air leak test to test whether there will be oil leakage during the operation or not. If the slip yoke fails the ir leak test which has some specified value of tolerance there may be high chances that it may also fail during the operation during its service. Therefore, such part must be rejected instantly. For this purpose the machine is programmed in such a way that if a part is rejected the part must be dumped into the rejection bin otherwise operation for the next cycle will not be executed.

Figure 28 Rejection bin

v) SUB-ASSEMBLY MACHINE

a) If Grease nipple is not aligned at the desired position

It is very nessesary that grease nipple must be at proper alighnment while the assembly of SY and the FY. For this purpose, a laser sensors are installed at the station that senses the presence and the alignment of the grease nipple. If somehow, grease nipple is aligned in opposite direction it will be lot more difficult to fill in the grease into the joints. Therefore, these laser sensor poka yoke ensures the exact alignment of the grease nipple.

Figure 29 Alignment of grease nipple in SY

Figure 30 Alignment of grease nipple in FY

b) To confirm if the circlip is not missing from the FY/SY assembly

Circlip is an important part of SY/FY assembly. It locks the bearing cup inside the joint and avoids the bearing cup to fall out of the joint during the operation. Therefore, it becomes really important to install a poka yoke that ensures the presence of circlip inside the SY/FY assembly. The sensor installed for this purpose is a proximity sensor and the process is that if the ciclip is not put over the proximity sensor before pressing the cycle execution button the cycle will not start and a alarm will be given that the circlip is missing.

Figure 31 Proximity sensor

vi) TIGHT JOINT AND SLIP JOINT ASSEMBLY ON SHAFT

a) If grease nipple direction is not towards the tube yoke

This machine is very much similar to the joint assembly machine. The only difference in this machine and the previous machine is only the operation taking place. In this machine the child part that are pre assembled in the previous station are assembled with the tube and tube yoke assemble that is the output of the MIG welding machine. Here, it is important to ensure the proper grease nipple orientation which is the grease nipple must be in inwards direction towards the tube yoke. For this purpose laser sensors are installed that senses the presense of grease nipple at the pre-defined location. If the grease nipple is not present at that position the machine will give an alarm about the grease nippke to be missing.

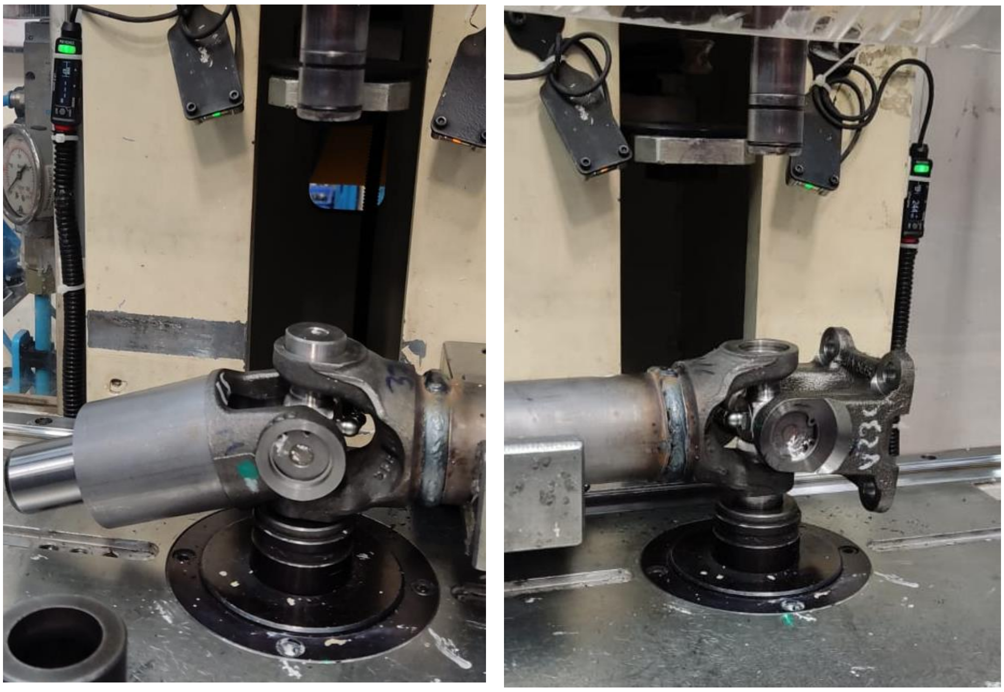


Figure 32 Poka yoke for grease nipple orientaion (LASER sensor)

In the above figure, we can clearly see the laser sensors to sense the orientation and position of the grease nipple.

b) Poka Yoke for confirmation of Circlip presence

Figure 33 PY for circlip presence

This poka yoke is as same as the poka yoke installed in the previous station for the circlip presence. The only difference is that here the direction of the grease nipple is in opposite direction.

vii) FLEX EFFORT CORRECTION MACHINE 1,2

a) To prevent any joint with incorrect flex effort to pass to check next joint

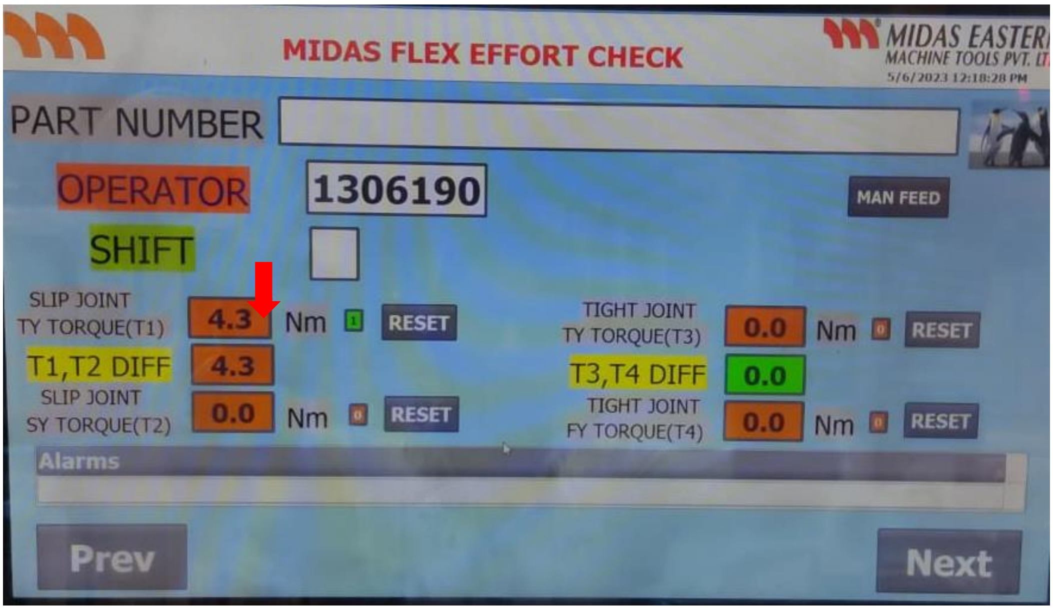


Figure 34 PY for preventing flex check bypass

Machine will not allow to check for the next joint until previous joint torque is within the specified limit. And it is important that any joint must not be bypassed without checking of its flex effort otherwise there will be more or less effort to rotate the joint. For this purpose, a program is installed that do not allow to check the next joint before previous one is checked and is within limits.

For this, Correct the flex effort of that joint and check again.

b) To restrict any part to pass to the next station whose flex effort could not be corrected

Sometimes, there come across some parts whose flex effort cannot be corrected after no. of efforts of correction. Such parts must not pass to the next station. So a poka yoke program is installed to prevent such part to pass to the next station.

Figure 35 Rejection bin for part not able to be corrected

viii) STRAIGHTENING MACHINE

a) To restrict any part in which straigtening could not be done within 5 cycles

This PY is important in order to sort out the NG part from the machine. If this PY will be not working there are high chances that high unbalance part will be passed to the next station. This machine is semi automatic. All the operator has to do is to clamp the shaft over the machine and press the push start button and the straightening cycle will be started.

In this machine the customer requirement is that the part must be straightened in n= 5 cycles otherwise the part will be rejected part. For this purpose, an internal program is installed in the machine that simply reject the partwhose straightening is not completed in n=5 cycles.

Figure 36 Rejection bin for straightening machine

ix) BALANCING MACHINE

a) To detect not marking of shaft at high unbalance point

There is a customer requirement that the shaft must be marked at opposite of its high balance points which will ensure that the unbalance value has been checked by the operator. For this task machine is installed with a proximity sensor that senses the lifting up of marking marker after checking the unbalance value.

Figure 37 Marker PY for balancing machine

After the unbalance values is displayed over the machine, operator has to remove the shaft from the machine, knock the weight with dolly and then mark the shaft.

b) To restrict part if part requires more than 25 grams of weight addition.

If a shaft requires addition of weight more than 25 gms that simply signifies that the amt. of unbalance it has is too high. So, we have to segregate this type of shafts from the line. And for this a program is installed into the machine that if the shaft requires addition of weight more than 25 gms, the machine will automatically reject the shaft.

Figure 38 Rejection bin for balancing machine

If such shaft is not rejected into the rejection bin by the operator, next cycle will not be executed.

CHAPTER 4 - EXPERIMENTAL SETUP

4.1 Details of Robo-MIG machine

For the experimental studies a FANUC ROBO-MIG machine model no. Arc Mate 100id was used that consists of two robotic arms each with 6 DOF that can rotate over its axis and the unit was setup in DAIPL, Dharuhera unit. The robot is abled to weld along 360 degrees points of rotation. The figure shows the Machine setup available at the floor space of the plant. Details of the Robo-MIG machine are as follows:-

S.No	Parameters	Values
1.	Controlled axes	6
2.	Repeatability	+- 0.02
3.	Mechanical weight	145kg
4	Voltage 50/60Hz 3 phase	380-575
5	Average power consumption	1 kW
6	Acoustic noise level	1 dB
7.	Ambient temperature	0-45 C degrees
8.	Body std. protection	IP54
9.	Wrist & J3 arm std protection	IP67
10.	Robot footprint [mm]	343mm x 343mm

Table 4: Machine specification

ARC Mate 100iD — Max. load capacity at wrist: **12 kg** — Max. reach: **1441 mm**

Controlled axes	Repeatability (mm)	Mechanical weight (kg)	Motion range (°)						Maximum speed (°/s)						J4 Moment/ Inertia (Nm/kgm²)	J5 Moment/ Inertia (Nm/kgm²)	J6 Moment/ Inertia (Nm/kgm²)
			J1	J2	J3	J4	J5	J6	J1	J2	J3	J4	J5	J6			
6	± 0.02*	145	340 (370)	235	455	380	360	900	260	240	260	430	450	720	26.0/0.90	26.0/0.90	11.0/0.30

Figure 39: Experimental set up of Robo-MIG

The welding was done on the FANUC ARC Mate 100iD. The setup over the machine consists of 2 V blocks over which the shaft rests, 2 dummy pins that helps to hold the shaft in position, and the clamps that is triggered by the push button and holds the shaft in position. After the start of the welding cycle, first the door closes and the robot senses the exact position for welding to avoid any weld shift. After the confirmation, of the correct weld position the robotic welding gun rotates 180 degrees and then it starts the welding while the shaft is rotated 390 degrees.

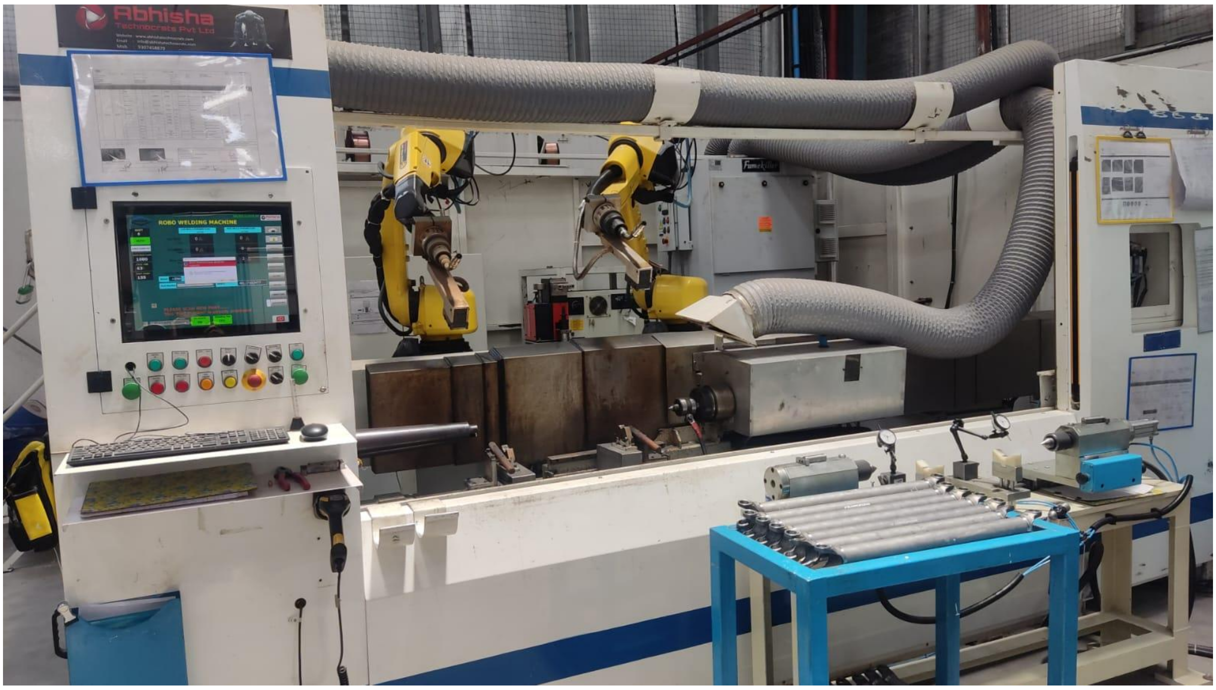


Figure 40 Fanuc ARCMate 100iD

Characteristics				Product / Process
No.	Product	Process	Class.	Specification / Tolerance
1	Bead height		(A)	0.8mm - 3.1 mm
2	Bead width		(A)	5.56 mm Min. (As per Standard -608 J)
3	Welding overlap position			Inline with tube yoke lug (As per Fig 1)
4	Welding overlap length			12.7 mm - 25.4mm (As per standard - 608 J
5	Weld penetration.		(A)	100% - 130%
6	Welding visual deffects			Free from surface blow holes,Pin hole, Zig Zag welding & incomplete welding
7		Cord distance		15mm ± 1mm
8		Torch angle (Degree)		76±1°
9		Stick out		14mm ± 1mm
10		Weld start angle		0°
11		Weld end angle		390°
12		Voltage in volts		21-25
13		Wire feed rate		8.1 - 8.4 mm/sec
14		Gas flow rate (Liter/min)		Min. 18 Ltr./min.

Fig41. Process/Product parameters for welding

4.2 Metal cutter

The next stage after the welding is to test the penetration of the weld. For this test to be done first we have to cut the shaft from near the weld bead with the help of cutter and thereafter it is cut into 2 pieces as shown in the figure. The cutting machine used for cutting operation is shown below :

Figure 42 Metal cutting machine at the facility of DAIPL,DHR

4.3 Microscope for penetration study

After the cutting of the shaft and preparation of the specimen, we apply weld penetration oil over the surface of the weld and the specimen is then ready for the penetration test. Then specimen is then put under the Banbros BSZ-608T which is stereo zoom microscope that can display magnified images directly over the screen of the software.

S. No	Parameters	Values
1.	Viewing Tube	30° Trinocular viewing head, Inclined at 30°
2.	Diopter Adjustment Eyepiece	WF10X/Ø23 Extra wide field eyepiece WF10X/Ø23
3.	Zoom Objective	0.6X-5X
4	Magnification	6X to 50X
5	Zoom Ratio	1:8.3
6	Working Distance	115mm
7.	Focusing Range	105mm
8.	Illumination	100V-240V/LED Incident Illumination 100V-240V/LED Transmitted Illumination
9.	Video Adapter	1x C Mount
10.	Diopter Adjustment Eyepiece	WF10X/Ø23 Extra wide field eyepiece WF10X/Ø23

Table 5 Machine specification

Figure 43 Banbros BSZ-608T Microscope at DAIPL facility.

4.4 Experimental procedure

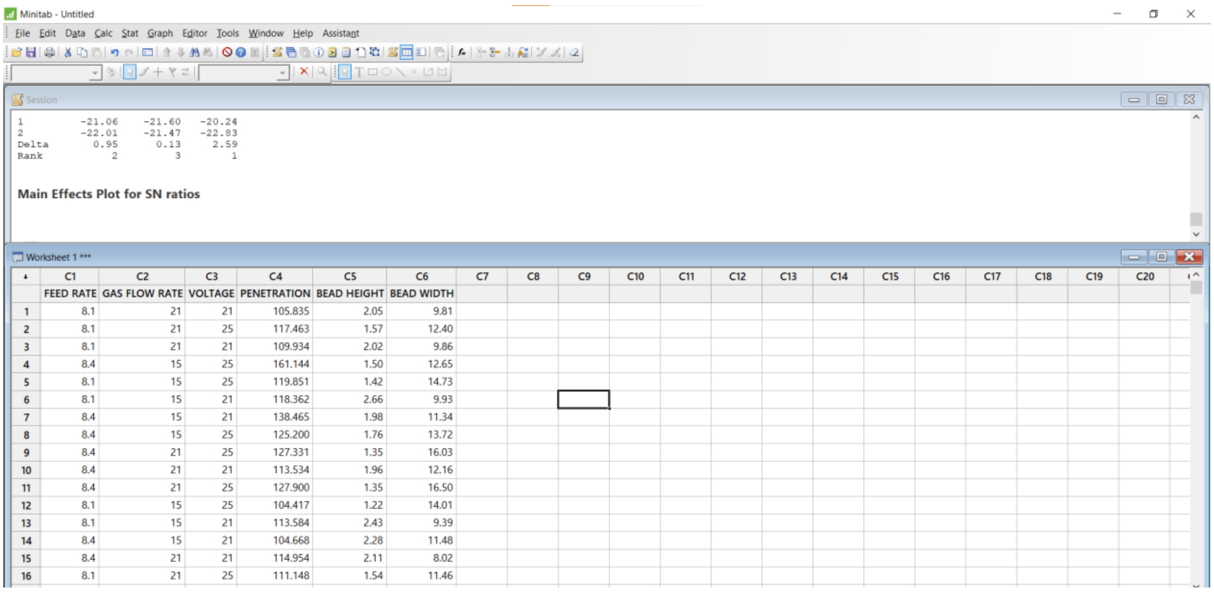
i) First, the DOE was made with the help of Minitab V17.1.0. A design of experiment was made in minitab software by using Taguchi DOE method. The three factors were choosen Wire feed rate, Voltage, and gas flow rate. The design of experiment that was obtained is shown below:

S.No.	INPUT PARAMETERS		
	Feed Rate	Gas Flow	Voltage/ Current
1	8.1	21	21/277
2	8.1	21	25/245
3	8.1	21	21/247
4	8.4	15	25/265
5	8.1	15	25/261
6	8.1	15	21/281
7	8.4	15	21/277
8	8.4	15	25/243
9	8.4	21	25/267
10	8.4	21	21/268
11	8.4	21	25/265
12	8.1	15	25/255
13	8.1	15	21/281
14	8.4	15	21/277
15	8.4	21	21/284
16	8.1	21	25/260

Figure 44 Taguchi DOE

After, using minitab for having DOE using Taguchi design we got 16 combination of these parameters.

ii) Then, after gettting the DOE the experiment was performed over 3 shafts for each



↓	C1	C2	C3	C4	C5	C6
	FEED RATE	GAS FLOW RATE	VOLTAGE	PENETRATION	BEAD HEIGHT	BEAD WIDTH
1	8.1	21	21	105.835	2.05	9.81
2	8.1	21	25	117.463	1.57	12.40
3	8.1	21	21	109.934	2.02	9.86
4	8.4	15	25	161.144	1.50	12.65
5	8.1	15	25	119.851	1.42	14.73
6	8.1	15	21	118.362	2.66	9.93
7	8.4	15	21	138.465	1.98	11.34
8	8.4	15	25	125.200	1.76	13.72
9	8.4	21	25	127.331	1.35	16.03
10	8.4	21	21	113.534	1.96	12.16
11	8.4	21	25	127.900	1.35	16.50
12	8.1	15	25	104.417	1.22	14.01
13	8.1	15	21	113.584	2.43	9.39
14	8.4	15	21	104.668	2.28	11.48
15	8.4	21	21	114.954	2.11	8.02
16	8.1	21	25	111.148	1.54	11.46

Figure 45 Minitab GUI

combination. For each experiment parameters were input into the Robo-MIG welding Machine (Wire feed rate, voltage, Gas flow rate).

iii) After welding 48 shafts for all 16 experiments, we have to cut the tube from near the weld bead and then cut it across its cross section as shown in the figure below:

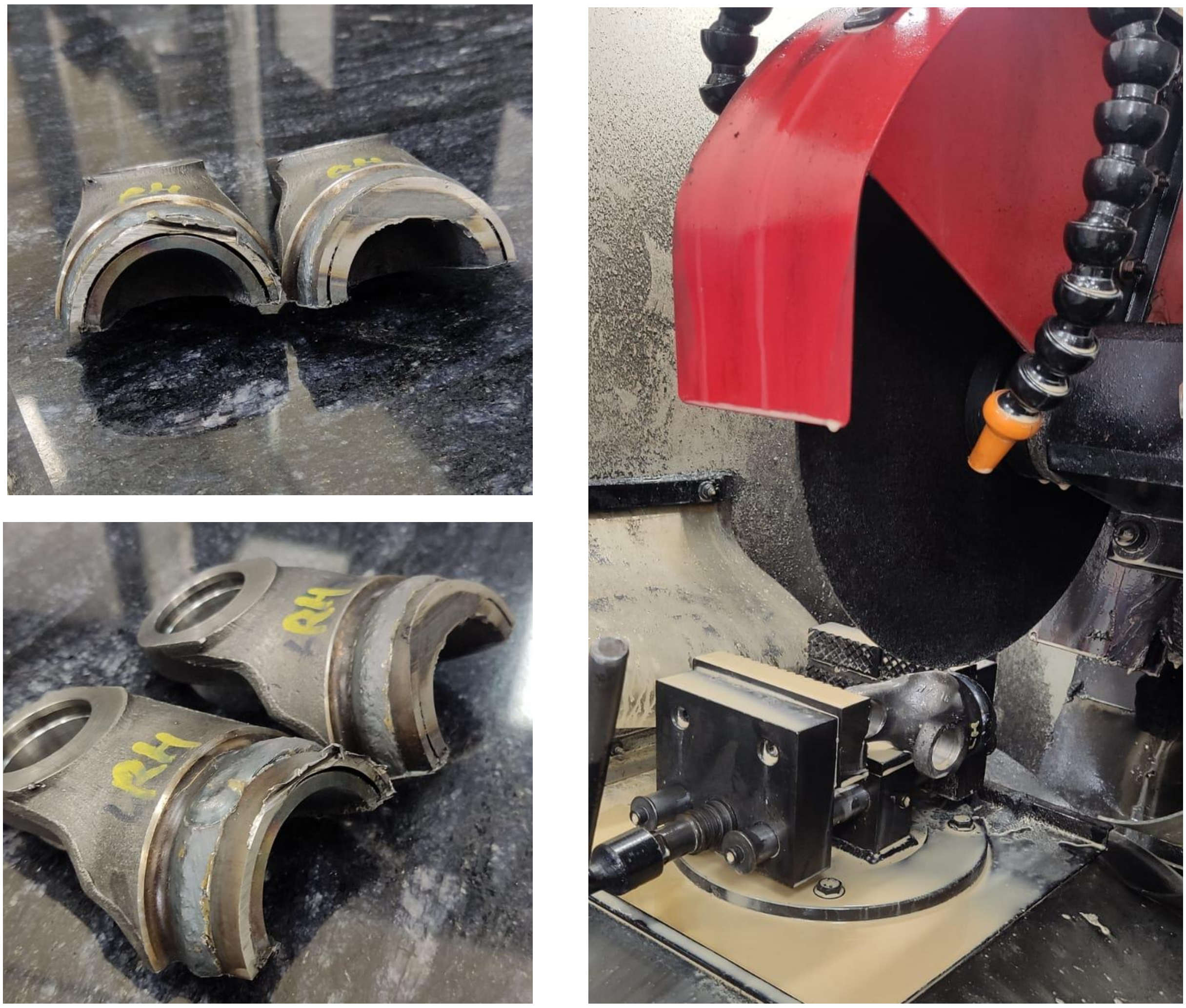


Figure 46 Cut section of shaft

iv) After the shafts cut into the cross sections the cut pieces are cleaned and then dipped into the weld penetration oil then after it is placed under the microscope and its weld penetration is calculated. An example for calculation is shown below:

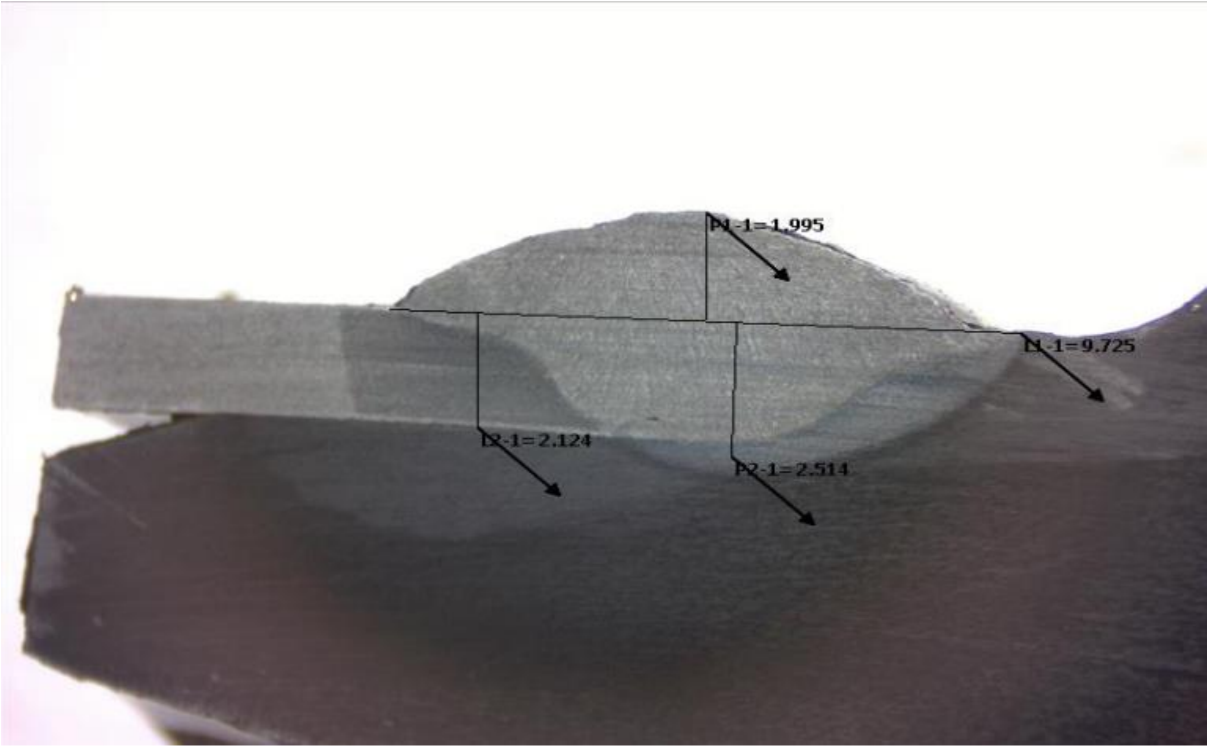


Figure 47 Specimen under microscope

S.No	Description	Thickness	Specification %	Penetration req	Penetration Observed in MM.	in %	Result
L1-1	Leg1		5.6-13.5		9.725		Pass
P1-1	Penetration1	10	0.79-3.1		1.995	19.95	Pass
L2-1	Leg2				2.124		
P2-1	Penetration2	10			2.514	25.14	
P	Penetration		(100-130)%		118.3615819		Pass

Figure 48 Sample penetration report

v) After completion of all the penetration test it is judged that which parameter is to be used for the welding of propeller shaft to obtain shaft with zero defect and of desired product parameters.

As per the MSIL requirement the bead width must be of 5.56 minimum and the weld penetration must be in range of 100% to 130%. Therefore, by the penetration tests we have to check the percentage of penetration into the base metal, where the higher penetration is considered to be better. The formula to calculate penetration is shown below:

$$\textbf{Penetration} = P_{2\text{-}1} / L_{2\text{-}1}$$

CHAPTER 5 - RESULTS AND DISCUSSIONS

The experiment was performed over Robo-MIG welding machine that was FANUC ArcMate 100iD at DAIPL facility, Dharuhera, Haryana. Before performing the experiments over the Robo-MIG welding machine it is important the process parameters of the machine and product parameters of the shafts. For the welding process to be optimal the parameters set must be optimal for the product parameter to be under the specification limits. For this, the tests was run according the run orders and the following penetration percentage was obtained along with the weld bead geometry, it must not contain any pinholes.

5.1 PENETRATION TEST RESULTS

It was necessary to know the penetration results of shafts over which the experiments was performed according to the DOE obtained by minitab software. Moreover, we experimented 3 shafts per experiment to exactly judge the penetration of the shafts. Out of 3 we have chosen the worst case i.e shaft with least penetration for the comparison to get the best output optimal values of the welding parameters. The 2 tests that were conducted to get the optimal value of the welding parameter are stated below:

a. Penetration test.

b. Pinhole detection test.

5.2 DESIGN OF EXPERIMENTS:

A total 16 DOE were made by using Taguchi DOE method in minitab software[21]. Every experiment is combination of one oth 3 welding parameters which were :

a) Wire feed rate

b) Current/Voltage

c) Gas flow rate

Each parameter has its own importance in the weld quality and weld geometry, hence it becomes important to know the best combination of all these 3 factors and enter the set parameter into the Robo-MIG welding machine such that all the shafts that will be produced by the machine will be of best quality and must be defects free the DOE and results is shown in the figure below:

S.No.	INPUT PARAMETERS			EXPERIMENTAL VALUES		
	Feed Rate	Gas Flow	Voltage	Penetration	Weld height	Weld width
1	8.1	21	21	105.83483	2.05	9.81
2	8.1	21	25	117.46261	1.57	13.4
3	8.1	21	21	109.93409	2.02	10.86
4	8.4	15	25	141.14389	1.5	13.65
5	8.1	15	25	119.85123	1.42	14.73
6	8.1	15	21	118.36158	2.66	10.93
7	8.4	15	21	138.465	1.98	12.34
8	8.4	15	25	125.2	1.76	14.72
9	8.4	21	25	127.33119	1.35	17.03
10	8.4	21	21	113.53383	1.96	13.16
11	8.4	21	25	127.9	1.35	17.08
12	8.1	15	25	120.23	1.22	15.01
13	8.1	15	21	113.58437	2.43	10.39
14	8.4	15	21	124.51	2.28	12.48
15	8.4	21	21	114.95417	2.11	10.48
16	8.1	21	25	111.14817	1.54	13.46

Figure 49 DOE and Results

The above results shows the value of various product parameters like weld height, weld width, overlap, run out and the weld penetration.

The final product parameter was defined for the shafts and accordance of that pre defined product parameters final optimized process parameters were to be judged.

5.3 PENETRATION REPORTS:

Pentration test was done for every experiments and the cut sections of the shafts were scanned under the microscope and then after the results were obtained by calculating the weld penetration percentage:

i) DOE 1 :

Feed rate : 8.1 , Gas flow : 21, Voltage :21 V

Penetration : 105.835 ,**Bead height :** 2.05 ,**Bead height :** 9.81

ii) DOE 2 :

Feed rate : 8.1 , Gas flow : 21, Voltage :25 V

Penetration : 117.463 ,**Bead height :** 1.57 ,**Bead height :** 12.4

iii) DOE 3 :

Feed rate : 8.1 , Gas flow : 21, Voltage :21 V

Penetration : 109.934 ,**Bead height :** 2.02 ,**Bead height :** 9.86

iv) DOE 4 :

Feed rate : 8.4 , Gas flow : 15, Voltage :25 V

Penetration : 161.144 ,**Bead height :** 1.5 ,**Bead height :** 12.65

v) DOE 5 :

Feed rate : 8.1 , Gas flow : 15, Voltage :25 V

Penetration : 119.851 ,**Bead height :** 1.42 ,**Bead height :** 14.73

vi) DOE 6 :

Feed rate : 8.1 , Gas flow : 15, Voltage :25 V

Penetration : 118.362 ,**Bead height :** 2.66 ,**Bead height :** 9.93

vii) DOE 7 :

Feed rate : 8.4 , Gas flow : 15, Voltage :21 V

Penetration : 138.465 ,**Bead height :** 1.98 ,**Bead height :** 11.34

viii) DOE 8 :

Feed rate : 8.4 , Gas flow : 15, Voltage :25 V

Penetration : 125.2 ,**Bead height :** 1.76 ,**Bead height :** 13.72

ix) DOE 9 :

Feed rate : 8.4 , Gas flow : 21, Voltage :25 V

Penetration : 127.33 ,**Bead height :** 1.35 ,**Bead height :** 16.03

x) DOE 10 :

Feed rate : 8.4 , Gas flow : 21, Voltage :21 V

Penetration : 113.534 ,**Bead height :** 1.96 ,**Bead height :** 12.16

xi) DOE 11 :

Feed rate : 8.4 , Gas flow : 21, Voltage :25 V

Penetration : 127.9 ,**Bead height :** 1.35 ,**Bead height :** 16.5

xii) DOE 12 :

Feed rate : 8.1 , Gas flow : 15, Voltage :25 V

Penetration : 104.417 ,**Bead height :** 1.22 ,**Bead height :** 14.01

xiii) DOE 13 :

Feed rate : 8.1 , Gas flow : 15, Voltage :21 V

Penetration : 113.584 ,**Bead height :** 2.43 ,**Bead height :** 9.39

xiv) DOE 14 :

Feed rate : 8.4 , Gas flow : 15, Voltage :21 V

Penetration : 104.668 ,**Bead height :** 2.28 ,**Bead height :** 11.48

xv) DOE 15 :

Feed rate : 8.4 , Gas flow : 21, Voltage :21 V

Penetration : 114.954 ,**Bead height :** 2.11 ,**Bead height :** 8.02

xvi) DOE 16 :

Feed rate : 8.1 , Gas flow : 21, Voltage :25 V

Penetration : 111.148. ,**Bead height :** 1.54 ,**Bead height :** 11.46

5.4 TAGUCHI DESIGN ANALYSIS:

After all the experiments are completed the results were optimized with the help of minitab software. This proved to be helpful in knowing the optimized value of all the three factors: Wire feed rate, Gas flow rate and the voltage[17].

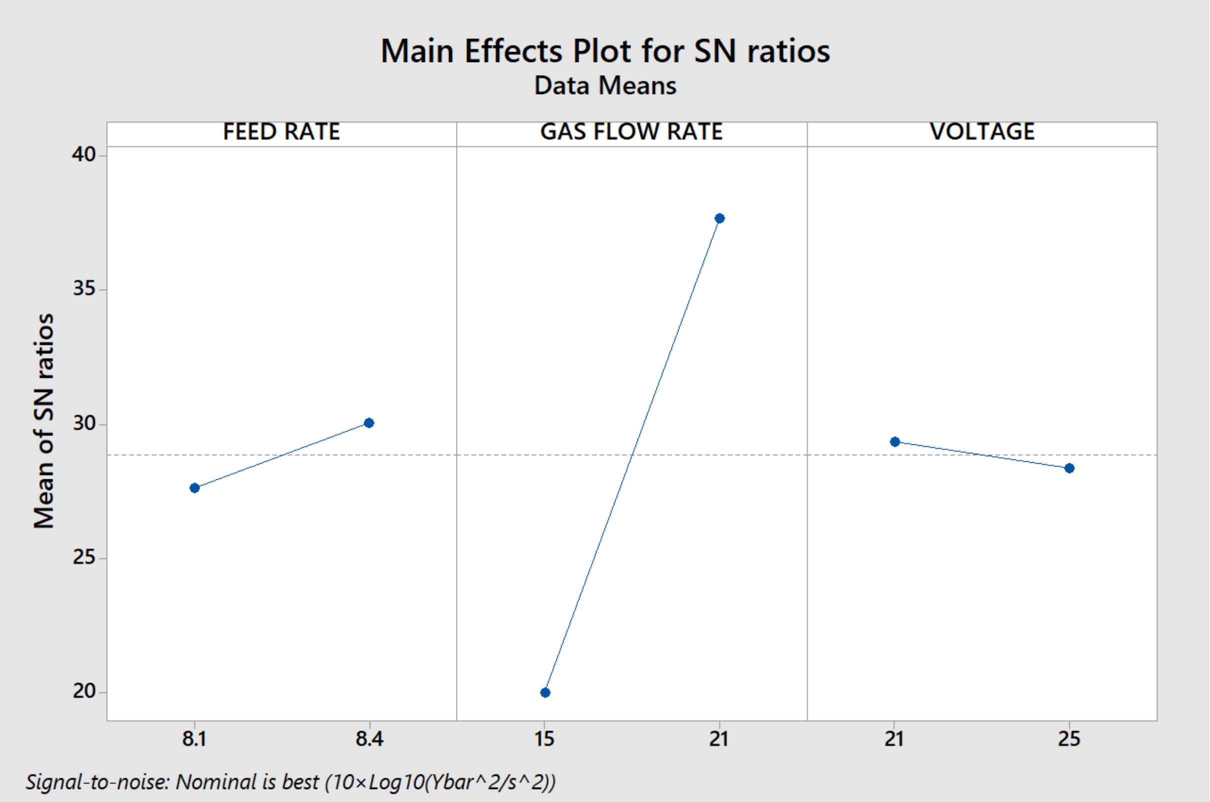


Figure 50Taguchi analysis for penetration

From the graph obtained above, it can be concluded that for the penetration to be optimum the value of process parameters is as follows:

i) Wire feed rate : 8.4 mm/sec

ii) Gas flow rate : 21 lt/min

iii) Voltage : 21 V

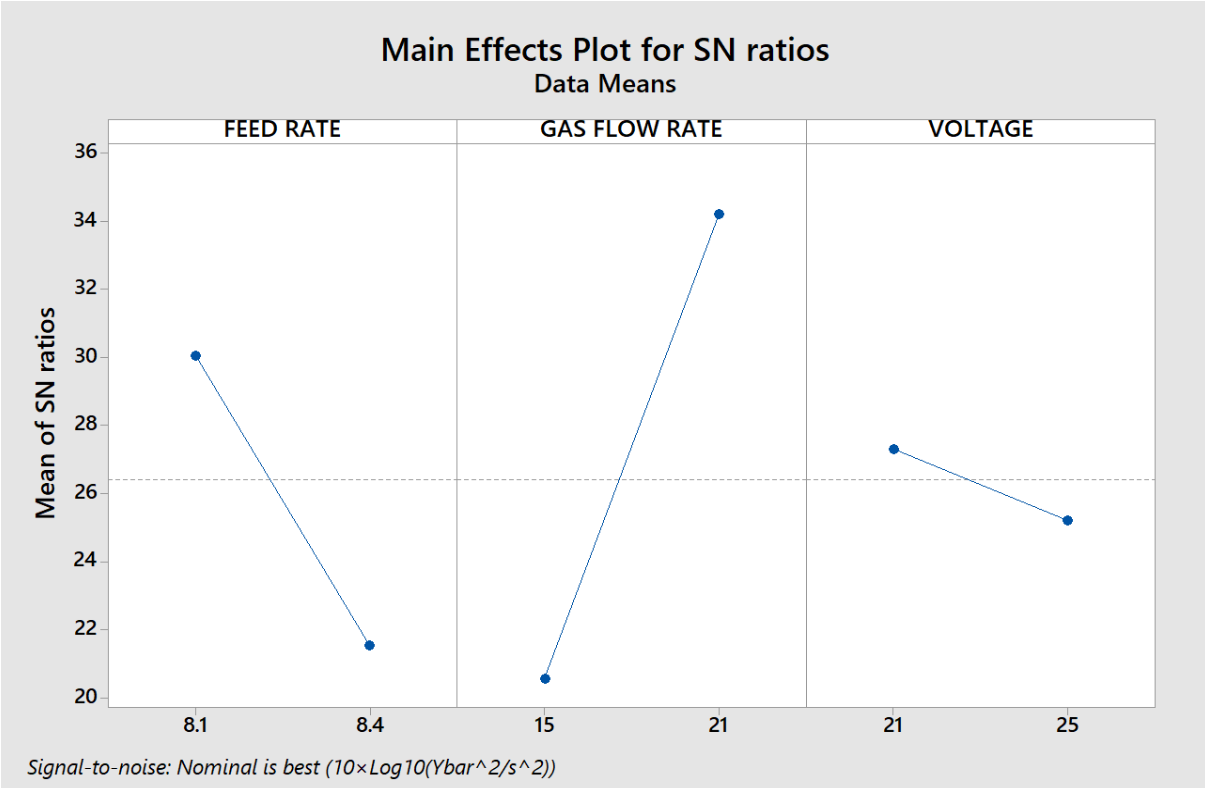


Figure 51 Taguchi analysis for Weld bead height

From the graph obtained above, it can be concluded that for the weld bead height to be optimum the value of process parameters is as follows:

i) Wire feed rate : 8.1 mm/sec

ii) Gas flow rate : 21 lt/min

iii) Voltage : 21 V

The final value of weld bead height according to the product parameter is defines between 0.8 mm to 3.1 mm. Hence, to achieve the nominal value the process parameters are obtained by the Taguchi analysis.

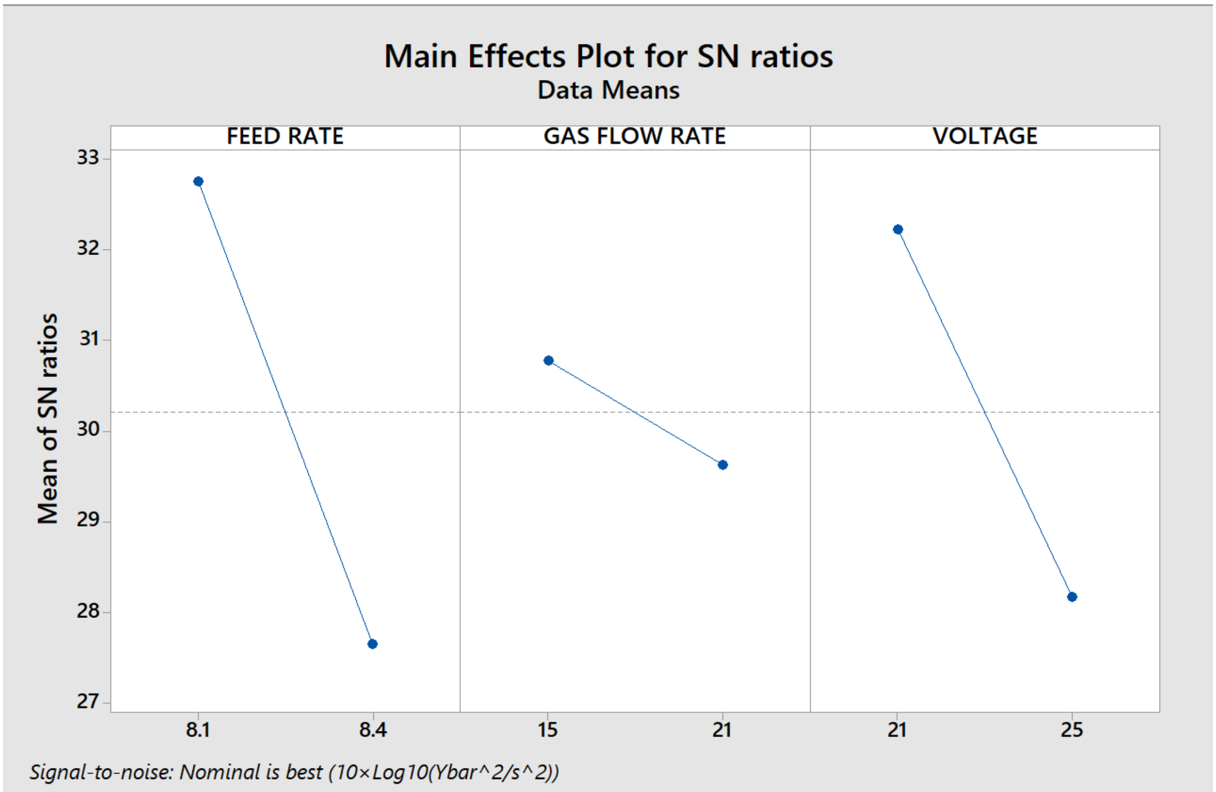


Figure 52 SN curve for weld bead width

From the graph obtained above, it can be concluded that for the weld bead width to be optimum the value of process parameters is as follows:

i) Wire feed rate : 8.1 mm/sec

ii) Gas flow rate : 15 lt/min

iii) Voltage : 21 V

By combining results of all the three output parameters we got into conclusion, the set value of parameters must be:

i) Wire feed rate : 8.2 mm/sec

ii) **Gas flow rate : 19 lt/min**

iii) **Voltage : 21 V**

When all the three parameters were optimized simultaneously the output parameter that comes out with the highest S-N ratio were :

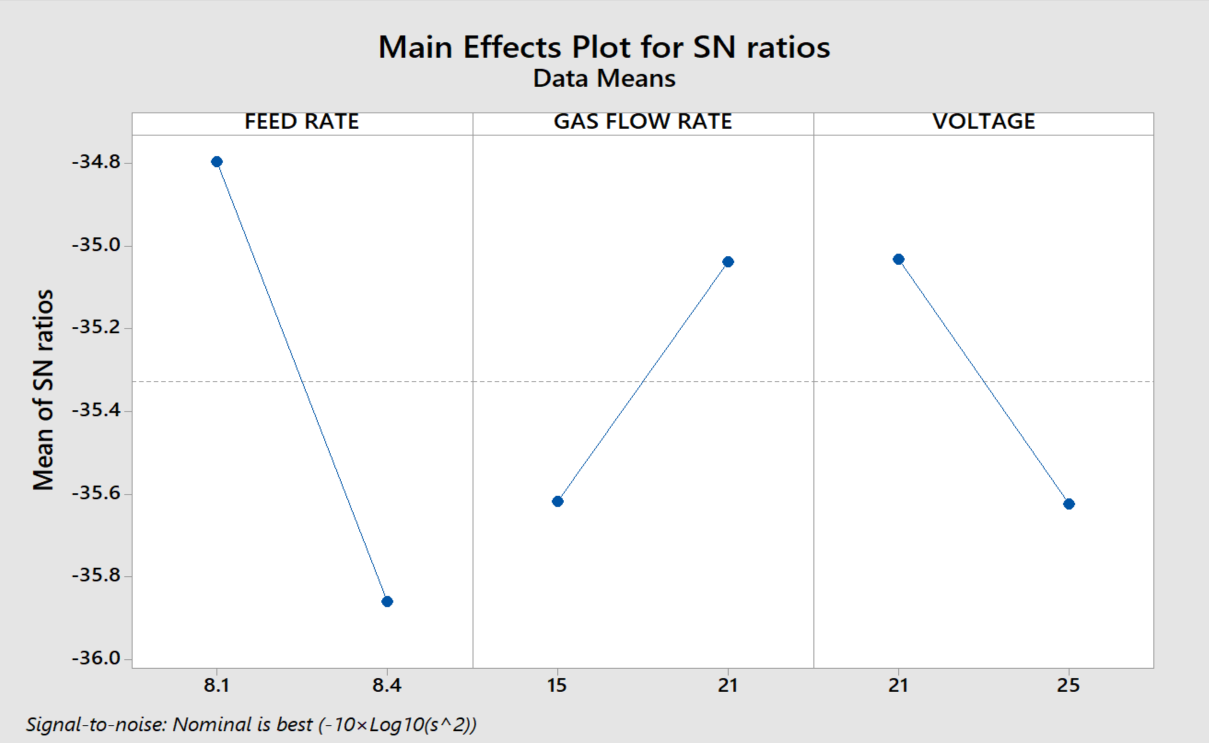


Figure 53 Combined SN curve of all 3 parameters

i) **Wire feed rate : 8.1 mm/sec**

ii) **Gas flow rate : 21 lt/min**

iii) **Voltage : 21 V**

After analyzing all the graphs, all the values were fitted to the equations, that clearly shows how all the output parameters were dependent on the input parameters Wire feed rate, Gas flow rate and the voltage.

The equations that were obtained after fitting the values into the regression model using ANOVA in design expert software:

Penetration=(-108.8827+41.372*feed rate+12.31655*gas flow-19.36928*voltage-2.49336*feed rate*gas flow+1.90311*feed rate*voltage+0.29251*gas flow*voltage)
Weld height=(+50.41562-4.74167*feed rate-0.06625*gas flow-2.17812*voltage-0.027778*feed rate*gas flow+0.21667*feed rate*voltage+0.011667*gas flow*voltage)
weld width=(+113.43687-12.25208*feed rate-10.37198*gas flow+1.02939*voltage+1.12361*feed rate*gas flow-0.12292*feed rate*voltage+0.048854*gas flow*voltage)

These equations were very helpful in getting the info about the output parameters by inputting the input parameters without performing the actual experiments.

The theoretical values of the output parameters were confirmed by putting the input parameters value into the equation. Theoretical values obtained by the equation is shown below:

S.No.	INPUT PARAMETERS			EXPERIMENTAL VALUES			THEORITICAL VALUES			ERROR %		
	Feed Rate	Gas Flow	Voltage	Penetration	Weld height	Weld width	Penetration	Weld height	Weld width	Penetration	Weld height	Weld width
1	8.1	21	21	105.8348	2.05	9.81	106.71856	2.1519992	9.762615	0.8350045	4.975571	0.48302752
2	8.1	21	25	117.4626	1.57	13.4	115.47304	1.4396552	14.0013	1.6937948	8.302217	4.48733582
3	8.1	21	21	109.9341	2.02	10.86	106.71856	2.1519992	9.762615	2.9249632	6.534614	10.1048343
4	8.4	15	25	141.1439	1.5	13.65	134.33934	1.514639	14.75636	4.8210053	0.975933	8.10518681
5	8.1	15	25	119.8512	1.42	14.73	118.87454	1.437116	14.29764	0.8149245	1.205352	2.93525458
6	8.1	15	21	118.3616	2.66	10.93	117.14029	2.429468	11.23145	1.0318305	8.666617	2.75795974
7	8.4	15	21	138.465	1.98	12.34	130.32136	2.246987	11.83767	5.8813679	13.48419	4.07074554
8	8.4	15	25	125.2	1.76	14.72	134.33934	1.514639	14.75636	7.2997923	13.94097	0.24699728
9	8.4	21	25	127.3312	1.35	17.03	126.4498	1.4671778	16.48252	0.6922057	8.679837	3.21478567
10	8.4	21	21	113.5338	1.96	13.16	115.41158	1.9195178	12.39134	1.6539082	2.065418	5.84089666
11	8.4	21	25	127.9	1.35	17.08	126.4498	1.4671778	16.48252	1.1338577	8.679837	3.49811475
12	8.1	15	25	120.23	1.22	15.01	118.87454	1.437116	14.29764	1.1273933	17.79639	4.74592272
13	8.1	15	21	113.5844	2.43	10.39	117.14029	2.429468	11.23145	3.1306464	0.021893	8.09860443
14	8.4	15	21	124.51	2.28	12.48	130.32136	2.246987	11.83767	4.6673874	1.447939	5.146875
15	8.4	21	21	114.9542	2.11	10.48	115.41158	1.9195178	12.39134	0.397904	9.027592	18.237958
16	8.1	21	25	111.1482	1.54	13.46	115.47304	1.4396552	14.0013	3.8910882	6.515896	4.02156761

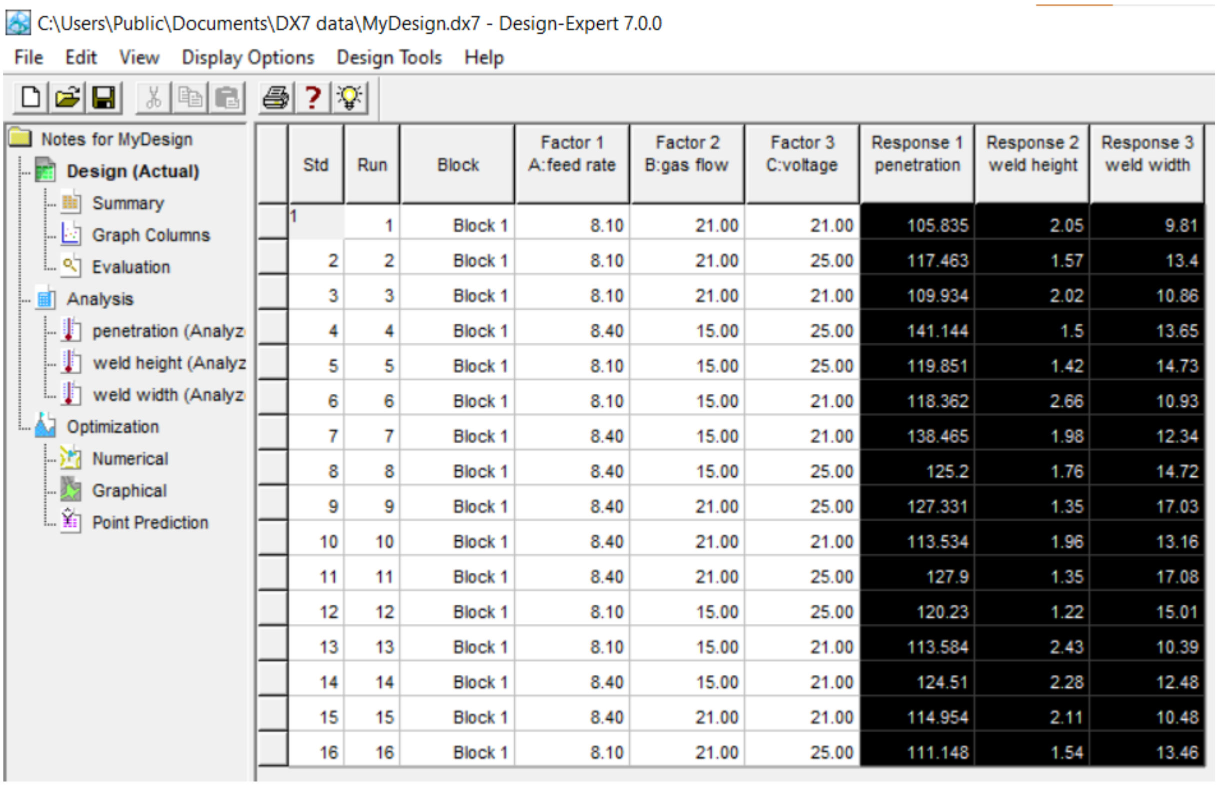
Figure 54 Comparison of experimental vs theoretical data

When optimized value of input facture were input into the Equation obtained by ANOVA analysis[25] using Design expert software we get :

i) Penetration : 106.718 mm

ii) Weld height : 2.152 mm

iii) Weld bead width : 9.762 mm



Std	Run	Block	Factor 1 A:feed rate	Factor 2 B:gas flow	Factor 3 C:voltage	Response 1 penetration	Response 2 weld height	Response 3 weld width
1	1	Block 1	8.10	21.00	21.00	105.835	2.05	9.81
2	2	Block 1	8.10	21.00	25.00	117.463	1.57	13.4
3	3	Block 1	8.10	21.00	21.00	109.934	2.02	10.86
4	4	Block 1	8.40	15.00	25.00	141.144	1.5	13.65
5	5	Block 1	8.10	15.00	25.00	119.851	1.42	14.73
6	6	Block 1	8.10	15.00	21.00	118.362	2.66	10.93
7	7	Block 1	8.40	15.00	21.00	138.465	1.98	12.34
8	8	Block 1	8.40	15.00	25.00	125.2	1.76	14.72
9	9	Block 1	8.40	21.00	25.00	127.331	1.35	17.03
10	10	Block 1	8.40	21.00	21.00	113.534	1.96	13.16
11	11	Block 1	8.40	21.00	25.00	127.9	1.35	17.08
12	12	Block 1	8.10	15.00	25.00	120.23	1.22	15.01
13	13	Block 1	8.10	15.00	21.00	113.584	2.43	10.39
14	14	Block 1	8.40	15.00	21.00	124.51	2.28	12.48
15	15	Block 1	8.40	21.00	21.00	114.954	2.11	10.48
16	16	Block 1	8.10	21.00	25.00	111.148	1.54	13.46

Figure 55 Design Expert GUI

CHAPTER 7 – CONCLUSION

The experimental studies were conducted to analyse the effect of welding parameters that were Wire feed rate, Gas flow rate and voltage over the product parameters which were Weld bead width, Weld bead height and weld bead penetration. The experiment was done to optimize the machine and reduce the part rejection over the machine due to improper process parameters. There were some final points of conclusion after the full analysis of the shafts done after the welding.

There were few points that were concluded after the completion of this work:

a) The final parameters that we got after the analysis were:

- **Wire feed rate : 8.1 mm/sec**
- **Gas flow rate : 21 lt/min**
- **Voltage : 21 V**

b) When these parameters were practically analysed over the shafts it was found that the parameters were optimized and given shafts with lesser defects.

- When the parameters were not optimized there were 7 defects in 100 shafts welded.
- After the parameters were optimized only 1 shaft was rejected that too due to pinhole.
- No out of specification penetration shaft was found after optimization of parameters.
- Rejection percent was reduced to 1% from 7%.
- Defects due to improper penetration are not reworkable but defects like pin holes are

reworkable.

c) The shafts with pinholes is shown below:

Figure 56 Pinhole

d) Pinholes were directly affected by the gas flow rate, with eduction in gas flow the pinholes increases in the weld bead.

e) Penetration was directly proportional to welding current. When welding current increases penetration also increases. But in constant voltage power source it was not possible to control current. Current is not directly controlled, to control the current we have to change the wire feed rate. When WFR is increased, current also increases.

f) Weld bead height and weld bead width is the function of voltage. When voltage increase weld bead flattens i.e weld bead depth to width ratio decreases[18].

g) Keeping in mind point d, e and f that value of optimized parameter were decided.

h) Effects of various welding process parameters over the product parameters

1) Stick out

The extension of wire electrode from the nozzle tip is stick out. When stick out increases :

Product parameter	Effect	Cause
Bead width	Decreases	Increasing the stick out increases the resistance to current flowing from machine to the shaft resulting in lesser welding power.
Bead height	Decreases	
Weld penetration	Decreases	
Weld overlap	No effect	

Table 5 Effect of stick out on product parameters

2) Cord off distance

The distance from nozzle tip to the weld surface is known as cord off distance. When cord off distance increases:

Product parameter	Effect	Cause
Bead width	Increases	Increasing the cord off distance increases the distance of shaft from nozzle. Hence, arc cone also increases which in turn makes weld bead wider.
Bead height	No effect	
Weld penetration	Increases	
Weld overlap	No effect	

Table 6 Effect of cord off distance on product parameters

3) Wire feed rate

The length of wire ejected from the nozzle per minute is WFR. When Wire feed rate increases:

Product parameter	Effect	Cause
Bead width	Increases	In MIG constant voltage power source is used. Hence, it is not possible to change current manually for that we change WFR which is directly proportional to current.
Bead height	Increases	
Weld penetration	Increases	
Weld overlap	No effect	

Table 7 Effect of WFR on product parameters

4) Voltage

When voltage increases:

Product parameter	Effect	Cause
Bead width	Increases	With the increase in voltage, arc length increases that increases the cone area of arc at the weld area.
Bead height	Decreases	
Weld penetration	Increases	
Weld overlap	No effect	

Table 8 Effect of voltage on product parameters

5) Welding speed

When welding speed increases:

Product parameter	Effect	Cause
Bead width	Decreases	With the increase welding speed lesser amount of heat is input to the weld bead.
Bead height	Decreases	
Weld penetration	Decreases	
Weld overlap	No effect	

Table 9 Effect of welding speed on product parameters

6) Gas flow rate

When gas flow rate increases:

Product parameter	Effect	Cause
Bead width	No effect	Incomplete insulation of weld bead from outer atmosphere when insufficient gas is used.
Bead height	No effect	
Weld penetration	No effect	
Weld overlap	No effect	
Weld quality	Lesser blow holes	

Table 10 Effect of gas flow rate on product parameters

7) Start to End weld angle

When weld angle increases :

Product parameter	Effect	Cause
Bead width	No effect	Incomplete insulation of weld bead from outer atmosphere when insufficient gas is used.
Bead height	No effect	
Weld penetration	No effect	
Weld overlap	Increases	

Table 11 Effect of weld angle on product parameters

CHAPTER 8 - REFERENCES

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