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Analysis of Defects in Metal Inert Gas Welding Of A312tp316l Stainless Steel Pipe Using Taguchi Optimization Method And Testing

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ABSTRACT
Research on welding of materials like stainless steel is still critical and ongoing. An attempt has been made to analyze the effect of process parameters in qualitative manner for welding of A312TP316L steel using processes of Metal Inert Gas Welding (MIG). Taguchi method is used to formulate the experimental layout. Exhaustive survey suggest that 5-9 control factors viz., arc voltage, arc current, welding speed, nozzle to work distance and gas pressure predominantly influence weld quality, even plate thickness and backing plate too have their own effect. Design of experiments based on orthogonal array is employed to develop the weldments. The weldments are subjected to testing to find the qualitative properties. The data obtained is checked for adequacy based on ANOVA. The result computed is in form of contribution from each parameter, through which optimal parameters are identified for minimum defects. The data in the present work is collected using eddy current, radiography and hardness testing and results are quantified accordingly. The testing of specimens indicated, the presence of defects like LOP, LOF, Blowhole, and Cracks.

KEYWORDS *: Stainless steel, welding defects, Taguchi analysis, microstructure, MIG, parametric contribution, charpy, brinnel hardness, eddy current and Radiography test.*

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I. INTRODUCTION

Welding is the simplest and easiest way to join sections of pipe. Welded pipe has reduced flow restrictions compared to mechanical connections and the overall installation costs are less. Two common processes welding of pipe are TIG and MIG. TIG welding, also known as GTAW, is a process which fuses metals by heating them with an arc between a tungsten electrode and the work piece. Shielding is obtained from a gas or gas mixture. Pressure and filler wire may or may not be used. The positive electrode does not melt and hence gas tungsten arc welding can be autogenous or non-autogenous if a filler wire is employed. MIG welding, also known as GMAW, differs from TIG in that the positive electrode is consumable. Some alloys of this type are prone to cracking and reduced corrosion resistance as well. Hot cracking is possible if the amount of ferrite in the weld is not controlled. Alleviating the problem when an electrode is used for deposition the weld metal contaminates with a small amount of ferrite. Gas tungsten arc welding (TIG) is most commonly used to weld non-ferrous materials, but I used MIG welding for stainless steel pipe and it can be applied to nearly all metals. The literature revealed works carried out by various investigators on stainless steel using different gas shielded arc MIG welding techniques, however there is a short fall of work carried out on **A312TP316L** steel by using Taguchi method and detection of defects by using eddy current and radiography test.

II. LITERATURE REVIEW

S.P.Gadewar et al. [1] investigated the effect of process parameters of TIG welding like weld current, gas flow rate, work piece thickness on the bead geometry of SS304. It was found that the process parameters considered affected the mechanical properties with great extent.

Jung [2]Selection of process parameters for optimum weld pool geometry for stainless steel is reported.

Tarng [3]Taguchi methods are applied for detecting TIG welding process parameters this study is carried out on mild steels for predicting optimal setting for each welding process parameters.

Giridharan [4] carried out optimization of bead Geometry of pulsed TIG welding applied for 304L stainless steel, mathematical models are developed and they are checked for adequacy.

Ross [5] the lucid explanation on Taguchi method formed a fundamental back bone for this present work.

Ugur Esme et al. [6] investigated the multi response optimization of TIG welding process to yield favorable bead geometry using Taguchi method and Grey relation analysis. The significance of the factors on overall quality characteristics of the weldment has been evaluated quantitatively by ANOVA. The experimental results show that the tensile load, HAZ, area of penetration, bead width, and bead height are greatly improved by using grey relation analysis in combination with Taguchi method.

T.Senthil Kumar et al. [7] studied the effect of pulsed TIG welding parameters and pitting corrosion potential of aluminium alloys. ANOVA method was used to find significant parameters and regression analysis has been used to develop the mathematical model to determine the pitting corrosion potential. It was found that peak current and pulse frequency have direct proportional relationship, while base current and pulse-on-time have inverse proportional relationship with the pitting corrosion resistance.

Mostafa and Khajavi, 2006 [8] predicting weld bead penetration as a function of welding process parameters.They optimized process parameters for maximizing weld penetration.

S.Kumanan et al. [9] determined submerged arc welding process parameters using Taguchi method and regression analysis. The % contribution of each factor is validated by analysis of variance method. The planned experiments were conducted in the semi-automatic submerged arc welding machine and SN ratios are computed to determine the optimum parameters.

P.Atanda et al. [10] conducted sensitization study of normalized 316L stainless steel. The work was concerned with the study of the sensitization and desensitization of 316L steel at the normalizing temperatures of 750-950°C and soaking times of 05, 1, 2 and 8 hours.

Sunniva R. Collins et al. [11] conducted weldability and corrosion studies of AISI 316L electro polished tubing and were orbitally and autogenously welded with welding parameters varied to achieve an acceptable weld.

Consonni et al. [12]: Authors developed new non-destructive testing techniques, qualifying non-destructive testing procedures, and obtaining mechanical property data in support of safety cases. The single most important criterion in producing defects or imperfections is that they must accurately simulate flaws which can occur in welded components and structures. For this reason, in certain applications, saw cuts or machined slots which are more easily detected may not be considered acceptable as planar imperfections/defects for the purpose of NDT training or validation. Therefore, TWI has developed techniques for producing realistic imperfections/defects and, in the case of cracks, the desired morphology, including roughness, angles of tilt and skew to the surface. This paper describes the techniques used to obtain the above-mentioned defects and, for the most commonly required defect types, the qualification procedure used by TWI. This consists of inspecting by testing of surface crack detection, ultrasonic or radiographic inspection and/or sectioning to demonstrate that the dimensional tolerance of the simulated imperfections. functionalities and flexibility. Prototype production and conceptual schemes are presented and discussed. Conceptual tests, applications and case studies are shown as per the state of the art. Particular reference is made to results obtained from data collected from materials containing welding. A discussion is provided of photonic (X-ray) and neutronic diffraction with corresponding limits and advantages. The hypothesis of creating a new mobile diagnostic device intended for the application of neutron diffraction is introduced.

III. T AGUCHI TECHNIQUE:

Welding is the simplest and easiest way to join sections of pipe. Welded pipe has reduced flow restrictions compared to mechanical connections and the overall installation costs are less. Two common processes welding of pipe are TIG and MIG. TIG welding, also known as GTAW, is a process which fuses metals by heating them with an arc between a tungsten electrode and the workpiece. Shielding is obtained from a gas or gas mixture. Pressure and filler wire may or may not be used. The positive electrode does not melt and hence gas tungsten arc welding can be autogenous or non-autogenous if a filler wire is employed. MIG welding, also known as GMAW, differs from TIG in that the positive electrode is consumable. The input parameters are the controllable welding equipment parameters, welded materials, and other parameters, which affect the properties of the finished welds [6] .indirect weld parameters affect the weld quality of TIG and MIG weld. Pre-selected weld parameters are selected prior to the start of the welding process and they cannot be changed during the welding process. These parameters, variables, include the electrode type, size, and tip geometry, the torch nozzle size, and the shielding gas type. The indirect weld parameters of the welding process include the arc voltage, arc current, travel speed, shielding gas, and wire feed rate (for filler metal process). Indirect weld parameters are parameters that can be modified in process. Once the pre selected variables are properly chosen, the quality of the weld can be controlled through proper selection and modification of the indirect weld parameters. In any welding process, the input parameters have an influence on the joint mechanical properties. By varying the input process parameters combination the output would be different welded joints with significant variation in their mechanical properties. Metal Inert of Gas welding is one the most widely used processes in industry. The input parameters play a very significant role in determining the quality of a welded joint. Infact, weld geometry directly affects the complexity of weld schedules and thereby the construction and manufacturing costs of steel structures and mechanical devices. Therefore, these parameters affecting the arc and welding should be estimated and their changing conditions during process must be known before in order to obtain optimum results; in fact a perfect arc can be achieved when all the parameters are in conformity. These are combined in two groups as first order adjustable and second order adjustable parameters defined before welding process.

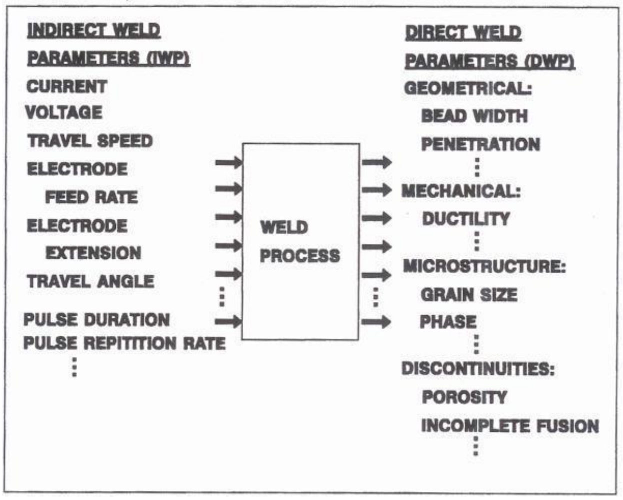


Figure :1. Input welding data to Output welding data

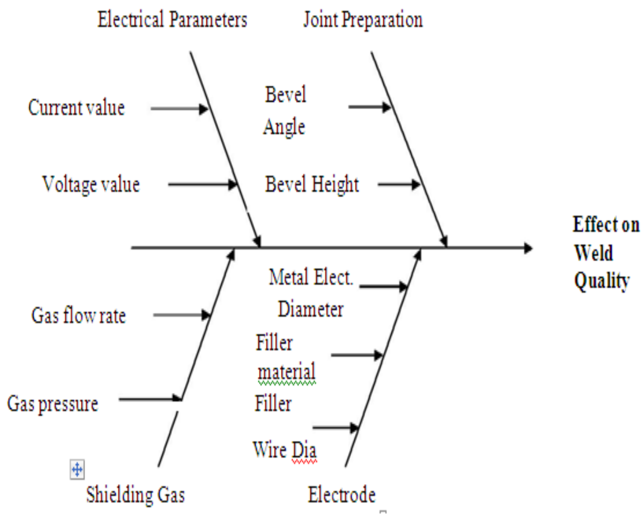


Figure:4 Effect on Weld Quality Diagram for MIG welding**(Fish Diagram)**

selected weld parameters, Former are welding current, arc voltage and welding speed. These parameters will affect the weld characteristics to a great extent. Because these factors can be varied over a large range, they are considered the primary adjustments in any welding operation. Their values should be recorded for every different type of weld reproducibility.to permit. The DOE using Taguchi approach can significantly reduce time required for experimental investigations 6-8. In this investigation, in the first stage, Taguchi's orthogonal arrays were used to conduct the experiments settings. To find the contributions of each factor and to optimize the welding parameter. Taguchi Technique is applied to plan the experiments. The Taguchi method has become a powerful tool for improving productivity during research and development, so that high quality products can be produced quickly and at Taguchi Technique is applied to plan the low cost. Dr. Taguchi of Nippon Telephones and Telegraph Company, Japan has developed a method based on "ORTHOGONAL ARRAY" experiments which gives much reduced "variance" for the experiment with "optimum settings" of control parameters. Thus the marriage of Design of Experiments with optimization of control parameters to obtain best results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results.

Signal-to-Noise Ratio

There are 3 Signal-to-Noise ratios of common interest for optimization

(I) Smaller-The-Better:

$n = -10 \, Log_{10}$ [mean of sum of squares of measured data]

(II) Larger-The-Better:

$n = -10 \, Log_{10}$ [mean of sum squares of reciprocal of measured data]

(III) Nominal-The-Best:

$$n = 10 \, Log_{10} \frac{\text{square of mean}}{\text{variance}}$$

Work Material for stainless steel pipe specimen:

The work material used for present work is A312TP316L, the dimensions of the work piece length 300 mm, width 150mm, thickness 5mm. Welding Gas: CO_2.

Table :1 Chemical composition of work material A312TP316L

Material (A312TP316L)	C	Si	Mn	Cr	Ni	Mo	P	S
% Wt.	.02	.29	1.58	16.25	11.90	2.27	.027	.003

Table:2 Observation for Stainless steel Tensile specimen

Test Parameters	Values
Ultimate Tensile Strength	513.18 MPa
Yield Strength	255.90 MPa
% Elongation in 50 mm GL	55.50%

Stainless Steel Microstructure

The microstructure of stainless steel pipe specimen is shown below. Figure : Microstructure of stainless steel A312 TP 316L The microstructure of stainless steel reveals the specimen in solution annealed condition. It is observed that particles of carbides (indicated by small black dots) are present and step between the grains with annealed twin boundaries are present in the matrix .

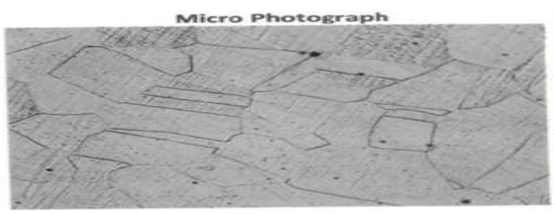


Figure: Stainless Steel Specimen Microstructure

Filler Metal

The filler metal used in this project is a stainless steel 309L grade filler rod of Ø2.5mm x 1000mm.

Table : 3 Chemical composition of filler Rod

Element	**C**	**Mn**	**Si**	**S**	**P**	**Cr**	**Ni**
Wt.%	.02 8	1.97	.3 9	.01 2	.01 7	23. 2	13. 9

Edge Preparation
The edges of the specimen are prepared using a portable grinding machine. The edge preparations are arranged to make the weld joint. A gap (1 mm to 2 mm) is maintained between the pieces to ensure proper penetration of the weld.

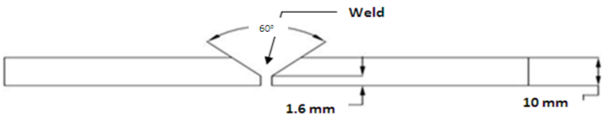


Figure : Joint Preparation

LEVELS FOR ANOVA:- Two levels are required for the experimentation and welding of the coupons is completed. By choosing these limits from standard data available in literature. ANOVA is also carried out on MIG welded coupons and the results of LOP and under fill are shown in Table.

Table:4Selection of Levels MIG welding stnless steel

Thickness	5mm
Groove type	V-notch
Electrode diameter	0.9 mm
Voltage	15-30Volt
Gas flow rate	10 l/min
Shielded gas	CO_2
Current I	60-120 Amp
Passes	1
Travel speed	2-6 mms^{-1}
Nozzle to work distance	14 mm

Table:5WeldingParameters And Their Levels Choose

Symbol	**Welding Parameters**	**Level 1**	**Level 2**	**Level 3**
A	Current	60	90	120
B	Voltage	15	22.5	30
C	Speed	2	4	6

For of the procedure selection taken reference handbook of Arc Welding & Welding Process Technology by P.T. Houldcroft.

Taguchi Level for Orthogonal Array

Taguchi's orthogonal design uses a special set of predefined arrays called orthogonal arrays (OAs) to design the plan of experiment. These standard arrays stipulate the way of full information of all the factors that affects the process performance (process responses). The corresponding OA is selected from the set of predefined OAs according to the number of factors and their levels that will be used in the experiment. Below Table No.2 shows L9 Orthogonal array from Table1.

Table:6 Orthogonal array for Taguchi Level : Process Parameters

Expt. No.	**Welding Current**	**Welding Voltage**	**Welding Speed**
1	A	A	A
2	A	B	B
3	A	C	C
4	B	A	B
5	B	B	C

6	B	C	A
7	C	A	C
8	C	B	B
9	C	C	A

ANALYSIS OF S/N RATIO

In the Taguchi Method the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (standard Deviation) for the output characteristic. Therefore, the S/N ratio to the mean to the S. D. S/N ratio used to measure the quality characteristic deviating from the desired value. The S/N ratio η is defined as

$\eta = -10 \log (M.S.D.)$

where, M.S.D. is the mean square deviation for the output characteristic.

To obtain optimal welding performance, higher-the-better quality characteristic for penetration must be taken. The M.S.D. for higher-the –better quality characteristic can be expressed

$$MSD = \frac{1}{m}\sum\frac{1}{Pi^2}$$

Where, Pi is the value of penetration

Table: 7 Experimental result for penetration and S/N ratio:

Expt. No.	Welding Current	Welding Voltage	Welding Speed	Penet ration	S/N Ratio
1	60	15	2	1.65	4.35
2	60	22.5	4	5.00	13.98
3	60	30	6	5,43	14.70
4	90	15	4	1.57	3.92
5	90	22.5	6	5,64	15.03
6	90	30	2	2.73	8.72
7	120	15	6	1.15	1.21
8	120	22.5	2	3.61	11.15
9	120	30	4	5.08	14.12

Regardless of the category of the quality characteristic, a greater S/N ratio corresponds to better quality characteristics. Therefore, the optimal level of the process parameters is the level with the greatest S/N ratio. The S/N response table for penetration is shown in Table No.4 as below

Table:8 S/N response table for Penetration

Symbol	Welding Parameters	Mean S/N Ratio		
		Level 1	Level 2	Level 3
A	Current	11.01	9.22	8.83
B	Voltage	3.16	13.39	12.51
C	Speed	11.17	7.97	9.92

Analysis of Variance (ANOVA) : The purpose of the analysis of variance (ANOVA) is to investigate which design parameters significantly affect the quality characteristic. This is to accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error. First, the total sum of squared deviations SST from the total mean S/N ratio n_m can be calculated as

$$SS_T = \sum(n_i - n_m)^2$$

The result of ANOVA is shown in the following table

Table:9 Result of analysis of variance for penetration

Symbol	Welding Parameters	DOF	Sum of squares	Mean e	F	Percentage (%)
A	Current	2	8.11	4.055	0.68	3.55
B	Voltage	2	192.85	96.43	16.23	84.42
C	Speed	2	15.61	7.805	1.31	6.83
Error	___	2	11.87	5.94	___	5.19
Total	___	8	228.44	___	___	100

CONFORMATION TEST

Once the optimal level of design parameters has been selected, the final step is to predict and verify the improvement of the quality characteristic using the optimal level of design parameters. The estimated S/N ratio using the optimal level of the design parameters can be calculated as

$$\hat{\eta} = \eta_m + \sum_{i=1}^{n}(\bar{\eta}_i - \eta_m)$$

Where, η_m is total mean of S/N ratio, $\bar{\eta}_i$ is the mean of S/N ratio at the optimal level, and n is the number of main welding parameters that significantly affect the performance.

The comparison of the predicted penetration with actual penetration using the optimal parameters, good agreement between the predicted and actual penetration being observed which is shown in the table

Table :10 Result of the conformation experiment

Symbol	Initial Welding Parameters	Optimal welding parameters	
		Prediction	Expt.
Level	A2B3C3	A1B2C1	A1B2C1
Penetration	4.11	6.45	5.25
S/N ratio	12.27	16.19	14.40

CONTRIBUTION OF WELDING PARAMETERS

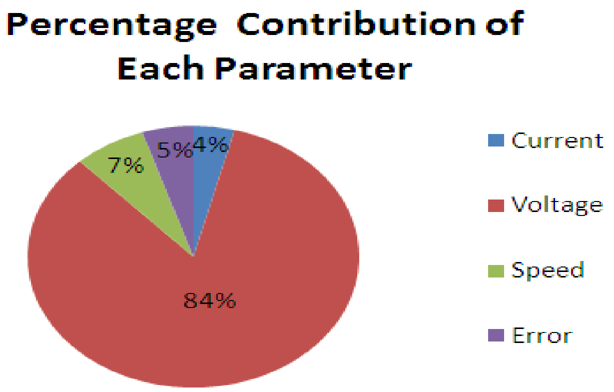


Figure : contribution of parameters

From the result, the percentage contribution of welding voltage is more than the welding current and welding speed and other parameters are constant.

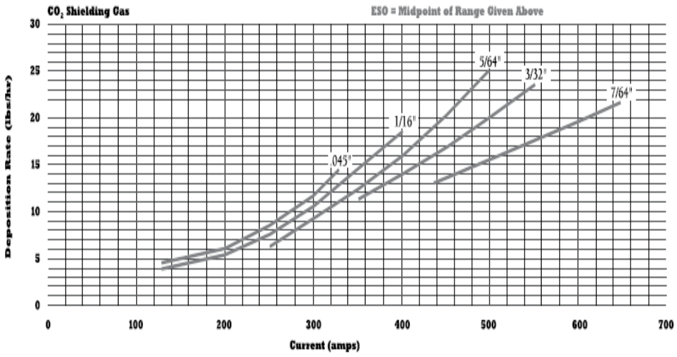
Characteristics for Recommended Welding Parameters:

Carbon & Low Alloy Steel Electrodes - Flux Cored - Flat and Horizontal - CO2 – DCEP

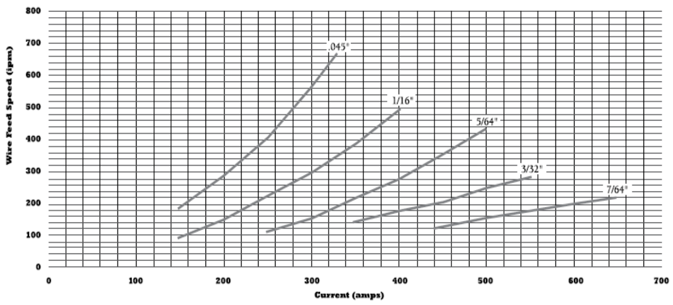
Graph plot for deposition Rates: From the result, the percentage contribution of welding voltage is more than the welding current and welding speed and other parameters are constant.

Characteristics for Recommended Welding Parameters:
Carbon & Low Alloy Steel Electrodes **-** Flux Cored **-** Flat and Horizontal **-** CO2 – DCEP

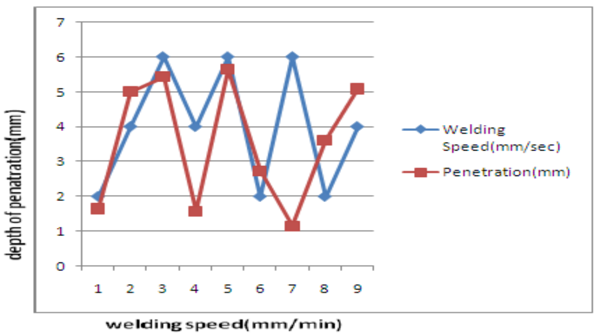
Graph plot for deposition Rates:



Graph plot between Wire feed and welding Current

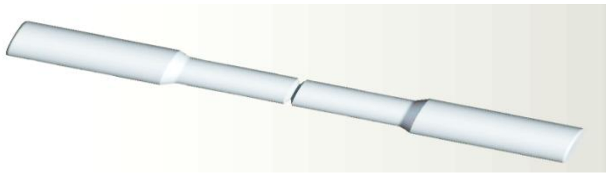


Graph plot between penetration and welding speed



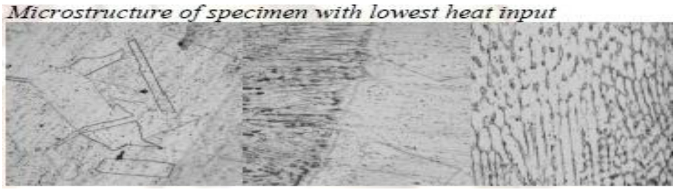
Microstructure of specimen with HAZ and Weld zone:- During welding of carbon steel and austenitic stainless steel, the material is subjected to elevated temperature (due to higher heat input). Due to this carbide

precipitation can cause the occurrence of chromium-depleted zones at the boundaries, leading to a phenomenon

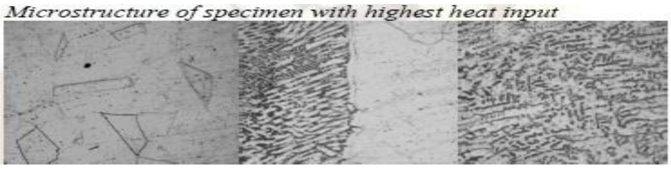


known as sensitization, in which the depleted zones

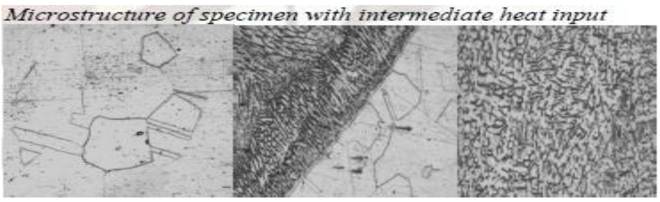
become the focus of intense corrosion. Higher heat input means slower cooling rate which can again lead to chromium carbide precipitation and become sensitized when subjected to sensitizing temperature for a longer time. At these elevated temperature the carbon diffuses to the grain boundaries, and then precipitates in the form of very small and thin chromium carbides which grow at grains and into the adjacent grain boundaries. In these areas the chromium level is substantially lower than required to form a protective film. The chromium depleted layer is actively corroded while the major portion of the grain remains un-attacked. This gives higher rate of corrosion even before being put into service and eventual failure. This is known as intergranular corrosion. specimens' susceptibility to intergranular corrosion. The test specimens are tested according to ASTM A262 Practice-A to determine the susceptibility.The specimens were initially sensitized at 675ºC for 1 hour. Then the specimens were electrolytically etched using oxalic acid. The specimens microstructure after sensitizing and etching were studied under a metallurgical microscope. Microstructures of the all 3 specimens revealed "step structure"



: Microstructure of base metal with HAZ and Weld zone



Microstructure of base metal with HAZ and Weld zone



Microstructure of base metal with HAZ and Weld zone

as in parent metal and interdendritic delta ferrite which reduces hot cracking and micro fissures are found in weld metal. The structures are found to be acceptable as per ASTM A262.

DESTRUCTIVE TESTING FOR WELDING JOINTS OF SPECIMEN:-The experiment setup will be developed at salasar Engineers Pvt. Ltd., jindal nagar, Gzb.(UP) for carrying out the present research work keeping in view the problem formulation. The joint should be prepared with changing one of the process parameter between its range and level regarding the thickness of the joint.

IV. SELECTION OF STEEL SPECIMEN

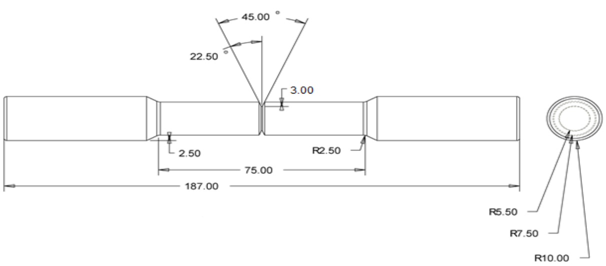


Figure : TENSILE TEST :- SELECTION OF STEEL

It has been decided to use 0.3% C commercial grade steel rod of welding sample for the present experiment.

PREPARATION OF TENSILE SAMPLING : This deals with the results and discussions of the experimental findings of welded joints prepared at different current, voltage, electrode size and welding technique (Down hand welding). The specimens prepared under different current, electrode size, heat input rates and welding speeds are having different effects.
The steel (0.3% C) tensile samples having the following details as shown in figure will be repared for the present work.

Table: 11Observation for Stainless steel Tensile specimen

Test Parameters	Values
UltimateTensile Strength	513.18 MPa
Yield Strength	255.90 MPa
% Elongation in 50 mm GL	55.50%

PERFORMANCE EVALUATION
The sustained and variable tensile loading of the steel samples (with notch and filled with weld) will be carried out by the Universal Testing Machine (UTM) (Max. Capacity 40 MT).Yield and tensile strengths were similar. As a result, can be seen that optimum welding parameters, breaking point on tensile bar, the suitability of post-tensioning yield and tensile strength values for acceptable values of materials, and percentage of extent quantity have significance.

Figure:Tensile Steel Sample with notch [mm]

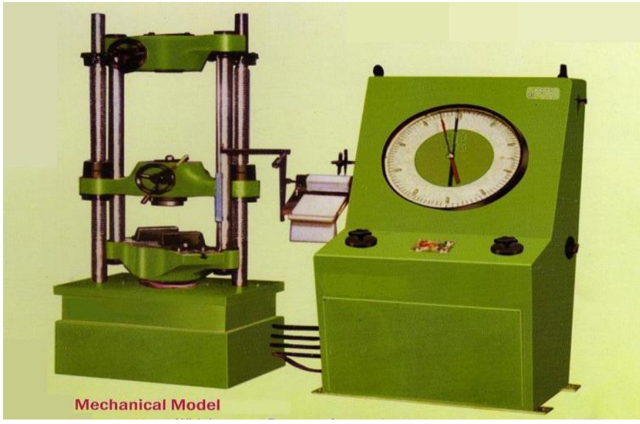


Figure:Universal Testing Machine (UTM)

HARDNESS TEST FOR WELDED JOINTS OF SPECIMEN:-
A 136 pyramide point Vickers type hardness test method was used for microhardness tests. Microhardness tests were carried out at a distance of 10 m to welding zone and parallel to welding cross-section. On this study

80 g load was used for the tests; however, a load from 25 g to 100 g could be applied on microhardness tester. Microhardness tests were carried out in the laboratory of **Salasar Stainlss Pvt. Ltd., Jindal nagar, Ghaziabad (UP).**

Figure : Hardness Testing Machine

NON DESTRUCTIVE TEST

a)RADIOGRAPHY TEST RESULT OF SPECIMEN JOINT SPECIMEN

Radiography is based on the differential absorption of short wavelength radiations such as X-rays and gamma rays on their passage through matter because of differences in densityand variations in thickness. The gamma ray source used in this project is Iridium-192. The radiography test procedure specification follows ASME Section V. The radiographic

Figure : Radiography test

Table : Radiography Test description

DESCRIPTION	
Source to film distance	16 inches
Source	I_r 192
Strength	18 C_i
Technique	Single wall single image
Penetrameter	ASTM 15
Lead screens	0.1mm(inside cover) 0.15mm(outside cover)
Film	Kodak AA 400
Speciman thickness	7.11mm
Film Density	2 to 2.5
Sensitivity	2T-2

b)EDDY CURRENT TESTING OF STAINLESS STEEL SPECIMEN

Eddy current testing is particularly well suited for detecting surface cracks but can also be used to make electrical conductivity and coating thickness measurements. Here a small surface probe is scanned over the part surface in an attempt to detect a crack. NDT develops practical solutions for nondestructive testing (NDT) of all types of semi-finished metal tube,bar and wire during production and in final inspection. The diverse range of applications varies from the testing of fine wire of only 0. 1 mm in diameter to the testing of tubes with diameters up to 1000 mm (40 in). These systems are demanded for their smooth operation, durability and high efficiency.

Figure: Eddy current testing machine

EFFECT OF OPTIMUM WELDING SPEED ON DEPTH OF PENETRATION: Readings of depth of penetration obtained through measuring instrument after cutting all the welded specimens perpendicular to the direction of welding are shown in the table and variations in the penetration are analyzed with the help of graph which is plotted between welding speed and penetration. Voltage (22.5V) and current (90A) are taken constant and arc time is varied during the welding of specimens. The depth of penetration increases with increasing welding speed up to 6.0 mm/min which was optimum value to obtain maximum penetration (5.64mm) because it begins to decrease linearly after this point. Increasing the speed of travel and maintaining constant arc voltage and current increases penetration until an optimum speed is reached at which penetration is maximum. Increasing the speed beyond this optimum results in decreased penetration.So it can be concluded from experimental analysis that for the mild steel specimen having dimension L-187 mm and diameter 20 mm, Gauge L-75 mm and Gauge diameter 7.5 mm , V notch depth 3 mm and angle 45^0 etc. The optimum welding can be achieved by considering the welding parameters as welding speed, 6.0 mm/min with current 90 Amp, arc voltage 22 Volt and electrode diameter 1.0 mm.

V. CONCLUSION

The present work which is aimed to minimizing the defects in stainless steel pipes without deteriorating the strength and durability. This project is expected to provide multiple benefits as given below-

[1] It will reduce the material cost for manufacturing of stainless steel pipes thereby reducing the overall cost of the steel pipe.
[2] It will reduce the physical testing cost of the company .
[3] Optimization method will reduce the defects of steel pipes.
[4] It will reduce the lead time of prototype manufacturing.
[5] Taguchi optimization method was applied to find the optimal process parameters for penetration.
[6] A Taguchi orthogonal array, the signal-to-noise (S/N) ratio and analysis of variance were used for the optimization of welding parameters.
[7] A conformation experiment was also conducted and verified the effectiveness of the Taguchi optimization method.
[8] The improvement of S/N ratio is 2.13. The experiment value that is observed from optimal welding parameters, the penetration is 5.25 mm and S/N ratio is 14.40.
[9] The overall welding defects value decreases at least 5% by using Taguchi's optimization Techniques.
[10] The company spends Rs. 2,15,250 per month for repaired or reworks and cost of rejection of stainless steel pipes.
[11] Successful optimization of welding for reducing the defects in stainless steel pipes would encourage further optimization of other defects in steel pipes.

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