ANALYSIS OF MECHANICAL BEHAVIOR OF TIG WELDED AISI321 AUSTENITIC STAINLESS STEEL PLATE

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ABSTRACT

Welding is used as a fabrication process in every industry large to small. It is a principal means of fabricating and repairing metal products. The process is efficient, economical and dependable as a means of joining metals. After the discovery of the electric arc in 1800 by Humphry Davy, arc welding developed slowly. C. L. Coffin had the idea of welding in an inert gas atmosphere in 1890, but even in the early 20th century, welding non-ferrous materials like aluminum and magnesium remained difficult, because these metals reacted rapidly with the air, resulting in porous and dross-filled welds.

In present study Experimental investigation has been carried out for TIG welding on austenitic stainless steelAISI321Material. An austenitic stainless steelAISI321, similar to SS 304 but stabilized with Titanium to avoid inter-granular corrosion. It has a good Weld ability and is used for exhaust stacks and manifolds, pressure vessels, large mufflers for engines, expansion bellows, stack liners, thin wall tubes etc where no post heat treatment of welds is desired.Response surface methodology used for analysis of AISI321 material for ultimate tensile strength, hardness. The input parameters are Weld current, voltage and flow rate. Selection of process parameters are based on the knowledge gained from the literature survey, weldingbrochures, specification of electrodes andvaluable discussion with industrial experienced persons.The total level are varying in five steps. ANOVA analysis carried out to analyze parametric effect for hardness and ultimate tensile strength. Percentage contribution calculated for each response with input parameters. Microstructure also varified for opimized parameters at weld zone , HAZ and base metal. Micro structure analysis shows substantially defect free AISI321 austenitic stainless steel .Optimization carried out using GRA and MOORA method. It is observed that the both method gives almost same set of process parameter for optimize the response.

Keyword: - *TIG Welding, RSM, Optimization, AHP, MOORA, GRA etc….*

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1. INTRODUCTION

Welding is used as a fabrication process in every industry large or small. It is a principal means of fabricating and repairing metal products. The process is efficient, economical and dependable as a means of joining metals. This is the only process which has been tried in the space. The process finds its applications in air, underwater and in space.

Why welding is used, because it is

- Suitable for thicknesses ranging from fractions of a millimeter to a third of a meter.
- Versatile, being applicable to a wide range of component shapes and sizes.

1.1 Process Principal of TIG Welding

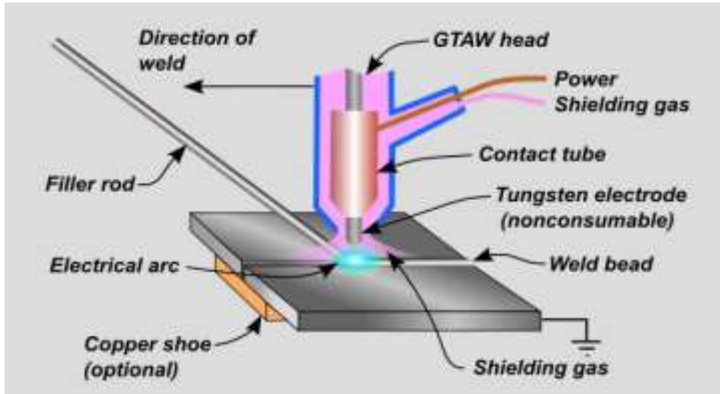

Fig -1 Simple Working Principle of TIG Welding

In the Gas Tungsten Arc Welding process (GTAW), also referred to as the Tungsten Inert Gas process (TIG) an electric arc is established between a tungsten electrode and the part to be welded. To start the arc a high voltage is used to break down the insulating gas between the electrode and the work piece. Current is then transferred through the electrode to create an electrode arc. The metal to be welded is melted by the intense heat of the arc and fuses together either with or without a filler material.

2. LITERATURE REVIEW

Prasad et al.(2016)studied 3Dsimulation of residual stress developed during TIG welding of stainless steel pipes deals with the effects of weld parameters on residual stress developed during TIG welding of pipes. The residual stress distribution developed during circumferential welding is predicted by 3D numerical simulation ANSYS code. Non-uniform distribution of plastic and thermal strains within and around the weld pool, large amounts of residual stresses and deformations are observed in all welded structures. The simulated results are validated using experimental results and the effects of welding current and pipe thickness on residual stress and temperature fields at different locations were assessed. Finally concluded:

- From the simulated finite element model, the temperature distribution and residual stress distribution can be plotted.
- The temperature distributions after the weld source passes are steady in nature.
- In designing the pressure vessels, heat exchanger and piping, axial residual stress variation along the thickness has much importance. From outer to inner surface, residual stress changes from compressive to tensile after the welding, and at a particular point it diminishes completely.
- The range of residual stress distribution became wider with increase in current value.[1]

Sriranganet al.(2016)investigate the Multi-response optimization of process parameters for TIG welding of Incoloy 800HT by Taguchi grey relational analysis. This study focuses on the multi-objective optimization using grey relational analysis for Incoloy800HTwelded with tungsten inert arc welding process with N82 filler wire of diameter 1.2 mm. The experiments were conducted with input parameter as welding current, Voltage and welding speed. The output response for quality targets chosen were the ultimate tensile strength and yield strength (at room temperature, 750 °C) and impact toughness. Grey relational analysis was applied to optimize the input parameters simultaneously considering multiple output variables. An optimum combination of three test parameters of grey relational grade for quality weld joints was found to be welding current of 110 A, voltage of 12V and welding speed of 1.5 mm/s. Based on the ANOVA results of GRG, it twas observed that the welding current (58%) exerted a significant influence on multiple responses followed by welding speed (30%)and voltage (12%). The mechanical properties were correlated with the metallurgical characteristics.[2]

Gohelat el.(2016)carried out Optimization of process parameter for tensile strength and hardness of S.S 304 by TIG welding, Aim of the study is to investigate and correlated the relationship between various welding parameters with hardness and tensile strength of single square butt joint and predicting weld bead qualities before applying to the actual joining of metal by welding. Austenitic stainless steel 304 is used for present work, the dimensions of the work piece are length 150 mm, width20mm, thickness 3 mm. Argon is used as a shielding gas. The specimen welded by TIG welding as per the standard of ASTMA240.Effect of Changing different welding parameters like welding current, voltage and Gas flow on the tensile strength and hardness of the weld joint has been investigated. Hardness value of the welded zone has been measured at the cross section to understand the change in mechanical property of the welded zone. Finally concluded that Optimum parameter setting for Tensile strength is obtained at current of 130 amps, 20 volt, and 25-litre/min-gas flow and for Hardness optimum parameter is obtained at current of 130 amps, 20 volt, and 25-litre/min-gas flow and from the ANOVA it is conclude that the welding current is most significant parameter for Tensile strength which contributes 58.49% and Gas flow rate is most significant parameter for Hardness which contributes 73.92%.[3]

Nakhodchi et al (2015) evaluate temperature distribution and microstructure for multipass welded AISI 321 S.S plates of different thickness. First and third run done by SMAW and intermideate second run carried out by GTAW to weld 6 mm and 10 mm thick plates.3 thermocouple attached on 6 mm thick and 4 on 10 mm thick plates, temperature observed during welding for 4000 seconds. Each successive weld pass shows increase in temperature. The peak point temperature corresponds to the time of welding torch nearest to thermocouple. Two FE model were used for analysis. In microstructure analysis, non uniform structure observed in HAZ, while course grain near to weld area [4]

Moslemi et al.(2015)studied the Effect of Current on Characteristic for 316 Stainless Steel Welded Joint Including Microstructure and Mechanical Properties, In this research work, SS316 pipes with outside diameter 73mm and 7.0mm thickness were joined using Tungsten Inert Gas (TIG) welding process. Various current settings were used to obtain the optimum joint characteristics and minimize defects that will contribute to cost effective. Mechanical characteristics of the welded alloys were carried out are tensile tests and hardness (HV). Metallographic examination was conducted to identify and observe the various fusion zones. Results show that the increase of welding current bring about the large amount of heat input in the welding pool, the enlargement of width and deepness of the welding pool, cumulative sigma phase in the matrix and reducing the chromium carbide percentage in 316 stainless steel welded joint. Arc current of 100A has been identified as the most suitable current since it gives the lowest defects and brings the highest value of strength and hardness for this material SS316.[5]

Ramachandran et al.(2015) perform on Experimental Investigations Of Weld Characteristics For a TIG Welding With SS316L, In present study, the austenitic stainless steel (316L) is welded by GTAW process and its mechanical property were studied and the process welding parameters like current, voltage and gas flow rate of TIG for obtaining maximum weldments condition, best mechanical properties and min HAZ. The destructive and nondestructive tests are carried out in this experiment, from the analysis of all experimental trials, it was found that the major effect of welding parameters such as welding current, voltage and gas flow rate on weldment. It is clear from the results phase that the following conclusions are drawn from the analysis of collected data of input and output parameters. For this Amps and voltage maximum depth of penetration is obtained with minimum failure is occurred.

Rao et al .(2014)perform Experimental investigation for Welding Aspects of Stainless Steel310 for the Process of TIG Welding, In this work, analysis and optimization of joining similar grades of stainless steel(SS 310) by TIG welding. The parameters such as current, filler rod, welding speed are the variables in the study. The mechanical properties and microstructure of 310austenitic stainless steel welds are investigated, by using stainless steel filler material of different grades as309L,316L and 347. Finally concluded that maximum tensile strength was achieved with a current 120A and 309L filler rod with least weld defects.[7]

Magudeeswaran et al.(2014)studied Optimization of process parameters of the activated tungsten inert gas welding for aspect ratio of UNS S32205 duplex stainless steel welds, in this study, the above parameters of ATIG welding for aspect ratio of ASTM/UNS S32205 DSS welds are optimized by using Taguchi orthogonal array (OA)experimental design and other statistical tools such as Analysis of Variance (ANOVA) and Pooled ANOVA techniques. The optimum process parameters observed are 1 mm electrode gap, 130 mm/min travel speed, 140 A current and 12 V voltage. The aspect ratio(The shape of a weld in terms of its width-to-depth ratio known as aspect ratio) and the ferrite content for the DSS joints fabricated using the optimized ATIG parameters are seen within the acceptable range and there is nomacroscopically evident solidification cracking observed.[8]

Mishra et al.(2014)carried out research of Study Of Tensile Strength of MIG and TIG Welded Dissimilar Joints of Mild Steel and Stainless Steel In the present study, stainless steel of grades 202, 304, 310 and 316 were welded with mild steel by Tungsten Inert Gas (TIG) and Metal Inert Gas (MIG) welding processes. The percentage dilutions of joints were calculated and tensile strength of dissimilar metal joints was investigated. The results were compared for different joints made by TIG and MIG welding processes and it was observed that TIG welded dissimilar metal joints have better physical properties than MIG welded joints.[9]

Mukesh et al.(2013)perform on Study of Mechanical Properties in Austenitic Stainless Steel Using Gas Tungsten Arc Welding (GTAW). The present study is to show the influence of different input parameters such as welding current, gas flow rate and welding speed on the mechanical properties during the gas tungsten arc welding of austenitic stainless steel 202 grade. The microstructure, hardness and tensile strength of weld specimen are investigated in this study. The stainless steel grade 202 was used explore the different input process parameters on the tensile strength and micro-hardness of the weld samples. ANOVA analysis was performed for the analysis

purpose which shows that current is the most significant parameters that influenced the tensile strength and micro-hardness of the weld. The highest tensile strength obtained in the research is 0.595 KN/mm 2 at a welding current of 210 amp, gas flow rate of 14 l/min and welding speed of 190 mm/sec. The maximum micro hardness is 80.473 HV obtained at a welding current of 210 Amp, gas f low rate of 12 l/min and welding speed of 180 mm/sec.[10]
Kumar et al.(2013)publish paper of Study Of Mechanical Behavior In Austenitic Stainless Steel 316 LN Welded Joints, In the present paper an attempt has been made to present the influencing factors on the weld ability of 316 LNSS. The welding processes such as single pass activated TIG (A-TIG), multi-pass activated TIG (MP-TIG) welding and Laser welding carried out on 316 LN austenitic stainless steel. Residual stresses have been analyzed and compared. Less amount of residual stresses found in activated flux TIG welding compared to MP-TIG welding Non-destructive techniques have been used For measuring residual stresses and defects in welding. The intense of this study is to investigate weld ability of 316 LN SS, study the useful good effect on fully austenitic steels with particular emphasis on nitrogen-alloyed and stabilized stainless steels.[11]

2.1 Research Summary

- It is observed that Most of researches have been carried out to study the effect of various process parameters on material properties and weld geometry and thermal aspects.
- Considerably few research and investigation observed on stabilized grade stainless steel.
- Very few research work seen with the use of TIG welding of austenitic stabilized stainless steel grade SS321
- Investigation of mechanical properties of SS321 (UNS 32100) or SA240 TP 321Material very rare observed.

2.2 Objective

The objectives of the thesis are listed below.
- To select suitable process parameter and their range for TIG welding
- To study effect of process parameter of TIG weld for hardness, tensile strength.
- Identify the significant process parameters that influence the mechanical properties.
- To optimize the process parameter for TIG welding for SS 321 material.
- To develop a mathematical model for selected response using statistical analysis software

2.3 Machine Set-Up and Company Profile

The experimental part regarding TIG welding of this research work was carried out at the Keepsake Engineering Consultancy Pvt. Limited (KECPL) on LORCH V50TIG Welding Machine.
KECPL is an Ahmedabad based professionally run decade and half old co. specialized in the field of thermal spray coatings & carbide wear parts. Team is headed by a technocrat who has decades of stint with engineering icons L & T. To produce quality coatings we have an excellent thermal spraying facility and highly skilled and trained team of engineers to do the job successfully. During the period of time co. has renewed their facilities according to the technical advancement adopted in the industry. We are presently equipped with six axis articulated arm robot to operate our Plasma transferred arc pulsed 350 amp power source, High velocity oxy-fuel systems, Arc spray systems and flame spray guns. We also have manipulators for down hand welding capability.
In this experimental work, the sample is welded at five different levels of welding parameter i.e. voltage, current and speed as shown in table 1.

Table-1: Welding parameter and their levels

Machining process parameter		Level				
		1	2	3	4	5
1	Current (Amp)	76	90	110	130	144
2	Voltage (Volt)	10	12	15	18	20
3	Gas Flow Rate (Litre/minute)	10	12	15	18	20

Table-2: Chemical Composition of SS321

Element	Found in Test plate	Required
Carbon	0.027	0.080 max
Silicon.	0.570	1.000 max
Sulfur	0.001	0.030 max
Phosphorus	0.022	0.045 max

Manganese	1.230	2.000 max
Nickel	9.060	9.000 to 12.000
Chromium	17.090	17.000 to 19.000
Moly	0.093	
Titanium	0.300	0.700 max
Nitrogen	0.010	0.100 max

Test pieces are prepared by cutting on shearing machine with size of 150 mm x 200 mm – 4 Qty. WEP carried out for single V butt joint with angle of 600, root gap of 1 mm. Proper setup established, two plates are tag welded first. Back purging strip used for weld back side protection. Argon 99.9 % pure used as shielding gas on front and back side of weld. TIG welding performed in 1G position.

Fig -2 Welded Sample

Central composite design (CCD) is the most popular class of second order designs suggested by Box and Wilson . Central composite rotatable design (CCRD) is capable of predicting independent, quadratic and interaction effects of different parameters on the responses.

Total 20 experiments (8 factorial runs, 6 axial runs, 6 central points) have been carried out at five levels. Table 3.4 shows the typical plan of experiments using CCRD.

Total twenty experiments were performed based on L20 orthogonal array shown in this research. The effect of different parameters such as welding Laser Power (Watt), Travelling Speed (mm/min) and Focal Position (mm) of above material was analysed and observed the tensile strength and hardness of all nine welded sample are also shown in Table 3. Then we Calculate ANOVA using Minitab 16.

3. RESULT AND DISCUSSION

3.1 Response Surface Regression: UTS versus A, B, C

R-Sq = 77.88% R-Sq(pred) = 0.00% R-Sq(adj) = 57.96%

Analysis of Variance for Ultimate Tensile Strength

Table - 3 ANOVA Table for Ultimate Tensile Strength

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage Contribution
A	1	797.51	797.51	797.51	4.58	0.058	10.13
B	1	483.12	483.12	483.12	2.77	0.127	6.13
C	1	178.76	178.76	178.76	1.03	0.335	2.27
A*A	1	1575.62	1821.82	1821.82	10.46	0.009	20.01
B*B	1	1.44	19.63	19.63	0.11	0.744	0.02
C*C	1	1063.84	1063.84	1063.84	6.11	0.033	13.51
A*B	1	36.13	36.12	36.12	0.21	0.659	0.46
A*C	1	820.13	820.13	820.13	4.71	0.055	10.41
B*C	1	1176.13	1176.13	1176.13	6.75	0.027	14.94
Residual Error	10	1742.3	1742.3	174.23			22.12
Total	19	7874.95					100.00

The above analysis helps to understand the impact of process parameters as an individual effect and with interaction.

F-test and P-test help to identify the key parameter in welding for stress analysis. The significant parameters based on F-test whose F-test values > 4 are current. Current and flow rate creates more significant over response as of interaction effect.

Significant parameters for ultimate tensile strength is current as its p value is <0.05 at 95% confidence level.

% contribution helps to identify the contribution of each parameter over response. Analysis state that current contributed more for stress.

3.2 Response Surface Regression: HAZ Hardness versus A, B, C

R-Sq = 78.00% R-Sq(pred) = 0.00% R-Sq(adj) = 58.20%

Analysis of Variance for HAZ Hardness

Table - 4 ANOVA Table for Hardness on HAZ

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage Contribution
A	1	257.38	257.38	257.378	3.97	0.074	8.74
B	1	212.97	212.97	212.969	3.29	0.1	7.23
C	1	529.72	529.72	529.721	8.17	0.017	17.98
A*A	1	27.53	14.86	14.858	0.23	0.642	0.93

B*B	1	0.64	0.39	0.386	0.01	0.94	0.02
C*C	1	203.48	203.48	203.479	3.14	0.107	6.91
A*B	1	415.73	415.73	415.729	6.41	0.03	14.11
A*C	1	308.39	308.39	308.389	4.76	0.054	10.47
B*C	1	342.3	342.3	342.304	5.28	0.044	11.62
Residual Error	10	648.11	648.11	64.811			22.00
Total	19	2946.24					100.00

The above analysis helps to understand the impact of process parameters as an individual effect and with interaction.
F-test and P-test help to identify the key parameter in welding for Hardness analysis. The significant parameters based on F-test whose F-test values > 4 is flow rate. Current - flow rate, voltage flow rate, current – flow rate all creates more significant over response as of interaction effect.
Significant parameters for stress is current as it'spvalue is <0.05 at 95% confidence level.
% contribution helps to identify the contribution of each parameter over response. Analysis state that flow rate contributed more for hardness on HAZ.

3.3 Response Surface Regression: Weld Zone Hardness versus A, B, C

R-Sq = 81.33% R-Sq(pred) = 6.59% R-Sq(adj) = 64.52%
Analysis of Variance for Weld Zone Hardness

Table - 5 ANOVA Table for Hardness on Weld Zone

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Percentage Contribution
A	1	47.74	47.74	47.7404	10.78	0.008	20.13
B	1	2.434	2.434	2.4336	0.55	0.476	1.03
C	1	72.171	72.171	72.1709	16.3	0.002	30.43
A*A	1	0.95	0.437	0.437	0.1	0.76	0.40
B*B	1	31.419	28.93	28.9303	6.53	0.029	13.25
C*C	1	4.013	4.013	4.0129	0.91	0.364	1.69
A*B	1	6.125	6.125	6.125	1.38	0.267	2.58
A*C	1	25.704	25.704	25.7044	5.8	0.037	10.84
B*C	1	2.354	2.354	2.3544	0.53	0.483	0.99
Residual Error	10	44.288	44.288	4.4288			18.67
Total	19	237.199					100.00

The above analysis helps to understand the impact of process parameters as an individual effect and with interaction.
F-test and P-test help to identify the key parameter in welding for hardness analysis. The significant parameters based on F-test whose F-test values > 4 is current and flow rate. Current and flow rate creates more significant over response as of interaction effect. No significant effect found as an interaction between voltage and flow rate.
Significant parameters for hardness is flow rate as it'spvalue is <0.05 at 95% confidence level.
% contribution helps to identify the contribution of each parameter over response. Analysis state that current and flow rate contributed more for weld zone.

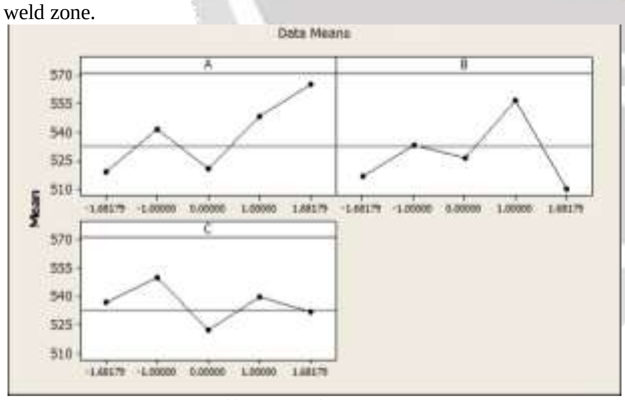

Fig-3 Main Effects Plot for Ultimate Tensile Stress

Graph state that as current increases the stress on weld area also increases.
As voltage increases the stress in intially decrease and then after it increases.
The effect of flow rate is affact to stress when it's value is less. Then after stress level become uniform.

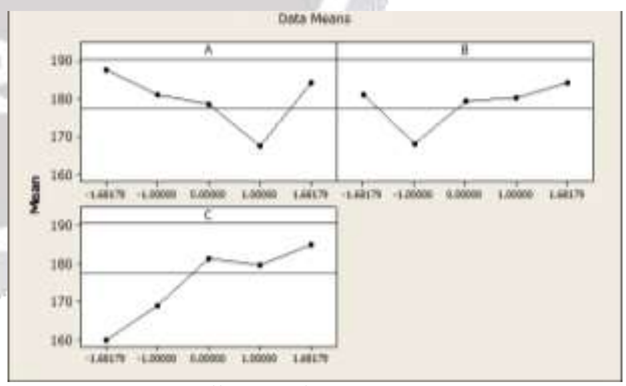

Fig-4 Main Effects Plot for Hardness on HAZ Zone

Graph state that as current increases the hardness in weld HAZ area decreases. This is because of high heat generation in weld zone.
As voltage increases the hardness increases in hardness on HAZ. It means this parameter is considered as the parameter for hardness requirement.
Gas flow rate affact to hardness with high impact. Increase in flow rate also increase in hardness on HAZ zone.

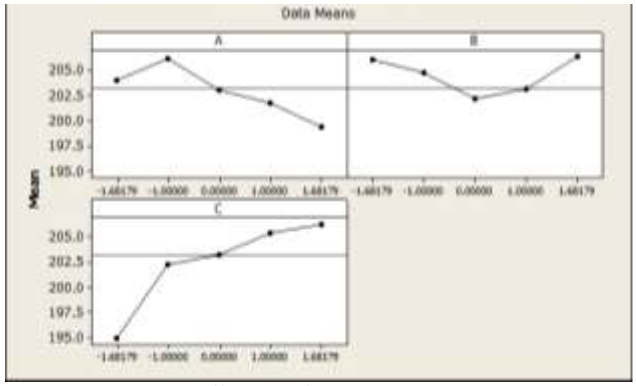

Fig-5 Main Effects Plot for Hardness on Weld Zone

Graph state that as current increases the hardness in weld area decreases. This is because of high heat generation in weld zone. The nature of curve state that it is in continuously decreasing nature means as current increases the hardness decrease on weld zone.

As voltage increases the hardness on weld zone initially decrease and then after increases.

Gas flow rate affect to hardness with high impact. Increase in flow rate also increase in hardness on weld zone.

4. MATHEMATICAL MODELING

Final Equation in Terms of Coded Factors:

Mathematical Model for Ultimate Tensile Strength

Ultimate Tensile Strength = 518.209 + (7.64176*A) + (5.94774*B) - (3.61789*C) + (11.2435*A*A) + (1.16722*B*B) + (8.59184*C*C) + (2.12500*A*B) - (10.1250*A*C) + (12.1250*B*C)

Mathematical Model for HAZ Hardness

HAZ Hardness = 179.655 - (4.34120*A) + (3.94896*B) + (6.22800*C) + (1.01539*A*A) - (0.163713*B*B)-(3.75758*C*C) + (7.20875*A*B) + (6.20875*A*C) - (6.54125*B*C)

Mathematical Model for Weld Zone Hardness

Weld Zone Hardness = 202.745 - (1.86968*A) - (0.422133*B) + (2.29882*C) - (0.174137*A*A) + (1.41685*B*B) - (0.527690*C*C)-(0.875000*A*B) + (1.79250*A*C) + (0.542500*B*C)

4. OPTIMIZATION

The results obtained for evaluation and selection of TIG welding process parameter using combine application of AHP/MOORA method and GRA is presented in research. In this table ranking of all 20 alternative is carried out based on the weighted assessment value. According to performed experimental design, it is clearly observed that experiment or alternative number 11 gives the best multi- performance features of the TIG welding process among the 20 experiments obtain by GRA method also find by AHP/MOORA method.

5. CONFIRMATION TEST

The confirmation test is the final step undertaken during this experiment on the optimize run no 11. The purpose of the confirmation runs is to validate the conclusion drawn during the analysis phases. In addition, the confirmation tests need to be carried out in order to ensure that the theoretical predicted model for optimum results using the software was accepted or in other word to verify the adequacy of the models that were developed.

Three confirmation tests were carried out in order to compare the experimental results from the prediction made by the ANOVA.

Table 5.5 shows the three series of parameters settings for the confirmation test. The parameters values were selected between the high and low range of the process factor that have been studied from previous experiment.

Table - 6 True value of confirmation test experiment

Exp. No.	CURRENT (A)	VOLTAGE (B)	GAS FLOW LPM(C)
11	110	15	20

Comparison of the test results

Based on the above discussed in chapter the comparison of the test results between the theoretically prediction and confirmation test results was the final consideration that will evaluate whether the optimum parameters predicted were in the allowable range.

Table - 7 Comparison test results

Exp. No.	Experimental (Confirmation test)			Prediction (by Mathematical Model		
	UTS N/mm2	WELD BHN	HAZ BHN	UTS N/mm2	WELD BHN	HAZ BHN
1	564.568	194.33	181	566.489	205.092	179.805
2	563.423	193.33	180			
3	568.258	197.00	183			

Tables 5.15 show the comparison of test results between theoretical prediction and confirmation test is very nearest.

6. CONCLUSIONS

- Quality weld is depending upon selection of process parameter.
- Power is effective parameter for ultimate tensile strength and hardness in weld zone as well as in HAZ. Too much power generates more energy which reduce weld strength and too low power gives adverse effect on ultimate tensile strength. So optimum set of power required for effective combined response.
- Travelling speed is second important parameter for ultimate tensile strength and hardness in weld zone as well as in HAZ. Low speed gives better ultimate tensile strength but it increase hardness in weld zone whichn is not desirable. So multiobjective optimization needed to get combined response effect. Focal length is important factor for hardness in weld zone.
- AHP/MOORA base multi objective optimization help to select set of process parameter which combines response. It is observed that MOORA base multi objective optimization state different set of parameter against single objective optimization.

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