中國機械工程學刊第四十卷第六期第 733~740 頁(民國一百零八年)
Journal of the Chinese Society of Mechanical Engineers, Vol.40, No.6, pp 733~740 (2019)

Grey Based Taguchi Technique for Optimization of MIG Welding Process Parameters of AISI 304 Austenitic Stainless Steel

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Keywords: AISI 304H, mechanical properties, SEM, Grey relational analysis.

ABSTRACT

The purpose of this study was to investigate the multi-response optimization of three welding parameters (wire feed speed, arc voltage, and shielding gas flow rate) for AISI 304H by using the Grey relational analysis and Taguchi technique. In this research work pure Argon was used as shielding gas. Experiments were conducted according to L_{16} ($4^{xx}3$) orthogonal array Design (sixteen experimental runs) and the mechanical properties such UTS, Vickers hardness (HV), Impact strength, optimized by Grey-based Taguchi method and Microstructure of AISI 304 H was studied. Analysis of variance (ANOVA) was applied to determine significant parameters. By analyzing the Grey relational grade matrix, the degree of influence for each controllable process factor on individual quality targets can be found. After conducting experiments and collecting the data S/N ratio were calculated and result shows that the optimal parameters combination was determined as A3B4C2 i.e. was welding speed at 350 IPM, voltage at 24 V, and gas flow rate at 10 l/min, and an optimal parameter combination of the welding operation was obtained via Grey relational analysis.

INTRODUCTION

Welding is a fabrication process which is used to bond same or different materials that can be either ferrous metals or non ferrous metals and most of welding process utilize heat, pressure or both for fabrication of joint. The Metal Inert Gas (MIG) welding is considered to be as a key of arc welding processes (R.S Parmar, 2007). The Metal Inert Gas (MIG) welding process provides high quality of mechanical properties and metallurgical welded joints.

Paper Received June, 2017. Revised Sepfember, 2018. Accepted October, 2019. Author for Correspondence: Saadat Ali Rizvi.

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AISI 304H is widely used in various industries such as petrochemical, automobile, thermal power plant, aerospace, paper,food process industries, kitchen application due to its corrosion resistance, superior tensile strength (Mc Guirw,M.F and C.Noval,2008 & 1977).Toughness & ductility of AISI 304H is excellent as thermal conductivity of Austenitic steel is minor, easy to heat to weld. In metal inert gas welding (MIG), the common variations of power supplies, shielding gases, and electrodes have significant effects resulting in several different and important process variations (Tusek,J and Suban,J.2001). (S. P. Sundar Singh Sivam et al 2018) applied grey based Taguchi technique to optimize the process parameters in FSW process and they concluded in their result that for tensile Strength, travel speed is (74.07 %), for the Yield Strength the travel speed is (73.34 %), for the elongation rotation speed is (50%), for the shear strength travel speed is (68.69 %), and for the grey relation grade rotation speed is (36.91 %).

(P Sathiya and M.Y abudul Jameel,2010) applied grey-based Taguchi technique to optimize the parameters during LASER welding process and they reveal that calculation of the grey relation grade helped to quantify the integrated performance of bead on plate of laser beam welding process.

(Sathish et al. 2012) optimized the TIG welding process parameters for welding of dissimilar pipe joints via Taguchi method and they mention in their conclusion that higher heat input resulted in lower tensile strength. (A. Hakan et al, 2010) examined for the optimization of friction stir welding process parameters for an optimal parametric combination to yield favorable tensile strength and elongation using the Taguchi based Grey relational analysis. (S.K Sharma et al, 2014) optimized the Turning parameters in turning operation of AISI 8620 Steel Using Taguchi and Grey Taguchi Analysis to obtain the acceptable surface roughness.

Nabendu Ghosh et al,2016) optimized the Metal Inert Gas (MIG) welding process parameters on 316L steel by Grey relational based Taguchi method and Current was found to be more significant parameter than gas flow rate influencing the strength of the welded joints. (Sourav Datta et al, 2008) applied Taguchi technique followed by grey relational analysis to solve multi response optimization problem during the submerged arc welding. (P. Sathiya et al, 2010) optimized the weld bead characteristics of super austenitic stainless steel (904L) by application of grey-based Taguchi method and they reported in their result that gray relational grade helps quantify the integrated performance of bead-on-plate welding of GMAW process.

RESEARCH METHOD

Experimental procedures

AISI 304H plates of dimensions 250mm × 70 mm× 5 mm were welded using Lincoln, USA GMAW machine, with Polarity Direct Current Electrode Negative [DCEN]. V-groove was fabricated on milling machine to get the proper penetration and strength.

Table.1. Composition of parent metal and filler wire

Material	% of C	% of Cr	% of Ni	% of Mn	% of Si	% of P	% of S	Fe
AISI 304H	0.06	18.68	8.54	1.9	0.41	0.031	0.005	rest
ER 308	0.058	18.3	8.64	1.87	0.39	0.035	0.005	rest

Table.1 depicts the chemical composition of parent metal and filler wire of 2.0mm diameter, which is used to weld the parent metal.Fig.1, shows the actual experimental setup.

Fig.1. Actual Experimental Setup

In the experiments, pure Argon (Ar) was used as shielding gas for spray transfer mode, was adopted during the Metal Inert Gas (MIG) welding, which produced reliable weld bead width and excellent bead appearance with a stable arc formation. After welding of 16 samples, tensile test samples have been fabricated as per ASTM (2013) standard by cutting and machining on shaper machine. The size and shape of each tensile test specimen, which is fabricated as per ASTM E8/E8M – 11 is shown in Fig. 3.

Optimization of welding process via Grey-based Taguchi analysis

Fig.2. shows that proposed flow chat of process adopting during the entire process. Entire process is completed in eight steps, starting from measurement of test data to validate result.

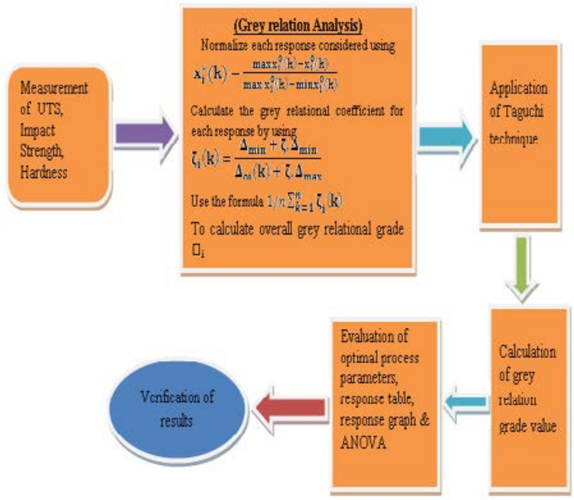


Fig.2. Proposed grey-based Taguchi technique

Experimental procedure

In the present research article, three level Metal Inert Gas (MIG) welding process parameters i.e. welding current, wire feed speed, and gas flow rate were selected. Value of process parameters are shown by Table 2. Optimum welding process parameters, which considered the multiple performance characteristics, were acquired. The initial values of the welding parameters were wire feed speed of 250IPM, gas flow rate of 5 l/min, and arc voltage of 21 V. Welding experiments for determining the optimal welding parameters were carried out by setting the wire feed speed at 250,300,350 and 400 IPM, arc voltage at 21, 22, 23 and 24 V, and Gas flow rate of 5, 10, 15 and 20 l/min.

Table.2. Welding process parameters and their levels

Factors	Parameters	Level I	Level II	Level III	Level IV
A	Wire feed rate (IPM)	250	300	350	400

B	Arc Voltage (V)	21	22	23	24
C	Gas flow rate (l/min)	5	10	15	20

The summary of experimental conditions is shown in Table 3. The experimental results after Metal Inert Gas (MIG) welding were estimated in terms of the following measured performance: (1) ultimate tensile strength (UTS), (2) absorbed energy (AE) of charpy impact test results of welded specimen, and (3) Vickers hardness (HV).

In order to attain supreme weldability, Taguchi's experimental design was utilized for conducting experiments. For this, a L_{16} orthogonal array was used for the experiment.

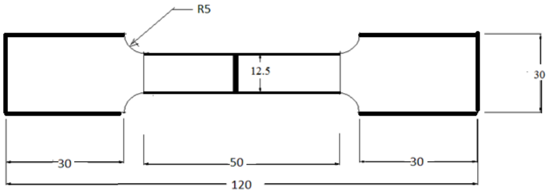


Fig.3. Tensile test diagram for gas metal arc welding as per ASTM (2013)

Standard specimens adopted in the tensile experiments are tested by UTM-40 at the room temperatures. Figure 4 shows the actual tensile test specimen prepared as per ASTM after fracture.

Fig.4. Actual Tensile test Specimen after fracture

GREY RELATIONAL ANALYSIS

Data preprocessing

Let the original reference sequence and sequence for comparison be represented as $x_o(k)$ and $x_i(k)$, i=1, 2,…, m; k=1,2,…, n, respectively, where m is the total number of experiment to be considered, and n is the total number of observation data.

Optimization of multiple responses can be simultaneously performed with Grey Relation Analysis to find out the optimal levels that consists of many outputs (Asif Ahmad, S.Alam, 2018, Edwin Raja Dhas, M. Satheesh, 2012 & Vinayagamoorthy, R and Xavior 2014). With the meager information available, GRA can judge or evaluate the performances of complex process that involves more than one output. In GRA, the raw data have to be pre-processed into a quantitative index for subsequent analysis (Gopalsamy B M et al, 2009 & Ugur Esme et al, 2009). Pre-processing raw data involves conversion or raw data into decimal sequence that lies between 0.00 and 1.00, which is useful for comparison. The sequence can be normalized for the condition Higher-the-better as

$$x_i(k) = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)} \quad (1)$$

X_i^* (k) represents the data sequence after pre-processing, x_i^o (k) represents the original sequence, largest value of x_i^o (k) is max x_i^o (k), smallest value of x_i^o (k) is min x_i^o (k) imply the. Normalizing the data for lower-the-better condition is given as

$$x_i(k) = \frac{\max x_i(k) - x_i(k)}{\max x_i(k) - \min x_i(k)} \quad (2)$$

Table.3. Experimental results for AISI 304H

Experiment No	UTS (MPa)	Impact strength (Joule)	Vickers hardness (HV)
1	437	246	190
2	510	198	181
3	497	266	179
4	518	222	189
5	623	212	206
6	502	282	200
7	600	184	224
8	590	232	190
9	574	208	186
10	652	220	216
11	559	174	180
12	670	200	223
13	507	190	194
14	474	250	203
15	577	264	219
16	688	196	198

However, if there is "a specific target value" then the original sequence is normalized using

$$x_i^*(k) = 1 - \frac{|\, x_i^o(k) - OB \,|}{\max\{\max . x_i^o(k) - OB,\ OB - \min . x_i^o(k)\}} \quad (3)$$

Where OB is the target value.

Alternatively, the original sequence can be normalized using the simplest methodology that is the values of the original sequence can be divided by the first value of the sequence,

$x_i^o(1)$

$$x_i^*(k) = \frac{x_i^o(k)}{x_i^o(1)} \quad (4)$$

Where$X_i^o(k)$ is the original sequence, $x_i^*(k)$ the sequence after the data preprocessing, $\max . x_i^o(k)$ the largest value of$x_i^o(k)$, $\min . x_i^o(k)$: the smallest value of $x_i^o(k)$

Grey relational coefficients and Grey relational grades

After pre-processing, a grey relation coefficient can be calculated with the pre-processedsequence.it express the relationship between actual and ideal normalized values results. A Grey relational coefficient (Nanda Naik Korra, K.R. Balasubramanian, 2012 & Deng, J) can be determined, as expressed in Eq. (5):

$$\xi_i(k) = \frac{\Delta \min + p\Delta \max}{\Delta x_i(k) + p\Delta \max} \quad (5)$$

Δ_{oi} (k) represents the deviation sequence, which is calculated by

$\Delta_{oi}(k) = \| X_o^*(k) - X_i^*(k) \|$, $\Delta_{max.}(k) = \underset{\forall j i \varepsilon}{max.} \underset{\forall k}{max} \| X_o^*(k) - X_i^*(k) \|$,

$\Delta_{min.}(k) = \underset{\forall j i \varepsilon}{max.} \underset{\forall k}{max} \| X_o^*(k) - X_i^*(k) \|$,$\zeta$ is the distinguishing coefficient and $\zeta = 0.5$ is generally used.

A Grey relational grade is a weighted sum of the Grey relational coefficients, and is defined as follows.

$$\sum_{k=1}^{n} \beta_k = 1$$

$$\gamma(x_0^*, x_i^*) = \sum_{k=1}^{n} \beta_k \gamma^n(x_0^*(k), x_i^*(k)) \quad (6)$$

Here, the Grey relational grade $\gamma(x_0^*, x_i^*)$ represents the level of correlation between the reference and comparability sequences. If the two sequences are identical, then the value of the Grey relational grade equals to one. The Grey relational grade also indicates the degree of influence exerted by the comparability sequence on the reference sequence. The Grey relational analysis is actually a measurement of the absolute value of data difference between the sequences, and can be used to approximate the correlation between the sequences.

RESULT ANALYSIS AND DISCUSSION

Result

The tensile test specimens, prepared corresponding to L_{16} Taguchi Orthogonal Array experiments, have been tested for Ultimate tensile strength (UTS), Impact strength, and Vickers hardness (HV) and the results obtained in experiments are listed in Table 4.

Table.4. Experimental data

Experiment No	Voltage (V)	Gas flow rate (l/m)	Wire feed speed (IPM)	UTS (MPa)	Impact strength (Joule)	Vickers hardness (HV)
1	21	5	250	437	246	190
2	21	10	300	510	198	181
3	21	15	350	497	266	179
4	21	20	400	518	222	189
5	22	5	300	623	212	206
6	22	10	250	502	282	200
7	22	15	400	600	184	224
8	22	20	350	590	232	190
9	23	5	350	574	208	186
10	23	10	400	652	220	216
11	23	15	250	559	174	180
12	23	20	300	670	200	223
13	24	5	400	507	190	194
14	24	10	350	474	250	203
15	24	15	300	577	264	219
16	24	20	250	688	196	198

Table.5. Proposed data, GRC and GRG for AISI 304H

Experiment No	**Normalized Value**			**Grey relation coefficient**				
	UTS (MPa)	**Impact strength (Joule)**	**Vickers hardness (HV)**	**UTS**	**Impact strength**	**Vickers hardness**	**Grey relation grade**	**Rank**
1	0.0000	0.6667	0.2444	1.0000	0.4286	0.6717	0.7001	4
2	0.29008	0.2222	0.0444	0.6328	0.6923	0.9184	0.7478	3
3	0.02390	0.8515	0.0000	0.9544	0.3699	1.0000	0.7747	2
4	0.3227	0.4444	0.2222	0.6077	0.5294	0.6923	0.6098	7

5	0.7410	0.3518	0.6000	0.4029	0.5870	0.4545	0.4815	12
6	0.6494	1.0000	0.4667	0.4350	0.3333	0.5172	0.4285	15
7	0.6494	0.0926	1.0000	0.4350	0.8437	0.3333	0.5373	9
8	0.6095	0.5370	0.2444	0.4506	0.4822	0.6717	0.5348	10
9	0.5458	0.3148	0.1555	0.4781	0.6136	0.7628	0.6182	6
10	0.8565	0.4259	0.8222	0.3686	0.5400	0.3781	0.4289	14
11	0.4860	0.0000	0.0222	0.5071	1.0000	0.9575	0.8215	1
12	0.9283	0.2407	0.9777	0.3501	0.6750	0.3384	0.4545	13
13	0.2788	0.1481	0.3333	0.6420	0.7715	0.6000	0.6712	5
14	0.1474	0.7070	0.5333	0.7723	0.4142	0.4839	0.5568	8
15	0.5577	0.8333	0.8889	0.4727	0.3750	0.3560	0.4012	16
16	1.0000	0.2037	0.4222	0.3333	0.7105	0.5422	0.5267	11

The experimental results were processed further with the requirements of grey relational analysis. The grey relational coefficient, grey relational grade and the rank of each experiment were found from Table 5 and the results too.

The GRG values offer a single representation for the three responses and a higher value of GRG is chosen. From Table 5, it is found that experiment number 11 has the highest grey relational grade of 0.8215. Therefore, parameter setting of experiment number 11 is likely to be optimal.

Fig.5. shows the main effect plot for S/N ratio of Ultimate Tensile Strength (UTS). The optimal welding parameters determined are A3B4C2 i.e. Arc voltage at 24V, Gas flow rate 10 l/min and wire feed rate at 350 IPM. Basically larger the S/N ratio is better the corresponding performance characteristics shown in fig. 5.

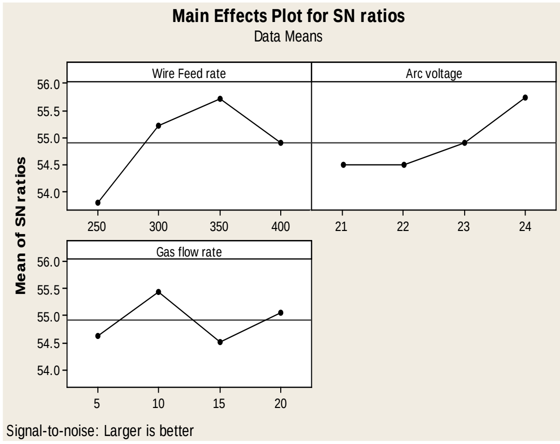


Fig.5. Main Effects Plot for SN ratios

Signals to Noise Ratios

Signal to noise ratio (S/N) is used to determine, which design of experiments significantly affect the quality characteristic. In this case for S/N ratio Larger is better considered.

Table.6. Response Table for Signal to Noise Ratios

Level	Wire feed speed	Voltage	Gas flow rate
1	53.79	54.49	54.63
2	55.22	54.49	55.45
3	55.73	54.92	54.51
4	54.90	55.74	55.06
Delta	1.94	1.25	0.94
Rank	1	2	3

ANOVA

Analysis of variance (ANOVA) is discovered by R.A. Fisher and it is referred as set of statistical models used to determine the difference between group means and their associated procedures. Purpose of ANOVA experimentation is to reduce and control the variation of a process. It is also used to test the quality of two or more population means by examining the variance of samples that are used.

Table.7 shows the ANOVA for UTS value. From table it is very clear that wire feed speed has most significant effect on UTS value where as arc voltage has least significant effect on UTS.

Table.7. ANOVA table for UTS

Source	DF	Seq.SS	Adj.SS	Adj.Ms	F-Value	P-Value	% Contribution
Wire feed speed	3	32272	32272	10757	15.59	0.003	62.71
Arc voltage	3	17812	17812	5937	1.75	0.257	7.031
Gas flow rate	3	8707	8707	2902	5.52	0.037	22.21
Error	6	22022	22022	3670			8.048
Total	15	80814					

Microstructural characterization

For microstructure examination of Weldment of AISI 304, the specimens were cuted from the Weldment and prepared for the microstructural characterization. The welded surface of the specimens for optical observation were polished on a disk polishing machine with the different grade of emery papers from 80 to 2000 micron for 10 min each and then chemically etched with Glyceregia and Swab up to 2 minutes. Hardness is measured by Vickers hardness (HV) tester with a constant load of 10 kg for 10 seconds. For microstructure optical microscope (Dewinter make, Itely) was used and for mode of fracture scanning electron microscope (SEM) were used. Few microstructures of weldment are also shown in fig. 6(a-d).

The microstructure of AISI 304 weldment consists of vermicular, lathy ferrite, and skeletal ferrite in the austenite matrix (Y.H. Kim et al, 2011, Lawrence O. OSOBA et al 2017 & Mirshekari, G.R et al 2014). δ- Ferrite transforms to austenite and then replaced by ferrite and carbide during cooling to the ambient temperature. In fig. 6 (a-d) dendrite structure of fusion zone which consist the skeletal ferrite has been distributed through matrix of austenite. The microstructure of HAZ normally finer than the parent metal (PM) microstructure and this lead resulting in the higher mechanical properties.

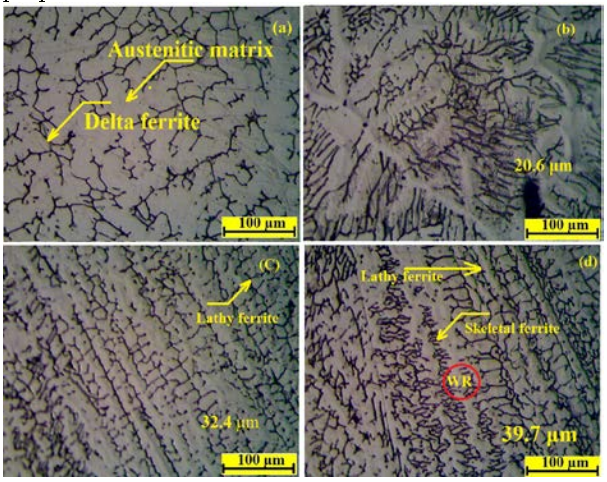
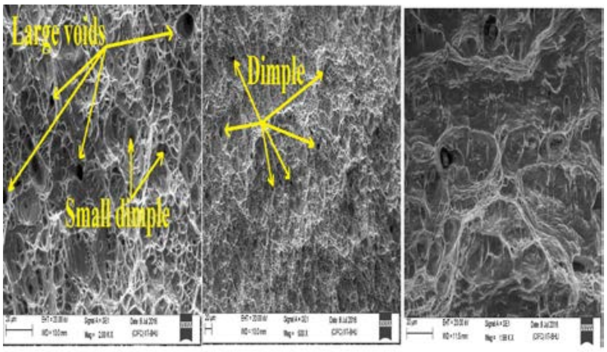


Fig.6.Microstructure of weld metal (skeletal delta ferrite in austenite matrix) in samples (a) no. 1, (b) no. 2, (c) no. 3, and (d) no. 4

Fractrography

Fig 7 (a), (b) & (c) depicts the Fractrographic studied of tensile test specimen, this studied were carried out by a SEM at room temperature. Figure 7 showed a dimpled pattern, which indicate that fracture is a ductile fracture with numerous dimples and it is also observed that there are some spherical particles with small and large dimensions are near at the bottom of dimples.

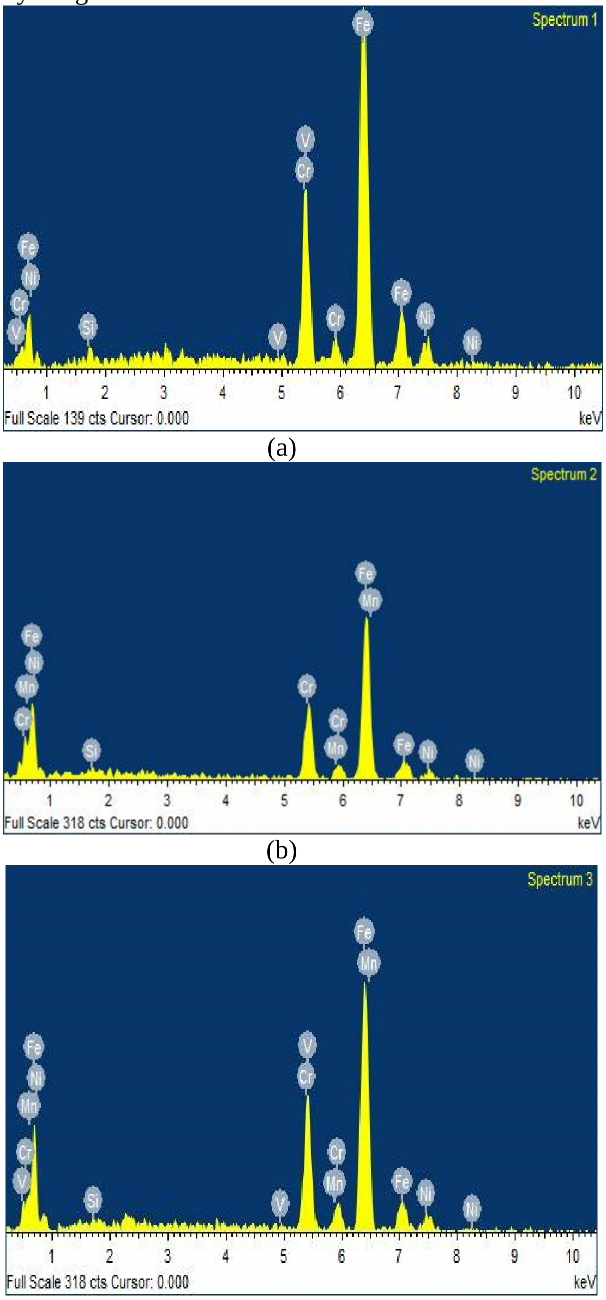


(a) (b) (C)

Fig.7. (a), (b) & (c) Fractography of a MIG welded joint after the tensile test at room temperature

Energy dispersive spectrometer (EDS)

Energy dispersive spectrometer (EDS) analysis was carried out of weldment test samples to determine micro inclusions generated in the Welded Joint. From fig.8. It is very clear from analysis that the HAZ of AISI 304 consisting the Fe, Ni, Cr and Mo as their main constitute. Whereas Mn, Nb and Si was found to be the lower quantity by weight.



(a)

(b)

(c)

Fig.8. Energy-dispersive spectroscopy (EDS) point analysis on the AISI 304 steel weldment

On the contrary, Al, S, and Si element rates are comparatively low. For commercial steels, the typical non-metallic inclusions are oxides, nitrides, and sulphides. Mn, S inclusions are effective in inducing AF formation.

INTERACTION CURVES

3-D fitting curves for voltage, impact strength, UTS, wire feed speed, hardness and gas flow rate is given below.

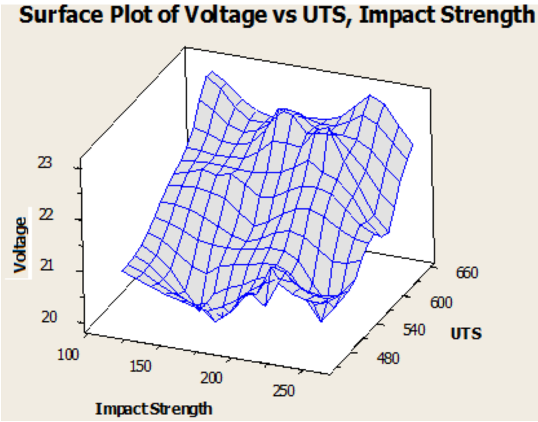


Fig.9. Interactive surface plot of Voltage versus IM and UTS

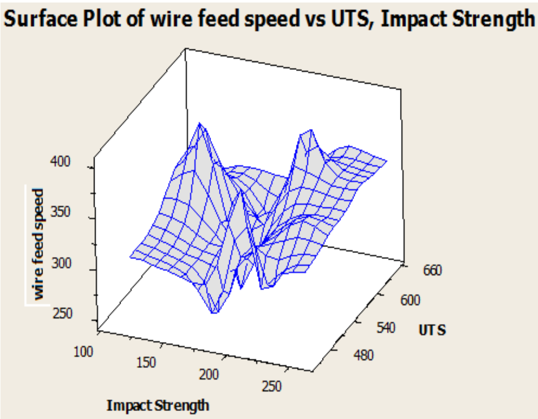


Fig.10. Interactive surface plot of WFR versus IS and UTS

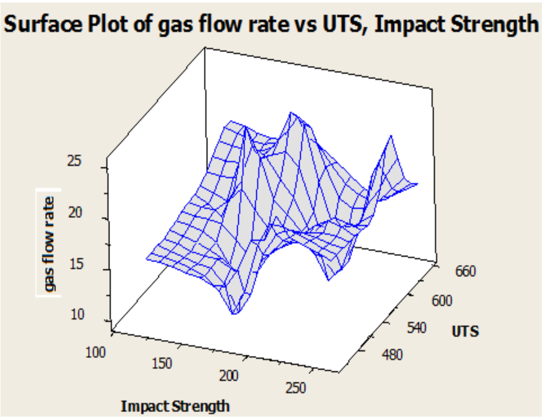


Fig.11. Interactive surface plot of GFR versus IM and UTS

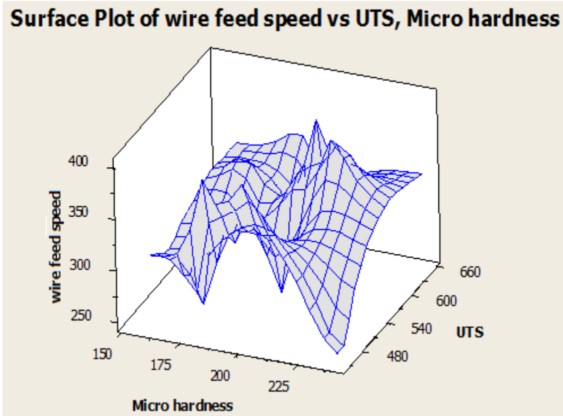


Fig.12. Interactive surface plot of WFS versus UTS and MH

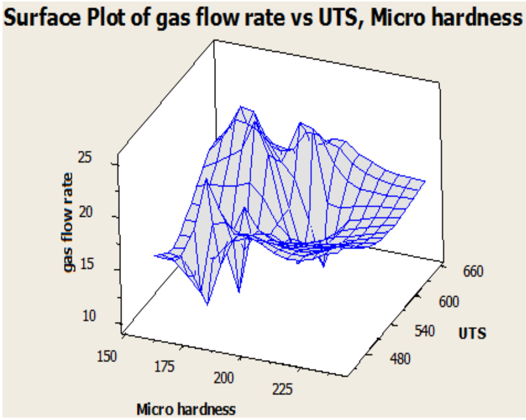


Fig.13. Interactive surface plot of GFR versus UTS and MH

CONCLUSIONS

The Grey relational analysis based on an orthogonal array of the Taguchi technique was away of optimizing the welding of AISI 304H. Based on the results and discussion the follows conclusions can be suggested:

1. Grey based Taguchi technique was successfully applied for optimization of the welding process parameters of AISI 304 steel weldment.
2. Optimization of the process parameters has been determined by using Grey based Taguchi methodology; optimum parametric combination has been examined. The optimal factor setting becomes **W3V4G2** (i.e. wire feed speed 350 IPM, arc voltage = 24V, and Gas flow rate = 10 l/min).
3. All weldment was necessary austenitic with the presence of few quantities of δ-ferrite.the ferrite was present in the form of lathy ferrite and skeletal ferrite with no precipitations in the weld.
4. from the SEM results. the presence of micro voids and dimples confirmed the ductile mode of fracture.
5. On increasing the gas flow rate, the weldments show the course grain whereas on decreasing the gas flow rate fine grain of microstructure is

formed.

6. From ANOVA table for UTS, it is clear that voltage has most significant effect on UTS value where as gas flow rate has least significant effect on UTS. The 3D surface plots are plotted considering the Taguchi design matrix by using software.

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