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Multi Objective Optimization by Application of Taguchi Based Grey Relational Analysis for GMA Welding of IS2062 Structural Steel

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Basic object of this research article was to investigate the parametric optimization of welding parameters such as arc voltage, wire feed speed and shielding gas flow rate for IS 2062 structural steel by integrating Taguchi method and Grey relational analysis. Experiments were conducted as per L_{16} ($4^{xx}3$) orthogonal array. Design and Mechanical properties such tensile strength, Microhardness, toughness, and Microstructure of IS 2062 structural steel optimized by Grey-based Taguchi analysis were investigated, as they were selected as quality targets. Based on result of the grey relational analysis, a set of optimum welding parameters was obtained. The observed data from result have been interpreted, discussed and analyzed by integration of Grey–Taguchi methodology to optimize tensile strength, microhardness and percentage elongation.

Keywords: structural steel, mechanical properties, Taguchi technique, Grey relational analysis, SEM.

1. Introduction

Now a day in modern manufacturing industries electric arc welding is a major joining process. Among the various types of electric arc welding, metal inert gas (MIG) welding is being increasingly used for joining wide variety of ferrous and non-ferrous materials in industries due to its inherent advantages such as high welding speed, deep penetration, high degree metal deposition rate, good quality weld bead, lower spatters, less probability of distortion and shrinkage, and lesser probability of porosity and fusion defects [1–2].Structural steel is widely used in industrial application due to its excellent weldability properties as well as good mechanical properties such as ultimate tensile strength and toughness[3] S. Srivastava and R. K. Garg [4] made an attempt to optimize the process parameters i,e wire feed speed,voltage,gas flow rate and travel speed by developing a mathematical models by using Response

Surface Methodology (RSM). B. K. Biswas et al [5] welded boiler quality steel by FCA welding process to optimize the process parameters by integrating RSM and Grey based Taguchi technique and authors informed that most influencing factor to mechanical properties are electrode wire feed rate, next is welding voltage followed by gas flow rate. P. Sathiya et al [6] welded super austenitic stainless steel 904L by GMA welding process to optimize the process via grey-based Taguchi method and they told that gray relational grade and using the recommendation of Taguchi experimental design for determining welding parameters are successful. N. Murugan and R. S. Parmar [7] used a four-factors 5-levels factorial technique to predict the weld bead geometry (penetration, width, reinforcement and % dilution) in the deposition of 316L stainless steel onto structural steel IS2062 using the MIG welding process. Saadat Ali Rizvi et al [8] optimize various welding process parameters by application of taguchi method on MIG welding during welding of IS2062 and authors mention in their result that welding current and welding voltage has significant effect whereas gas flow rate has insignificant effect on tensile strength of the weldment.S.K Sharma et al [9] optimized process parameter during the turning of AISI 8620 Steel Using Taguchi and Grey Taguchi Analysis and authors found in result that feed rate is the most significant factor for affecting the surface roughness and material removal rate together. Cutting speed and depth of cut is found to be insignificant effect from the ANOVA study. Different optimization technique used to optimize the data is given in Fig. 1, in this welding process Taguchi technique is coupled with grey relation analysis.

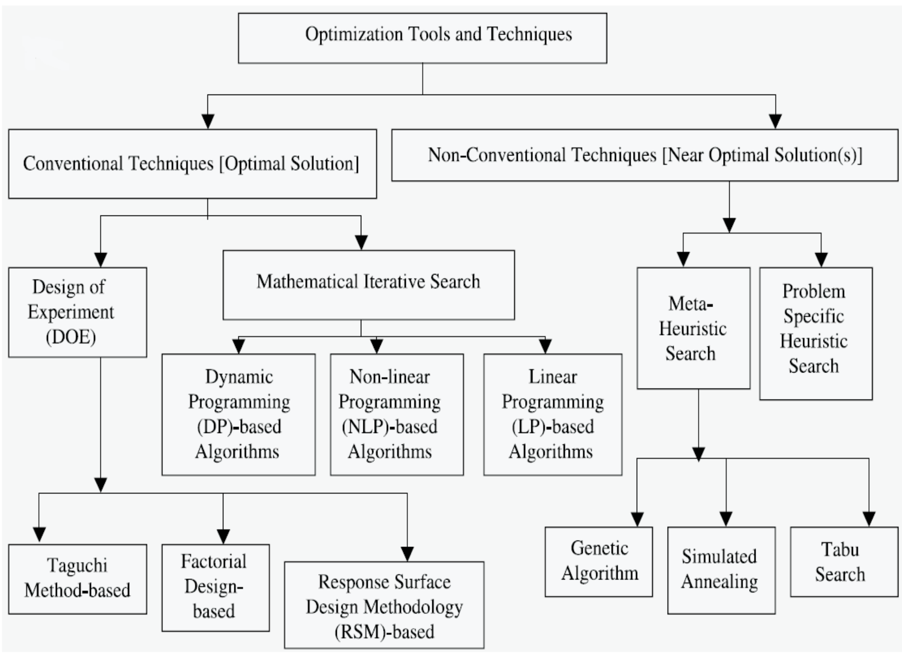

Figure 1 Classification optimization and modelling technique in welding problem [15]

2. Research

2.1. *Experimental work*

IS 2062 structural steel plates (300 mm x120 mm x10 mm) having V groove were used for butt welding at 2-5 mm gap conditions by MIG welding to get full penetration. A continuous copper coated wire was used as filler material with 75%Ar+25%CO_2 as shielding gas to produced consistent bead and proper strength of welded joint. Chemical composition of base material is given by Table 1. Taguchi based L_{16}

Table 1 Chemical composition of IS 2062 steel Grade A (weight percentage)

C	Mn	S	P	Si	Fe	C equivalent
0.22	1.5	0.049	0.050	0.37	rest	0.42

Orthogonal Array has been used to select four level three factors design matrix. Accordingly 16 numbers experiments have been performed. The process parameters and their levels are shown in Table 2. The experimental layout using L_{16} Orthogonal Array and their corresponding values of predefined coded and UN coded controllable parameters are shown in Table 2.

Table 2 Welding process parameters and their levels

Factors	Parameters	Level I	Level II	Level III	Level IV
A	Gas flow rate (l/min)	10	15	20	25
B	Arc Voltage (V)	25	26	27	28
C	Wire feed rate (IPM)	300	350	400	450

Fig. 2 shows the position of fracture in tensile test after tested on a UTM.

Figure 2 Fracture location of tensile specimen at room temperature

3. Grey relational analysis

3.1. *Data preprocessing*

Let the original reference sequence and sequence for comparison be represented as $x_i^0(k)$ and $x_i^0(k)$, $i = 1, 2, \ldots, m$; $k = 1,2, \ldots, n$, 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 [10–12]. With the meagre 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 [13–14]. 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:

$$X_i^*(k) = \frac{x_i^0(k) - \min x_i^0(k)}{\max x_i^0 - \min x_i^0(k)} \tag{1}$$

$X_i^*(k)$ represents the data sequence after pre-processing, $x_i^0(k)$ represents the original sequence, largest value of $x_i^0(k)$ is max $x_i^0(k)$, smallest value of $x_i^0(k)$ is min $x_i^0(k)$ imply the. Normalizing the data for lower-the-better condition is given as:

$$X_i^*(k) = \frac{\max x_i^0(k) - x_i^0(k)}{\max_i^0 - \min_i^0(k)} \tag{2}$$

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

$$X_i^*(k) = 1 - \frac{|x_i^0(k) - OB|}{\max\{\max x_i^0(k) - OB,\, OB - \min x_i^0(k)\}} \tag{3}$$

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, $x_i^0(1)$:

$$X_i^*(k) = \frac{x_i^0(k)}{x_i^0(1)} \tag{4}$$

Where $x_i^0(k)$ is the original sequence, $x_i^*(k)$ the sequence after the data preprocessing, $\max x_i^0(k)$ the largest value of $x_i^0(k)$, $\min x_i^0(k)$ the smallest value of $x_i^0(k)$.

3.2. *Grey relational coefficients and Grey relational grades*

After completing data preprocessing, in order to express a relationship between actual and ideal normalized values, a Grey relational coefficient is determined, as expressed in Eq. (5):

$$\zeta_i(k) = \frac{\Delta_{\min} + \zeta\Delta_{\min}}{\Delta_{0i}(k) + \zeta\Delta_{\max}} \tag{5}$$

Table 3 Experimental results for IS2062 structural steel

Exp. No.	Gas flow rate (L/min)	Voltage (V)	WFS (IPM)	UTS (MPa)	Impact strength (J)	Micro hardness
1	10	25	300	526	182	178
2	10	26	350	480	180	200
3	10	27	400	355	222	240
4	10	28	450	535	184	198
5	15	25	350	390	160	161
6	15	26	300	498	170	184
7	15	27	450	438	162	185
8	15	28	400	422	120	206
9	20	25	400	410	240	188
10	20	26	450	494	260	175
11	20	27	300	408	222	202
12	20	28	350	463	232	187
13	25	25	450	470	216	215
14	25	26	400	532	210	216
15	25	27	350	388	142	218
16	25	28	300	570	216	198

$\Delta_{oi}(k)$ represents the deviation sequence, which is calculated by:
$\Delta_{0i}(k) = ||X_0^*(k) - X_i^*(k)||$
$\Delta_{max}(k) = \frac{\max}{\forall j i \epsilon} \frac{\max}{\forall k} ||X_0^*(k) - X_i^*(k)||$
$\Delta_{min}(k) = \frac{\min}{\forall j i \epsilon} \frac{\min}{\forall k} ||X_0^*(k) - X_i^*(k)||$
ζ 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:

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

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.

4. Result and discussion

IS 2062 structural steel was welded as per L16 orthogonal array to determine the effect of different welding parameters, namely arc voltage, shielding gas flow rate, wire feed speed on the output response namely, toughness, ultimate tensile strength

(UTS) and Vickers hardness. In this experimental work an attempt has been made to find out the optimal set of welding parameters effetely and efficiently. The grey relational coefficient, grey relational grade and the rank of each experiment were found from Table 4 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 4, it is found that experiment number 15 has the highest grey relational grade of 0.7220. Therefore, parameter setting of experiment number 15 is likely to be optimal.

Table 4 Proposed data, GRC and GRG for IS 2062 structural steel

Exp. No	UTS MPa	Imp. str. J	VHN	Normalized			GRC			GRG	Rank
				UTS	Imp. str.	VHN	UTS	Imp. str.	VHN		
1	526	242	171	0.7953	0.8446	0.2820	0.3860	0.3718	0.6393	0.4657	3
2	480	258	199	0.5814	1.000	1.0000	0.4623	0.3333	0.3333	0.3763	13
3	355	222	181	0.000	0.6504	0.5384	1.0000	0.4346	0.4815	0.6387	10
4	535	246	180	0.8372	0.8834	0.5128	0.3739	0.3614	0.4936	0.4096	9
5	390	200	178	0.1630	0.4368	0.4615	0.7541	0.5337	0.5200	0.6026	8
6	498	155	189	0.6651	0.0000	0.7435	0.4291	1.0000	0.4020	0.6104	12
7	438	212	178	0.3860	0.5533	0.4615	0.5643	0.4746	0.5200	0.5196	7
8	422	198	172	0.3116	0.4174	0.3076	0.6160	0.5450	0.6191	0.5933	4
9	410	202	181	0.2558	0.4563	0.5384	0.6615	0.5228	0.4815	0.5552	10
10	494	208	166	0.6465	0.5145	0.1538	0.4361	0.4928	0.7647	0.5645	2
11	408	156	183	0.2465	0.0097	0.5897	0.6697	0.9809	0.4588	0.7031	11
12	463	190	175	0.5023	0.3398	0.3846	0.4988	0.5953	0.5652	0.5531	6
13	470	218	180	0.5348	0.6116	0.5128	0.4831	0.4498	0.4936	0.4755	9
14	532	200	166	0.8232	0.4368	0.1538	0.3787	0.5337	0.7647	0.5590	2
15	388	232	160	0.1534	0.7475	0.0000	0.7652	0.4008	1.0000	0.722	1
16	570	194	174	1.0000	0.3786	0.3589	0.3333	0.5690	0.5821	0.4948	5

With the help of Response graph for mean grey relational grade Fig. 3. The optimal welding parameters determined are A4B2C1 i,e Gas flow rate 25 l/min, Arc voltage at 26 V and wire feed rate at 300 ipm. Basically larger the S/N ratio is better the corresponding performance characteristics shown in Fig. 3.

Fig. 4 shows grey relation grade values from Table 4, for all 16 experiments run as per L16 orthogonal arrays and it is observed from Fig. 4 that change in the response when factors go from one level to other. It is also very clear from figure that experiment no 15 has the highest grey relation grade value. Therefore it is proved that all 16 run has optimal parameters setting for best multi response characteristics

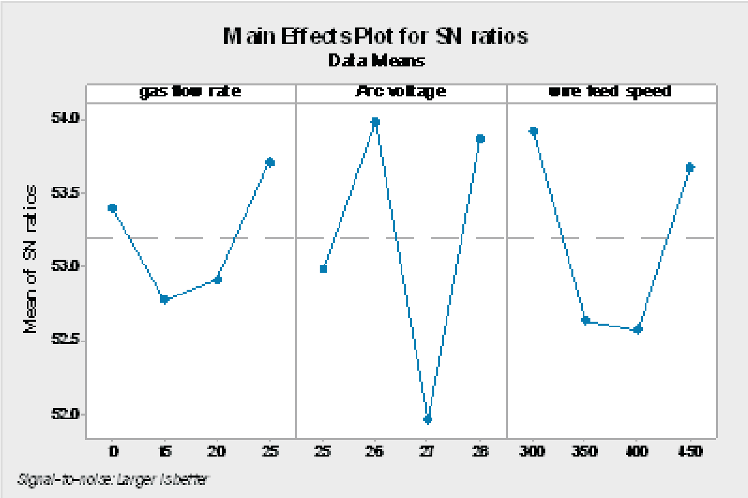

Figure 3 Main effect plot of Grey relation grade UTS

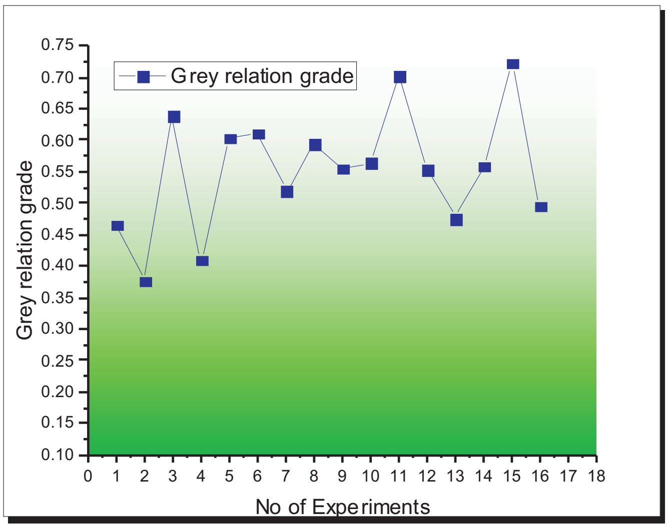

Figure 4 Grey relation grade for multi response

Each MIG welding parameter and their level value was calculated and response table for GRG is listed in Table 5. As GRG shows the level of correlation between comparability and reference, higher the GRG value means the comparability sequence represent a strong correlation with reference sequence. From Table 5 and Fig. 5 it is also observed that A3, B3 and C3 represent highest value of GRG. Hence A3, B3 and C3 are the optimal parameter condition for MIG welding.

Table 5 Response Table for grey relation grade

Symb.	Welding parameters	Level I	Level II	Level III	Level IV	Min-Max
A	Gas flow rate	0.4726	0.5815	0.5940	0.5628	0.1214
B	Arc voltage	0.5247	0.5276	0.6459	0.5127	0.1331
C	Wire feed speed	0.5685	0.5635	0.5866	0.4923	0.0943

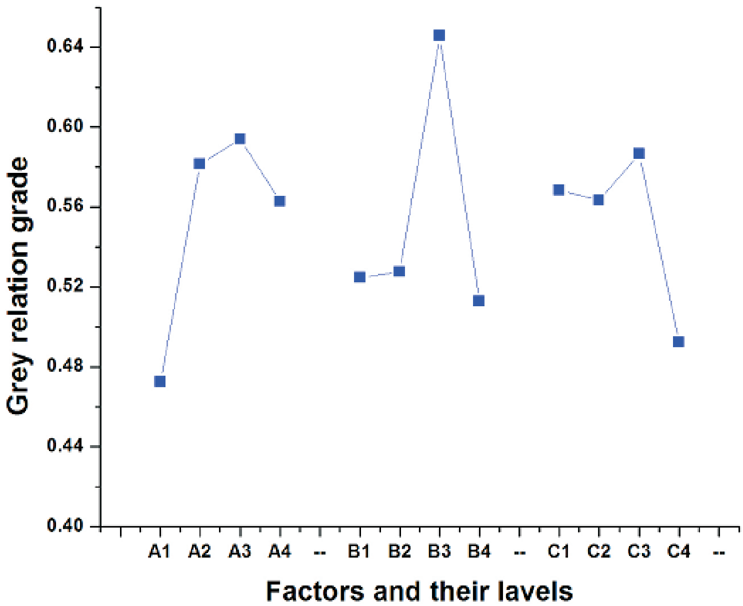

Figure 5 Effect of MIG Welding parameter levels on multi response

4.1. *ANOVA*

ANOVA is developed by R.A. Fisher and it is defined as collection of statistical models used to analyze 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 investigate which design parameters significantly affect the quality characteristic. To calculating ANOVA, statistical software namely Mini tab is employed to determine the significant effect of welding parameters on output paramerts. ANOVA is determined using GRG to analyze the importance of parameters. From ANOVA Table no 6 it is very clear that from UTS arc voltage (48.74%) has the most significant effect followed by wire feed speed (27.4%) and gas flow rate (12.86). ANOVA table shows that results are nearby related with grey relation method.

Table 6 ANOVA for response and GRD

Response	Parameter	DF	SS	Adj MS	F	P	% contribution
UTS	Gas flow rate	1	7534	2511	2.35	0.172	12.86
	Voltage	1	28561	9520	8.92	0.791	48.74
	Wire feed speed	1	16091	5364	5.02	0.755	27.4
	Error	12	6407	1068			11.0
	Total	15	58592				
Impact Strength	Gas flow rate	1	14664.7	488.2	6.01	0.031	66.44
	Voltage	1	932.8	310.9	0.38	0.770	4.22
	Wire feed speed	1	1590.8	530.3	0.65	0.610	7.23
	Error	12	4883.5	813.9			22.12
	Total	15	22071.7				
Micro hardness	Gas flow rate	1	2066.2	688.7	4.26	0.062	36.1
	Voltage	1	1383.7	461.2	2.85	0.127	24.16
	Wire feed speed	1	1307.2	435.7	2.7	0.139	22.83
	Error	12	969.9	161.6			17
	Total	15	5726.9				

DF – Degree of freedom, SS – Sum of squared deviation, MS – Mean squared deviation, F – Fisher's F ratio, P – Probability of significance

4.2. *Microstructure analysis*

Microstructure of few weldment samples is shown in Fig. 6a–i at different voltages. It is observed from figure that format of grain of all weldment samples are not uniform. As current increases, heat input increases and microstructure of weldment depends up on the cooling rate. On increasing current microstructure of weldment becomes coarser, coarse grain in microstructure depicts lower hardness and lower strength. Microstructure of weldment consisting pearlite and ferrite, no formation of martensite take place Fig. 6a constitute. HAZ constitute of grain refine zone Fig. 6b. As there is a constitute of pealite and ferrite, hence harness of weldment is lower. Ferrite is the most common constituent in plain carbon and low-alloy steels. Because ferrite contains very little carbon, it is very soft when compared with the other constituents.

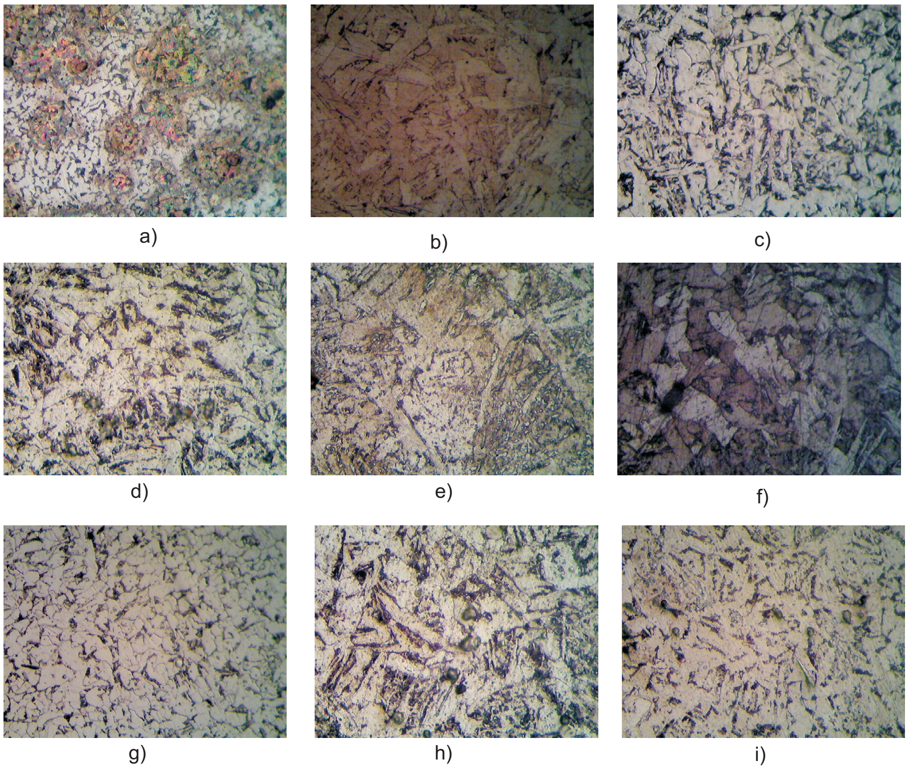

Figure 6 Microstracture of samples at different voltage

4.3. *Factrography analysis*

Impact test specimens of weldment were tested for mode of fracture with scan electron microscope (SEM) to analysis the type of fracture was occurred. Fracture are usually two types, i,e ductile fracture and brittle fracture. It is very important to when how ductile fracture occurred and when brittle fracture occurred. When fracture surface was examined reticulated dimpled was obtained. Such fracture Fig. 7a–b depicts ductile fracture. Fracture surface of weldment at high heat input Fig. 7c exhibit brittle fracture. From Fig. 7c it was observed that transgranular fracture by quasi-cleavage due to high heat input.

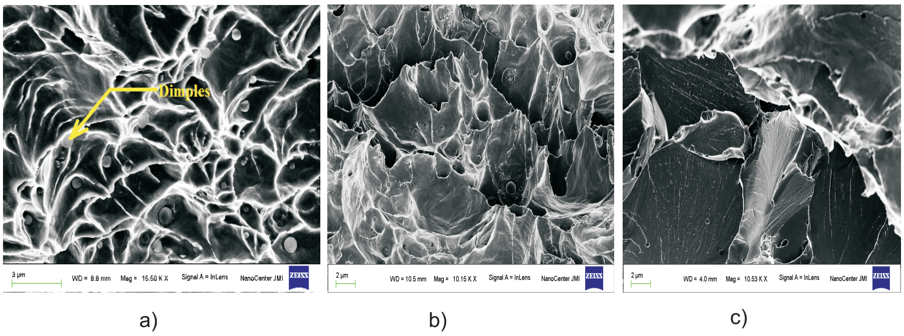

Figure 7 SEM images of fracture surface of samples under low, medium and high heat input

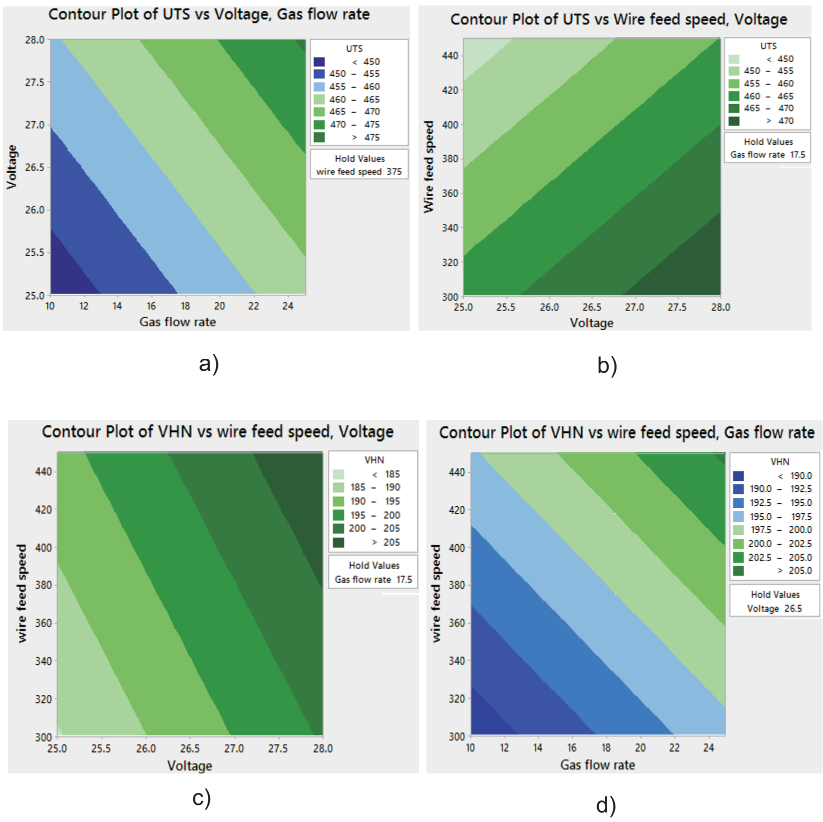

Figure 8 Contour plots (2D) between different welding parameters

4.4. *2D contour plots*

2D contour plots, plotted to consider Taguchi design matrix Fig. 8a shows contribution of Gas flow rate and voltage on UTS and toughness. Fig. 8a–b exhibit that how voltage (y) and gas flow rate (x) affect the UTS of welment. Whereas Fig. 8c–d exhibit effect of welding parameters i,e wire feed speed, voltage and gas flow rate affect the VHN of weldment.In counter plot it is very clear that dark green acquired area where value of UTS and VHN are highest. Whereas light green shades cover area where are less value of UTS and VHN.when parameter value increases, value of UTS and VHN increases.

5. Conclusion

In this research work, Taguchi L16 orthogonal array coupled with Grey relation analysis to optimized the multiple performance characteristic (MPC) such as UTS, toughness and micro hardness in the field of MIG welding process. Following conclusion are drawn from the result.

1. Optimal combination of MIG welding parameters and their level from optimum multiple performance characteristics of MIG welding process are A4B2C1 (i,e Gas flow rate 25 l/min, Arc voltage at 26 V and wire feed rate at 300 ipm) for UTS.
2. High heat input is responsible for coarse grain which are more pronounced in HAZ also responsible for low toughness
3. Based on ANOVA for multiple performance characteristics, gas flow rate having most significant effect, next is voltage followed by wire feed speed as welding process parameters on weld quality.
4. 2D contour plot was developed which are very help full to identify which input parameters are responsible to affect the output parameter.
5. Mechanical properties were correlated by metallurgical characterization.
6. SEM image of Toughness shows that on low heat input mode of fracture was ductile where as on high heat input image shows brittle fracture.

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