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OPTIMIZATION OF WELD BEAD GEOMETRY IN TIG WELDING PROCESS USING GREY RELATION ANALYSIS AND TAGUCHI METHOD

OPTIMIZACIJA GEOMETRIJE TIG-VARKOV Z GREYJEVO ANALIZO IN TAGUCHIJEVO METODO

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This study investigated the multi-response optimization of tungsten inert gas welding (TIG) welding process for an optimal parametric combination to yield favorable bead geometry of welded joints using the Grey relational analysis and Taguchi method. Sixteen experimental runs based on an orthogonal array of Taguchi method were performed to derive objective functions to be optimized within experimental domain. The objective functions have been selected in relation to parameters of TIG welding bead geometry; bead width, bead height, penetration, area of penetration as well as width of heat affected zone and tensile load. The Taguchi approach followed by Grey relational analysis to solve the multi-response optimization problem. The significance of the factors on overall quality characteristics of the weldment has also been evaluated quantitatively by the analysis of variance method (ANOVA). Optimal results have been verified through additional experiments. This shows application feasibility of the Grey relation analysis in combination with Taguchi technique for continuous improvement in product quality in manufacturing industry.

Keywords: TIG welding; Grey relation analysis; Tensile test

Predstavljeni so rezultati optimizacije odgovorov pri varjenju v inertni atmosferi z volframovo elektrodo (TIG) za dosego optimalne geometrije varka z uporabo analize po Greyju in Taguchijevi metodi. Šestnajst eksperimentalnih varkov je bilo nanesenih v ortogonalni razporeditvi po Taguchijevi metodi, da bi določili parametre, ki jih je treba ekspimentalno optimirati. Ti parametri, izbrani v povezavi s parametri TIG-varjenja, so: geometrija varka, širina varka, višina varka, penetracija, površina penetracije, širina toplotne zone in natezna obremenitev. Taguchijevemu približku je sledila Greyjeva racionalna analiza zaradi optimizacije več odgovorov pri problemu optimizacije. Pomen dejavnikov za karakteristike splošne kakovosti zvarov je kvantitativno ocenjen z analizo po meodi variance (ANOVA). Optimalne rezultate smo verificirali z dodatnimi poskusi. To kaže na možnost uporabe Greyjeve analize v kombinaciji s Taguchijevo tehniko za stalno rast kakovosti v predelovalni industriji.

Ključne besede: TIG-varjenje, Greyjeva analiza, natezni preizkus

1 INTRODUCTION

In today's manufacturing world, quality is of vital importance. Quality can be defined as the degree of customer's satisfaction as provided by the procured product. The product quality depends on the desired requirements gained in the product that suits its functional requirements in various areas of application.

In the field of welding, weld quality mainly depends on the mechanical properties of the weld metal and heat affected zone (HAZ), which in turn is influenced by metallurgical characteristics and chemical compositions of the weld.

Moreover, these mechanical-metallurgical features of the weldment depend on the weld bead geometry, which are directly related to welding process parameters. In other words, weld quality depends on welding process parameters [1].

Tungsten inert gas (TIG) welding is a multi-objective and multi-factor metal fabrication technique. Several process parameters interact in a complex manner resulting direct or indirect influence on weld bead geometry, mechanical properties and metallurgical features of the weldment as well as on the weld chemistry. Basically, TIG weld quality is strongly characterized by the weld bead geometry as shown in **Figure 1**.

Bead geometry variables; heat affected zone, bead width, bead height, penetration and area of penetration are greatly influenced by welding process parameters; welding speed, welding current, shielding gas flow rate and gap distance and also it plays an important role in

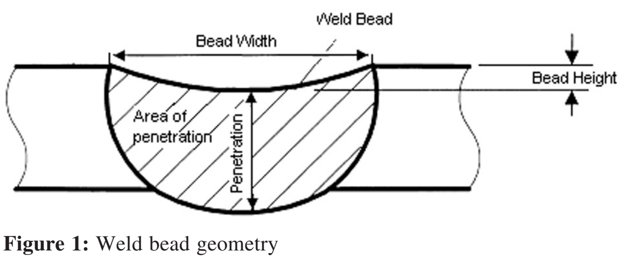

Figure 1: Weld bead geometry
Slika 1: Geometrija varka

determining the mechanical properties of the weld such as Tensile load.

It is necessary to find an optimal process condition capable of producing desired weld quality. However, this optimization should be performed in such a way that all the objectives should fulfill simultaneously. Such an optimization technique is called multi-response optimization.

Literature shows that work has been explored on various aspects of modeling, simulation and process optimization in TIG welding. In this study, detailed analysis has been made to establish relationships between welding parameters and weld bead geometry and weld quality leading to an optimal process.

Saurav Datta and et al. [1] developed a grey-based Taguchi method for multi-response optimization of bead geometry in submerged arc bead-on-plate welding process. Jackson and Shrubsall [2] performed optimization, neural networks and regression analysis in submerged arc welding process. Xie Yan-Min and et al. [3] used grey relational analysis for optimizing the square hole flanging process parameters with considerations of the multiple response characteristics. Lin and Lin [4] studied on the use of the grey-fuzzy logic based on orthogonal array for optimizing the electrical discharge machining process with multi-response characteristics. Murugan et al. [5], developed mathematical models using a five-level factorial technique to predict the weld bead geometry for depositing 316L stainless steel onto structural steel IS2062. Gunaraj and Murugan [6] determined the main and interaction effects of process control variables on important bead geometry parameters including bead volume quantitatively and represented the results graphically in submerged arc welding process.

The Taguchi method is very popular for solving optimization problems in the field of production engineering, Yang et al. [7], Rowlands et al. [8]. The method utilizes a well-balanced experimental design (allows a limited number of experimental runs) called orthogonal array design, and signal-to-noise ratio (S/N ratio), which serve the objective function to be optimized (maximized) within experimental domain. However, traditional Taguchi method cannot solve multi-objective optimization problem. To overcome this, the Taguchi method coupled with Grey relational analysis has a wide area of application in manufacturing processes. This approach can solve multi-response optimization problem simultaneously [1,9].

Planning the experiments through the Taguchi orthogonal array has been used quite successfully in process optimization by Chen and Chen [10], Fung and Kang [11], Tang et al. [12], Vijian and Arunachalam [13], Yang [14] as well as Zhang et al. [15]. Therefore, this study applied a Taguchi $L_{16}(4^4)$ orthogonal array to plan the experiments on TIG welding process. Four controlling factors including welding speed (V), welding current (I), shielding gas flow rate (F) and gap distance (G) with four levels for each factor were selected. The Grey relational analysis is then applied to examine how the welding process factors influence the bead geometry; bead width (BW), bead height (BH), penetration (P), area of penetration (AP) and heat affected zone (HAZ), as well as tensile load (TL). An optimal parameter combination was then obtained. Through analyzing the Grey relational grade matrix, the most influential factors for individual quality targets of TIG welding process can be identified. Additionally, the analysis of variance (ANOVA) was also utilized to examine the most significant factors for the bead geometry in TIG welding process.

2 GREY RELATIONAL ANALYSIS

2.1 Data Preprocessing

In Grey relational analysis, experimental data i.e., measured features of quality characteristics are first normalized ranging from zero to one. This process is known as Grey relational generation. Next, based on normalized experimental data, Grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Then overall Grey relational grade is determined by averaging the Grey relational coefficient corresponding to selected responses [1]. The overall performance characteristic of the multiple response process depends on the calculated Grey relational grade. This approach converts a multiple response process optimization problem into a single response optimization situation with the objective function is overall Grey relational grade. The optimal parametric combination is then evaluated which would result highest Grey relational grade. The optimal factor setting for maximizing overall Grey relational grade can be performed by Taguchi method [1].

In Grey relational generation, the normalized HAZ, BW and BH corresponding to the smaller-the-better (SB) criterion which can be expressed as:

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

TL, P and AP should follow the larger-the-better (LB) criterion, which can be expressed as:

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

where $x_i(k)$ is the value after the Grey relational generation, min $y_i(k)$ is the smallest value of $y_i(k)$ for the k^{th} response, and max $y_i(k)$ is the largest value of $y_i(k)$ for the k^{th} response. An ideal sequence is $x_0(k)$ (k = 1, 2, 3, ..., 16) for the responses. The definition of Grey relational grade in the course of Grey relational analysis is to reveal the degree of relation between the 16 sequences [$x_0(k)$ and $x_i(k)$, i = 1, 2, 3, ...,16]. The Grey relational coefficient $\xi_i(k)$ can be calculated as:

$$\xi_i(k) = \frac{\Delta_{\min} - \psi\Delta_{\max}}{\Delta_{0i}(k) + \psi\Delta_{\max}} \quad (3)$$

where $\Delta_{0i} = ||x_0(k) - x_i(k)||$ difference of the absolute value $x_0(k)$ and $x_i(k)$; ψ is the distinguishing coefficient $0 \le \psi \le 1$; $\Delta_{\min} = \forall j^{\min} \in i \forall k^{\min} ||x_0(k) - x_i(k)||$ = the smallest value of Δ_{0i}; and $\Delta_{\max} = \forall j^{\max} \in i \forall k^{\max} ||x_0(k) - x_i(k)||$ = largest value of Δ_{0i}. After averaging the Grey relational coefficients, the Grey relational grade γ_i can be computed as:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k) \quad (4)$$

where n is the number of process responses. The higher value of Grey relational grade corresponds to intense relational degree between the reference sequence $x_0(k)$ and the given sequence $x_i(k)$. The reference sequence $x_0(k)$ represents the best process sequence; therefore, higher Grey relational grade means that the corresponding parameter combination is closer to the optimal. The mean response for the Grey relational grade with its grand mean and the main effect plot of Grey relational grade are very important because optimal process condition can be evaluated from this plot [1].

3 EXPERIMENTAL PROCEDURE AND TEST RESULTS

3.1 Experimental Details

The experiments were conducted according to the design matrix at random order to avoid systematic errors infiltrating the system. Weld beads were laid on the joint to join 1.2 mm AISI 304 thin stainless steel plate with the dimensions of (25 × 240) mm. The chemical composition of the workpiece material is given in **Table 1**.

Table 1: Composition (%) of AISI 304 steel workpiece
Tabela 1: Sestava (%) vzorca jekla AISI 304

C	Mn	P	S	Si	Cr	Mo	Ni	Cu
0.08	2.00	0.04	0.030	1.00	19	0.20	10.5	0.02

Fronius Variostar WTU 305 type arc welding machine was used in the experiments. The specimens were joined using a single pass butt welding with AWS A 5.12-80 EW Th-2 thoriated tungsten electrode and pure argon (99.99 %) as shielding gas.

The experimental set up was designed and constructed to control the linear movement of the torch along the weld pad center line. The welded joints were sectioned to produce specimens for examining the quality parameters (BW, BH, P and AP) of weld bead shape in the welded specimens. These specimens were prepared by the usual metallurgical polishing methods and etched with Marble's etching reagent ($CuSO_4$ + HCl + H_2SO_4). Macrographs were then taken for each cross section using stereo microscope with 50X lens. In macro examinations of the specimens, Motic stereo microscope with image capture device mounted on top of the lens section of the microscope was used.

The weld bead profile was outlined by using Image-pro Plus 4.5 and NIH ImageJ software. The spatial calibrations were made on the macrographs before the measurement. The line drawings of the bead profiles were then used to take measurements on UW, UH, P, AP and HAZ.

Tensile load values were recorded from tensile testing of the specimens prepared in accordance with the EN 895 Standard. Tensile test specimens were taken from the weld bead according to the transverse tensile test method. Tensile test specimens were prepared in such a way that the weld zones were centered in the gage length. At the same time, heat affected zone was placed in the gage length perpendicular to the weld.

3.2 Process Parameters and Test Results

In full factorial design, the number of experimental runs exponentially increases as the number of factors as well as their level increases. This results huge experimentation cost and considerable time [1]. So, in order to compromise these two adverse factors and to search the optimal process condition through a limited number of experimental runs Taguchi's $L_{16}(4^4)$ orthogonal array consisting of 16 sets of data has been selected to optimize the multiple performance characteristics of TIG welding bead geometry.

Experiments have been conducted with the process parameters given in **Table 2**, to obtain butt welding on AISI 304 1.2 mm thickness stainless steel plate with 25 mm × 240 mm dimensions by TIG welding process.

Table 2: Process parameters and their limits
Tabela 2: Parametri procesov in njihove limite

Parameters	Notation	Unit	Levels of factors			
			1	2	3	4
Travel speed	*V*	mm/s	1.06*	1.99	2.31	3.55
Current	*I*	A	40*	55	70	85
Gas flow rate	*F*	L/min	8*	10	12	14
Gap distance	*G*	mm	1.5*	2	2.5	3

*Initial factor settings

Table 3 shows the selected design matrix based on Taguchi $L_{16}(4^4)$ orthogonal array consisting of 16 sets of coded conditions and the experimental results for the responses of TL, HAZ, BW, BH, P and AP. All these data have been utilized for analysis and evaluation of optimal parameter combination required to achieve desired quality weld in terms of bead geometry within the experimental domain.

Table 3: Orthogonal array $L_{16}(4^4)$ of the experimental runs and results
Tabela 3: Ortogonalna porazdelitev L_{16} (4^4) eksperimentalnih varkov in rezultatov

Run no	Process parameters				Experimental results					
	V	*I*	*F*	*G*	TL (N)	HAZ (mm)	BW (mm)	BH (mm)	P (mm)	AP (mm^2)
1	1	1	1	1	11429	5.255	7.383	0.185	1.098	7.809
2	1	2	2	2	11870	6.204	8.391	0.230	1.190	8.899
3	1	3	3	3	12047	7.077	9.253	0.265	1.258	9.848
4	1	4	4	4	11772	7.874	9.972	0.291	1.302	10.654
5	2	1	2	3	11576	3.985	6.840	0.114	1.060	6.948
6	2	2	1	4	12066	4.895	7.835	0.118	1.130	7.704
7	2	3	4	1	12213	5.344	7.840	0.162	1.213	8.078
8	2	4	3	2	12606	6.172	9.017	0.183	1.265	9.072
9	3	1	3	4	11282	3.649	6.432	0.112	1.006	6.453
10	3	2	4	3	11625	4.343	6.880	0.125	1.107	7.022
11	3	3	1	2	12508	5.157	8.115	0.126	1.195	7.970
12	3	4	2	1	12753	5.714	8.670	0.159	1.245	8.514
13	4	1	4	2	9270	2.931	4.459	0.096	0.887	4.695
14	4	2	3	1	10006	3.573	5.304	0.097	1.017	5.429
15	4	3	2	4	10281	4.405	6.201	0.107	1.039	6.033
16	4	4	1	3	10448	4.955	6.670	0.099	1.133	6.481

4 PARAMETRIC OPTIMIZATION OF TIG WELDING PROCESS

4.1 Evaluation of Optimal Process Condition

First, by using Eqs. (1) and (2), experimental data have been normalized to obtain Grey relational generation. The normalized data and Δ_{0i} for each of the responses of bead geometry as well as TL and HAZ have been furnished in **Table 4** and **Table 5** respectively. For TL, P and AP larger-the-better (LB) and for HAZ, BW, BH smaller-the-better (SB) criterion has been selected.

Table 4: Grey relational generation of each performance characteristics
Tabela 4: Generiranje Greyjeve odvisnosti za vsako značilno perfomanco

Run no	TL	P	AP	HAZ	BW	BH
	Larger-the-better			*Smaller-the-better*		
Ideal sequence	1	1	1	1	1	1
1	0.620	0.509	0.523	0.530	0.470	0.544
2	0.746	0.730	0.706	0.338	0.287	0.312
3	0.797	0.593	0.300	0.161	0.130	0.131
4	0.718	1.000	1.000	0.000	0.000	0.000
5	0.662	0.417	0.378	0.787	0.568	0.908
6	0.803	0.586	0.505	0.603	0.388	0.886
7	0.846	0.785	0.568	0.512	0.387	0.663
8	0.958	0.911	0.735	0.344	0.173	0.552
9	0.577	0.286	0.295	0.855	0.642	0.918
10	0.676	0.529	0.391	0.714	0.561	0.852
11	0.930	0.741	0.550	0.550	0.337	0.848
12	1.000	0.862	0.641	0.437	0.236	0.679
13	0.000	0.000	0.000	1.000	1.000	1.000
14	0.211	0.314	0.123	0.870	0.847	0.997
15	0.291	0.365	0.225	0.702	0.684	0.947
16	0.338	0.593	0.300	0.590	0.599	0.986

Table 5: Evaluation of Δ_{0i} for each of the responses
Tabela 5: Ocena Δ_{0i} za vsak odgovor

Run no	TL	P	AP	HAZ	BW	BH
Ideal sequence	1	1	1	1	1	1
1	0.380	0.491	0.477	0.470	0.530	0.456
2	0.254	0.270	0.294	0.662	0.713	0.688
3	0.203	0.407	0.700	0.839	0.870	0.869
4	0.282	0.000	0.000	1.000	1.000	1.000
5	0.338	0.583	0.622	0.213	0.432	0.092
6	0.197	0.414	0.495	0.397	0.612	0.114
7	0.154	0.215	0.432	0.488	0.613	0.337
8	0.042	0.089	0.265	0.656	0.827	0.448
9	0.423	0.714	0.705	0.145	0.358	0.082
10	0.324	0.471	0.609	0.286	0.439	0.148
11	0.070	0.259	0.450	0.450	0.663	0.152
12	0.000	0.138	0.359	0.563	0.764	0.321
13	1.000	1.000	1.000	0.000	0.000	0.000
14	0.789	0.686	0.877	0.130	0.153	0.003
15	0.709	0.635	0.775	0.298	0.316	0.053
16	0.662	0.407	0.700	0.410	0.401	0.014

Table 6 shows the calculated Grey relational coefficients (with ψ = 0 of each performance characteristic using Eq. (3).

Table 6: Grey relational coefficient of each performance characteristics (ψ = 0)
Tabela 6: Koeficient Greyjeve relacije za karakteristike vsake performance(ψ = 0)

Run no	TL	P	AP	HAZ	BW	BH
Ideal sequence	1	1	1	1	1	1
1	0.568	0.504	0.512	0.515	0.485	0.523
2	0.664	0.649	0.629	0.430	0.412	0.421
3	0.711	0.551	0.417	0.373	0.365	0.365
4	0.640	1.000	1.000	0.333	0.333	0.333
5	0.597	0.462	0.446	0.701	0.537	0.845
6	0.717	0.547	0.503	0.557	0.449	0.815
7	0.765	0.699	0.536	0.506	0.449	0.597
8	0.922	0.848	0.653	0.433	0.377	0.528
9	0.542	0.412	0.415	0.775	0.583	0.859
10	0.607	0.515	0.451	0.636	0.532	0.772
11	0.877	0.659	0.526	0.526	0.430	0.767
12	1.000	0.784	0.582	0.470	0.396	0.609
13	0.333	0.333	0.333	1.000	1.000	1.000
14	0.388	0.422	0.363	0.794	0.765	0.993
15	0.413	0.441	0.392	0.626	0.613	0.904
16	0.430	0.551	0.417	0.550	0.555	0.974

The Grey relational coefficients, given in **Table 7**, for each response have been accumulated by using Eq. (4) to evaluate Grey relational grade, which is the overall representative of all the features of weld quality. Thus, the multi-criteria optimization problem has been transformed into a single equivalent objective function optimization problem using the combination of Taguchi approach and Grey relational analyses. Higher is the value of Grey relational grade, the corresponding factor combination is said to be close to the optimal [1].

Table 7: Grey relational grade
Tabela 7: Razred Greyjeve relacije

Run no	Grey relational grade	Rank
1	0.5180	15
2	0.5342	14
3	0.4637	16
4	0.6066	6
5	0.5977	8
6	0.5980	7
7	0.5922	10
8	0.6268	4
9	0.5975	9
10	0.5855	11
11	0.6307	3
12	0.6402	2
13	0.6667	1
14	0.6208	5
15	0.5650	13
16	0.5794	12

Table 8 shows the S/N ratio based on the larger-the-better criterion for overall Grey relational grade calculated by using Eq. (5).

$$S/N = -10\lg\left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right] \qquad (5)$$

where n is the number of measurements, and y_i is the measured characteristic value.

Table 8: S/N ratio for overall Grey relational grade
Tabela 8: Razmerje S/N za splošno Grayjevo odvisnost

Run no	S/N
1	–5.71
2	–5.45
3	–6.68
4	–4.34
5	–4.47
6	–4.47
7	–4.55
8	–4.06
9	–4.47
10	–4.65
11	–4.00
12	–3.87
13	–3.52
14	–4.14
15	–4.96
16	–4.75

Table 9: Response table for the mean Grey relational grade
Tabela 9: Tabela odgovorov za povprečje odvisnosti Greyjevega razreda

Factors	Grey relational grade				
	Level 1	Level 2	Level 3	Level 4	Max-Min
V	0.53	0.60	0.61	0.61	0.08
I	0.59	0.58	0.56	0.61	0.05
F	0.58	0.58	0.58	0.61	0.03
G	0.59	0.61	0.56	0.59	0.05

Total mean Grey relational grade is 0.59.

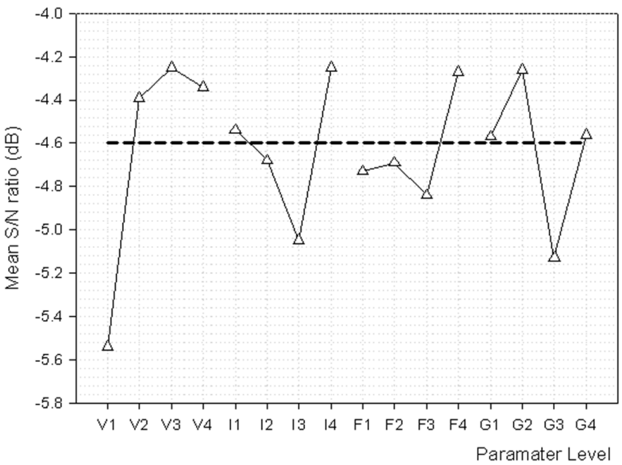

Figure 2: S/N ratio plot for the overall Grey relational grade
Slika 2: S/N odvisnost za splošno Greyjevo relacijo

Graphical representation of S/N ratio for overall Grey relational grade is shown in **Figure 2**. The dashed line is the value of the total mean of the S/N ratio.

As indicated in **Figure 2**, the optimal condition for 1.2 mm AISI 304 stainless steel becomes $V_3I_4F_4G_2$. **Table 9** shows the mean Grey relational grade ratio for each level of the process parameters.

4.2 Analysis of Variance (ANOVA)

The purpose of the analysis of variance (ANOVA) is to investigate which welding parameters significantly affect the performance characteristic. This is accomplished by separating the total variability of the grey relational grades, which is measured by the sum of the squared deviations from the total mean of the grey relational grade, into contributions by each welding parameters and the error. Thus;

$$SS_\mathrm{T} = SS_\mathrm{F} + SS_\mathrm{e} \tag{6}$$

where

$$SS_\mathrm{T} = \sum_{j=1}^{p} (\gamma_j - \gamma_\mathrm{m})^2 \tag{7}$$

and

SS_T Total sum of squared deviations about the mean
γ_j Mean response for j^{th} experiment
γ_m Grand mean of the response
p Number of experiments in the orthogonal array
SS_F Sum of squared deviations due to each factor
SS_e Sum of squared deviations due to error

In addition, the *F* test was used to determine which welding parameters have a significant effect on the performance characteristic. Usually, the change of the welding parameter has a significant effect on the performance characteristic when the *F* value is large. ANOVA for overall Grey relational grade is shown in **Table 10**.

Table 10: ANOVA results
Tabela 10: ANOVA-rezultati

Parameter	Degree of Freedom	Sum of Square	Mean Square	*F*	Contribution (%)
V	3	0.0180	0.006109	4.42	52.41
I	3	0.00529	0.001765	1.28	15.40
F	3	0.00312	0.001042	0.75	9.09
G	3	0.00691	0.002305	1.67	20.12
Error	3	0.00102	0.000346	-	2.97
Total	15	0.03434			100

Result of the ANOVA indicates that the welding speed (52.41 % contribution) is the most effective parameter on the responses under the multi criteria optimization (higher tensile load, penetration, area of penetration and lower heat affected zone, bead width, bead height). The percent contributions of other parameters are gap distance (20.12 %), current (15.40 %) and shielding gas flow rate (9.09 %).

4.3 Confirmation Test

After evaluating the optimal parameter settings, the next step is to predict and verify the enhancement of quality characteristics using the optimal parametric combination. The estimated Grey relational grade $\hat{\gamma}$ using the optimal level of the design parameters can be calculated as:

$$\hat{\gamma} = \gamma_\mathrm{m} + \sum_{i=1}^{o} (\bar{\gamma}_i - \gamma_\mathrm{m}) \tag{8}$$

where γ_m is the total mean Grey relational grade, $\bar{\gamma}_i$ is the mean Grey relational grade at the optimal level, and o is the number of the main design parameters that affect the quality characteristics. **Table 11** shows the comparison of the predicted bead geometry parameters as well as TL and HAZ with that of actual by using the optimal TIG welding conditions; good agreement between the actual and predicted results have been observed (improvement in overall Grey relational grade).

Table 11: Results of confirmation test
Tabela 11: Rezultati potrditvenega poskusa

	Initial factor settings	Optimal process condition	
		Prediction	Experiment
Factor levels	$V_1I_1F_1G_1$	$V_3I_4F_4G_2$	$V_3I_4F_4G_2$
TL	1165		1285
P	1.098		1.226
AP	7.809		8.518
HAZ	5.255		5.747
BW	7.383		8.569
BH	0.185		0.152
S/N ratio of overall Grey relational grade	–5.71	–3.14	–1.60
Overall Grey relational grade	0.52	0.69	0.83
Improvement in Grey relational grade is 0.31			

In Taguchi method, the only performance feature is the overall Grey relational grade; and the aim should be to search a parameter setting that can achieve highest overall Grey relational grade. The Grey relational grade is the representative of all individual performance characteristics. In this study, objective functions have been selected in relation to parameters of bead geometry as well as TL and HAZ; and all the responses have been given equal weight age. The results showed that using optimal parameter setting ($V_3I_4F_4G_2$) caused higher P, AP and TL.

5 CONCLUSION

Taguchi method is a very effective tool for process optimization under limited number of experimental runs. Essential requirements for all types of welding are deeper penetration with higher tensile load and lower heat affected zone, bead height and bead width for reducing weld metal consumption. This study has concentrated on the application of Taguchi method coupled with Grey relation analysis for solving multi criteria optimization problem in the field of tungsten inert gas welding process. Experimental results have shown that the tensile load, heat affected zone and penetration, area of penetration, heat affected zone, bead width and bead height of the weld bead in the TIG welding of stainless steel are greatly improved by using Grey relation analysis in combination with Taguchi method.

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