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Full Length Article

Multi-response optimization of process parameters for TIG welding of Incoloy 800HT by Taguchi grey relational analysis

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ABSTRACT

Incoloy 800HT which was selected as one of the prominent material for fourth generation power plant can exhibit appreciable strength, good resistance to corrosion and oxidation in high temperature environment. This study focuses on the multi-objective optimization using grey relational analysis for Incoloy 800HT welded with tungsten inert arc welding process with N82 filler wire of diameter 1.2 mm. The welding input parameters play a vital role in determining desired weld quality. The experiments were conducted according to L_9 orthogonal array. The input parameter chosen were the 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. The optimal parameters combination was determined as $A_2B_1C_2$ i.e. welding current at 110 A, voltage at 10 V and welding speed at 1.5 mm/s. ANOVA method was used to assess the significance of factors on the overall quality of the weldment. The output of the mechanical properties for best and least grey relational grade was validated by the metallurgical characteristics:

1. Introduction

Incoloy 800H is an austenitic iron-nickel-based super alloy that has good strength and appreciable resistance oxidation and carburization at high temperatures [1]. This alloy was selected as one of the prominent material for IV generation nuclear power plants. The superior mechanical property combines with resistance to high temperature corrosion and makes this alloy useful for many applications involving long-term exposure to elevated temperatures in corrosive atmospheres. Other applications of Incoloy 800H are super heater tubes in power generation units and in high temperature heat exchanger tubes in gas-cooled nuclear reactors [2]. TIG welding uses a non-consumable electrode and shielded by an inert gas like helium or argon to protect the molten weld pool and red hot filler wire from atmospheric contaminants. TIG welding is a multi-objective and multi-factor metal fabrication technique. This process can be used for joining a number of common metals such as steel, magnesium and aluminum of thickness 1-6 mm in almost all positions [3]. The process parameters interact directly or indirectly on the weld bead geometry, mechanical and metallurgical properties of the weldments. The quality of the weld joint has an essential dependence on the input process parameter [4]. The control of input process parameters was a common problem to manufacturer to obtain a good welded joint with the required weld quality [5]. Traditionally, skilled operators or engineers choose parameters based on trial and error method which was time consuming for every new welded product to obtain a welded joint with the required specifications. Then welds are examined to determine whether they meet the specification or not [6]. Nowadays, application of design of experiment (DoE), evolutionary algorithms and computational network are widely used to develop mathematical relationships between the welding process input parameters and the output variables of the weld joint in order to determine the welding input parameters that lead to the desired weld quality. Sapkal and Teslang [7] applied Taguchi method to optimize the process parameter current, voltage and welding speed to obtain maximum depth of penetration on mild steel. Patel and Chaudhary [8] investigated the effect of process parameter on the weld bead hardness of AISI 1020 material for TIG and MIG welding processes using GRA. Balasubramanian [9] obtained mathematical model equations for pulsed TIG welding of titanium sheets and concluded that the mathematical relationships developed can be employed easily in automated welding in the form of a program, for obtaining the desired weld bead dimensions. Haragopal et al. [10] optimized the process parameters for enhancing the mechanical properties of MIG welded aluminum alloy joints. The

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Table 1
Chemical composition of the base metal.

C	Mn	S	Si	Cu	Cr	Fe	Al	Ti	Ni
0.065	0.688	<0.010	0.094	0.091	20.79	46.30	0.477	0.380	30.65

experiments was conducted according to l9 orthogonal array. It was concluded that current was the most significant factor on ultimate tensile strength and pressure for impact energy. Sathish et al. [11] optimized the TIG welding parameters for dissimilar pipe joints using Taguchi method. They concluded that higher heat input resulted in lower tensile strength. Padmanabhan et al. [12] optimized the pulsed TIG parameters in using GRA to obtain maximum tensile strength on AZ31B magnesium alloy. Aydin et al. [13] studied optimization of friction stir welding process for an optimal parametric combination to yield favorable tensile strength and elongation using the Taguchi based Grey relational analysis. Sathiya et al. [14] optimized the friction welding process parameter of Incoloy 800H joints using artificial neural network and concluded that the low heating pressure, upsetting time and high upsetting pressure, heating time to obtain sound quality joint. From the above literatures, it is clear only a few works have been carried out in optimization and characterization of Incoloy 800HT. It was also clear that GRA can be used to optimize the TIG welding process parameter to obtain the desired quality weldments. In this work, multi-objective optimization using GRA has been carried out to optimize the TIG welding process parameter (welding speed, current and voltage). The output response was tensile strength and yield strength (room temperature, $75^0 0$ C) and impact toughness. By analyzing the grey relational grade, the most influential factor was determined. ANOVA method was applied to find the effect of individual factors. Further, the best and least grey grade obtained experiments mechanical properties were validated by their metallurgical features like micro structure and SEM fractography.

2. Experimental procedure

Incoloy 800HT plates of dimension 150 × 100 × 4 mm was butt welded using Lincoln TIG machine, with Polarity Direct Current Electrode Negative [DCEN]. The chemical composition of the base material is given in Table 1. The input process parameters used for welding were the welding current, voltage and welding speed. Argon was used as the shielding gas at the flow rate of 15 lpm. Several trials were carried out to select the upper and lower levels of the process parameter. Taguchi L9 orthogonal array was selected, and the experiments were carried out accordingly. The process parameter and their levels are given in Table 2. The objective function chosen were the ultimate tensile strength and yield strength (room temperature, 750 °C) and impact toughness. The tensile test and hot tensile test were carried out according to ASME SEC IX standard. The impact test was carried out according to ASTM E23-04 guidelines. The measured values are presented in Table 3. The welded specimens were cut in the weld cross section and were polished with different grades of emery sheet followed by alumina polishing and diamond polishing to get 0.05 µm finish. The etchant used for revealing the micrograph of the joint was 15 ml HCL+10 ml HAC+10 ml HNO_3. Metallographic analyses like microstructure and SEM fractographic analysis were done to find the characteristics of the weldments.

Table 2
Control factors and levels.

Factor	Unit	Level 1	Level 2	Level 3
Welding Current	A	90	110	130
Voltage	V	10	12	14
Welding Speed	mm/s	1.2	1.5	1.8

Table 4
Calculated S–N ratio.

Exp. no.	UTS [R.T]	Y.S [R.T]	UTS [750 °C]	Y.S [750 °C]	Toughness
1	55.76818	52.20426	55.33331	51.82552	34.64788
2	55.81794	52.1446	55.43248	51.9086	35.56303
3	55.44834	52.91493	55.12527	51.0609	34.96376
4	55.95961	52.59655	55.51425	52.11278	35.56303
5	55.46446	51.92974	55.28771	52.11386	34.96376
6	55.74638	52.05118	55.28472	51.84176	35.26856
7	55.45391	52.11967	55.10942	51.21391	34.32007
8	55.08911	51.91433	54.71326	50.55775	34.48552
9	55.39006	51.74569	55.04297	51.14461	34.32007

Table 5
Sequences of each performance characteristic after data processing.

Exp. no	UTS [R.T]	Y.S [R.T]	UTS [750 °C]	Y.S [750 °C]	Toughness
1	0.78009	0.392195	0.774111	0.814708	0.263732
2	0.83726	0.341169	0.897923	0.868097	1
3	0.412675	1	0.514375	0.323341	0.517872
4	1	0.727704	1	0.999308	1
5	0.431194	0.157415	0.717176	1	0.517872
6	0.755046	0.261278	0.713444	0.825141	0.763093
7	0.419077	0.31985	0.494589	0.421668	0
8	0	0.144235	0	0	0.13311
9	0.345721	0	0.41163	0.377132	0

3. Grey relational analysis (GRA)

The transformation of S–N ratio values from the original response values was the initial step. For that the equation (1) of 'larger the better' was used. Subsequent analysis was carried out on the basis of these S/N ratio values. This is shown in Table 4.

Table 3
Experimental layout using L_9 orthogonal array and performance result.

Exp. no.	Welding current (A)	Voltage (V)	Welding speed (mm/s)	UTS [R.T (MPa)	Y.S [R.T] (MPa)	UTS [750 °C] (MPa)	Y.S [750 °C] (MPa)	Toughness (J)
1	90	10	1.2	614.34	407.58	584.34	390.19	54
2	90	12	1.5	617.87	404.79	591.05	393.94	60
3	90	14	1.8	592.13	442.33	570.51	357.31	56
4	110	10	1.5	628.07	426.41	596.64	403.31	60
5	110	12	1.8	593.23	394.9	581.28	403.36	56
6	110	14	1.2	612.8	400.46	581.08	390.92	58
7	130	10	1.8	592.51	403.63	569.47	363.66	52
8	130	12	1.2	568.14	394.2	544.08	337.2	53
9	130	14	1.5	588.17	386.62	565.13	360.77	52