Chapter 17
Study of Impact Strength in TIG Welding of Incoloy-800 Super Alloy: An Experimental Investigation and Optimization

Himanshu Bisht, Ravi Pratap Singh, and Varun Sharma

Abstract Super alloys are well known for their superior and versatile properties, especially high strength at high temperature, highly resistant to surface degradation like corrosion and oxidation, high toughness, creep resistant, etc. The present article has been targeted to experimentally investigate the impact strength in TIG welding of Incoloy-800 super alloy under the varying parametric conditions of several welding variables. Taguchi's approach has been employed to design the experiments by selecting L9 orthogonal array. The welding speed, welding current, and the gas flow rate have been considered as the numerous process factors; however, impact strength of the welded joint is studied as the welding response. The variance analysis has also been performed to reveal out the significant process factors. The optimization of the impact strength has also been conducted using Taguchi approach. An optimum combination for sound weld joint has been determined to be welding current of 120A, welding speed of 8 mm/s, and gas flow rate of 18Lpm, i.e., A2B2C3.

Keywords TIG welding · Super alloy · Incoloy-800 · Optimization · Taguchi OAs

Nomenclature

OA	Orthogonal array
WS	Welding speed
GFR	Gas flow rate
TIG	Tungsten inert gas
ANOVA	Analysis of variance

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17.1 Introduction

Super alloys, as the name suggests, these are the alloys having superior properties. Super alloys are iron-base, cobalt-base, nickel-base, or a blend of nickel, iron, or cobalt. Other metals like chromium, iron, cobalt, tungsten, molybdenum, aluminum, titanium, tantalum, niobium, etc., are added in small quantity to further enhance their properties [1]. Super alloys have been widely used in industries due to their advanced properties. Super alloys have superior strength at elevated temperature, highly resistant to surface degradation like corrosion and oxidation, high toughness, and creep resistant [2].

There are numerous uses of such alloys, such as in—(a) steam turbine power plant, e.g., turbine blades, reheaters, etc.; (b) nuclear power plants, e.g., springs, control rod mechanisms, ducting, valve stems, etc.; (c) aerospace industry, e.g., gas turbine blades, vanes, combustion chambers, bolts, etc.; (d) automobile industry, e.g. exhaust valves, turbocharger, hot plugs, etc.; (e) chemical and petrochemical plants, e.g., bolts, valves, reaction vessels, piping, pumps, etc.; (f) heat processing apparatus, e.g., trays, fixtures, conveyor belts, etc.; (g) processing of metals, e.g., casting dies, hot-process tools, dies, etc.; (h) medical apparatus components, e.g., prosthetic equipment, dentistry, etc. [2].

Incoloy-800 also known as Incoloy-800 super alloy is an iron-nickel-chromium alloy which is highly resistant to oxidation and carburization in high temperature exposure beacause of its superior properties. Gas tungsten arc (TIG) welding is an arc-based welding process in which a joint is produced by an arc between a workpiece and a non-consumable tungsten electrode [3]. For sound welding, the welding zone should be protected from atmospheric gases contamination, for that purpose argon or helium is used as shielding gases. TIG welding can be performed with or without filler material. When filler material is needed, it is added separately to the weld pool. Since the electrode is non-consumable, TIG welding is generally used with direct current electrode negative (DCEN) in which heat is distributed approximately two-third at the workpiece and one-third at the tungsten electrode. Materials like aluminum are prone to oxide layer formation while welded by AC TIG welding [4, 5].

The reasoning and explanations for surface roughness behavior have also been elaborated in several advanced machining-based studies [6–8]. Srirangan and Paulraj [9] employed TIG welding on Incoloy-800HT super alloy and optimization of process parameters using Taguchi gray relation analysis. The process parameters were voltage, welding speed, and welding current. The responses measured were impact toughness, ultimate tensile strength, and yield strength. To optimize output responses, Taguchi L9 array with gray relational analysis was used. It was found that for quality weld joints, voltage of 12 V, 110 A of welding current, and 1.5 mm/s of welding speed is an optimum combination. Based on ANOVA results, it was found that welding current is the chief factor which influences output responses (58%) followed by welding speed (30%) and voltage (12%). Fractography analysis was done by SEM to investigate the type of fracture. It was observed that for high voltage and high current, mixed brittle and ductile fracture occurred, and for medium voltage and current, ductile fracture occurred. Microstructural analysis showed that for higher current, harder dendrites were formed, and at low current, fine cellular structure were formed [9]. Wang et al. [10] have studied the reliance of tensile properties, morphology, microstructure, and the fracture of welds of nickel-base super alloys on the variables of TIG welding, such as welding speed, welding current, impulse frequency, grooves, and weld re-melting index. TIG welding is used to process butt weld of nickel-base super alloy grade GH99 plated with equal thickness. Samples for metallographic observations were focused at three positions, the arc striking end, the arc retreating end, and middle part.

Gas tungsten arc (TIG) welding is an arc-based joining process in which an arc is produced between a workpiece and a non-consumable tungsten electrode. It is generally used with shielding gases like argon and helium to protect weld pool from atmospheric contamination. The small intense arc provided by the pointed electrode is ideal for high quality and precision welding. Because the electrode is not consumed during welding, the welder does not have to balance the heat input from the arc as the metal is deposited from the melting electrode. When filler material is needed, it is added separately to the weld pool. Since the electrode is non-consumable, TIG welding is generally used with direct current electrode negative (DCEN) in which heat is distributed approximately two-third at the workpiece and one-third at the tungsten electrode. TIG is used with AC when materials have oxide film problem like in aluminum. Figure 17.1 shows the classification of super alloys, Fig. 17.2 shows the classification of welding, and Fig. 17.3 shows a schematic diagram of TIG welding.

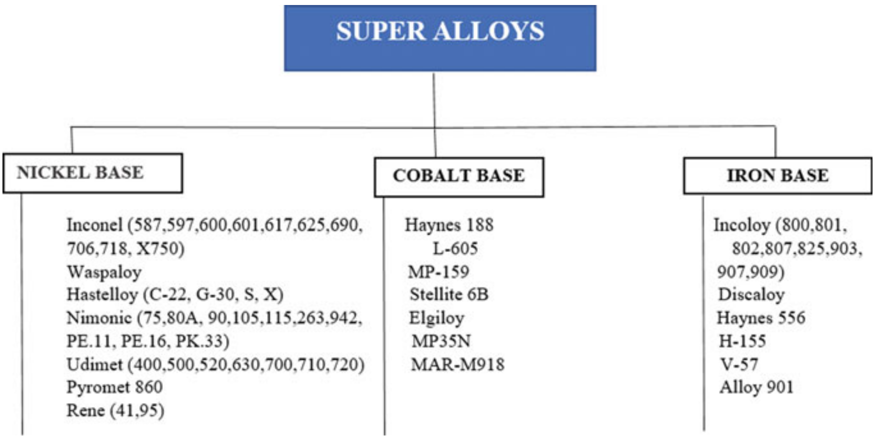

Fig. 17.1 Classification of super alloys

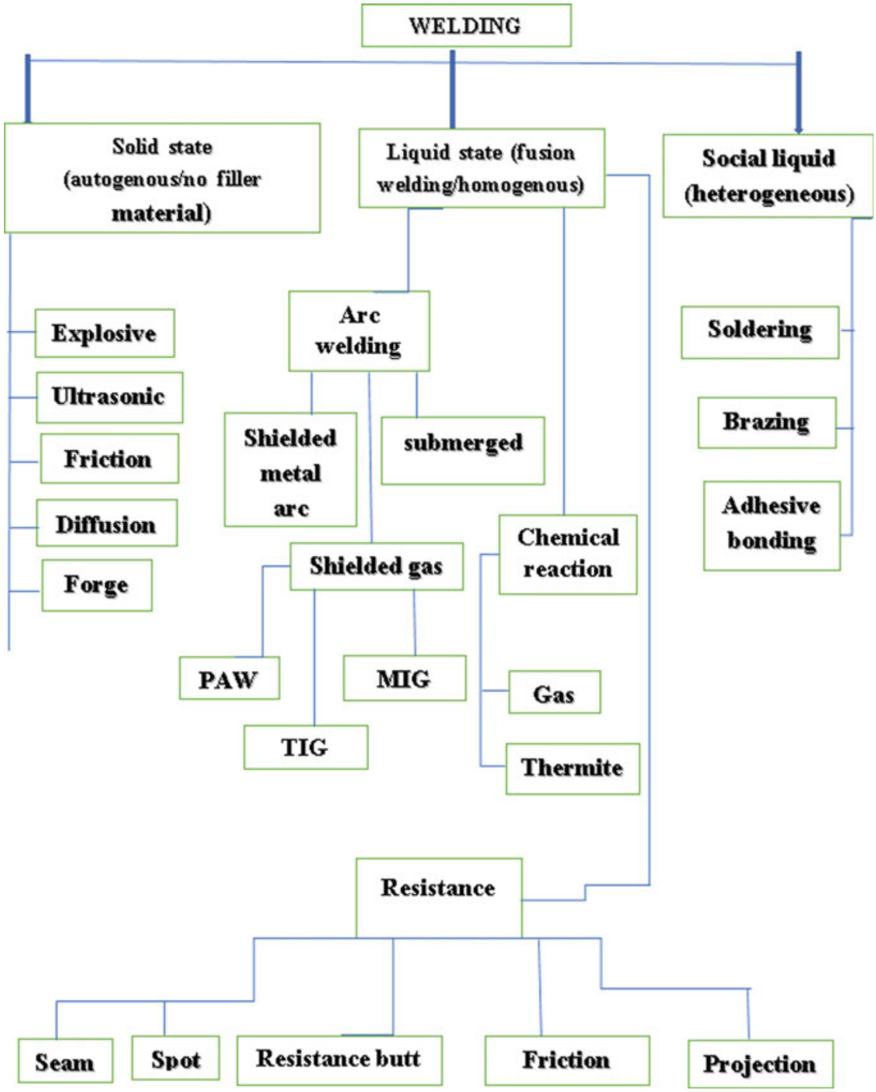

Fig. 17.2 Classification of welding

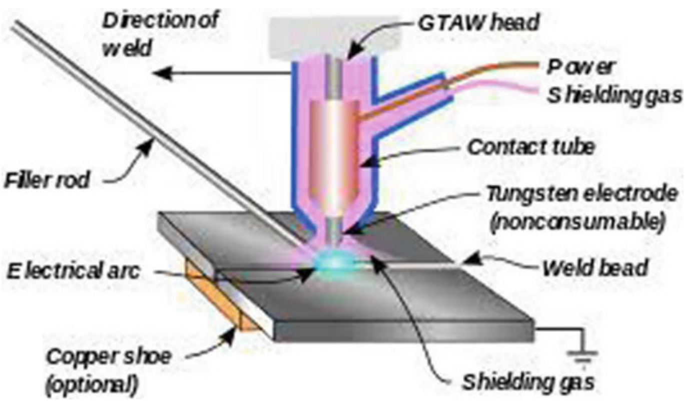

Fig. 17.3 Tungsten inert gas welding

17.2 Experimentation

17.2.1 Material and Method

Incoloy-800 is a nickel-iron-chromium alloy having sufficient resistance to oxidation and carburization at high temperatures and also a good chloride stress corrosion cracking resistant. With such superior properties, Incoloy-800 is widely used in furnace components, ammonia effluent coolers, heat exchangers, carburizing fixtures, etc. Incoloy-800H and Incoloy-800HT are identical to Incoloy-800 except for increased level of carbon percentage in Incoloy-800H and the addition of up to 1.2% titanium and aluminum in Incoloy-800HT. The increased content of carbon in Incoloy-800H helps to control grain size to optimize stress rupture properties. To ensure optimum high temperature properties, there is further addition of titanium and aluminum in Incoloy-800HT [9].

Incoloy-800 plates of 100 × 50 × 5 mm dimension were butt welded using Sunson WSE-315P TIG welding machine using direct current straight polarity (DCSP) or direct current electrode negative (DCEN). The chemical composition of the selected material is given in Table 17.1. The input process parameters were the welding speed, gas flow rate, and welding current. Argon was chosen as the shielding gas for sound welding. Several pilot tests had been performed to select the lower and upper levels of the input process parameters. The experiments were carried out according to Taguchi L9 orthogonal array [8]. Several welding responses such as tensile strength, yield strength, elongation, and impact toughness were measured under varied input process parameters. Figure 17.4 shows Incoloy-800 plates, Fig. 17.5 shows TIG

Table 17.1 Chemical composition of Incoloy-800

Fe	Cr	Ni	C	Mn	Si	Cu	Al	Ti	S
39.5 min	19–23	30–35	0.10 max	1.50 max	1.00 max	0.075 max	0.15–0.60	0.15–0.60	0.015 max

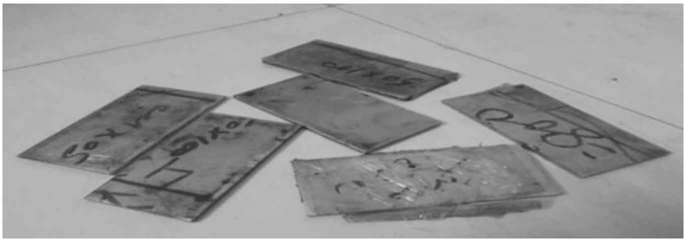

Fig. 17.4 Incoloy-800 plates

Fig. 17.5 TIG welding process

welding process, Fig. 17.6 shows TIG welding setup, Fig. 17.7 shows the samples (55 × 10 × 5 mm) for impact test, and Fig. 17.8 shows impact test setup.

Taguchi Method

Taguchi method is a statistical method developed by Taguchi. Success in attaining the required outcomes requires careful selection of process parameters. Selection

Fig. 17.6 TIG welding setup

Fig. 17.7 Samples for impact test

Fig. 17.8 Impact testing setup

of control variables must be produced to nullify the impact of noise variables [11–15]. Taguchi method includes identifying appropriate control variables to achieve the process's optimum outcomes. The full factorial design needs a big amount of experiments to be performed as mentioned above. If the number of factors increases, it becomes laborious and complicated. To overcome this problem, Taguchi suggested a specially designed method called the use of orthogonal array to study the entire parameter space with lesser number of experiments to be conducted.

Orthogonal arrays (OA) are used to perform a number of tests. The findings of these researches are used to assess the data and to predict the quality of the produced components. Taguchi therefore proposes using the loss function to assess the performance features that deviate from the required target value [14, 16–18]. The value of this loss function is further converted into the signal-to-noise ratio (S/N). The signal-to-noise ratio measures how the response varies relative to the nominal or target value under different noise conditions. One can choose from different signal-to-noise ratios, depending on the goal of the experiments conducted. Usually, there are three categories of the performance characteristics to analyze the S/N ratio. They are nominal-the-best, larger-the-better, and smaller-the-better [17–20].

Table 17.2 Factors and levels

Factor	Unit	Level 1	Level 2	Level 2
Welding current	A	100	120	140
Gas flow rate	L/min	10	14	18
Welding speed	mm/s	6	8	10

Table 17.3 Design of experiment table

S. No.	Welding current	Welding speed	Gas flow rate
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Using Minitab software, Taguchi method can be applied on the study. For that purpose, firstly level of design and number of factors are selected in Table 17.2. Then, a number of controls are to be selected, and their values are to be provided. Based on these input data, a Taguchi design table is created as shown in Table 17.3. This design table is a well-planned set of process parameters which helps in executing our study accurately. Then, experimentation process is conducted according to that design table, and respective results are calculated and given in Table 17.4. Now, the obtained result is to be analyzed. For analyzing the required graphs and options for which response table required is selected. Then response is selected for which main effect plots and probability plot is required. The software will analyze the results and shows the selected graphs to show the variation of output response with input process parameters as given in Table 17.5.

17.3 Results and Discussions

TIG welding was employed on Incoloy-800 according to L9 orthogonal array to examine the influence of input process parameters such as welding speed, welding current, and gas flow rate on the output response such as impact toughness. An experimental study was performed to find the best possible combination for sound TIG welding of Incoloy-800 super alloy. Figure 17.9 represents the main effects plot for means and SN ratio of output response for impact strength of Incoloy-800 weld

Table 17.4 Experimental results

S. No.	Welding current (A)	Welding speed (Mm/S)	Gas flow rate (Lpm)	Mean impact strength (J)
1	100	6	10	6.75
2	100	8	14	15.5
3	100	10	18	29.00
4	120	6	14	21.00
5	120	8	18	30.00
6	120	10	10	7.25
7	140	6	18	10.75
8	140	8	10	5.25
9	140	10	14	7.50

Table 17.5 Analysis of variance for SN ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P
WC	2	91.316	91.316	45.658	7.11	0.123
WS	2	3.203	3.203	1.601	0.25	0.800
GFR	2	175.349	175.349	87.675	13.65	0.068
Residual error	2	12.843	12.843	6.421		
Total	8	282.711	91.316	45.658	7.11	0.123

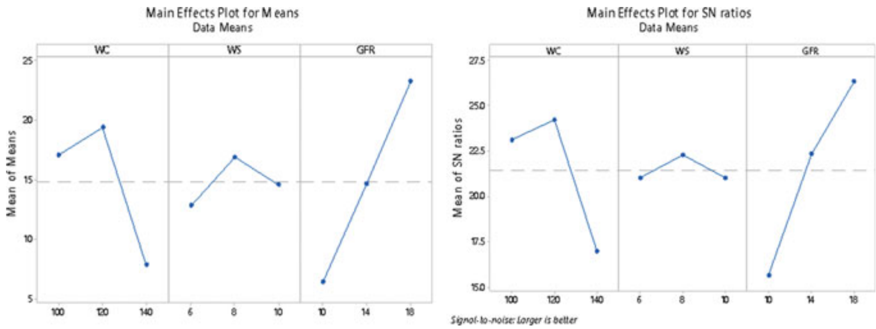

Fig. 17.9 Main effect plots for means and SN ratio

joints welded by TIG welding. From Fig. 17.10, it is revealed that with the increase of welding current and welding speed, the impact strength first increases and then decreases and with the increase of gas flow rate impact strength increases.

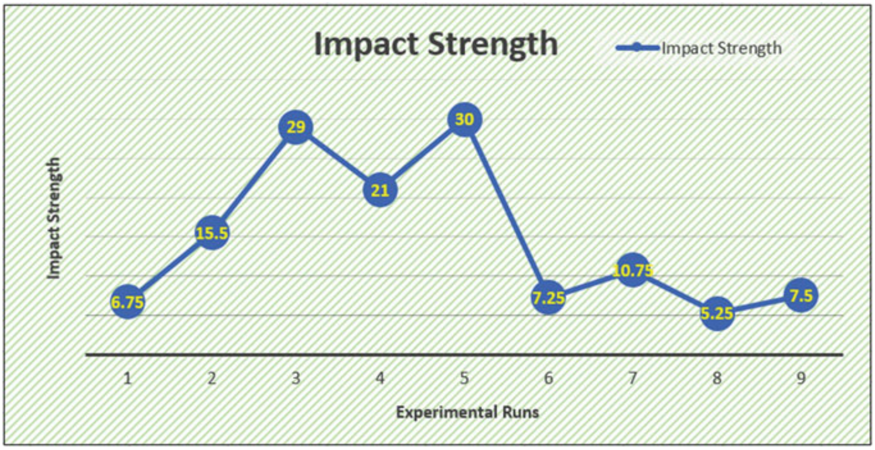

Fig. 17.10 Variation of impact strength under several experimental trials

17.4 Conclusions

From the present experimental study, the following conclusions have been drawn:

- Input process parameters, i.e., welding current, welding speed, and gas flow rate have been found influential; however, there has been no significant process parameter found that affects material properties, impact strength drastically.
- An optimum combination for sound weld joint has been determined to be welding current of 120 sA, welding speed of 8 mm/s, and gas flow rate of 18 Lpm, i.e., A2B2C3.

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