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Research paper

Comprehensive Analysis of TIG Welded Inconel–718 Alloy for Different Heat Input Conditions

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Abstract

In this research, the effects of heat input on tensile properties and microstructure were investigated for super alloy Inconel-718 sheets weld by Tungsten Inert Gas (TIG) welding process. The tensile properties and microstructure of weld joints were evaluated. The experiment was conducted with six different combinations of welding parameters like welding current, voltage and welding speed, which were give in six different welding heat input combinations of welding parameters. The experimental results shows that the welding joints weld with low welding heat input was yield higher tensile properties. From the experimentation it was understand that the tensile properties increases when the welding heat input decrease. Drastic grain coarsening was evidenced when the heat input was increases. For the weld joints experimented in this research it was also observed that amount of laves phase was increased with increase in the welding heat input which is the major fact for noticeable variation in the ultimate tensile strength of the weld joints welded by TIG welding process with different welding heat input.

Keywords: *Tungsten inert gas welding, tensile properties, welding parameters, laves phase.*

1. Introduction

Super alloy inconel-718 is the non ferrous nickel based alloy. It has been generally used by the manufacturing industries due to its outstanding resistance to oxidation and mechanical properties at high temperature [1]. In general most of the fabricators favored Inconel-718 alloy because of its superior weldability in age hardened and annealed conditions. Some of the unique applications of this alloy admire to use as a base metal for fabrication of gas turbine, nuclear plants and aircraft engines [2].
This alloy shows particularly good resistance to liquation cracking. But it is more sensitive to heat affected zone (HAZ) microfissuring [3]-[6]. According to the past research conclusion it was proved that this alloy is more prone to form laves phase (Intermetallic compounds) during welding. [7]. It is challenging that to reduce the amount of laves phase in the weld metal, since laves phase is detrimental to mechanical properties, fatigue properties and creep properties of weld joint [8]-[13]
It was understood from previous research findings that control the quantity of laves phase in the weld joints is a major task to achieve quality weld. Researchers investigated with Inconel-718 alloy weld by TIG welding process and found that cooling rate of the weld joint after welding is play a major role to control the laves phase formation [14]. The cooling rate can be restricted through control the heat input of the weld joint. It is well known that the heat input is inversely proportional to cooling rate of the weld joint. Hence there is the need to study the effect of heat input on Inconel-718 alloy weld by TIG welding process.
Most of the research works published on Inconel-718 is welded by high energy density welding process like Electron beam welding and laser beam welding. Because those processes have high energy density heat source and produce superior weld quality with narrow HAZ [1]-[2], [7]. This high heat density welding process are not reliable for most of the small and medium scale industries, because of them high equipment cost, need of skilled operator and suitability for the working environments.
TIG welding is the only welding process to fabricate quality weld with minimum cost than any other welding process. It was proved by past studies that TIG welding can produce quality weld with ferrous and non-ferrous base metals [15]-[17].
The team of researchers involved experimentation on microstructure and mechanical properties of Er-modified aluminum alloy weld by TIG welding process [18]. They concluded that TIG welding process is the suitable process for welding new generation aluminum alloy. Experimental study has been carried out for TIG welded 316L stainless steel [19]. They study the effect of hydrogen in argon shielding gas. They find that the hydrogen addition in shielding gas will affect the grain size of weld metal and weld profile dimension. Effect of welding heat input on weld defect of duplex stainless steels was welded by submerged arc welding was investigated [19]. The finding of the investigation reveals that using high welding heat input produce quality weld than low heat input weld.
From the history of research findings it is concluded that no organized experimentation on the consequences of welding heat input on tensile properties and microstructure of TIG welded Inconel-718 alloy has been published. Hence the current research has planned to do the experimentation on TIG weld Inconel-718 alloy for studying the effect of welding heat input on tensile and microstructure properties.

2. Experimental Investigation

Base Metal and Filler Wire

The base metal for current research was rolled and solution annealed (980^0C) Inconel-718 sheets which have the dimension of (150mm x 60mm x 2mm). The filler wire was ER-Ni Fe Cr-2 of 1.6mm diameter. The chemical elements of base metal are shown in Table 1. The mechanical properties of the base metal are listed in Table 2.

Table 1: Chemical Composition of Base Metal

Element	Ni	Cr	Nb	Mo	Ti	Al	C	B	Si	S	P	Fe
wt. %	53	17.5	5.08	3.13	0.97	0.51	0.02	0.003	0.03	0.002	0.005	Bal

Table 2: Mechanical Properties of Base Metal

UTS (MPa)	1034
YS (MPa)	829
% Elongation	20
Hardness	40 RC

Selection of Process Parameters

In this research there is six different weld heats input combination of welding parameters have been used that are tabulated in Table 3.

Table 3: Welding Parameters–Different Heat Input Combinations

Weld Id	1	2	3	4	5	6
Current (Amp)	40	40	50	50	60	60
Voltage (Volt)	10	10	12	10	10	12
Speed (mm/sec)	1	0.8	1	0.67	0.67	0.8
Heat Input (KJ/mm)	0.4	0.5	0.6	0.7	0.8	0.9

Welding Procedure

In this research work square butt design was used to fabricate the test coupon. Prior to welding the base metal sheets were cut in a required dimension by using EDM wire cutting machine. Before welding the base metal sheets were cleaned to remove oil, rust, scale and moisture by using mechanical and chemical methods. After cleaning the base metal sheets were arranged together to form a square butt design by using fixture and mechanical clamp as view in Figure 1.

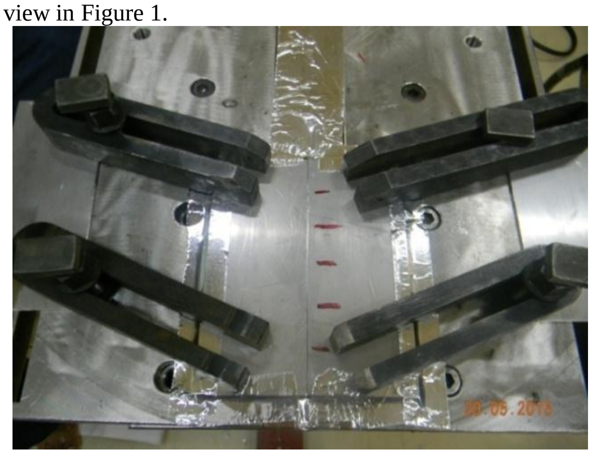

Figure 1: Preparation-square butt design

The polysoud made automatic TIG welding machine with manual mode was used for this experimentation. No free heat temperature has been maintained. Shielding gas for welding was argon with 15L/min flow rate. The welding was done with 2mm throated tungsten electrode. The welding was achieved full penetration with single pass welding. The welding speed was calculated at most care, since manual mode TIG welding was used for experimentation. The welding speed was calculated based on arc timing and weld length dimension. Figure 2 shows the photograph of the weld joints (coupons).

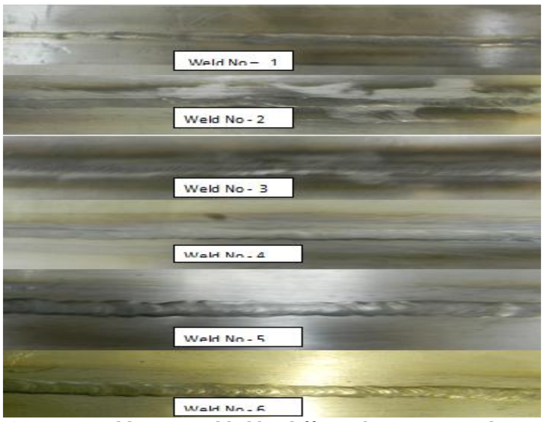

Figure 2: Weld joints welded by different heat input conditions

Preparation of Test Specimens

From each weld test coupons there is three tensile specimens and one microstructure specimen were machine at the middle of the weld joint. The tensile specimens were machined based on the configuration diagram shown in Figure 3 (According to ASTM E8). The tensile specimen's photographs were shown in Figure 4.

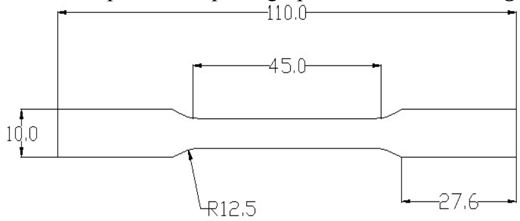

Figure 3: Tensile specimen–configuration diagram

Figure 4: Test specimen–tensile test

Tensile Test

It is a standard procedure to increase the tensile properties and reduce the laves phase of Inconel-718 alloy. According to ASTM B637 test specimens were heated at718^0C for eight hours then furnace cooled to 621^0C and kept at 621^0C for eighteen hours and air-cooled up to room temperature range.

Tensile Test

Tensile testing was carried out by Instron made computer controlled tensile test machine. These are the following tensile properties ultimate tensile strength (UTS), yield strength (YS) and percentage elongation (%E) were measured and tabulated in Table 4.

Table 4: Tensile Properties

Weld Id	UTS (MPa)	YS (MPa)	Elongation (%)
1	1310	1096	6
2	1302	1089	5.7
3	1284	1070	4.5
4	1270	1064	4
5	1245	1042	3.5
6	1239	1035	3.1

Micrograph

The volume of various microstructure phases and grain size can be varied due to uneven heating and cooling take place during welding. Microstructure study is one of the methods to study the effect of heat input on weld joint. The microstructure specimens were polished with different grade silica paper starting the grade from 220 grit to 1200 grit. Then the specimens were fine polished with diamond paste by using disc polisher. According to ASTM E409 – 99 glyceregia solutions was used to etch the specimens for expose the microstructure. The weld zone microstructure of various heat input weld specimens were captured by using optical microscope that are shown in Figure 5.

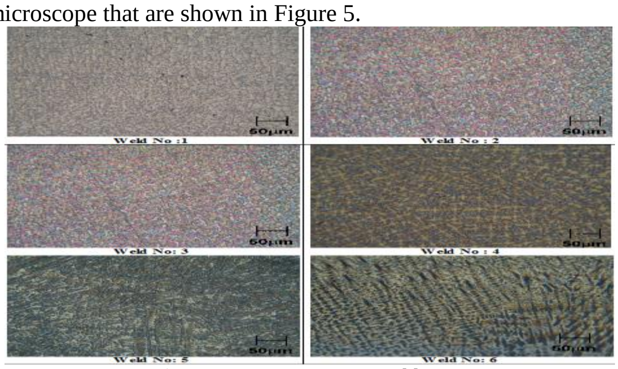

Figure 5: Microstructure–weld zone

3. Discussion

Tensile Properties

Tensile properties of six weld coupons have been tested. From each weld coupon three tensile specimens were experimented. The tensile properties that are tabulated in Table 4 are based on the average tensile values of three tensile specimens were tested. The tensile properties acquire from all the six weld coupons were reveals that the maximum tensile properties were obtained from weld coupon welded by using heat input of 0.4 KJ/mm (low heat input) and minimum tensile properties were obtained from heat input of 0.9KJ/mm (High heat input).From the tensile test result it was understand that the tensile properties were increases when the heat input is decrease.
Figure 5 shows the microstructure details of weld zone in terms of grain size and the amount of laves phase. The weld joint using low heat input shows very fine grain size with high proportion of grain boundary region and lesser quantity laves phase, which credited high tensile properties for joint weld by using low heat input. When the heat input is gradually increases the grain size is get coarse and the amount of lave phases also increases this is due to slow cooling rate happened after welding. Because of above said metallurgical reason the high heat input joints were yield low tensile properties. Figures 4, 5 and 6 demonstrate the effect of heat in put on UTS, YS and elongation respectively.

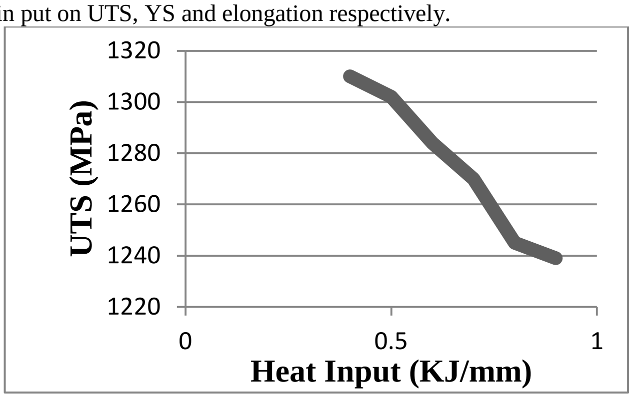

Figure 6: Heat input Vs UTS

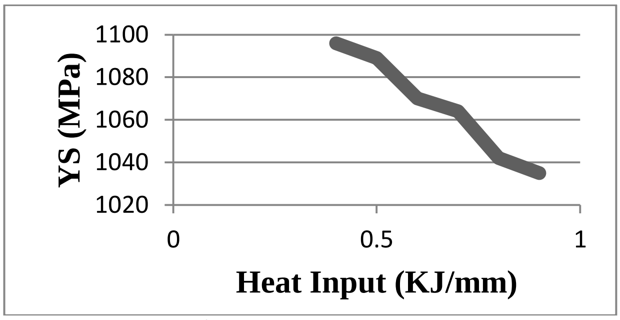

Figure 7: Heat input Vs YS

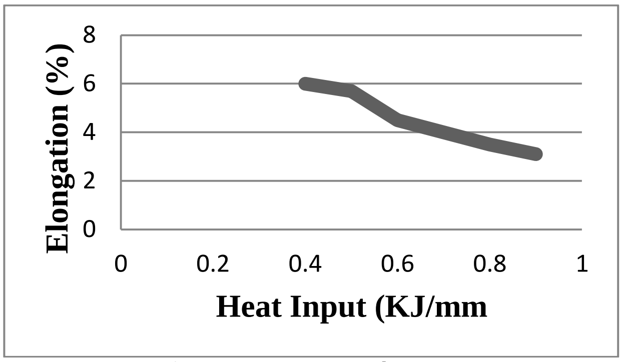

Figure 8: Heat input Vs elongation

Microstructure Study

Figure 5 shows the micrographs of weld zone for different heat input weld joints. It is understood from these micrographs that the grain size and amount of laves phase of weld zone increases as the weld heat input increase. This micrograph variation can be due to the cooling rate is comparatively lower at high heat input condition. This is the fact that gradual temperature gradient are observed in the weld zone, which will allow adequate time for grains to grow and develop lave phases. But at low heat input cooling rate is rapid, which offer inadequate time for grains to grow and develop laves phase.

4. Conclusion

These are the following recommendation can be suggested from the present research

- All the six weld joints exhibited superior joint strength, which proved that TIG welding process is the suitable process for welding of 2mm thick Inconel 718 alloy with wide range of parameters.
- As the welding heat input is low the weld joints exhibited high tensile properties then those weld joints welded by using high welding heat input.
- As welding heat input decreases, weld zone grain size and quantity of laves phase decrease. Rapid grain

coarsening was observed when the heat input is increases.

According to the present research findings it is suggested that low welding heat input must be preferred to obtain superior tensile properties when welding Inconel 718 alloy by using TIG welding process.

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