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Investigation of the Combined Effect of Input Parameters on Liquidus Temperature and Arc Length in TIG Welding

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Abstract

The liquidus temperature of a weld is that temperature at which a metal in solid form completely turns into the liquid state. In as much as a high liquidus temperature is desired in the welding process, extremely high values of the liquidus temperature can lead to spatter which will not augur well for the weld joint. Arc length is the distance between the welding electrode tip and surface of the weld pool. Decrease in arc length during welding, positively affects the welder's comfort and the weld product. The application of the surface plot in the investigation of the combined effect of input parameters on liquidus temperature and arc length was pursued in this study. The central composite design matrix was used to obtain data from sets of experiments. Mild steel coupons measuring 60mm x 40mm x 10mm were welded with tungsten inert gas welding process. The result of the surface plot shows that a desired value of arc length depends on both current and voltage.
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1. Introduction

Welding is the process of joining two pieces of metal together by forming a strong metallurgical bond between them either with heat or pressure, or even both to get a permanent bond. The fundamental basis of welding is the possibility of atoms to bond. Over the years, as the demand for welding new materials and larger thickness components arouse, mere gas flame welding, which was formerly used by welding engineers, has been seen to be inadequate. As a result, better suited welding methods such as Metal Inert Gas Welding, Tungsten Inert Gas Welding (TIG), Electron and Laser Beam Welding, and several others has evolved [1]. Tungsten inert gas (TIG) welding is a thermal process that mainly depends upon heat conducted through the weld joint materials [2]. The melting temperature needed to weld the materials in the TIG welding is achieved by inducing an arc between the work piece and a tungsten electrode. The weld pool temperatures can advance up to 2500°C. In TIG welding, a non-consumable tungsten electrode with diameter varying from 0.5 to 6.5 mm is employed with an inert shielding gas to protect the weld pool from atmospheric effect. Both AC or DC can be used as power supply sources in this process. TIG welding generally uses a direct current (DC) arc, where the tungsten electrode has a negative polarity, consequently the tungsten electrode turns into the cathode and the work piece turns into the anode and the polarity is known as straight polarity or direct current electrode negative (DCEN). All welding positions are possible in this process while others are restricted to one or a few welding positions. The basic equipment for TIG welding is power source, welding torch, supply of an inert shielding gas, supply of filler wire and water cooling system. TIG welding is applied in pressure vessels, aero, rocket, missile, nuclear and marine industries. TIG welding has greatly been improved upon by researchers over the years since it's invention (late 1930s). TIG welding is a multi-objective and multi factor metal fabrication technique. Tungsten Inert Gas (TIG) welding is regularly used in fabrication industries [3]. Distortion is problematic due to reworks, as a result, time and cost are affected. So, it has to be controlled. The TIG welding process can be used for the welding of a number of materials though the most common ones are aluminum, magnesium and stainless steel done in almost all positions with metal thickness ranging from 1 to 6 mm generally. Gas tungsten arc welding produces high quality welds most consistently because the welds obtained are pure weld [4]. It can weld metals in any configuration. But it is not economical to apply it on heavy section. TIG welding is very reliable process for improving quality characteristics of weld pool. A mathematical model was developed for the prediction of TIG weld bead characteristics [5]. The weld bead was characterized with its quality features such as upper bead width, lower bead width, penetration depth etc are mathematically related to the input parameters such as welding speed, welding current, shielding gas flow rate and arc gap distance. Arc length' is the distance between the welding electrode tip and surface of the weld pool" [6]. Decrease in arc length during welding positively affect the welder's comfort and the weld product. Arc length has a relationship with weld penetration and welding current, such that increase or decrease in current can result in increase or decrease in both arc length and weld penetration depth. Studies have revealed that weld penetration is affected by welding current, polarity, arc travel speed, electrode diameter etc. [7]. In Gas metal arc welding, welding voltage affects the arc length. Increase in arc length consequently leads to increase in the arc voltage due to the fact that extension of the arc exposes the entire arc column to the cool boundary of the arc [8]. When compared with short circuiting transfer, the arc length can be adjusted easily, without spatter welding seam using pulsed current, leading to the merits that the step of removing spatter on the base metal can be avoided and the manufacturing efficiency can be increased. However, the base current time (or datum current time) has not been seen as a parameter that can affect ODPP but rather a parameter for adjusting the welding arc length. As a matter of fact, the arc length affects the arc shape directly, including the heat transfer and heat dissipation mode of the droplets [9–11]. For example, a certain arc space is needed for a droplet from growth to detaching the wire. If the arc length is too small to provide enough space, the droplet would contact the molten pool but still on the wire, contributing to a short circuit [12].

2.0 Methodology

2.1 Materials

As regard the design of experiment used for this study,100 pieces of mild steel coupons measuring 60mm x 40mm x 10mm were used for the experiments. The experiment was performed 20 times, using 5 specimens for each run. The tungsten inert gas welding equipment was used to weld the plates after the edges have been bevelled and machined.

Figure 1: Welding torch

Figure 2: TIG equipment

Figure 3: Digital thermometer

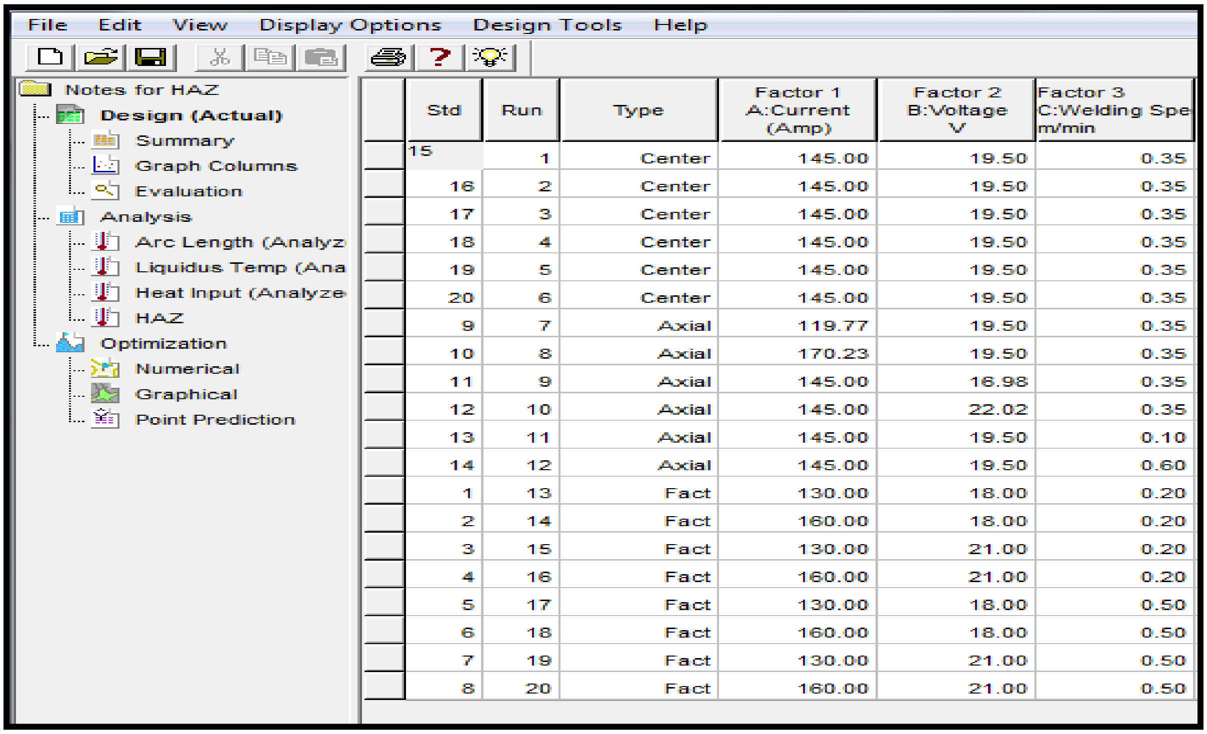
Figure 4: Weld sample

Table 1: Process parameters and their levels

Parameters	Unit	Symbol	Coded value	Coded value
			Low (-1)	High (+1)
Current	Amp	A	100	180
welding speed,	M/min	F	0.10	0.6
Voltage	Volt	V	16	22

2.2 Method of data collection

The central composite design matrix was developed, using the design expert software, producing 20 experimental runs. The input parameters and the responses make up the experimental matrix. The responses (arc length and liquidous temperature) recorded from the weld samples were used as the data. The arc length was measured with the aid of a measuring tape while the liquidous temperature was measured with the aid of a digital thermometer alongside a thermocouple connection cable. Figure 5 shows the central composite design matrix.

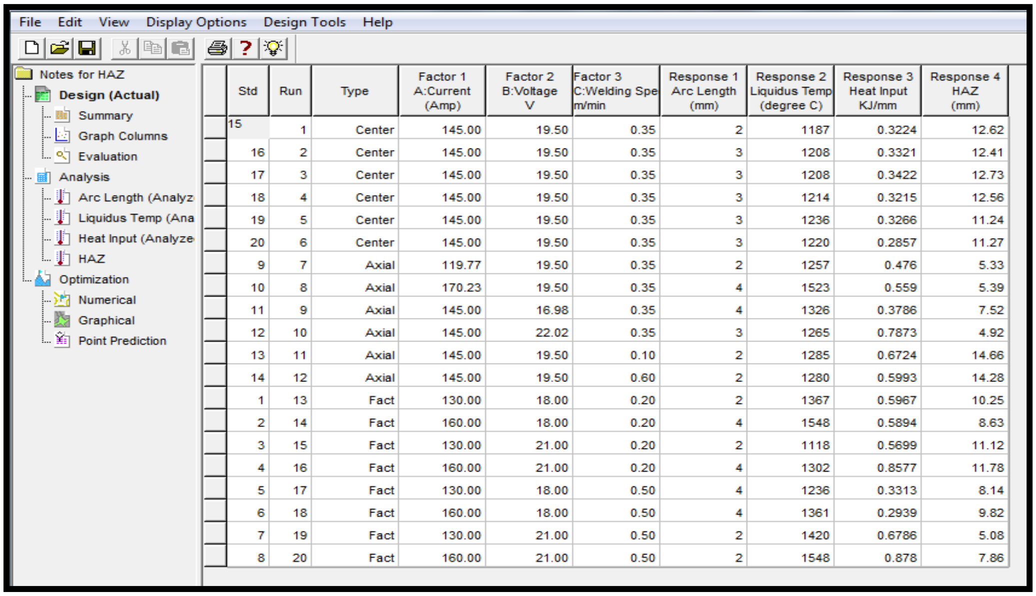


Std	Run	Type	Factor 1 A:Current (Amp)	Factor 2 B:Voltage V	Factor 3 C:Welding Spe m/min
15	1	Center	145.00	19.50	0.35
16	2	Center	145.00	19.50	0.35
17	3	Center	145.00	19.50	0.35
18	4	Center	145.00	19.50	0.35
19	5	Center	145.00	19.50	0.35
20	6	Center	145.00	19.50	0.35
9	7	Axial	119.77	19.50	0.35
10	8	Axial	170.23	19.50	0.35
11	9	Axial	145.00	16.98	0.35
12	10	Axial	145.00	22.02	0.35
13	11	Axial	145.00	19.50	0.10
14	12	Axial	145.00	19.50	0.60
1	13	Fact	130.00	18.00	0.20
2	14	Fact	160.00	18.00	0.20
3	15	Fact	130.00	21.00	0.20
4	16	Fact	160.00	21.00	0.20
5	17	Fact	130.00	18.00	0.50
6	18	Fact	160.00	18.00	0.50
7	19	Fact	130.00	21.00	0.50
8	20	Fact	160.00	21.00	0.50

Figure 5: Central Composite Design Matrix (CCD)

3.0 Results

The randomized design matrix consisting of the input variables and responses namely (arc length and liquidus temperature) in real values is shown in Figure 6.



Std	Run	Type	Factor 1 A:Current (Amp)	Factor 2 B:Voltage V	Factor 3 C:Welding Spe m/min	Response 1 Arc Length (mm)	Response 2 Liquidus Temp (degree C)	Response 3 Heat Input KJ/mm	Response 4 HAZ (mm)
15	1	Center	145.00	19.50	0.35	2	1187	0.3224	12.62
16	2	Center	145.00	19.50	0.35	3	1208	0.3321	12.41
17	3	Center	145.00	19.50	0.35	3	1208	0.3422	12.73
18	4	Center	145.00	19.50	0.35	3	1214	0.3215	12.56
19	5	Center	145.00	19.50	0.35	3	1236	0.3266	11.24
20	6	Center	145.00	19.50	0.35	3	1220	0.2857	11.27
9	7	Axial	119.77	19.50	0.35	2	1257	0.476	5.33
10	8	Axial	170.23	19.50	0.35	4	1523	0.559	5.39
11	9	Axial	145.00	16.98	0.35	4	1326	0.3786	7.52
12	10	Axial	145.00	22.02	0.35	3	1265	0.7873	4.92
13	11	Axial	145.00	19.50	0.10	2	1285	0.6724	14.66
14	12	Axial	145.00	19.50	0.60	2	1280	0.5993	14.28
1	13	Fact	130.00	18.00	0.20	2	1367	0.5967	10.25
2	14	Fact	160.00	18.00	0.20	4	1548	0.5894	8.63
3	15	Fact	130.00	21.00	0.20	2	1118	0.5699	11.12
4	16	Fact	160.00	21.00	0.20	4	1302	0.8577	11.78
5	17	Fact	130.00	18.00	0.50	4	1236	0.3313	8.14
6	18	Fact	160.00	18.00	0.50	4	1361	0.2939	9.82
7	19	Fact	130.00	21.00	0.50	2	1420	0.6786	5.08
8	20	Fact	160.00	21.00	0.50	2	1548	0.878	7.86

Figure 6: Design matrix showing the real values and the experimental value

4.0 Discussion

To study the effect of combined input parameters on the arc length, the 3D surface plot was employed. This is presented in Figure 6.

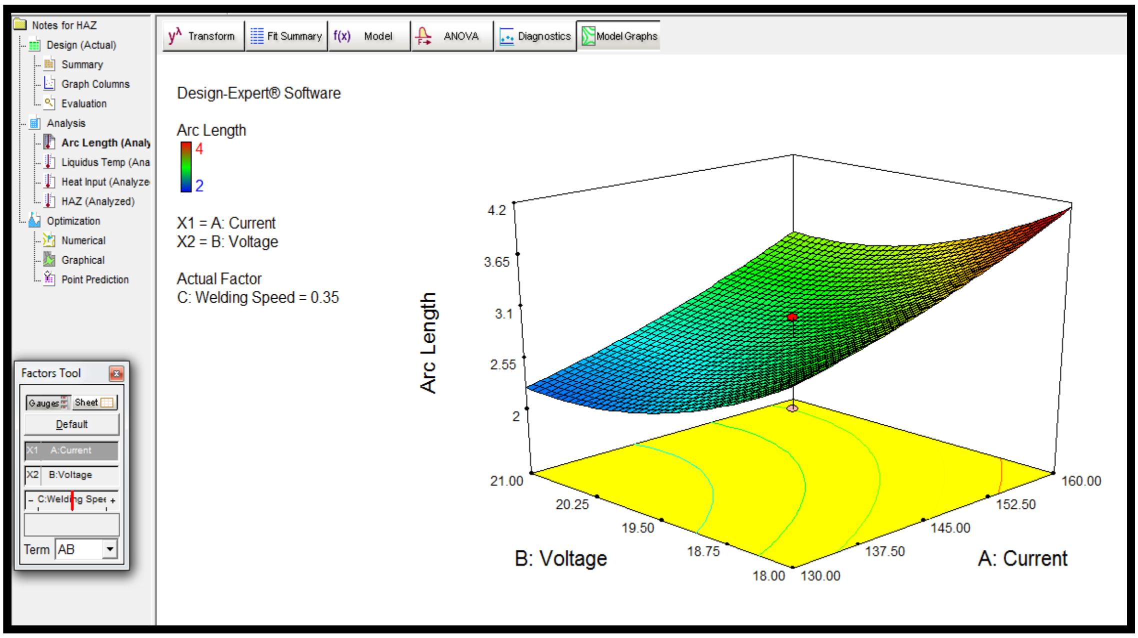


Figure 7: Effect of current and voltage on the arc length

From Figure 7, it is shown that the arc length is affected by both current and voltage. This is in relative agreement with [7] and [8] in the literature review section. To study the effect of combined input parameters on the liquidous temperature, the 3D surface plot was employed. This is presented in Figure 8.

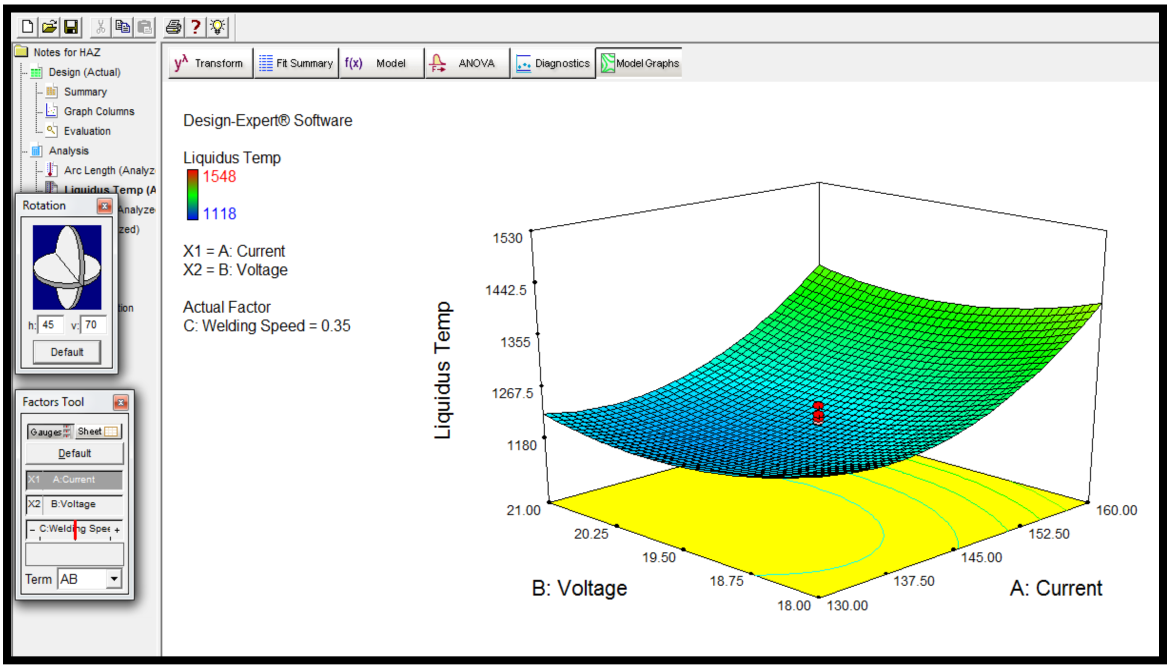


Figure 8: Effect of current and voltage on the liquidous temperature

The 3D surface plot as observed in Figures 7 and 8 shows the relationship between the input variables (current, voltage and welding speed) and the response variables (Arc length and liquidus temperature). It is a 3 dimensional surface plot which was employed to give a clearer concept of this study. Although not as useful as the contour plot for establishing responses values and coordinates, this view may provide a clearer picture of the surface.
Using the colour palette, as the colour of the curved surface gets darker, the arc length decreases proportionately while the liquidus temperature increases. The presence of a coloured hole at the middle of the upper surface gave a clue that more points lightly shaded for easier identification fell below the surface.
Increase in current leads to increase in both arc length and liquidous temperature but has a higher effect on the arc length. Increase in voltage leads to increase in the arc length but has no reasonable effect on the liquidous temperature.

5. Conclusion

From this study, it has been deduced that to achieve a desired value of arc length, both current and voltage should be considered. Result has shown that increase in current and decrease in voltage will lead to increase in arc length. While a desired value of liquidous temperature can be achieved with the consideration of the current without voltage. As increase in current will result to increase in liquidous temperature.

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