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Effect on Various Parameter of Stainless Steel 316L Weld Bead Geometry using Cold Metal Transfer (CMT) Process

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Abstract

This study influences the effect of various process parameters on Cold Metal Transfer (CMT) of stainless steel 316L using mild steel as substrate. CMT has a benefit of a minimal heat input, a high deposition rate, and increased efficiency. Typically, single pass weld beads are utilized for repair and remanufacturing. The geometry of the beads determines the cladding performance of additively produced components. Therefore, optimal range of bead characteristics is necessary to ensure superior mechanical qualities. The parameters includes as: welding current, travel speed and feed speed, were tuned to produce joints with complete penetration depth and zero defects. The weld bead with lower wire travel speed of (2.9 m/min) and higher wire feed speed of (4.9 m/min) at current value of (141A) shows the optimum value of (bead width: 3.56 mm, bead height: 1.72mm, weld penetration: 3.83mm and dilution: 1.5%). This was attributed to the decreases of wire travel speed and increases of wire feed speed ensuring better penetration and larger molten metal. While a higher current value causes the convexity area of the bead to rise, it displays a stronger penetration and minimal dilution.

Keywords: *CMT, Stainless steel 316L, Process Parameters & Weld bead geometry*

1.0 Introduction

Additive manufacturing (AM) is an attractive method in which components are manufactured layer by layer approach to formed parts [1]. Direct energy deposition uses wire or powder as a source of energy from an electron beam, plasma arc and laser. Wire arc additive manufacturing (WAAM) is a direct energy deposition technique utilizing wire feedstock and an electric arc as the energy source [2]. WAAM can be reached by using multiple energy forms. Gas Metal Arc Welding (GMAW), Gas Tungsten Arc Welding (GTAW) and Plasma Arc Welding (PAW) are the different sources. WAAM delivers a faster deposition rate than powder-based systems and other forms of metallic additive fabrication [3]. WAAM continues to be more cost-effective than completely subtractive machining since less material is wasted. In aerospace industry, the ratio of material used in raw material stock to the final component is known as Buy-to-Fly (BTF) and used to assess material waste during part manufacture [4]. Cold Metal Transfer (CMT) is a new joining technique with minimal thermal input, high deposition rate and less splatter [5].

Austenitic stainless steel 316L are widely employed in various sectors as: automobile, construction, marine, oil & gas industry, defense and bio-medical implants [6]. The SS316L steels are mostly utilized in the automotive, aeronautical, construction, marine, and oil & offshore industries [7]. The high chromium, nickel,

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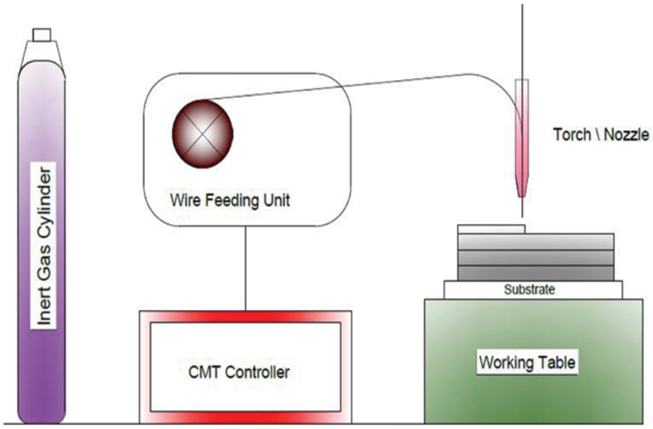

Figure 1: Schematic illustration of CMT-WAAM Process

and molybdenum content of this stainless steel can greatly improve its corrosion resistance. Austenitic stainless steels are easily connected by a variety of joining methods with good mechanical qualities produced using various arc welding processes [8]. In the current study stainless steel 316L was connected using the CMT technique and the effect of welding procedure characteristics on weld bead parts was evaluated. Figure 1 shows the schematic diagram of CMT- WAAM process.

Figure 2: Experimental set-up of CMT-WAAM process

2.0 Experimental Procedure

The CMT welding process was successfully performed using ER 316L filler wire at diameter of 1.2 mm are shown in Figure 2. The substrate material for the deposition technique is a mild steel plate with dimensions of 250x250x15mm^3. Tables 1 and 2 indicates the chemical composition of substrate metal and filler wire. The shielding gas mixture (80% Argon and 20% Carbon di-oxide) was used and performed at flow rate of 16 L/min.

The torch was held at a 10° angle from the perpendicular axis and the CMT welding technique was utilized. The most important parameters affecting bead properties are A, WFS &WTS. The welding input parameters were set using a trial and error method during experimentation in order to produce the best outcomes with no flaws and complete penetration depth. In this study, welding current, feed speed, travel speed, shielding gas flow, and torch angle are configuration parameters. The levels of parameters used in this experiment were Welding Current: 130-160 A, Wire Travel Speed: 2.5-5m/min, and Wire Travel Speed: 4.5-6m/min. The heat input is measured based on the amount of energy delivered per unit area of weld length. Heat input (J) was calculated by using the formulae:

$$\text{Heat input} = \eta \times \frac{60\times VI}{v}$$

Where
'V'- Voltage (volts)
'I' - Current (Amps)
'v' - Travel speed (mm/min) and
'η' - Factor of efficiency having 0.09

The CMT joining process exhibits an efficiency factor (η) of 0.99. The spectrometry analysis is performed to determine the weight (%) of element compositions. The size and structure of the deposited beads were inspected using 3D optical-microscope and the weld bead geometry are determined with Image J software. Table 3 illustrates input process parameters of CMT-WAAM process. The dilution was calculated using the following formula:

% Dilution= B/A+B * 100 Where
'A' – Area of reinforced metal and
'B' – Area of penetrated metal

Table 1: Filler metal chemical composition (wt%)

Element	Cr	Ni	Mn	Mo	Cu	Si	P	S	C	Fe
Composition (%)	18.4	11.1	1.52	2.1	0.26	0.37	0.26	0.8	0.24	Bal

Table 2: Base metal composition (wt%)

Element	C	Si	Mn	Sn	P	Co	Cu	Al	Ni	Mo	Fe
Composition(%)	0.57	0.13	0.30	0.005	0.01	0.01	0.02	0.02	0.07	0.07	Bal

Table 3: Process Parameters of CMT 316L

	Weld current (A)	Voltage (V)	Wire feed speed (m/min)	Wire travel speed (m/min)	Heat Input (J)
1	131	18.5	4.5	2.4	545.2
2	151	20.2	5.3	3.5	470.6
3	151	20.2	5.3	3.4	484.4
4	151	20.3	5.3	3.5	472.9
5	141	19.5	4.9	2.9	511.9
6	151	20.1	5.3	3.5	468.2
7	141	19.2	4.9	2.9	504
8	141	19.4	4.9	2.9	422
9	160	20.4	5.3	3.5	503.5
10	161	20.5	5.8	4.3	414.8
11	151	20.1	5.3	3.5	468.2
12	151	20.3	5.3	3.4	466.8
13	170	21.2	6.2	5	389.2
14	161	20.4	5.8	4.3	412.4
15	151	20.2	5.3	3.5	470.6

3 Results and Discussion

3.1 Weld Bead Geometry

In the CMT process, the geometry of the weld bead and the amount of energy absorbed playing a major role. Heat input affects the geometry of the weld seam, which is mainly due to differences in seam width and penetration. As the temperature increases, the depth of penetration increases, resulting in a good appearance. As the heat input increases, the gap in weld seam width between the top and bottom of welds decreases. This is owing to the fact that when the heat input increases, the cooling rate decreases [10]. Consequently the greater volume of base metals melted at higher intakes, allowing more heat to be generated during solidification [11].

Since thermal input is moderate for higher speeds and low currents, the penetration is moderately uneven from top to bottom region. Figure 3 shows the schematic figure of weld bead geometry. Increases of welding current with lower travel speed offers the linear heat input on the base metal and stable molten pool, it causes decreases the bead width, larger penetration and symmetric bead shape. Figure 4 illustrate the weld bead deposition of cladding layers on substrate material.

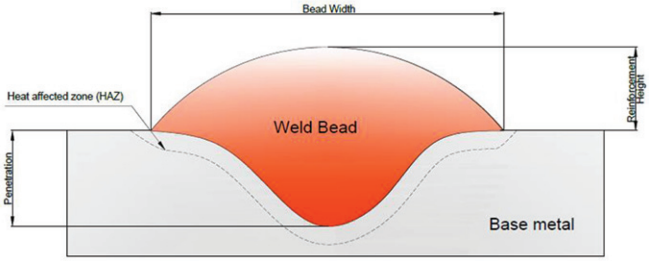

Figure 3: Schematic diagram of weld bead geometry

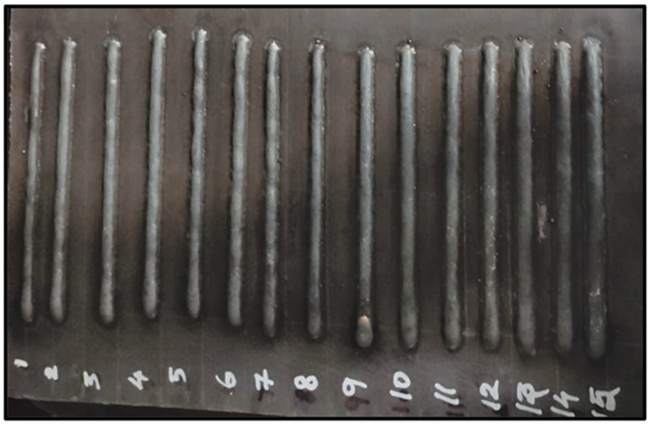

Figure 4: Stainless deposition of cladding layers on mild steel substrate

3.1 Macro-graphic Analysis

The macro-graphic examination is performed by cross-sectioning area of the weld bead trials. Table 4 shows the output response of process parameters and Figure 5 illustrates the macro-images of weld bead profile.

In WAAM technology, uniform bead geometry is essential to minimize material loss in the cutting and machining process and maximize cost-effective efficiency [12]. The average value of bead height, bead width, dilution and depth of penetration were measured and indicates the optimal parameters can be achieved with fine weld bead shape with low dilution and minimum penetration.There was also strong metallurgical adhesion between the deposited seams. In this study we observed the difference in weld bead geometry caused by the difference of the current and voltage at similar heat inputs through the precise control of voltage and current. The reason for the differences in bead shapes was that the ratios of voltage and current to the total amount of heat input was different [13]. Single layer deposition was performed to observe the efficiency of the deposition under welding conditions by applying thick wall components.

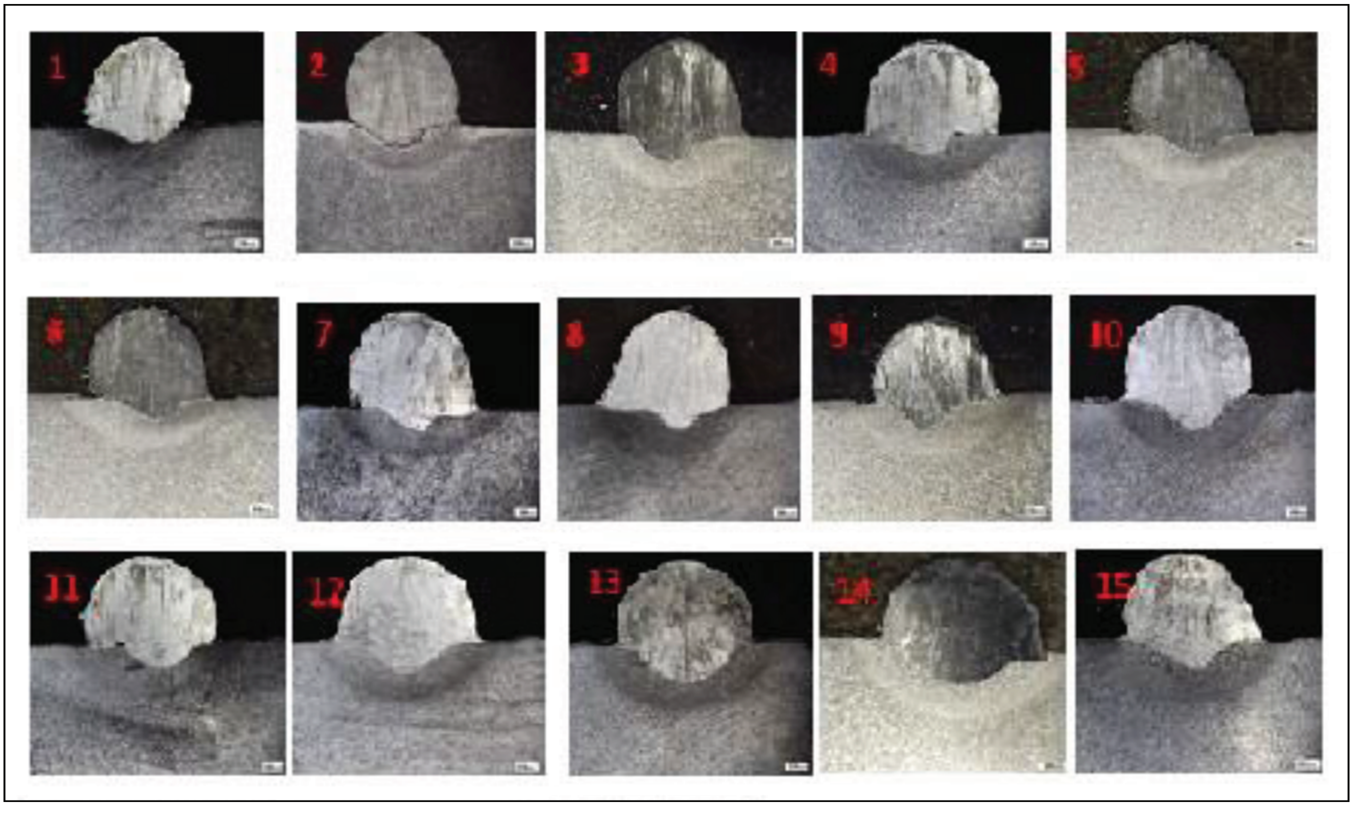

Figure 5: Macro-images of weld bead profile

Table 4: Output response of Process Parameters

	Weld current (A)	Voltage (V)	Bead width (mm)	Bead height (mm)	Dilution (%)	Weld Penetration (mm)
1	131	18.5	2.15	1.87	7.4	2
2	151	20.2	3.08	1.81	3.31	4.14
3	151	20.2	2.52	1.92	7.1	2.23
4	151	20.3	3.44	1.78	6.87	2.45
5	141	19.5	3.36	1.83	3.03	5.1
6	151	20.1	2.01	1.88	6.85	1.89
7	141	19.2	3.54	1.76	2.5	5.32
8	141	19.4	3.56	1.72	1.5	3.83
9	160	20.4	3.24	1.86	2.92	4.75
10	161	20.5	3.46	1.9	4.42	3.78
11	151	20.1	3.08	1.91	12.07	1.66
12	151	20.3	3.64	1.82	2.6	5.52
13	170	21.2	3.39	1.92	2.62	4.86
14	161	20.4	3.79	1.95	4.64	4.06
15	151	20.2	3.64	1.78	2.6	3.64

4.0 Conclusions

In this work 316L stainless steel weld bead was fabricated and employed by using CMT-WAAM process with different parameters. The process parameters of weld current, wire travel speed and wire feed speed and their influence on characteristics bead dimensions were studied. The heat input is the most important property that correlates linearly with the characteristics of bead dimensions including bead height, bead width, dilution and weld penetration. Formation of weld bead shows the inverse relationship between the hardness and heat input.

1. Single weld bead was successfully deposited using the cold-metal transfer deposition technique.
2. An increase in current causes the higher material flow and increases the bead width, further more heat input is concerned with increases the current as well as weld penetration is increased.
3. At higher travel speed, the bead width decreases also cause the depth of a melted surface and depth of penetration drops substantially.
4. The height of the bead grows linearly with the wire feed speed. Material depth-melting decreases dramatically with increasing the travel speed.
5. Both weld current and travel speed inversely affect the heat input through similar deposition strategy. Increasing the travel speed or reducing the weld current reduces the melt-through depth.
6. There was no significant effects on gas flow rate, inter-pass temperature, contact angle and stand off distance, therefore maintain the gas flow rate at constant level to avoid the oxidation.
7. The optimum process parameters for maximum bead width, maximum bead height, minimum weld penetration and minimum dilution are found to be at weld current:141 A, wire travel speed: 2.9 m/min and wire feed speed: 4.9 m/min respectively.

5.0 Acknowledgements

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