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Investigation of process parameters in CuAl8 deposition under the influence of different material deposition angles via CMT-based WAAM process

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Abstract

Wire arc additive manufacturing (WAAM) is an emerging technology for additive manufacturing of metals due to its prominent features of high production rate and low energy consumption. Additive Manufacturing (AM) produces parts/products through a layer-by-layer material deposition. The material used is copper-based alloy wire CuAl8 (ERCuAl-A1). Copper-based alloys are arc weldable by choosing suitable process parameters, but this weldability is lower than steel. The main challenge in such types of materials is high thermal conductivity. Additionally, welding copper-based alloys is more challenging in inclined positions like PB (horizontal) and PC (transverse) than welding in PA (normal) position. This issue has to be investigated for producing components with complex geometries where material deposition in inclined positions is required. This research study investigates the effect of process parameters, i.e., different wire feed speed to torch travel speed ratios on the weld bead geometry produced via Cold Metal Transfer (CMT) based WAAM process in different welding orientations. Different ratios of wire feed and torch travel speed will be used in each position, and the deposition angles used for this investigation are 0°, 30°, 60° and 90°. This work showed the feasibility of copper-based alloy deposition in inclined positions and showed that wire feed speed and torch speed significantly affect the weld bead geometry. This study also showed that as the deposition angles increases, the possibility of depositing ERCuAl-A1 decreases and the highest width-to-height ratio was obtained in the PA position.

Keywords: Wire arc additive manufacturing; Copper-based alloys; CMT; Material deposition; WAAM

1. Introduction

WAAM (Wire arc additive manufacturing) has been derived from classical arc welding technology, one of the DED (directed energy deposition) technology [1]. In WAAM process, the wire is melted by heating via an electric arc and then transferred to the metal melt pool. Later, it solidifies at the melt pool boundary and makes the desired product layer-by-layer [2]. WAAM has the potential to develop structures that can be extended to tens of meters and can fabricate fully dense parts with large dimensions, along with higher manufacturing efficiency, i.e. high material deposition rate and low material waste. WAAM technology is still in the development phase of technological improvement and faces many challenges. Process parameters are crucial in WAAM process and vary according to the WAAM technology used for depositing material, i.e. gas tungsten arc welding (GTAW), plasma arc welding (PAW), and gas metal arc welding (GMAW) and the material type deposited.

WAAM of copper-based alloys is challenging due to its higher thermal conductivity [3]. Identification of the feasible process parameters for depositing copper-based alloy, ERCuAl-A1 (CuAl8), is essential for obtaining defect-free weld beads. Thus, it will ensure a defect-free structure and better mechanical properties. Oražem [4] studied the impact of interpass temperature during the WAAM of CuAl8. It was also stated that the interpass temperature during multi-layer deposition must not exceed 260 °C, and wire feed speed should not be 4 mm/sec or lower as excessive heat input may occur and may cause an overflow of the deposited material. Chen et al. [5] studied the effect of interpass temperature on the microstructure and mechanical properties in ultrasonic vibrations assisted (UVA) WAAM of copper-based alloy (Cu-8Al-2Ni-2Fe-2Mn) and showed that better mechanical properties could be achieved by keeping the interpass temperature under 100 °C in UVA WAAM process. Xiong et al. [6] studied the effects of different process parameters, like inter-layer temperature, wire feed speed (WFS), torch speed (TS) and a constant ratio of WFS/TS on the surface roughness in WAAM of low-carbon steel (H08Mn2Si) wire. It was revealed that increasing the WFS will increase surface roughness and reduce product quality.

Through extensive literature review, it was identified that the weld bead geometry is affected by serval factors in WAAM process. In these parameters, one of the crucial process parameters for obtaining a defect-free structure is the wire feed speed to torch speed (WFS/TS) ratio. However, a research gap was identified regarding the effects of the WFS/TS ratio and different orientations on weld bead geometry in WAAM of copper-based alloys. This paper will give an insight into parameters investigation for depositing copper-based alloy, ERCuAl-A1, outside the ideal (PA) welding position.

2. Methodology and equipment

Cold Metal Transfer (CMT) is an advanced version of GMAW and ensures a low heat input in the process, and thus, it is used in this study for depositing copper-based alloy ERCuAl-A1 wire. The wire diameter was 1 mm, and the S235JR plate was used as a substrate having a 6 mm thickness, 25 cm length and 20 cm width for depositing material. Pure argon was used as shielding gas. The chemical composition of the wire used in this study is presented below in table 1.

Table 1. Composition of ERCuAl-A1 (%)

Composition of ERCuAl-A1 (%)						
Cu including Ag	Zn	Mn	Si	Al	Pb	Other
Remainder	0.20	0.50	0.10	6-8	0.02	0.5

Welding torch was installed on a 3-axis machine. The torch and the substrate can be oriented from 0˚ to 90˚ in this machine setup. The relative angle between torch and substrate is kept constant at 90° in every position to simplify the process and reduce the programming required for an automatic WAAM process. The experimental setup used in the PA position is shown below in figure 1.

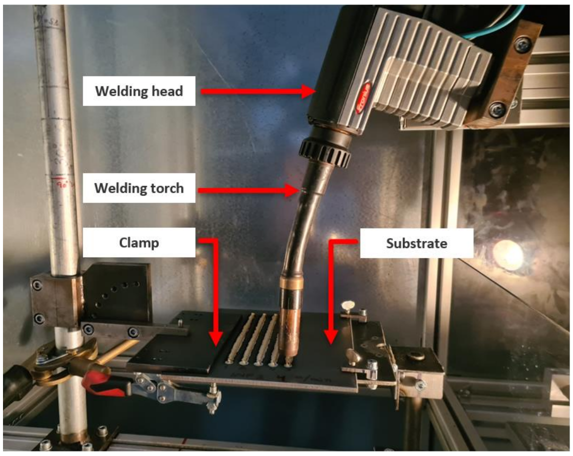

Figure 1. WAAM equipment

The following four torch and substrate orientations are utilised for investigating the combination of different WFS and TS ratios.

a. Substrate angle 0˚
b. Substrate angle 30˚
c. Substrate angle 60º
d. Substrate angle 90˚

These different setups of the equipment are presented below in figure 2.

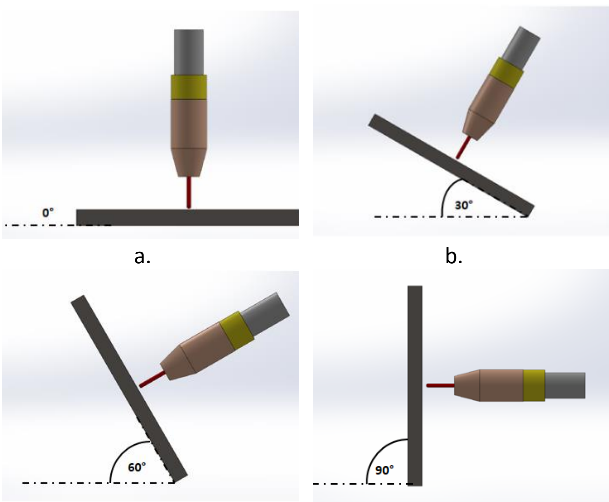

Figure 2. Experimental setup for material deposition at different orientation angles a) substrate angle 0˚ b) substrate angle 30˚ c) substrate angle 60˚ d) substrate angle 90˚

In each of the above-shown experimental setups in figure 2, five levels of WFS and TS are used for investigating material depositions. These levels are presented below in table 2. Other process parameters used in this study include gas flow rate at 15 litre/min and contact tip-to-work distance of 12 mm. The WAAM process was conducted inside a metallic cabin to protect the welding from environmental influences and to ensure a good WAAM process.

Table 2. Experimental factors and their levels

Parameters		Levels				
		1	**2**	**3**	**4**	**5**
A	WFS (m/min)	4	5	6	7	8
B	TS (m/min)	0.3	0.4	0.5	0.6	0.7

The full factorial design of the above parameters is presented below in table 3 for the PA position.

Table 3. Full factorial design

S. no.	WFS (m/min)	TS (m/min)	WFS/TS
1	4	0.3	13.33
2	4	0.4	10.00
3	4	0.5	8.00
4	4	0.6	6.67
5	4	0.7	5.71
6	5	0.3	16.67
7	5	0.4	12.50
8	5	0.5	10.00
9	5	0.6	8.33
10	5	0.7	7.14
11	6	0.3	20.00
12	6	0.4	15.00
13	6	0.5	12.00
14	6	0.6	10.00
15	6	0.7	8.57
16	7	0.3	23.33
17	7	0.4	17.50
18	7	0.5	14.00
19	7	0.6	11.67
20	7	0.7	10.00
21	8	0.3	26.67
22	8	0.4	20.00
23	8	0.5	16.00
24	8	0.6	13.33
25	8	0.7	11.43

For investigating the WFS/TS ratios for obtaining a defect-free weld bead structure, the full factorial design in table 2 was utilised for each setup shown in figure 2. The obtained weld beads are presented in figures 3, 4, 5 and 6 below.

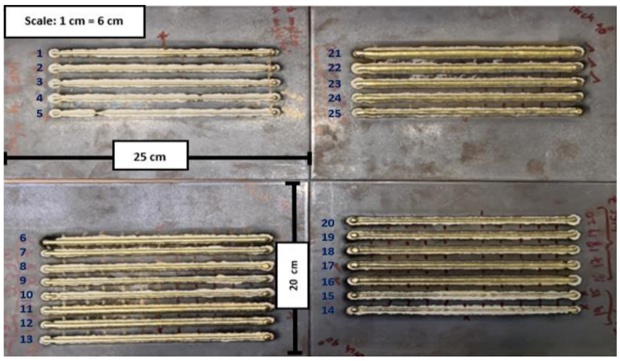

Figure 3. Weld beads at substrate angle 0°

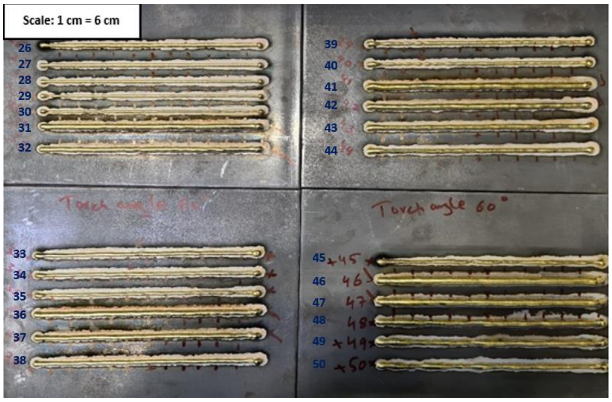

Figure 4. Weld beads at substrate angle 30°

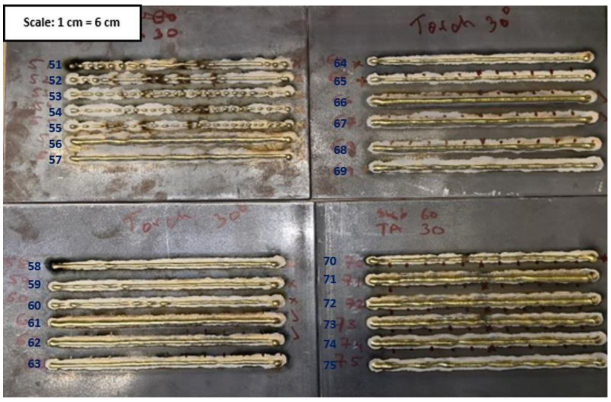

Figure 5. Weld beads at substrate angle 60°

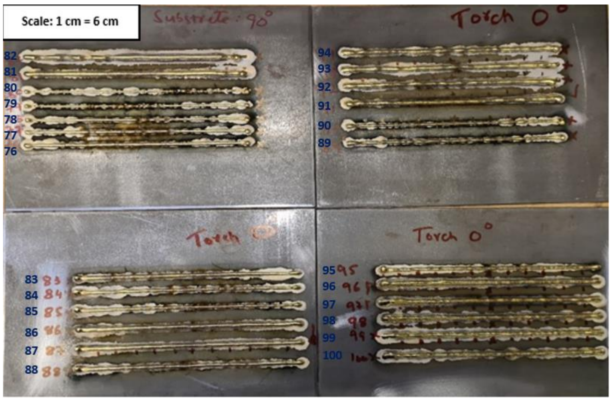

Figure 6. Weld beads at substrate angle 90°

For each position, twenty five single weld beads were deposited. Each weld bead was deposited at room temperature. Ten readings were taken for measuring weld bead width (W), and the average was taken using digital Vernier caliper. Similarly, for weld bead height (H), ten readings were taken on each side of the bead, and the average value was calculated.

3. Results and discussion

This study showed that it is possible to deposit the ERCuAl-A1 alloy other than the ideal PA position. But it gets more challenging to deposit this alloy as the substrate angle increases. In PA position, there is a broad range of WFS/TS working ratios, but as the substrate angle increases, these working ratios only reduce to a few ratios. This result is presented in Table 4 and in figure 7 below. For WFS/TS ratios, which resulted in bad quality weld beads, the W/H ratios are marked with dashes (-) in table 4.

Table 4. W/H ratio of different weld beads obtained at different WFS/TS

S.no.	WFS/TS	W/H for different substrate angles			
		0°	30°	60°	90°
1	13.33	1.22	1.18	-	-
2	10.00	1.23	1.13	-	-
3	8.00	1.35	1.18	-	-
4	6.67	-	-	-	-
5	5.71	-	-	-	-
6	16.67	1.49	1.57		1.42
7	12.50	1.52	1.62	-	-
8	10.00	-	-	-	-
9	8.33	-	-	-	-
10	7.14	-	-	-	-
11	20.00	1.43	1.54	1.52	
12	15.00	1.46	1.54	1.44	1.40
13	12.00	1.52	1.60	-	-
14	10.00	-	-	-	-
15	8.57	-	-	-	-
16	23.33	1.65	1.71	1.40	1.19
17	17.50	1.69	1.61	1.30	-
18	14.00	1.64	1.58	1.19	-
19	11.67	1.58	1.38	-	-
20	10.00	1.59	-	-	1.62
21	26.67	2.02	1.91	1.66	1.41
22	20.00	1.98	1.99	1.80	1.39
23	16.00	1.94	-	1.93	1.64
24	13.33	1.93	-	-	-
25	11.43	-	-	-	-

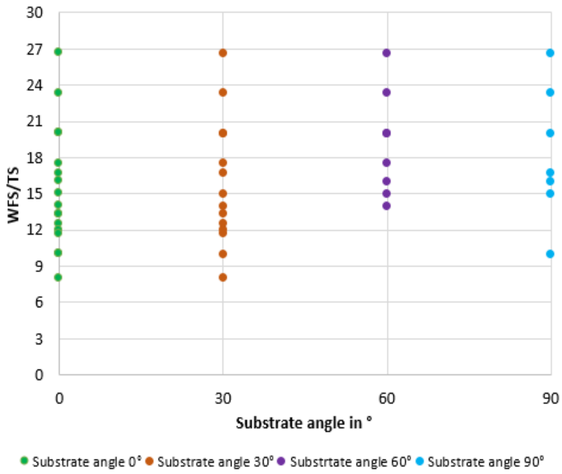

Figure 7. WFS/TS ratio obtained at different substrate angles for comparing possibility of WAAM in different orientations

One of the significant and only defects that were observed in these experiments was the humping defect as shown below in figure 8.

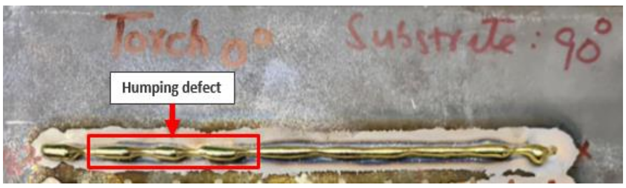

Figure 8. Humping defect

The highest width-to-height ratio was obtained at 0° substrate angle compared to the other substrate angles presented below in figure 9.

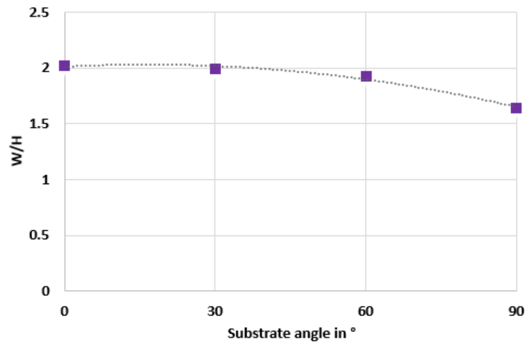

Figure 9. Highest W/H ratio obtained at different substrate angles

Furthermore, another interesting observation in this study was that as WFS/TS increases, the W/H ratio increases for substrate angles 0° and 30°. But as the angle increases to 60° and 90°, the W/H ratio decreases as the WFS/TS increases. These results are shown in the graphs below in figures 10, 11, 12, and 13. It is more visible in figure 13, where the substrate angle is 90°. This effect could be due to the influence of gravity, resulting in lower width and high height as it does not allow the molten, hot alloy to spread along substrate.

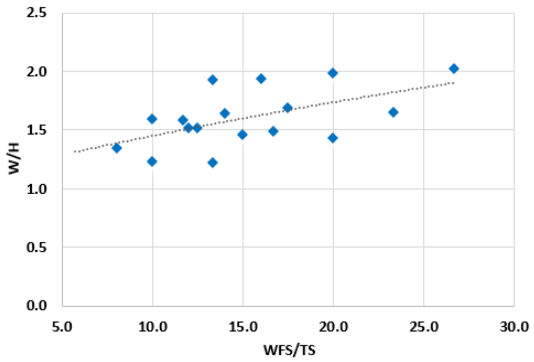

Figure 10. W/H ratio at different WFS/TS ratio (substrate angle 0°)

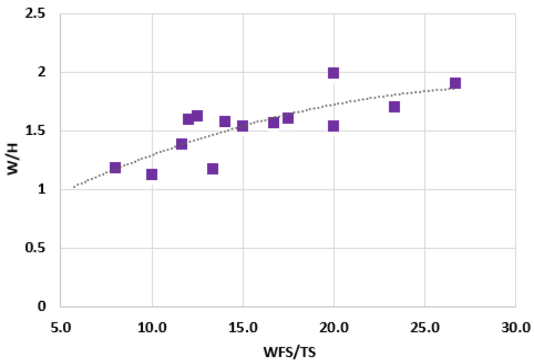

Figure 11. W/H ratio at different WFS/TS ratio (substrate angle 30°)

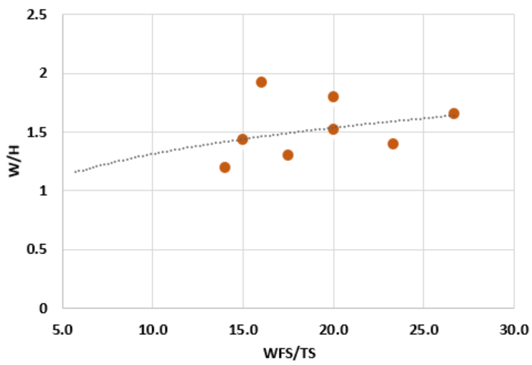

Figure 12. W/H ratio at different WFS/TS ratio (substrate angle 60°)

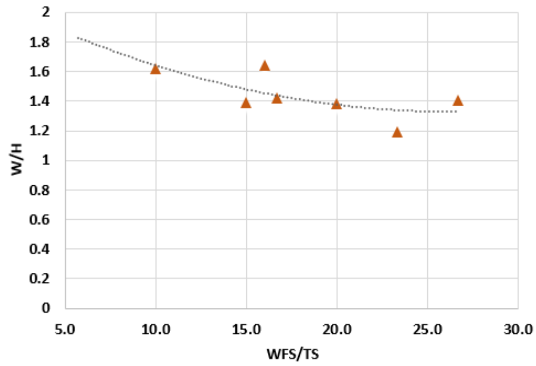

Figure 13. W/H ratio at different WFS/TS ratio (substrate angle 90°)

Furthermore, it was observed that the parameters through which it is difficult to obtain a defect-free weld bead in the PA position, it is also challenging to get a desired weld bead in other positions.

4. Conclusion

Through this research work, it was identified that the deposition of the ERCuAL-A1 or CuAl8 is possible by choosing a suitable WFS/TS ratio. The ideal welding position for this material is the PA-position, like for other materials. Still, its deposition is not limited to PA position, and depositing it in different orientations is possible. Good weld beads are obtained when a tending high WFS and lower TS is used, as presented in table 4. High TS mostly resulted in weld beads with humping defect. Thus for obtaining a weld bead with better W/H ratios, high WFS and lower TS is recommended.

5. Future work

This work can be further extended to analyse the interaction of different process parameters in WAAM of ERCuAl-A1 and conduct parameter optimisation for multi-layer structure development. Furthermore, this study can also be broadened to investigate the process parameters for enhancing mechanical properties.

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