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Using the cold metal transfer (CMT) method for wire arc additive manufacturing (WAAM) applications

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Abstract: This work deals with the possibilities of applying the *MAG-CMT* welding method for the purpose of wire arc additive manufacturing (*WAAM*). The *WAAM* method was operated using an industrial robot and welding device for *MAG* welding. The aim of the work was to compare three methods of laying layers in order to assess their mutual mixing. Cross-shaped perpendicular walls that were mutually connected as of the welded component were assessed. The geometry, macrostructure, and total operating costs of individual variants were evaluated. The result was the determination of the most accurate and most economical variant of laying layers.

Keywords: *MAG-CMT*; *WAAM*; welding

INTRODUCTION

Wire arc additive manufacturing (*WAAM*) was patented in 1920, making it one of the oldest methods of additive manufacturing [1]. Now it is mainly used for local repair of damaged or worn components and to manufacture new components or pressure vessels. With the advent of sufficiently powerful software for designing and manufacturing (*CAD/CAM*), it enabled significant development of *WAAM* technology and expanded the area of its use. Current technologies make it possible to weld with an accuracy of 0.1 mm and with a melting rate between 1 $kg \cdot h^{-1}$ and 10 $kg \cdot h^{-1}$, depending on the welding method used. The *WAAM* method consists of placing many individual weld layers next to each other (or on top of each other). Components are thus formed by successive welding of individual layers along the trajectory of the future contour of the component (always from bottom to top) with a constant or adaptive thickness of welding wall, or by depositing material into these contours to create solid parts. Therefore, accurate models for the geometry of individual weld beams play an important role in determining the surface and dimensional accuracy of manufactured products.

Additive manufacturing by arc welding with cold welding wire is mainly used in the aviation, naval, automotive, and space industry [2]. The biggest advantage is the possibility of using existing welding and robotic equipment. All filler materials, such as structural steels, high-alloyed steels, aluminium, titanium, nickel, copper and their alloys, can be used for processing by the *WAAM* [3-5]. It is therefore an economic alternative for the production of parts made of expensive (or difficult to process) materials, where conventional machining often results in an extremely high *BTF* (Buy to fly) ratio. This is the ratio of the "*input*" production material to the "*output*" material.

In terms of material costs, the welding wire used in *WAAM* is significantly cheaper than metal powder. This is because the *WAAM* is based on welding, an already well-established manufacturing technology. Additive arc welding technology hardware typically includes common welding equipment that is less expensive than many metal 3*D* printers available on the market. In addition, wire is usually easier to handle than powder, which requires the use of special protective equipment [2].

1 MATERIALS AND METHODS

The aim of the experimental part is the design and manufacturing of 3 different variants of depositing layers in the additive manufacturing of *WAAM* using *MAG-CMT* technology. The main goal is to produce a semi-finished part with the shape of a cross, with arm length 60 mm, arm width 5 mm and height of 50 mm (Fig. 1). Individual layers of welds are welded to a

12 mm-thick steel plate made of structural steel *S355J2+N*.

The filler material for welding was welding wire *G3Si1* with a diameter of Ø 1.0 mm (*EN ISO* 14341-*A*: *G* 42 4 *C1*/*M21* 3*Si1*). *G3Si1* is a copper-coated welding wire for welding structural steels with a minimum yield strength of up to 420 MPa and unalloyed structural steels with a maximum strength of 530 MPa.

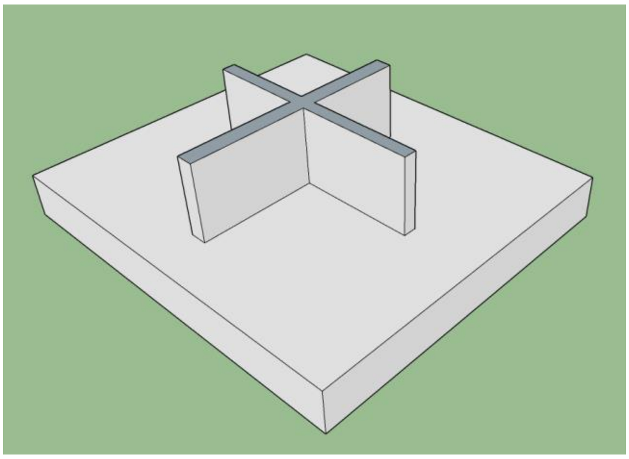

Fig. 1. Design of a semi-finished product made by the *WAAM* method

1.1 Welding procedure

The *TPS* 4000 device (*Fronius*, *Austria*) was used as the welding device. The torch of the welding machine was attached to the *KUKA VKR* 250/2 robotic arm. The assembly adapted in this way enables the accuracy of depositing layers up to 0.1 mm. Welding was performed by *MAG* technology in the *Cold Metal Transfer* (*CMT*) mode. As a shielding gas a mixture of 18 % CO_2 and 82 % of *Ar* was used. Welding parameters which are identical for all variants are shown in Tab. 1.

Tab. 1. Welding parameters for *MAG-CMT* welding

I [A]	*U* [V]	*WFS* [m·min^{-1}]	Travel speed [mm·s^{-1}]	Gas flow [l·min^{-1}]
104	21.1	5.3	8.0	8.0

1.2 Variants of layering

Three variants of layering the test piece's weld layers were proposed. A total of 36 layers were applied to the welding of each method. The coordinates of the layer deposition direction are different in the variants to find out which variant will have the best geometry in the final evaluation and, at the same time, the best welding wire consumption, shielding gas consumption, and the smallest total welding time. Individual variants are shown in Fig. 2, Fig. 3, and Fig. 4. The welding process can be seen in Fig. 5 and the final part manufactured by the *WAAM* can be seen in Fig. 6.

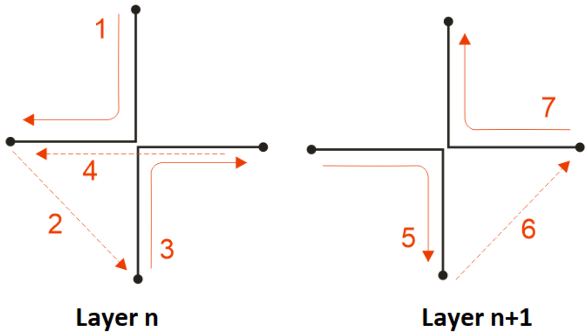

Fig. 2. Variant of layering No. 1

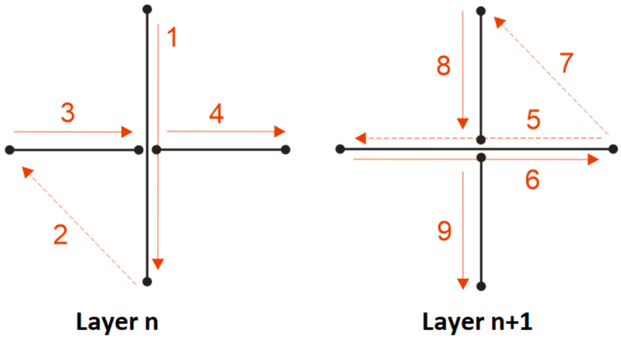

Fig. 3. Variant of layering No. 2

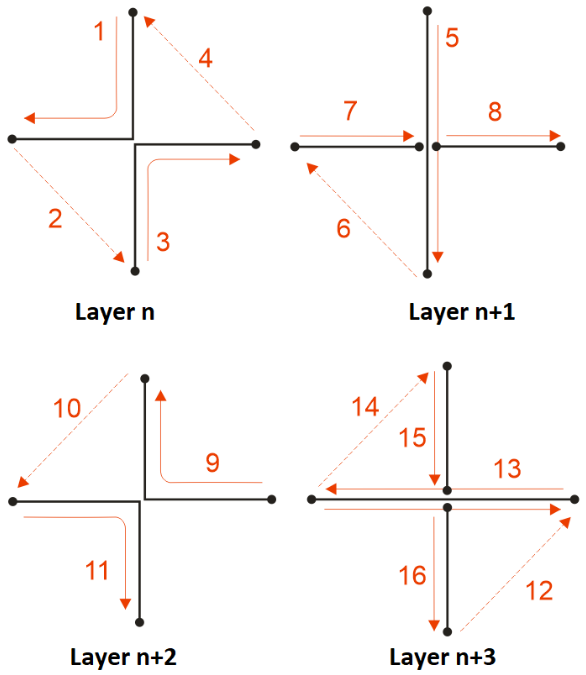

Fig. 4. Variant of layering No. 3

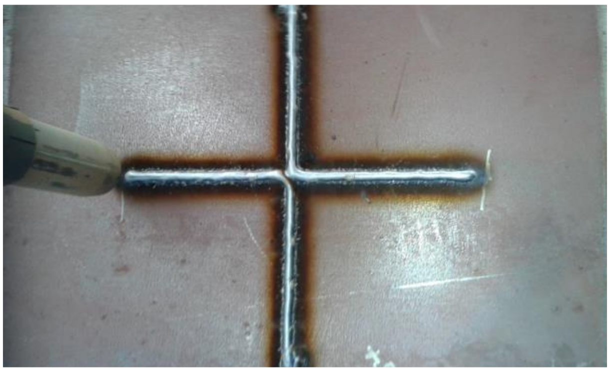

Fig. 5. The first layer welding of variant No. 3

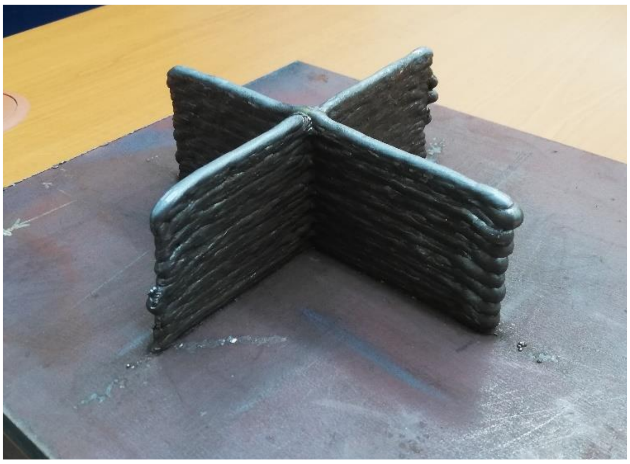

Fig. 6. Final part made by the *WAAM* as Variant No. 3

2 RESULTS AND DISCUSSION

The method of measuring the height and the width of individual arms at control points was chosen to compare the individual variants with each other. The control points are shown in Fig. 7 and are identical for each variant.

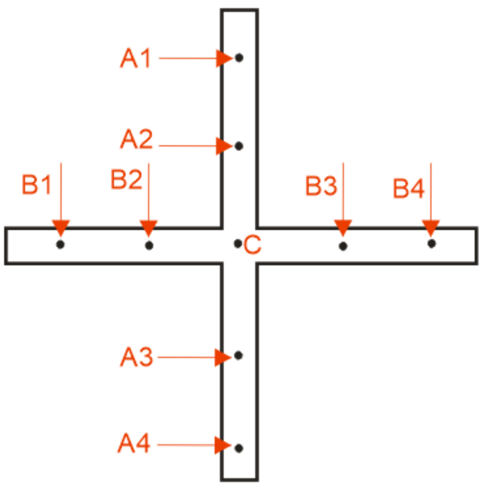

Fig. 7. Control points for measuring the height and the width of the samples

The results of measuring the height of the samples are shown in Tab. 2.

Tab. 2. Results of the height measurements at the control points [mm]

Variant No.	*A1*	*A2*	*A3*	*A4*	*C*
1	48.9	51.1	52.6	49.4	56.8
2	52.5	51.9	51.2	50.3	52.3
3	54.8	54.8	54.6	53.3	55.5
Variant No.	***B1***	***B2***	***B3***	***B4***	
1	52.7	53.0	52.8	52.2	
2	52.4	52.0	50.9	48.6	
3	53.1	53.5	52.5	51.7	

Tab. 3. Results of the width measurements at the control points [mm]

Variant No.	*A1*	*A2*	*A3*	*A4*	*C*
1	5.0	5.0	4.9	4.9	-
2	5.0	5.0	4.9	4.9	-
3	4.9	4.9	4.8	4.9	-
Variant No.	***B1***	***B2***	***B3***	***B4***	
1	5.0	5.0	5.3	5.2	
2	5.2	5.2	5.3	5.2	
3	4.9	4.9	5.1	5.0	

Together with the geometric parameters, the total manufacturing times, the consumption of the filler material and the consumption of the shielding gas were also assessed on all the test pieces. These values are listed in Tab. 4.

Tab. 4. Total time and material consumption for selected variants of the *WAAM* process

Variant No.	Total time of welding	Consumption of the filler material	Consumption of the shielding gas
1	23.3 min	0.88 kg	184 l
2	22.9 min	0.86 kg	181 l
3	23.0 min	0.87 kg	182 l

The total welding time was determined by the calculation in which the net welding time, and the net time performed by fast forward were included. Times were determined based on the common welding speed (8.0 mm·s^{-1}) and fast forward speed (1000 mm·s^{-1}). The calculations were based on the trajectories according to Fig. 2, Fig. 3 and Fig. 4.

Macrostructural analysis showed that the layers are connected without significant internal and external defects (e.g. cold joints, porosity, overflows, etc.). Macrostructure of the variant No. 1 is shown in Fig. 8 and microstructure of the variant No. 2 is shown in Fig. 9.

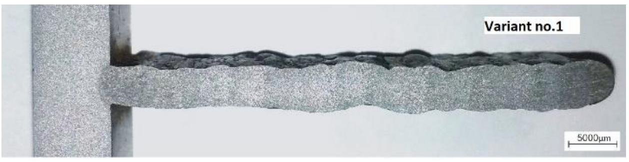

Fig. 8. Macrostructure of Variant No. 1

Fig. 9. Macrostructure of Variant No. 2

The cross-section was performed at the level of control point *A*3 for every assessed test piece (excluded the variant No. 3). For the variant No. 3 the macrostructural analysis wasn't performed.

CONCLUSIONS

Based on the measurements of the experimental test pieces, it is possible to state the differences between the assumed and actual geometric values. It is also possible to observe the difference between the individual variants of depositing the weld layers. The height measurements show that the variants No. 1 and No. 2 did not meet the requirements for the height of the test piece (50 mm). Shoulder width measurements showed that only variant No. 3 does not meet the required parameters (5 mm).

The indicators related to the total production time, the consumption of the filler material and the consumption of the shielding gas showed minimal differences between the individual variants. If the manufactured parts were not planned as serial production, the given differences can be considered negligible.

The height measurements showed that in the case of variant No. 3, it is sufficient to make only 35 layers to achieve the required height. By reducing the number of layers, it is possible to save approx. 5 l of shielding gas, 0.02 kg of the filler material and 0.6 min of the total welding time. Despite the insufficient arm width in the variant No. 3, the variant No. 3 can be considered the best.

Acknowledgement

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