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High deposition additive manufacturing by tandem plasma transferred arc welding

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Abstract

Plasma Transferred Arc Welding (PTA) is an important method for efficient component coating. In that field PTA has advantages, such as the free integration and mixing of a variety of filler materials as well as the largely independent material supply in relation to the energy input. Increasingly, the market is being driven by the challenge of providing efficient, high-performance, and safe coatings of complex geometries and components with flexible material depositions, as well as increasing the deposition rate. These tasks are fulfilled by the systematic coupling of two plasma transferred arc welding systems to form a tandem PTA system. Both PTA torches are positioned in such a way that they act in a common melt pool. In previous research it was provided that, deposition rate is 140 % increased with tandem PTA method in comparison to conventional single torch PTA coating method.

In this research, a direct comparison with conventional single torch PTA with parallel driven tandem PTA for additive manufacturing was done. The additive deposition capacity of tandem PTA is 56 % higher than conventional PTA for specified time.

Keywords: Additive manufacturing, Tandem welding, Plasma transferred arc, High deposition rate, Stainless steel

1. Introduction

Surface modifications are critical for mechanical components. In this context, the component life factor is one of the most important factors of components exposed to wear or corrosive environments. On the other hand, cost and time pressure as well as geometric and material constraints are limiting factors. Increasingly, the market is being driven by the challenge of providing efficient, high-performance, and safe coatings of complex geometries and components with flexible material depositions, as well as increasing the deposition rate. There are a variety of suitable processes for coating, such as plasma transferred arc welding (PTA), laser powder cladding, metal inertia gas (MIG) welding as well as tungsten inert gas (TIG) cladding with wire material, thermal spraying, etc., which have individual advantages and disadvantages. [1]–[3]. However, most of these deposition coating methods are usable also for additive manufacturing [4], [5].

PTA is one of the most important surface modification process. High deposition rates, a controllable dilution and heat-affected zone, a wide range of filler materials in powder form, fine control of important welding parameters, i.e. powder feed rates as well as an individual adaptable welding current as well as heat input, are general advantages of this method [6]–[9]. However, recent research shows that tandem PTA is able to upgrade conventional PTA. By the systematic coupling of two plasma transferred arc welding systems fulfilled to form a tandem PTA system. Both PTA torches are positioned in such a way that they act in a common melt pool. In previous research, it was provided that, deposition rate of coating is reached 240 % with tandem PTA method in comparison to conventional single torch PTA method [1].

Austenitic stainless steel and super-duplex stainless steel have received major attention in the industries as they offer better corrosion resistance and good mechanical properties. 1.4404 austenitic steel with a low-carbon, high molybdenum content has wide range of applications in oil and gas, petroleum, marine and nuclear industries, and also in orthopedic implants in bio-medical field [10].

In this research, additive manufactured walls were performed by using austenitic stainless steel 1.4404 with 20 cm^3 volume by tandem PTA and conventional PTA. A comparison of deposition rates, mechanical behavior and geometrical aspects with tandem PTA and conventional PTA was done.

2. Material and methods

2.1. Materials

Substrates in the form of plates 250 x 100 x 10 mm^3 (l x w x h) of the austenitic CrNi material 1.4301 were used. 1.4404 austenitic stainless steel was applied as filler material in powder form (spherical, powder size

50...150 µm). Table 1 shows the chemical composition of base material and filler material.

Table 1. Chemical compositions of base material and powder in wt % [11], [12].

	Base Material	Powder
Grade	1.4301	1.4404
C	<0,07	0.03
Cr	17.5 – 19.5	16.6
Ni	8,0 - 10.5	12.6
Mn	<2.0	0.4
Si	<1.0	0.8
Mo	-	2.1
Fe	Base	Base

2.2. Methods

Tandem PTA system consist of two plasma welding power sources, twice PTA welding torches (MV230 with 3.2 mm electrodes), corresponding power feed units, and a 6 axis robot, which realizes the real-time torch handling. Two flexible and freely adjustable axes was adapted to the robot arm as torch holder, enabling both PTA welding torches to be positioned and fixed in place, as seen in Fig.1.

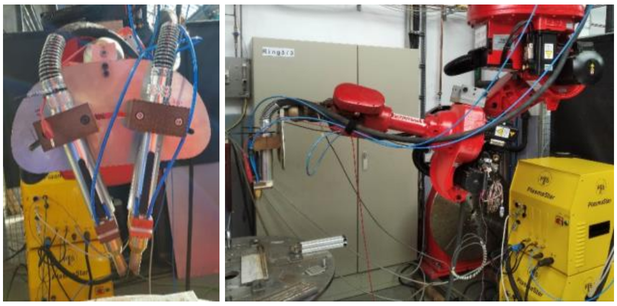


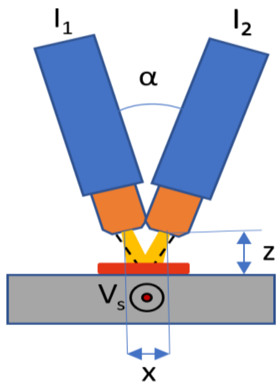
Fig 1. Tandem PTA with handling system.

The constant values of the weld parameters using PTA process are defined by a gas type argon, shielding gas rate 12 l/min, powder gas rate 3 l/min, powder type 1.4404 and a base material 1.4301 that has 10 mm thickness.

2.2.1. Parameters of the conventional PTA and parallel driven tandem PTA for additive manufacturing

Table 2. Welding and torches parameter of conventional PTA and Parallel Driven Tandem PTA for Additive Manufacturing.

Welding Parameters	**Conventional PTA Stringer**	**Parallel Driven Tandem PTA**
Current - Torch 1 in A	200	190
Current - Torch 2 in A	-	190
Welding speed in cm/min	30	40
Powder feeding rate in g/min	46.9	97.0
Welding angle α in °	-	30
Nozzle – Base material distance z in mm	10	10
Nozzle – Nozzle distance x in mm	-	20



3. Results and discussion

3.1. Comparison of single seam with parallel driven tandem PTA and conventional PTA

The influence of main parameters on the coating quality was carried out using parallel tandem PTA as well as conventional "single torch" PTA welding. As a result for the tandem PTA it was determined that a specific torch angle between both PTA torches of α = 30 °, the current pulsing with f = 10 Hz, an anode-base material spacing of z = 8 mm and anode-anode spacing of x= 20 mm leads to a uniform and wide coating. Comparing to the conventional "single torch" PTA coating, the process data and metallographic results are shown in Table 3 and Fig. 2, respectively. It is obvious that the Tandem PTA process achieves a weld width that is increased by approx. 75 % if the same penetration (approx. e = 0.90 mm) is taken as a reference value.

Table 3. Comparison of conventional PTA with tandem PTA process.

Welding Outputs	Conventional PTA Stringer	Parallel Driven Tandem PTA
Welding widht in mm	8.09	13.84
Penetration depth in mm	0.86	0.91
Penetration rate in %	16.1	21.5

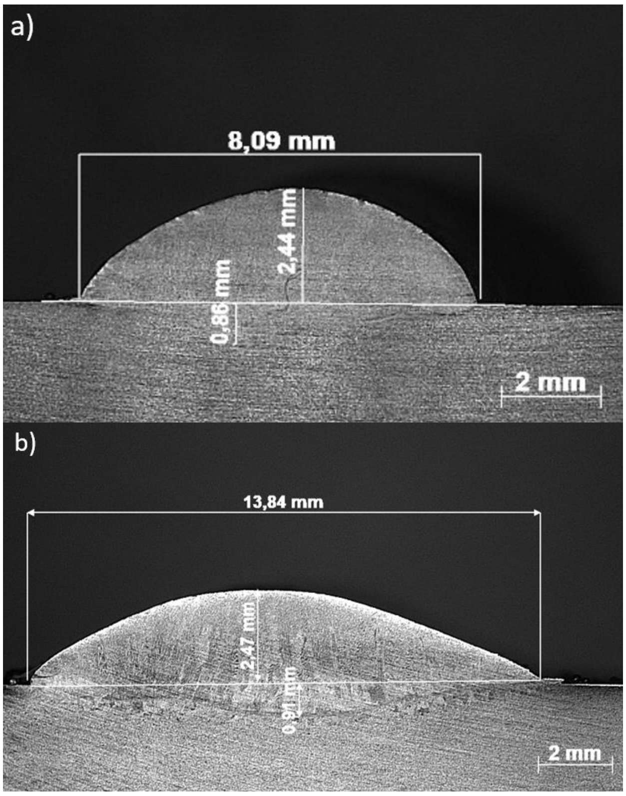


Fig 2. Cross-section of conventional PTA (a) and parallel driven tandem PTA (b) process.

3.2. Comparison of conventional PTA and parallel driven tandem PTA for additive manufacturing

Table 4 illustrates welding outputs and Fig. 3 shows a general view of additive manufactured wall by conventional PTA stringer compared to parallel driven tandem PTA methods. The useful area of samples are formed with determination of maximum useful width and height, respectively, which are illustrated via dashed lines in Fig. 4. The reference volume of deposition applied with 20 cm^3 with h=15 ± 2 mm height and w = 9 ± 0.5 mm width of the useful area that is demonstrated via microscope images of cross-sections of conventional PTA and parallel driven tandem PTA in Fig 4. Parameters were chosen to generate specified geometries and to achieve the maximum welding speed as well as maximum deposition rate. The specified parameters were given in Table 2. Each layer consists of twin weld pass for conventional PTA which are driven, separately. However, parallel driven tandem PTA works with two synchronizer acting PTA torches within one common weld pool. Due to that possibility the number of layers can be decreased, deposition rate, layer width and process efficiency is increased applied. Interlayer temperature was limited to maximum 200 °C. The deposition time of conventional PTA for 20 cm^3 was 280 s. The time per cm^3 is 14 s. The deposition time of parallel driven tandem PTA for 20 cm^3 is 182 s. The time per cm^3 is 9 s. To compare the deposition capacity of tandem PTA is 56 % higher than conventional PTA for specified time.

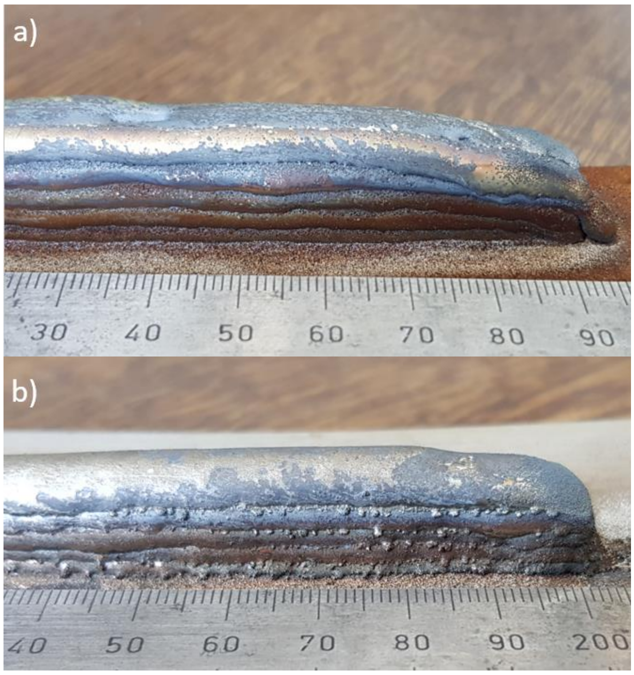


Fig 3. General view of additive manufactured wall by conventional PTA stringer (a) and parallel driven tandem PTA (b) methods.

Table 4. Welding outputs of additive manufactured wall by conventional PTA method and parallel driven tandem PTA.

Welding Outputs	Conventional PTA Stringer	Parallel Driven Tandem PTA
Time per volume (20 cm^3) in s / Required Time	280 / 100%	182 / 64%
Deposition time per cm^3 in s	14	9
Relative deposition capacity for the specified time in %	100	156

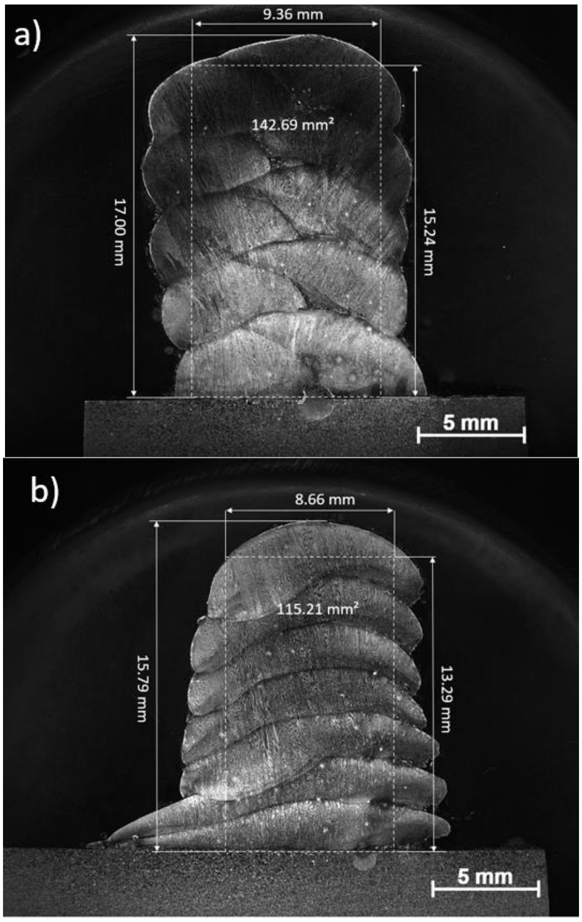


Fig 4. Cross-section of conventional PTA (a) and parallel driven tandem PTA (b) process.

4. Conclusions

The results demonstrate that additive manufacturing can be realized with the Tandem PTA process efficiently. Tandem PTA process is a high-performance deposition process, which also provides a separated control of the welding performance, powder rate and powder type of both PTA systems. Main conclusions of the article are:

- Additive manufacturing with Tandem PTA system is reproduceable
- Parallel driven tandem PTA is usable for expanded layer width to manufacture large components or with high deposition rates
- 56 % increase of the deposition capacity of tandem PTA in comparison to conventional PTA for specified time.

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Author's statement

Conflict of interest: Authors state no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: The research related to human use complies with all the relevant national regulations, institutional policies and was performed in accordance with the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

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