PULSED-PTA DEPOSITION OF TITANIUM

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Abstract

Welding and additive manufacturing of titanium and other sensitive materials are particularly problematic due to their high oxygen affinity. The melting pool has to be protected from oxidation not only during the welding proces but also after its crystallization up to about 300 Celsius degrees. In order to protect titanium-melting pool during and after the welding, pure inert gases such as argon or helium with purity 99.999 % should be used. The present study describes the procedure and basic principles for additive manufacturing of Ti. In order to improve the protection of the melting pool, the small chamber with low overpressure was developed in house and it was used to reduce the oxygen content in the welding area due to argon filling. Based on preliminary tests, some basic parts of titanium gr. 1. were welded by PTA method on plasma hardfacing automate PPC25 R6.Text of abstract should have extent to 250 words.

Keywords: Pulsed PTA, additive manufacturing, titanium

1. INTRODUCTION

The plasma transferred arc (PTA) is widespread technology in domain of surface engineering. This technology uses plasma jet flowing from plasmatron to melt both the filler and the base material and make a layer on the surface of some industrial part [1], [2]. This technology can be considered as a development of gas tungsten arc welding technique, while plasma plum is constricted by water cooled copper orifice and tungsten rod is placed inside the torch. The constricted and focused plasma jet is needed in welding processes, however in case of hardfacing the wide and soft plasma plum is required in order to minimalize penetration, resp. dilution [3], [4] of filler material by parent material. Use of current pulsation is well known in GTAW as a way of increasing bead geometry characteristics[5], [6], [7] but in plasma welding and hardfacing only restricted number of studies can be found[8], [9]. Deposited material fed in the plasma jet can be used in form of wire [10], or powder [11], [12]. While wire-based method is often focused on high melting rate and productivity, the method using powders as an added material is working well in domain of special alloy deposition, as for example materials based on cobalt or nickel [13]. Cermets can be also deposited by powder-based PTA technology [14].

Titanium is metal with a silver color, low density, and high strength. Two crystal structures exist:, hexagonal close-packed (alpha) below 883 °C; body-centred cubic (beta) above 883 °C. Its combination of high strength, low density and excellent corrosion-resistance make it useful for many parts of an aircraft, spacecrafts, missiles, and ships. Titanium is also used in prosthetic devices, because it does not react with fleshy tissue and bone. Even that titanium constitutes 0,44 percent of the Earth's crust, its price on global market is elevated because of its difficult preparation [15]. Commercially pure titanium is characterized by relatively low (200 HV) hardness, while its alloy (grade 5) present vickers hardness more than 340 HV [16], [17]. The presence of oxygen in the structure of titanium also increases hardness, however one-to-one relation between microhardness and oxygen concentration does not exist [18]. Welding and welding-based deposition of titanium is difficult namely because of an extremely low tolerance for any foreign constituent in the shielding gas [19], [20], [21]. This issue is in industrial practice solved by additional shielding devices [22], [23] or by closing of the welded parts into a tight chamber filled with pure argon or another inert gas or in a vacuum chamber [24], [25], [26].

Although it has been patented 100 years ago, additive manufacturing (AM) technologies have shown significant advances in past few years. All AM technologies are based on building-up the part by material deposition layer by layer. While technologies based on powder bed fusion techniques offer high resolution of final parts, direct energy deposition based technologies offer also the ability to add material on existing parts and to remanufacture/repair damaged parts [27], however this technologies have not as high resolution of final part as powder bed fusion based ones. Laser, electron beam or electric arc are the most often used sources of heat needed to melt both the additive and the base material during the layer by layer deposition [28], [29], [30], [31], [32]. PTA as a heat source was reported in modification PTA-wire melting, while PTA-powder based method is much less frequent [33], [34].

2. EXPERIMENTAL

Pure titanium powder gr. 1 (TLS technik, Germany) was used as additive material in order to build-up a rectangular deposit. Chemical composition is listed in **Table 1**. Size of powder particles was 90-200 µm (93 %).

Table 1 Chemical composition of Ti powder

C	Fe	H	N	O	Ti
0.013	0.019	0.001	0.005	0.05	Rest.

Powder particles consist of small, agglomerated particles of diameter lower than 30 to 40 µm (**Figure 1**). Plate of Cr-Ni austenitic steel (AISI 316), 10 mm thick, was used as a base material. Depostion was carried out on commercially available plasma hardfacing automate PPC 250 R6 (KSK, s.r.o., Czech Republic). This machine is designated for glass industry applications, mainly for hardfacing of glass mold edges. The hardfacing automate can work with plasma current pulse up to 200Hz between 40 and 250 A. Pulsation between 45 and 155 A was used with frequency of 3Hz. Torch speed in direction of deposition was 0.4 $mm.s^{-1}$, waving of 18 mm vide and 8 $mm.s^{-1}$of speed was used to make 14 layers of deposit. Plasma deposition was made in a sealed chamber (**Figure 2**) filled with pure argon (99.999 %). IndentaMet apparatus (Buehler) was used to measure microhardness.

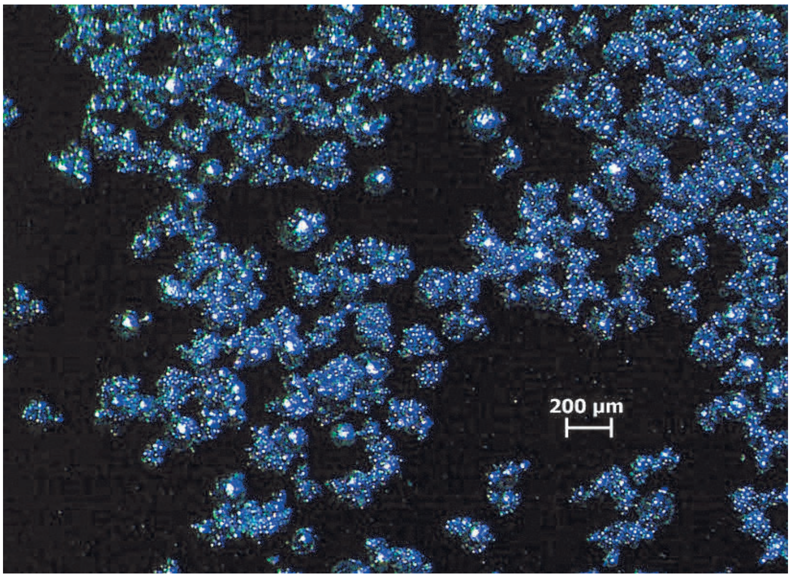

Figure 1 Particles of Ti powder

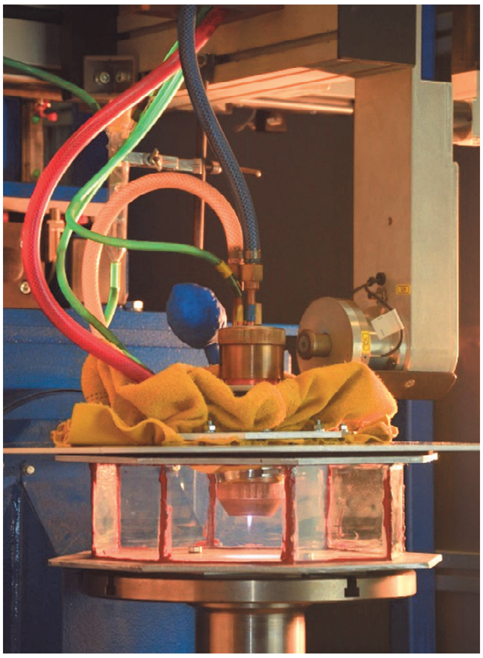

Figure 2 Sealed chamber for Ti deposition

3. RESULTS AND DISSCUSION

Pulsed PTA deposition started after more than 15 min of purging the chamber by argon flow of 2 l.min[1]. The deposition process was stable; however, some irregularities in powder feeding caused different thickness of layers. This instability of powder feeding was caused by heterogeneous shape of agglomerated powder particles. To prevent overheating of the substrate and the deposited layer, dwell time 1 to 1,75 min between each layer deposition was applied. After deposition of the sixth layer the deposit started to delaminate from the substrate. Due to delamination the thermal conduction was lower and, consequently, the dwell time became longer (up to 1,75 min). The deposit was completely delaminated during cutting of the substrate. To make a cross section, two part (substrate and deposit) were cut on metallographic saw together and embedded in resin. The cross section of deposit (**Figure 3**) showed some non-melted parts in the structure. This phenomenon could be explained by low heat input, but most probable reason is the synergic effect of low heat input and powder feeding instability. Although cavities and pores are undesirable, their presence reveals that the surface inside the cavities presents no contamination by oxygen and/or nitrogen. The microhardness plot (**Figure 4**) shows that the microhardness at the fusion line is much higher than that of the base material and the rest of the deposit. This hardness increasing can be explained by creation of an intermetallic phase in the diluted region of deposit. The rest of the deposit presents low microhardness, which is quite close to the theoretical titanium microhardness.

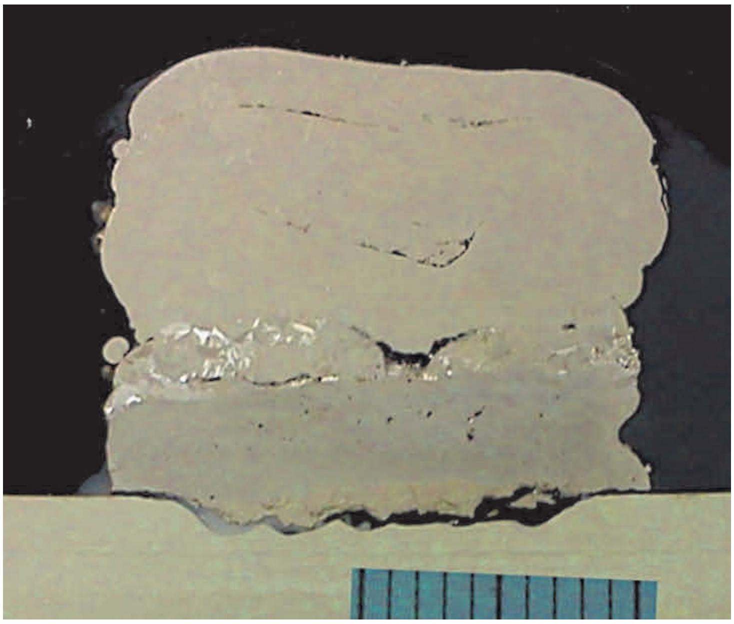

Figure 3 Cross section of deposit of Ti

4. CONCLUSION

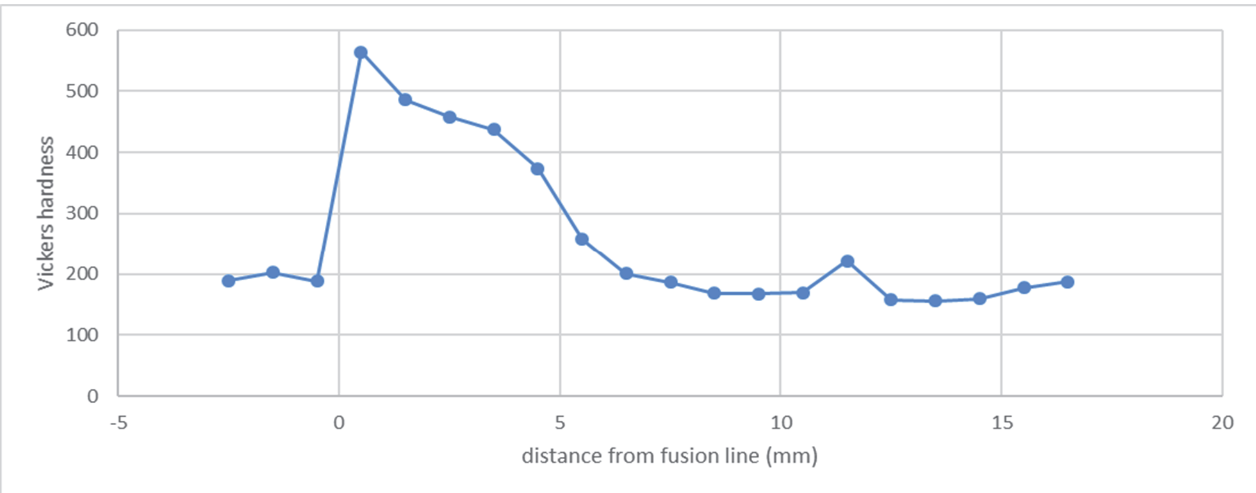

Figure 4 Vickers hardness from the fusion line

- The tight chamber for plasma deposition of titanium on PTA automate was designed and fabricated
- Optimization of parameters was carried out in order to find a suitable parametric envelope for plasma transferred arc deposition of titanium.
- Deposit of weight more than 72g was made by an automatic layer by layer PTA deposition
- Porosity and non-melted cavities were found in structure of the deposit
- Next research will be focused to stabilization powder feeding process and decreasing of heat input.

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