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Microstructural characterization of diode laser deposited Ti-6Al-4V

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Abstract

Laser Direct Metal Deposition (DMD) is an effective approach to manufacturing or repairing a range of metal components. The process is a layer-by-layer approach to building up a three dimensional solid object. The microstructure influences mechanical properties of the deposited parts. Thus, it is important to understand the microstructural features of diode laser deposited parts. This paper presents a microstructure analysis of a diode laser deposited Ti-6Al-4V onto a Ti-6Al-4V substrate.

1. Introduction

DMD (Direct Metal Deposition) process can be used to construct engineering components in Titanium alloys, realizing time, labor and material savings over traditional processes. This laser additive manufacturing technique allows quick fabrication of fully-dense metallic components directly from Computer Aided Design (CAD) solid models. Due to its high strength and the severe temperature rise at the tool-chip interface, Ti-6Al-4V is classified as one of the extremely difficult-to-machine materials using conventional machining, thus it is a good fit for the DMD process [1]. DMD is capable of producing net shape parts, so the machining volume is significantly decreased.

The mechanical properties of titanium alloys are very sensitive to the microstructure, thus, it is important to understand the microstructural features. In this work, microstructure of the diode laser deposited Ti-6Al-4V is studied from the bottom of the substrate to the top of the parts by using the scanning electronic microscopy. The substrate material and the powder are Ti-6Al-4V, which is a common used material in aerospace, marine, power generation and offshore industries. Table 1 shows the nominal composition of Ti-6Al-4V [2].

Table 1. The main composition of Ti-6Al-4V

Element	C	Ti	Al	V	N_2	Fe	O_2	H_2	Other, Total
Composition (%)	0.10	87.58-89.83	5.50-6.75	3.50-4.50	0.05	0.40	0.020	0.015	0.40

* Other, Each (Maximum) = 0.1%

** For AMS 4928 (Bar, Billet, Forgings) Hydrogen = 0.0125% and Iron = 0.3%

2.1 Laser-based Repair System Framework

The LAMP system mainly consists of a 5-axis CNC machining center, a 1.0 KW Diode laser, a powder feeder, and a real–time control system from National Instruments. During deposition, the substrate is fixtured on a 5-axis CNC. The nozzle through which the laser and metal powder is transmitted is fixed to Z-axis of the CNC. The laser is focused on a small area of the substrate and creates a molten pool, and the metal powder is delivered by the powder feeder system into the molten pool to create the deposition. The X, Y and Z table positions and velocities are regulated via the CNC machining center controller according to the program generated from the CAD model [3]. This hybrid repair system employs 5-axis positioning system which includes of 3 linear axis and 2 rotating axis. The advantage of it over conventional 3-axis positioning system is that it does not require support material to build overhang features for 3D parts. This capability allows both the deposition and machining in a single set-up for a part even with intricate or hidden features. Figure 1 shows the Direct Laser Deposition process.

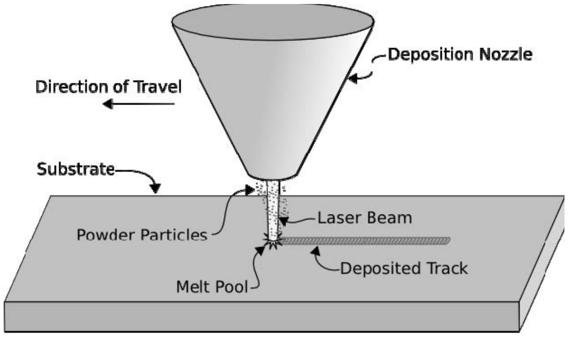

Figure 1: Schematic of a typical laser deposition system

2.2 Experimental Procedure

Direct Metal Deposition (DMD) system from MST- LAMP (Laser aided manufacturing process) lab which consists of a 1kw Diode laser, powder delivery unit, 5-axis CNC machine, and monitoring subsystem, to deposit the Workpiece. Parameters used in the deposition: Scanning speed: 20 ipm, Powder feeding rate: 5 g/m, Laser type: diode laser, Laser power: 700W. A Cross-section of the deposit and the substrate was prepared to observe the microstructure under the scanning electron microscope (Hitachi, model 570). The samples were etched for 8s by the Kroll's reagent composed of 5 parts HNO_3, 10 parts HF and 85 parts of H_2O to reveal α and β phases. The images were captured at 25 kV using secondary detector and SEM scale at every 0.5 mm from the substrate to the top of the deposit.

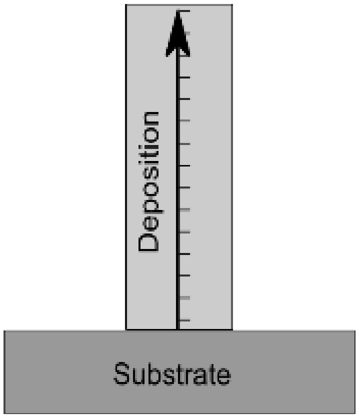

Figure2. Image capture sequence

3. Results and Discussions

The substrate used is commercial Ti-6Al-4V alloy, which has microstructure of globular crystals of β in α matrix, obtained by mill annealing. At the heat affected zone, which begins at Z=2.63mm under the current parameters, it can reach the temperature of approximately equal 1000°C. This temperature is below the β transus, where some of the β is transformed to secondary α. The microstructure consists of secondary α, primary α, and β. The micrographs show equiaxed α in an acicular α (transformed β) matrix. At he fusion zone, which was above β-transus temperature, the microstructure consists of blocky and plate-like acicular α (transformed β) and α at prior β grain boundaries. From the fusion zone to 12 mm into the deposit we observe α plate-like acicular alpha (transformed β) and α at prior β grain boundaries due to slower cooling rate than at the fusion zone. A steady state is reached from above 12-22 mm and not much difference was seen in the microstructure which revealed basically a widmansttaten basketweave structure of α and β with some α colonies [4, 5].

The general trend is that at the lower end of the deposit, the widths of alpha plates are greater because of the heat treatment effect of subsequent laser passes for later layers, so alpha plates have more time to grow at the lower section than at the upper section. β

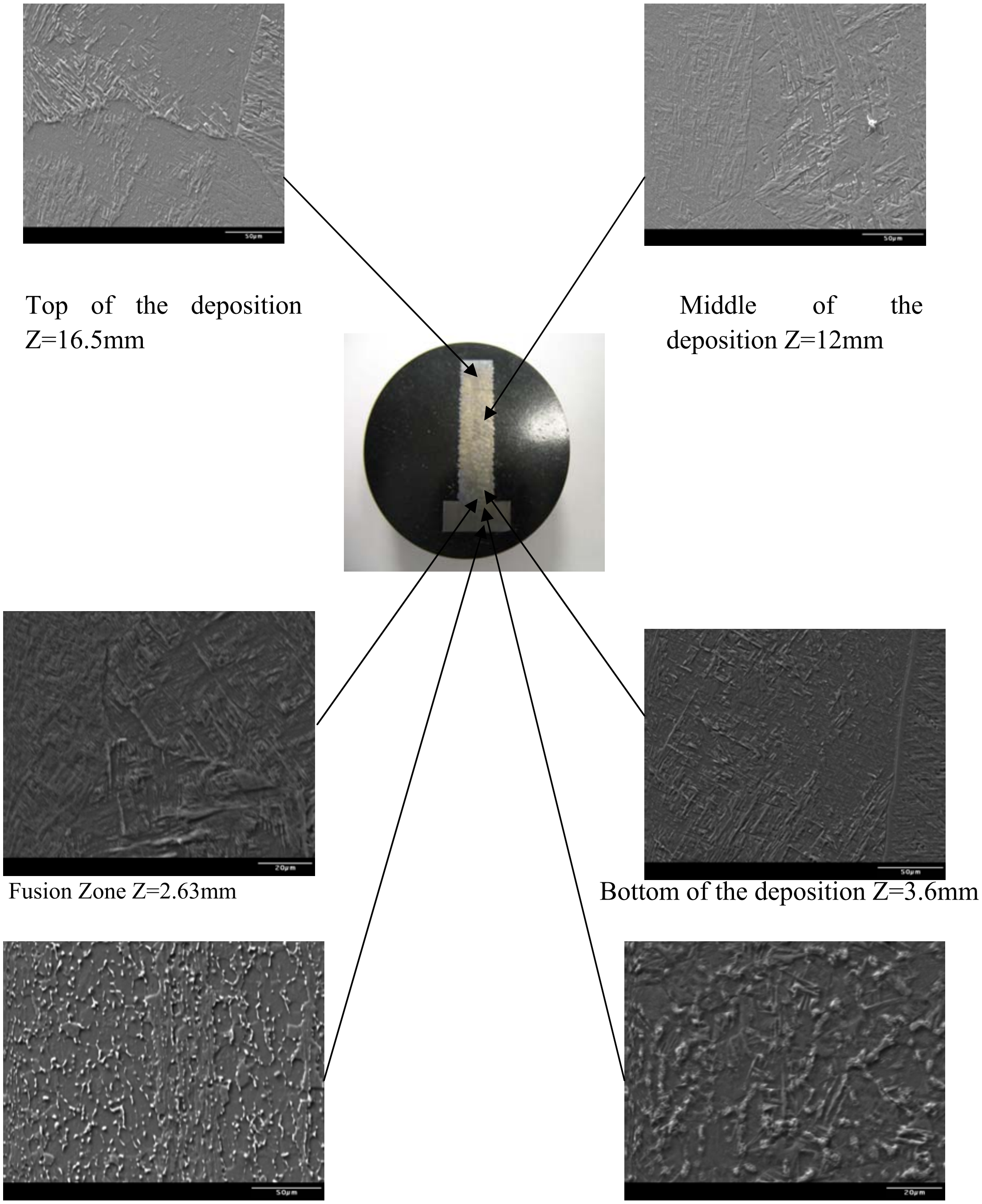

Figure 3. SEM micrographs of the Ti-6Al-4V deposit processed by laser deposition. (The micrographs were taken from the middle of the deposit in the horizontal direction. The z value is the distance calculated from the bottom of the substrate.)

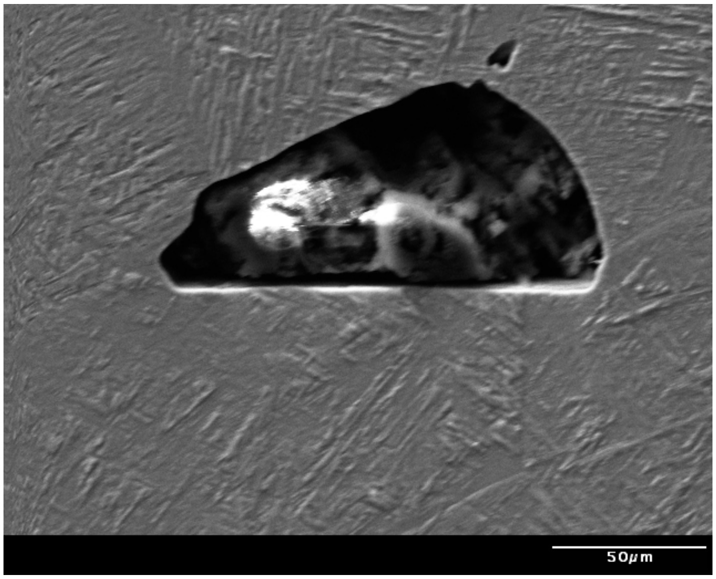

Figure 4. Porosity in the deposition

In Figure 4, a defect can be seen at the bottom of the deposition. The reason for this is the ratio of height to width of each layer is too high due to the parameter of the laser deposition does not match very well , when the second layer deposit on the first layer, the liquid can not drop into the clearance of the first two layers. Thus, a defect is generated.

4. Future work

In-depth study will be carried out to understand the influence of laser process parameters on the microstructure and mechanical properties of the Ti6Al4V deposit

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