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Effect of Hot Isostatic Pressure treatment on the Electron-Beam Melted Ti-6Al-4V specimens

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Abstract

The main advantages of additive manufacturing (AM), including fabrication of complex geometry lightweight objects, lattice structures, chain and gear mechanisms, better environment saving materials and resources and energy, better tool life of component, etc. are already well known. The main challenge in AM of metals is to achieve proper mechanical properties and performance, especially for safety critical parts. Thus, post-processing procedures for AM come to the front.
In the framework of this research were prepared specimens by Electron Beam Melting (EBM). In case of the EBM, the greatest problem is porosity, which is especially critical for airspace components. One of the procedures recommended for decreasing porosity is Hot Isostatic Pressure (HIP) treatment, and its effect should be thoroughly studied to widespread its application.
To investigate this aspect, Ti-6Al-4V cylinder parts were printed on the ARCAM EBM A2X machine using a 210×210 mm building platform. The microstructure and mechanical properties of the EBM specimens were tested before and after the HIP treatment. High cycle fatigue tests (HCFT), fracture surface examination, as well as micro-CT evaluation were performed.

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Keywords: Electron beam melting; Addititve manufacturing, EBM, HIP, Ti-6Al-4V, High cycle fatigue test

1. Introduction

The EBM and laser AM are rapidly developing technologies, exciting new markets and industrial sectors [1]. Investigation of post-processing and treatment modes should be done keeping in mind that for the production of safety relevant parts, the static and fatigue strength is especially important [2]. Electron beam melting (EBM) is a powder

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bed based process for AM utilizing a high-power electron beam which delivers the energy needed for high productivity and high melting capacity [3, 4]. The EBM technology capabilities are currently limited by the size of the electron beam spot in the melting zone with a diameter of 0.25 -1.0 mm, whereas when using a laser, this value is an order of magnitude smaller.

Most of the EBM research as well as industrial activities is done on titanium alloys, especially Ti-6Al-4V. This two-phase titanium alloy consists of a hexagonal close-packed (hcp) α-phase and a body-centered cubic (bcc) β-phase [5]. The transition temperature between the two phases for Ti-6Al-4V is 995 °C [6-8]. Titanium alloys are used as an important lightweight material in modern airspace structures and bio-medical implants, which require high structural efficiency, with high performance at moderate operating temperatures, as well as good fatigue and creep strength [6].

The Hot Isostatic Pressure (HIP) treatment is a well-known post-processing procedure for EBM parts. It is a recommended procedure by GE-Arcam, producer of EBM machines, and now HIP is widely implemented by industry to decrease porosity of EBM additive manufactured components before utilization. Nevertheless, due to innovative character of AM, there have not been enough data reporting on the evaluated efficiency of pore closure in HIP-treated EBM components with extensive statistics [9].

HIP treatment became a highly used method for removing residual porosity in Ti-6Al-4V castings, because of its efficiency in significant fatigue life improvement of critical parts [7, 8]. This treatment involves simultaneous use of high pressure to a Ti-6Al-4V component under high temperature conditions in inert gas atmosphere. The high pressure applied causes closure of pores by low-scale plastic flow and material transfer, which under optimal conditions may also bond the pore interfaces.

The best microstructure examination from the viewpoint of porosity is performed by computed tomography (micro-CT). The latter can be used to analyze porosity in cast or printed Ti-6Al-4V specimens before and after HIP, and to investigate the effectivity of heat-treatment parameters chosen for the closure of pores. However, for the evaluation of HIP treatment effectivity from the viewpoint of mechanical properties improvement, the high-cycle fatigue tests should be performed.

There are several ASTM standards of AM regulating the HIP parameters. However, the problem with them is, in fact, that they were probably copied from some standards for Ti-6Al-4V castings, e.g. AMS 4991, and are not 100% suitable for the EBM.

In a number of previous works, the Ti-6Al-4V powder produced by different methods was studied [see, e.g. 10-12], and the problem of porosity was mentioned there, as well as clear correlation between the size and geometry of spherical pores in powders and in built materials.

The goal of the current study is to widen the database on effect of HIP on porosity closure of as-built Ti-6Al-4V EBM as-printed parts for airspace application, as well as to investigate the positive impact of HIP treatment on their fatigue resistance.

2. Experimental setup and method of measurement

The investigated Ti-6Al-4V powder, used for AM with normal particle size distribution of 45-120 μm, was supplied by GE-Arcam. The chemical analysis, the composition of the tested powder is as follows: 6.54% Al, 4.05% V, 0.2% Fe, 0.02% C, 0.02% N, 0.11% O and 0.002% H.

ARCAM A2X EBM machine under vacuum below 1.510-4 was used to perform the electron beam melting process. Arcam A2X is an industrial machine designed for processing of titanium alloys, as well as materials that require high temperatures during melting. The machine is primarily positioned for the use in airspace industry [3, 13].

At the beginning of the building process, an initial steel plate is heated to 730 °C. The temperature is measured by a thermocouple underneath. The nominal thickness of the new layer of powder was of 50 μm. The fresh powder is preheated by fast scanning with a defocused electron beam. After the part contours solidification, the specimen interior part is molten by a focused electron beam (with maximum beam power of 3kW and focus offset of 3 mA) with 15 mA current and a speed function of 98. In this case, the beam speed is 3.2 m/s, the line energy is 280 J/m and the beam step (Hatch) is 0.1 mm. The principal scan direction between each layer is alternated from x-axis to y-axis. The parts are oriented in the build space in such way that the direction of the subsequent mechanical testing is coincided with the building direction (z-axis) [6].