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Laser beam welding of titanium additive manufactured parts

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Abstract

In this paper the joinability of titanium Additive Manufactured (AM) parts is explored. Keyhole welding, using a pulsed laser beam, of conventionally produced parts is compared to AM parts. Metal AM parts are notorious for having remaining porosities and other non-isotropic properties due to the layered manufacturing process. This study shows that due to these deficiencies more energy per unit weld length is required to obtain a similar keyhole geometry for titanium AM parts. It is also demonstrated that, with adjusted laser process parameters, good quality welds for aerospace applications in terms of pressure resistance and leak tightness are achievable.

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Keywords: Laser beam welding; Keyhole welding; Additive manufacturing; Selective laser melting; Titanium (Ti6Al4V) alloy

1. Introduction

Additive Manufacturing (AM) is a relative new type of production technology. Parts are generally built using a layered approach, thus enabling the formation of part features that are impossible to produce using reductive manufacturing techniques (e.g. turning, milling, etc.). At first the AM of polymers was used predominantly to produce models for visual purposes. However as the processes are maturing and with the option to produce metals as well, AM is establishing itself as an advanced type of production technology and design engineers are increasingly embracing its unique properties to design parts with complex embedded functionalities.

In this paper, the joining process of titanium AM parts is investigated. Ideally all required features are integrated into one part; however, this is not always possible. For instance, due to the size of the build chamber, due to the fact that multiple features demand multiple part orientations or simply due to cost aspects. In such, and other cases, multiple parts may be produced that need to be joined as a secondary process step.

Metal AM processes typically use a laser beam as energy source to fuse particles together. This process is similar to the much researched process of Laser Beam Welding (LBW); the difference being the fusing of particles in a powder bed versus the fusing of a seam between typically two solid parts. The interaction of the fused and unfused particles in the powder bed and its effect on the mechanical properties of the final parts are still ill understood phenomena in the area of metal AM.

1.1. Research question

The main research question for this study is: Can we join titanium AM parts with similar process settings as LBW of conventional titanium parts?

It is well known that powder bed based laser beam AM processes (e.g. SLM, SLS, DMLS, laser cusing, etc.) typically do not reach full density. In this study, the effect of remaining porosities in the AM parts on the weldability is researched, as this is believed to have a negative influence. The weld characteristics and process settings for LBW of conventional parts and AM parts are compared.

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The application of this research is primarily for butt welding for aerospace applications. This demands a pressure resistant hermetic weld that is 100% leak tight along the entire weld joint.

1.2. Research approach

To compare the weldability of conventional and AM parts, a test part is designed that is produced both conventionally (i.e. by turning) and by AM, in this case Selective Laser Melting (SLM). Titanium alloy Grade 5 (i.e. Ti6Al4V) is chosen as base material, because of its relative low density (low weight), corrosion resistance and good processability [1]. For aerospace applications Ti6Al4V is a very common alloy.

The test part is composed of essentially two cylindrical disks that are joined along the circumference, as shown in Figure 1. The outer diameter is 32mm. An internal cavity, connected through a connection tube, is inserted to test the pressure resistance and leak tightness of the weld connection. Also, thermocouples are attached along the bottom part to measure the amount of heat conducting into the part during the welding process.

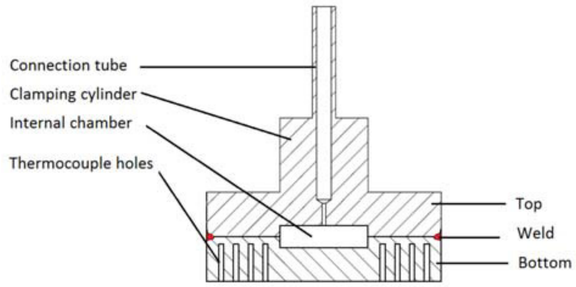

Fig. 1. Test part consisting of a top and bottom half welded together.

For the AM parts, the build direction was vertically upwards with respect to Figure 1 in order to keep the connection tube circular. The AM parts for this study are produced using an SLM Solutions 280HL machine.

The pressure resistance and leak tightness of the weld joint and the accompanying part process temperature are critical for this study, as for the real application electronics are embedded into a pressurized part.

Before welding the test part, a series of test welds are performed in a bead-on-plate configuration to find the best set of process parameters (i.e. laser power, pulse duration, pulse frequency and welding speed). Naturally, for the conventional test part a conventionally produced piece of material was used, and similarly for the AM test part an AM produced piece of material was used.

1.3. Outline

The paper is structured as follows. Chapter 2 gives a short literature background on metal AM. In Chapter 3 the process settings for keyhole welding using a pulsed laser are compared for convention and AM parts. Chapter 4 presents the application results and weld quality for the LBW of the test part of Figure 1 for aerospace applications. Finally, in Chapter 5 the conclusions of this study are presented.

2. Metal additive manufacturing

Powder bed based metal AM processes build a 3D structure in a layered approach. Features are produced by fusing raw material, a fine powder, layer by layer, stacking layers until the full 3D part is ready. This is illustrated in Figure 2. Loose powder is rolled from the powder supply side to the part build area. Here, the powder is fused where needed by the laser beam, using the part's computer (CAD) model. After producing a layer, a new layer of loose powder is rolled onto the previous. This cycle continues until the complete (end-) part is produced.

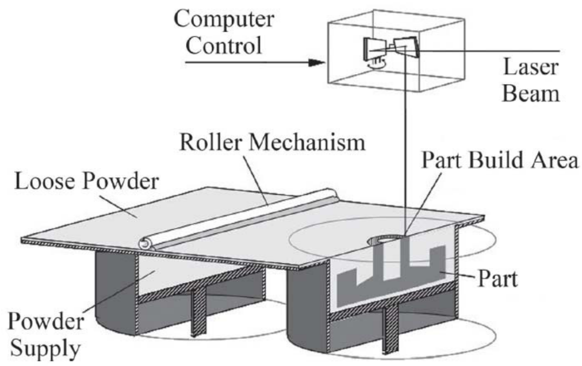

Fig. 2. Powder bed based metal additive manufacturing process [2].

Typically, AM parts are prone to small imperfections (e.g. remaining porosities) as shown in Figure 3, where cross-sections of SLM processed titanium are shown. Full density is usually not reached and parts are sensitive to non-isotropic behavior caused by the layered process and the subsequent build direction. Also, a relative high surface roughness compared to conventional manufacturing is common [3]. Surface roughness values (R_a) in the range of 10μm and higher are to be expected for titanium alloys [4]. As LBW requires a surface roughness of 1.6μm or better, in such cases the joining surfaces of the AM parts have to be post processed (e.g. by turning).

To reach full pressure resistance and 100% leak tightness of the welded test part itself, laser sintering is