

Combination of LPBF and welding: A practical application Manufacturing of the epee for Dominique Perrault

Verfasser des Aufsatzes: Schwarz, Alexander; Dizdar, Gül; Wohlfarth, Marcel

IwF GmbH - Institut für werkzeuglose Fertigung

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Abstract

One of the limiting factors of the actual LPBF machines is the size of their build chamber, their productivity, and the process stability. The welding of LPBF parts can be used to overcome these problems, but at the moment it is mostly shown on demonstrators and not used for real world applications. This paper describes the manufacturing of an epee, which was used for the inauguration ceremony of Dominique Perrault at the French Académie des Beaux-Arts. Only by a combination of additive manufacturing with the Laser powder bed fusion (LPBF) process followed by a manual laser welding process, the requirements of the design could be fulfilled.

Introduction

One of today's major limitation of additive manufacturing in general, but especially for the Laser powder bed fusion process (LPBF) is the size of the build chamber. The last few years have shown, that manufactures follow the demand of the industry by developing and introducing larger LPBF machines. For example Concept Laser started with the XLine 1000 (build chamber size: 630 x 400 x 500 mm) [1], followed by the XLine 2000R with a build chamber size of 800 x 400 500 mm [2]. The newest machine presentation of Concept Laser is the project A.T.L.A.S. with a build size of 1100 x 1100 x 300 mm [3]. But also new competitors, like Kurtz Ersa with the "Flying Ray" [4], E-Plus-3D with the EP-M1250 [5], or Adria from Portugal are introducing larger machines for the LPBF process [6].

The enlargement in the build chamber size goes hand in hand with different drawbacks:

- Higher costs for the material storage
- Longer process times
- Higher risks of failures
- High hourly costs for the machines.

There are different approaches to solve the previous stated drawbacks. For example SLM Solutions recently revealed a new machine with 12 x 1 kW Laser to increase the productivity and a build chamber of 600 x 600 600 mm [7]. The previous maximum were four Lasers in one machine (SLM Solutions SLM 500 [8]).

Another approach to overcome the size limitations of today`s LPBF machines is the combination of additive technology with welding technology. Different publications proofed the weldability of parts made with LPBF. For 1.4404 it was proofed by Laitinen [9], Matilainen [10] and Casalino [11], for AlSi10Mg a research group of the Aachen University of applied sciences showed a working principal with Laser welding in vacuum [12]. But most of the publications showing only working principles on test specimen with a weld groove preparation known from welding of conventional parts. Schwarz, et. al. [13] showed the possibility of using new weld groove designs, which are only possible in an economic way by additive manufacturing. Another study was carried out by a consortium, consisting of EDAG, Siemens, Constellium, Concept Laser, Fraunhofer IAPT, and the BLM group, which presented a steel frame knot, made by the L-PBF process and connected to standard steel profiles [14]. The combination of different manufacturing processes was used, to reduce the costs in contrast to solely use additive manufacturing process to print the entire complex shaped knot. The second generation of the spaceframe made out of aluminum was presented at the Hannover Messe in 2019 [15]. Instead of welding the profiles, the second generation of the space frame uses adhesives for the connection [16].

Based on the experience gathered by the production of molds for foaming processes, where the weld seam should not be visible on the foamed product, a new application was found when the French architect office Dominique Perrault (DPA) asked for the manufacturing of a one meter long epee for his inauguration ceremony into the French Académie des Beaux-Arts. The requirements of the epee were partially like the requirements for the molds, as it should look like made from a single piece and especially no welding seams should be visible.

Design of the epee

The idea of DPA was the combination of traditional elements from the field of construction industry (armor iron) with new manufacturing technology to build a bridge between the old traditions of the Académie des Beaux-Arts and new manufacturing technologies. The design idea is shown in figure 1.



Figure 1: Idea of the epee design

Two major design elements are inspiring the design of the epee. First the armor iron, which represents one of the most used materials in the construction industry. The second influencing element are olive leaves, as motif of the academician's uniform. The whole epee is a simple metal cone which should look like made from one single piece, as shown by figure 2.



Figure 2: Design of the epee for Dominique Perrault

The first idea was to use lathing as manufacturing technology. But due to the long and slender design of the epee with the decorative elements on it, see figure 2, there would be problems with vibrations during the manufacturing process. These vibrations would result in marks on the surface of the manufactured part.

The only manufacturing technology, which can produce this long slender design with the elements of armor iron on it is LPBF. An additional advantage in this case, although it is generally considered as a disadvantage of the LPBF process, is the rough surface. The surface structure resulting from the LPBF process is like the structure of an armor iron and therefore suits very well to the desired design aspect. The disadvantage of the technology is of course the limitation of the build chamber size. Even the XLine 2000R, which is currently the machine with the largest build chamber available on the market, is not big enough for the epee, as shown in figure 3. Additionally, support structures would be necessary for the process if the epee is positioned as shown in figure 3. The support structures would lead to marks on the surface which must be removed in a manual and elaborate process. Additionally, only AlSi10Mg can be used on the machine without a tremendous amount of effort to change the powder material in the machine.

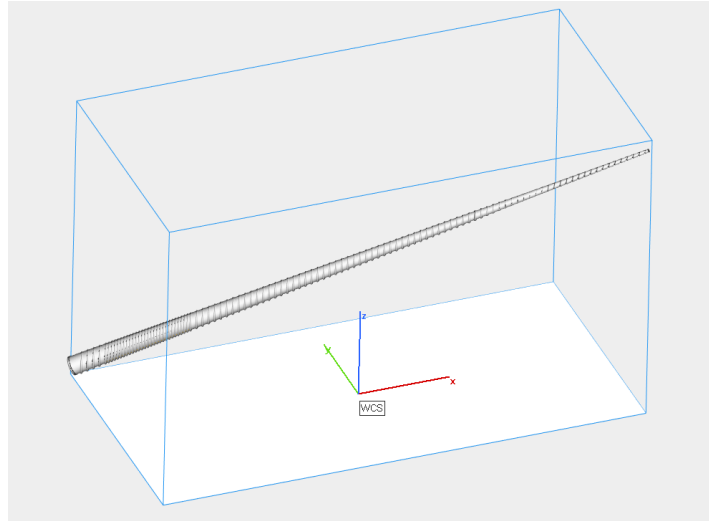


Figure 3: Diagonally positioned epee in XLine

Due to the size of the epee, it is decided to split it into five single pieces and build it on the Concept Laser M1 (build chamber size: 250x250x220 mm), which is available at the Aachen University of applied sciences. This enables an upright positioning, which also allows the smallest surface roughness, of the single pieces and supports are only required at the end faces of the parts, as shown in figure 4.

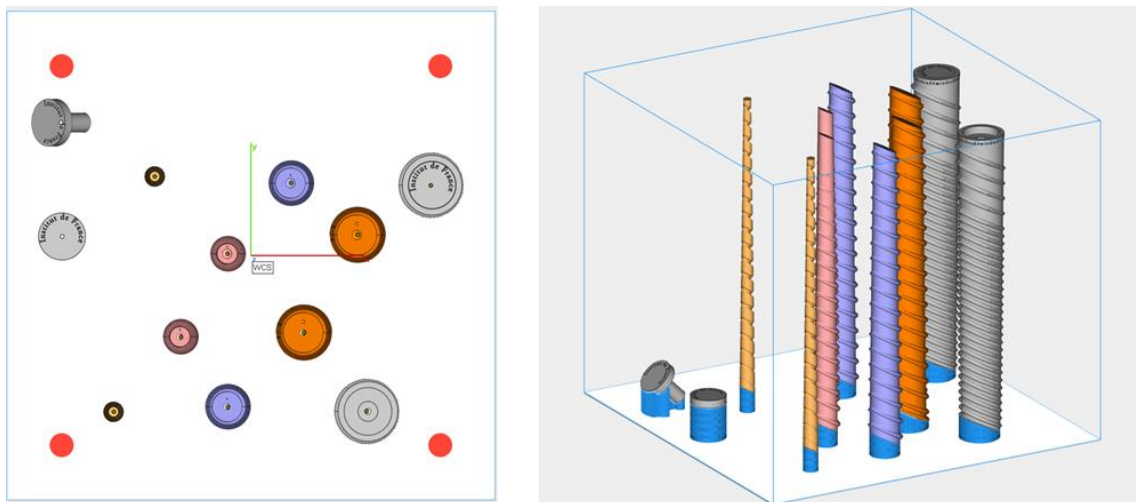


Figure 4: Split epee parts positioned in the Concept Laser M1

For the final design and appearance of the epee, it is crucial, that the weld seams are located between and parallel to the design of the iron armor decoration and do not cut it. Figure 5 shows how the sections are placed between the decorative elements of the epee. A cutting of the decoration would lead to a clearly visible mark on the surface.

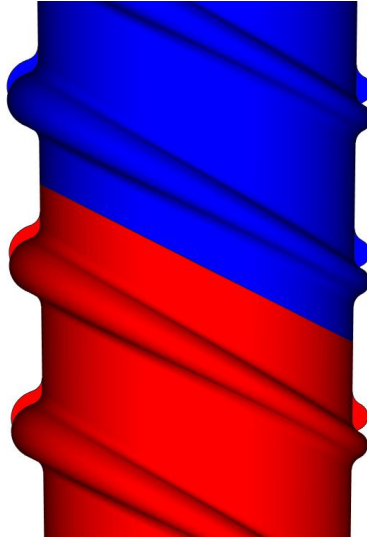


Figure 5: Detail of one split in the epee

As the fine laser welding device, which is used to create the surface welds, will not have the possibility to create structural strong parts, the epee is reinforced by internal metal bars. The metal bars are used as a kind of skeleton to take bending forces, which occur due to the net weight of the epee. Of course, the epee is only suitable for decorative use and not for fencing.

LPBF process of the epee

The manufacturing process of the epee uses a height of 210 mm, which is nearly the full height of the machine. The splitting of the epee offers the possibility to produce all parts in a single process, which increase the productivity in contrast to multiple processes. The manufactured parts are shown in figure 5.

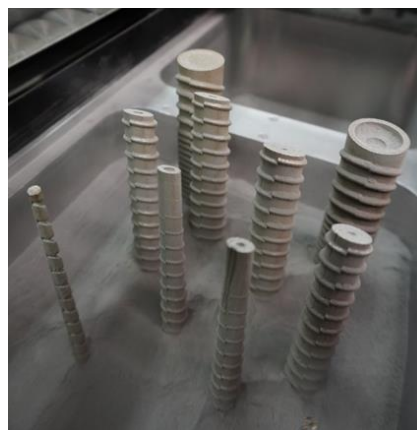


Figure 5: Manufactured parts of the epee

Of course, a post-processing of the parts must take place for different reasons. As described by Schwarz, et. al., the surface roughness of the LPBF process is too high for a laser welding process that needs to be used to reach the required optical appearance. The end faces of the parts are filed to

reach the surface smoothness. Another aspect are the resulting tarnish colors of the LPBF-process, as tarnish colors reduce the corrosion resistance of stainless-steel parts, therefore a sandblasting process is utilized to remove them [17].

To create the suitable diameter for the internal metal bars, a lathing process is used, for which special clamps are manufactured by fused layer modeling (FLM) and offer the shape of the epee, see figure 6.

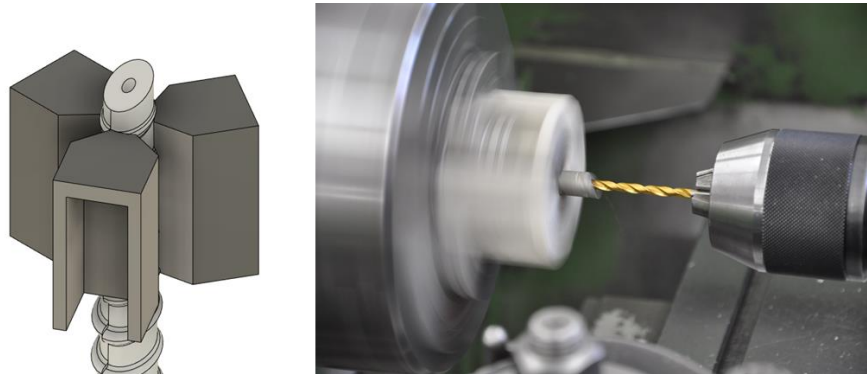


Figure 6: Clamping and lathing of the epee

Welding of the epee

The welding process of the epee is carried out by a hand guided laser welding device, as it is known from the dental industry, and shown in figure 7. The laser source is Trumpf/Haas Nd:YAG Laser, with a maximum pulse energy of 5 kW. As the original laser welding device was not suitable in size for the welding of the epee, cut-outs are drilled to offer the possibility to weld long, slender parts, as seen in figure 7. To ensure the laser safety when in normal use, polymer covers are additively manufactured to close the cut-outs.

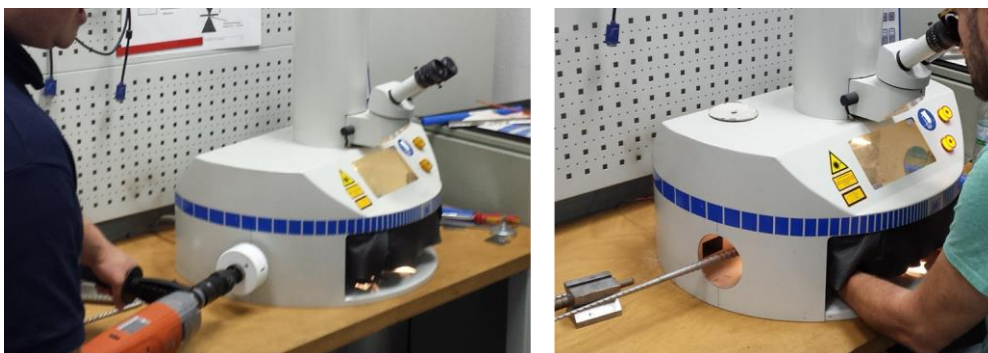


Figure 7: Adaptions of the laser welding device

The welding of the epee is shown in figure 8. The upper half of the figure shows the unwelded area (red mark) while the lower half shows the already welded area. Of course, due to the welding at atmosphere, tarnish colors are visible on the weld seam. Therefore, a post processing of the epee

must take place, which consists of a sandblasting of the weld seams and a polishing of the sword tip, to meet the desired appearance as shown in figure 9.

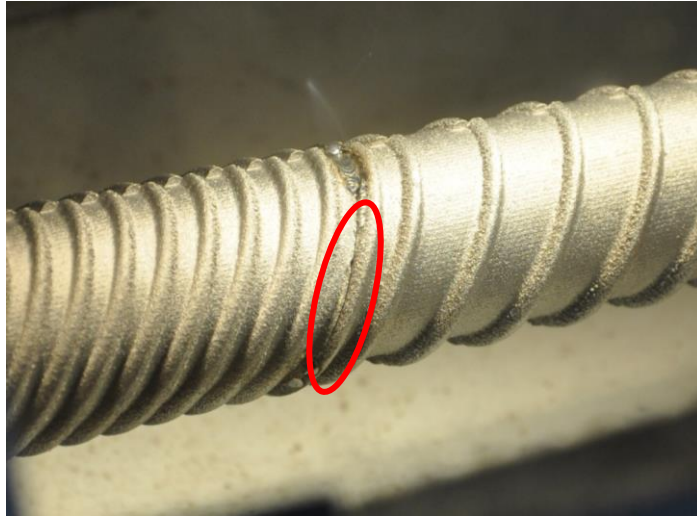


Figure 8: Laser hand welding of the epee

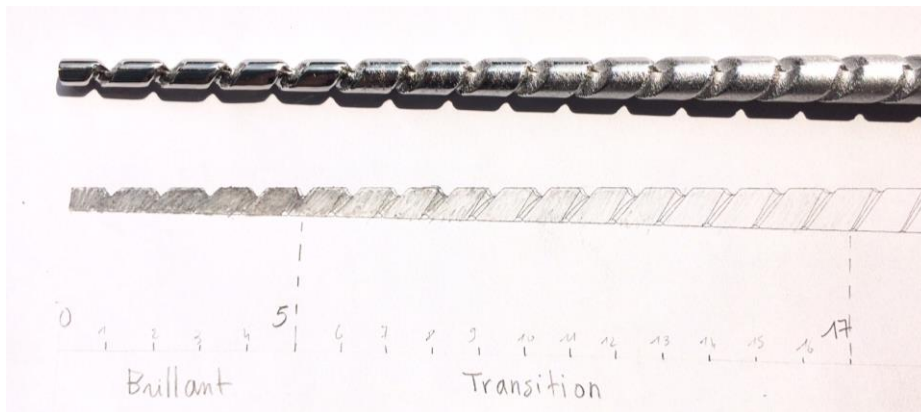


Figure 9: Polished tip of the epee

Due to the bevel of the end faces of the parts, they can only be fitted together in one position. Similar to the described pattern in [13], the bevel fulfils two major functions. On the one hand it has a decorative function and avoids visible marks on the iron amor decorations. But the second function is the exact positioning of the parts relative to each other. This avoids a twist of the epee over the whole length of it. Flat end faces would require additional fixtures, to ensure the angle of the parts to each other. This can be avoided with the design of the parts and therefore a more cost-efficient joining process is established. As it can be seen from the following figure 10, the laser weld seam is invisible on the surface, with no marks that can be seen.



Figure 10: Weld seam on the epee

Conclusion

The project has proved the advantages of a design, which can only be made by additive manufacturing for a welding application. The design freedom, which is offered by the LPBF process is used in an advantageous way, to reduce the effort, necessary for the positioning of different parts for the welding process. By splitting the desired component into smaller pieces, an advantageous orientation of the parts could be kept during the manufacturing process. Additionally, a machine with a smaller build chamber size can be utilized to produce the parts, which is more cost efficient than a large machine would be.

Only the combination of different manufacturing process along a process-chain enabled the manufacturing of the epee. By using the advantages of the single processes, a cost-efficient and realizable solution to produce this epee was possible.

The epee was given to Dominique Perrault during his inauguration ceremony and is exhibited at the Academy des Beaux-Arts. Figure 11 shows Domonique Perrault after the ceremony with the epee (left) and in discussion about the design and manufacturing of the epee with the former French president François Hollande (right).



Figure 11: Dominique Perrault in front of the Académie des Beaux-Arts (left) and with the former French president François Hollande (right)

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Contact

Dr. Alexander Schwarz
IwF GmbH - Institut für werkzeuglose Fertigung
Campus-Boulevard 79
52074 Aachen
Email: a.schwarz@iwf-research.de
WEB: www.iwf-research.de

Gül Dizdar
IwF GmbH - Institut für werkzeuglose Fertigung
Campus-Boulevard 79
52074 Aachen
Email: g.dizdar@iwf-research.de
WEB: www.iwf-research.de

Marcel Wohlfarth
IwF GmbH - Institut für werkzeuglose Fertigung
Campus-Boulevard 79
52074 Aachen
Email: m.wohlfarth@iwf-research.de
WEB: www.iwf-research.de