FUNCTIONAL PROTOTYPE FOR THE VALIDATION OF THE INNOVATIVE METAL ADDITIVE MANUFACTURING SLEDM PROCESS

Franz Haas, Tiefnig Raphael – Institute of Production Engineering (IFT)
Graz University of Technology, Kopernikusgasse 24/I, Austria
E-Mail: franz.haas@tugraz.at

ABSTRACT

Additive manufacturing has found its way into industrial series production. However, market growth has only been possible by the introduction of new AM-technologies and the continuous improvement of existing processes. This paper covers the practical implementation of a prototype for research and validation of the unique SLEDM process patented by TU Graz. The demonstrator includes a feature for vibration-based powder coating for the melting process as well as the concept of power input via an LED-based light source. The prototype enables up to now simple and fast melting of different low-melting powder materials such as tin, zinc and aluminum within an inert gas atmosphere. In addition, the experimental setup forms the basis for the development and adaptation of a suitable light source for the next generation SLEDM process. The goal is to test the additive manufacturing concept with the innovative LED light source and analyze the produced metal parts. The evaluation of the recorded measurement data and the analysis of the test results provide important knowledge about the potential of the SLEDM process for further research and industrial manufacturing.

KEYWORDS

Metal Additive Manufacturing, SLEDM, Selective Laser Melting, Powder Layer Fusion, LED-Technology, Support-Structure-Optimization

1. INTRODUCTION

Additive manufacturing (AM) [1] is based on the principle of building up three-dimensional physical objects layer by layer. In these processes, the work piece is produced in a tool-free manner. The AM-process chain starts with a CAD model represented by a surface mesh of triangles (STL-Format) sliced into layers by software. Each layer contains information about the contour in the XY-plane, the layer thickness, the layer number (or Z-coordinate) and the corresponding machine parameters. This data set is transferred to the machine, which begins to build up the work piece layer by layer. In each work step, the contour of the respective layer is created and connected to the layer below [1]. Through this process principle, additive manufacturing offers numerous advantages over conventional processes (machining, forming, casting). Production of highly complex geometries with internal cavities, the generation of grid structures and functional integration are comparably easy to realize [2]. Due to the high flexibility in AM, a high degree of individualization [3] of the component is also possible.

Up to now, several processes have become established in the field of metal additive manufacturing. Selective laser melting (SLM) and selective laser sintering (SLS) use laser radiation to generate component contours [4]. In electron beam melting (EBM), the energy of the electron beam is used to create and melt the component layers [4]. Methods that are categorized as built-up welding [5] use electric arcs or gas flames as energy sources for additive manufacturing.

The mentioned processes, characterized by the bottom to top built-up principle and the fusion in the powder bed, bring disadvantages in addition to the already mentioned advantages. These cover, for example, the high machine and process costs, hazardous risk of remaining powder in the final product and the manufacturing restrictions by overhanging work piece contours [6]. The focus of this work is therefore on the investigation of a new process concept, that has been presented 2019 by TU Graz and has already been patented [7].

2. SELECTIVE LED-BASED MELTING

The "SLEDM" process [7] developed by TU Graz uses an LED-based light source for material processing. The schematic structure of this process concept is shown in Figure 1. The variability of the focus in particular should bring advantages in terms of construction time. The use of high-power LEDs increases additionally the safety level [8] of the system and lowers the risk of overheated zones caused by the very high power density of laser or electron beam spots. The SLEDM process operates in contrast to SLM according the top-down built principle. The radiant power of the energy source is directed into the building space from below through a quartz glass plate. The powder material to be processed is located on top of the quartz glass plate. The build platform position is above the powder slice. By selected light exposure to the powder onto the glass plate, the component cross section is created and the connection to the build platform above or the previous layer is created. Contrary to the established powder bed fusion process (PBF), the new process represents a powder layer fusion process (PLF).

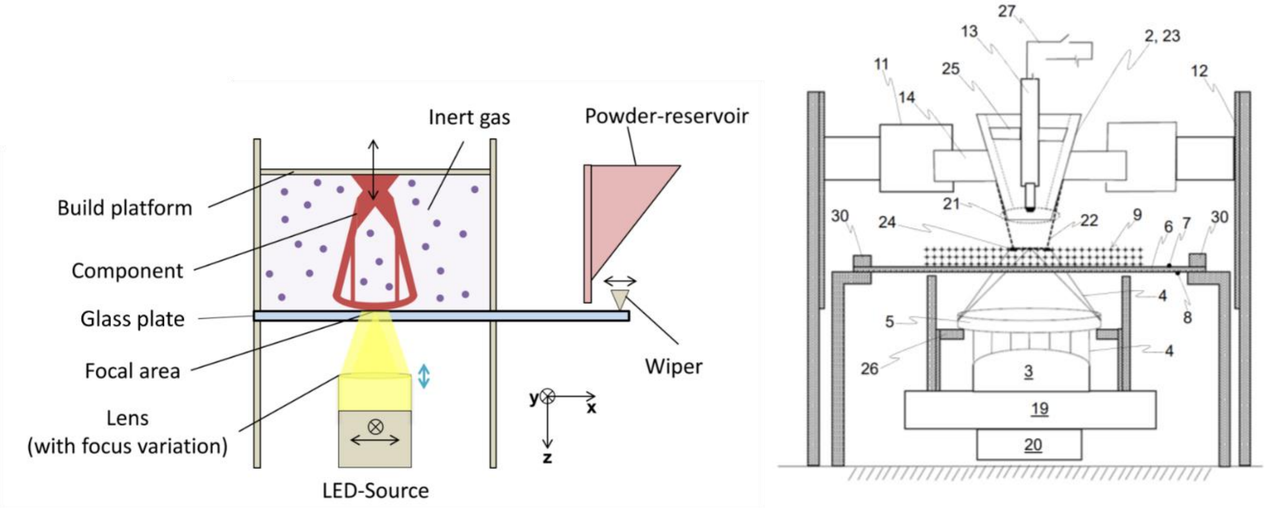

Fig. 1: SLEDM process operation principle, patent [7] [9]

Based on this working principle, there are significant advantages compared with existing processes in the field of additive manufacturing. SLEDM works with the least possible powder volume in the system compared to all other competitive processes. This fact reduces material costs to an absolute minimum. Furthermore, the new process concept offers the possibility to produce hollow parts without the inclusion of loose powder. The already built part volume is completely free accessible for post-processing and quality inspection. All these benefits save time and costs and make SLEDM to a very economically alternative for metal additive manufacturing.

3. FUNCTIONAL PROTOTYPE

The functional prototype has been developed considering the basic construction principles simplicity, robustness and capability of process parameter measurement. Using the presented demonstrator, the key functions of the new SLEDM process are being investigated and an initial melting test program has been carried out. The measurement and experimental setup of the SLEDM prototype is shown in Figure 2. The core elements of the functional prototype are its mechanical structure made of stainless steel, the light source including flexible mounting and adjusting and the control and measuring system.

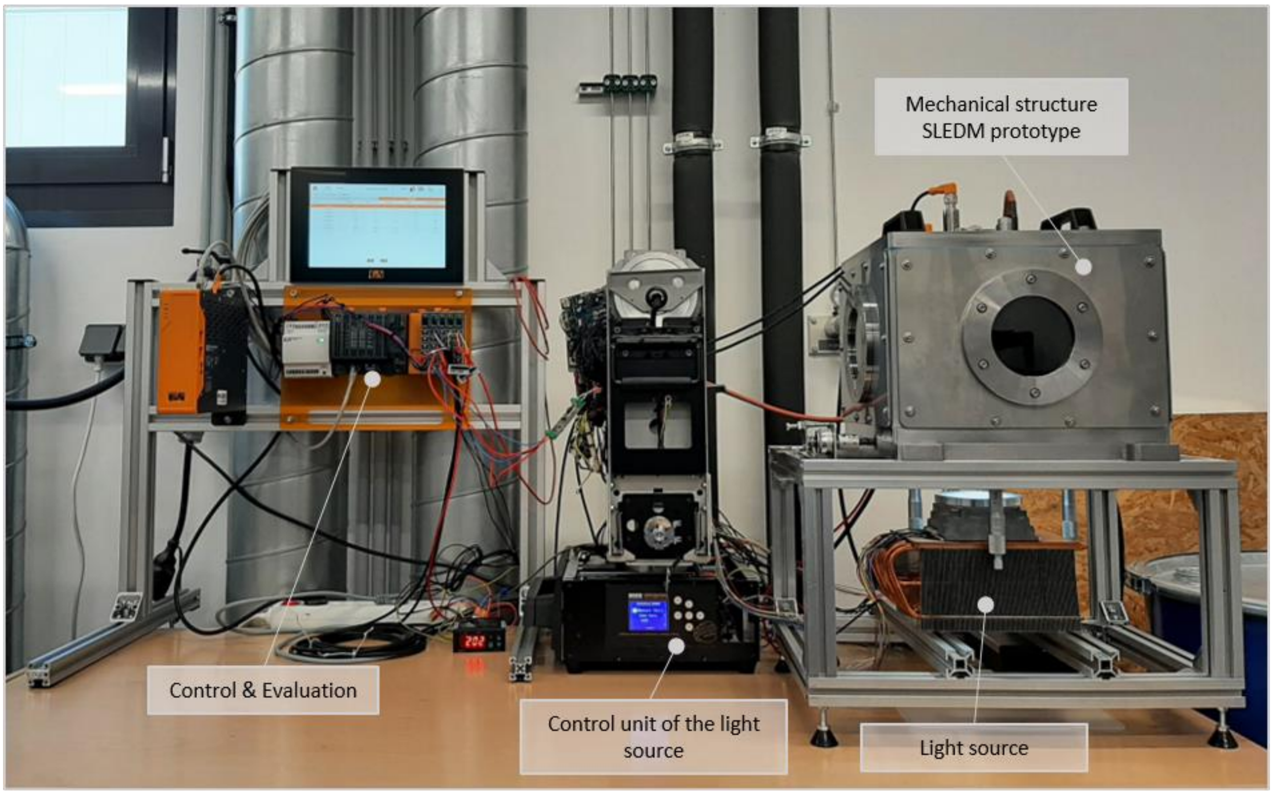

Fig. 2: Measurement and SLEDM prototype test setup [6]

3.1 MECHANICAL STRUCTURE

The prototype consists of a hermetic housing, which is fluted with argon as inert shield gas to protect the melt pool form oxidation during the printing process. The casing contains the preheated build platform with integrated temperature sensor, which can be precisely positioned in the Z-direction via three micrometer gauges in a manual manner to lift it up. This linear positioning will be automated in the next extension stage. The whole build platform or an intermediate plate must be made of the same material as the powder material being processed, so that a substance to substance bond of the powder on the platform is guaranteed. At the bottom of the casing there is a base plate with an integrated transparent quartz glass disk, through which the focused LED light beam enters the 3D-printer supplying the melting power for the material deposited onto the glass.

In order to be able to control the base plate temperature very precisely, an internal water cooling circuit is integrated. Figure 3 shows a schematic cross section through the functional prototype.

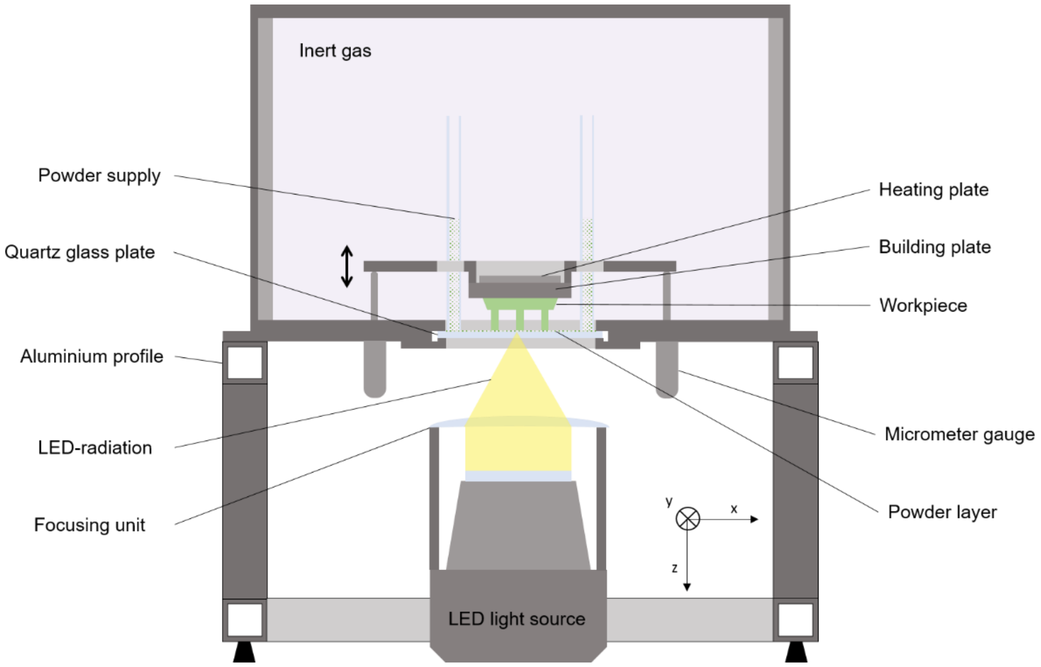

Fig. 3: Cross section through the SLEDM prototype [6]

The powder is evenly applied to the quartz glass plate by means of vibration. In the next step, the construction plate is lowered via three micrometer gauges and lays on top of the powder layer. The light source located underneath the glass plate melts the powder in the focus and thus creates the component contour, which is connected to the build platform. The platform then moves up and the next powder layer is created. By constantly repeating this process, the component is built up from top to bottom. [6]

The prototype is connected to a controller, which makes it possible to read the measurement signals from the installed sensors. Temperature sensors (Pt100) measure the temperature of the heating and construction plate as well as the temperature at several points in the installation space. A zirconium oxygen sensor from SST monitors the oxygen content in the build space and an overpressure sensor records the overpressure in the build space. The controller converts the measurement signals into the corresponding measured variable. An OrangeBox from B&R, which is connected to the controller, makes it possible to visualize the measurement data on the connected display. [6]

3.2 LIGHT SOUCRE

The light source used in the prototype is a high-power spotlight from High End Systems. The model used is the SolaWash 2000, an LED spotlight with a 700 W beam [10]. For the use in the SLEDM prototype, the spotlight must be slightly modified. Mechanical control elements as well as the assembly for focus shifting are dismantled. The resulting reduction in size allows the light source to be positioned below the mechanical structure of the prototype.

The light-emitting unit of the headlight is made up of several individual LEDs that emit white light. In order to use the emitted light power for the SLEDM process, the light must be focused in a focal point. To achieve this, the light beams of the LEDs must be parallelized and subsequently focused. Figure 4 shows the schematic structure of this process.

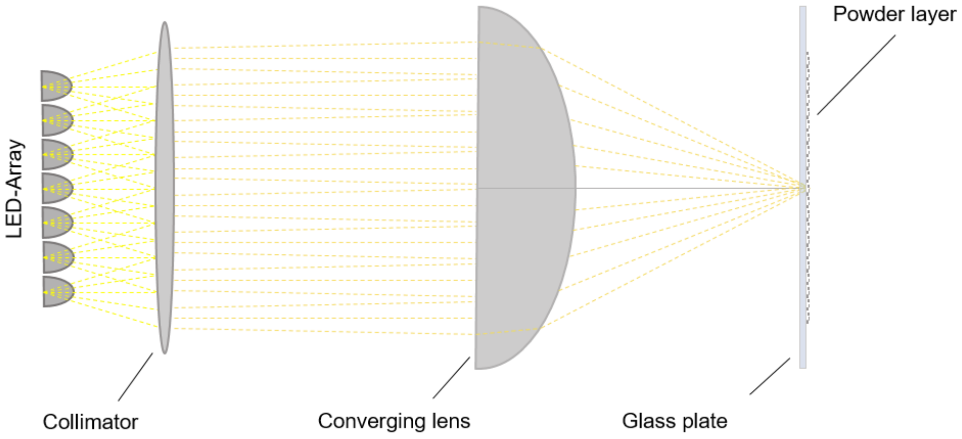

Fig. 4: Schematic illustration of the beam guidance in the SLEDM prototype [6]

Parallelization of light beams is only approximately possible and poses great challenges for optical components. Large light sources require a collimator with a large focal length to ensure sufficient parallelization. The large focal length implies a larger distance to the light source, which means that part of the radiation is no longer detected by the lens. [11] In the SLEDM prototype, beam steering is currently performed in a simplified form with only one lens. Another topic is the dependence of the absorption behavior of different materials on the wavelength of light [12]. Unlike a laser, LEDs do not emit monochromatic light. The light from the LED source is composed of several wavelengths, whereby the material only absorbs a certain proportion of the light.

The problem with light bundling and the absorption can be circumvented by changing the light source. The design of the prototype allows the use of other light sources without major adjustments to the mechanical structure. One possible alternative would be the use of a laser source instead or in addition to the current LED light source.

4. RESULTS AND DISCUSSION

Practical experiments with the assembled prototype provide important insights into the process concept itself and help in the further development of the prototype towards industrial applicability. The first test is used to check the built-in functions of the prototype. For this purpose, the heating process and the tightness of the build envelope are checked.

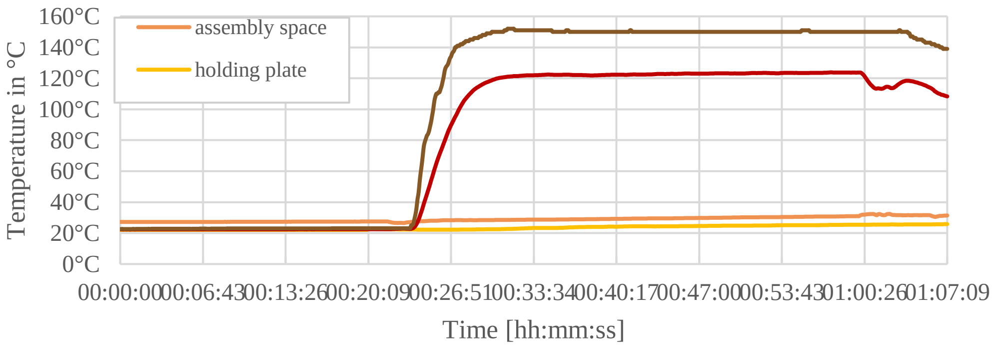

Fig. 5: Temperature characteristics during heating of the building plate [6]

The heating process starts after approx. 23 min (Figure 5) and it takes about 4 minutes for the controller to set the desired setpoint temperature. The controller keeps the build platform temperature constant until the switch-off time (after 1h 4min). The mechanical structure of the prototype heats up only slightly during this test, so no external cooling is required.

Figure 6 shows the progress of the oxygen concentration during a tightness test of the build housing. The experiment shows that the oxygen content increases very slowly. The overpressure, on the other hand, dissipates relatively quickly via smallest leaks in the housing.

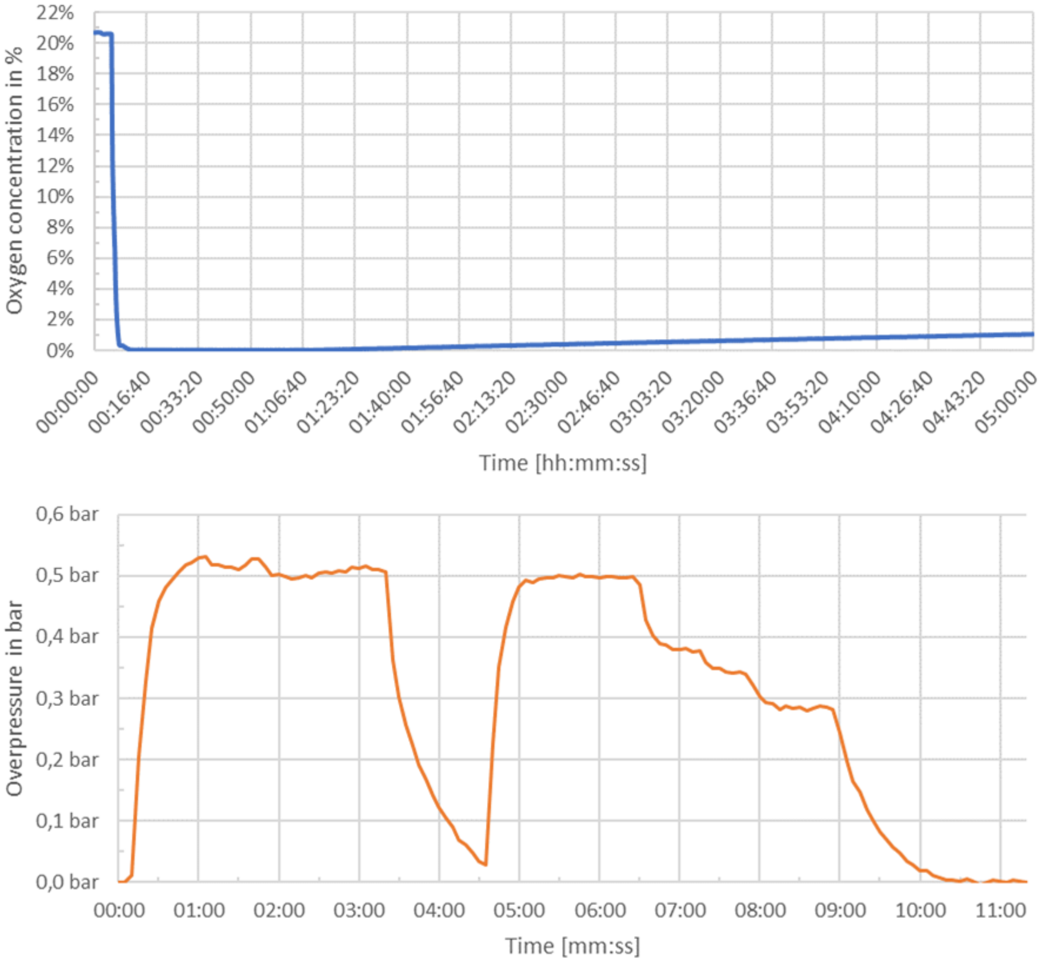

Fig. 6: Oxygen concentration (top) and overpressure (bottom) curves in the build space [7]

For the melting experiments carried out later, the heat input by the light source is essential. Further experiments record the temperature gradient at the focal point of the light source by using a thermal element. Figure 7 shows the results from these measurement experiments and Table 1 provides the appropriate legend.

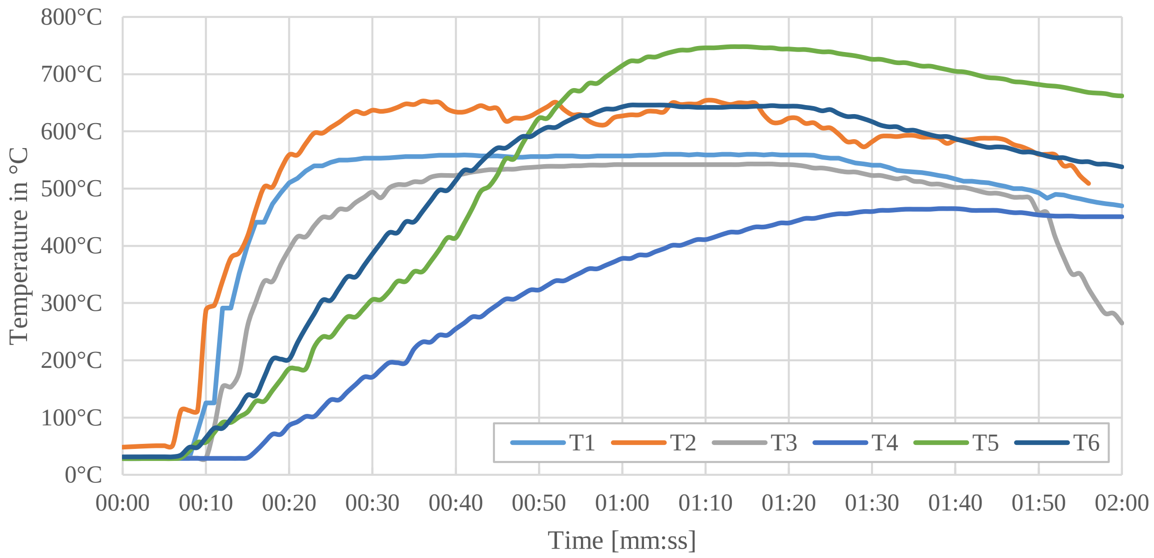

Fig. 7: Temperature curves from the measurement tests for the heat input of the LED source

Table 1: Description of the temperature curves from the measurement tests for heat input

Nr.	Switch-on time	max. Temperature	Sensor position
T1	00:08	560°C	Underneath quartz glass disk; building plate lying on top
T2	00:06	654°C	Underneath quartz glass disk; building plate ≈ 1 mm distance
T3	00:10	543°C	Sensor lying on top of the quartz glass disk
T4	00:14	465°C	Sensor lying on top of the glass disk with AlCu powder layer
T5	00:06	748°C	Sensor lying on top of the glass disk with Zn powder layer
T6	00:06	646°C	Sensor lying on top of the glass disk with Sn powder layer

From the practical experiments, it is clear that the heat input depends very much on the conditions in the focal point of the light source. On the one hand, the power density in the focus is decisive to achieve the temperature requirements. The temperature increases squarely with decreasing focus diameter. On the other hand, the absorption behavior of the material very strongly influences the temperature at the focal point of the LED light source.

The conclusion of the practical test series is formed by simple melting tests with low-melting metals. The materials are powder materials made of tin and zinc. The properties of the powder materials and the test parameters are summarized in Table 2.

Table 2: Properties of the powder materials and test parameters

Material	Tin	Zinc
Melting point	231.9°C	419.5°C
Particle size	< 80 µm (spherical)	< 63 µm (spherical)
Purity	> 99.85 %	> 98 %
Focal diameter	20 mm	20 mm
Layer thickness	500 µm – 800 µm	< 300 µm
Exposure time	5 min – 10 min	5 min – 10 min
Building plate temperature	200°C – 420°C	200°C
Oxygen concentration	0.03% - 0.3%	0.07%

From the tests with tin powder, it can be seen that this powder material is not suitable for carrying out melting tests. An even distribution of the powder on the quartz glass plate is only possible with very large layer thicknesses (> 500 µm). Also, the exposure experiments show that, despite the large exposure times, only individual powder particles fuse in the focal point of the light source. No full surface tin coating is formed.

The zinc powder material is much easier to deposit on the quartz disc and smaller layer thicknesses (> 300 µm) are possible. Figure 8 shows the comparison between a loose powder layer and an exposed powder layer (exposure time approx. 5 minutes) from the melting tests carried out with zinc powder.

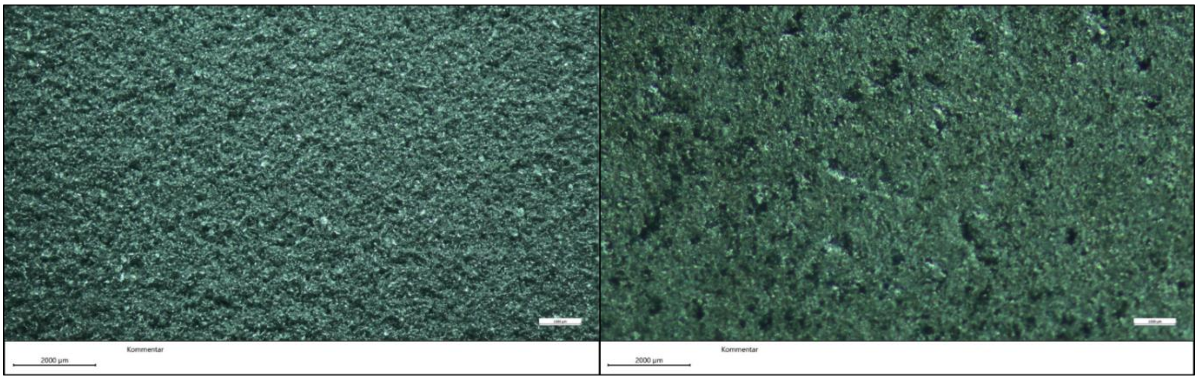

Fig. 8: Comparison between loose powder layer (left) and melted powder layer (right) using the example of zinc powder

The microscope images show that the heat input from the LED source causes the powder particles to melt at the focal point. A zinc layer with a very rough surface is formed. However, the power density at the focus of the light source is not high enough to melt the particles completely or to generate a molten bath. In some cases, the powder particles fuse only on the surface, a sintering process takes place. The particle shape remains, resulting in the rough structure of the surface.

5. CONCLUSION AND OUTLOOK

The prototype developed forms the basis for initial practical trials to test the innovative "SLEDM" manufacturing process. The tests carried out with the prototype provide important findings for the further development of the process concept and the practical test setup. The energy input by means of an LED source and the powder distribution on the glass pane still require some development work. In particular, beam shaping causes great difficulties with the current light source. There is the possibility of using other light sources with better radiation behavior. Tailor-made powder developments will also contribute for better printing results.

The goal in the near future is to produce material samples that can be used to analyze the material structure. The focus is on low-melting metals such as zinc or aluminum, but tests with powder mixtures of plastic and metal are also planned. The systematic further development of the SLEDM prototype aims to turn the manufacturing concept into a usable manufacturing process for industrial production in the field of additive manufacturing.

REFERENCES

[1] A. GEBHART, J. KESSLER, L. THURN, 3D-Drucken: Grundlagen und Anwendungen des Additive Manufacturing (AM), Carl Hanser Verlag, München (2016).

[2] I. GIBSON, D. ROSEN, B. STUCKER, Additive Manufacturing Technologies: 3D Printing, Rapid Prototyping and Direct Digital Manufacturing. Springer Verlag, New York (2015).

[3] A. WINKELMANN, C. FLATH, F. THIESSE, Sharing Economy in der Industrie: Unternehmensübergreifende Auslastung von Produktionskapazitäten am Beispiel der additiven Fertigung, Springer Gabler Verlag, Wiesbaden (2021), p. 83 – 99.

[4] J. ILG, Systematische Eignungsanalyse zum Einsatz additiver Fertigungsverfahren. Springer Gabler Verlag, Wiesbaden (2019).

[5] F. KLOCKE, Fertigungsverfahren 5: Gießen, Pulvermetallurgie, Additive Manufacturing, Springer-Vieweg Verlag (2015).

[6] R. TIEFNIG, Untersuchung eines LED-basierten Verfahrenskonzepts im Bereich der metall-additiven Fertigung, Master Thesis, Graz (2022)

[7] F. HAAS, A. REINBACHER, T. SAMS, P. ASCHAUER, M. ERKINGER, G. BRUNBAUER, Vorrichtung zur Additiven Fertigung, TU Graz (2019), Nationales Patent AT 523200 A1.

[8] M. LÖFFLER-MANG, Optische Sensorik: Lasertechnik,Experimente, Light Barriers. Vieweg+Teubner Verlag, Wiesbaden (2012).

[9] F. HAAS, P. ASCHAUER, AM 2025 - Wohin geht die Reise in der Additiven Fertigung mit den neuen Verfahren "SAT 3D" und "SLEDM". DGM Fachtagung Werkstoffe und Additive Fertigung, Graz (2020), https://graz.pure.elsevier.com/files/30555127/AM_2025_SLEDM_SAT_3D_Haas.pdf

[10] High End Systems. SolaWash 2000, https://www.preworks.at/images/preworks_downloads/SolaWash_2000_Datasheet_revF.pdf, visited 24.08.2022

[11] Edmund Optics, Überlegungen zur Kollimation. https://www.edmundoptics.de/knowledge-center/application-notes/optics/considerations-in-collimation, visited 24.08.2022

[12] R. POPRAWE, Lasertechnik für die Fertigung, Springer Verlag, Berlin Heidelberg (2005), p. 28 -39.