

# Direct Generation of Metal Parts and Tools by Selective Laser Powder Remelting (SLPR)

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## Abstract

For the direct manufacture of metallic prototypes and tools Fraunhofer ILT is developing the new rapid prototyping (RP) process Selective Laser Powder Remelting (SLPR). The objective of this development is to manufacture metallic prototypes and tool prototypes out of serial materials with a density of 100 %, thus the manufactured parts can be immediately installed without time consuming post-processing like e.g. infiltration. Therefore, basic investigations for process analysis are being carried out to attain a fundamental understanding of the process. Process parameters have been determined and process procedure strategies have been developed to manufacture parts of different materials with a density > 99 % without any binder component. The materials under investigation are stainless steel, tool steel, aluminum alloys and titanium alloys. Due to the high density the tensile strength and yield strength of the parts produced by SLPR are in the range of the specification of the bulk material. Based on these results a prototype plant for SLPR is being designed and realized. With this machine complex functional prototypes as well as prototype mold inserts for injection molding and die casting can be manufactured out of different materials.

## Introduction

A relatively large number of rapid prototyping techniques are available on the market [1]. All these techniques depend on very special materials. The functional properties of the models produced by these techniques are limited extensively by the material used and the manufacturing process. For many functional tests, especially for tests of loading ability, it is nevertheless required to have functional prototypes that have at least serial properties and are available in large numbers. This is certainly not directly possible with the current commercially available RP techniques, especially not with metals. The way to achieve metal parts relies on different time-consuming post processes, e.g. vacuum casting or waste wax casting, where the RP model serves as a master pattern.

In order to manufacture metal parts directly by a RP-technique, the powder based process

Selective Laser Sintering (SLS) has been enlarged for the processing of metal powder. Right now two strategies for the manufacture of metallic components through SLS are being followed, the so called indirect and the direct selective laser sintering. Both strategies rely on their own very special metal powder systems [2],[3]. A problem arises through the development of a special powder, which is well adapted to the SLS process, but the functional properties of the manufactured part are severely limited. The reason is, that the properties of the special sinter material differ from the later production material to a high degree. Therefore, the part must be infiltrated or sintered again to increase the density and strength [4]. To avoid this problem, the development of SLPR for metallic materials at the Fraunhofer Institute for Laser Technology is consequently focused on the demands for serial metal components. ILT is carrying out a process development with serial single component metal powder materials.

### The Principle of Selective Laser Powder Remelting

The basic principal of SLPR is similar to SLS. The parts are manufactured layer by layer using a laser beam, which locally fuses a powder material. The SLPR plant is also very similar to a SLS plant. The prototype plant for SLPR, shown in Fig.1, fulfills the basic functions of a SLS- machine. It mainly consists of the SLPR chamber with lowerable work platform and powder feeding platform as well as the powder leveling system. The SLPR chamber is closed and can be floated with an inert gas like argon. A Nd:YAG laser with a maximal output power of about 110W is used in cw-operation. The beam scanning is done by a scanner unit. The software, which is used for the SLPR process, is a stereolithography software of the company Fockele & Schwarze GmbH with special modifications for the SLPR process.

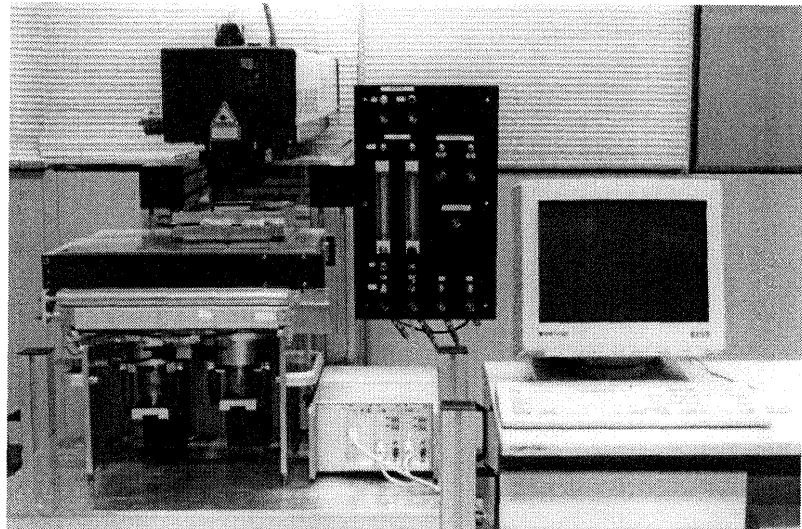
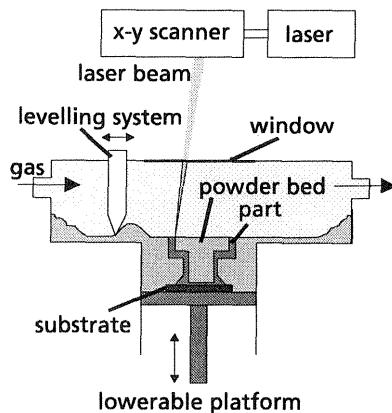


Fig. 1 Prototype plant for the SLPR process

The first main difference between SLS and SLPR is the kind of powder, which is used for the process. While the SLS process requires very special powder systems with a binder component, the SLPR technique uses common single component powder. The powder is processed without any binder material and without any kind of pre-treatment. Serial materials like stainless steel (309 L, 316 L) and tool steel (1.2343) can be processed. The only requirement is a spherical particle shape with a particle size in the range of 20 - 50  $\mu\text{m}$  (Fig. 2).

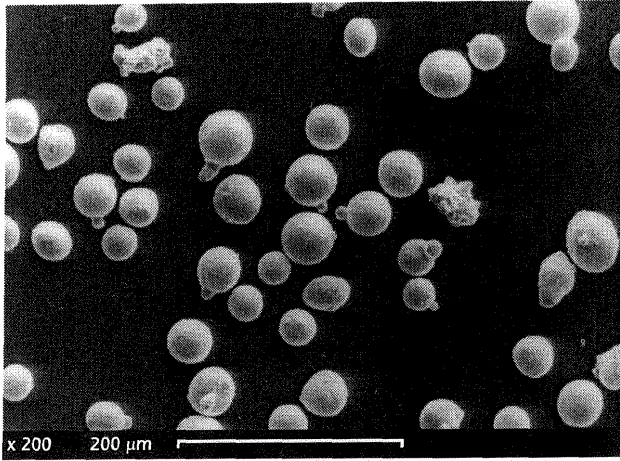


Fig. 2 Stainless steel powder for the SLPR process

In order to manufacture parts with a high density using one-component powders without any binder material, it is necessary to melt the powder particles completely. If these particles are only partially melted, the powder layer cannot sufficiently densify and the density of the part will not be significantly higher than the density of the powder layer. A problem of a complete melting of the powder particles is that the physical processes in the interaction zone of melt and laser beam lead to the formation of spherical structures of the metal melt due to its relatively high surface tension (Fig. 3 a). Hollow areas remain and a porous structure

is formed. This leads to low strength and rough surfaces, which does not match the user requirements.

To avoid this problem fundamental investigations of the physical interrelations between the process parameters and the behavior of the metal melt were carried out [1],[5],[7],[8]. The process parameters which influence the behavior of the melt were determined. The parameters laser power, scan speed, hatch distance and layer thickness are crucial for the processing results. These parameters are dependant upon one another and therefore have to be adapted accordingly to each other. The influence of scanning strategies and protection gas flow was determined. An effective shielding of the interaction zone for atmospheric oxygen through a protection gas (such as argon) is of great importance so that the wetting properties of the melt are not reduced by formation of an oxide skin layer. In addition a special scanning strategy with a limited length of each scan vector has to be used to achieve high density of the parts. Based upon this knowledge a suitable process layout could be set up, which enables the influence and control of the melt's behavior. By the SLPR process the powder of each single track is completely melted by the laser beam and the melted material solidifies without forming spherical structures (Fig. 3, b).

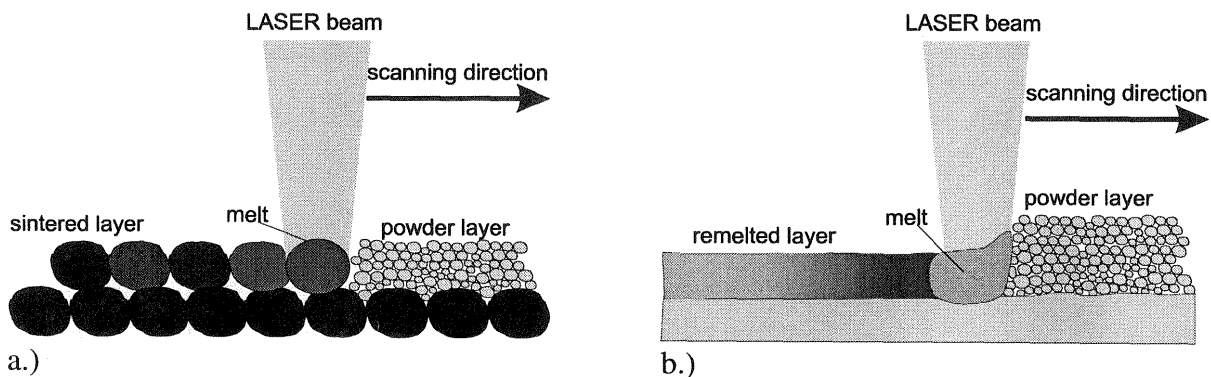


Fig. 3. Melting process of single component powder with a laser beam.  
 a.) porous structure by SLS  
 b.) dense structure by SLPR

## Quality of the SLPR - parts

Considering the suitable process procedure strategies, process parameters can be determined with which parts out of different materials can be manufactured with a density up to 99% directly by the SLPR-process. Post-processes like infiltration to improve density and strength are not necessary. Fig. 4 shows cross sections of a stainless steel 316 L sample and a TiAl6V4 sample produced by SLPR. The cross sections show, that the material of every track is bonded to the next track as well as to the layer below through a melt metallurgic bond.

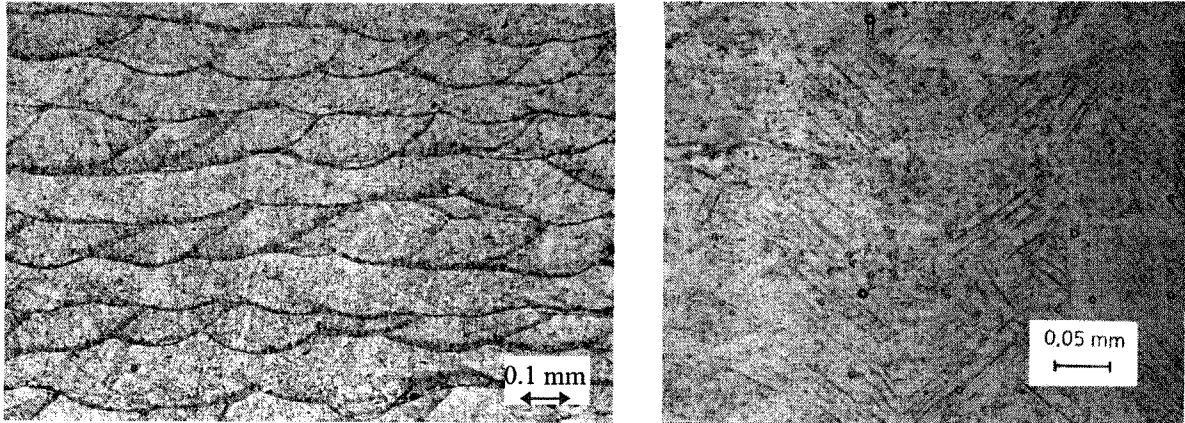


Fig. 4 Cross section of a sample manufactured out of stainless steel 316 L (left) and TiAl6V4 (right) by SLPR. The density of the samples is approx. 99 %.

The high density leads to a high strength of the parts. Tensile strength, yield strength and breaking elongation have been determined by a tensile test. Tensile test rods have been build out of stainless steel 316 L and TiAl6V4. For stainless steel test rods with an orientation of the layers perpendicular and parallel to the tension direction have been tested separately.

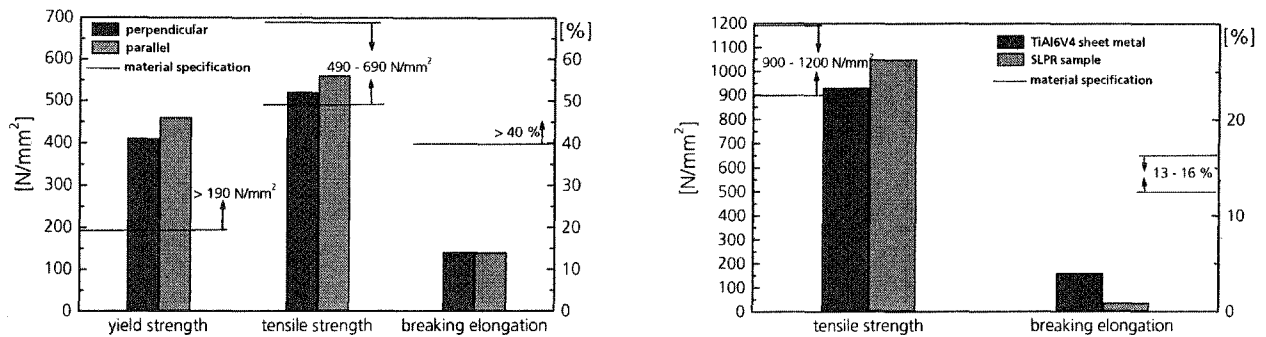


Fig. 5 Results of tensile tests of SLPR-parts out of stainless steel 316 L (left) and TiAl6V4 (right)

The tensile test results of the parts manufactured by SLPR are compared with the material specification and in case of TiAl6V4 with a sheet sample. The results are demonstrated in Fig. 5. The diagrams show that the tensile strength of the SLPR-steel parts of approx. 550 N/mm<sup>2</sup> as well as yield strength with approx. 450 N/mm<sup>2</sup> are in the range of the materials specification. There is no significant difference between the parts with perpendicular and parallel orientation of the layers to the tension direction. The tensile test for TiAl6V4 shows similar results. The tensile strength of approx. 1050 N/mm<sup>2</sup> of the SLPR test rods is in the range of the material specification. Both of the tested materials show a brittle fracture which leads to significant less breaking elongation of the SLPR parts in comparison to the material

specification. The rapid solidification of the metal melt during the SLPR process leads to a more brittle material structure in comparison to sheet metal.

In addition to density and strength the accuracy and surface quality of the parts are important properties which determine the acceptance of this technique for industrial applications. Investigations have shown, that an accuracy of approx. 0.1 mm can be achieved by the SLPR process for parts without undercuts. The accuracy of overhangs depends on position and shape of the support structure.

The surface roughness of the parts strongly depends on the layer thickness. The Rz value of parts built with a layer thickness of 0.05 to 0.1 mm is in the range of 60 to 80  $\mu\text{m}$ . Depending on different applications, a surface finish with manual techniques like grinding and polishing is necessary. With these techniques a mirror-like surface can be achieved (Fig. 6).

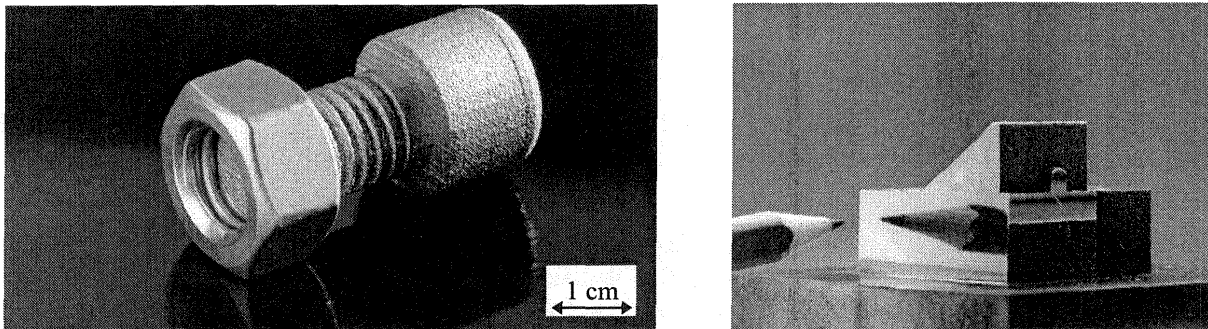


Fig. 6 Test parts for the demonstration of accuracy and surface quality of the SLPR technique. Left: Screw M12 manufactured by SLPR out of 316 L. Nut can be screwed on by hand without any reworking at the screw. Right: Mirror-like surface of an SLPR-part by manual surface finish technique.

### Applications of SLPR

One of the most important application of the SLPR technique is Rapid Tooling. The complex shape of injection mold tools and die casting tools can be manufactured rapidly by SLPR. Thus, prototype plastic parts can be manufactured out of the serial material and with the serial manufacturing process, e.g. injection molding. As an example for this application Fig. 7 shows an injection mold tool which has been manufactured by SLPR out of stainless steel 316 L. The manufacturing time was approx. 4 hours for the core and approx. 7 hours for the cavity. After the manufacturing process the mold release surfaces had to be manually smoothed and core and cavity had to be fitted into a mother tool.

With this tool thermoplastic parts as well as rubber parts have been manufactured. The lifetime test of the tool is in process.

In order to manufacture prototype tools with properties as close to the serial tool as possible, investigations with the tool steel 1.2343 were carried out.



Fig. 7 Prototype tool out of 316 L, manufactured by SLPR

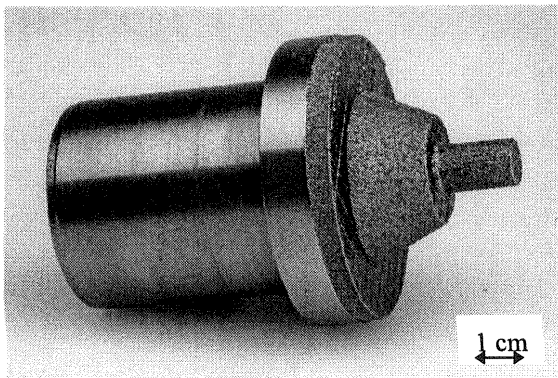


Fig. 8 Slider for a die casting tool manufactured out of 1.2343 by SLPR.

A slider for a die casting tool has been manufactured out of 1.2343 (Fig. 8). The slider was fitted into the tool, which was manufactured with conventional techniques. With this tool housings made out of AlSi12 where produced at a casting temperature of 700°C and a pressure of approx. 800 bar. A check of the slider after the production of 4800 parts showed no visible wear at the slider.

In addition to prototype tools functional prototypes are also manufacturable with the SLPR technique. Due to the high density and strength the prototypes can be used for almost all functional tests. Generally the SLPR technique allows the manufacturing of all shapes with almost no limitation in complexity. Parts with undercuts can be manufactured without a support structure if the angle between the perpendicular axis and the surface of the undercut is less than 50°. If the angle exceeds 50°, the undercuts have to be fixed by a support structure to avoid or minimize distortion during the building process. Once the part is completed, the support structure can be removed manually and distortion is avoided by the stiffness of the part itself. Fig. 9 shows examples of prototypes out of different materials. The parts have been build with a layer thickness of 0,05 mm without support structure. The building time is approx. 4 hours per part.

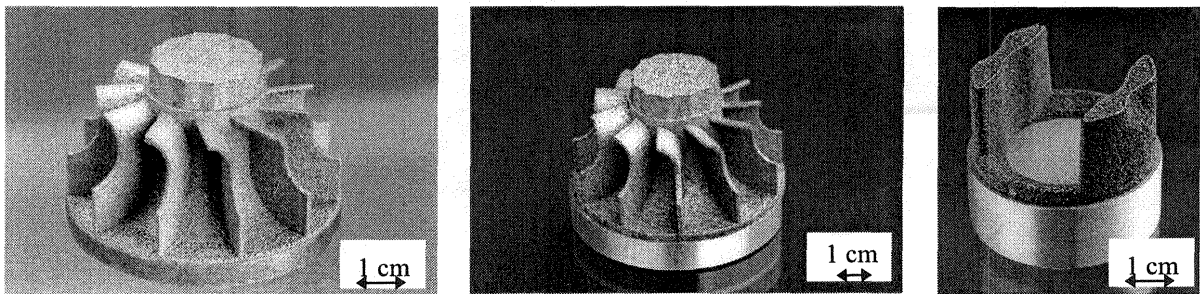


Fig. 9 Functional prototypes out of stainless steel 316 L (left), TiAl6V4 (center) and AlSi30 (right) manufactured by SLPR

In future works other components like tools and functional prototypes will be produced and will be tested in cooperation with industrial users in practice.

In the area of process development, the aims of further investigations are the improvement of surface quality and form precision of the components.

## References

- [1] A. Gebhardt Rapid Prototyping: Werkzeuge für die schnelle Produktentwicklung Hanser Verlag München Wien, 1996

- [2] Hejmadi, McAlea  
Selective Laser Sintering of Metal Molds: The Rapid Tool Process  
Proceedings of the Solid Freeform Fabrication Symposium, Austin, Texas 1996
  
- [3] C. Wilkening Fast Production of Technical Prototypes Using Direct Laser Sintering  
of Metals and Foundry Sand.  
Proceedings of the Solid Freeform Fabrication Symposium, Austin, Texas 1996
  
- [4] J. Lorenzen, F. Breitingner  
Rapid Tooling- Verfahren zur schnellen Herstellung von Prototypwerkzeugen  
Euroforum Konferenz Rapid Prototyping in der Anwendung, Bad Homburg, Juni 1997
  
- [5] W. Meiners, K. Wissenbach, R. Poprawe  
Mit Selektivem Laser Sintern zu metallischen Prototypen aus seriennahen Werkstoffen  
Proceedings of 6<sup>th</sup> European Conference on Laser Treatment of Materials, ECLAT'96  
Stuttgart 1996
  
- [6] E. Hoffmann  
Herstellung metallischer Bauteile durch Laserstrahlgenerieren  
Dissertation RWTH Aachen, Shaker Verlag, Aachen 1998
  
- [7] W. Meiners, A. Gasser, K. Wissenbach, R. Poprawe  
Direct Selective Laser Sintering of steel powder  
Proceedings of LANE '97, Meisenbach Bamberg 1997
  
- [8] W. Meiners  
Direktes Selektives Laser Sintern einkomponentiger metallischer Werkstoffe  
Dissertation RWTH Aachen, 1998

