SLS MOULDS: AN ANALYSIS OF THE EFFECTIVE FIELD OF APPLICATION

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Abstract

Selective laser sintered (SLS) mould inserts are becoming increasingly popular as a solution for fast series of moulded plastic products. However, the delivered part quality is far from optimal when it comes to surface roughness and even dimensional accuracy. Fast series in SLS moulds usually also mean limited series, as the technique has proven useful for the injection of a few ten thousands of parts, but certainly not for hundreds of thousands. The sintered material has a much lower hardness than mould steels, and the grain like structure is prone to erosion.

While working with SLS moulds offers many possibilities, it is not an all-round answer. Before applying – or dismissing – the use of SLS moulds, one should carefully consider the advantages and disadvantages of the technique. Which criteria are absolute and which can be compromised in favour of these necessary requirements? And how can we try to transform a short-series SLS mould into a production mould when it delivers satisfactory products?

This paper tries to set boundaries for a field of application in which working with SLS moulds yields an optimal effect, as well as measures that can be taken to use an SLS mould as a production mould.

Introduction

The authors are part of the IWT-funded project "Improving life time, surface quality and dimensional accuracy of Rapid Tooling moulds", which is supported by a group of industrial partners, ranging from product designers over mould manufacturers to injection moulders. Experience from this and other projects, as well as many extensive discussions with the industrial partners, demonstrated that there is a lack of clear guidelines about working with SLS moulds. Everybody knows these SLS moulds exist and have many possibilities, as well as limitations, but usually no one is entirely certain where these possibilities and limitations meet each other and define an application area for which SLS moulds are an optimal solution.

When working with laser sintered –as opposed to conventional – moulds, there are a few criteria that need to be weighed against one another:

- Tool delivery time ("speed")
- Tool life time
- Tool price
- Quality of the moulded product
  - Surface roughness
  - Dimensional accuracy

Of course, there is no way to have them all. The end user should carefully consider which of these criteria are of importance, in order to decide whether or not to use an SLS mould.

SLS – State of the Art

Two systems are prominently represented in the market of selective laser sintering of metal powders, namely SLS 3D Systems (formerly DTM) and Direct Metal Laser Sintering (DMLS) by EOS.

3D Systems profiles itself with the bronze-infiltrated Laserform material; EOS has both the bronze-alloy Direct Metal (DM) and the "full" steel alloy Direct Steel (DS). Table 1 gives an overview of some of the material properties of the latest version of these powders, as provided by their manufacturer. Contrary to its predecessors DM100 and DM50, DM20 no longer needs to be infiltrated after manufacturing, due to its decreased porosity (8% for DM20, as to 20% for DM50).

Material	**Direct Metal 20**	**Direct Steel 20**	**Laserform ST-100**
company	EOS	EOS	3D Systems
% bronze	70	-	40
% steel	-	100[1]	60
grain size	20 µm	20 µm	20 µm
infiltration	no	no	yes, bronze
Base plate	yes	yes	no
hardness HB	110	220	210

Table 1: material properties, as provided by manufacturers

[1] Within the scope of the PhD research of one of the authors, analysis at Hogent has proven that the material contains at least 10% bronze

There is an almost constant development in these powder materials, steadily reducing the grain size. Currently, the metal powders for SLS have been diminished to a grain size of 20 µm, where they once started out at 100 µm. These smaller metal particles have a direct positive influence on the evolution of the sintered part's surface roughness and dimensional accuracy, which ensures that the SLS technique continues to broaden its range of applicability.

When referring to a SLS mould, naturally a steel "mother" mould with SLS inserts is intended.

As a loose guideline[2] for the manufacturing of an SLS mould qua time and cost, one could use:

- *DM20*:
  - Build speed: 4 – 16 cm³/h
  - Price estimate:
    - 6 – 25 €/cm³
    - 25 – 100 €/h
- *DS20*:
  - Build speed: 3 – 10 cm³/h
  - Price estimate:
    - 9 – 65 €/cm³
    - 30 – 175 €/h

These prices include the entire production of the mould insert, from 3D file to the shot peened end part. The variation on speed and time is dependent on the geometry of the part (e.g. higher parts will take longer to build).

Short series

In the end user's mind, the concept of SLS moulds is routinely linked to fast, short series of moulded products. But how fast is fast and exactly how short is short? And what quality can one expect from parts produced in SLS moulds?

When speed is of the essence

One of the greater advantages of SLS moulds is their delivery time. The core and cavity need not be machined, as they are built with the layer-wise SLS process. The "mother" mould can be built from standard mould parts, with only a few manufacturing adjustments such as for the placement of the ejector pins and the core and cavity inserts. Moreover, these two production tracks need not be consecutive and can be run alongside one another just up to the assembly of the complete mould.

Realistically, a SLS mould can be delivered in less than 3 weeks. Two weeks is possible when all members of the production chain are carefully tuned into one another and can cooperate to a maximum, or when the machining of the steel mother mould can be done in-house with the end user. This is considerably faster than a conventional mould, which easily takes up 5 weeks or more for tool delivery time.

Limitations of the SLS technique

Balancing against this benefit of speed, are the limitations imposed by the use of SLS moulds.

These limitations are inherent to the sintering process and material; without post-treatment of the sintered mould surface, they are not to be overcome.

First of all there is a certain surface roughness, caused by the grain like structure. This is diminished by the standard shot-peening after the manufacturing of the insert, but even then the remaining surface roughness is considerable. Apart from the surface quality of the moulded part, this will also affect the release behaviour of parts with deep cavities and a small release angle.

material	***DS20***	***Laserform ST-100***
Ra after manufacturing[3] (µm)	**10**	**10**
Ra after shot peening[4] (µm)	**8**	**4**
Dimensional accuracy[3] (mm)	**± 0,1**	**± 0,1**
Surface hardness HV[3]	**220**	**170**

Table 2: properties of SLS mould inserts

The second major limitation is the dimensional accuracy of SLS parts. A two-sided tolerance of 0,1mm is not a problem, but there is no guarantee for a higher accuracy. Contrary to the surface roughness (which can be polished away), this tolerance is inherent to the metal sintering process and beyond the end user's control.

The low surface hardness of sintered materials is responsible for a lower wear-resistance of the mould, when compared to conventional steel moulds. The grain like structure is more vulnerable to erosion, as grains can break out of the sintered matrix.

[2] based on an estimate for DMLS at CRIF-WTCM Luik.

[3] as provided by material manufacturer
[4] measured by researchers at Hogent or DNI

SLS moulds are typically fit for series of 20 000 to a 100 000 shots. Of course this number depends on the geometry of the mould and the injected plastic, 100 000 shots may very well be feasible for a simple cavity injected with polypropylene, while a mould for a very complex part or one injected with a glass filled polymer may not even make 50 000 shots.

Compromising speed and quality

Depending on the end user's priorities, the mould delivery speed can be compromised in favour of surface quality. Polishing offers a solution for the surface roughness, but is very time-consuming and not all of the mould surface may be accessible to polishing.

In order to correct small deficiencies in dimensions, micro welding can offer a solution. Detail as small as 0,01 mm can be adjusted in this manner. Again, such precision work requires both skill and time. When resorting to these correction methods, the "rapid" fades out of Rapid Tooling and – considering the hours of manual work – the price will rise considerably.

Production series

Occasionally an end user is so satisfied with the products delivered from an SLS mould, that he wants to produce as large a series as possible with this mould. In other words, he wants to turn the SLS mould, that was originally intended as a fast short-series tool into a production mould and wring as many parts from it as he can. In order to do this, he will have to overcome the low hardness of the mould material and seek to reduce wear to a minimum.

Surface coatings may offer a solution here. Physical Vapour Deposition (PVD) and Plasma Assisted Chemical Vapour Deposition (PACVD) of micro-layer coatings are a relatively fast and easy way to improve the surface hardness of the SLS mould inserts. The results of this modification are not as significant as with conventional steel moulds. The relative softness of the base material leads to an "eggshell" effect, undermining the hardness of the coating layer itself. Nonetheless, the surface hardness of SLS moulds can be improved to over 30 HRc (≅ 300 HV). An overview of the improvement of the surface hardness of a DS20 mould is given in table 3.

coating	**none**	**DLC**[5]	**TiN**
method	-	PACVD	PVD
Hardness HV	220	340	345

Table 3: surface hardness of coated DS20 by micro hardness Vickers

Also, some surface coatings (mainly the carbon-based coatings such as DLC) greatly improve the release behaviour of the mould. This reduces friction between mould and injected part, in turn reducing the wear on the mould.

The absolute advantage of SLS moulds

Complex shapes

A strong advantage of SLS over other tooling techniques is the freedom of form. Due to the layer wise building method, any geometry can be built without the restrictions of difficult angles, undercuts or hard-to-program features. This allows for very complex geometries to be manufactured in exactly the same time and with the same minimal effort as a simple part of the same volume.

Reducing cycle time

An immediate example of such complex shapes is conformal cooling. In a conventional mould, the placement of cooling channels is restricted by the fact that they must be drilled, creating a network of straight lines. The placement in regard to the product cavity is limited by the largest dimension of the product, and the designer must ensure that the cooling channels do not intersect ejector pins. Therefore, the distance from the cooling channel to the cavity varies with the dimensions of the cavity. Cooling of the hot plastic part does not occur equally throughout the cavity.

Conformal cooling is a placement technique where the cooling channels are designed to follow the cavity, leaving an equal amount of mould material between coolant and cavity or – for example where "hot spots" occur – vary this distance according to the requirements of the product, so that the cooling is even throughout the part.

As mentioned above, SLS allows for such a geometry to be built. The designer must however take into account that the loose metal powder has to be able to be removed from the cooling channels after the sintering of the mould. This requires some attention in the design and will limit the possibility of a perfectly conformal cooling.

[5] Diamond Like Coating, carbon based.

Given that conformal cooling can be used to bring cooling channels closer to the cavity and to have cooling proceed in a more even manner, this approach allows for a considerable cooling time reduction. When applying SLS moulds for this purpose, the gain of the technique is in cycle time reduction and the financial gain of an improved production capacity per hour. Fast tool delivery time is usually of secondary importance, so the user can afford to spend that extra week post finishing the mould through polishing or the application of a coating.

Conclusions

Working with SLS mould inserts offers many possibilities, but also knows a few limitations. It is important that the end user understands what he can expect from SLS moulds. There is no such thing as a fast, cheap mould that produces a large series of high quality products.

The first main venue for SLS moulds is a fast prototype series of moulded products. The tool can be delivered very fast, but one must take into account that without post treatment the mould will have a surface roughness Ra up to 8µm, a dimensional accuracy of 0,1mm and it will suffer wear a lot sooner than a conventional mould, limiting the quantity of parts it can deliver. Compensating these limitations is possible to a certain degree, when the user is willing to compromise the speed of the mould delivery.

If the end user wants to bring the SLS mould into full production, it is advisable to apply a surface coating that will heighten the surface hardness of the mould and/or improve release behaviour.

A second very interesting application for SLS moulds, is the manufacturing of complex shapes that are either impossible or very time-consuming and expensive with conventional tooling. As a very specific example, building conformal cooling into the mould structure will allow for a better, even cooling and result in a considerable cycle time reduction.

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Keywords

Injection Moulding, Rapid Tooling, Selective Laser Sintering, Field of Application, Limitations, Surface Coatings, Complex Geometries, Conformal Cooling.

Bibliography

[1] EOS, DS and DM product data sheets
[2] 3D Systems, Laserform ST100 product data sheet
[3] End Report “Injection moulding with SLS cavities”, HOBU-IWT project, DNI, 2002
[4] Intermediate report “Improving life time, surface quality and dimensional accuracy of Rapid Tooling moulds”, HOBU-IWT project,DNI & Hogent, 2004

Illustrations

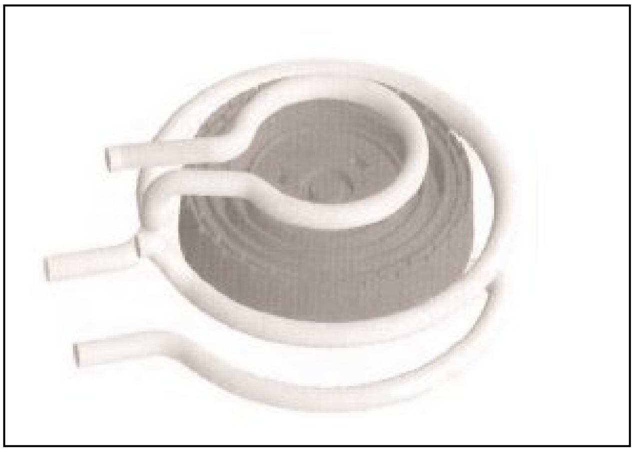

Fig. 1. Example illustrating the principle of conformal cooling; shown are the part and the cooling channels

Fig. 2. The difference between an unpolished and polished SLS mould surface. Cavity half is unpolished; core is polished. Moulded part also shown (under).

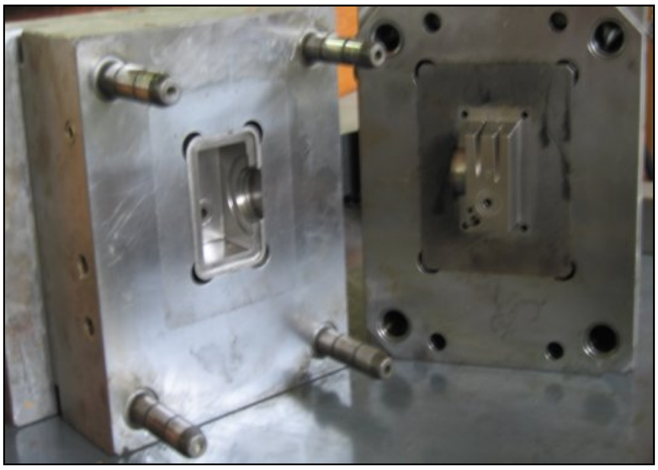

Fig. 3. Example of an SLS mould of a benchmark part