3D Printing of stainless steel components

Photo: Automotive heat exchanger. Photo: EOS GmbH

The publicity surrounding the 3D printing of metal parts is increasing daily and at almost any trade show you can learn more about this advanced mode of production. Some years ago, this theme was as a voice crying in the wilderness and was hardly taken seriously. The situation today is completely different simply because modern society needs this technology. Environmental issues and the drive to reduce the use of raw materials are also giving major boosts to serious considerations of using this technology as an alternative to casting, forging and machining.

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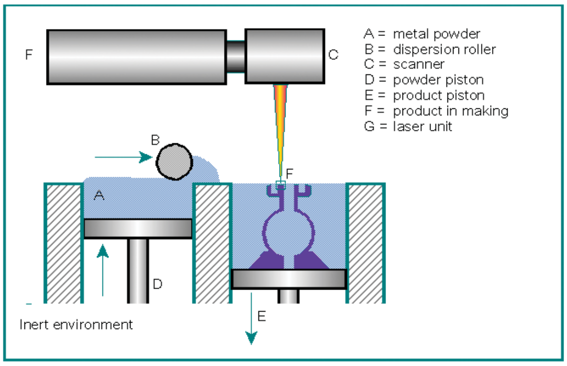
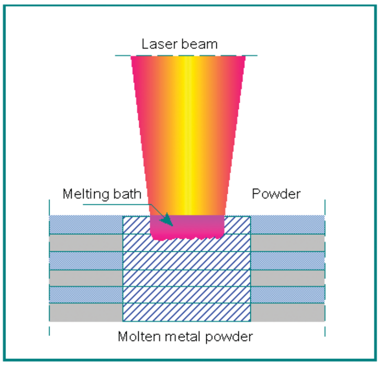
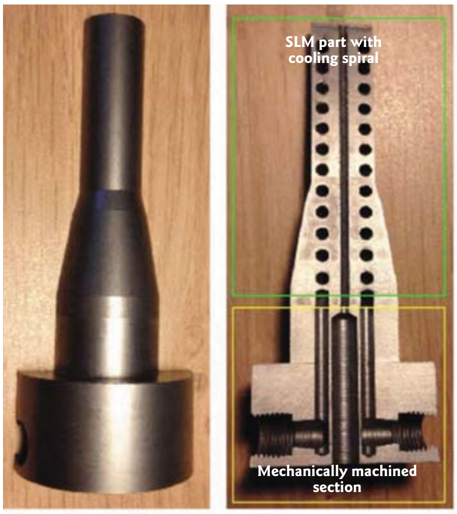
The 3D printing of metal parts is officially called 'Select Laser Melting' (SLM) or 'Additive Manufacturing' (AM). In fact, this involves materialising a virtual design into a functional product using metal powder that is partially melted by laser energy. The principle is based on the fact that, from a CAD design after digital conversion, people can realise a product that is layer-stacked. This is also called 'Layer Technology'. These layers have a thickness varying between 20 and 100 μm. At the places where the material has to be situated, the laser will be activated using a computer, which allows for the metal powder to melt together. After this action, a new layer of metal will be applied. This will be melted with the metal layer which has originated for that purpose. The entire process takes place in a building area where an atmosphere prevails so that the metal powder cannot oxidise. Eventually a functional product will be generated, as schematically represented in Figure 1.





Enlargement point F

Figure 1: Schematic representation of Additive Manufacturing



Hybrid mould insert　　Cross section

Figure 2: a hybrid product that is constructed from a mechanically worked part and a SLM part

On the left side, you can see two plungers, which go up and down. The left plunger dispenses metal powder; the right plunger is lowered progressively as the product is generated. The laser locally melts the metal powder, so that the desired product can be obtained. On the right side, an enlargement of section F can be seen.

Once the metal product is completed, it is removed from the base plate. It can then undergo treatments such as annealing, grinding and/or mechanical finishing. The metal powder which is not melted will be returned to the stock container. This can be re-used because the quality is not affected, due to the inert atmosphere present in the working space. In other words, there is almost no metal loss in contrast to casting, where risers and chamfers must be removed and later remelted.

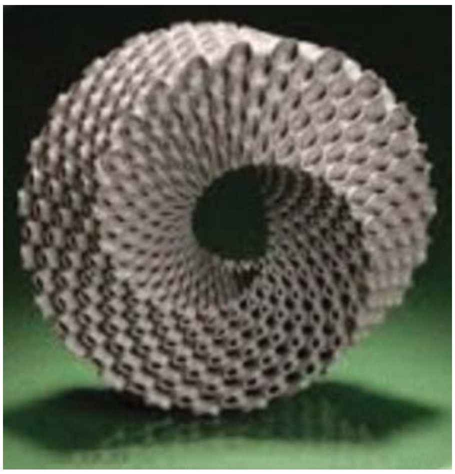


Figure 3: It is impossible to realize this scallop structure of stainless steel using a different manufacturing technique

The special feature of this technique is that you can freely choose a geometry or shape that applies both internally and externally. There are almost no limits to the design that has to be achieved. During this process, even internal helical cooling channels can be created without any problems. This is especially important in complex mold inserts, as can be seen in Figure 2. This is related to a part that is made of stainless steel AISI 316.

Figure 3 shows a sculpture of stainless steel which is developed due to the SLM technique and it is obvious that no conventional method could achieve such a product in terms of form.

Cost issues

If you take into consideration the different characteristics, the issue of cost will always dominate, whether an innovation is to be used by the market or not. Although this new technique is still quite expensive at the moment, it is becoming more interesting as the technology is rapidly decreasing in price and there is a rapid increase in the size and complexity of the products that can be made.

Other production methods are integrally seen as more expensive due to the increasing scarcity of raw materials, energy and environmental issues. Moreover, using the SLM technology, it is not necessary to manufacture expensive casting molds and/or forging dies. This affects the manufacturing of smaller series using this technique.

Another great advantage is the relatively fast availability for a buyer. This is also called ‘short time to market’ effect. In addition the stocking of spare parts and components is mostly not necessary, because using this technique, the parts can be produced relatively fast at the customer’s request. This will be an advantage for the virtual warehouse. Even a broken part can be scanned and materialised again, because a scatterplot has been created during the spatial scan.

The structure

The mechanical properties of these products are very special because dislocations in the atomic lattice were stuck on the transitions of this layered structure. In Figure 4, a micrograph of the layered structure can be seen. For comparison, an image of a sintered product is shown.

The latter shows a considerable porosity, while a printed portion is closed. In Figure 5, a metallographic image of a stainless steel 316 structure can be seen, which has been created using the SLM technique. An unetched recording and a recording after it has been etched with oxalic acid can be seen. Especially in the unetched figure, you can see that the material is free from micro-cavities, etc., while the etched structure clearly shows the layered metal tracks.

Stainless steel 316 normally has a yield strength of 205 MPa, and it will be increased to approximately 495 MPa using the SLM process. On the other hand, the elongation decreases from 40 to 25% and the impact strength from 85 to 30 J/cm2. Because the geometry can be chosen freely, it is possible to print honeycomb structures, where one gets an optimal balance between strength and weight.

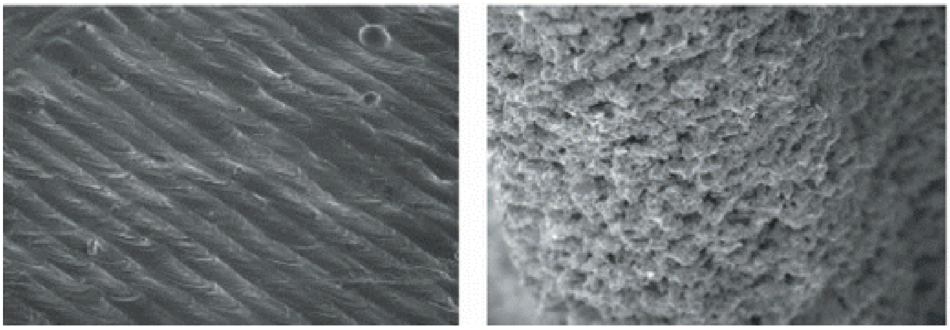


Figure 4: On the left side a micrograph of the layered SLM structure and on the right a porous sintered product.

Hybrid products

The realisation of hybrid products is a particular feature of this technology. These are products which consist of various metals or a combination of a mechanically machined part and a SLM part. If the products consist of different metals, the powders must be able to meld thermally to each other. In this manner, you can save precious metal if it’s needed on one side only.

An example is a Hastelloy layer melted on a stainless steel part. In Figure 2, a

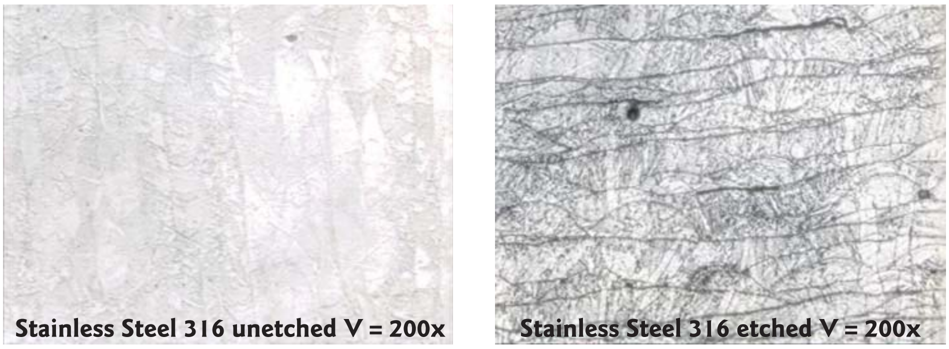


Figure 5: Microscopic images of unetched stainless steel and on the right side images that are etched with oxalic acid.

sectional view of a hybrid product can be seen. The lower part is achieved by mechanical working using a machining centre while the upper part is achieved by SLM technology. The whole is an insert of a mold. The holes that can be seen are part of a spiral cooling channel.

The following indicators and data are worth mentioning:

- Diameter of the laser beam = 0.2 mm;
- Accuracy of the SLM method = + / - 50 µm;
- Layer thicknesses range from 25 to 100 µm (the thinner the layer the smoother the surface);
- Density is at least 99.7%;
- You can achieve multiple products at once if the building space is optimally filled;
- The machine is unmanned and operates, if desired, continuously.

Some applications of SLM products are:

- Medical sector, such as implants;
- Dental sector such as crowns and braces;
- Automotive;
- Aviation;
- Virtual stock of spare parts;
- Instrumentation;
- Pumps;
- Cocks and valves;
- Gadgets and jewellery.

Briefly said, SLM is suitable for:

- Mainly complex products, such as mold inserts that are simultaneously provided with complex cooling passages possibly;
- Rapid prototyping and functional products with a short 'time to market' effect;
- Parts that cannot be realised with conventional processing techniques;
- Parts with small series;
- Parts that should have thin-walled sections, such as thin blades for pump impellers;
- Almost unlimited freedom in external and internal geometry.

The achievable product size is increasing quickly and today there are already SLM machines available that can make products with a size of 630 x 400 x 500 mm. Work is underway on a machine that can print up to 1000 mm wide using multiple lasers. It is obvious that the upscaling depends on the demand of the market, because the technology principle is the same. Some examples of SLM products can be seen in Figure 6. There is no doubt that this production method will continue to develop and that the sizes of items produced will become larger. It goes without saying that various metalworking companies will invest more in this remarkable technology.

The unsalable stocks decrease the operating profit and therefore a virtual warehouse can provide a good solution. The customer places an order and the products will be materialised using the correct file that has been previously stored in the virtual warehouse. Only the steel powders have to be kept in stock. A variant of this may be that the desired components are produced in the vicinity of the customer, so that the expensive physical transport costs are reduced to a minimum. In this case, in the near future they can use a network of SLM machines that will be installed in many places worldwide. This is going to take place using 'Remote Control' technology. This technique is also called 'Digital Parts Transfer 'and obviously this can be done globally. This will lead to substantial cost savings. However, attention must be paid to certification, surface condition and control. The machines can be blocked digitally if wrong stainless steel powder is used accidentally using an automatic PMI control.

The virtual warehouse means:

- Almost no physical stocks;
- The physical warehouse is replaced by a virtual warehouse;
- Stock of various types of stainless steel powder is necessary;
- No unsalable stocks of 'store daughters';
- If necessary on a 'remote control' base, also known as 'Digital Parts Transfer';
- Certification of the product.

Figure 6. Stainless steel watch case and sieve produced by 3D printing. Photos: EOS GmbH

Virtual storehouse

It may sound ambitious and futuristic, but nevertheless, one should not be surprised that the time will come where stainless steel warehouses will replace a significant part of their stocks with a virtual warehouse. Such a warehouse contains files in various geometrical dimensions of many components. Examples can be: threaded fittings, flanges, elbows, caps, tees, etc. If you ever walk through warehouses where these components are stored, then you will realise how much loss of interest, storage costs, etc. this entails.

It is also possible, if desired, to implement a modification to an existing virtual product. In other words, it will be possible to focus on custom-made products. The expectation is that due to the lightning fast development of SLM technology, this utopia will be a reality much sooner than is believed at the moment.

For more information: www.innomet.nl
http://www.metalvalley.eu/nl/3d-printen-van-metalen-onderdelen
http://www.eos.info/en