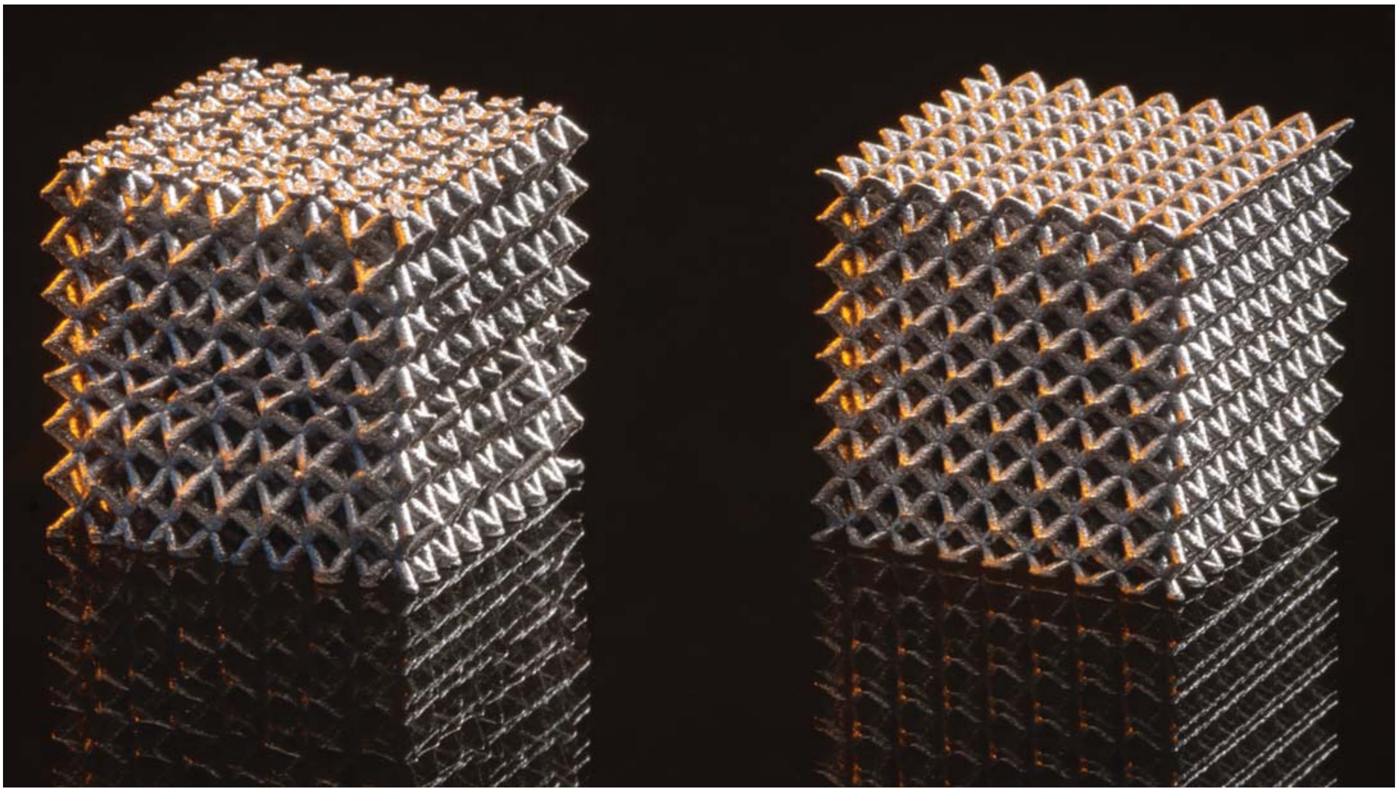

Production of stainless steels, titanium, nickel and aluminium components using additive manufacturing/digital parts transfer

Components made out of aluminium and stainless steels are developed in advanced countries in abundance. However, the production of a substantial quantity of these products is outsourced to low-wage countries to save on costs. Nevertheless, more and more companies in the West are bringing their production back from these countries and are consciously choosing to produce at home again. In this way, they respond to the demand of their clients for customisation, impeccable quality, and short delivery times. The emerging opportunity for 'reshoring' products in the West is given further impetus by the increasing use of 3D-printing. An important reason for this is that 3D printing is almost devoid of labour production costs but there are many more arguments for its use as discussed below.

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In The Netherlands there are around 24,000 active controlled processing centres. According to insiders, 10% of these machines will be replaced by machines which make metal products through 3D-techniques within five years. The expectation is that these methods will replace a substantial share of the production of machined parts, as well as castings and forgings.

The research company Berenschot, has this to say about additive manufacturing: "The advantage of additive manufacturing is that it enables a quicker market introduction of new products because production can be executed in a shorter time and more cheaply. In addition, fewer raw materials are needed, because the products are built up layer-by-layer using an exact amount of material. Moreover, by manufacturing products closer to the consumer sustainable production can be achieved, with a minimal amount of transport. In conclusion, 3D printing results in a better performance, because the products can be personalised for a relatively small price."

3D-printed products are also increasingly adapted to more and more applications. Not all possibilities are yet achievable but a lot of companies show that much is already possible and is happening. Investments are being made in research in the area of technology and material development.

Although developments with regard to additive manufacturing are occurring very fast, also in relation to the measurement and choice of materials, it is still early days for these developments and implementations. This is why a number of organisations are currently working on this matter through R&D – a good example being the TNO. Within this organization they additionally study and research 'multi-metal' printers – printers that can generate products from several types of metal. They also investigate whether it will be possible to combine the printing of metals and plastics. They anticipate that one day they will be able to print a complete mobile phone (without a SIM card), if this is then still needed. As such, products can be designed according to the wishes and demands of the user and can justifiably be called 'tailor-made'.

In practice, there are concerns and doubts related to the quality of 3D-printed products. Yet, when I study the material, the opposite seems to be true. Certainly, the higher yield strengths that can be achieved make it feasible to construct in a lighter way. Thanks to the layered composition of the components, barricades are created for sliding surfaces and dislocations in the atomic lattice, whereby the yield strength is raised. This, however, comes at the expense of the yield and impact strength. Also, microstructural concerns that the produced material is too rough or too brittle do not seem to be true because after the annealing of such components, it appears that the characteristics create an attractive whole. With additive manufacturing (AM), one can produce thinner layers than with, for example, casting and forging. A good illustration is a stainless steel pump impeller, which has, when cast, an impeller blade of circa 5 mm, and through AM, this can be reduced to tenths of millimetres. This means that the efficiency of the pump is increased significantly.

Aluminium - Stainless Steel

The principle

3D printing of metal components involves materialisation of a virtual design to a functional product. The raw material is always metal powder, which is partially melted by a solid-state laser. This principle is based on the fact that one can create a product from the CAD design phase after digital conversion, which is layered step-by-step. This is also called 'Layer Technology'. These layers have a thickness varying between 20 and 100 µm. At the points where the material can be found, a laser is activated by a computer and the metal powder is melted together. After this, a new metal layer is created, which once again is melted with the layer which was formed immediately below it. Where no material is needed, the laser is deactivated so the metal powder remains in its original form.

The whole process takes place in a construction area where an inert gas environment exists, so the metal powder cannot oxidise. In this way, after the process, a functional product with superior characteristics is created. In Fig. 1, you can see this schematically. Left and right, you can see plungers which dose the metal powder by going up and down. The roller on the left creates a thin metal layer on top of the construction area, found in the middle. The middle plunger sinks further towards the bottom after a new layer is melted. In this way, the desired product is ultimately created.

When the metal product is ready the base plate is removed and can then receive an after treatment of annealing, grinding and/or mechanical processing. The metal powder, which cannot be melted is put back in the stock container. This can be used again because the quality has not been affected thanks to the inert atmosphere present in the work space. In other words, there is almost no loss of metal in comparison to where the risers and chamfers have to be removed, which can be melted again. So, AM is a sustainable process which will benefit the environment as remaining material can be re-melted, and this also has a damping effect on CO_2 emissions.

If the shape of the product calls for it, printing can be carried out along the supporting material, so no unwanted deformations will occur. This supporting material forms, as it were, little pillars, which have to be removed afterwards. With aluminium, this is less necessary than with stainless steel, because of the difference in weight. Such supporting material unfortunately results in a little more 'waste', which can, nevertheless, be recycled. The resulting quantity of waste is not comparable with the results from mechanical operations.

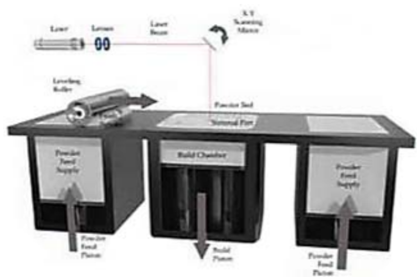

Fig. 1. Schematic presentation of Additive Manufacturing (Dreams Laboratory).

Fig. 2. RVS 316 heat exchanger, which has been printed in 3D (photo EOS).

Another big advantage, is that one has unlimited freedom in the geometry of the product, both internally and externally. One can even apply cooling channels, which can be spiral shaped. In Fig. 2, you can see a stainless steel heat exchanger, which has been 3D printed.

3D printing also offers the possibility to produce hybrid products which can be achieved in two ways, with a spinning part provided with a 3D printed part of a product partly made out of stainless steel, and partly out of expensive nickel alloy. In the first instance, it is possible to make the part cheaper with a CNC operated machine.

Afterwards a complex part is attached to the existing part using AM. In the second instance, one can save on expensive metal but this only counts if the two metals or alloys can be melted with each other thermally.

AM functions for the most part unmanned, whereby 'reshoring' is easier because the labour factor is very low. It is clear that this kind of system can operate without downtime. The work spaces can be filled up with several products, which all have the same quality of metal, significantly improving efficiency. Stainless steel, aluminium, cobalt/chrome, tool steel, titanium, nickel alloys and even gold are materials which are now often used for the purpose of AM.

Digital Parts Transfer

Thanks to the digitalizing of several processes, there is now a new logistic service in development which is conveniently called Digital Parts Transfer (DPT). Instead of being physically transported, metal components are sent as a digital geometric file to the desired location anywhere in the world. At the desired location, the product is 'materialised' with the help of AM. This requires a complex 'supply chain', also because of legal and financial aspects.

The maintainability of the whole is taken into account so that no illegal copies of the products can be made. Such services can usually be sent through the cloud. This system is also protected against the usage of incorrect materials, whereby one can ultimately issue a certificate for the created product.

Fig. 3: Schematic representation of Digital Transfer Parts. Printers, wherever in the world, are operated by a server.

The big advantages created by DPT are, inter alia:

- Being able to supply metal components at very short notice anywhere in the world. This will reduce the failure time on systems, leading to substantial savings.
- It is possible to 'transport' complete units through a digital transfer of separate components, which can be assembled after materialisation by the recipient.
- It will save on transportation costs with the exception of the costs made during the 'last mile delivery'.
- The use of hybrid products will enable cost savings to be made on the use of expensive metals.
- Time-consuming customs issues can be bypassed, as can import duties.
- Goods can be saved in a virtual warehouse on the cloud. In this way there will be no more unsaleable products left on the shelf. Uncollected interest is hereby reduced to a minimum.
- Products can be customized with minor changes to CAD files.
- DPT will reduce the emission of CO_2 and other harmful substances because it virtually removes physical transportation.

Cost Price

The price of an innovation ultimately determines whether or not it is picked up by the market. Although AM is currently still quite expensive, interest is rapidly increasing because it is integrally cheaper and also because it is becoming possible to make larger and more complex products.

Conventional production methods are becoming more expensive due to increasing scarcity. They are also more expensive because they consume more raw materials, energy, labour, and adversely affect the environment.

In addition, from a political standpoint, it will be necessary to reduce the creation of 'construction chippings', because these are bad for the environment. Chippings have to be destroyed by using cutting oil. Re -melting of this kind of residues takes a lot of energy and generates a lot of CO_2.

For the production of an Airbus A380 (Fig. 4), about 140 tons of titanium is needed, which will be 'chipped into several components' like the moving parts of wings, etc.

After the operation, approximately 15 tons of components remain, which will ultimately be installed in the aircraft. This means that 125 tons of chipping is left, which must be cleaned and re-melted. After melting, the material is immediately 'down cycled', which means that it can no longer be used for aircraft construction. Therefore, Additive Manufacturing is a very good alternative, because only a small percentage of 'waste' is generated. It is clear that 3D technology will play a big role in solving this problem since European legislation has already been put forward that in the future only a small amount of the semi-finished products can be chipped (perhaps even less than 30%). This refers to all metals.

When casting metal parts, one first needs to make models or scallops, so that the melted metal takes its desired form. When forging, it is mainly matrices that are the basis of achieving the desired product. With Additive Manufacturing, no costly casting moulds and/or forge matrices are needed so that the technique has become interesting mainly for making smaller series. Another advantage is that a product can be made available relatively quickly for a customer – a short-time-to-market' effect. In addition, keeping spare parts and components in stock can be forgotten for the most part, as with this technique, one can produce parts quickly according to the requirements of the customer. Even a broken part can be glued and scanned, and materialised again if this is permissible with the owner.

Fig. 4. An airbus A380. of the 140 tons of titanium required, approximately 90% is chipped.

Key figures related to Additive Manufacturing:

- *The laser beam diameter = 0.2 mm*
- *Accuracy of Additive Manufacturing = +/- 50 μm;*
- *The layer thicknesses may be allowed to vary from 25 to 100 μm. The thinner the layer the smoother the surface and the longer the production time.*
- *The density of the finished product is at least 99.8%.*

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Literature

3D printing of stainless steel components – Stainless Steel No. 6 of 2014 of Ko Buijs Innomet b.v.

About the author

Ko Buijs is a recognized metallurgical/corrosion specialist for stainless steels as well as special metals. He is also a lecturer for several organizations such as stainless steel associations, Technical High Schools and innovation centres. He has published over 150 papers in a number of technical magazines.