Metal Printing - A Strategic Research Program Transforming Your Designs to Physical Objects and Beyond…

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Abstract

Metal Printing and building objects layer by layer is a relatively new research area that has advantages over traditional manufacturing technologies such as machining and casting. This paper describes the new technique, and looks at the challenges that needs to be overcome before a final Metal Printing machine can be built. The behavior of metal powder in strong electric fields is emphasized, as this is an important issue regarding attraction and deposition of metallic particles with a photoreceptor.

Introduction

What is Metal Printing?

Printing in two dimensions using a photoreceptor has been known since Chester Carlson invented his photocopier in mid thirties. And even the ancient Greeks knew that objects can be put together by layers. But is it possible to combine these two thoughts and techniques to be able to build a three-dimensional object layer by layer using xerographical technology? This was the question that led to two Ph.D. thesises by Bakkelund[1] and Karlsen.[2] They concentrated on two different parts of the process. While Karlsen concentrated on the sintring process, which is necessary to transform the layers into an object, Bakkelund concentrated on the layer fabrication. SINTEF, The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology, has now started a project called **metalprinting**™ based on funding from The Research Council of Norway and Lockheed Martin.

The idea behind Metal Printing is that since all objects can be divided into layers, it should be possible to make this object by putting layer by layer on top of each other, and find a way to transform these layers into one solid object. To slice the object into layers, software that has i.e. a CAD-drawing as input and slices with wanted thickness as output can be used. If the technology known from xerography is used, but instead of toner; metal and ceramic powder is used, these layers can be produced. For each layer produced this way, a process called sintring can be used to 'glue' the layers together. By using microwaves or strong electric current through the deposited powder, an atomic diffusion is achieved. The atomic diffusion takes place only in the outer layer of each powder particle, making the particles melt together and thereby creating a density close to what we get with moulding.

When a three-dimensional object is built, there will often come a point where an overhang needs to be built. This could be a problem, since in these cases there is nothing to deposit the powder on. The use of support powder solves this problem. The support powder needs to have the same packing properties as the building powder, but will not be solid during sintering. When the object is finished, we need to remove the excessive material, and it is also important that the support powder do not pollute the object. By using the technique from color printers, we can deposit both support powder and building powder in each layer, assuring that the next layer always has something to rest on.

There are two main differences between what is done in off the shelf copiers and laser printers, and what is done in Metal Printing. The first difference is obvious; the metal or ceramic powders. Our powder has greater size than toner (average size of 50 μm), and may be electrical conductive. The powder being conductive makes it hard, if not impossible, to create a layer on the photoreceptor that is thicker than the size of the powder. The other difference is that the deposition is onto an object. This makes it impossible to put a tungsten wire behind it to create an electric field to draw the metal powder down on the object. It might be tempting to apply voltage to the object itself, but this will create nonuniform electric field lines. Hence another solution to the deposition problem has to be found.

In the Future

If building such a machine is possible, who will need it? The technique obtained from color printers makes it possible to create objects of several materials. For instance: by changing the ratio of two different materials, an object can be made that changes from i.e. 100% metal to 100% ceramics in a gradual change.[3]

An industry that has shown interest in Metal Printing is companies that use moulds for mass production of plastic parts. Making moulds can be an expensive experience, and large production quantities are needed in order to justify the investments. Metal Printing may offer manufacturing of complex moulds for both mass production and small series in an economical manner. The freedom in choice of geometry will make it possible to place the cooling channels with constant distance to the cavity. This will dramatically reduce the production cycle time.

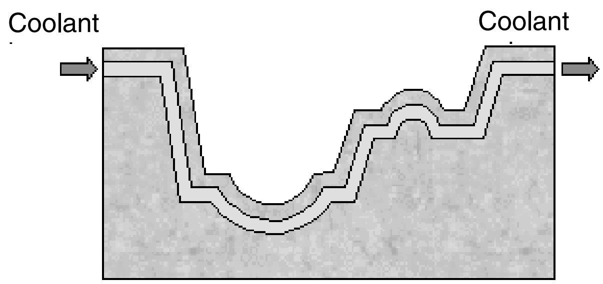

Figure 1. Cooling channels with constant distance to cavity

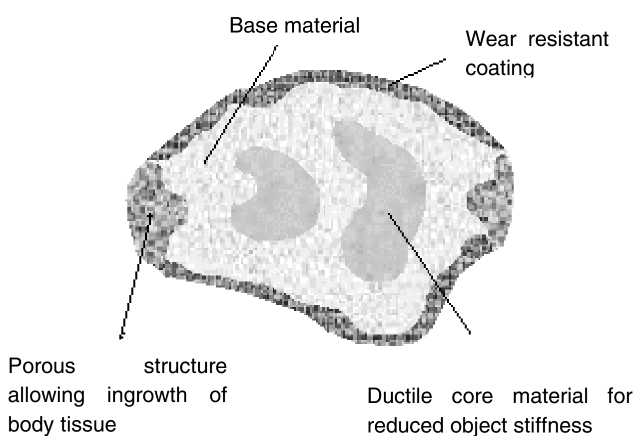

Figure 2. Cross-section of an artificial hipbone, made with four different materials.

Another example: Artificial bones need to be individual adapted, and this is a fact that makes them expensive to produce with the present technology. By using Metal Printing technology these hipbones could be made with a soft core and hard surface, making them just as light and strong as the original one.

Simultaneous sintering of two geometrically separated powders, one conducting and one insulating, can be used for building multi-layered printed circuit boards fabricated layer-by-layer with metallic pathways in an insulating ceramic base-structure.

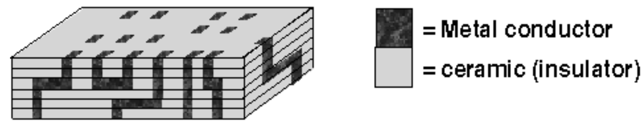

Figure 3. Multiple-material structures with geometrically separated powders

Metal Printing machines can be located in places where spare parts not easily can be obtained, i.e. on aircraft carriers or a space station. Instead of having all spare parts in stock, only a Metal Printing machine and different powders are needed. Based on a computer drawing, the Metal Printing machine will re-manufacture the indigent part in a few hours.

The Work Done So Far

Bakkelund proved that a photoreceptor is capable of attracting a layer of loose particles in a variety of powders.[1] Karlsen has demonstrated that a density of 92% can be obtained, using electric contact sintering.[2] A work done by Mugaas, using a print card instead of a photoreceptor is investigating the correlation between electric fields and attraction of metal powder.[4] What needs to be found, is a good way to combine the two technologies; that is layer fabrication and sintring. A good way to deposit powder into a system that can sinter the layer on a growing object is yet to be found.

Methods

Materials

The scorotron is picked from a Minolta. To expose the photoreceptor, a LED printhead made by Kyocera is used. This printhead (KNL-135-300AG2) is made for use with an a-Si-drum, but worked adequately with our Kodak ektaprint D organic photoreceptor as well. The photoreceptor is originally an image loop, but a rectangle of approximate 10x12 cm has been cut from it. This is due to the simplification in the experiments when using a flat photoreceptor instead of a circular one. The photoreceptor is glued to a plate of glass, and the conducting layer is grounded.

Different Types of Powder Used

The powders used so far have the descriptions NC 300.29, NC 100.24 and ASC 100.29. These are all iron powders, but varies in size and shape. The NC100.24 and ASC100.29 have a size that is normally distributed around 150 µm, while the NC300.29 is normally distributed around 50 µm. The size of the powder that is actually being lifted has not yet been measured accurately, and is left for future work.

Equipment

A test rig to conduct the experiments has been built. The glass plate and photoreceptor are mounted on a cradle, which is moved back and forth with a stepper motor. The motor moves the photoreceptor over the different stations; charging, measuring of electric field, exposing, attraction and deposition. The distance from each station to the photoreceptor can easily be changed using the micrometer.

A weight with milligram resolution is used to measure the amount of powder attracted.

A field mill is placed 7 cm from the photoreceptor to be able to measure the surface potential on it. The field mill is originally to be placed 10 cm from the surface that should be measured. The photoreceptor is however too small to get correct result at this distance. To calibrate the distance, the photoreceptor was replaced with a metal plate set to a given voltage.

The voltage supply has a large scale, so setting of an exact voltage is difficult. Improvement of this has been tried by connecting a voltage divider in parallel to the scorotron and measuring the voltage by a twenty-one-part of the total voltage, and this has eliminated some of the uncertainty.

The Dielectric Constant

The dielectric constant of the metal powder in use is not known at present time. Iron oxide has a dielectric constant of 14.2, but since loose powder is used in these experiments, the constant is smaller than this. The constant will also vary with the degree of packing of the powder. A value of 5 has been chosen in the coming calculations. This value is based on experiments not presented in this paper.

Calculation of Electric Field

When the photoreceptor is placed in a given distance above the powder bed, the system can be looked at as three capacitors connected in series. The first is the photoreceptor, which has a given capacitance. The second is the air gap, where the capacitance varies with the distance between photoreceptor and powder bed, and the third is the powder bed, which has a fixed depth of 2 mm. To find the electric field in the air gap, which is the major parameter for lifting powder particles, the following formula has been used.[5]

$$V = \int \vec{E} \cdot d\vec{l} \quad (1)$$

In this formula, the applied voltage is known. The three electric fields kan be expressed as

$$E_i = \frac{E_0}{K_i} \quad (2)$$

where E_i is each electric field, K_i its corresponding dielectric constant and E_0 the electric field if it had been vacuum. Assuming that the width of the different layers are much larger than their thickness, creating a homogenous field, and combining these formulas give

$$V = E_0 \sum_{i=1}^{n} \frac{l_i}{K_i} \quad (3)$$

Here n is the number of layers. Solving for E_0 gives a good approximation to the electric field of the air gap.

Experiment 1

Most of the work done so far is based on the desire to know more about powder behavior in strong electric fields. To take a closer look at this, one side of a print card was connected to a power supply, and an appropriate voltage was applied to it. The other side was turned towards the metal powder that lay in a grounded metal basin. This way, the effect the electric field had on the metal powder could be observed, even in daylight.

In this experiment, the print card was placed in fixed distances from the powder bed, and the voltage on the back of the print card slowly raised until powder was attracted. This was done with different distances between print card and powder bed, and with powder of different sizes.

Experiment 2

To investigate the attraction of metal powder to a photoreceptor in daylight, the experimental setup in figure 5 was built. Here different voltages can be applied to the conductive layer of the photoreceptor, to the deposition table, and also to the powder bed. If the electric field strength between the photoreceptor and the powder bed exceeds the strength needed to lift powder, the photoreceptor will be covered with a layer of metal powder. This powder was removed with the help of a magnet and then weighed.

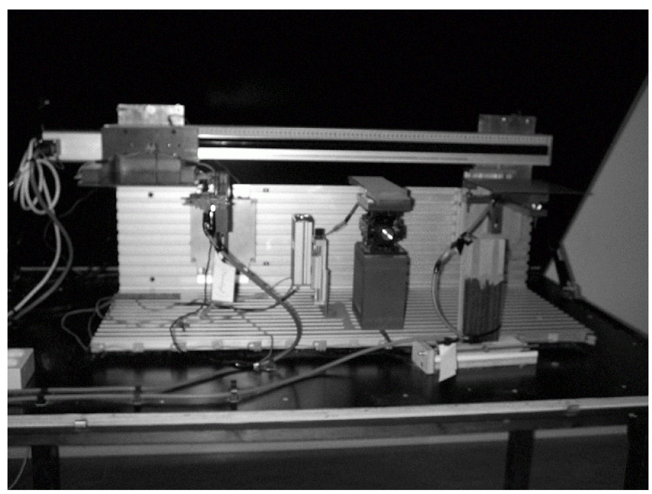

Figure 4. Setup for Experiment 2, with stations for charging, measuring of electric field, powder attraction and powder deposition.

Other Experiments

Corresponding equipment is also mounted in a darkroom, for easier testing with the photoreceptor. Tests on attraction and deposition have been done, using voltage on the powder bed, deposition table, and conductive layer of the photoreceptor. Results from these experiments are not presented in this paper.

Results

Experiment 1

By varying the distance between the print card and the powder bed, and increasing the voltage until powder is attracted, the graphs in figure 5 are found.

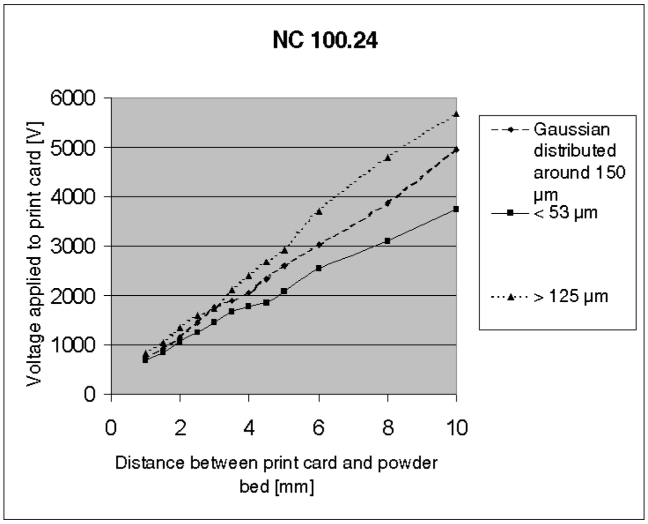

Figure 5. Voltage needed to lift different sizes of powder, with varying distance between print card and powder bed.

Experiment 2

By grounding the powder bed, and varying the voltage applied to the conductive layer of the photoreceptor, as well as the distance between the photoreceptor and the powder bed, the electric field that influence on powder attraction is changing. The voltage was varied between -300 V and -2700 V, and the distance from 0.4 mm to 2.4 mm. The attracted powder was weighed, and the results are shown in figure 6.

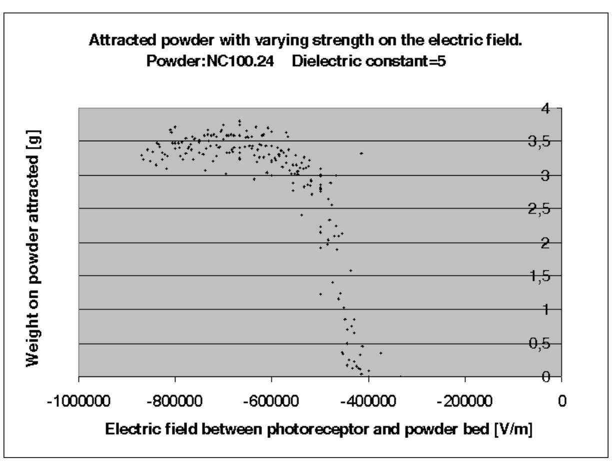

Figure 6. Amount of attracted powder at different strengths of the electric field between photoreceptor and powder bed.

Discussion

Experiment 1

As can be seen from figure 5, small powder will be attracted first, while the larger particles need a stronger electric field. The powder with a Gaussian distributed particle size requires an electric field between the two former. This is an unexpected result, since this powder also contains the small particles we find in the smallest powder. A reason could be that the capacitive properties of the powder bed changes with different compositions of the powder sizes. The results give a good indication of electrical field strength needed for powder attraction.

Experiment 2

Figure 6 shows that increasing field strength leads to more powder attracted. But when a certain limit is reached, the amount of attracted powder is not increasing, even if the strength of the electric field increases. This means that increasing the charge on the photoreceptor beyond the point where there is an electric field of 600 V/mm does not seem to influence the amount of attracted powder. The dielectric constant will have effect on this value.

A goal has always been to attract a layer that is 0.1 mm thick after sintering. The only way of doing this may be to attract a single layer of powder with the appropriate particle size, instead of multi-layered layers consisting of smaller particles.

Conclusion

Building prototypes can be very expensive, and often requires a lot of machinery just to build one item. Being able to build prototypes in a cheaper way is interesting for many kinds of industries. The principle of Metal Printing can meet these desires. Some problems remain to be solved, among them the layer fabrication. This paper has showed that the layer thickness on the photoreceptor is limited by the size of the powder, and that creating thicker layers seems to require several depositions on top of each other.

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