Metal Printing Process - Challenges and Potentials

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Abstract

A new method of rapid manufacturing called the Metal Printing Process (MPP) is under development at SINTEF in Norway. This method is using xerography and powders of metals and ceramics to build objects layer by layer. Each layer is transferred from the photoreceptor onto a punch which is used to press the new layer onto the growing object in a die. The compressed powder can subsequently be sintered into a functional object.

In principle there is no limit on the number of materials in each layer, but the different materials do have to have some properties in common, i.e. about the same melting temperature, size and electric properties. By making patterns in each layer, and also varying the layers in the vertical direction, objects with graded materials can be made.

To build overhangs a support powder must be used. This powder must have physical properties comparable to the building powder, but needs to behave differently when the part is sintered. This paper is presenting the process, based on the prototype built at SINTEF.

Introduction

There is an industrial trend towards production methods that reduce time consuming and costly machining operations. The purpose of the Metal Printing Process (MPP) research program is to develop a new and revolutionary production technology to meet this challenge. The MPP is a process that builds components ready for use directly from metal (and ceramic) powders using layer manufacturing principles. The MPP research program aims to develop, build and demonstrate a Metal Printing prototype machine with industrial functionality.[1]

Metal Printing Process Overview

A potential solution for part-producing industry for on-demand, cost-effective manufacture, re-supply, or low volume production of functional objects is the emerging technology arena known as Rapid Manufacturing. Rapid Manufacturing technologies offer a significant reduction of time and cost to bring new products to the market. The SINTEF Metal Printing Process is aimed at developing the equivalent of a high-speed photocopier that produces three-dimensional objects from powder material. This technique is based upon the commercially proven technology of photocopiers that use photo-masking and electrostatic attraction. The MPP technique uses the same fundamental functions to build solid objects on a layer-by-layer basis.[2,3]

Data Capture

The part is represented by a 3D CAD drawing, which can be drawn by a desired CAD-program. The material needed for the part can easily be represented in the program, but for the graded materials, no standard has been made. Several research environments are however working on this matter. By using the API in the CAD-program, it can be controlled by the main software; leading the machine to constantly be fed with new pictures, representing the slice at the desired height. These slices are typically 0.1 millimeter in height, but this is dependent on the size of the material that is used. The full cycle will therefore be:

1. Measure how tall the growing object is.
2. Main software sends a message to the CAD-program saying which slice is required.
3. The CAD-program draws the slice and sends it back to the main software.
4. The slice is fed to the machine

Image Capture

The layer fabrication process is illustrated in figures 1 and 2. To generate the layers, the process uses the laws of electrostatic charge and fields. A photoreceptor is charged to a specified charge density using a scorotron. Using a computer controlled LED printer head, the charge is removed from the photoreceptor on those areas where powder is wanted. In this way a negative electrostatic image of the part slice is created on the photoreceptor. The light exposure causes the photoreceptor to discharge the electrostatic charge only for the image of the slice. This is what in xerographic language is called write-black. A powder reservoir which has applied a voltage in the same range as that of the charged photoreceptor is used as a source of powder. The photoreceptor plate is aligned horizontally over the powder reservoir where the electrostatic force causes the powder to be attracted to the plate in the exact image of the part slice. The layer of powder is then deposited on the building table or directly into the die.[4] By using a second (or third) combination of a LED exposing station and a powder reservoir, a second (or third) powder can be attracted to the same photoreceptor. In this way, one powder layer with several powders can be made. This method, illustrated in Figs. 3 and 4, is similar to the method used in color photocopiers.

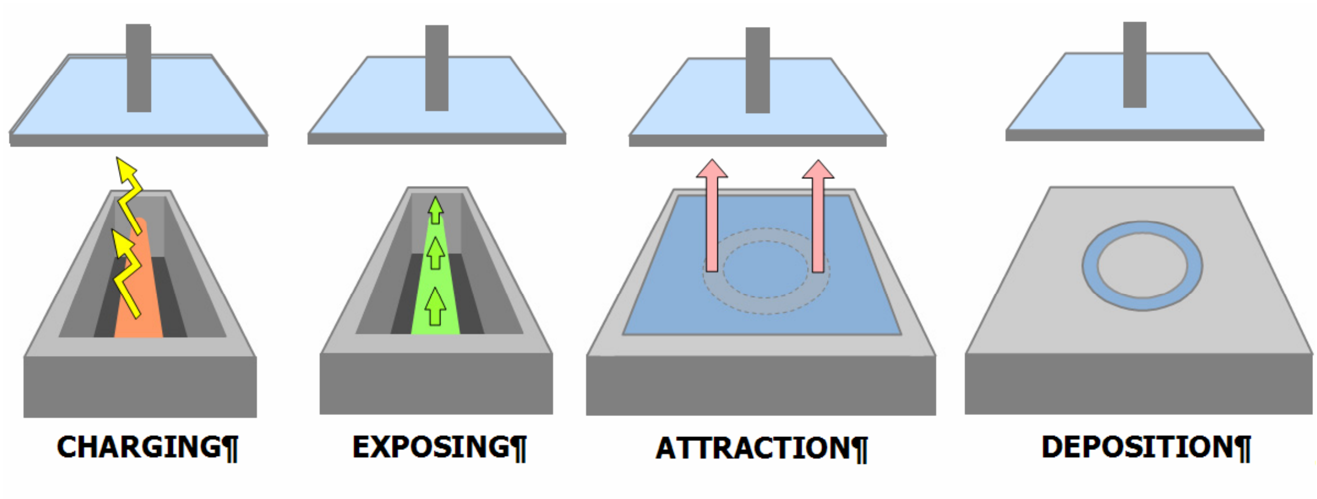

Figure 1. A schematic illustration of the process steps during layer fabrication.

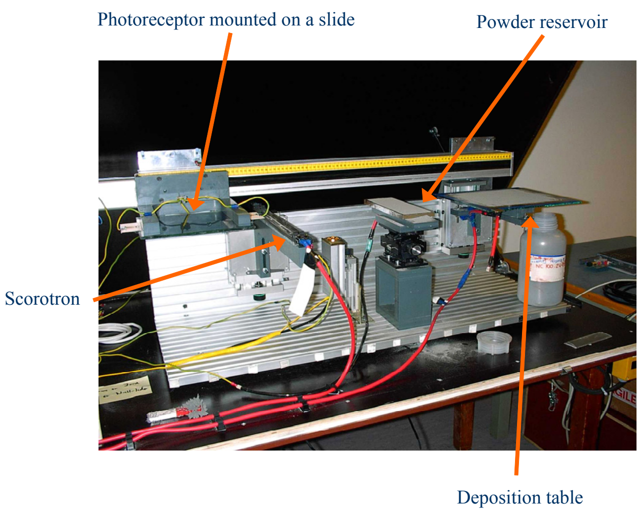

Figure 2. Laboratory set-up of the layer fabrication process sketched in Fig. 1 apart from the LED exposing station

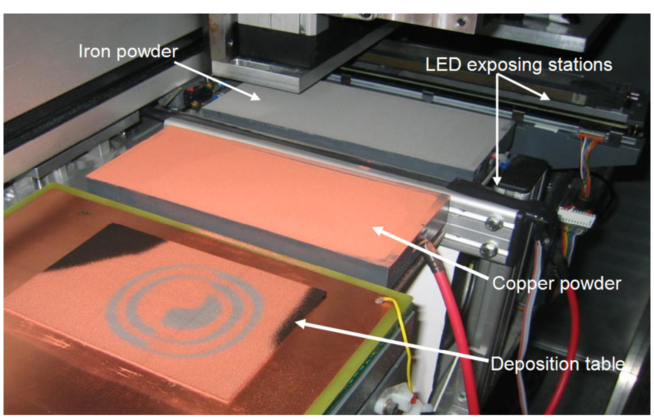

Figure 3. Layer fabrication of two different powders in the same layer

Figure 4. A graphite sheet with copper and iron powder (dark) deposited on it.

Consolidation

In the Metal Printing Process, powder layers are created on the photoreceptor and then transported to the consolidation system. The photoreceptor is illuminated with a strong light source above the die such that it looses its charge and the powder is deposited. The loose powder layer is then cold compacted by a powerful press. This cycle is repeated until the product is finished. After the final layer is deposited, the compact is hot pressed at sintering temperature. The consolidation stage of the MPP is illustrated in figure 5. Several heating methods like induction and electric resistance heating have been investigated for the consolidation cycle. Each of these methods has their specific advantages and disadvantages depending on the specimen size, type of powder material and required sintering temperature.[5-7]

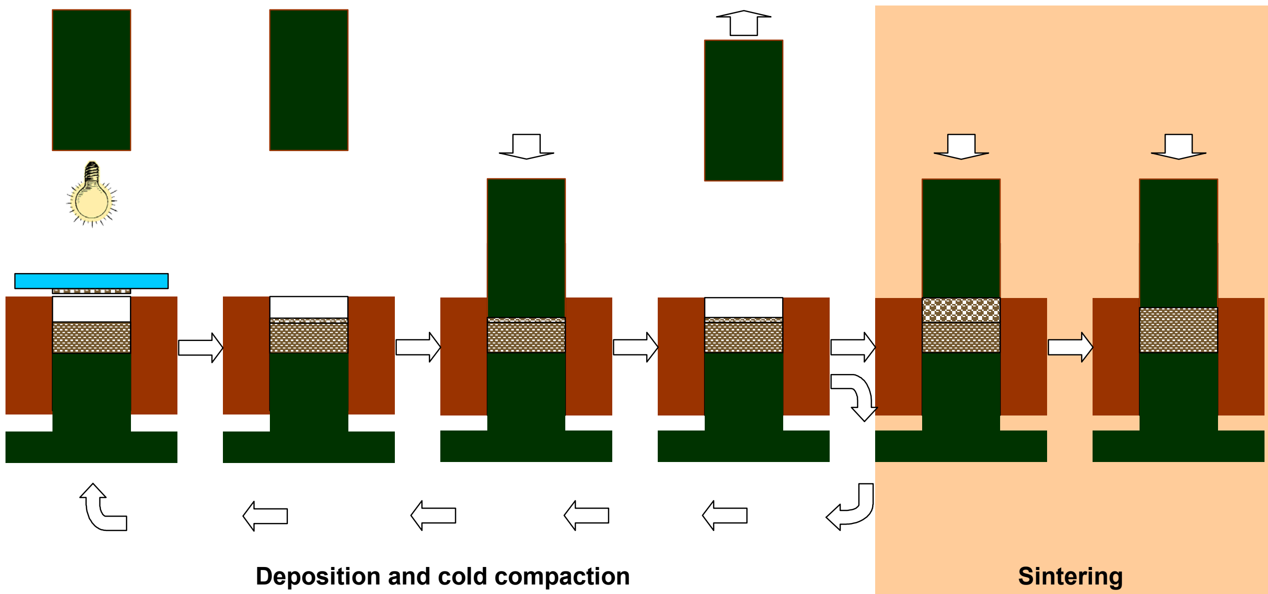

Figure 5. Schematic representation of the compaction cycle and subsequent sintering

Potentials of the Process

Shaped Components

As shown in figures 3 and 4, a powder layer can consist of two (or more) different powder materials. By choosing two powders with very different sintering temperatures, for example copper and alumina powder, and hot pressing them at a temperature where only the copper is sintered, one can produce a complex shaped component with overhangs and internal passages. The alumina powder functions in this case only as a medium to transfer the pressure and to support the shape of the component. This is illustrated in figure 6.

Graded Materials

By changing the powder in the powder reservoir from layer to layer, graded materials can be produced. An example of such for a copper-iron graded material is shown in figures 7 to 9. In this case, pure iron powder is first inserted into the machine, after which it is exchanged by mixtures of iron and copper powder with gradually increasing weight fraction of copper until there is only pure copper powder used. This example demonstrates the possibility to produce functionally graded materials or mix elementary powders which react to intermetallic compounds during sintering via MPP.

Graded Materials, the Smart Way

To use premixed powder as described above is the easiest way to achieve graded materials, but the method has several weaknesses when it comes to usage. One needs i.e. to have mixed powder of every type, and also in different fractions (i.e. 80% Cu and 20% Fe, 60% Cu and 40% Fe and so on). A better way to do it is to use the knowledge from the color printing industry, and transform this into the third dimension.

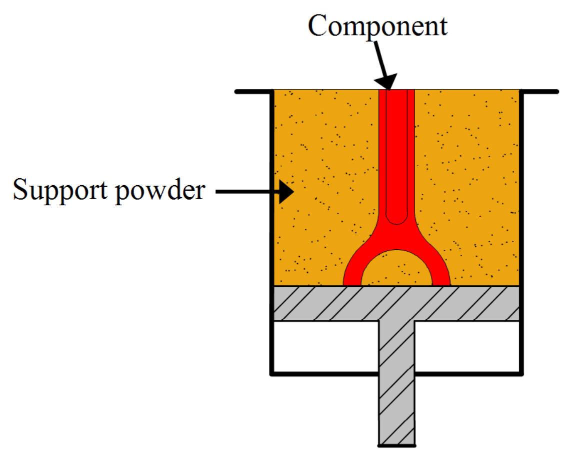

Figure 6. Method with which shaped components can be build using two different powders

Looking at only one layer, we have the possibility to mix powders on an area by attracting i.e. Cu first to a dice pattern, and then Fe to the remaining squares. Due to the characteristics of the powders, they are highly conductive, it is hard to get small squares, and one layer built like this will not be considered very graded. By switching the two powers in the next layer, one will get a mix of the powders. This is good when mixing in a 50/50 ratio, but when the desired fraction is i.e. 80/20, one can not switch powders every second layer. This will of course lead to a 50/50 mix. This can however be prevented by shifting the dice pattern in both directions, thereby letting the layers infiltrate each other. This is illustrated in figure 10. This way of making graded materials can be done because of the fact that the layers are only one particle deep. With regards to if a dice pattern is the most suitable, and how much, if any, the shift of the pattern in both of the directions should be, this is still to be investigated.

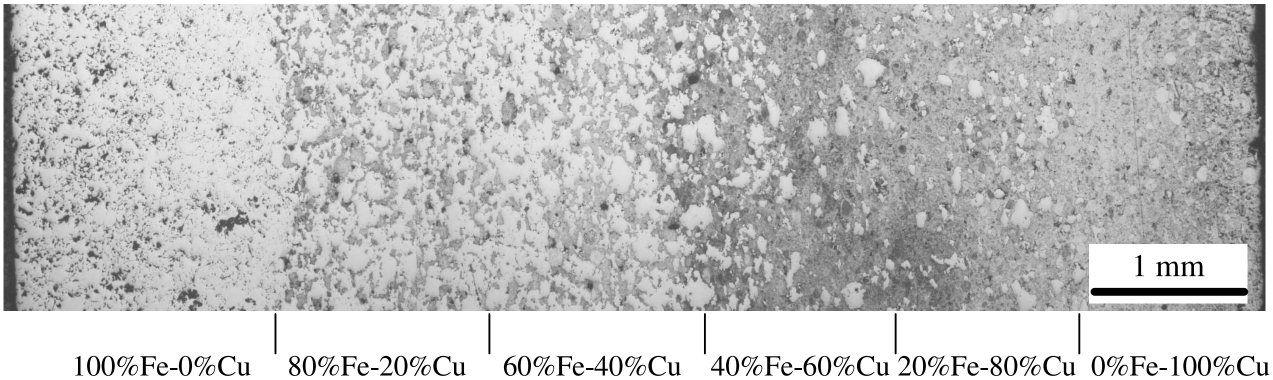

Figure 7. Sintered structure with a progressive change from iron to copper.

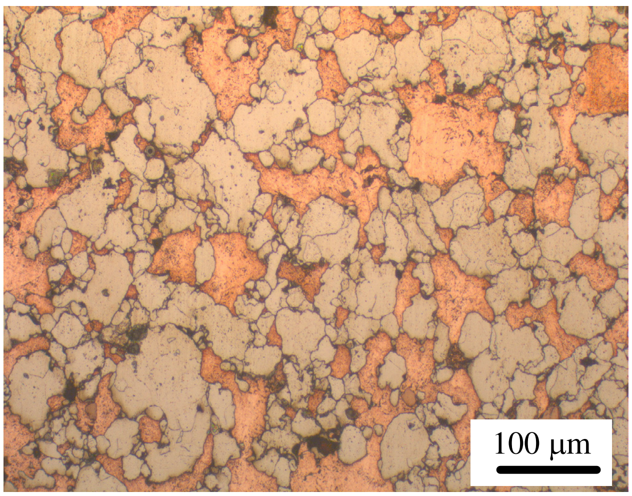

Figure 8. Distribution of Fe particles in Cu matrix.

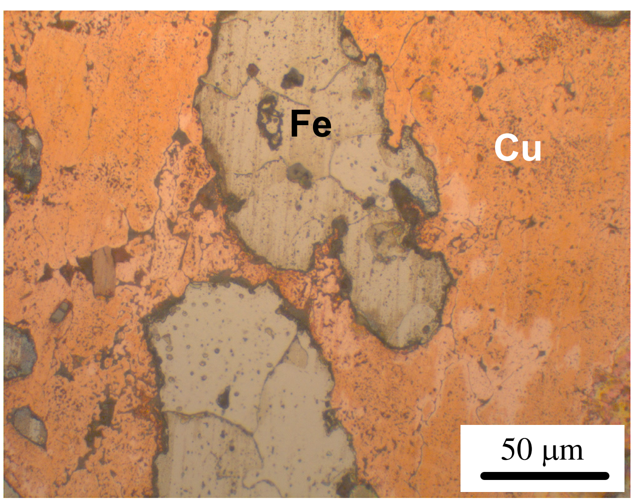

Figure 9. Iron powder particles in copper matrix.

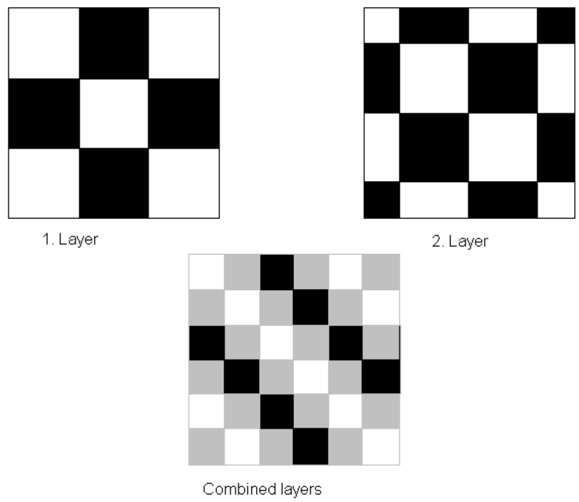

Figure 10. Suggested method to build graded materials.

Controlled Porosity

By sintering after the deposition of a small number of layers, the porosity of the material can be locally controlled. This gives the possibility to produce filters or membranes which integrate various materials with different local porosity.

Acknowledgements

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Author Biography

Øyvind Kolnes received his M.Sc. in cybernetics in 1996. He started working at AquaMetric AS as a system developer, but has since 2001 been working at SINTEF ICT, Applied cybernetics, using most of this time to work on the Metal Printing Process, especially with focus on layer fabrication. He has recently moved to SINTEF Petroleum Research, Drilling and Well Construction, but is still working a little bit on the MPP-project.