

Electrophotographic powder deposition for freeform fabrication

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Abstract

Research at the University of Florida on electrophotographic freeform fabrication is presented. In this fabrication technique, powder is picked up and deposited using a charged photoconducting surface and deposited layer by layer on a build platform. The process enables precise deposition of powder in the desired shape on each layer. A test-bed was designed and constructed to study this approach to solid freeform fabrication. Methods for charging and depositing powders on a platform using a photoconducting drum were studied. Preliminary results obtained using this test-bed are presented.

1. Introduction

Solid Freeform Fabrication (SFF) is a new class of manufacturing technologies that is characterized by a layer-by-layer build-up of parts (Ashley, 1991, Kochan, 1993). Due to the layer-by-layer building approach, it is possible to create significantly more complex parts in one fabrication step than was previously possible. In addition, due to the relatively simple process planning required, the potential has been demonstrated to automatically fabricate a part under computer control given a solid model of the part.

Over the last decade many different technologies for Solid Freeform Fabrication have evolved. Broadly, the SFF techniques available currently can be classified as stereolithography, solid fusion and solidification, laminated object manufacturing, and powder based techniques (Kochan 1993). The earliest solid freeform fabrication technology was based on stereolithography (Kodama, 1981). Stereolithography builds parts by solidifying a liquid photopolymer using a laser beam. Parts are constructed layer by layer by hardening the photopolymer using a laser beam that is projected in the shape of the cross-section of the part. Examples of solid fusion and solidification technique are Fused Deposition Modeling (FDM) and Shape Deposition Manufacturing (SDM). FDM involves depositing ABS plastic, wax, etc by extruding the material through a nozzle in a fused state (Crump, 1992). Shape Deposition Manufacturing (SDM) integrates material deposition and material removal (Amon et al 1998). Layers of part material are deposited by microcasting and machined to net-shape before additional material and further layers are deposited. Laminated object Manufacturing (LOM) builds parts by gluing foils or sheets of material on top of the one another (Feygin et al 1991). A laser beam is used to cut the sheet into the desired shape of the cross-section.

The two main powder-based techniques that have been commercialized are Selective Laser Sintering and 3D printing. For powder based methods no support structures are

typically required to create complex shapes. Powder is selectively consolidated into a part and the remaining powder can be easily removed. In the SLS process (Bourell, 1992) a thin layer of powder is deposited in a workspace container and the powder is then fused together using a laser beam that traces the shape of the desired cross-section. The process is repeated by depositing layers of powder thus building the part layer by layer. In the 3D printing process (Sachs et al 1992), a binder material selectively binds powder deposited in layers. Ink-jet printing technology is used to print the binder in the shape of the cross-section of the part on each layer of powder.

Freeform Powder Molding (FPM) process is a two-powder method, that uses a “tool” powder of a different material than the part to be manufactured. The two powders are deposited layer-by-layer. Although, no specific method for powder deposition has been developed a method of depositing powders through nozzles has been proposed. Rock and Gilman (1995), have presented application of this process for tool manufacture using metal powders.

A powder based freeform fabrication technology is described here that builds parts by depositing powders layer-by-layer. Powder is deposited using electrophotographic powder deposition method described in section 2. Section 3 describes the compaction or sintering process required for consolidating the part. Implementation of the test-bed and conclusion are presented in sections 4 and 5 respectively.

2. Electrophotographic powder deposition technique

A solid freeform fabrication method is described where powder is deposited layer-by-layer using electrophotography. The powder particles are picked up and deposited by electrostatic force by a charged surface. This process is currently patent pending. Powder

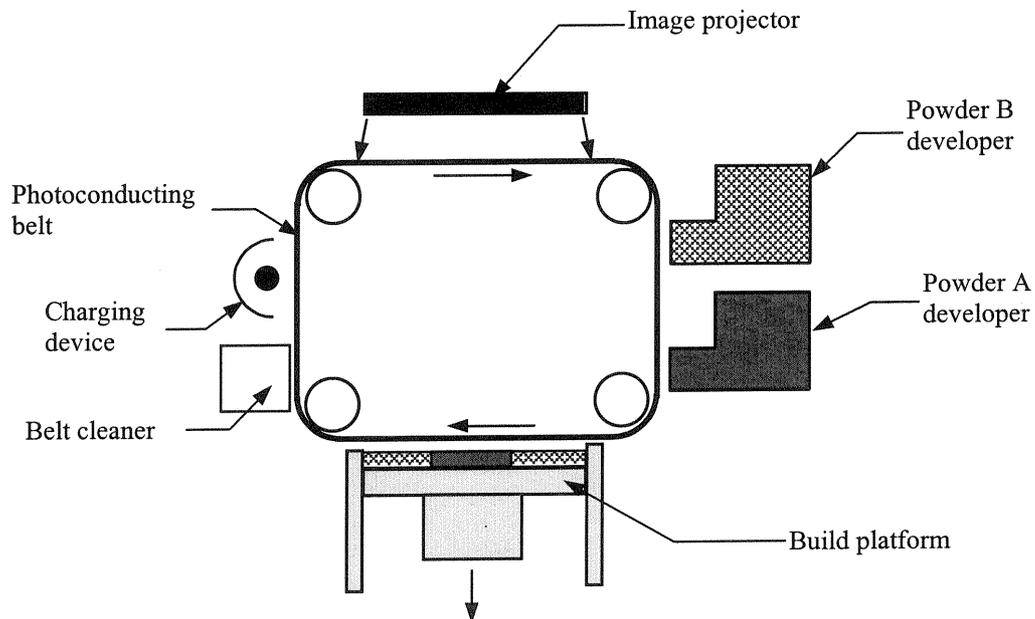


Figure 1. Powder deposition system

can be picked up using a photoconducting belt or a drum. A configuration based on photoconducting belt is illustrated in Figure 1. The belt has a coating of photoreceptive material on one side. This material is non-conducting in the dark but becomes conducting when light falls on the surface. The belt is cleaned and charged by the belt cleaner and charging device respectively. The image projector then discharges the belt selectively by projecting light on the belt so that only an area in the desired shape remains charged. Light can discharge the photoconductor because it becomes conductive in the region where the light falls and charge flows to the ground in such regions. Later, when the belt comes in contact with the image developer, powder particles jump on to the region of the belt that is still charged. The developer not only acts as powder container but it also charges and transports the powder to the photoconductor. The figure shows two developers so that the system could deposit more than one powder. The powder picked up by the belt is deposited on to the build platform, which is charged in the opposite polarity to attract the powder particles. This process is repeated to deposit powder layer by layer. Very fine powder can be used in this process so that each layer can be as little as 5-10 microns thick. The sub-systems and the process involved are described in more detail below.

2.1 Corona charging

Photoconducting material (also called the photoreceptor) can be charged using a corona-charging device. The device is schematically shown in Figure 2. High voltage is applied between the corona wire and the shield. Due to this high voltage, the air near the wire is ionized. The ions having the same polarity as the wire are repelled from the wire towards the photoconducting surface.

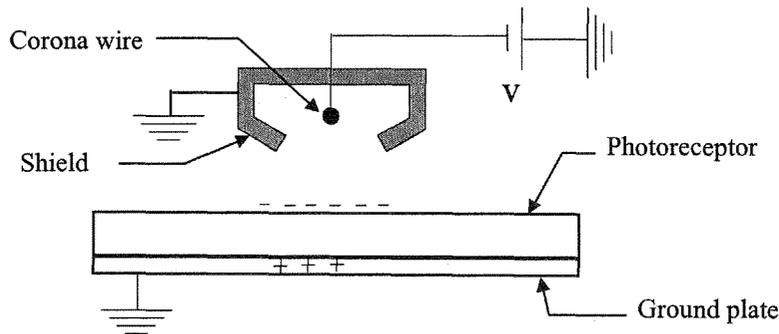


Figure 2. Charging the photoconductor

2.2 Image projection

Photoconducting surfaces are widely used in many image-processing applications such as photocopiers. In most small copiers, photoconducting drums are used that have a layer of photoreceptor deposited on the surface of the drum. Some of the larger and high-speed photocopiers use photoconducting belts. Many photoreceptors have now been developed. The earliest material used in photocopiers was amorphous selenium. More recently, many organic photoreceptors (Schien, 1988) have been developed. The photoconductor

becomes conductive and gets discharged when light falls on it. A latent image of the desired shape can be formed on the photoconducting surface by projecting light on the region to be discharged. This was achieved using an array of laser beams that project the desired image line by line on to the photoconductor.

2.3 Image developing system

The image developing system (or image developer) must electrostatically charge the powder to be deposited and bring it to the vicinity of the latent image on the photoconducting belt. The charged particles would then adhere to the latent image due to the electric field created by the charge on the photoreceptor. This will create a real image on the belt consisting of a uniform layer of powder deposited on the charged areas of the belt.

We are currently experimenting with various types of development systems to identify the system most suitable for our application. Most photocopiers and printers use a two component developing system, where “carrier” particles are mixed with the toner particles. These carrier particles are made of a magnetic material so that they can be transported using magnetic force. The carrier particles serve two purposes. Firstly, they induce electrostatic charge on the toner particle during mixing. Secondly, toner particles, which are much smaller in size than the carrier particles, adhere to the carrier particle. Therefore, they get transported along with the carrier particles on magnetic rollers.

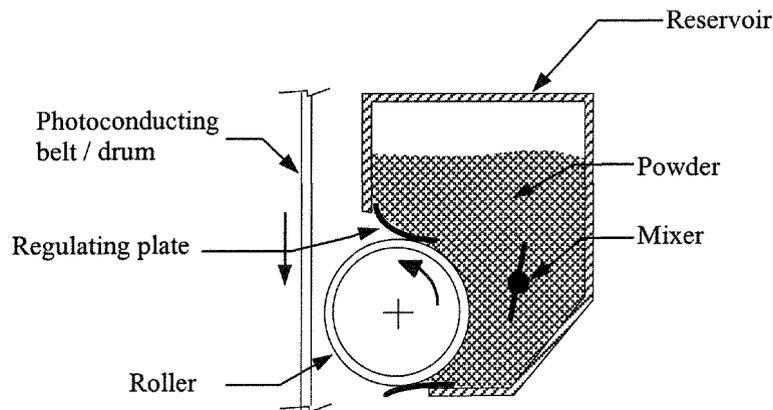


Figure 3. Image developer for depositing powder on belt

Currently, we are using a mono-component development system where the powder particles are charged using an a.c. field. The field creates a powder cloud that gets charged tribo-electrically due to the contact with a regulating plate. A schematic illustration of the developer depositing powder on the belt or drum is shown in Figure 3.

2.4 Powder deposition or transfer

The powder picked up by the belt has to be deposited on the build platform so that it is deposited over the previous layers with precise alignment. To facilitate the transfer of

powder from the belt to the platform, it is necessary to charge the platform / top layer of powder to a reverse polarity than the belt and the powder. In addition, after depositing each layer the powder has to be fused to the previous layers to build green strength by applying a compressive load / heat.

2.5 Cleaning system

After the powder has been deposited, the photoconducting belt has to be discharged and cleaned to remove any residual particles. This can be achieved by exposing the belt to a bright light to discharge it and subsequently using brushes and / or scraper blades to remove residual particles.

3. Consolidating the part

Parts can be built by depositing powder of a single material layer by layer and fusing each layer to the previous layer by application of pressure and heat via a compacting device. In this case temporary support structures have to be created to support any overhanging features. Alternatively, the powder deposition method described above can be used to deposit two powders in each layer, one powder of the material with which the part is to be made while the other powder provides support by holding the part powder in the required shape during subsequent compaction and sintering. The idea is illustrated in Figure 4. Powders of materials A and B are deposited as shown in a box-like container. Powder B acts as *support material* that surrounds powder A, the *part material*.

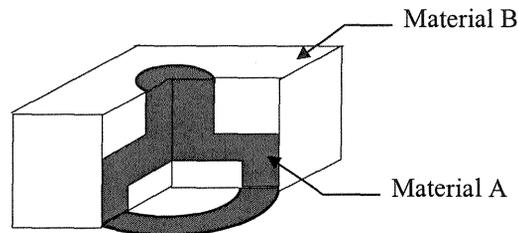


Figure 4. Powder based freeform fabrication

If material B has a relatively high melting point compared to material A, then upon compacting and sintering, powder A will fuse together and consolidate while material B will remain in powder form. The material B therefore serves as a die within which powder A is compacted and sintered. Since both powders are deposited layer by layer, the part and the “die” are being built simultaneously.

Compaction and sintering will enable the creation of fully dense parts. The powder layers will be compacted by subjecting it to uniaxial compression within a die during sintering. The support powder will transmit the pressure around the part being consolidated to apply nearly isostatic pressure on the part. If fully dense parts are not required then compaction is not necessary. Both compacting and sintering are associated with shrinkage in volume. In order to hold the part dimensions within a desired tolerance, it is essential to be able to predict the shrinkage fairly accurately.

4. Test-bed results

A test-bed was designed and constructed to test the powder deposition scheme described here. It consists of a movable build platform on which powder is deposited by a photoconductor drum. The photoconductor drum was charged using a charging roller, which is a contact charging device (Kadonaga et al, 1999). The latent image is formed on the drum using an array of laser beams. The developer used consists of a container for holding powder and a magnetic roller that transports powder. A magnetized polymer toner powder was deposited layer by layer on to the platform. To transfer the powder on to the platform or the previous layers of powder, the top layer was charged using a charging roller. After the deposition of each layer, a heat roller was used to fuse the powder to the platform or previous layers. The test-bed is not yet fully automated and requires manual set up to print each layer. However, it serves as a useful facility to test layer by layer deposition of powder.

Preliminary results indicate that the approach described here is capable of printing powder with precision consistent with electrophotography used in printing and photocopying applications. The test-bed is capable of achieving an accuracy of roughly 600 dots per inch. However, positioning subsequent layers precisely over previous layers will require robust control system which is currently being designed.

5. Conclusions

Electrophotography appears to be a promising means of depositing powder in desired shapes of freeform fabrication or rapid prototyping. The process is capable of highly accurate control over the shape of powder deposition. Further research is needed to study and model techniques for charging and transporting a variety of powders. A test-bed was constructed to enable this research.

6. Acknowledgement

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7. References

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