Ink-Jet Three-dimensional Printing of Photopolymers: A Method of Producing Novel Composite Materials

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Current additive type manufacturing technologies such as Ink-Jet Three-Dimensional Printing are used in rapid production of three dimensional (3D) objects, directly from Computer Aided Design (CAD) data. Ink-Jet 3D Printing provides fast feedback to designers and thus considerably shortens the design and development process of different articles.

Today, a new technological breakthrough has enabled the extension of the use of CAD and Ink-Jet 3D Printing into the field of material development. This breakthrough allows the development and production of novel UV-curable Composite Materials, which could not have been produced in the past by any formerly existing manufacturing technology.

Introduction

In the last couple of decades we have been witness to the development of new and revolutionary manufacturing technologies, sometimes collectively known as *Solid Freeform Fabrication (SFF)*. Although *SFF* enables fast and economic manufacture of complicated structures, directly from *CAD* and without the need for tooling, inefficiencies still existing in *SFF* have limited its adoption particularly into *R&D* and design related fields; for example, for the production of prototypes for visualization and demonstration, where *SFF* provides fast and effective feedback to designers, thus shortening product development cycles and significantly improving design quality.

In contrast to more standard manufacturing technologies, e.g., *CNC* (*Computer Numerical Control*), which implements a ***subtractive fabrication process*** whereby objects are manufactured by the calculated removal of material from a block of raw material, *SFF* technologies employ an ***additive building process***, whereby objects are manufactured by the repeated addition of material layers.

The SFF process can be divided into two main steps: *Slicing* and *Recoating*.

In the *Slicing* step, a software data file containing a virtual representation of the desired object is translated into a set of data files, each file containing a virtual representation of single thin *3D* object slices. The thinner the slices, the more accurate the virtual representation of the *3D* object.

In the *Recoating* step, the *3D* object is physically built up according to the slice data files, a slice at a time, and one on top of the other, in a layer-by-layer building process.

Today *SFF* encompasses many different approaches to the additive fabrication process, including *Stereolithography*[1] (*SLA*), *Selective Laser Sintering*[2] (*SLS*), *Fused Deposition Modeling*[3] (*FDM*), *3D Printing*[4] and others.

Any *SFF* method can be described by the specific ***Recoating*** method used, namely, the specific process used to deposit the layers of building material, as well as by the type of building materials and methods used to support the object during the building process[5].

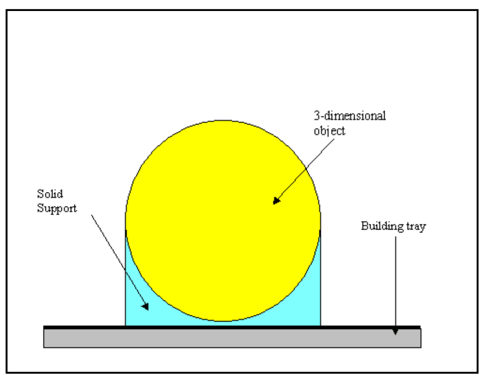

Fig 1: Schematic representation of the result of a *PolyJet Ink Jet 3D Printing* process showing a *3D* model and the solid support construction.

Different *SFF* technologies employ different methods and materials to support the *3D* object. In *SLS* for example, the same material used to build the desired *3D* object is used to support the object. In this method, at the end of the building process, the desired *3D* object is obtained immersed in non-sintered powder. In comparison, in *PolyJet Ink Jet 3D Printing*, two different building materials are used, one for building the desired *3D* object (*Modeling* material) and a second for building a support construction (*Supporting* material), to enable the printing of undercut areas [Fig 1].

Although numerous improvements and different *SSF* approaches have been developed over the years in most *SFF* approaches, material properties have not enabled the broader adoption of *SFF* into different manufacturing areas. Instead, *SFF* has been used mainly for rapid prototyping.

Very recently, *PolyJet Matrix*[6], a breakthrough in *Ink Jet 3D Printing* of *UV*-curable materials, for the first time has enabled the simultaneous use of two different *UV*-curable *Modeling* materials in a single building process. This novel capability, in combination with the existing digital capabilities of *PolyJet Ink Jet 3D Printing*, has enabled the incorporation of *CAD* not only into the design and development of *3D* articles, but also for the development of building materials, namely a novel type of *Composite Material* known as *Digital Material*.

Digital Materials

PolyJet Matrix systems work very similarly to standard 2-dimensional (*2D*) printing systems, but instead of using a set of colored inks, two different *UV*-curable *Modeling* materials are used for building the desired *3D* object and one *Supporting* material used for supporting undercut areas.

Immediately after the deposition of a layer of building material, the newly deposited material layer is briefly exposed to *UV* radiation from a flood *UV* radiation source, prior to the deposition of a subsequent layer. At the end of the building process, the cured *Supporting* material is removed manually or with the aid of water.

Although a broad range of advanced materials have already been developed for use in *PolyJet* systems, one of the challenges remains the development of materials with improved properties for more demanding applications.

Digital Materials are novel type *Composite Materials*, designed by *CAD* and produced by the selective deposition of two *UV*-curable compositions, via *Ink Jet 3D Printing.*

The utilization of *CAD* for the design of *Composite Materials* focuses on the design of the 'phase structure'. This is a new approach which allows the production of materials with a broad range of properties. As in *Composite Materials*, in *Digital Materials* one material phase may be continuous and another dispersed [Fig 2a]. Alternatively, both phases may be continuous, e.g., interconnecting [Fig 2b] or may even both be non continuous [Fig 2c].

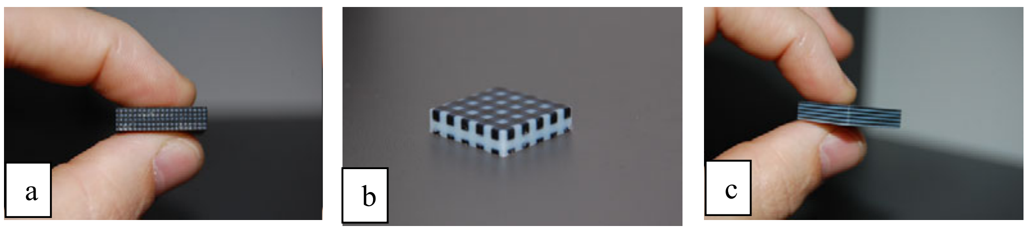

Fig 2: Examples of different types of Digital materials: (a) one material phase is continuous in black and the other one dispersed in white; (b) both phases are continuous; (c) both phases are non continuous.

Due to the high resolution of *Ink-Jet 3D* printing systems, the dimensions of each *Digital Material* phase may be almost microscopic [Fig 5].

In addition, because *Digital Materials* are defined by means of precise software design, special anisotropic materials and graded materials are also possible.

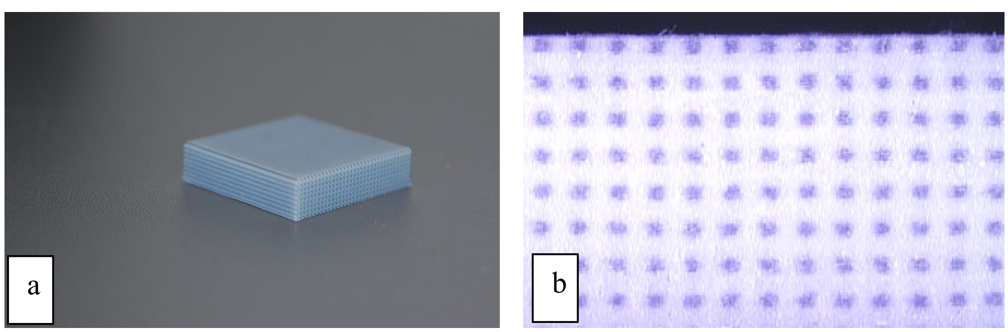

Fig 5: Example of *Digital Material* reinforced by fine "fibers". (a) View showing a *Digital Material* piece; (b) Microscopic view showing 200 micrometer diameter "fibers" cross- section.

Digital Materials being accurately developed by *CAD*, the number of different *Digital Materials* that can be produced using two different *UV* curable materials is almost unlimited [Fig 6].

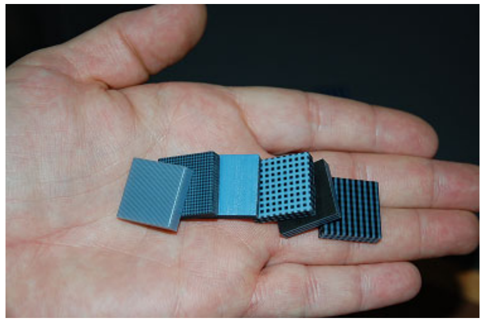

Fig 6: Examples of different Digital Materials produced from two different *Modeling* materials, in a single printing job.

Due to the combination of different *UV*-curable compositions, *Digital Materials* may have properties similar to any one of the parent *UV*-curable materials. Alternatively, their properties may also be a product of their homogeneous combination.

In addition it is expected that due to the *Composite Material* phase structure, synergistic effects will result in *Digital Materials* whose performance exceeds that of each of the parent *UV*-curable compositions; properties difficult to obtain from single *UV*-curable compositions, e.g., high impact strength together with high thermal stability, or high tensile strength together with high elongation to break, are also possible. For example, if one of the component *UV*-curable materials is soft and elastic and the other is strong and brittle, *Digital Materials* with intermediate or varying mechanical properties can be produced [Fig 7].

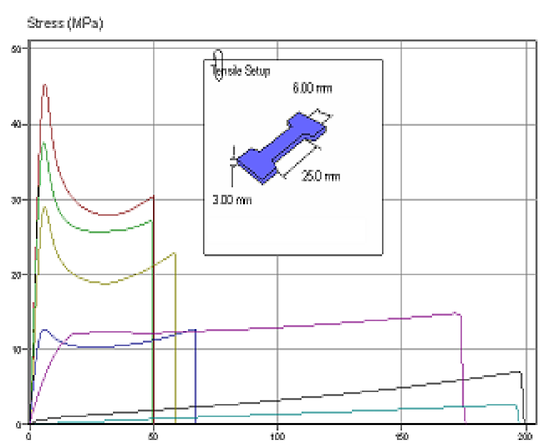

Fig 7: Stress-Strain curves of different *Digital Materials* created from the same parents *Modeling* materials. All these *Digital Materials* where built simultaneously.

PolyJet Matrix enables the production of materials with different colors. If, for example, one of the parent *UV*-curable compositions is white and the other black, *PolyJet Matrix* allows the simultaneous production of *Digital Materials* having different gray shades [Fig 8].

Fig 8: Example of part built using a combination of different gray shades *Digital Materials*.

PolyJet Matrix has brought about a profound change in the way materials are developed. Traditionally, formulators have devoted all their skills and experience to developing different formulations for different applications, each formulation possessing an entire set of properties required to make it function properly in a specific application scenario. In contrast, with the *PolyJet Matrix* approach, the formulator first develops two basic or 'parent' compositions, each lacking at least some desirable material properties, but at the same time distinguished by other significant properties. In a second step, the formulator designs the *Digital Material's* specific phase structure, utilizing the two parent compositions, which will finally result in a material having the required material properties, including the significant properties of each parent composition.

Summary

The *PolyJet Matrix* digital combination of two *Modeling* materials has significantly broadened the scope of *Ink Jet 3D Printing* systems. This technology breakthrough not only enables the simultaneous production of a variety of different materials in a single printing process, but due to the incorporation of *CAD* into the material development field, also enables the production of materials having properties which could not have been obtained using any other existing manufacturing technology. The incorporation of *CAD* is a key feature of this new technology and it is expected that in the future it will facilitate the incorporation of *Ink Jet 3D Printing* into applications which are presently inaccessible using single material *SFF* methods.

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