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Selective laser sintering of three-dimensional geometries and structures of quartz glass - possibilities and limits

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ABSTRACT:

Additive processes offer the possibility to create complex and three-dimensional geometries with great freedom of design. This technology is already very well developed for metallic materials and plastics. For silicate materials this innovative technology is still in its infancy. The special material properties of these hard and brittle materials are one reason for this.

A new selective laser sintering process for glass powder is presented in this paper. With this process compact glass bodies can be built up, which have a residual porosity of about 25%. The maximum printable footprint of the building platform is 120 mm so far. In the course of the investigations a test geometry was designed to evaluate the resolution and the current structural limits of the process.

As a result, the various printed geometries are analysed and metrologically evaluated. A comparison is made with the sintering processes for metals and plastics. Possibilities and limits of this novel sintering technology are evaluated and the future potential is shown.

Image:

The 3D printing processes of laser metal deposition (LMD) and directed energy deposition (DED) are revolutionizing how the aerospace industry designs and builds high-value components across the manufacturing spectrum from prototyping to production.

3D printing company, Formalloy, is producing parts using a laser-based process because of its ability to create new advantageous shapes. "Our technology is known as LMD. That's a method where you blow power and heat it with a laser.

Keywords: Energy Scenario, Renewable Energy Systems, Solar PV materials, Technology, Environmental impacts

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INTRODUCTION

Added substance producing (AM) contains various assembling rehearses used to portray various advances which have been showing up throughout the years. It is a procedure frequently useful for low-scale creation, with minimal specialized information, and with lower introductory costs; it is an easy to use way to deal with item improvement [1]. It has seen a quick development all through its long history. Right now, AM has advanced from being an exploratory prototyping instrument into a biological system giving devices to the assembling of segments which is impossible with conventional techniques; in like manner, it has seen a more slow, yet minimal increment in assembling of conclusive segments as opposed to proof-of-idea models [2]. When contrasted with customary assembling techniques, AM profits by streamlined procedures engaged with the fulfillment of an item. Essentially to customary techniques, CAD abilities, a fundamental comprehension of the innovation being utilized and its confinements, and general properties of the material being utilized are required to build up a model for printing. In correlation, customary techniques by and large require machine lengthier activity abilities, post-preparing, security guideline consistence, and manual per-material changes [3]. On a very basic level, the term AM explains its layered nature; parts are created by included layers evolving cross-sectional regions as indicated by the geometry of an item. The term AM has seen a slight, yet quickened, dislodging welcomed on by the more typical term "3D printing". This is generally because of the mass customer situated promoting behind the term 3D printing, while AM is often connected with specialized or modern procedures. Gebhardt [2] ventures to guarantee that the term 3D printing will supplant AM by and large given how it is simpler for individuals to picture it when it is related to notable advances like paper printing just as its nearby connection to 3D demonstrating programs which makes-up a huge piece of the base usefulness of the procedure. It is generally viewed as that a 3D model is more valuable than a drawing or specialized particular sheet; in addition to the fact that models contain all the dimensional data important to reproduce an item, they likewise can be controlled and adjusted to all the more likely comprehend the 2 item and to repeat easily. Besides, models are essential paying little mind to the presence of drawings or specialized sheets to approve the item before creation. Among the advantages of executing 3D imprinting in assembling, is the conceivable expense and time decrease of creation lines. A few pieces of an item can regularly bring convoluted strategies into the creation. Odd shapes or confused to-machine segments can essentially build the expenses of creation by diminishing rate or having the requirement for complimentary advances. A few parts of an item may likewise not need greater methodology to be created and can without much of a stretch be supplanted by less-exorbitant 3D printing forms [4]. AM is described by some novel attributes. Their creation requires no tooling except if post-preparing is applied and can be delivered in any direction. Their creation is conceivable gratitude to STL (stereolithography) records which permit printing by methods for calculations which convey the development steps vital for the material to be produced with exactness. Moreover, printed parts frequently have obvious layers which can be distinguished as bended edges all through the segment when delivered with liquid statement forms or a permeable structure when created with powder-based strategies. The degree of materials which can be delivered by means of AM forms is as of now broad enough to cover numerous material gatherings, yet glasses are still under-investigated and in this way, immature. The field of examination of glass softening isn't new yet does not have the broad advancement which can be seen with different materials. Moreover, particular laser dissolving of glasses is almost non-existent.Additive Manufacturing

Additive Manufacturing (AM) is an appropriate name to describe the technologies that build 3D objects by adding layer-upon-layer of material, whether the material is plastic, metal, concrete or one day human tissue.

Common to AM technologies is the use of a computer, 3D modeling software (Computer Aided Design or CAD), machine equipment and layering material. Once a CAD sketch is produced, the AM equipment reads in data from the CAD file and lays downs or adds successive layers of liquid, powder, sheet material or other, in a layer-upon-layer fashion to fabricate a 3D object. The term AM encompasses many technologies including subsets like 3D Printing, Rapid Prototyping (RP), Direct Digital Manufacturing (DDM), layered manufacturing and additive fabrication. AM application is limitless. Early use of AM in the form of Rapid Prototyping focused on preproduction visualization models. More recently, AM is being used to fabricate end-use products in aircraft, dental restorations, medical implants, automobiles, and even fashion products. At MIT, where the technology was invented, projects abound supporting a range of forward-thinking applications from multi-structure concrete to machines that can build machines; while work at Contour Crafting supports structures for people to live and work in.

Some envision AM as a complement to foundational subtractive manufacturing (removing material like drilling out material) and to lesser degree forming (like forging). Regardless, AM may offer consumers and professionals alike, the accessibility to create, customize and/or repair product, and in the process, redefine current production technology. Whether simple or sophisticated, AM is indeed AMazing and best described in the adding of layer-upon-layer, whether in plastic, metal, concrete or one day human tissue".

Design in AM

Designing for manufacturing and assembly has traditionally meant considering the multiple aspects of the long chain of events which take place for a product to be produced. This involves considering stakeholders, assembly lines, running costs, down-time costs, and many other factors which affect the final production costs and capabilities of the process. This means that designers constantly are looking for new ways which improve on the formula and ideally reduce these costs by adapting new technologies into the equation. If we look back at the trends which shaped the controversial design paradigm-shifts of the 20th century, we have two main theorems which vastly improve on traditional formulas and do so by innovating on the process and reducing the number of steps taken to complete a product. These are Design for Assembly (DFA) and Lean Manufacturing. Intrinsically, Design for Assembly is a methodology which aims at improving the workflow of the process of assembling a product by simplifying the process and making it more controlled and less cumbersome. This method uses multiple numerical algorithms which calculate the cost of various manufacturing processes and recommends ways to improve. These processes range from casting, transporting the part along a conveyor belt, and even the costs related to the down-time of changing tools [8]. At its core, it focuses on considering the assembly line when designing a product. This intends to reduce the costs and work done by simply tweaking aspects of the component. Lean manufacturing on the other hand, is a production balance between individualcomponent crafting, mass production, and their related advantages and setbacks. It aims to reduce the variability and lack of variety of mass production while marginally increasing the yield capabilities of craft production. It does so by implementing methods which use less resources than mass production. Furthermore, mass production focuses on the principle of reducing the amount of failures while achieving a good-enough quality while lean explicitly focuses on perfection and aims to optimize the process to achieve it. 17 While perfection is never actually reached, lean producers do have an increased efficiency and product quality when compared to traditional mass production methods [4].

AM using photopolymers can be currently achieved with the following three methods.

1. Stereolithography (SLA) Machines using this technology function by pointing a laser scanning exposure apparatus, also called a galvanometer scanner, at the resins to start the curing process and rapidly solidify them. These machines have a container where the resins are stored, an installation space, and a build-plate which moves vertically. The resin container fills-up the installation space and the head lowers until it is barely in contact with the resin. A laser then proceeds to "etch" the 2D topography directly on the resin, thus curing it onto the plate layer-by-layer. The laser is aimed on the surface by a mirror which is controlled by the computer interpreting the G-code. Due to the nature of the curing process, components printed with this method tend to undergo minor shrinkage. This phenomenon has been reduced with the introduction of epoxy resins however, they require a longer curing time. Components printed with this method usually are structurally weak before the curing process takes place, therefore adding to the deformation phenomena. Post-processing SLA components is lengthier than with most other processes. First, it is necessary to remove the print from the print bed and to remove the support material which is generated as legs of the same material added to the model; these need to be cut-off or broken-apart. Next, it is necessary to gently wash-off or sand-off the excess epoxy from the surface of the component. Finally, the component is put in an UV chamber for hours to finish the curing process.

2. Digital Light Processing (DLP) While holistically like SLA, DLP functions based on a different process and aims to obtain different results. The construction and operation of the machines is overall the same; the difference lies in the light source. DLP machines replace the laser and mirror with a DLP projector. Most projectors use Liquid Crystal Displays (LCDs) to shape color light sources into a combined image which is projected onto a screen via a lens. DLP projectors on the other hand, have a very different operating principle. These systems contain a chip called a Digital Micromirror Device (DMD) which contains millions of miniature mirrors which can instantly switch between ON or OFF positions. When in ON position, the mirror reflects the light through the lens, and when in OFF position, they do not. This principle has made DLP projectors attractive to video enthusiasts as they offer true-black color management with image reproduction, whereas LCD projectors still emit light in dark 25 spots. This also gives way to DLP printing, where light is shed on the resin only at the spots where the micro mirrors are switched ON. DLP projectors have the potential of becoming the fastest AM technology, as they solidify a full layer at the same time rather than a single spot throughout the layer. This makes for a continuous process which can give very high resolutions in a short amount of time given a powerful-enough laser.

3. Material Extrusion

Material extrusion has become the most common consumer 3D printing process. It is inexpensive to produce, usually requires simple post-processing, and is approachable for average consumers. The process is based on the melting and extrusion of a material through a nozzle which hovers above a print-bed. This material which is being extruded can either be a solid filament-based material which is melted into liquid plastic, or a premixed, viscous liquid which solidifies by means of heat or photocuring.

Glass AM

AM has become a trend in the industry and research is done constantly in many different fields to expand the technology into new fields by adding new materials. It is therefore surprising to see the lack of research and, mostly, discoveries done with glass AM. Given its wide-spread use and nearly unique set of properties, glass plays a major role in industrial processes and thus would be a good inclusion in the catalogue of materials which can be 3D printed. The reasons why research has been deemed a failure so far is that the results do not carry the properties which make glass special, namely transparency and strength. While other materials can achieve similar or higher strengths, it is the combination of its properties which makes glass valuable [18]. The experiments in this paper attempt to accomplish the following: • Generate optically transparent components (inclusion of failures might be present, yet the component is clear enough to allow seeing through). • Generate components with a higher tensile strength than what has been achieved in previous research. • Find the optimal parameters for SLM AM of glass powders to assist future research. • Test the effect on porosity of powders with a particle size between 2-20μm. Furthermore, this thesis focuses on one specific type of glass, silica, which has specific properties suitable for initial testing in the field of glass AM. This glass is characterized by having the lowest coefficient of thermal expansion amongst non-ceramic glasses, useful to prevent the creation of residual stresses in the finished components which make it susceptible to cracking. This chapter will discuss all relevant research done in the field of AM of glass, focusing mainly on those which have been either successful, SLM or SLS-based, or using silica powders. Other relevant research, not-excluding metallic or plastic SLS, will be covered and their relevance will be brought-up. Consequently, the phenomena which have 44 historically impeded glass AM to succeed, will be discussed, explained, and analyzed to explain the factors related to their appearance.

Discussion and Conclusions

The main purpose of this thesis was to test multiple hypotheses surrounding the concept of SLS or SLM printing of glass powders without any added substances, the most relevant of which are the possibility of achieving fully-dense prints by using powders in the range of 2-20μm and the possibility to increase the powder density by tapping or pressing each layer together. Likewise, yet to a lesser degree, the feasibility of using energy density as a parameter to define a linear set of parameters suitable for printing, was tested and further analyzed. The goal was to achieve optically-transparent components which require littleto-none post-processing for the manufacture of optical glass components. Silica glass was selected as the material most suitable for these tests given its low thermal expansion coefficient which, in theory, should prevent cracks from happening when cooling. This material is also amongst the hardest of glasses, thus allowing a larger range of possible uses in various industries which require resistant materials. The selection process was lengthy and intricate which serves the purpose of validation of material choices. This final chapter delves deeper into the mechanisms involved in the success or failure of the multiple tests undertaken by the samples and attempts to give a comprehensive explanation as to why these took place and how they can possibly be improved upon or fixed, in the case of failure, for future development of the field.

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