A Study on the Effect of Slicing Procedures in Layered Manufacturing

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Abstract

In all RP (Rapid Prototyping) processes, the solid model of a component to be produced is created in CAD (Computer Aided Design) environment and is sliced before transferring the data to the RP machine. model can be created as a solid model (by using primitive instancing or constructive solid geometry) or a surface model (by using B-rep). A tessellated (.STL)(Standard Tessellation Language) version of the CAD model can then be exported. Slicing of the CAD model can be carried out either directly on a solid or a surface model of the product or on a tessellated model. In slicing, sets of horizontal planes are intersected with CAD model. This results in closed curves or polygons. The space between any two consecutive horizontal planes is referred to as a slice. This work presents a study on the effect of slicing procedures in layered manufacturing material degradation through the time. The specimens were tested with 0, 30, 60, 90 and 120 days aging. Mechanical properties such as tensile strength, Young's modulus, strain at Yield Point and deformation (microstrains) will be analysed.

***Keywords**: Rapid prototyping, mechanical properties, resin, additive manufacturing.*

1. Introduction

1.1. Background

Rapid Prototyping (RP) enabled the conversion of parametric CAD (computer aided design) data to physical prototypes which could be tested to check if they met the design criteria [1]. This saved not only time but also allowed the testing of multiple models Rapid prototyping has gained widespread industrial acceptance as a means of quickly and economically producing small quantities of physical objects. In addition to its commercial applications, rapid prototyping tools have the potential to drastically influence the ways people create and their reasons for doing so. Digital fabrication promises individuals means of creating complex objects with virtually no prerequisite skill.

CNC machining is a subtractive method of construction as material is removed from a block of material. CNC machining is closely related to manufacturing, and depending on the machine and material, may require placement into a manufacturing setting, as opposed to the office setting in most design and architectural firms. "A prototype is usually a partial representation of the intended system, used as an aid in analysis and design rather than as production software. The construction activity leading to such a prototype is called rapid prototyping". Rapid prototyping is an additive manufacturing technique in which plastics are widely used. Plastics can be additively manufactured from powders, wires and flat sheets that are melted using a variety of different technologies. Compared to the large variety of plastic materials that can be manufactured by adopting conventional processes, a limited numbers of plastics can be additively manufactured effectively, with acrylonitrile butadiene styrene (ABS) and polyactide (PLA) being the most commonly employed polymers [2].

The important mechanical properties of rapid prototyping parts are strength, hardness, ductility and stiffness [3]. The first step in the process is creating the digital (i.e. mathematical) representation of a concept. This is accomplished using a computer software package known as a *computer aided design* (CAD) tool. Most modern CAD tools include fancy visualization features which render the object exactly as it will appear in real life.

The emergence of Additive Manufacturing (AM) processes upsets our knowledge in terms of design. Indeed, in AM, parts are built layer-by-layer, allowing the realization of any shape, which cannot be done by conventional processes like machining [4].

Fundamentally, the development of Rapid Prototyping technology can be split into four primary aspects: Input, Method, Material, and Applications. Input refers to the electronic information required to describe the physical object with numerical data. In the last decade, a number of techniques for Rapid Prototyping have been developed. There are several methods employed in different Rapid Prototyping systems provided by each vendor. Applications can be grouped into design, education, engineering and analysis, and manufacturing and tooling.

3D printing as it is referred to in the media, is a group of manufacturing technologies which are capable to produce complex, three dimensional objects without the need for individual tooling [5]. RP systems take information from a CAD solid model file via an STL file and convert it into a sliced model. They then use this information to drive an SFF process (defined below) to physically build the layers. These layers are deposited on top of each other to form the final part.

- **Solid Freeform Fabrication (SFF):** SFF refers to a collection of techniques for manufacturing solid objects by the sequential delivery of energy and/or material to specified points in space to produce that solid.

- **3D Printing (3DP):** 3DP refers to the category of RP processes which implement the simplest of the SFF technologies to achieve fast and affordable 3D printers. Whilst 3DP is currently a term favoured by the media, its scope is limited to the simplest of SFF techniques. For consistency and clarity this thesis will use the term Rapid Prototyping (which refers to all SFF techniques) throughout, despite the fact it would be equally accurate to refer to 3D printing in some instances.

Normally, commercial manufacturers of printers only provide information on layer thickness, but no information is given as to dimensional accuracy, and the surface characteristics obtained in manufactured components [6]. RP is extremely versatile. Unlike traditional subtractive approaches, part design complexity carries no overhead.

The samples were located on the machine platform at different angles to the printing direction. The material used for the construction of samples was ABS [7]. Tensile tests are conducted on a single material specimen to analyze the influence of various experiment variables that may add up to the enhancement of the mechanical properties of 3D printed products [8]. In order to make 3-D printed parts to be more useful for engineering applications the mechanical properties of printed parts must be known [9]. The benefits provided by Rapid Prototyping include reduced lead time and cost to produce components, improved ability to visualize design geometry directly, earlier detection and reduction of design errors, and optimized part design to meet customer requirement. The major reason for weak strength may be attributed to distortion within or between the layers [10]. RP systems can suffer from some basic limitations:

- It is sometimes difficult, occasionally impossible, to remove support material from cavities.
- Distortion, shrinkage and warping can occur due to residual stresses in print material solidification..

- Build features must not be too small, too closely spaced, or require accuracy beyond the technology's capabilities.
- Overhanging features may affect the surface flatness.
- Surface finish is dependent on material, build orientation, layer thickness, sloped surfaces, intricate features, and curves surfaces.
- The maximum size of the part is defined by the build volume of the RP system.

1.2. Various rapid prototyping machines :

1.2.1. Stereolithography (SLA): SLA was invented by Charle Hull of 3D Systems Inc. It is the first commercially available rapid prototype and is considered as the most widely used prototyping machine. The material used is liquid photo-curable resin, acrylate. Parts are built by sintering when a CO_2 laser beam hits a thin layer of powdered material. The interaction of the laser beam with the powder raises the temperature to the point of melting, resulting in particle bonding, fusing the particles to themselves and the previous layer to form a solid. The next layer is then built directly on top of the sintered layer after an additional layer of powder is deposited via a roller mechanism on top of the previously formed layer.

1.2.2. Jetted Photopolymer (J-P): A similar system to 'Single Jet Inkjet' (below) is available using photopolymers and a curing lamp. It subsequently completely cures each layer after it is deposited with a UV flood lamp mounted on the print head. The support material, which is also a photopolymer, is removed by washing it away with pressurized water in a secondary operation.

1.2.3. Single Jet Inkjet (SJI): The illustration uses a single jet each for a plastic build material and a wax-like support material, which are held in a melted liquid state in reservoirs. The liquids are fed to individual jetting heads which squirt tiny droplets of the materials as they are moved in X/Y fashion in the required pattern to form a layer of the object. The materials harden by rapidly dropping in temperature as they are deposited. After an entire layer of jetting, a milling head is passed over the layer to make it a uniform thickness. Particles are vacuumed away as the milling head cuts and are captured in a filter. The process is repeated to form the entire object

1.2.4. Selective Laser Sintering (SLS): The SLS technique uses a laser beam to selectively fuse powdered materials into a solid objects. Parts are built upon a platform which sits just below the surface in a bin of the heat fusable powder. A laser traces the pattern of the first layer, sintering it together. The platform is lowered by the height of the next layer and powder is reapplied. This process continues until the part is complete.

1.2.5. Laminated Object Manufacturing (LOM): Parts are built, layer by layer, by laminating each layer of paper or other sheet-form materials and the contour of the part on that layer is cut by a CO2 laser. The Z control is activated by an elevation platform which lowers when each layer is completed, and the next [paper] layer is [rolled over the build] then laminated [to the top of the build] ready for cutting. No additional support structures are necessary as the "excess" material, which is cross-hatched for later removal, acts as a support. The LOM processes produce parts from bonded paper plastic, metal or composite sheet stock. LOM machines bond a layer of sheet material to a stack of previously formed laminations, and then a laser beam follows the contour of part of a cross-section generated by CAD to cut it to the required shape. The layers can be glued or welded together.

1.2.6. Fused Filament Fabrication (FFF): Filament is fed into an extrusion head and heated to a semi liquid state. The semi liquid material is extruded through the head and then deposited in ultrathin layers from the head, one layer at a time. Since the air surrounding the head is maintained at a temperature below the material's melting point the material quickly solidifies.

1.2.7. Solvent jet printing (also sometimes referred to as Three- Dimensional Printing): The machine spreads a layer of powder from the feed box to cover the surface of the build piston. The printer then prints binder solution onto the loose powder forming the first cross section. The powder is glued together where the binder is printed. The remaining powder remains loose and supports the layers that will be printed above. When the section is completed, the build piston is lowered, a new layer of powder is spread over its surface and the process is repeated

1.3. Control System Problems

Perhaps the most daunting aspect of building a rapid prototyping machine is the control system. Several issues make this standard architecture sub-optimal for machine development:
* The motion controller must be carefully configured with the parameters of the machine.
* The motion controller executes rigidly coded routines which cannot be easily modified by the user.
* Expensive interface cards are often necessary between a computer running motion control software and stepper motor controllers.
* The number of motors is limited.
* Accessory inputs and outputs, such as those used for hand encoder wheels or limit switches, are pre-prescribed and limited.
* Large bundles of cables must be run between the stepper motor controllers and their respective axes.

1.4. Indirect RT approaches for mould fabrication

All indirect RT approaches start with the fabrication of a RP pattern of the final desired casting. The finished pattern is used to cast the required mould. As such, mould quality depends greatly on the quality of the RP patterns.

- **Silicone rubber tooling**

In this process, a degassed liquid silicone and hardener mixture is cast around a RP pattern contained in a mould box. Runner and gating channels are incorporated by embedding ABS or Perspex rods into the liquid silicone or by cutting the channels in the cured silicone block. Upon curing, the rods are removed to form through channels and the pattern is subsequently removed to form the mould cavity by cutting along the parting line. Silicone rubber tooling allows quick production of inexpensive multiple moulds for small and large parts with good part cosmetics.

- **Epoxy resin tooling**

To produce epoxy resin moulds, the RP pattern is embedded in clay up to the pre-determined parting line. Runner and gating channels are formed by attaching ABS rods onto the pattern. The assembly is spray coated with release agent before liquid resin or a resin/aluminium powder mixture is cast around the pattern. Upon curing, the pattern is separated from the hardened mould half, cleaned and re-coated with release agent in preparation for casting the second mould half. Holes forming the alignment and locking features for the mould set are milled onto the surface of the existing mould half. Matching pegs will form on the second mould half by resin occupying the empty volume of these holes during casting. The prepared pattern is replaced onto the existing mould half and the procedures for casting are repeated. The formation of residual stresses between the two mould halves during curing will require the mould set to be heat treated before the halves are separated.

- **Spray metal tooling**

To create a spray metal mould, minute droplets of molten metal such as tin-zinc, or steel are sprayed onto a RP pattern using an arc spray process. The thin shell of deposited metal constitutes the mould surface. To strengthen the shell, a solid backing is cast around the shell using pure epoxy, metal-filled epoxy or low-melt alloy backfill materials. With a proper choice of backfill material and the incorporation of cooling channels, a spray metal mould exhibits good injection cycle times. Other advantages include the ability to cater for large moulds at relatively low costs, high tolerances due to minimal shrinkage encountered during and after the spraying process, and good tooling life of approximately 10,000-100,000 injections.

- **Cast metal tooling**

In this approach, expendable RP mould patterns are used to investment cast the production moulds in aluminium or steel. Its main disadvantages compared to other indirect RT processes are the relatively longer lead-times and lower levels of accuracy achievable due to additional steps taken in investment casting the mould. However, tight tolerances for critical features on the cast metal mould can be brought into specifications with secondary machining operations or local inserts. Depending on the metal used, cast metal tooling were estimated to be capable of producing several thousands to beyond 200,000 plastic components. Leyshon Miller Industries has utilised FDM fabricated wax patterns to successfully investment cast aluminium mould inserts.

- **3D Keltool tooling**

The 3D Keltool process (3D Systems Inc.) starts with an impression of the RP pattern created using silicone rubber tooling. The silicone mould is used to cast the required mould inserts from a tool steel powder and binder mixture. The cured “green” parts are fired in a furnace to debind and sinter the steel powders. Sintered parts are infiltrated with copper to produce fully dense structures with compositions of 70% steel and 30% copper. 3D Keltool mould inserts are limited to small product sizes and have an estimated life exceeding 1,000,000 shots in plastic injection moulding.

2.Methodology

A systematic and scientific approach needs to be followed for a reliable report and critical analysis of the results. The proposed methodology for this project

1**.Collection of data :** Specimens produced by fused deposition modelling were tested and to be evaluated for degradation at 0, 30, 60, 90 and 120 days of lifetime and data regarding this are collected.

2. Comparing results with previous papers: The data collected will be compared with the results obtained with the previous year papers .

3.Comparison and analysis of actual and standard data: The results of experiment are described_based on different tests applied at different moments_(specimen ages). This experiment has been also used in a previous work with different material however it_is not the material used in this paper.

3. Results and Discussions

Effect of slicing procedures in material degradation will be analysed by its mechanical properties. Test realized will be tensile strength test (standard tests ASTM). The specimens were tested with 0, 30, 60, 90 and 120 days aging. Mechanical properties such as tensile strength, Young's modulus, strain at Yield Point and deformation (microstrains) will be analysed.
Additive Manufacturing (AM) is starting to replace conventional manufacturing processes where complex parts with small lead time and lot sizes are needed [11]. In the scope of this experiment, a test has to be performed for an extended period time. The purpose was to check the time required for significant changes occurred in the specimen. With the increased use of such printers, it is important to study both the dimensional accuracy of the printed parts and their mechanical properties [15].

4.Conclusion

The work presented has the influence of time in the variation of the mechanical properties of the resin used i.e. ABS. For this experiment, a test will be performed for a long period of time with 0, 30, 60, 90 and 120 days aging, checking the beam for a static load and other mechanical properties.

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