RAPID PROTOTYPING/RAPID TOOLING – A OVER VIEW AND ITS APPLICATIONS IN ORTHOPAEDICS

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ABSTRACT
This research focuses a new method of using data obtained from CT images combined with digital CAD and rapid prototyping model for the surgical planning of difficult corrective and this new application enables the surgeon to choose the proper configuration and location of internal fixation of plate on humerus bone in the field of orthopaedics. This paper presents the procedure for making model of humerus bone using rapid prototyping technologies [RPT]. Production of prototypes for medical modeling (orthopaedics) in general can be classified into two broad categories based on manufacturing process route and type of data available, i.e. designed data and scanned/digitized data. Designed data is data that is created according to a person's idea on computer aided design (CAD) system. For this type of data, the designer has total control to modify, adjust and manipulate his design ideas to serve the functional purpose of his design. Producing models with this type of data is very straightforward and no further data treatment is required. CAD solid model can be directly converted to STL format for use in subsequent rapid prototyping process. For this type of data, the user has limited capability to modify and manipulate the geometry and further processing is required before they can be readily used by rapid prototyping system. For example, further data treatment is needed for Scanned data from computed tomography (CT) and magnetic resonance imaging (MRI) scanners which capture soft and hard tissue information based on density threshold value. The undesired soft tissue data is removed before it is sent to rapid prototyping machine for fabrication. This procedure can be a daunting task for complex structure and one has to repeat the procedure many times until satisfactory result is achieved. There are a number of commercial software’s such as MIMICS, and Go-build which translate this data to the format required by RP systems. Also, this paper describes rapid tooling methods.

KEYWORDS: Rapid Prototyping (RPT); Rapid tooling (RT); Computer Tomography (CT); CAD; CAD; Orthopaedics.

INTRODUCTION
Rapid Prototyping (RP) can be defined as a group of techniques used to quickly fabricate a scale model of a part or assembly using three-dimensional computer aided design (CAD) data. What is commonly considered to be the first RP technique, Stereolithography, was developed by 3D Systems of Valencia, CA, USA. The company was founded in 1986, and since then, a number of different RP techniques have become available.

Rapid Prototyping has also been referred to as solid free-form manufacturing, computer automated manufacturing, and layered manufacturing. RP has obvious use as a vehicle for visualization. In addition, RP models can be used for testing, such as when an airfoil shape is put into a wind tunnel. RP models can be used to create male models for tooling, such as silicone rubber molds and investment casts. In some cases, the RP part can be the final part, but typically the RP material is not strong or accurate enough. When the RP material is suitable, highly convoluted shapes (including parts nested within parts) can be produced because of the nature of RP. There is a multitude of experimental RP methodologies either in development or used by small groups of individuals. This section will focus on RP techniques that are currently commercially available, including Stereolithography (SLA), Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM), Fused Deposition Modeling (FDM), Solid Ground Curing (SGC), and Ink Jet printing techniques.

In recent years, an industry of producing three-dimensional models directly from 3D CAD data has grown rapidly. Several companies produce machines that can fabricate a physical three-dimensional model out of various materials including plastic, paper and metal. Generally, the machines run unattended and quickly produce an accurate model directly from CAD data without the need for a highly skilled model-maker or machinist. These machines are generally known as rapid-prototyping machines and the industry that has developed around these machines is called the rapid-prototyping industry.

These methods are unique in that they add and bond materials in layers to form objects. Such systems are also known by the general name free form fabrication (FFF), solid freeform fabrication (SFF) and layered manufacturing.

Rapid prototyping is the automatic generation of 3D free-form shapes from virtual 3D models is a crucial process in contemporary design and manufacture of commercial products. Current modeling applications are limited in that they may only generate a small subset of all realizable 3D shapes automatically. Typically only smooth and simple surfaces can be quickly designed using the latest Computer-Aided Design (CAD) software such as AutoCAD or Computer-Aided Modeling (CAM) software. Modeling complex shapes using these software packages requires a large amount of time. In these cases Rapid Prototyping is used to create the model within minimum time.

Rapid prototyping isn’t a solution to every part fabrication problem. After all, CNC technology is economical, widely understood and available, offers wide material selection and excellent accuracy.
However, if the requirement involves producing a part or object of even moderately complex geometry, and doing so quickly - RP has the advantage. It's very easy to look at extreme cases and make a determination of which technology route to pursue, CNC or RP. For many other less extreme cases the selection crossover line is hazy, moves all the time, and depends on a number of variably-weighted, case-dependent factors. While the accuracy of rapid prototyping isn't generally as good as CNC, it's adequate today for a wide range of exacting applications. The materials used in rapid prototyping are limited and dependent on the method chosen. However, the range and properties available are growing quickly. Numerous plastics, ceramics, metals ranging from stainless steel to titanium, and wood-like paper are available. At any rate, numerous secondary processes are available to convert patterns made in a rapid prototyping process to final materials or tools. The names of specific processes themselves are also often used as synonyms for the entire field. Among these are stereolithography (SLA for stereolithography apparatus), selective laser sintering (SLS), fused deposition modeling (FDM), laminated object manufacturing (LOM), inkjet systems and three dimensional printing (3DP). Each of these technologies - and many others - has its singular strengths and weaknesses.

**WHY RAPID PROTOTYPING?**

- To increase effective communication.
- To decrease development time.
- To decrease costly mistakes.
- To minimize sustaining engineering changes.
- To extend product lifetime by adding necessary features and eliminating redundant features.
- Rapid Prototyping decreases development time by allowing corrections to a product to be made early in the process. By giving engineering, manufacturing, marketing, and purchasing a look at the product early in the design process, mistakes can be corrected and changes can be made while they are still inexpensive.
- The trends in manufacturing industries continue to emphasize the following:
  - Increasing number of variants of products.
  - Increasing product complexity.
  - Decreasing product lifetime before obsolescence.
  - Decreasing delivery time.
  - Rapid Prototyping improves product development by enabling better communication in a concurrent engineering environment.

**THE BASIC PROCESS**

Although several rapid prototyping techniques exist, all employ the same basic five-step process. The steps are:

1. Create a CAD model of the design
2. Convert the CAD model to STL format
3. Slice the STL file into thin cross-sectional layers
4. Construct the model one layer atop another
5. Clean and finish the model

**CAD Model Creation:** First, the object to be built is modeled using a Computer-Aided Design (CAD) software package. Solid modelers, such as Pro/ENGINEER, tend to represent 3-D objects more accurately than wire-frame modelers such as AutoCAD, and will therefore yield better results. The designer can use a pre-existing CAD file or may wish to create one expressly for prototyping purposes. This process is identical for all of the RP build techniques.

**Conversion to STL Format:** The various CAD packages use a number of different algorithms to represent solid objects. To establish consistency, the STL (stereolithography, the first RP technique) format has been adopted as the standard of the rapid prototyping industry. The second step, therefore, is to convert the CAD file into STL format. This format represents a three-dimensional surface as an assembly of planar triangles, "like the facets of a cut jewel." The file contains the coordinates of the vertices and the direction of the outward normal of each triangle. Because STL files use planar elements, they cannot represent curved surfaces exactly.

Increasing the number of triangles improves the approximation, but at the cost of bigger file size. Large, complicated files require more time to pre-process and build, so the designer must balance accuracy with manageability to produce a useful STL file. Since the .stl format is universal, this process is identical for all of the RP build techniques.

**Slice the STL File:** In the third step, a pre-processing program prepares the STL file to be built. Several programs are available, and most allow the user to adjust the size, location and orientation of the model. Build orientation is important for several reasons. First, properties of rapid prototypes vary from one coordinate direction to another. For example, prototypes are usually weaker and less accurate in the z (vertical) direction than in the x-y plane. In addition, part orientation partially determines the amount of time required to build the model. Placing the shortest dimension in the z direction reduces the number of layers, thereby shortening build time. The pre-processing software slices the STL model into a number of layers from 0.01 mm to 0.7 mm thick, depending on the build technique. The program may also generate an auxiliary structure to support the model during the build. Supports are useful for delicate features such as overhangs, internal cavities, and thin-walled sections. Each PR machine manufacturer supplies their own proprietary pre-processing software.

**Layer by Layer Construction:** The fourth step is the actual construction of the part. Using one of several techniques (described in the next section)
RP machines build one layer at a time from polymers, paper, or powdered metal. Most machines are fairly autonomous, needing little human intervention.

Clean and Finish: The final step is post-processing. This involves removing the prototype from the machine and detaching any supports. Some photosensitive materials need to be fully cured before use. Prototypes may also require minor cleaning and surface treatment. Sanding, sealing, and/or painting the model will improve its appearance and durability.

**METHOD OF RAPID PROTOTYPING**
- CAD solid model
- ‘.STL’ file
- Slicing the file
- Final build file
- Fabrication of part
- Post processing

The basic methodology for all current rapid prototyping techniques can be summarized as follows:

A CAD model is constructed, and then converted to STL format. The resolution can be set to minimize stair stepping. The RP machine processes the .STL file by creating sliced layers of the model. The first layer of the physical model is created. The model is then lowered by the thickness of the next layer, and the process is repeated until completion of the model. The model and any supports are removed. The surface of the model is then finished and cleaned.

**RAPID PROTOTYPING PRINCIPLE**
Rapid prototyping works on the basis of adding or removing layers of material to form the desired shape. The majority of commercial rapid prototyping system build object by adding one layer after another. For simplicity, it can be visualized as stacking slices of bread until complete three-dimensional bread loaf is achieved. Rapid prototyping is a highly automated layer manufacturing process. The object is designed in any solid modeling software (CAD) and the data is converted into a standard format widely known as standard triangularisation language (STL) which is understandable by the rapid prototyping machine. Rapid prototyping software receives data in this format and creates a complete set of instructions for fabrication on rapid prototyping machine such as tool path, layer thickness, processing speed, etc. Rapid Prototyping machine then manufactures the object using layer manufacturing method. Upon completion of a three-dimensional model, it is subjected to post-processing treatment for removing support material that was used to support overhang features during fabrication.

A variety of model materials are available depending on the RP system used as shown in Table.

**Table 1: Different Prototyping Processes**

<table>
<thead>
<tr>
<th>Material</th>
<th>SLA</th>
<th>FDM</th>
<th>SLS</th>
<th>LCM</th>
<th>SEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing Speed</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Maximum part size (mm)</td>
<td>508 x 508 x 610</td>
<td>610 x 508 x 610</td>
<td>381 x 330 x 457</td>
<td>812 x 559 x 508</td>
<td>508 x 609 x 406</td>
</tr>
<tr>
<td>Accuracy (mm)</td>
<td>0.05-0.1</td>
<td>0.1-0.3</td>
<td>0.1-0.2</td>
<td>0.25</td>
<td>0.2-0.3</td>
</tr>
<tr>
<td>Fabrication technique</td>
<td>Laser curing of liquid photopolymer</td>
<td>Fused deposition of Molen polymer</td>
<td>Selective laser melting of powder polymer layer</td>
<td>Laser cutting and stacking of glued sheets</td>
<td>Adhesive glue Bonding of powdery material</td>
</tr>
</tbody>
</table>

**COMPARISON OF RAPID PROTOTYPING WITH TRADITIONAL PROTOTYPING**

<table>
<thead>
<tr>
<th>RAPID PROTOTYPING</th>
<th>TRADITIONAL PROTOTYPING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prototype manufacture comes early in the product development cycle.</td>
<td>Prototype manufacture comes late in the product development cycle.</td>
</tr>
<tr>
<td>Early visualization of design and manufacturing problems</td>
<td>Late visualization of design and manufacturing problems</td>
</tr>
<tr>
<td>Materials used are expensive or toxic</td>
<td>Materials used are cheap and non toxic</td>
</tr>
<tr>
<td>Design of jigs, fixtures etc. not required for prototype manufacture</td>
<td>Design of jigs, fixtures etc. required for prototype manufacture</td>
</tr>
<tr>
<td>Prototypes are build directly from its CAD model</td>
<td>Prototype building has to go through various steps of manufacturing.</td>
</tr>
<tr>
<td>Materials used are brittle</td>
<td>Actual materials can be used</td>
</tr>
<tr>
<td>A very few tests are carried out</td>
<td>All tests are carried out</td>
</tr>
<tr>
<td>Design changes are not costly</td>
<td>Design changes are costly</td>
</tr>
<tr>
<td>Product development cycle time is drastically reduced</td>
<td>Product development cycle time is very long</td>
</tr>
<tr>
<td>Rapid prototyping is agile</td>
<td>Conventional prototyping is not agile</td>
</tr>
<tr>
<td>Easy to convert 3D-CAD model to prototype</td>
<td>Requires high skill</td>
</tr>
<tr>
<td>Made of ABS, plastics, plastomers, metals etc...</td>
<td>Made of plastic or wood</td>
</tr>
<tr>
<td>Very short lead time</td>
<td>Larger lead time</td>
</tr>
<tr>
<td>Difficult to produce Complex designs</td>
<td>Very easy</td>
</tr>
</tbody>
</table>
PROBLEMS IN RPT
These technologies are still in their developing stage. Due to the economic and material constraints it has to cover a long way, before it can be fully commercialized. The major problems in the current systems include part accuracy, mechanical performance and limited material variety.

PART ACCURACY:
The main errors in developing CAD to get accurate prototype are: mathematical, process and material related.

1. Mathematical related: It includes fact approximation of the part surface in the standard input to the prototyping system, limited layer resolution along the Z-direction, such as stair steps and accuracy of vertical dimension. A 5 axis CNC technique milling machine is developed to eliminate the steps in newly developed Rapid prototyping. These machines also maintain the accuracy of vertical dimension by away the excess material.

2. Process related: These include the error in the shape along X-Y and Z axis. This mainly depends on the accuracy of prototyping machine and operator experience.

3. Material related: Material related error occurs due to shrinkage and distortion. Some times the shrinkage is not identical along X, Y and Z-axis. So, during solidification stress may be developed in different sections. This effect can be minimized by selecting appropriate manufacturing control parameters, exploring new materials with relative small shrinkage and stress relief methods.

For SLA system, 3D systems uses star –weave method to limit distorting by curing more resin in the vat, hatching inside cross sectional area on each layer.

VARIOUS PROTOTYPING PROCESSES

Sterolithography(SLA)
Laminated Object Manufacturing(LOM)
Selective Laser Sintering(SLS)
Fused Deposition Modeling(FDM)
Solid Ground Curing(SGC)
3D-Printing(3DP)

STEREOLITHOGRAPHY
Stereolithography is a common rapid manufacturing and rapid prototyping technology for producing parts with high accuracy and good surface finish. A device that performs stereolithography is called an SLA or Stereolithography Apparatus Stereolithography is an additive fabrication process utilizing a vat of liquid UV-curable photopolymer "resin" and a UV laser to build parts a layer at a time. On each layer, the laser beam traces a part cross-section pattern on the surface of the liquid resin. Exposure to the UV laser light cures, or, solidifies the pattern traced on the resin and adheres it to the layer below.

After a pattern has been traced, the SLA's elevator platform descends by a single layer thickness, typically 0.05 mm to 0.15 mm (0.002” to 0.006”). Then, a resin-filled blade sweeps across the part cross section, re-coating it with fresh material. On this new liquid surface the subsequent layer pattern is traced, adhering to the previous layer. A complete 3-D part is formed by this process. After building, parts are cleaned of excess resin by immersion in a chemical bath and then cured in a UV oven.

Stereolithography requires the use of support structures to attach the part to the elevator platform and to prevent certain geometry from not only deflecting due to gravity, but to also accurately hold the 2-D cross sections in place such that they resist lateral pressure from the re-coater blade. Supports are generated automatically during the preparation of 3-D CAD models for use on the stereolithography machine, although they may be manipulated manually. Supports must be removed from the finished product manually; this is not true for all rapid prototyping technologies.

ADVANTAGES
- Unattended building process - The system is very stable. Once started the process is fully automatic and can be unattended until the process is completed.
Good dimensional accuracy - The process is able to maintain the dimensional accuracy of the built parts to within +/- 0.1 mm.

Good surface finish - Glass-like finishing can be obtained on the top surfaces of the part although stairs can be found on the side walls and curve surfaces between build layers.

The process is of high resolution and capable to build parts with rather complex details.

3D Systems Inc. have developed a software called "Quickcast" for building parts with hollow interior which can be used directly as wax pattern for investment casting.

It is the most widely used process in the RP field.

DISADVANTAGES

Curling and warping - The resin absorb water as time goes by resulting curling and warping especially in the relatively thin areas.

Relatively high cost (US$200-500K) - However, it is anticipated that the cost will be coming down shortly.

Narrow range of materials - The material available is only photo sensitive resin of which the physical property, in most of the cases, cannot be used for durability and thermal testing.

Post curing - The parts in most cases have not been fully cured by the laser inside the vat. A post curing process is normally required.

High running and maintenance cost - The cost of the resin and the laser gun are very expensive. Furthermore, the optical sensor requires periodical fine tuning in order to maintain its optimal operating condition which will be considerable expensive.

APPLICATION AREAS

Prototypes for concept models

Form-fit for assembly tests and process planning

Models for investment casting, replacement of the wax pattern

Patterns for metal spraying, epoxy moulding and other soft tooling.

HIGHLIGHTS OF STEREOLITHOGRAPHY

The first Rapid Prototyping technique and still the most widely used. Inexpensive compared to other techniques. Uses a light-sensitive liquid polymer requires post-curing since laser is not of high enough power to completely cure. Long-term curing can lead to warping. Long-term curing can lead to warping. Parts are quite brittle and have a tacky surface. No milling step so accuracy in z can suffer. Support structures are typically required. Process is simple: There is no milling or masking steps required. Uncured material can be toxic. Ventilation is a must.

SELECTIVE LASER SINTERING (SLS)

SLS works by selectively fusing a layer of powder material on a powder bed enclosed within a build chamber. A powder supply roller supplies layer of powder onto the work area, then carbon dioxide laser scans and fuses the layer. The fused layer is lowered into a part build chamber. The process is repeated until a complete part is formed. Once completed, the part is removed from the build chamber and the loose powder is removed and reused.

The powder supply system (E) is similar in function to the build cylinder. It also comprises a cylinder and piston. In this case the piston moves upward incrementally to supply powder for the process. Heat from the laser melts the powder where it strikes under guidance of the scanner system (F). The CO2 laser used provides a concentrated infrared heating beam. The entire fabrication chamber is sealed and maintained at a temperature just below the melting point of the plastic powder. Thus, heat from the laser need only elevate the temperature slightly to cause sintering, greatly speeding the process. A nitrogen atmosphere is also maintained in the fabrication chamber which prevents the possibility of explosion in the handling of large quantities of powder.

After the object is fully formed, the piston is raised to elevate the object. Excess powder is simply brushed away and final manual finishing may be carried out. That's not the complete story, though. It may take a considerable length of cool-down time before the part can be removed from the machine. Large parts with thin sections may require as much as two days of cooling time. No supports are required with this method since overhangs and undercuts are supported by the solid powder bed. This saves some finishing time compared to stereolithography. However, surface finishes are not as good and this may increase the time. No final curing is required as in stereolithography, but since the objects are sintered, they are porous. Depending on the application, it may be necessary to infiltrate the object with another material to improve mechanical characteristics. Much progress has been made over the years in improving surface finish and porosity. The method has also been extended to provide direct fabrication of metal and ceramic objects and tools. This process is developed by DTM Corp. CAD files are transferred to the system, where they are sliced and drawn, one cross-section at a time, by applying the laser beam to a thin layer of powder. The laser beam fuses the powder particles to form a solid mass that matches the CAD design. As each layer is drawn, the prototypes take shape within the system.
The environment of the process chamber is tightly controlled. The temperature within the chamber is regulated at a level slightly lower than the melting point of the material being used. The chamber is also filled with nitrogen to prohibit the oxidation of the materials at the elevated temperature. At the beginning of the process, a thin layer of powder is deposited onto the part building cylinder within the process chamber. A heat generated CO2 laser traces the cross section of the object, elevates the temperature of the powder to the melting point, and fuses the powder particles to form a layer of solid mass. A new layer of powder is deposited on the top of the fused layer and the previous process is repeated with each layer fusing to the layer underneath.

After processing, the part is removed from the process chamber and the powder falls away. SLS parts may then require some post-processing, such as sanding, depending upon the application. Compared to other processes, however, this post-processing is minimal.

**THE MATERIAL AVAILABLE FOR SLS ARE:**
- Nylon for prototypes
- Polycarbonate
- Wax for investment casting
- CastForm PS. Polystyrene powder for investment casting

**ADVANTAGES**
- Capable of producing the toughest part compared with other processes
- Large variety of material can be used, including most engineering plastic, wax, metal, ceramic, etc.
- Parts can be produced in short time, normally at a rate of up to 1 inch per hour
- No post curing of parts is required
- During the building process, the part is fully supported by the powder and no additional support is required.
- Parts can be built on top of others

**DISADVANTAGES**
- The powder material requires to heat up to the temperature below the melting point before the building process which takes about 2 hours. After building the parts, it also takes 5 to 10 hours to cool down before removing the parts from the powder cylinder.
- The smoothness of the surface is restricted to the size of the powder particles and the laser spot resulting that the surface of the part is always porous. Smooth surface can only be obtained by post-processing.
- The process chamber requires continuous supply of nitrogen to provide a safe environment for the sintering process to be taken place resulting expensive running cost of the process.
- Toxic gases will be generated from the process which leads to an environmental issue.

- Process using different material require different license.

**APPLICATION AREAS**
- Visual representation
- Parts are durable enough for most functional tests
- Pattern for making soft tooling,
- Making of electrodes for EDM and patterns for casting
- Direct manufacture of metal mould
- Small batch production run

**HIGHLIGHTS OF SELECTIVE LASER SINTERING**
Patented in 1989. Considerably stronger than SLA; sometimes structurally functional parts are possible. Laser beam selectively fuses powder materials: nylon, elastomer, and soon metal; Advantage over SLA: Variety of materials and ability to approximate common engineering plastic materials. No milling step so accuracy in z can suffer. Process is simple: There is no milling or masking steps required. Living hinges are possible with the thermoplastic-like materials. Powdery, porous surface unless sealant is used. Sealant also strengthens part. Uncured material is easily removed after a build by brushing or blowing it off.

**THREE-DIMENSIONAL PRINTING (3DP)**
This method is very similar to selective laser sintering. Here the Laser is replaced by an inkjet head. The "three dimensional printers" allow designers to quickly create tangible prototypes of their designs. The three-dimensional printing system receives input CAD file in STL, DXF and HPGL format. Sliced formation is then created as in other systems. Powder is supplied on a platform and a roller spreads the powder. Layer evenly. Printing head as in inkjet printer, releases jets of binder to bond powder material. The platform is lowered one layer thickness and the next layer is built until the part is completed. One advantage of 3DP is that, no support structure is needed.

- The multi-channel jetting head (A) deposits a liquid.
- Adhesive compound onto the top layer of a bed of powder object material (B).
- The particles of the powder become bonded in the areas where the adhesive is deposited.
- Once a layer is completed the piston (C) moves down by the thickness of a layer.
- The powder supply system (E) is similar in function to the build cylinder as in selective laser sintering.
- The piston moves upward incrementally to supply powder for the process and the roller (D) spreads and compresses the powder on the top of the build cylinder.
- The process is repeated until the entire object is completed within the powder bed.
LAMINATED OBJECT MANUFACTURING (LOM)
In LOM, a sheet with single-sided heat activated glue is supplied from a sheet supply roll onto the platform. Laser is used to cut cross-sectional outline of the layer. A new layer is bonded to the previously cut layer and a new cross-section is created and cut. Once all layers have been laminated and cut, excess material is removed to expose the finished model.

ADVANTAGES
- It is a relatively high speed process as the laser is only required to trace the contour and no need to scan the entire cross section. The more volume of material within the part, the more greater is the speed gain.
- Parts can be used immediately after the process and no post curing is required.
- No support structure is required as the part is supported by its own material.
- Simple to use and no environmental concern

DISADVANTAGES
- Although there is some choice of materials including paper, plastic, ceramic and composite, the most commonly used material is only paper. Others are still under development.
- The built parts absorb moisture quickly resulting that the built parts must be post processed immediately and impregnating with epoxy that is specially designed for LOM technology, such as LOMPOXY
  - Inherent deficiency in building fin-shape parts, in other words the process is restricted to build complex parts
  - Since it is very difficult, if not impossible, to remove the waste materials from inside, the process is incapable of building reentrant shapes
  - Fire hazard is occasionally happened when the working chamber becomes too hot

HIGHLIGHTS OF LAMINATED OBJECT MANUFACTURING
- Layers of glue-backed paper form the model.
- Low cost: Raw material is readily available.
- Large parts: Because there is no chemical reaction involved, parts can be made quite large.
- Accuracy in z is less than that for SLA and SLS No milling step.
- Outside of model, cross-hatching removes material
- Models should be sealed in order to prohibit moisture.
- Before sealing, models have a wood-like texture.
FUSED DEPOSITION MODELING (FDM)

FDM is the second most widely used rapid prototyping technology, after stereolithography. A plastic filament, approximately 1/16 inch in diameter, is unwound from a coil (A) and supplies material to an extrusion nozzle (B). Some lower-cost configurations of the machinery use plastic pellets fed from a hopper rather than a filament. The nozzle is heated to melt the plastic and has a mechanism which allows the flow of the melted plastic to be controlled. The nozzle is mounted to a mechanical stage (C) which can be moved in horizontal and vertical directions. As the nozzle is moved over the table (D) in the required geometry, it deposits a thin bead of extruded plastic to form each layer. The plastic hardens immediately after being squirted from the nozzle and bonds to the layer below. The entire system is contained within an oven chamber which is held at a temperature just below the melting point of the plastic. Thus, only a small amount of additional thermal energy needs to be supplied by the extrusion nozzle to cause the plastic to melt. This provides much better control of the process.

Support structures must be designed and fabricated for any overhanging geometries and are later removed in secondary operations. Several materials are available for the process including a nylon-like polymer and both machinable and investment casting waxes.
The introduction of ABS plastic material led to much greater commercial acceptance of the method. It provided better layer to layer bonding than previous materials and consequently much more robust fabricated objects. Also a companion support material was introduced at that time which was easily removable by simply breaking it away from the object. Water-soluble support materials have now also become available which can be removed simply by washing them away. The recent introduction of polycarbonate and poly(phenyl)sulfone modeling materials have further extended the capabilities of the method in terms of strength and temperature range. Several other polymer systems as well as ceramic and metallic materials are under development.

The method is office-friendly and quiet. FDM is fairly fast for small parts on the order of a few cubic inches, or those that have tall, thin form-factors. It can be very slow for parts with wide cross sections, however. The finish of parts produced with the method have been greatly improved over the years, but aren't quite on a par with stereolithography. The closest competitor to the FDM process is probably three dimensional printing. However, FDM offers greater strength and a wider range of materials than at least the implementations of 3DP from Z Corp. which are most closely comparable.

Stratasys is the only western supplier. Similar technology has also been under development in China.

The FDM process works as follows: first, a 3D solid model exported to the FDM Quickslice TM software using the stereo lithography (STL) format. The software generated the process plan that controls the FDM machine’s hardware. The concept is that an ABS filament is fed through a heating element, which heats it to a semi-molten state. FDM machine builds part by extruding a semi-molten filament through a heated nozzle onto a platform. When one layer is complete, the platform moves down by one layer thickness and the process of extruding another layer continues. After completion of all layers, the part is removed from the platform and support material can be peeled off or it can be removed by ultrasonic vibration and solvent in an ultrasonic tank. This is desirable for parts with internal cavities which are not accessible by hands.

15.6.2 PROCEDURAL STEPS OF FDM

A CAD file or 3-D model file of humerus bone is converted into a .stl file. The file is then opened in Stratasys’s program

- CAD files converted to an STL format are read into the software called Quick slice.
- It breaks the model into individual slices.
- Each slice represents one layer of material and generates tool paths to fill slices.
- These tool paths form the Stratasys Modeling Language (SML) file.
- SML file is downloaded to the FDM hardware for modeling.
- FDM head moves in two horizontal axes across a foundation and deposits a layer of material for each slice. The material filament is pulled into the FDM head by the drive wheels.
- Molten plastic material extruded from a nozzle.
- Turns CAD geometry into models.
- It is heated inside the liquidifier in the FDM head so it comes out in a semi-liquid state.
- Features the Break Away Support System (BASS), allowing the designer to create models with greater speed and precision.
- BASS uses a second nozzle to extrude the support material.
- The support tip extrudes a material that supports any overhanging portions.
- Successive layers fuse together and solidify to build up an accurate, three-dimensional model of the design.
- The drawing is then sliced into layers.
- The FDM builds the model, it builds it in horizontal layers, from the bottom up.
- When the FDM receives the design, it starts an initial stage of calibration.
- The machine must be aligned itself on the X, Y and Z axes
- After calibration the machine is set at its initial starting point and then begins to dispense the plastic material (ABS) onto a Styrofoam platform
- The FDM dispenses one very thin horizontal layer at a time, until the entire model is complete. Build Material: 270 degrees Fahrenheit.
- When the model is completed, the support is easily broken off.
- Finished product look better with minimal post-modeling finishing.
- After production took place Bone model has been removed from the FDM. The next step was final preparations which included: pulling the model from the Styrofoam platform, carefully removing the support material, and finally making final touches to clean the model up and that was it! After those steps completed successfully taken a 3-D CAD drawing and turned it into a tangible physical model that we could hold, touch, and experience.

MATERIAL USED IN FDM PROCESS:

ACRYLONITRILE BUTADIENE STYRENE (ABS):

- This is the main build material used by the FDM. It’s also used for the support material
- Support Material --- used to fill in spaces that would otherwise have no material, for building purposes.

Acrylonitrile Butadiene Styrene (C₈H₈N) is a common thermoplastic used to make light, rigid, molded products. ABS plastic ground down to an average diameter of less than 1 micrometer is used as the colorant in some tattoo inks. It is a copolymer made by polymerizing styrene and acrylonitrile in the
presence of polybutadiene. The proportions can vary from 15 to 35% acrylonitrile, 5 to 30% butadiene and 40 to 60% styrene. The result is a long chain of polybutadiene cross-linked with shorter chains of poly (styrene-co-acrylonitrile). The nitrile groups from neighboring chains, being polar, attract each other and bind the chains together, making ABS stronger than pure polystyrene.

**PROPERTIES OF ACRYLONITRILE BUTADIENE STYRENE:**

ABS is derived from acrylonitrile, butadiene, and styrene. Acrylonitrile is a synthetic monomer produced from propylene and ammonia; butadiene is a petroleum hydrocarbon obtained from the C4 fraction of steam cracking; styrene monomer is made by dehydrogenation of ethyl benzene - a hydrocarbon obtained in the reaction of ethylene and benzene. The advantage of ABS is that this material combines the strength and rigidity of the acrylonitrile and styrene polymers with the toughness of the polybutadiene rubber. The most important mechanical properties of ABS are resistance and toughness. The impact resistance can be amplified by increasing the proportions of polybutadiene in relation to styrene and also acrylonitrile although this causes changes in other properties. Impact resistance does not fall off rapidly at lower temperatures. Stability under load is excellent with limited loads.

**FDM BUILD TEMPERATURES**

Before the FDM machine can build the model, it has to meet certain temperature requirements to dispense the ABS plastic. Temperatures are as follows:

- Build Material: 270 degrees Fahrenheit
- Support Material: 265 degrees Fahrenheit

**ADVANTAGES**

- The advantage to using FDM include the speed and safety of the machine
- The machine does not use any toxic materials, so it can be installed in office environment
- Build time for the machine is faster than SLA
- There is no part clean-up needed for a part made by FDM
- Cost of the FDM machine is usually lower than the SL machines
- There are only a few materials commercially available for the FDM: ABS, medical grade ABS, elastomer and investment casting wax.
- The process is clean, simple, easy to operate and produce no waste
- Fast building for bottle like structure or hollow parts
- True desktop manufacturing system that can be run in office environment.
- There is no worry of exposure to toxic fume and chemicals
- Materials used are very cost effective
- Material is supplied in spool form which is easy to handle and can be changed in minute

**DISADVANTAGES**

- Mid range of performance
- A good variety of material is available including colour ABS and Medical ABS.

**APPLICATION AREAS**

- Conceptual modeling
- Fit, form and functional test
- Pattern for investment casting
- MABS (methyl methacrylate ABS) material is particularly suitable for medical applications.

**PROBLEMS DURING THE PROCESS**

The only major problem we encountered was that many of the 3-D files we found online were simply not transferable for slicing. I encountered many errors in most of the files, making them unable to be modeled as they were.

**HIGHLIGHTS OF FUSED DEPOSITION MODELING**

- Standard engineering thermoplastics, such as ABS, can be used to produce structurally functional models.
- Two build materials can be used, and latticework interiors are an option.
- Parts up to 600 × 600 × 500 mm (24 × 24 × 20 inches) can be produced.
- Filament of heated thermoplastic polymer is squeezed out like toothpaste from a tube.
- Thermoplastic is cooled rapidly since the platform is maintained at a lower temperature.
- Milling step not included and layer deposition is sometimes non-uniform so "plane" can become skewed.
- Not as prevalent as SLA and SLS but gaining ground because of the desirable material properties.

**Data acquisition**

The morphological data of the humerus bone was collected using the above mentioned CT scanner. A 3D data set was acquired producing 119 slices with a slice thickness of 1 mm. The reconstructed CT data was transferred to a CD and loaded into the MIMICS software.

**Software**

The humerus scanning data and model STL manipulation were processed using MIMICS RP Software (Fig. 5.2.1). The modeling software is a general purpose segmentation programme for grey value images. This software can generate both the frontal and lateral view from the CT scans (Fig. 5.2.2). From CT data 3D model of humerus bone has been created. RP made a real copy of the bone (Fig. 5.2.3). The real copy was used for planning of orthopedic surgery (Fig. 5.2.4) especially choice of implant type, implant position and application procedure.
Teaching purposes: RP models can be used as teaching aids for students in the classroom as well as for researchers. These models can be made in many colors and provide a better illustration of anatomy, allow viewing of internal structures and much better understanding of some problems or procedures which should be taken in concrete case. They are also used as teaching simulators.

RAPID TOOLING

The term Rapid Tooling (RT) is typically used to describe a process which either uses a Rapid Prototyping (RP) model as a pattern to create a mold quickly or uses the Rapid Prototyping process directly to fabricate a tool for a limited volume of prototypes. RP techniques can also be used to make tooling (referred to as Rapid tooling) and even production-quality parts (Rapid manufacturing). For small production runs and complicated objects, rapid prototyping is often the best manufacturing process available. Of course, "rapid" is a relative term. Most prototypes require from three to seventy-two hours to build, depending on the size and complexity of the object. This may seem slow, but it is much faster than the weeks or months required to make a prototype by traditional means such as machining. These dramatic time savings allow manufacturers to bring products to market faster and more cheaply. In 1994, Pratt & Whitney achieved "an order of magnitude [cost] reduction [and] . . . time savings of 70 to 90 percent" by incorporating rapid prototyping into their investment casting process.

RT VS CONVENTIONAL TOOLING

- Tooling time is much shorter than for a conventional tool. Typically, time to first articles is below one-fifth that of conventional tooling.
- Tooling cost is much less than for a conventional tool. Cost can be below five percent of conventional tooling cost.
- Tool life is considerably less than for a conventional tool.
- Tolerances are wider than for a conventional tool.

IMPORTANCE OF RAPID TOOLING

- Tooling is one of the slowest and most expensive steps in the manufacturing process, because of the extremely high quality required.
- Tools often have complex geometries, yet must be dimensionally accurate to within a hundredth of a millimeter.
- In addition, tools must be hard, wear-resistant, and have very low surface roughness (about 0.5 micrometers root mean square).
- To meet these requirements, molds and dies are traditionally made by CNC-machining, electro-discharge machining, or by hand.
All are expensive and time consuming, so manufacturers would like to incorporate rapid prototyping techniques to speed the process.

**CATEGORIES OF RAPID TOOLING**

- Indirect Tooling
- Direct Tooling

**INDIRECT TOOLING**

Most rapid tooling today is indirect. RP parts are used as patterns for making molds and dies. RP models can be indirectly used in a number of manufacturing processes.

**DIRECT TOOLING**

To directly make hard tooling from CAD data is the Holy Grail of rapid tooling. Realization of this objective is still several years away, but some strong strides are being made.

**VARIOUS INDIRECT TOOLING**

- Vacuum Casting
- Sand Casting
- Investment Casting
- Injection molding

**VACUUM CASTING**

- It is the simplest and oldest rapid tooling technique, a RP positive pattern is suspended in a vat of liquid silicone or room temperature vulcanizing (RTV) rubber.
- When the rubber hardens, it is cut into two halves and the RP pattern is removed.
- The resulting rubber mold can be used to cast up to 20 polyurethane replicas of the original RP pattern.
- A more useful variant, known as the Keltool process, involves filling the rubber molds with powdered tool steel and epoxy binder.
- When the binder cures, the "green" metal tool is removed from the rubber mold and then sintered.
- At this stage the metal is only 70% dense, so it is infiltrated with copper to bring it close to its theoretical maximum density.
- The tools have fairly good accuracy, but their size is limited to under 25 centimeters.

**SAND CASTING**

- A RP model is used as the positive pattern around which the sand mold is built.
- LOM models, which resemble the wooden models traditionally used for this purpose, are often used.
- If sealed and finished, a LOM pattern can produce about 100 sand molds.

**INVESTMENT CASTING**

- Some RP prototypes can be used as investment casting patterns.
- The pattern must not expand when heated, or it will crack the ceramic shell during autoclaving.
- Both Stratasys and Cubital make investment casting wax for their machines.

**RAPID TOOL**

- Paper LOM prototypes may also be used, as they are dimensionally stable with temperature.
- The paper shells burn out, leaving some ash to be removed.
- To counter thermal expansion in stereolithography parts, 3D Systems introduced QuickCast, a build style featuring a solid outer skin and mostly hollow inner structure.
- The part collapses inward when heated.
- Likewise, DTM sells Trueform polymer, a porous substance that expands little with temperature rise, for use in its SLS machines.

**INJECTION MOLDING**

- CEMCOM Research Associates, Inc. has developed the NCC Tooling System to make metal/ceramic composite molds for the injection molding of plastics.
- First, a stereolithography machine is used to make a match-plate positive pattern of the desired molding.
- To form the mold, the SLA pattern is plated with nickel, which is then reinforced with a stiff ceramic material.
- The two mold halves are separated to remove the pattern, leaving a matched die set that can produce tens of thousands of injection moldings.

**VARIOUS DIRECT TOOLING**

- Rapid Tool
- Laser-Engineered Net Shaping (LENS)
- Direct AIM
- LOM Composite
- Sand Molding

**Rapid Tool**

- A DTM process that selectively sinters polymer-coated steel pellets together to produce a metal mold. The mold is then placed in a furnace where the polymer binder is burned off and the part is infiltrated with copper (as in the Keltool process). The resulting mold can produce up to 50,000 injection moldings.
- In 1996 Rubbermaid produced 30,000 plastic desk organizers from a SLS-built mold. This was the first widely sold consumer product to be produced from direct rapid tooling.
- Laser-Engineered Net Shaping
- It is a process developed at Sandia National Laboratories and Stanford University that can create metal tools from CAD data.
- A laser beam melts the top layer of the part in areas where material is to be added. Powder metal is injected into the molten pool, which then solidifies. Layer after layer is added until the part is complete.
- Materials include 317 stainless steel, Inconel 625, H13 tool steel, tungsten, and titanium carbide cermets.
Unlike traditional powder metal processing, LENS produces fully dense parts, since the metal is melted, not merely sintered. The resulting parts have exceptional mechanical properties, but the process currently works only for parts with simple, uniform cross-sections.

Direct AIM (ACES Injection Molding)
- A technique from 3D Systems in which stereolithography-produced cores are used with traditional metal molds for injection molding of high and low density polyethylene, polystyrene, polypropylene and ABS plastic.
- Very good accuracy is achieved for fewer than 200 moldings.
- Long cycle times (~ five minutes) are required to allow the molding to cool enough that it will not stick to the SLA core.
- In another variation, cores are made from thin SLA shells filled with epoxy and aluminum shot. Aluminum’s high conductivity helps the molding cool faster, thus shortening cycle time. The outer surface can also be plated with metal to improve wear resistance.
- Production runs of 1000-5000 moldings are envisioned to make the process economically viable.

**PROCEDURAL STEPS FOLLOWED TO MAKE A MOLD BY INDIRECT TOOLING**

1. **Determine the approximate volume of plaster needed.**
   - Volume = length x width x height for rectangles.
2. **Prepare the proper amount of plaster and water to be mixed.**
3. **Prepare the molds or forms.**
   - Before beginning, arrange the containers for clean-up, molds or forms, and a container or cardboard box to dispose of excess plaster before it hardens in the bucket. Plaster releases well from leather-hard clay. For other materials, “size” the mold with mold soap (available from Ceramics suppliers) or several layers of a water-soluble release like Oil Soap (actually water-soluble). Using an oil-based releases like Vaseline will release, but the oils can block the mold pores and decrease absorbency of the mold.
4. **Mix by hand for 2-6 minutes or with a paddle for 1-2 minutes.**
   - It is recommended mixing with a paddle for several minutes and doing the last minute by hand. The plaster has begin to set, and I was able to see a faint trail by my finger drag across the surface of the plaster. Tap the bucket several times to bring trapped bubbles of air to the surface. Plaster was setting and ready to pour.
5. **Pour plaster slowly to avoid air bubbles or splashing.**
   - Tap the container or jiggle the table gently to release bubbles. Pouring too early will allow the water in the plaster to degrade the mold soap and may cause release problems. Pouring too late may result in uneven plaster pours; it sets and reaches maximum expansion in about 20 minutes, then contracts slightly. It is a good idea, to wait at least an hour before taking molds apart to get two mold of (2 half of dies) the above process has been repeated.
6. **Clean up the mold.**
   - Use a metal rib or Surform to round sharp edges. Molds should be dry before using.

**CONCLUSION**
RP technologies are definitely widely spread in different fields of medicine and show a great potential in medical applications. Various uses of RP within surgical planning, simulation, training, production of models of hard tissue, prosthesis and...
Implants, biomechanics, tissue engineering and many other cases open up a new chapter in medicine. Due to RP technologies doctors and especially surgeons are privileged to do some things which previous generations could only have imagined. However this is just a little step ahead. There are many unsolved medical problems and many expectations from RP in this field. Development in speed, cost, accuracy, materials (especially biomaterials) and tight collaboration between surgeons and engineers is necessary and so are constant improvements from RP vendors. This will help RP technologies to give their maximum in such an important field like medicine. An artificial bone model was fabricated using ABS (Acrylonitrile Butadyine Styrene) by Rapid Prototyping Technology. This technique helps to analyze the actual bone structure and plate fixation can be done more accurately. Due to RP technologies doctors and especially surgeons are privileged to do some things which previous generations could only have imagined. However this is just a little step ahead. There are many unsolved medical problems and many expectations from RP in this field. Development in speed, cost, accuracy, materials (especially biomaterials) and tight collaboration between surgeons and engineers is necessary and so are constant improvements from RP vendors. This will help RP technologies to give their maximum in such an important field like medicine and new technologies can not only improve and replace conventional methods; they also offer the chance for new types of products and developing procedures.

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