Study of Fused Deposition Modelling (FDM)

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***Abstract*:- This paper presents a method for analyzing the environmental performance of Solid Freeform Fabrication (SFF) processes. In this method, each process is divided into life phases. Environmental effects of every process phase are then analyzed and evaluated based on the Environmental & Resource Management Data. These effects are combined to obtain the environmental performance of the process. The analysis of the environmental performance of SFF processes considers the characteristics of SFF technology, includes material, energy consumption, processes wastes, and disposal. Case studies for three typical SFF processes: Stereolithography (SL), Selective Laser Sintering (SLS), and Fused Deposition Modeling (FDM) are presented to illustrate this method.**

1. INTRODUCTION:

Fused Deposition Modeling (FDM) is a solid-based rapid prototyping method that extrudes material, layer-by-layer, to build a model. The system consists of a build platform, extrusion nozzle and control system.

The build material, production quality thermoplastics, is melted and then extruded through a specially designed head onto a platform to create a two-dimensional cross section of the model. The cross section quickly solidifies, and the platform descends where the next layer is extruded upon the previous layer. This continues until the model is complete; it is then removed from the build chamber and cleaned for shipping.

1.1 Rapid Manufacturing

Proto CAM is on the cutting edge of rapid manufacturing technologies, where rapid prototyping techniques are use to create the final part, item, or component. Traditionally, rapid prototyping has been used for making parts that are used in the design or testing phase. Rapid manufacturing means taking that one step further making the finished item that will be used by the end user [1]. Typically this is a short production run, from a single piece, to a few dozen pieces, to a few hundred items. Rapid manufacturing is sometimes known as on-demand manufacturing.

1.2 Rapid Manufacturing Main Characteristics

- Manufacturing of real models using directly solid 3D CAD files.
- The manufacturing of the model is taking place layer by layer from the bottom upwards, based on the solid CAD file.
- RM methods can result in time reduction compared with the conventional manufacturing methods.
- Production of highly customized products with no need of tooling

1.2 Rapid Prototyping Capabilities

- Models
  - Initial models (Concept models)
  - Design verification models
  - Communication models
- Form-Fit-Function Prototypes used for:
  - Assembly checking
  - Mechanical characteristics & behaviour
  - Thermal behavior & Aerodynamic behaviour
- Patterns for the production of moulds
  - Manufacturing of the appropriate negatives for the production of tools/moulds.

1.3 Advances in Rapid Manufacturing and Resins

The use of rapid manufacturing for creating the final parts is a relatively new development in our business. The biggest driver for this change is the improvements in resins that are used in these processes. For example, just a couple of years ago, a prototype part created with stereolithography would not have been suitable for use as a finished item. Typically, the part would not have been durable enough to use. The prototype would have been good for form and fit, but usually would not have the complete functional attributes. Now, the latest, most advanced resins are used in rapid manufacturing to create fully functional items that can be immediately used [2]. It's the advancements in resins that now create the opportunity to use rapid manufacturing to create the finished goods. And these resins are only going to get better, allowing more and more items to be created with rapid manufacturing.

1.4 Benefits of Rapid Manufacturing

Rapid manufacturing is used to create an item directly from the 3D CAD model of the piece, with the following benefits:

- Eliminates the creation of any tooling and tooling costs, which are usually high.
- Low production cost overhead
- Production speed
- Time to market

Characteristics of a Good Rapid Manufacturing Part

A typical item that can be created with rapid manufacturing has these characteristics:

- Small size
- Low quantity
- Previously made with low volume injection molding, epoxy, or aluminum tooling
- Limited product life span
- Defined quantities needed

- Geometry that cannot easily be made using traditional manufacturing methods

Rapid Manufacturing Example

Here's a scenario where using rapid manufacturing is a good fit: A supplier of a specialty pipe interconnect needs to make 200 pieces for this month's sales. In the course of assembling of interconnect; needs a fixture with complex internal geometry [3]. In addition, the interconnect goes through tweaks every couple of months. Instead of investing in expensive prototype tooling to make the part (and its complex inner geometry), instead orders a set of 200 SLA prototypes from Proto CAM to use as fixture.

2. PROCESS OF FDM:

The process of FDM is relatively simple and fast but its use is limited to thermoplastic materials

Step 1: The thermoplastic material in the form of filament is heated to just above its solidification temperature.

Step 2: The extrusion head is heated and moves according to the pattern of the cross section of each layer of the part.

Step 3: The material is extruded on the foundation or previously built layer. As it is extruded, it is cooled and thus solidifies to form the required pattern of part.

Step 4: Repeat 2 and 3 until the top layer of the part is generated.

Step 5: Part finishing may be required

2.1 Application of FDM:

- Models for conceptualisation and presentation
- Prototypes for design, analysis and functional testing
- Patterns and masters for tooling. Models can be used as patterns for investment casting, sand casting and moulding

2.2 Fused Deposition Modeling (FDM):

i. A spool of thin plastic filament feeds material to FDM head
ii. Inside FDM, filament is melted by a resistance heater
iii. The semi liquid thermoplastic is extruded through FDM head
iv. Material is deposited in a thin layer on formation
v. Material solidifies, forming a laminate
vi. Next layer is formed on previous- lamina fuse together

FDM modelers typically use nylon or some wax. The material is non toxic and can be used anywhere, including offices. Machines can be equipped with second head to extrude a support structure (BASS breakaway support system).

2.3 Materials

The FDM process at present uses only plastic materials. The material comes in a spool, 5000 feet long, approximately 0.050" diameter. The available materials include ABS (acrylonitrile butadiene styrene), medical grade ABS, E20 (thermoplastic polyester based elastomer), and investment casting wax.

2.3.1 Materials For FDM:

There are only a few materials commercially available for the FDM: ABS, medical grade ABS, an elastomer and machinable wax.

Developments are being made for ceramic or metallic filaments, but both are new technologies.

Acrylonitrile butadiene styrene (ABS): for functional prototypes with good mechanical strength and chemical resistance. It is available in different colors.

Polycarbonate (PC): for functional prototypes with a very high impact resistance and a thermal deflection of 125°C.

Polyphenylsulfone (PPSU): for functional prototypes with an extremely high temperature resistance (> 200°C) and good mechanical strength.

Fused Deposition Modeling (FDM) Material Properties Characterization:

Build Parameter Considerations process control parameters that were likely to affect the properties of FDM parts

Bead (or road) width: This is the thickness of the bead (or road) that the FDM nozzle deposits. It can vary from .012 to .0396 for the T12 nozzle which is currently installed on our Stratasys FDM 1650 machine.

Air Gap: This is the space between the beads of FDM material. The default is zero, meaning that the beads just touch.

It can be modified to leave a positive gap, which means that the beads of material do not touch.

This results in a loosely packed structure that builds rapidly. It can also be modified to leave a negative gap, meaning that two beads partially occupy the same space [4]. This results in a dense structure which requires a longer build time.

Model Build Temperature: The temperature of the heating element for the model material. This control how molten the material is as it is extruded from the nozzle.

Raster Orientation: The direction of the beads of material (roads) relative to the loading of the part.

Color: FDM ABS material is available in a variety of colors: white, blue, black, yellow, green, and red.

The other possible parameters that affects of envelope temperature (the temperature of the air around the part), slice height (which is similar to bead width in the vertical direction), and nozzle diameter (the width of the hole through which the material extrudes).

3. CASE STUDY

Digital manipulation of prosthesis data for the introduction of advanced manufacturing techniques

- ***Design stage***
  - Digitize and carve socket and cosmesis shapes
  - Modify socket shape to meet patient's demands
  - Construct, fit and align trial socket
- Manufacture stage
  - Merge socket and cosmesis manufacture final prosthesis by rapid prototyping.
  - Variations using different file manipulation and construction
- Modify socket shape to meet patient's demands:
  - The modification of the socket shape is done using Seattle Shape maker.
  - Templates that change the shape of certain defined areas can be defined by the user and are a very useful tool in this stage.
- Construct, fit and align trial socket:
  - A trial socket can be manufactured by using the Seattle Carver which produces a polyurethan foam

socket shape.

- The foam shape acts as a negative to pull a heated sheet of transparent thermoplastic material over it either in the Seattle Thermo Former or by hand.
- A distal adaptor is added and endoskeletal prosthesic components are attached.
- If the socket fits well on the patient and a suitable alignment has been found, the alignment can be transferred on to the socket shape in the software.

4. MANUFACTURE OF A RAPID PROTOTYPED PROSTHESIS USING FDM:

Fused Deposition Modeling is a technique of rapid prototype manufacture which involves the depositing of auto adhering material in specific computer controlled sequence as to build a prototype in space [5].

Fig.3 Prototype prosthesis using FDM

ABS - (Acetyl Butyl Styrene - an engineering grade plastic that can be machined, glued, painted and is both strong and light)

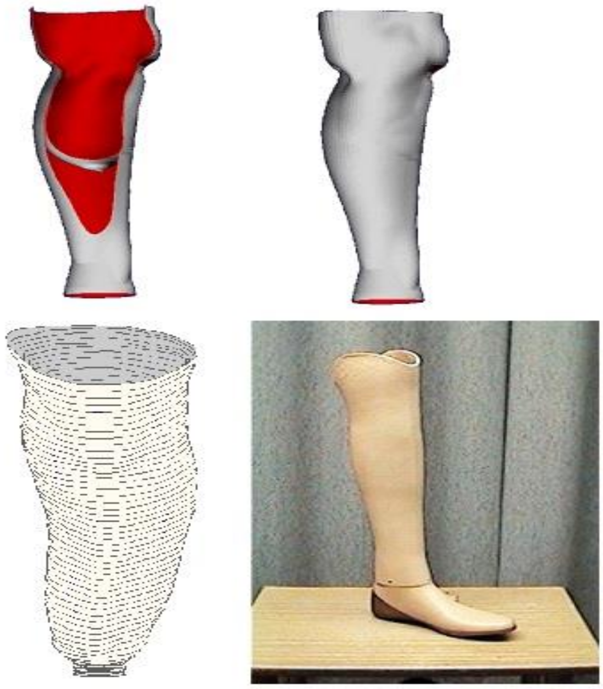

Fig.4 Prosthesis designed, merged and constructed (7mm wall thickness)

5. CONCLUSION:

The first ABS prosthesis was constructed with a variable wall thickness and will soon undergo clinical trials and then Finite element analysis combined with destructive strength testing! The weight difference between the ABS and the limb made using "conventional lamination" is only 15 grams. Variations using different file manipulation and construction. Also the file information can be used to construct prosthesis in a "conventional" manner; however the process of manufacture is much simpler. A lamination is made on an external frame and a lamination is made on the socket BUT they fit inherently together. No shaping or fitting is required. The same technique can yield a foam cover also.

6. REFERENCE

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