ADDITIVE MANUFACTURING

UNIT – I

Definition of a Prototype

An approximation of a product (or system) or its components in some form for a definite purpose in its implementation.

Prototype is an important and vital part of the product development process. In any design practice, the word "prototype" is often not far from the things that the designers will be involved in. In most dictionaries, it is defined as a noun, e.g. the Oxford Advanced Learner's Dictionary of Current English

A prototype is the first or original example of something that has been or will be copied or developed; it is a model or preliminary version;
e.g.: A prototype supersonic aircraft.

Types of Prototypes

The general definition of the prototype contains three aspects of interests:

(1) The implementation of the prototype; from the entire product (or system) itself to its sub-assemblies and components,
(2) The form of the prototype; from a virtual prototype to a physical prototype, and
(3) The degree of the approximation of the prototype; from a very rough representation to an exact replication of the product.

The implementation aspect of the prototype covers the range of prototyping the complete product (or system) to prototyping part of, or a sub-assembly or a component of the product. The complete prototype, as its name suggests, models most, if not all, the characteristics of the product. It is usually implemented full-scale as well as being fully functional. One example of such prototype is one that is given to a group of carefully selected people with special interest, often called a focus group, to examine and identify outstanding problems before the product is committed to its final design. On the other hand, there are prototypes that are needed to study or investigate special problems associated with one component, sub-assemblies or simply a particular concept of the product that requires close attention. An example of such a prototype is a test platform that is used to find the comfortable rest angles of an office chair that will reduce the risk of spinal injuries after prolonged sitting on such a chair. Most of the time, sub-assemblies and components are tested in conjunction with some kind of test rigs or experimental platform.

Roles of the Prototypes

The roles that prototypes play in the product development process are several. They include the following:
(1) Experimentation and learning
(2) Testing and proofing
(3) Communication and interaction
(4) Synthesis and integration
(5) Scheduling and markers

To the product development team, prototypes can be used to help the thinking, planning, experimenting and learning processes whilst designing the product. Questions and doubts regarding certain issues of the design can be addressed by building and studying the prototype. For example, in designing the appropriate elbow-support of an office chair, several physical prototypes of such elbow supports can be built to learn about the “feel” of the elbow support when performing typical tasks on the office chair.

Prototypes can also be used for testing and proofing of ideas and concepts relating to the development of the product. For example, in the early design of folding reading glasses for the elderly, concepts and ideas of folding mechanism can be tested by building rough physical prototypes to test and prove these ideas to see if they work as intended.

ADVANTAGES OF RAPID PROTOTYPING

Today’s automated, toolless, patternless RP systems can directly produce functional parts in small production quantities. Parts produced in this way usually have an accuracy and surface finish inferior to those made by machining. However, some advanced systems are able to produce near tooling quality parts that are close to or are the final shape. The parts produced, with appropriate post processing, will have material qualities and properties close to the final product. More fundamentally, the time to produce any part — once the design data are available — will be fast, and can be in a matter of hours.

The benefits of RP systems are immense and can be categorized into direct and indirect benefits.

CLASSIFICATION OF RAPID PROTOTYPING SYSTEMS

While there are many ways in which one can classify the numerous RP systems in the market, one of the better ways is to classify RP systems broadly by the initial form of its material, i.e. the material that the prototype or part is built with. In this manner, all RP systems can be easily categorized into

(1) liquid-based
(2) solid-based and
(3) powderbased.

Liquid-Based

Liquid-based RP systems have the initial form of its material in liquid state. Through a process commonly known as curing, the liquid is converted into the solid state. The following RP systems fall into this category:

(1) 3D Systems' Stereolithography Apparatus (SLA)
(2) Cubital's Solid Ground Curing (SGC)
(3) Sony's Solid Creation System (SCS)
(4) CMET's Solid Object Ultraviolet-Laser Printer (SOUP)
(5) Autostrade's E-Darts
(6) Teijin Seiki's Soliform System

Solid-Based

Except for powder, solid-based RP systems are meant to encompass all forms of material in the solid state. In this context, the solid form can include the shape in the form of a wire, a roll, laminates and pellets.
The following RP systems fall into this definition:

(1) Cubic Technologies' Laminated Object Manufacturing (LOM)
(2) Stratasys' Fused Deposition Modeling (FDM)
(3) Kira Corporation's Paper Lamination Technology (PLT)
(4) 3D Systems' Multi-Jet Modeling System (MJM)
(5) Solidscape's ModelMaker and PatternMaster

Powder-Based

In a strict sense, powder is by-and-large in the solid state. However, it is intentionally created as a category outside the solid-based RP systems to mean powder in grain-like form. The following RP systems fall into this definition:

(1) 3D Systems's Selective Laser Sintering (SLS)

(2) EOS's EOSINT Systems
(3) Z Corporation's Three-Dimensional Printing (3DP)
(4) Optomec's Laser Engineered Net Shaping (LENS)
(5) Soligen's Direct Shell Production Casting (DSPC)
(6) Fraunhofer's Multiphase Jet Solidification (MJS)
(7) Acram's Electron Beam Melting (EBM)
(8) Aeromet Corporation's Lasform Technology
(9) Precision Optical Manufacturing's Direct Metal Deposition (DMD™)
(10) Generis' RP Systems (GS)
(11) Therics Inc.'s Theriform Technology
(12) Extrude Hone's Prometal™ 3D Printing Process

LIQUID-BASED RAPID PROTOTYPING SYSTEMS

Most liquid-based rapid prototyping systems build parts in a vat of photo-curable liquid resin, an organic resin that cures or solidifies under the effect of exposure to laser radiation, usually in the UV range. The laser cures the resin near the surface, forming a hardened layer. When a layer of the part is formed, it is lowered by an elevation control system to allow the next layer of resin to be similarly formed over it. This continues until the entire part is completed. The vat can then be drained and the part removed for further processing, if necessary. There are variations to this technique by the various vendors and they are dependent on the type of light or laser, method of scanning or exposure, type of liquid resin, type of elevation and optical system used.

STEREOLITHOGRAPHY APPARATUS (SLA)

Models and Specifications

3D Systems produces a wide range of machines to cater to various part sizes and throughput. There are several models available, including those in the series of SLA 250/30A, SLA 250/50, SLA-250/50HR, SLA 3500, SLA 5000, SLA 7000 and Viper si2. The SLA 250/30A is an economical and versatile SLA starter system that uses a Helium Cadmium (He–Cd) laser. The SLA 250/50 is a supercharged system with a higher powered laser, interchangeable vats and Zephyr recoater system, whereas the SLA 250/50HR adds a special feature of a small spot laser for high-resolution application. All SLA 250 type systems have a maximum build envelope of 250 □□250 □□250 mm and use a He–Cd laser. For bigger build envelopes, the SLA 3500, SLA 5000 and SLA 7000 are available. These three machines use a different laser from the SLA 250 (solid-state $Nd{:}YVO_4$). The SLA 7000 (see Figure 3.1) is the top of the series. It can build parts up to four times faster than the SLA 5000 with the capacity of building thinner layers (minimum layer thickness 0.025 mm) for finer surface finish. Its faster speed is largely due to its dual spot laser'sability. This means that a smaller beam spot is used for the border for accuracy, whereas the bigger beam spot is used for internal crosshatching for speed. 3D Systems' new Viper si2 SLA system is their first solid imaging system to combine standard and high-resolution part building in the same system. The Viper si2 system lets you choose between standard resolution, for the best balance of build speed and part resolution, and high resolution (HR mode) for ultra-detailed small parts and features. All these are made possible by a carefully integrated digital signal processor (DSP) controlled high speed scanning system with a single, solid-state laser that delivers a constant 100 mW of available power throughout its 7500-hour warranty life. The Viper si2 system builds parts with a smooth surface finish, excellent optical clarity, high accuracy, and thin, straight vertical walls. It is ideal for a myriad of solid imaging applications, from rapid modeling and prototyping to injection molding and investment casting. Specifications of these machines are summarized in Tables

Table: Summary specifications of SLA-250 machines (Source from 3D Systems)

Model	SLA 250/30A	SLA 250/50	SLA 250/50HR
SYSTEM CHARACTERISTICS			
	SmartStart. An economical and versatile SLA starter system.	A supercharged system with higher powered laser, interchangeable vats, and Zephyr recoating system.	A specialty system with small spot laser for high-resolution applications.
VAT CAPACITY			
Maximum Build Envelope	$250 \times 250 \times 250$ mm^3 $10 \times 10 \times 10$ in^3	$250 \times 250 \times 250$ mm^3 $10 \times 10 \times 10$ in^3	$250 \times 250 \times 250$ mm^3 $10 \times 10 \times 10$ in^3
VOLUME			
L (U.S. gal)	29.4 (7.8)	32.2 (8.5)	32.2 (8.5)
LASER			
Type	Helium Cadmium (He–Cd)	Helium Cadmium (He–Cd)	Helium Cadmium (He–Cd)
Wavelength	325 nm	325 nm	325 nm
Power at Vat @ hrs	@ 2000/hrs 12 mW	@ 2000/hrs 25 mW	@ 2000/hrs 6 mW
Warranty	2000 hrs	2000 hrs	2000 hrs
OPTICAL & SCANNING			
Dual Spot	No	No	No
Beam Diameter; Border @ l/e^2	0.24 +/– 0.04 mm (0.0095 +/– 0.0015 in)	0.24 +/– 0.04 mm (0.0095 +/– 0.0015 in)	0.07 +/– 0.01 mm (0.003 +/– 0.0005 in)
Beam Diameter; Hatch @ l/e^2	0.24 +/– 0.04 mm (0.0095 +/– 0.0015 in)	0.24 +/– 0.04 mm (0.0095 +/– 0.0015 in)	0.07 +/– 0.01 mm (0.003 +/– 0.0005 in)
RECOATING SYSTEM			
	Doctor	Zephyr	Zephyr

Table 3.1(a): (Continued)

Model	SLA 250/30A	SLA 250/50	SLA 250/50HR
	FEATURES		
Interchangeable Vat	Available Option	Yes	Yes
SmartSweep	No	No	No
Auto Resin Refill	No	No	No
	SOFTWARE		
3D Lghtyear / Windows NT	With Build-station 3.8.4	With Build-station 3.8.4	With Build-station 3.8.4
Buildstation O/S	MS DOS	MS DOS	MS DOS
	RESINS		
General Purpose Durable	SL 5149, SL 5170, N/A SL 5220	SL 5149, SL 5170, N/A SL 5220	SL 5149, SL 5170, N/A SL 5220
High Temperature	SL 5210	SL 5210	SL 5210
	WARRANTY		
	1 yr from installation date	1 yr from installation date	1 yr from installation date

Table 3.1(b): Summary specifications of the rest of the SLA machines (Source fro

Model	SLA 3500	SLA 5000	SLA 7000
SYSTEM CHARACTERISTICS			
	A mid-sized system up to 2.5 times faster than SLA 250 with productivity enhancements like auto resin refill and SmartSweep.	A large-frame system with three times the build volume of SLA 3500.	A supercharged large-frame system two times faster than SLA 5000 with the capability building thinner layers for fi surface finish.
VAT CAPACITY			
Maximum Build Envelope	350 × 350 × 400 mm^3 13.8 × 13.8 × 15.7 in^3	508 × 508 × 584 mm^3 20 × 20 × 23 in^3	508 × 508 × 600 mm^3 20 × 20 × 23.6 in^3
VOLUME			
L (U.S. gal)	99.3 (25.6)	253.6 (67)	
LASER			
Type	Solid-State (Nd:YVO$_4$)		
Wavelength	354.7 nm		
Power at Vat @ hrs	@ 5000/hrs 160 mW	@ 5000/hrs 216 mW	@ 5000/hrs 800 mW
Warranty	5000 hrs		
OPTICAL & SCANNING			
Dual Spot	No		Ye
Beam Diameter; ^{2}	0.25 +/− 0.025 mm		

Border @ l/e	(0.010 +/− 0.001 in)	
Beam Diameter; 2 Hatch @ l/e	0.25 +/− 0.025 mm (0.010 +/− 0.001 in)	0.7615 +/− 0.0765 mm (0.03 +/− 0.003 in)
RECOATING SYSTEM		
	Zephyr	

Table 3.1(b): (Continued)

Model	SLA 3500	SLA 5000	SLA 7000
FEATURES			
Interchangeable Vat	Yes		
SmartSweep	Yes		
Auto Resin Refill	Yes		
SOFTWARE			
3D Lghtyear / Windows NT	Buildstation 5.1		
Buildstation O/S	Windows NT 3.5.1		

RESINS			
General Purpose	SL 5190, SL 5510	SL 5195, SL 5510	SL 7510
Durable	SL 5520		
High Temperature	SL 5530 HT		
WARRANTY			
	1 yr from installation date		

Principle

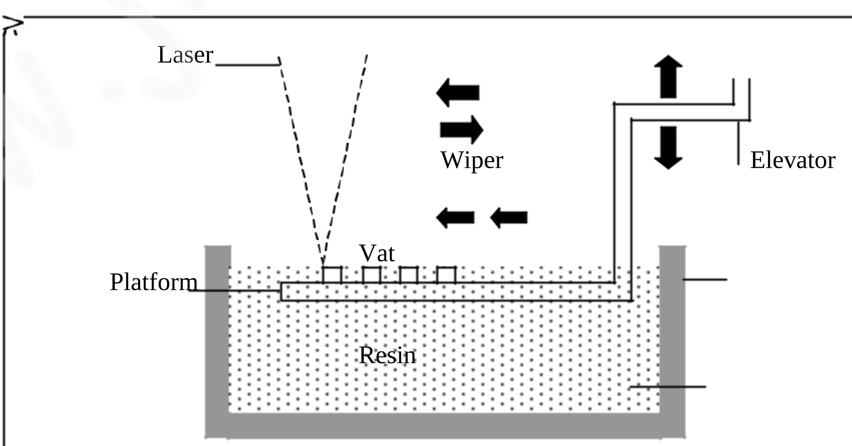
The SLA process is based fundamentally on the following principles [3]:

Parts are built from a photo-curable liquid resin that cures when exposed to a laser beam (basically, undergoing the photo-polymerization process) which scans across the surface of the resin. The building is done layer by layer, each layer being scanned by the optical scanning system and controlled by an elevation mechanism which lowers at the completion of each layer.

These two principles will be briefly discussed in this section to lay the foundation to the understanding of RP processes. They are mostly applicable to the liquid-based RP systems described in this chapter. This first principle deals mostly with photo-curable liquid resins, which are essentially photopolymers and the photo-polymerization process. The second principle deals mainly with CAD data, the laser, and the control of the optical scanning system as well as the elevation mechanism

Process

3D Systems' stereolithography process creates three-dimensional plastic objects directly from CAD data. The process begins with the vat filled with the photo-curable liquid resin and the elevator table set just below the surface of the liquid resin (see Figure 3.2). The operator loads a three-dimensional CAD solid model file into the system. Supports are designed to stabilize the part during building. The translator converts the CAD data into a STL file. The control unit slices the model and support into a series of cross sections from 0.025 to 0.5 mm (0.001 to 0.020 in) thick



The computer-controlled optical scanning system then directs and focuses the laser beam so that it solidifies a two-dimensional cross-section corresponding to the slice on the surface of the photo-curable liquid resin to a depth greater than one layer thickness. The elevator table then drops enough to cover the solid polymer with another layer of the liquid resin. A leveling wiper or vacuum blade (for Zephyr™ recoating system) moves across the surfaces to recoat the next layer of resin on the surface. The laser then draws the next layer. This process continues building the part from bottom up, until the system completes the part. The part is then raised out of the vat and cleaned of excess polymer.

The main components of the SLA system are a control computer, a control panel, a laser, an optical system and a process chamber. The workstation software used by the SLA system, known as 3D Lightyear exploits the full power of the Windows NT operating system, and delivers far richer functionality than the UNIX-based Maestro software. Maestro includes the following software modules

3dverify™ Module: This module can be accessed to confirm the integrity and/or provide limited repair to stereolithography (STL) files before part building without having to return to the original CAD software. Gaps between triangles, overlapping or redundant triangles and incorrect normal directions are some examples of the flaws that can be identified and corrected

View™ Module. This module can display the STL files and slice file (SLI) in graphical form. The viewing function is used for visual inspection and for the orientation of these files so as to achieve optimal building.

MERGE Module. By using MERGE, several SLI files can be merged into a group which can be used together in future process.

Vista™ Module. This module is a powerful software tool that automatically generates support structures for the part files. Support structures are an integral part to successful part building, as they help to anchor parts to the platform when the part is free floating or there is an overhang.

Part Manager™ Module. This software module is the first stage of preparing a part for building. It utilizes a spreadsheet format into which the STL file is loaded and set-up with the appropriate build and recoat style parameters.

Slice™ Module. This is the second stage of preparing a part for building. It converts the spreadsheet information from the Part Manager™ module to a model of three-dimensional cross sections or layers.

Converge™ Module. This is the third and last stage of preparing a part for building. This is the module which creates the final build files used by the SLA.

Advantages

The main advantages of using SLA are:

Round the clock operation. The SLA can be used continuously and unattended round the clock.

Good user support. The computerized process serves as a good user support.

Build volumes. The different SLA machines have built volumes ranging from small to large to suit the needs of different users.

Good accuracy. The SLA has good accuracy and can thus be used for many application areas.

Surface finish. The SLA can obtain one of the best surface finishes amongst RP technologies.

Wide range of materials. There is a wide range of materials, from general-purpose materials to specialty materials for specific applications.

Disadvantages

The main disadvantages of using SLA are:

Requires support structures. Structures that have overhangs and undercuts must have supports that are designed and fabricated together with the main structure.

Requires post-processing. Post-processing includes removal of supports and other unwanted materials, which is tedious, time-consuming and can damage the model.

Requires post-curing. Post-curing may be needed to cure the object completely and ensure the integrity of the structure.

Applications

The SLA technology provides manufacturers with cost justifiable methods for reducing time to market, lowering product development costs, gaining greater control of their design process and improving product design. The range of applications include:

Models for conceptualization, packaging and presentation.

Prototypes for design, analysis, verification and functional testing.

Parts for prototype tooling and low volume production tooling.

Patterns for investment casting, sand casting and molding.

Tools for fixture and tooling design, and production tooling.

Photopolymers

There are many types of liquid photopolymers that can be solidified by exposure to electro-magnetic radiation, including wavelengths in the gamma rays, X-rays, UV and visible range, or electron-beam (EB) [4, 5]. The vast majority of photopolymers used in the commercial RP systems, including 3D Systems' SLA machines are curable in the UV range. UV-curable photopolymers are resins which are formulated from photoinitiators and reactive liquid monomers. There are a large variety of them and some may contain fillers and other chemical modifiers to meet specified chemical and mechanical requirements [6]. The process through which photopolymers are cured is referred to as the photo-polymerization process.

Photopolymerization

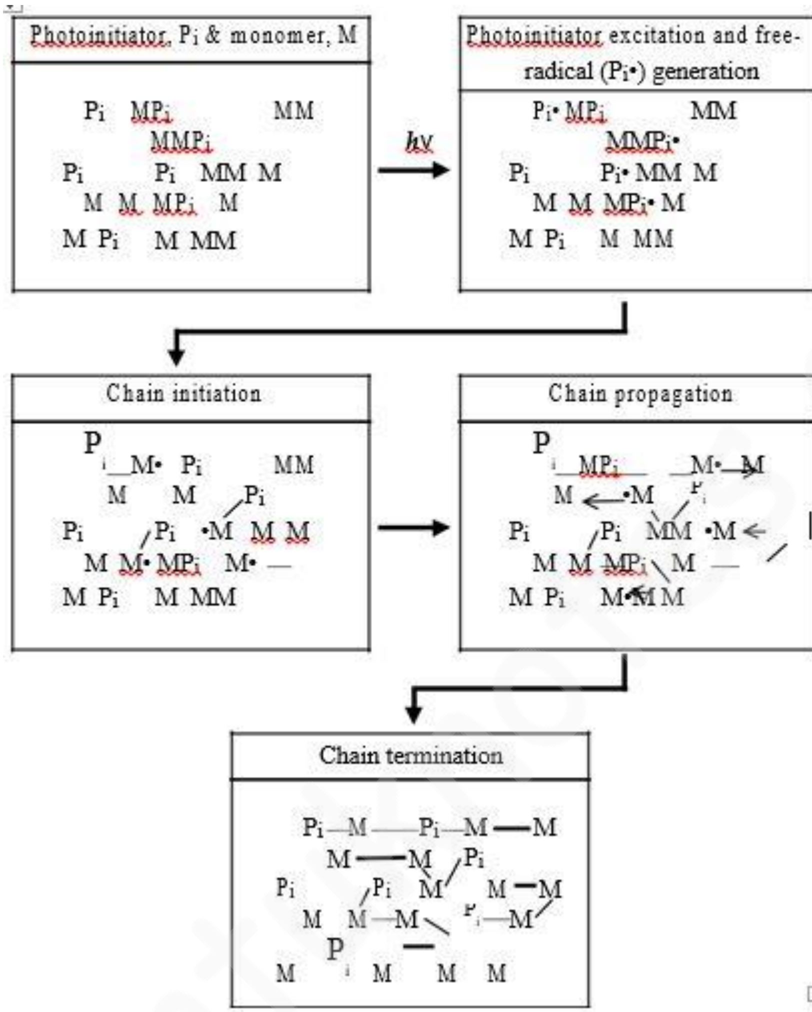
Loosely defined, polymerization is the process of linking small mole-cules (known as monomers) into chain-like larger molecules (known as polymers). When the chain-like polymers are linked further to one another, a cross-linked polymer is said to be formed. Photopolymeri-zation is polymerization initiated by a photochemical process whereby the starting point is usually the induction of energy from the radiation source [7].

Polymerization of photopolymers is normally an energetically favorable or exothermic reaction. However, in most cases, the formu-lation of a photopolymer can be stabilized to remain unreacted at ambient temperature. A catalyst is required for polymerization to take place at a reasonable rate. This catalyst is usually a free radical which may be generated either thermally or photochemically. The source of a photochemically generated radical is a photoinitiator, which reacts with an actinic photon to produce the radicals that catalyze the poly-merization process.

The free-radical photopolymerization process is schematically presented in Figure 3.3 [8]. Photoinitiator molecules, P_i , which are mixed with the monomers, M, are exposed to a UV source of actinic photons, with energy of hν. The photoinitiators absorb some of the photons and are in an excited state. Some of these are converted into reactive initiator molecules, P•, after undergoing several complex chemical energy transformation steps. These molecules then react with a monomer molecule to form a polymerization initiating molecule, PM•. This is the chain initiation step. Once activated, additional monomer molecules go on to react in the chain propagation step, forming longer molecules, PMMM• until a chain inhibition process terminates the polymerization reaction. The longer the reaction is sustained, the higher will be the molecular weight of the resulting polymer. Also, if the monomer molecules have three or more reactive chemical groups, the resulting polymer will be cross-linked, and this will generate an insoluble continuous network of molecules.

During polymerization, it is important that the polymers are sufficiently cross-linked so that the polymerized molecules do not re-dissolve back into the liquid monomers. The photopolymerized molecules must also possess sufficient strength to remain structurally sound while the cured resin is subjected to various forces during recoating.

While free-radical photopolymerization is well-established and yields polymers that are acrylate-based, there is another newer “chemistry” known as cationic photopolymerization [9]. It relies on cationic initiators, usually iodinium or sulfonium salts, to start polymerization. Commercially available cationic monomers include epoxies, the most versatile of cationally polymerizable monomers, and vinylethers. Cationic resins are attractive as prototype materials as they have better physical and mechanical properties. However the process may require higher exposure time or a higher power laser.



Layering Technology, Laser and Laser Scanning

Almost all RP systems use layering technology in the creation of prototype parts (see Chapter 2). The basic principle is the availability of

computer software to slice a CAD model into layers and reproduce it in an "output" device like a laser scanning system. The layer thickness is controlled by a precision elevation mechanism. It will correspond directly to the slice thickness of the computer model and the cured thickness of the resin. The limiting aspect of the RP system tends to be the curing thickness rather than the resolution of the elevation mechanism.

The important component of the building process is the laser and its optical scanning system. The key to the strength of the SLA is its ability to rapidly direct focused radiation of appropriate power and wavelength onto the surface of the liquid photopolymer resin, forming patterns of solidified photopolymer according to the cross-sectional data generated by the computer [10]. In the SLA, a laser beam with a speci-fied power and wavelength is sent through a beam expanding telescope to fill the optical aperture of a pair of cross axis, galvanometer driven, beam scanning mirrors. These form the optical scanning system of the SLA. The beam comes to a focus on the surface of a liquid photopoly-mer, curing a predetermined depth of the resin after a controlled time of exposure (inversely proportional to the laser scanning speed).

The solidification of the liquid resin depends on the energy per unit area (or "exposure") deposited during the motion of the focused spot on the surface of the photopolymer. There is a threshold exposure that must be exceeded for the photopolymer to solidify.

To maintain accuracy and consistency during part building using the SLA, the cure depth and the cured line width must be controlled. As such, accurate exposure and focused spot size become essential.

Parameters which influence performance and functionality of the parts are the physical and chemical properties of the resin, the speed and resolution of the optical scanning system, the power, wavelength and type of the laser used, the spot size of the laser, the recoating system, and the post-curing process

CUBITAL'S SOLID GROUND CURING (SGC)

Models and Specifications

Cubital's products include the Solider 4600 and Solider 5600. The Solider 4600 is Cubital's entry level three-dimensional model making system based on Solid Ground Curing. The Solider 5600, Cubital's sophisticated high-end system, provides a wider range and options for the varied modeling demands of Solid Ground Curing. Table 3.2 summarizes the specifications of the two machines. Cubital's system uses several kinds of resins, including liquid resin and cured resin as materials to create parts, water soluble wax as support material and ionographic solid toner for creating an erasable image of the cross-section on a glass mask.

Model	**Solider 4600**	**Solider 5600**
Irradiation medium	High power UV lamp	
XY resolution (mm)	Better than 0.1	
Surface definition (mm)	0.15	0.15
Elevator vertical resolution (mm)	0.15	0.1–0.2
Minimum feature size (mm)	0.4 (horizontal, X–Y) 0.15 (vertical, Z)	0.4 (horizontal, X–Y) 0.15 (vertical, Z)
Work volume, XYZ (mm × mm × mm)	350 × 350 × 350	500 × 350 × 500

Production rate (cm^3/hr)	550	1311
Minimum layer thickness (mm)	0.06	0.06
Dimensional accuracy	0.1%	0.1%
Size of unit, XYZ (m × m × m)	1.8 × 4.2 × 2.9	1.8 × 4.2 × 2.9
Data control unit	Data Front End (DFE) workstation	
Power supply	380 –415 V_{AC} , 3 phase, 50 kW	380 –415 V_{AC} , 3 phase, 50 kW

Principle

Cubital's RP technology creates highly physical models directly from computerized three-dimensional data files. Parts of any geometric complexity can be produced without tools, dies or molds by Cubital's RP technology.

The process is based on the following principles:

Parts are built, layer by layer, from a liquid photopolymer resin that solidifies when exposed to UV light. The photopolymerization process is similar to that described in Section 3.1.4, except that the irradiation source is a high power collimated UV lamp and the image of the layer is generated by masked illumination instead of optical scanning of a laser beam. The mask is created from the CAD data input and "printed" on a transparent substrate (the mask plate) by an nonimpact ionographic printing process, a process similar to the Xerography process used in photocopiers and laser printers [15]. The image is formed by depositing black powder, a toner which adheres to the substrate electrostatically. This is used to mask the uniform illumination of the UV lamp. After exposure, the electrostatic toner is removed from the substrate for reuse and the pattern for the next layer is similarly "printed" on the substrate.

Multiple parts may be processed and built in parallel by grouping them into batches (runs) using Cubital's proprietary software.

Each layer of a multiple layer run contains cross-sectional slices of one or many parts. Therefore, all slices in one layer are created simultaneously. Layers are created thicker than desired. This is to allow the layer to be milled precisely to its exact thickness, thus giving overall control of the vertical accuracy. This step also produces a roughened surface of cured photopolymer, assisting adhesion of the next layer to it. The next layer is then built immediately on the top of the created layer.

The process is self-supporting and does not require the addition of external support structures to emerging parts since continuous structural support for the parts is provided by the use of wax, acting as a solid support material.

Process

The Cubital's Solid Ground Curing process includes three main steps:

1. Data preparation,
2. Mask generation and
3. Model making

Data Preparation:

In this first step, the CAD model of the job to be prototyped is prepared and the cross-sections are generated digitally and transferred to the mask generator. The software used, Cubital's Solider DFE (Data Front End) software, is a motif-based special-purpose CAD application pack-age that processes solid model CAD files prior to sending them to Cubital Solider system. DFE can search and correct flaws in the CAD files and render files on-screen for visualization purposes. Solider DFE accepts CAD files in the STL format and other widely used formats exported by most commercial CAD systems.

Mask Generation

After data are received, the mask plate is charged through an “image-wise” ionographic process (see item 1, Figure). The charged image is then developed with electrostatic toner

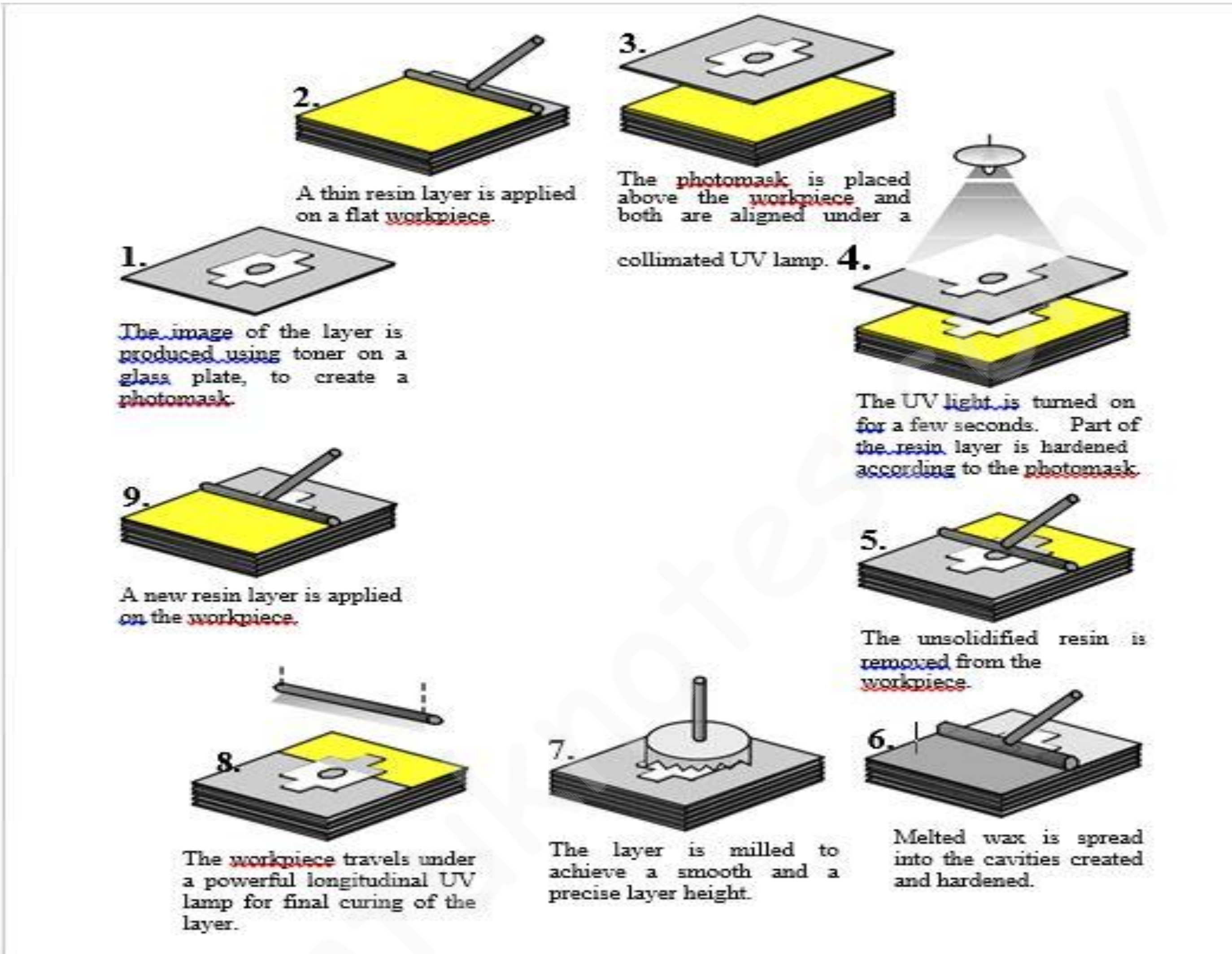
Model Making

In this step, a thin layer of photopolymer resin is spread on the work surface (see item 2, Figure 3.6). The photo mask from the mask generator is placed in close proximity above the workpiece, and aligned under a collimated UV lamp (item 3). The UV light is turned on for a few seconds (item 4). The part of the resin layer which is exposed to the UV light through the photo mask is hardened. Note that the layers laid down for exposure to the lamp are actually thicker than the desired thickness. This is to allow for the final milling process. The un-solidified resin is then collected from the workpiece (item 5). This is done by vacuum suction. Following that, melted wax is spread into the cavities created after collecting the liquid resin (item 6). Consequently, the wax in the cavities is cooled to produce a wholly solid layer. Finally, the layer is milled to its exact thickness, producing a flat solid surface ready to receive the next layer (item 7).

In the SGC 5600, an additional step (item 8) is provided for final curing of the layer whereby the workpiece travels under a powerful longitudinal UV lamp. The cycle repeats itself until the final layer is completed.

The main components of the Solider system are (see Figure 3.7):

- Data Front End (DFE) workstation.
- Model Production Machine (MPM). It includes:
    - Process engine,
    - Operator’s console,
    - Vacuum generator.
- Automatic Dewaxing Machine (optional).



Advantages and Disadvantages

The Solider system has the following advantages:

Parallel processing. The process is based on instant, simultaneous curing of a whole cross-sectional layer area (rather than point-by-point curing). It has a high speed throughput that is about eight times faster than its competitors. Its production costs can be 25% to 50% lower. It is a time and cost saving process.

Self-supporting. It is user-friendly, fast, and simple to use. It has a solid modeling environment with unlimited geometry. The solid wax supports the part in all dimensions and therefore a support structure is not required.

Fault tolerance. It has good fault tolerances. Removable trays allow job changing during a run and layers are erasable.

Unique part properties. The part that the Solider system produces is reliable, accurate, sturdy, machinable, and can be mechanically finished.

CAD to RP software. Cubital's RP software, Data Front End (DFE), processes solid model CAD files before they are transferred to the Cubital's machines. The DFE is an interactive and user-friendly software.

Minimum shrinkage effect. This is due to the full curing of every layer.

High structural strength and stability. This is due to the curing process that minimizes the development of internal stresses in the structure. As a result, they are much less brittle.

No hazardous odors are generated. The resin stays in a liquid state for a very short time, and the uncured liquid is wiped off immediately. Thus safety is considerably higher.

Disadvantages

The Solider system has the following disadvantages:

Requires large physical space. The size of the system is much larger than other systems with a similar build volume size.

Wax gets stuck in corners and crevices. It is difficult to remove wax from parts with intricate geometry. Thus, some wax may be left behind.

Waste material produced. The milling process creates shavings, which have to be cleaned from the machine.

Noisy. The Solider system generates a high level of noise as compared to other systems.

Applications

The applications of Cubital's system can be divided into four areas:

General applications. Conceptual design presentation, design proofing, engineering testing, integration and fitting, functional analysis, exhibitions and pre-production sales, market research, and inter-professional communication.

Tooling and casting applications. Investment casting, sand casting, and rapid, tool-free manufacturing of plastic parts.

Mold and tooling. Silicon rubber tooling, epoxy tooling, spray metal tooling, acrylic tooling, and plaster mold casting.

Medical imaging. Diagnostic, surgical, operation and reconstruc-tion planning and custom prosthesis design.