RAPID PROTOTYPYING A NEW CONCEPT IN MANUFACTURING

Bui Tri Si – Erik L.J Bohez – Banh Tien Long
Asian Institute of Technology
(Received on 03/20/1999)

ABSTRACT: Rapid Prototyping (RP), e.g. Stereolithography – a new concept in manufacturing can generate 3D models directly from 3D Computer Aided Design model data, making a design tangible within a short period of time. In the design developing process, RP dramatically reduces time and cost. Compare with the conventional machining method, the RP technology has many of advantages such as: no tooling preparation time, no fixture cost, reduce design iteration time by utilizing the simultaneous engineering, able to build the extremely complex model which can not be manufactured on CNC machine because of undercut problem, as well as to apply computer integrated manufacturing concept by helping of computer network at any place in over the world.

Increasing design standards and shortening product life cycle create new demands to the product development. Using RP is one optimum option to gain the desired quality and productivity improvement in product design.
Accuracy, cost, surface finish and material used are different from process to process. Launched in 1997, RP today is representing already more than 30 different technologies.
This paper was the first step to develop a methodology that helps the practice to select the best technology for the specific prototyping problem. A plastic injection moulding part was designed as a test model. Then prototypes were made with several technologies (SLA,SLS) a Silicone rubber mould and a resin casting part of "*an upper half of mobile telephone*" were produced. Evaluation for the whole process was made to analyze the accuracy, time and cost of each process.

II- INTRODUCTION

With the increasing in demand of new, up to date consumer products, the demand of speed and quality of product design has increased greatly. The need for environment friendly products leads to plastic injected moulding part because they are light and cheap. In the design process prototyping is an important and difficult step.

Easy and fast available prototypes of good quality improve the design process in speed and quality. The new emerging technologies of RP offer a solution for easy prototyping and though can have a big impact to the product design. Particularly for the fast growing Asian market there is a big need for prototyping to develop Asia specific competitive products.

Products are frequently changed and product life becomes shorter. To survive in the competing in the industry, many companies try to use CAD/CAM/CAE for product design, mould design and manufacturing. They try to find some feasible ways for the product design and manufacturing section to reduce the existing problems such as: Long product design cycle time and manufacturing time; Defects in plastic injection parts by faulty deign; To improve the surface and internal quality of injection moulding part; To improve the production rate to meet demand; Selection problem of dedicated CAD/CAE/CAM software.

III- METHODOLOGY

"In traditional product design, the desirable changes in part design usually become evident only after major investments in tooling and testing have already been made". It is time consuming. To figure out, how RP can improve this process will be done by the following procedures:

1. Computer aided design taking moulding restriction into consideration
2. Analyze interface to rapid prototyping
3. Build prototype model
4. Analyze the whole process

3.1 Computer Aided Design for Plastic Injection Moulding Part

The geometric modeling was done on the Unigraphics CAD/CAM software running on the Hewlett-Packard UNIX platform in Asian Institute of Technology.

The use of CAD/CAM in process strategy will result to the following benefits such as: Manufacturing flexibility; Improve manufacturing performance and quality; Reduce repetitive input; Design flexibility; Faster response to market.

3.1.1 The Part Design Factors Related to Injection Process

- Wall thickness: thin section is required from the point of view of fast production rate to reduce cycle time. Thickness of the part should be as uniform as possible. Many of defects could be happened because of the effect of non-uniform.
- Radii and Fillet: the purpose of use adequate radii is to reduce stress concentration and results in making a molded product stronger and to minimize the abruptness of transitions from one flat surface to another.
- Bosses: bosses are used to reinforce holes, to support metal insert, or to mount subassemblies.
- Draft: in order to eject part from the mold, a taper or draft angle is required all surfaces normal to the parting plane of the mold.
- Tolerance: extreme accuracy of dimensions in molded part is difficult, expensive, and sometimes impossible to achieve. Tolerances closely related to shrinkage but also to the nature of the particular plastic.

3.2 Analyze Interface to RP

3.2.1 CAD System Data Representation

Data transfer between the CAD systems and RP processes is mainly based on data exchange formats capable of representing faceted models.

The start of all RP process begins with the initial part geometry contained in the CAD model. Usually, the CAD file must be pre-processed by running a CAD to STL translation program, to generate an STL file. This can be carried out in most solid modeling CAD system.

The STL file basically consists of the X,Y and Z co-ordinates of the three vertices of each surface triangle, as well as an index that describes the orientation of the surface normal. The later feature is necessary to ensure that a clear distinction is made between inner and outer surfaces. The STL has become the defacto standard of the RP&M field, and is now supported by over 40 CAD system suppliers.

To process the selected surfaces, the system must determine surface adjacencies, triangulate each surface making sure all edge vertices match, and determine normal to the triangles with point toward the outside of the surfaced model.

To process the selected solids, the system directly triangulates the solids. The system finally outputs the triangles and normal to the output file for use with the exterior rapid prototyping program.

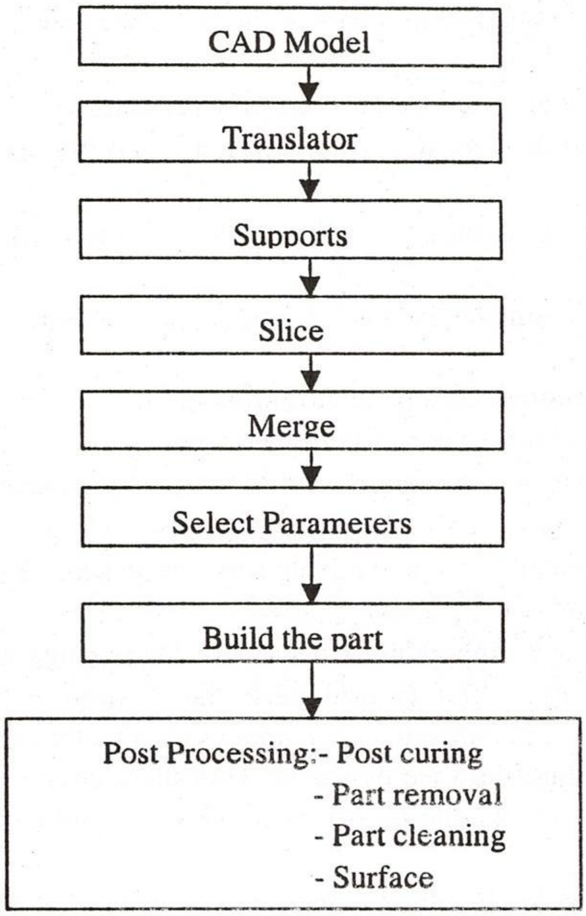

Figure 3.2 Basic RP Operation

3.2.2 CAD Parameters

The triangulation tolerance determines how smooth the approximation of the surface/solid will be (i.e. how close the triangles approximate the surface and how close the sides of the triangles which lie along the edges are to the edges of the surface).

The adjacency tolerance determines when two surfaces meet along an edge. The adjacency tolerance has no affect on the processing of solid.

Scaling the part geometry to account for shrinkage can be accomplished in the RP software.

The part geometry must reside in the positive X, Y, Z octant, meaning all CAD values are positive numbers. Keeping the parts close to the x and y origin minimizes the extent of the part and allows the use of a maximum slice resolution factor.

3.2.3Part Orientation

Many factors contribute to the definition of the orientation of build. Some of these factors included: surface finish, build time, support structures, shrinkage, curling, distortion, roundness/flatness, part tolerance, resin flow, material cost and trapped volume.

Part orientation within the building chamber will have an impact on build time, part resolution, and surface finish. Obviously, minimizing the height of the geometry will reduce the number of layers required, thereby decreasing build time.

3.2.4Drain Holes

Totally enclosed volumes must have drain holes to allow the uncured resin to escape.

3.2.5Support and Base

Support and base are used for the following reasons:

1. To ensure that the recoater blade will not strike the platform upon which the part is being built.
2. To ensure that any small distortions of the platform will not lead to problems during part building.
3. To provide a simple means of removing the part from the platform upon its completion.
4. To prevent bending, curling due to shrinkage.
5. To support the built-feature wherever necessary.

Design of the support structure need to take into consideration the orientation of the part, overhang features, ensuring safe part removal, etc. Support can be generated automatically or manually on the available software in some RP systems.

3.2.6Slicing

Both the part and support must be sliced. During this step, the layer thickness, the intended building style, the cure depths, the desired hatch spacing, the line width compensation value, and the shrinkage compensation factor are selected.

The user can adjust the slice thickness. Thin slices create a smoother and more accurate surface, but require more time to process, both at the slice computer and during the SLA building process.

Sloping surfaces that proceed along the axis will be layered and have a distinct 'stair-step' appearance. The height of each step is the layer thickness used in that portion of the part.

3.2.7Merge

In this step, the supports, the part as well as any additional supports and parts have their computer representations merged.

3.2.8Scaling to Compensate the shrinkage

Scaling adjustment in rapid prototyping equipment affords the advantage of being able to dynamically adjust the boundary locations to account for shrinkage that occurs during the build process. The goal is to scale the shape so that final part is correct.

3.3Build Prototype Model

Some process build the part under certain temperature environment. So it may need cool down time after processing before removal. Postprocessing are part cleaning, drying, posturing and surface finishing, etc.

IV- CLASSIFICATION OF RAPID PROTOTYPING TECHNOLOGIES

Nowadays, more than 30 different processes (not all commercialized) with high accuracy and a large choice of materials exist. These processes are classified in different ways: by material used, by energy used, by lighting of photopolymers, or by typical application range. All RP systems can be easily categorized into

(1) Liquid-based systems: 3D system's stereolithography Apparatus (SLA); Cubital's solid ground curing (SGC); Sony's solid creation system (SCS); EOS's stereos systems

(2) Solid-based systems: Helisys's Laminated Object Manufacturing (LOM); Stratasys' Fused Deposition Modeling (FDM); KIRA's Selective Adhesive and Hot Press (SAHP); 3D System's Multi-Jet-Modeling System (MJM); Sander Prototype Inc's Model Maker MM-6B

(3) Powder-based systems: DTM's Selective Laser Sintering (SLS); Soligen's Direct Shell Production Casting (DSPC); EOS's EOSINT Systems; BPM Technology's Ballistic Particle Manufacturing (BPM); MIT's 3-Dimensional Printing (3DP)

In our paper we only mention three recently essential technologies that are SLA, SCS and SLS technology.

4.1 3D systems' stereolithography Apparatus (SLA)

STL file can be exported from the available CAD systems after the design is finished. The SLA format is transferred to and analyzed by the SLA systems computer which generally divides the computer-generated model into horizontal slices with a thickness depending upon the degree of resolution required. An elevator platform is precisely positioned below the liquid resin surface at a distance equal to the desired thickness of the slice to be formed. Then starting with the lowest slice of the object on the surface of the liquid resin. The slice adheres to the elevator platform and the elevator is then lowered slightly to submerge the cured layer in liquid resin and then raised precisely so that a thin layer of resin covers the cured surface. The next slice of the object is created on the liquid surface by another exposure to the laser beam. The second slice adheres to the top of the first slice and the process is then repeated with the third and successive layers of the object. In this manner the entire solid object is built on the elevator, slice by slice. (see figure 4.1)

Table 4.1 3D Systems' product and its specifications

Model	SLA-190	SLA-250	SLA-350	SLA-500
Laser	HeCd	HeCd	Solid State ND: YVO_4	Argon Ion
Laser Power (mW)	7.5	16	160	132-264
Spot size (mm)	0.2-0.29	0.2-0.29	0.25±0.025	0.2-0.25
XY Scan Speed (m/s)	0.762	0.762	5	5
Evelator vertical Resolution	0.0025	0.0025	0.0018	0.0018
Vat capacity (litre)	-	29.5	99.3	253.6
Work Volume XYZ (mmxmmxmm)	190x190x250	250x250x250	350x350x400	508x508x584
Minimum Layer thixkness (mm)	0.1	0.1	0.05	0.1
Size of Unit, XYZ (mmxmmxmm)	0.7x102x106	0.7x1.2x1.6	1x1x2	1.8x1.2x2
Approximate Price	70,000$	100,000-170,000$	380,000$	490,000$

4.2 Sony Solid Creation System, SCS

The system utilizes the stereolithography process and create a 3D solid model by UV laser curing polymer layer by layer subsequently. Slicing process in SCS software using 3D data from the CAD system. Slicing can be done both ON or OFF line. The SCS software consists of two parts: the slice data generator, which uses inputs from various CAD systems and creates slices and the editing software for slice data which includes the automatic support generation software. (see Figure 4.2)

Table 4.2 Solid Creation Systems Specification (Source: Sony Corporation

	SCS-1000HD	JSC-2000	JSC-3000
Laser	He-Cd/Argon	Ar Laser	
Modulating device	High Speed Modulator		
Deflector device	Galvanometer system (focus by sweep)		
Object Drawing range (mm)	300x300x300	500x500x500	1000x800x500
Spot size (mm)	0.05-3.0	0.15 or less	0.3 or less
Vertical position indicator	0.001 mm		
Tank Capacity (liters)	60	210	420
Temperature Control	Up to 50°C		
Data Control Unit			SONY NEWS Workstation
Dimension of main unit (m)	0.38x0.35x1.55	1.65x1.4x1.8	1.9x1.55x2.5
Power Supply	AC 100V-10A	AC 200V (3 phases)	
Approximate Price	40 million $	40 million $	80 million $

4.3 DTM's Selective Laser Sintering Process (SLS)

4.3.1 Principle

The University of Texas at Austin developed a method for sintering powder materials. Instead of a liquid polymer, powders of different materials are spread over a platform by a roller. A laser sinters selected areas causing the particles to melt and then solidify. There is only one phase transition, in sintering there are two: from solid to fluid, back to solid again. The materials being used or investigated include plastics, wax, metals and coated ceramics. (see Figure 4.3)

Briefly, the SLS process creates three-dimensional objects, layer by layer, from powdered materials with heat generated by a CO_2 laser within the Sinterstation 2000 System. First, your three-dimensional CAD data must be in the industry standard *.STL format. Then process is follow:

- As the SLS process begins, a thin layer of the heat-fusible power is deposited onto the part-building cylinder within a process chamber.
- An initial cross section of the object under fabrication is selectively "drawn" on the layer of powder by a heat generating CO_2 laser. The intensity of the laser beam is modulated to melt the powder only in areas defined by object's design geometry.
- An additional layer of powder is deposited via a roller mechanism on top of the previously scanned layer.
- The process is repeated, with each layer fusing to the layer below it. Successive layers of powder are deposited and the process is repeated until the part is complete. After processing, the part is removed from the build chamber and the loose powder falls away.

SLS parts may then required some post-processing, such as sanding, depending upon your application. Compared to other process, however, this post-processing is minimal.

4.3.2 Material used and its applications

• Wax: a standard investment casting wax used by foundries world wide.

• Polycarbonate: a standard engineering thermoplastic used to create concept and functional models and prototypes, durable investment casting patterns for metal prototypes and cast tooling (with the Rapid Casting (TM) process), masters for duplication processes and sand casting patterns.

• Nylon: it is a standard engineering thermoplastic. It is used to create models and prototypes that can withstand and perform in demanding environments.

• Fine nylon: it is a standard engineering thermoplastic. It is used to create fine-featured parts for working prototypes

• Metal: It is steel/copper matrix material with a thermoplastic binder. It is used with DTM's RapidTool (TM) process on the standard Sinterstation 2000 System platform; used to create mould cavity and score inserts for prototype tooling. It's characteristics exhibits material properties that exceed those of 7075 aluminum; when used for RapidTool moulds, it can produce more than 50,000 parts.

V IMPLEMENTATION

5.1 CAD process

We apply to implement the CAD model in form of Solid model. Because a Solid model can be defined as a geometric representation of bounded volume. This volume is represented graphically, via curves and surfaces, as well as nongraphically through a topological tree structure which provides a logical relationship that is inherent only with solid models'.

To verify the design with RP the existing surface model of ***an upper half of telephone*** was selected and it was modified to be a solid model using the available CAD software in AIT (Asian Institute of Technology) with version Unigraphics 11.0. The model was a plastic moulding part and composed of freeform surfaces. (see Figure 5.1, Figure 5.2)

Existing Model Specification

Number of sheet body : 28

Part overall size, XYZ : 170mm x 57mm x 13.6mm

CAD software : Unigraphics Version 11.0 in AIT

Existing model part file size : 3035186 Bytes

5.2 To make the STL file

The STL file format interface specification was defined by 3D systems. It has become the defacto standard file format for the RP&M industry. The STL file is consists of STL Binary and ASCII format file.

- **STL model**

In Unigraphics II CAD software, it is available to export STL file both text and binary formats. The Unigraphics geometry must reside in positive coordinate space in the current WCS (Word Coordinate System) before using this interface. The coordinate or the output triangle vertices as found in the operating system output file are relative to the WCS.

- **Properties of STL model**

STL model can be viewed visually on **Magics View** software and checked the properties as shown in Table 5.2. It depends on the accuracy of the required model that we select the triangulation tolerance of the model. The binary STL model with 0.05mm triangulation tolerance here was chose to build the 3D physical model using RP machines.

Table 5.2 Properties of STL model

Triangulation Tolerance (mm)	Format	File size (bytes)	No. of Triangle	X	Y	Z	Gaps	Volume (mm^3)
0.05	ASCII		39844	169.9999	57.000	13.909	1	23211
0.05	BINARY		39836	169.9999	57.000	13.909	0	23212

VI PART BUILDING

The Binary STL file was used to build RP models. In this study we select The Stereolithography Model and the Selective Laser Sintering (SLS) Model were chosen to build the RP models.

6.1 Stereolithography Model

Stereolithography model was built using SONY Solid Creator JSC-2000 System in National University of Singapore and that machine can fabricate models up to 500x500mm in size.

SLA part building process includes as following steps: 1- Check STL file on Solid Creation System (SCS) software; 2- STL file transfer to the machine computer; 3- Support structure preparation and slicing; 4- Part fabrication on the machine layer by layer; 5- Part removal; 6- Part cleaning and washing in alcohol; 7- Post curing in the UV oven; 8- Surface finishing.

In this study the STL file was sent directly from Unigraphics software in Asian Institute of Technology, Bangkok-Thailand to the SONY Solid Creator JSC-2000 System in National University of Singapore.

The results of implementation were shown in figure 6.1.1 to figure 6.1.5 respectively.

6.2 Selective Laser Sintering (SLS) Model

Selective laser sintering model was built using Sinterstation 2000 available in German-Singapore Institute.

The process includes as following steps: 1- Design the model on the CAD system, create STL file, and transfer it to the Sinterstation 2000 system computer; 2- Prepare the STL files and a build packet using the Sinterstation 2000 software; 3- Preheating the build chamber; 4- Build parts in the process chamber; 5- Cool down the building chamber; 6- Part removal and cleaning; 7- Dipping in the water base polymer; 8- Drying; 9- Surface finishing.

The results of implementation were shown in figure 6.2 respectively.

VIIRESULTS, CONCLUSIONS AND RECOMMENDATIONS

7.1Results of Implementation

SLA Model: **SLS Model:**

Estimated time total: 17hours Estimated time total : 32hours

Weight of the Model: 30.45gam Weight of the Model : 34.14gam

Price of resin : US$1333.3/kg Price of resin : US$958/15kg

Material Cost : US$4.06 Material Cost : US$2.18

7.2Conclusions

The accuracy of the prototypes resulted as the expected value within 0.1 to 0.2mm after comparing the sizes between the CAD model and the real part model on CMM (Coordinate Measurement Machine) in AIT. From this study, the following conclusions can be made:

1. CAD software is a key in the Rapid Prototyping Process to creates good STL file of the model. Since the input data to the RP machine is generally STL model.

2. STL model's properties depend on its tolerances in the transforming from CAD file in Unigraphics (*.prt format file). The gaps, file sizes, number of triangles, dimensions and volume of the STL model depend on its tolerances.

3. For very complex part that the conventional machining method is not able to produce, RP technology is a better one.

4. The advantages of the Rapid Prototyping Technology are: No tooling preparation time, no fixture cost, reduce design iteration time by utilizing the simultaneous engineering, able to build the extremely complex model.

5. In the design iteration stage, SLS process is an excellent one.

6. For the optimized model with high accuracy, complexity and detail model then SLA process is one to be selected.

7.3Recommendations for further Study

Even though RP technology can produce the model within the short period of time in compare with the conventional method, there are some limitations on the accuracy, materials used and work volume and the machine price is relatively high to invest for the application area. The following works should be done:

1. Development of new RP materials: model cost, accuracy, toxicity, curing time and mechanical properties depend on the material used.

2. Development of laser device: the machine price on some processes depends on the laser technology.

3. Development of producing Rapid EDM (Electrode Discharge Machine) electrodes: using RP technology, useful complex electrodes that can not be produced by traditional method may be produced using advanced materials.

4. The comparison with RP and high speed milling machine for the particular application.

KỸ THUẬT TẠO MẪU NHANH – MỘT KHÁI NIỆM MỚI TRONG CHẾ TẠO MÁY

Bùi Trí Sỹ – Bành Tiến Long – L.J. Bohez

TÓM TẮT : Kỹ thuật tạo mẩu nhanh hay còn gọi là kỹ thuật đồ họa in hình nổi khuôn mẩu là một khái niệm mới mẻ trong lãnh vực chế tạo máy hiện nay mà nó có thể tạo ra vật thể thật không gian 3 chiều trực tiếp từ dử liệu không gian 3 chiều của mô hình CAD với thời gian ngắn. Trong quá trình thiết kế cơ khí, Kỹ thuật này góp phần tiết kiệm đáng kể thời gian và chi phí thiết kế. So sánh với phương pháp gia công cơ khí cổ điển công nghệ này có nhiều ưu điểm như không cần chuẩn bị dụng cụ cắt gọt, không tốn tiền đồ gá, giảm thời gian sửa đổi thiết kế lại chi tiết, có thể thiết kế những chi tiết có hình dáng phức tạp mà khi gia công trên máy điều khiển chương trình số dể bị phế phẩm do lẹm dao, cũng như có thể áp dụng khái niệm phối hợp chế tạo dùng máy tính bằng việc sử dụng mạng máy tính tại bất kỳ nơi nào trên thế giới hiện nay.
Nâng cao các tiêu chuẩn thiết kế và rút ngắn chu kỳ tuổi thọ của sản phẩm tạo nên những yêu cầu mới của sự phát triển sản phẩm mới. Việc sử dụng Kỹ thuật tạo mẩu nhanh là sự lựa chọn tối ưu để đạt được chất lượng mong muốn và nâng cao năng suất trong việc thiết kế sản phẩm.
Độ chính xác, giá thành, bề mặt sản phẩm cuối cùng và vật liệu sử dụng thì khác biệt giửa quá trình này với quá trình khác. Ra đời vào năm 1997, Kỹ thuật tạo mẩu nhanh đang tồn tại hơn 30 công nghệ khác nhau.
Bài báo này là bước khởi thủy trong việc phát triển một phương pháp dùng trợ giúp trong thực tế chọn lựa công nghệ tối ưu nhất cho vấn đề tạo mẩu đặc biệt. Một khuôn mẩu dùng trong máy ép nhựa được thiết kế dùng làm mô hình cho kiểm chứng. Sau đó khuôn mẩu này sẽ được chế tạo bằng nhiều công nghệ tạo mẩu khác nhau như SLA, SLS , một khuôn mẩu bằng Silicon và nhựa thông của một nửa trên chi tiết điện thoại cầm tay được chế tạo. Sau cùng việc đánh giá toàn bộ quá trình thực hiện bằng việc phân tích độ chính xác, thời gian gia công và giá thành sản phẩm của từng công nghệ tạo mẩu nhanh.

TÀI LIỆU THAM KHẢO.

1. Chua Chee Kai and Leong Kah Fai, 1997. *Rapid Prototyping: Principle and Applications in Manufacturing*. John Willey & Sons, Inc.

2. Dickens, P M, 1995. *Research Development in Rapid Prototyping*. I Mech E publishing.

3. Donahue, R. J. and Tunner, R. S., 1991. *CAD Modeling and Alternative Methods for Information Transfer for Rapid Prototyping Systems*. Second International Conference on Rapid Prototyping, University of Dayton, Conference Proceedings, pp. 221-232.

4. Georges M. Fadel and Chuck Kirschman, 19955. *Accuracy issues in CAD to RP translations.* MCP University Press.

5. Herbon, KY and Austin, TX, Mike Durham, Todd Grimm, 1996. *SLS and SLA: Different Technology for Different Applications.* Accelerated Technologies, Inc.

6. John Wright Editor, 1997. *Rapid Prototyping Leads to Rapid Products.* Electronic Data Systems (EDS).

7. Leonead Loh, Teddy Ong and David Wong, 1997. Injection Mould Insert Fabrication Using Rapid Tool Process. *Automation and Manufacturing,* MEN, May/Jun.

8. Meng Mo Zhen, 1996. *A Computer Aided Design Methodology for Plastic Injection Mold Design,* M. Eng. Thesis, Asian Institute of Technology.

9. Paul f. Jacobs, Ph. D., 1992. *Rapid Prototyping & Manufacturing, Fundamentals of StereoLithography.* SME publishing.

10. Paul f. Jacobs, Ph. D., 1996. *Stereolithography and other RP & M Technologies, from Rapid Prototyping to Rapid Tooling.* SME publishing.

11. Vendaraman Sriaman, 1996. Rapid Prototyping and the IE page. *IM* May/June, 12-16.

12. 3D Systems Co. Annual Report. USA, Dec. 1996.

13. CAD/CAM Publishing, Inc. Rapid Prototyping Report. USA, Jan 1997, p.4.

14. "The Sinterstation 2000 system, Selective Laser Sintering. Guide to materials. Optimization and Understanding the process", DTM corporation, ABF Goodrich Company, 1996.

15. "Selective laser sintering", Hensinki University of Technology, Jul, 1994."

16. "Stereolithography", Helsinki University of Technology, Jul, 1994.

17. "MIT – Three Dimensional Printing", IIT Research Institute, March 1993.