DEPARTMENT OF MECHANICAL ENGINEERING

Lecture Notes on

ADDITIVE MANUFACTURING PROCESSES.

6TH Semester MECHANICAL ENGG.

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Module I

- Introduction: Definition of GMP and Rapid Prototyping
- Types of prototype, need for the compression in product development,
- Survey of applications,
- Issues related to GMP,
- Classifications of RP systems.

Stereolithography Systems:

- Principle,
- Process parameter,
- Process details,
- Data preparation,
- Data files and machine details,
- Physical layer model development,
- Applications.

1. Introduction

The importance of manufacturing is now recognized by all sections of our society. It influences the GNP, international trade and employment. In India the manufacturing scenario is undergoing major changes due to two reasons- revolutionary advancements in technology and opening up the economy to the world. This will force our industries to be more competitive. It is expected that there will be substantial changes in the manufacturing industries of our country. So, awareness regarding the trends of development in manufacturing is essential. A number of revolutionary concepts have emerged in the recent years. The most significant and the newest among them being Rapid Prototyping——a technology which has the potential of directly converting the CAD (computer aided design) data into the real object which has been the ultimate dream of the manufacturing technologists. This monograph is intended to provide a rudimentary introduction to the subject which is expected to play a major role in manufacturing in the coming century.

Manufacturing Processes: Recent Developments

Manufacturing processes could be classified into three major classes-(i) forming processes, (ii) removal processes and (iii) joining processes. In forming type of processes, the required amount of work material is given the required shape by 'deformation'. This deformation can be a plastic deformation of the solid work material or the required shape is given to the liquid work material as in casting and injection moulding. In removal processes, the required shape and size are obtained by removing the excess material from the workpiece (whose original volume is obviously more than that of the required object). Such removal type of process is called machining. The forming processes are generally used in the primary stages of manufacturing. In many cases the material has to undergo secondary processes like machining to achieve the final result. Machining is very often the secondary process and is needed to provide the final result. This is usually needed because of the following reasons:

(i) The finish and accuracy acquired by parts produced by machining are much better than by other processes.

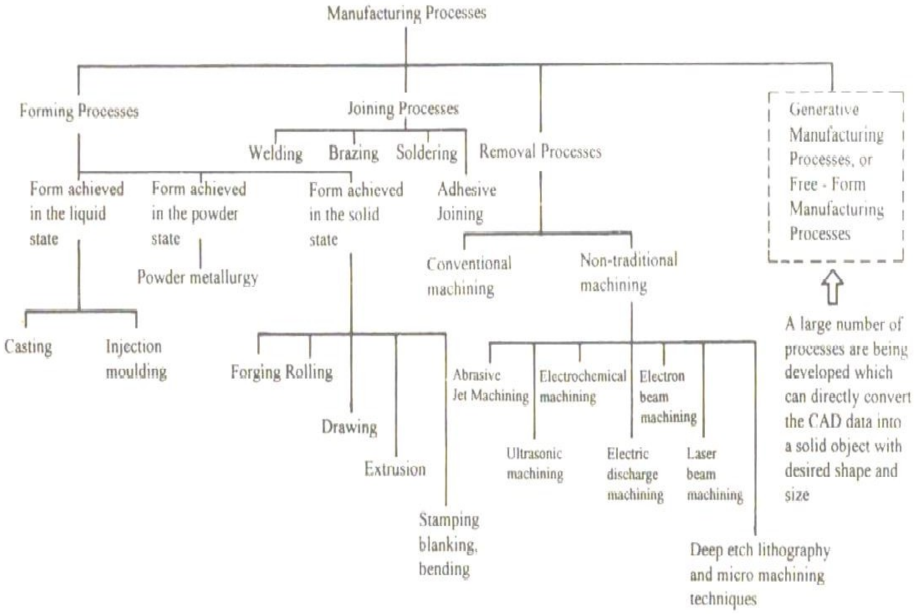
(ii) A higher degree of geometric complexity can be imparted to the work.

(iii) Force and power involved in machining are independent of the overall work size.

(iv) Bulk material properties of the workpiece are not affected by machining.

Joining processes like welding, brazing etc., are primarily used for fabrication and are not of much relevance for shaping of objects.

A fundamentally new concept in shaping of objects has emerged in the recent past and a fourth group can now be added to the previous three classes of manufacturing processes. They are the 'material increase' or 'material grow' or 'material incress'[1] manufacturing processes. In these recently developed processes the final object is obtained by either gradual addition of material (like construction of buildings) or by gradual binding or solidification of material according to requirements. This development is considered to be as important as the emergence of numerical control machine tools in the fifties and the development of non-traditional machining processes (ultrasonic machining, electrochemical machining, electric discharge machining, electron beam and laser beam machining etc.) in the sixties and seventies. Since the development of these processes based on gradual build up by material addition (or by gradual solidification, binding etc.) is still going on the terminologies have not stabilized. Researchers have used different names to identify this class of processes. In this book we will use the term 'generative manufacturing processes' (GMP), as all these processes are based on gradual generation of the overall shape. This group is considered by many to be the ultimate development in manufacturing, as these processes represent 'free-form' manufacturing without the need of any tool, die or mould. When fully developed these processes will be capable of directly generating parts from computerized data - the ultimate dream of the manufacturing engineers. Figure shows the different classes of manufacturing processes.



All the processes are divided into four groups of which joining processes involve joining different components to realize a final part. The three others are classified according to the primary characteristics of shape generation (i.e. by material conservation, by material removal and by material addition). Further subdivision of each group, shown in the tree diagram, is self- explanatory. Figure below indicates the product development cycle and the prototypes for different stages. In the early stages of product development a 'design model' and a 'geometric prototype' are prepared. The 'design model' is made primarily to decide the overall appearance and it is used for er- gonomic analysis. Some early market analysis is also carried out using this model. Since there is no functional requirement these models are easy to process; non-metallic materials can be used for making these models. On the other hand in 'geometric prototypes' the dimensional features of the product, accuracy and tolerances are of primary importance. These prototypes are also made of model making materials as functional aspects are of secondary importance. These prototypes are used primarily for process planning. Usually two to five 'functional prototypes' are prepared to ensure the functional principle and optimize the functional parameters. Appearance and many geometric features are not considered at this stage. In these prototypes, of course, some of the materials used can be same as those intended in the final product. But still there is no one to one correspondence with the final product so far as the materials are concerned. In the next step three to twenty 'technical prototypes' are made using the same material and the same manufacturing processes as the intended final product. The technical prototypes are useful in assessing various product qualities like reliability, product life etc. After the necessary final modifications the 'first series' of the product (usually up to 500) is manufactured and marketed.

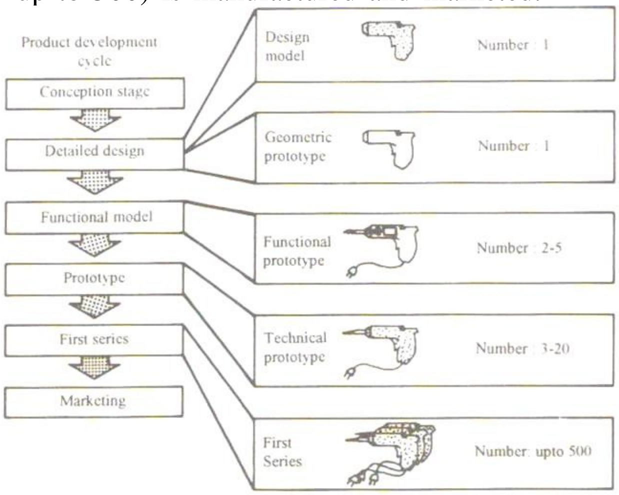
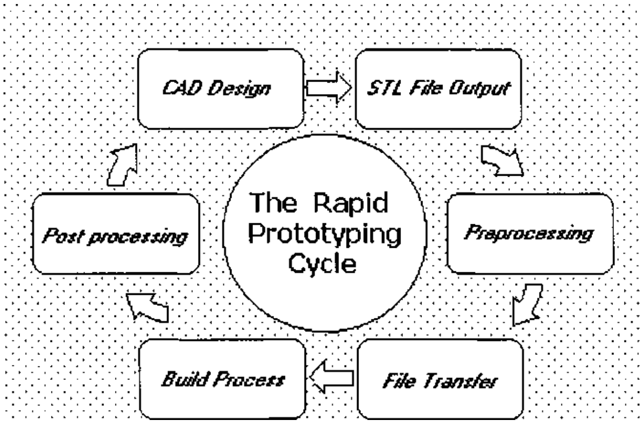


Fig 1.1 Types of prototypes at different stages of product development

Rapid Prototyping

Though the principle of CE is quite clear and the advantages of the concept for improved quality and reduced cost are implicit it is not possible to incorporate CE effectively in the absence of some technique for quick development of prototypes. To reduce the development time and adopt concurrent engineering in its true spirit, quick and inexpensive fabrication of prototype parts is essential and 'rapid prototyping (RP)' technology has made that possible. By rapid prototyping processes a solid object with prescribed shape, dimension and finish can be directly produced from the CAD based geometric model data stored in a computer without human interventions. Conventional methods for producing parts (e.g., casting, forming, machining, etc.,) are not suitable for this purpose and a host of new processes for shaping objects directly from the CAD data have been developed during the last decade. Some of these processes are well developed and machines are in the market. Some RP techniques are in the stage of research and development and have not yet been marketed.



The RP cycle begins with the CAD design, and may be repeated inexpensively several times until a model of the desired characteristics is produced.

Rapid prototyping can be of two types. The part obtained by RP technology can form the prototype directly, without requiring any further processing. Else the parts obtained by RP technology can be used to make moulds for casting the prototype components. The second type is needed because till today, the commercially available RP machines use non-metallic materials with low strength and low melting temperature. Research to develop RP technology which will be able to deliver metallic components that may be directly used for making the functional prototype is being actively pursued. Since the technology is very recent the terminologies used in this area have considerable variation and it will take some time to stabilize. In the previous chapter we have used the term 'generative manufacturing processes (GMP)' for the processes used to produce solid parts from CAD data directly. Among the other names given to the group of these processes, the prominent ones are ‘free- form manufacturing processes’, ‘material incress manufacturing’, ‘material grow manufacturing’. In all generative manufacturing processes, the shape of the workpiece is not obtained by removal of chips or forming, or casting. It is achieved by addition of material without any prior recognizable form or shape and no tool is necessary.

In all types of GMP’s, the CAD model is split into layers as indicated in Figure 1.2. The slice thickness and the slicing direction can be varied for convenience of generation. To generate an object of the same shape as that of the sliced CAD model, the distance between the slicing planes (t) must be equal to the thickness of the corresponding layers during the actual generation process.

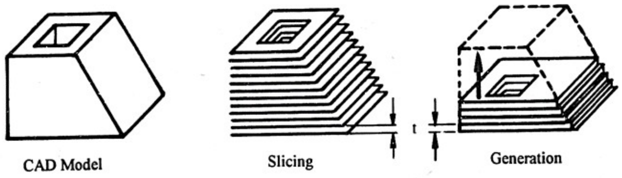
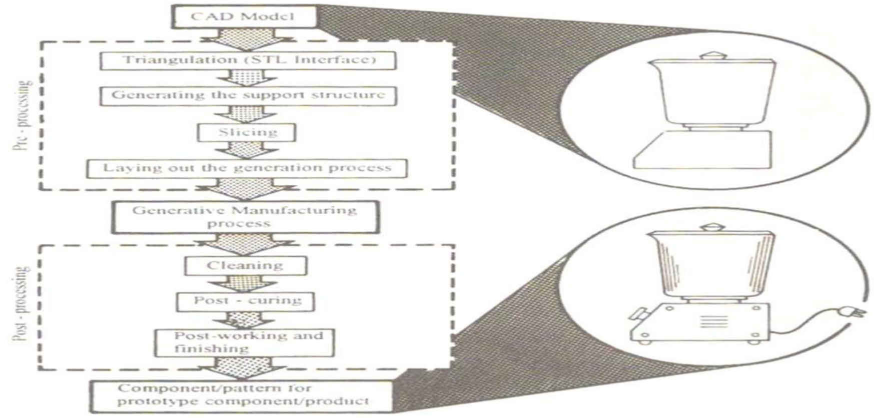


Fig. 1.2 Basic principle of the generative manufacturing processes

Different manufacturing processes have been developed for the generation of the solid object. The general procedure for obtaining a solid component from a CAD file is shown in Figure 1.3.



Steps involve in RP

Till now in all the commercially developed and technically demonstrated methods of GMP's, the development of the part is done by the slicing technique. However, a direct 3-dimensional building up technique is also under serious consideration. In this technique it will not be necessary to define the part in terms of thin layers, and the process will not require the generation of the lower parts before the upper part is generated. Thus, the freedom and flexibility in shape creation are enhanced, but it puts a great burden on programming the generating equipment. In the next chapter more detailed discussion on this technique will be presented. Figure 1.4 shows the whole process chain of rapid product development using RP technology. The conventional as well as new procedures for beginning the design work are indicated at the start of the whole process. Even though CAD is an essential feature in most modern manufacturing industries, many aspects of the classical technology for design are still useful and still play an important role in design. However, as mentioned earlier, CAD data are converted to the required prototype components. Only on some rare occasions can the part produced by RP technology be directly used as the prototype. In most cases such objects are used as the patterns for making the prototype with the help of various processes commonly grouped under the heading 'follow up technology'. Once the prototypes are studied and evaluated, modifications in the design are suggested. Some minor modifications may be incorporated manually, but in general a redesign is carried out by 'reverse engineering' of the functional and technical prototypes. The data obtained from this operation is fed to the CAD database and a new CAD design is arrived at. This then becomes the starting point of the next iteration cycle. Once an acceptable prototype is arrived at, it undergoes quality and reliability

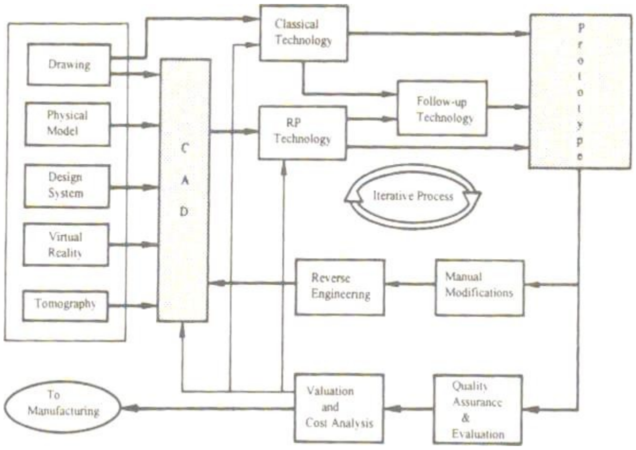


Figure 1.4: Process chain for rapid prototype development

analysis, valuation and cost analysis. Even at this stage some less drastic modifications may be necessary and there may be one more iteration cycle before the design is frozen. It emerges from the previous discussion that the key element in making such an iterative design procedure technically and economically feasible is the successful conversion of CAD data into a solid object. Thus, the generative manufacturing processes are of great importance. The next chapter presents the basic schemes and the technological aspects of the GMP's developed so far.

General Features and Classification of GMP or RP

The generative manufacturing processes represent a major breakthrough in manufacturing. In fact, the GMP's do not fit in with the basic concepts of manufacturing processes which have remained prevalent since the beginning of the history of technology. One important aspect which makes these processes so eminently suitable for the future is its basic nature being so amenable to computer control. The conventional processes did not develop with the basic aim of using computers for controlling the processes and consequently the introduction of flexible automation has remained plagued with serious difficulties. On the other hand, GMP's do not face many of the traditional problems because these processes 'create' material where it is needed. At present, the materials used for these processes are mostly non-metallic and do not possess the requisite amount of density and strength needed for functional purposes. Hence these techniques of part production are employed primarily for prototyping. However, the ongoing research indicates that in the near future it may be possible to produce actual parts made of materials suitable for functional components. Hence, the day is not far off when these processes will make desktop manufacturing possible and the ultimate dream of the manufacturing technologists will be realized. Table 3.1 presents the major advantages of these processes as compared to the conventional methods of manufacturing.

A large number of techniques and machines have already been developed in the area of GMP and, therefore, classification/grouping of these processes will be used in presenting the descriptions in a structured format. Classification of these processes can be done from two perspectives - (i) the way material is created/solidified and (ii) the way the shape is generated. A number of processes are still in the R&D stage and some are only in the conceptual stage. The state of the material[1] used for shape production by a GMP can be (i) liquid, (ii) solid or (iii) powder. Table 1.2 shows the different possibilities and the processes classified according to the state of the raw material.

Table 1.1: Advantages of the generative manufacturing processes

Task/ Activity	Nature of advantage
Design	1. Need for feature based design is eliminated. A three-dimensional surface or solid model is adequate. 2. Manufacturing process is quite independent of the part features and, so, there is no need for conversion from design to manufacturing features.
Planning	There is no need to define a blank geometry as no blanks are required. Minimum operation or process planning. GMP's are based on one operation only. No complicated scheduling and routing problem. The part is made in one set up.
Tooling/Jig-Fixtures	1. GMP's are tool-less processes and the whole complex tasks of tool selection and tool management are not needed. 2. No clamping required. Complex jigs and fixtures are also eliminated. 3. Mould dies and tool design, die design are eliminated.
Automation	1. Introduction of flexible automation is very convenient as the whole shape generation process is generalized in character. 2. The shape generation is done using a computer and interfacing the manufacturing unit with the whole system is very simple.

The beginning of GMP's started with liquid photopolymers, and even today the processes based on liquid polymers are most well developed and more numerous. For reasons already stated earlier the processes based on solid material (like the conventional and unconventional removal type processes - i.e., machining processes) are very few and are limited to thin foils only. Process classification based on the techniques in which the shapes are generated is shown in Table 1.3. Development of three-dimensional objects can be done either by direct three- dimensional technique or by depositing layer upon layer. Layers can be either developed as an agglomeration of points and lines gradually or the full layer be created simultaneously. When shape building is done by solidification of a liquid polymer, two- dimensional layer-by-layer technique is appropriate. In this approach all lower layers have to be created as the next layer has to be deposited on top of it. Though it is conceptually possible for a layer to be solidified in one go as a single layer, most processes create a solid layer by scanning and solidifying it in a point-by-point or line-by-line manner. Direct three-dimensional techniques do not require creation of the lower layers first, and therefore, grant more flexibility in shape creation. However, the burden on programming the unit is more. In direct three-dimensional techniques, a whole surface can be created in one go as a layer or it can be produced in a point-by-point or line-by-line manner.

Table 1.2: Classification of the GMPs/RP based on the state of raw material

State of material	Type	Mechanism	Energy type	Energy source	Process
Liquid	Photo-polymers	Liquid photo-polymerization	Monochromatic light	Lamp	Solid ground curing (SGC)
				Laser beam	Stereolithography (STL)
				Holography	Holographic interference solid (HIS)
			Light(two frequencies)	Two laser beams	Beam interference solidification (BIS)
	Thermo	Liquid thermal	Heat	Laser beam	Thermal stereolithography (TSTL)
	Non-metals	Melting and solidification	Heat	Heated nozzle	Fused deposition modelling (FDM)
					Ballistic particle manufacturing (BPM)
	Metals	Melting and solidification	Heat	Electric arc	Shape melting
				Laser beam	Fused deposition modelling (FDM)
				Electrochemical discharge	Fused deposition modelling (FDM)

Table 1.2: Classification of the GMPs/RP based on the state of raw material (continued)

State of material	Type	Mechanism	Energy type	Energy source	Process
Solid	Thin sheets and foils	Selective gluing and cutting	Adhesive bonding and	Glue and laser beam	Laminated Object manufacturing (LOM)
	Semi-polymerized plastic foils	Foil polymerization	Light	Lamp	Solid foil polymerization (SFP)
Powder	Single component	Selective sintering	Heat	laser beam	Selective laser sintering (SLS)
	Coated powder	Selective sintering	Heat	laser beam	Selective laser sintering (SLS)
	One component and one binder	Selective powder binding	Chemical bond	Fine droplet beam of binder liquid	3D-printing or, MIT process, or, selective powder binding (SPB)

Table: 1.3 classification of GMP/RP based on shape building approach

Development of soild object	Basic element of creation	Nature of connectivity	Processes
Two-dimensional layer-by-layer technique	Point	Discrete	• Stereolithography • Thermal polymerization • Foil polymerization • Selective laser sintering • Selective powder binding • Ballistic particle manufacturing
		Continuous	• Stereolithography • Fused deposition modelling • Shape melting
	Layer	——	• Laminated object manufacturing • Solid ground curing • Repetitive masking dnd depositing
Direct	Point	Discrete	• Beam interference solidification

three-dimensional technique			- Ballistic particle manufacturing
		Continuous	- Fused deposition modelling - Shape melting
	Surface	—	- Holographic interference solidification
	Volume	—	- Programmable moulding

Issues Related to CAD and GMP Software

Modelling

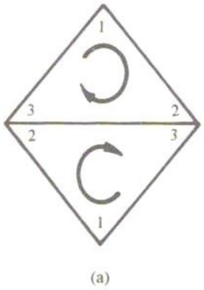
Since the generation of a part using any GMP is primarily a conversion of CAD data to the real object the computer representation and its accuracy are of significance. Most RP systems receive their data from CAD systems in either 3D surface models or 3D solid models. RP systems require data in a particular format. Since the 3D Systems Inc., who first marketed a GMP based on Stereolithography (STL), developed an STL file forrat, and such machines far outnumber all other types of machines, the STL format has become the de facto standard for all RP technologies. This system is based upon creating a mesh of connected 3D triangles (actually triangular laminae oriented three-dimensionally) whose vertices are ordered to in dicate which side of the triangle contains material and needs to be created in the process. Figure 1.5 indicates how triangles can be used to create surfaces and objects. Of course, the number of triangles has to be very much larger in an actual STL file for accurate representation of the object to be created. It is also important to keep the orientations of the vertices correct to represent which side of the triangle the material of the object exists. Figures 1.6 (a) and (b) show the correct and incorrect triangle orientations, respectively.

Figure 1.5: Representation of surfaces by connected triangles

The slicing of the CAD model is done by using a ray-tracing algorithm which scans through a particular z-level of the model. The resulting cross-section would be one or more closed paths and a complete representation of the area filled with material. Cross-hatching algorithms create paths for quick development of the material (either by solidification or by deposition). The orientation of the object has to be judiciously chosen for optimization of the process time and accuracy. The software needed for slicing and generation of data to control the GMP system movements is not a general one and depends on the specific GMP system. The new file (SLI) pilots the movements of the processing unit. Figure 1.7 indicates the pre-processing of data diagrammatically.

The resolution of the CAD model depends on the accuracy desired i.e. the maximum deviation of the desired surface from the chords generated in the CAD model. Allowing smaller deviation makes the model more accurate, but the STL file size increases which leads to increased slice time and slice file size. Scaling the part geometry to take care of shrinkage (which is an unavoidable phenomenon in Stereolithography and a number of other GMP’s) can be accomplished in the RP software.

The smallest feature size depends on the specific process used for RP. In processes where a laser beam is used (either for curing or for sintering or cutting) the beam diameter plays a crucial role in deciding this. It is usually in the range 0.175 mm to 0.3 mm.



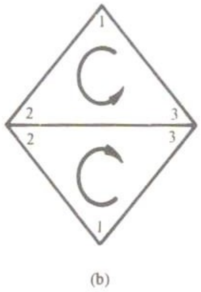


Figure 1.6: Correct and incorrect orientations of adjacent triangles

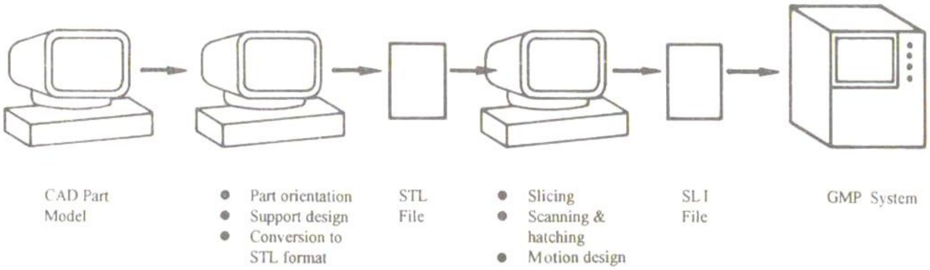


Figure 1.7: Pre-processing of CAD data

Choice of part orientation is important as the orientation within the processing chamber influences the build time, part resolution and surface finish. Higher resolutions can be obtained in curved surfaces by orienting them in the horizontal plane (normal to the direction of layer deposition). Figures 1.8(a) and (b) show clearly how the 'stair-step' appearance can be avoided by a proper choice of orientation. In cases where formation of curved surfaces in the direction of layer deposition is unavoidable multiple layer thickness within a building cycle is feasible. Surfaces with large slants should be developed by using thinner layers to reduce the 'stair-step' effect. The orientation can also affect the trapped volume in case of liquid-based GMP's. The trapped volume is represented by that space which holds liquid that is completely separate from the liquid in the main vat. Figure 1.9 shows how a correct choice of orientation can eliminate (or reduce) the problem.

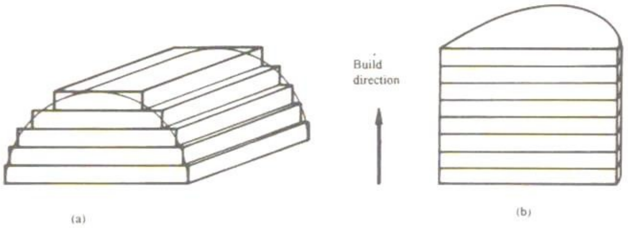


Figure 1.8: Effect of orientation on accuracy and finish

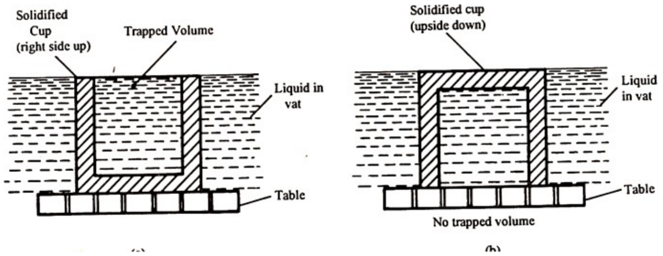


Fig. 1.9: effect of part orientation on trapped volume.

Slicing

The slice programme converts the three-dimensional object in the STL file into two-dimensional cross- sections. The slice axis is defined as the normal to the plane created by slicing and this is also the build direction while creating the part by GMP. The thickness of slice dictates the texture, accuracy and build time. The layer thickness is normally in the range 0.0625 mm to 0.75 mm. It is, however, not correct to assume that using thicker layers (and reducing the number of layers) leads to reduced build time in all cases. In many processes the speed of scanning of the activating element (laser beam in many processes) depends greatly on the layer thickness. So, the time required for creating individual layers increases greatly when large thickness is used. Figure 1.10 shows the typical characteristics of how the build time changes when the layer thickness is gradually increased for three different power levels of the beam used. It is seen that the range 0.125 mm to 0.25 mm is the optimum irrespective of the beam power.

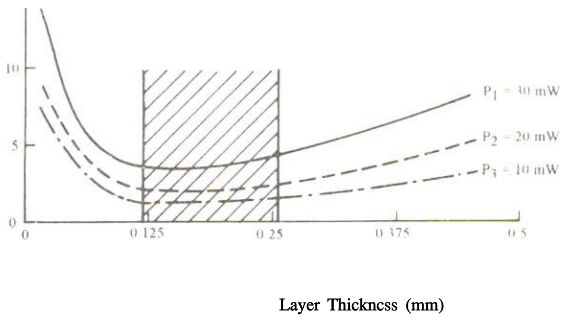
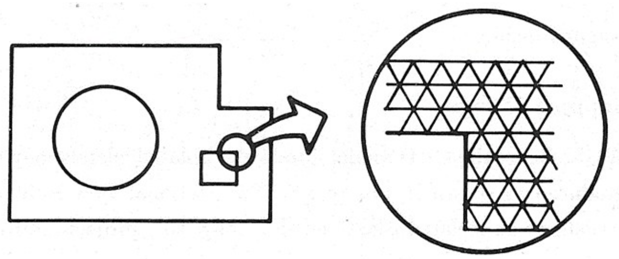


Figure 1.10: Effect of layer thickness on build time

Internal Hatching and Surface Skin Fills



To solidify (or to create) the area inside the part surrounded by the outer boundaries, internal hatching is used to reduce build time. Initially the boundary lines are created and then the interior is criss-crossed with lines, giving the part adequate internal stiffness. The style of hatching can vary. The pattern may consist of parallel lines making 0°, 60° and 120° with the x-axis resulting in an internal structure which consists of equilateral triangles as indicated in Figure 1.11. The spacing between the consecutive lines is about 0.625 mm, and this common hatching pattern is called Tri-Hatch. When liquid photopolymers are used in the process, the material trapped inside the triangles remains liquid till the part is post cured following the completion of the shaping process. Recently, a new pattern has been introduced which is called WEAVE™. In this, the scanning lines are parallel to the x- and y-axis, the spacing being about 0.28 mm when the layer thickness is about 0.25 mm. When the layer thickness is 0.127 mm, the spacing is made to be 0.229 mm. In the Tri-Hatch system too much (« 50%) liquid material remains trapped and this leads to considerable post curing distortion. Attempts to reduce the fraction of trapped volume in the Tri-Hatch system by reducing the hatch spacing lead to increased curl distortion. With the WEAVE™ system, a reduction of the fraction of trapped residual volume without resulting in large curl distortion is possible.

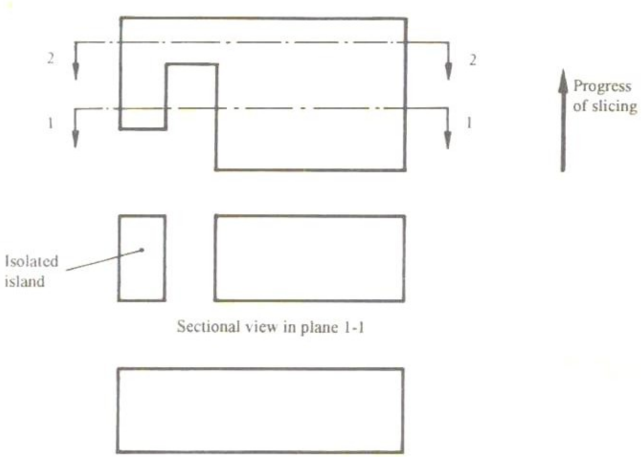
Figure 1.11: Tri-Hatch pattern

It is obvious that the outer surfaces of the generated solid cannot end up being porous. Thus, skins are created by skin fills which consist of closely spaced scan lines. The spacing between the scan lines is in the range 0.0762 mm to 0.127 mm. The skin fills are scanned after the borders and internal hatch. However, with the introduction of WEAVE™ the importance of skin fill has been greatly reduced since very little residual liquid remains trapped inside.

1.4. 5. Support Design

While slicing the CAD model into layers isolated islands may be produced as shown in Figure

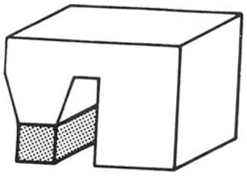
1.12. The sectional view in plane 1-1 shows an isolated island which belongs to a projection from



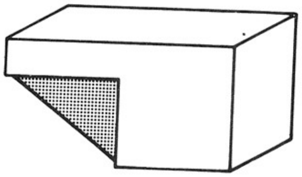
Sectional view in plane 2-2

Figure 1.12: Formation of isolated islands

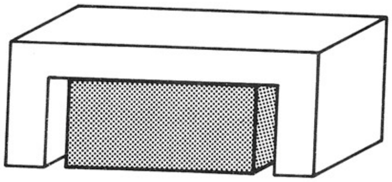
the main object. The connection of the projection to the parent body is from the top and while generating the shape by a GMP it will be built later. Thus it becomes essential to de sign a support for the isolated islands to prevent their fall under gravity, as they are created if the process is liquid- based like Stereolithography. When the whole object is formed the extra supports are removed. Due to similar reasons, supports are essential for long cantilevered projections also. Though isolated islands are not formed, the thickness of the projection may be too thin to support the weight of the cantilever. Thus, supports in a GMP system are analogous to job holding devices for conventional machining. In addition to preventing the fall of isolated islands, supports are generally provided to hold the main part body also. In future suitable materials for GMP may be developed to eliminate the need of supporting the main object. At present supports are essential to hold the material during operation even if the component is devoid of cantilevers and projections. Figure 1.13 shows different types of supports.



Island



Gussets



Ceiling

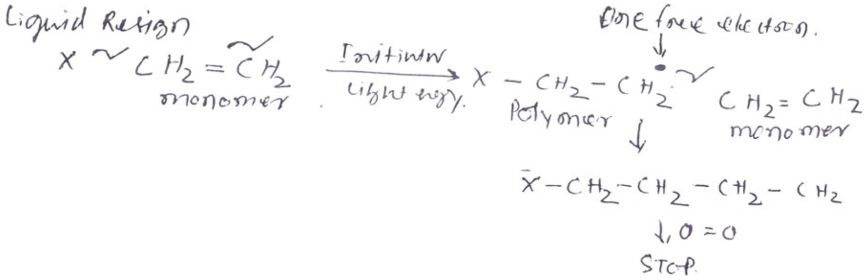
1.13: Various types of Supports

2. **Stereolithography (SL) with Photopolymerization**

This is the first GMP developed, and one of the most commonly used and the most investigated one. Stereolithography machines use curing of a liquid photopolymer (or monomer) by an ultraviolet laser beam, point-by-point or line-by-line. The Chemistry behind photo polymer.

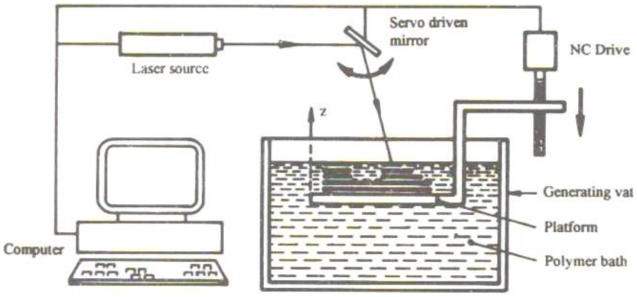
Photo-Polymer Chemistry

Photo-Polymerization is basically a light based process. It requires three chemical components: a monomer, a photo-initiator and a reaction terminator. The mor and the photo-initiator are mixed in the initial liquid resin. The terminator normally comes from the oxygen in atmosphere. Impact of light activator the photo-initiator, which is decomposed in radicals having free electors. Those radicals react with a monomer chain to form a larger molecular chain still having a free electron, further reaction with monomer molecules, lengthens the chain causing polymerization to proceed. The reaction can be stopped by binding the free electron with an oxygen atom. As large as the light remains the formation of radicals will super side the availability of free oxygen molecules in the liquid. As the light disappears, the lack of new radicals will leave free way to the oxygen to react with the remaining free electron and prohibit further polymerization. The presence of oxygen of the liquid's surface and its diffusion within the surface layer are thus essential for controlled solidification.

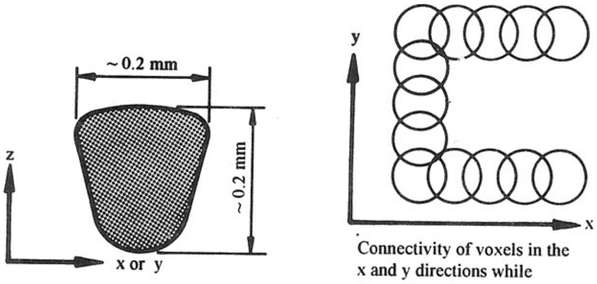


2.1 1. Process details

The basic unit is shown in Figure 2.1. The generating vat contains a UV sensitive liquid photopolymer. An elevator platform, which is driven vertically by an NC drive system, is initially positioned along the top surface of the liquid. A suitable UV laser beam is reflected on to the liquid surface with the help of mirrors mounted on a pair of orthogonally scanning galvanometers whose position is controlled by the computer. A computer controls the movement of the reflecting mirror so that the beam traces the required paths on the surface to generate the cross section of the first layer of the object (usually the support structure for the real object). The interaction of the beam with the liquid cures (and, thus, solidifies) the liquid by photopolymerization to a depth of a few tenths of a millimeter which is adjusted to be the thickness of a layer between two consecutive slices. Once the first layer is cured the platform is lowered by a distance equal to the thickness of a layer and the liquid is allowed to cover the generated layer. Then, the laser beam scans the next cross section. The cycle is repeated till the topmost layer of the object is generated. Subsequently the generated object is removed from the vat and ultrasonic cleaning removes excess material from crevices and openings. An alcohol bath is used to clean any unused polymer. The process of post curing is carried out by applying intense long wave UV radiation to solidify an uncured liquid trapped in the honeycomb like structure. In most stereolithography machines solidification occurs in a point-by-point fashion. In some cases, solidification takes place curing lines at a time. A laser beam scans the liquid surface so that a series of voxels (volume picture cells) get solidified as shown in Figure 1.2(a). The voxel size should be adequate to ensure connection with the neighboring voxels (Figure 4.2(b)) and also with the layer solidified prior to the current one (Figure 4.2c). When a low power laser is employed, voxel formation is obtained by a point-to-point NC control of the mirror that causes the laser beam to stop at each voxel point. The beam is not switched off in between voxels. The traversing speed being high, polymerization during the traversing period between two consecutive voxels does not occur. High power lasers require shutting off of the laser between two voxels. The parameters which control the voxel overlap are the distance between voxels, the laser power, the stay time and the layer thickness.



2.1 Scheme of stereolithography (SL)



A single voxel

(a)

Connectivity of voxels in the x and y directions while generating a layer

(b)

Connectivity of adjacent layers

(c)

1.2 Generations of line and layers using voxcals

1.1.2 Laser-induced polymerization

A locally limited polymerization can be started by one of the two processes:

Reproduction of entire layer by a smaller scale mask with the aid of a powerful ultraviolet light source.

Exposure to an ultraviolet laser beam, which “writes” the desired contours into the resin surface by means of certain scanning strategies.

Although there are also processes that work with masks, laser Stereolithography is the most important with respect to industrial implementation.

In the following passage some specialities are discussed which result from the use of laser- radiation sources for photo-polymerization.

1.Depth of the Cure Track:

The local degree of polymerization and the rate of polymerization depend on the number of photons that pass through a certain activation cross section of the resin, thereby potentially reacting with the initiators.

From a critical surface energy (critical energy) onward so many photons react with the resin that it is transformed from a liquid to a solid state. This transformation point is called the gel point. At first the resin does not have any mechanical stability; only after the surface energy is increased the resin sufficiently polymerized to cary mechanical strain. The boundary surface inside the resin between the solid and liquid state is formed by that surface in which the surface energy exactly corresponds with the critical energy.

For the surface energy irradiated on average onto the resin surface (z=0), which is also the maximum energy affecting the resin surface, the following applies:

$$E_{max} = \frac{P_L}{v_s \cdot h_s} \qquad (1)$$

With E_{max}= Surface energy on the surface at z = 0

P_L = average laser-performance

v_s = speed of the laser beam

h_s = hatch width

The absorption within the resin follows the Beer-Lambert equation:

$$E(z) = E_{max} \, .\exp\left(-\frac{z}{D_p}\right) \qquad (2)$$

With $E(z)$ = Surface energy in depth z.

E_{max}= Surface energy on the surface at z = 0

D_p = optical penetration depth of the resin.

The optical penetration depth D_p of a material is defined as the path lenth after which the intensity of a transmitted beam has dropped to the 1/e-fold part, or its energy to the $1/e^2$-fold part.

With the aid of the Beer-Lambert equation and the definition of critical energy E_c the cure depth C_d, down to which the resin is cured, is given as.

$$C_d = z(E_c) = D_p \, .\ln\left(\frac{E_{max}}{E_c}\right) \qquad (3)$$

With the first relationship between the laser performance and energy on the surface it follows:

$$C_d = D_p \,.\ln\left(\frac{P_L}{\mathrm{v}_s \,.\, \mathrm{h}_s \,.\, E_c}\right) \tag{3a}$$

As C_d is proportional to the logarithm of E_{max}, a straight line results if logarithm representation is employed. The gradient of the straight line is defined by the value of D_p. The critical energy density, at which the cure depth is zero, is defined by the intersection of the straight line with the abscissa. As the curve is dependent only on the resin constant and is also called a working curve (Figure 1).

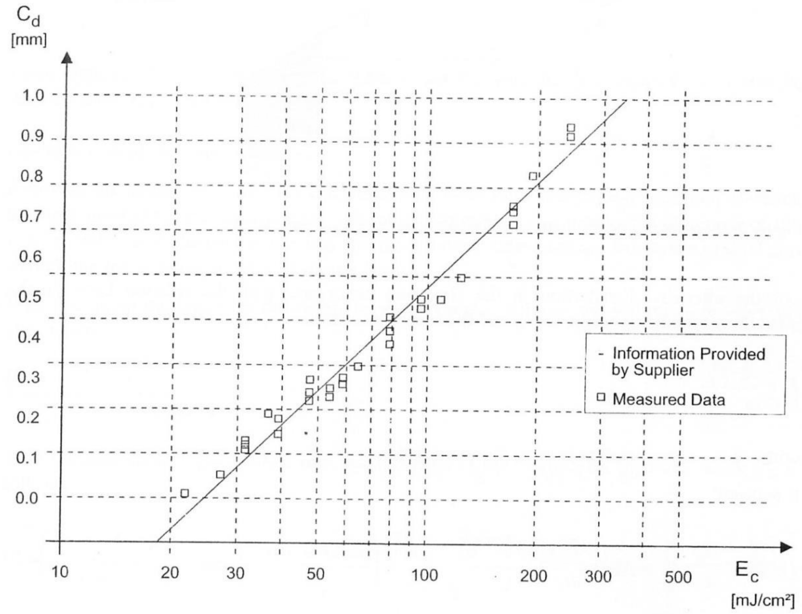


Figure 1: Curve depth as a function of the surface energy and the resin parameters, working curve for the resin HS 660.

Given the resin parameters E_c, D_p and a constant laser performance P_L the cure depth of the resin can be established on the basis of the speed of laser.

Counter of the Curve Track

In addition to the cure depth, the width and the shape of the curved track are significant. This calculation cannot be based on an average surface energy; the energy distribution of the Gaussian beam must be taken into account. For this purpose a system of coordinates is fixed with its x-axis in the direction of laser speed vector and its z-axis in the direction of the beam. The surface fixed by the x-axis and the y-axis coincides with the resin surface. A cutting plane is laid through the zero point onto which the counter of the cure track is to be calculated. The distance between the midpoint of beam and a point Q on the cutting plane is called r (Figure 2).

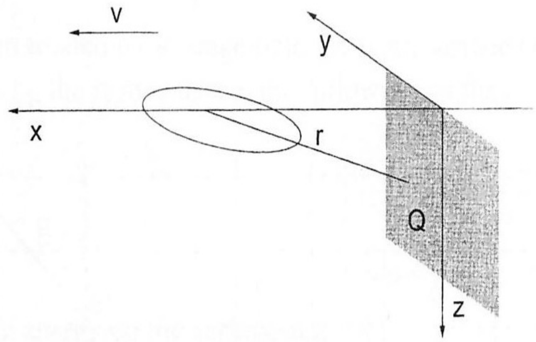


Figure 2: System of coordinates for calculation of track geometry.

For the intensity distribution in the Gaussian beam and with the relation between the intensity in the beam midpoint I_0 and the laser performance P_L at a Gaussian beam.

$$I_0 = \frac{2 \,.\, P_L}{\pi \,.\, \omega_0} \qquad (4)$$

With 0 = beam radius on the resin surface. It

follows:

$$I(r,0) = \frac{2 \,.\, P_L}{\pi \,.\, \omega_0} \,.\, \exp\left(\frac{-2 \,.\, r^2}{\omega_0^2}\right) \qquad (5)$$

The surface energy at a specific point on the section (y, z = 0), over which a laser beam runs with the intensity $I(r,0)$, equals the temporal integration over intensity. By replacing I_0 according to equation (4) the surface energy on the resin surface results.the periphery is to be found exactly

where E(y, z) equals the critical energy E_c. By equating $E(y^*, z^*) = E_c$ and transforming, we

arrive at the following equation:

$$\left(\frac{2}{\omega_0^2}\right) . y^{*2} + \left(\frac{1}{D_P}\right) . z^* = \ln\left[\sqrt{\frac{2}{\pi}} \,.\, \left(\frac{P_L}{v_s \,.\, \omega_0 \,.\, E_c}\right)\right] \qquad (6)$$

Equation (6) is the definition of parabola. The cure track therefore has the geometry of a parabolic cylinder as shown in Figure 3.

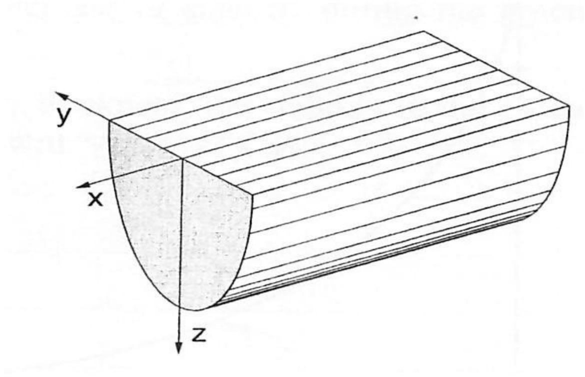


Figure 3: Parabolic shape of the curve track under the influence of a Gaussian-beam on a photo- polymer.

Optimization of the layer thickness

Knowing the geometry of the cure track enables a layer thickness to be determined in which the time needed for curing a certain volume is minimal. For a reasonable coverage of the volume with parabolic cure tracks it is assumed that the cure track has a distance of 0.02 mm to both the lower layer and the adjoining layer.

With d as layer thickness for the curing time of a certain volume, the following proportionality results:

$$\sim \frac{1}{v_S \,.\, d\,(L_W + 0.02\ mm)}$$

T (7)

With the cure depth C_d = d — 0.02 mm and insertion of the relation for the track width L_w it follows:

$$T \sim \left\{ d \,.\, \sqrt{\frac{2}{\pi} \,.\, \frac{P_L}{\omega_0 \,.\, E_c} \,.\, exp\left(-\frac{d-0.02\ mm}{D_P}\right)} \,.\, \left[\frac{\omega_0}{\sqrt{2}} \,.\, \sqrt{\frac{d-0.02\ mm}{D_P}} + 0.02\ mm \right] \right\}^{-1} \quad (8)$$

The minimum of the function is d = 0.3706 mm for an assumed optical penetration depth

D_p =

0.25 mm. As only proportionalities were investigated there are no resulting absolute values for the ordinate.

The penetration depth D_p of 0.2 to 0.3 mm of different resins lies within the technically sensible dimension of 0.1 to 0.5 mm. if deeper layers are required, the surface energy needs to be increased, which simultaneously lowers the scan speed. Therefore, attempts are being made to produce resins that have a greater penetration depth. As shown in the following subsection, the alteration of the penetration depth also influences the stability of the components.

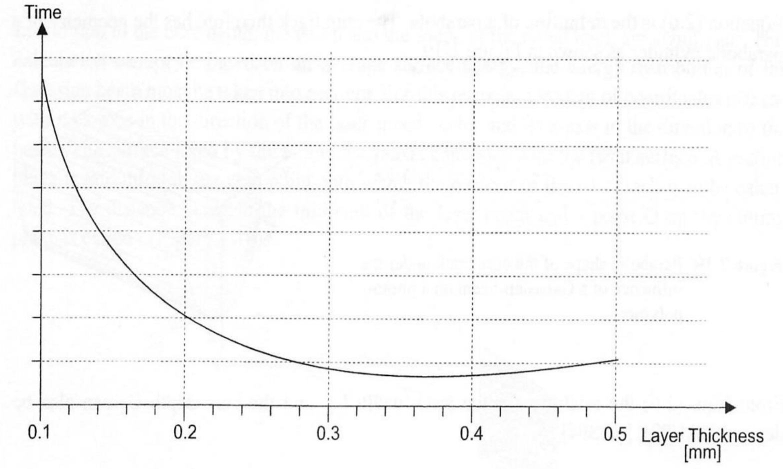


Figure 4: The time needed for curing in relation to layer

If resins with a greater optical penetration depth are used it should be taken into account especially in combination with higher powered lasers — that leakage radiation can result far more easily in undesired polymerization than previously and thereby have a negative influence on the accuracy of the components and above all on the aging of the resin.

Effect of the penetration depth and stability of the component

By increasing the penetration depth D_p of the resin with a constant cure depth C_d the required surface energy on the surface of the resin is lowered. Accordingly, fewer photons are absorbed and the rate of polymerization decreases, which results in less stability of the component. The relevant value excess energy E_x is introduced here. This is a measure for the amount of energy available for the polymerization in addition to E_c. a useful definition for E_x is given in equation (9).

$$E_s = \left(\frac{1}{C_d}\right) . \int_0^{C_d} (E(z) - E_c) \, .dz \qquad (9)$$

After implementing equation (2) it follows that

$$\frac{E_x}{E_c} = \left(\frac{D_p}{C_d}\right) . \left[\exp\left(\frac{D_p}{C_d}\right) - 1\right] - 1$$

(10)

This function is illustrated graphically

The following fundamental relationships derive from equation (10) and Figure 5:

The excess energy is directly proportional to the critical energy E_c. a reduction of E_c to achieve shorter build times will result in a direct decrease of stability during the green phase.

By reducing the penetration depth or raising the layer thickness, the stability in the green state is increased. The defect is especially prominent with values of $C_d/D_p > 3$.

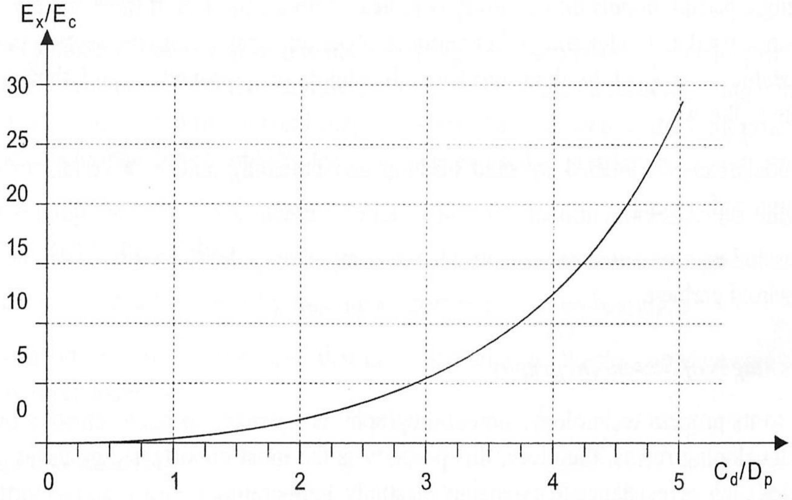


Figure 5: Excess energy relative to the curve depth and the optical penetration.

The fundamental relationships discussed are valid for all photopolymerization processes, especially for laser-supported Stereolithography processes.

Advantages of Stereolithography

Stereolithography, also known as stereography, is at present the most accurate of all rapid prototyping construction processes. Its accuracy is limited by the machine, but not by physical limits. For example, the minimal depictable land widths are in principle a function a function of the laser beam diameter. The tenuity of the z-stepping is not limited by the process. It is limited by the wettability of a solid layer by the following liquid monometer layer, expressed as the relationship of volume force (proportional to the layer thickness) and the surface tension. Thin layers consequently tend to “rip”. These physical obstacles can be overcome if the layer thickness is limited by solids such as glass plates rather than a free surface.

It is in principle possible to contour the boundary of the x-y planes in the z-direction by appropriate control (five-axis) and exposure strategies (variation of pulse-pause relationship and laser performance) and thus to achieve a quasi-continual z-modelling. Stereolithography not only allows the production of internal hollow spaces, as do nearly all the other rapid prototyping process, but also permits their complete evaluation as a result of the process technology. For this a drainage opening I necessary this should be clearly much smaller than the diameter of the hollow space. Together with the further advantage of the materials being transparent or opaque, these facilities the visual judgement of internal hollow spaces as is, for example, necessary for medicinal use (e.g., mandible, mandibular nerve channel). Complex model, or those of larger dimensions than the build chamber, can be assembled from single partial models into arbitrary complex complete models. If the same photosensitive resin is used as binder and UV radiation sources for local curing, the section points are unnoticeable in respect to their mechanical- technological properties and they are also invisible to the eye.

The model can be finished by sand blasting and polishing and, to a certain extent, by machining and coating. Non-cross linked monomers can be reused, and completely polymerized resin can be treated as household garbage.

Disadvantages of Stereolithography

Owing to its process technology, stereolithography is restricted to photosensitive material. When developing resins, therefore, this property is the most important. The usual primary properties such as resistance to extension, elasticity, temperature stability, and so forth are of secondary importance. Further, material development is limited to stereolithographic usage and in view of the costs apportion able to the product it is correlated only with this market.

Stereolithography is in principle a two-stepped process in which the models are first solidified to a high percentage (> 95%) in the actual stereolithography machine; afterwards the finished model is placed into an oven to build up further crosslinkages until it is cured completely (this does not apply to printing processes or mask processes, SGC).

The green product must be cleaned with solvent (TMP, isopropanol). This requires the storage, handling, and disposal of solvents and is another time — consuming process. When making stereolithography models unsupported structures and certain critical angles of over-lapping model parts cannot be realized without support, as during its generation in the resin bath the model is still a relatively soft green product. On the one hand these supportive structures need to be fitted when the model making is in preparation, and on the other hand they have to be removed manually from the green product or from the cured model.

To a small extend, photosensitive acrylates absorb oxygen, whereas epoxy resins are hydroscopic; this has to be taken into account when storing and processing the material. The models tend to creep even after being completely cured. After a few days or weeks unsupported walls show saggings that disappear if the model is turned over or supported. The newest epoxy resins show these characteristics less prominently.

MODULE II

- Selective laser sintering
    Type of machine Principle
    of operation Process
    parameters
    Data preparation for SLS
    Applications
- Fusion Deposition Modeling
    Principle
    Process parameter Path
    generation Applications
- Solid ground curing
    Principle of operation
    Machine details
    Applications
- Laminated Objective Manufacturing
    Principle
    LOM materials Process
    details Application

Selective Laser Sintering

History of Selective Laser Sintering

The Selective Laser Sintering (SLS) process was developed by The University of Texas in Austin, and was commercialized by DTM, Corporation out of Austin, TX in 1987 with support from B.F. Goodrich. Since DTM is now essentially a subsidiary of B.F. Goodrich, the company has a strong parent to help absorb any financial burdens that may be incurred. The first SLS system was shipped in 1992, and there are currently several systems in use worldwide.

Selective Laser Sintering Technology

SLS is a rapid prototyping (RP) process that builds models from a wide variety of materials using an additive fabrication method. The build media for SLS comes in powder form, which is fused together by a powerful carbon dioxide laser to form the final product. SLS currently has 10 different build materials that can be used within the same machine for a wide variety of applications. The SLS technology is housed in the Sinterstation line of systems by DTM. The current model is the Sinterstation 2500, which has various improvements over its predecessor, the Sinterstation 2000. Figure 11.1 shows the Sinterstation 2500. The SLS process begins, like most other RP processes, with the standard .STL CAD file format, which is exported now by most 3D CAD packages. The DTMView software can import one or several .STL files, and allows you to orient or scale the parts as you see necessary. The 2500 systems have "auto- nesting" capabilities, which will place multiple parts optimally in the build chamber for the best processing speed and results. Once the .STL files are placed and processing parameters are set, the models are built directly from the file.

Figure 1.1 The DTM Sinterstation 2500 (Courtesy of DTM Corp.).

The Sinterstations have a build piston in the center and a feed piston on either side. The models are built up in layers like other RP processes, so the build piston (15" X 13" x 16.7") will begin at the top of its range, and will lower in increments of the set layer size (0.003" through 0.012") as the parts are grown. With the build piston at the top, a thin layer of powder is spread across the build area by a roller/sweeper from one of the feed pistons. The laser then cures in a raster sweep motion the cross-sectional area of the parts being built. The part piston then lowers, more powder is deposited, and the process continues until all of the parts are built. Figure 11.2 shows the SLS system process chamber.

When the build media is removed from the machine, it is essentially a cake of powder with the parts nested inside. This cake is taken to the Break Out Station (BOS) table, where the excess powder is removed from the parts manually with brushes and hobby picks. The BOS has a built- in air handler unit to filter any airborne dust particles from the area, so no respiratory equipment is needed. Also, the BOS has a sock tube that attaches to a sieve on the table and to a powder canister underneath, so that the excess powder being removed from the parts can be kept for recycling and reuse.

At this point, some materials will require additional finishing, whereas others will be in end-use form. Some finishing techniques include glass-bead grit blasting (equipment can be purchased from DTM with the Sinterstation unit); sanding and polishing; drilling and tapping; and coating or infiltration.

Excess powder from each build for most materials can be recycled through a Vorti-Sieve for reuse in the system, therefore practically no material is wasted on support structures or the like.

Figure 11.2 The SLS build chamber (Courtesy of DTM Corp.).

Purpose of Selective Laser Sintering

The SLS technology was developed, like other RP technologies, to provide a prototyping tool to decrease the time and cost of the design to product cycle. The strong point of the SLS process is that it can use a wide variety of materials to accommodate multiple applications throughout the manufacturing process. SLS was marketed early with three main applications: conceptual models, functional prototypes, and pattern masters. Since then they have added

on an extra module, which incorporates rapid tooling.

Since the Sinterstation products are high end and require a large amount of up-front capital, the market range they targeted were large manufacturing industries with the capability to handle such specifications. DTM was looking to provide a cost-effective alternative for prototyping to these larger industries that spend millions of dollars to develop mass-produced products.

Current State of Selective Laser Sintering

The SLS technology currently has a high-quality product in the Sinterstation line, with their three main advantages being a wide range of build materials, high throughput capability, and the selfsupporting build envelope. These advantages make the Sinterstation products better suited for industries with a wide range of needs and a demand for higher output. The main disadvantages lie in initial cost of system; peripherals and facility requirements; and maintenance and operation costs of the systems.

Advantages

Wide Range of Build Materials

The SLS technology currently employs 10 main build materials, which were previously grouped for sale into 3 central modules. Any or all of the build materials can now be purchased for use in the same Sinterstation machine, without requiring separate licenses. The modules are described as follows.

1. *The Casting Module.* The casting module include 5 different materials. All of the materials in the casting module are obviously directed at the metal casting/foundry industry, from investment shell casting to conventional sand casting. These materials are *Polycarbonate, TrueForm, CastForm, and SandForm Zr II & Si.*

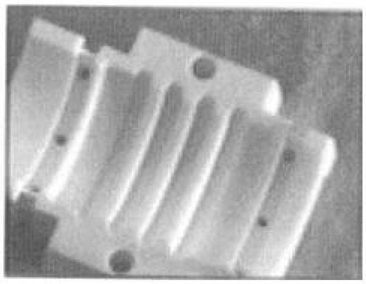


Figure 1.3 Polycarbonate material for the SLS system (Courtesy ofDTMCorp.).

Polycarbonate was one of the original SLS casting pattern materials, but has now been discontinued from use. It is a fairly porous material, which allows for easy burnout from an investment shell for casting and a low 0.025% ash residue. The minimum feature size and wall thickness for polycarbonate parts is around 0.060", due to the brittle nature of the material and a 0.010" accuracy capability. The polycarbonate does run at a higher oxygen level, ~ 5.3%, therefore less nitrogen is used in keeping the build chamber inert. The porosity of the material also allows for the infiltration of epoxies or other thermosets to have stronger models, but some of the other materials are better suited for direct applications. Figure 1.3 shows a Polycarbonate part.

TrueForm is an acrylic-styrene polymer that was released after the polycarbonate material as casting pattern media. It has about a 1 % ash residue on burnout, but can maintain a higher- dimensional accuracy, at 0.005", and can build thinner walls and features down to 0.030". The TrueForm has high feature and edge definition, and can therefore be used as secondary tooling patterns as well. Figure 1.4 shows a TrueForm part prior to removal from the SLS machine.

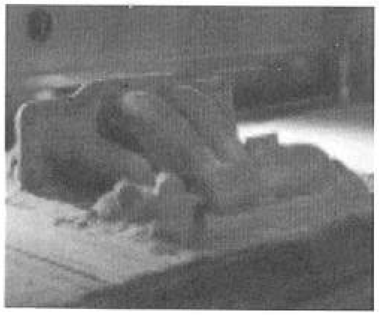


Figure 1.4 TrueForm material for the SLS system (Courtesy of DTM Corp.).

A new material in the casting module, and a successor to True Form, is called Cast Form. The Cast Form material is deemed to be more "foundry friendly" than even True Form, in that it requires less effort to burn out the pattern in the investment shell-firing process. Figure 11.5 shows a sample part fabricated from Cast Form.

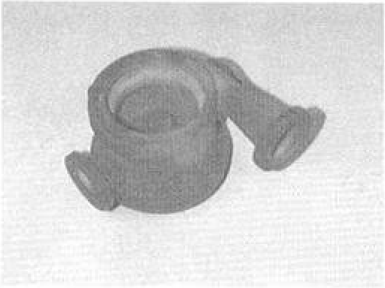


Figure 1.5 Sample casting pattern made with CastForm.

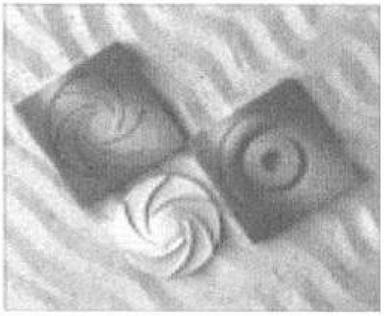


Figure 1.6 SandForm material for the SLS system (Courtesy of DTM Corp.).

SandForm Zr II and Si are direct Zircon and Silica foundry sands. They are for use as sand casting cores and molds and can maintain accuracy to 0.020". The sands can be used directly for casting, and provide the advantage of building complex cores that could not be produced using standard cope and drag techniques. Finally, the SandForm materials are compatible with both ferrous and aluminum casting processes. Figure 1.5 shows SandForm patterns.

2.The Functional Prototyping Module. The functional prototyping module consists of 5 different materials that are intended for direct-use applications as concept models, secondary tooling patterns, or functional hardware components. The materials licensed under the functional prototyping are *DuraForm, Nylon, Fine Nylon, ProtoForm, and Somos 201.*

DuraForm is a polyamide material recently released for creating highly detailed concept models. DuraForm has good surface quality, heat and chemical resistance, and can be polished for use in secondary tooling applications. Finally, it can be used to create features down to 0.030", and holds dimensional tolerances of 0.010". A DuraForm part is shown in Figure 1.7.

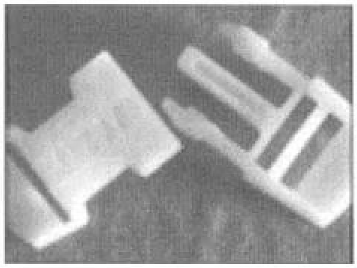


Figure 1.7 DuraForm material for the SLS system (Courtesy of DTM Corp.).

Nylon, Fine Nylon, and ProtoForm composite are the three nylon products used in the SLS process, that were essentially replaced by DuraForm. The nylons exhibit good toughness qualities, making them ideal for functional prototyping. The dimensional tolerance of the nylons is around 0.010", with a minimum feature size of 0.030". Finally, the ProtoForm composite, which is a glass-filled nylon, has strengths capable of withstanding high stresses in wind-tunnel type applications.

Somos 201 is a thermoplastic elastomer, marketed by DuPont, that has properties similar to some rubbers, which allows for flexible components (Shore A hardness = 81) to be directly rapid prototyped. This material is advantageous in applications such as seals, moldings and shoe soles where a functional flexible prototype is needed before expensive extrusion dies are created. The Somos 201 gets dimensional tolerances down to 0.010" and has elongation properties over 100%. Figure 1.8 shows a Somos 201 part.

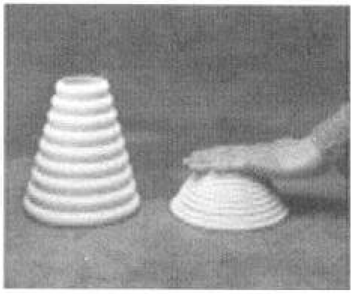


Figure 1.8 Somos 201 material for the SLS system (Courtesy of DTM Corp.).

2. The Rapid Tooling Module. The rapid tooling module currently consists of three materials, which are RapidSteel, Copper Polyamide, and LaserForm. As more innovative direct application materials are introduced they will become part of this module.

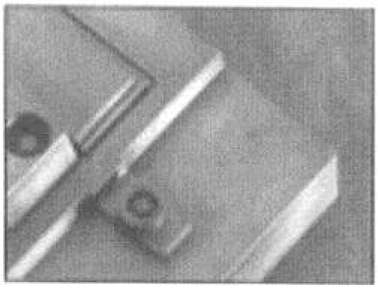


Figure 1.9 RapidSteel material for the SLS system (Courtesy of DTM Corp.).

RapidSteel is a polymer-coated 1080 carbon steel powder that is fused in the SLS process to create a green part. This green part must then be fired in a furnace to remove the polymer binder, and the porous steel part is infiltrated, or wicked, with copper to produce the final metal component. The final product has strength and hardness properties much like aluminum, therefore it can be used to produce short-run tooling for preproduction plasticinjection molding or similar applications. The quoted tolerance is 0.010", before the fire and infiltration steps occur, wherewith after tolerances can range up to 0.030". Figure 1.9 shows a RapidSteel part.

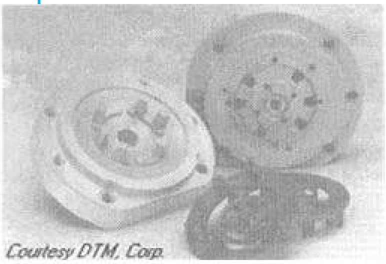


Figure 1.10 Copper Poly amide tooling inserts made with SLS process.

Copper Polyamide is a polymer-coated copper than can produce directly usable soft tooling without the postprocessing time and costs associated with RapidSteel. Unfortunately, strength and durability are sacrificed by going this route, so the application will ultimately choose with tooling material to use.

High Throughput Capability

The Sinterstation systems have high throughput capability compared to other RP machines due to several advantages. These capabilities will vary between the different build materials, but overall can be described as follows.

1. *Scanning Speed.* The scanning speed is essentially the velocity of the laser movement across the part surface while it fuses the build material together. Since the systems are equipped with a powerful 50 watt carbon dioxide laser, the scanning speed for most of the build materials is very fast, so that large-part cross sections can be scanned in seconds. This high rate allows for multiple parts to be built in a short turnaround time.
2. *3D Part Nesting*. Since the SLS process builds parts in a powder-bed media, multiple parts can be "nested" throughout the build chamber in all axes. This allows the user to maximize the build output by completely filling the build chamber side to side and top to bottom with parts if necessary. This way the start-up and shut-down time is reduced as it is divided among many parts instead of just those that would fit in the -x, -y build plane. A second advantage to this system is that each part can be built with separate parameters, i.e. laser power, and if trouble occurs with one part in a batch it can be terminated without affecting the rest of the build.

3. *Large Build Envelope.* In conjunction with the high scan speed and three-dimensional nesting capabilities, a large build envelope (15" X 13" x 16.7") provides for a high part throughput in that many small parts or several larger parts can be fabricated in a single build run.

Self-Supporting Build Envelope

To cap off the exclusive advantage of the Sinterstation systems, a self-supporting build envelope provides several key bonuses over other RP technologies. Not only are parts faster to complete due to the lack of postprocessing, but they also stand less of a chance of being damaged during mechanical- or chemical-support removal. Also, as mentioned earlier, this self-supporting powder bed also eliminates any waste materials, so that only the material needed to create the part is used and the rest is recycled for building more parts.

Disadvantages

Initial Cost of the System

The initial cost of the Sinterstation systems range from $250,000 to $380,000, depending on the options and peripherals acquired and excluding facility modifications.

Peripherals and Facility Requirements

There are various peripherals necessary for optimum operation of the Sinterstation systems, including a BOS Table; air handler and sifter; and a glass-bead blaster for finishing. Combined, these components take up about 30 square feet of floor space. In addition, a Hydrogen Lindbergh furnace for firing and infiltration of the metal parts is necessary for the rapid-tooling module, which requires special facility and safety requirements for operating gases and general maintenance. All of these systems have various facility requirements in addition to the hard- wired 240V/70A power requirements of the Sinterstation itself, which also requires a large amount of floor space on the order of 200 square feet. Finally, the Sinterstation weight combined is 6,275 pounds, which will require a sturdy floor to accommodate it.

Maintenance and Operation Costs

Since the Sinterstations are large and complex systems, the maintenance contracts currently run in the $35,000 annual range. Also, the powders must be properly stored and recycled for further use. The power consumption of the system and all its peripherals can be high and must be taken into account, along with the smaller costs of expendable inerting gases, build materials, and part finishing supplies.

Impact of the Technology

Although there are only a few hundred Sinterstation systems installed worldwide, the SLS process has had a significant impact on the prototype manufacturing industry.

Mainly due to the

wide range of build materials and higher output rates, the SLS systems have mainly been used in the RP job shop and production manufacturing arenas.

An impact directly on the RP industry was the release of the RapidSteel metal build material. Although it still has some drawbacks in that it is a multistep process that makes it much less "rapid," it was at least the first metal released for any RP system, which will more than likely lead to significant advances of this and other technologies in the future.

Interrelation with Other Technologies

The Sinterstation systems rank as one of the high-end RP systems due to the advantages listed previously. The part build times are on the average faster than many of the other systems, and thus the build times are used more effectively. The wide range of build materials is not seen in other RP systems as well, but there are disadvantages to deal with partially because of the advantages.

The capital investment for a Sinterstation 2500 system, as well as its large physical size and the extensive installation required are all characteristics not imposed by smaller RP systems. Also, the high cost of routine maintenance, expendable inerting gases used high electrical power usage can damper the effectiveness of the systems if they aren't used frequently and resourcefully. Otherwise, the network capabilities, ease of use and repeatability rank about the same as other RP systems used for similar applications.

Future of the Selective Laser Sintering Technology

The future of the SLS technology has high possibilities due to the robust systems designed from the start. With recent advances in powder metallurgy and ceramic powder technology, the SLS systems could be making quality ceramic and metallic hardware in the near future.

The first advancement will probably be in the metals realm, as DTM already has a head start with the RapidSteel system. Modifications to the RapidSteel, or alternative metallic powders that will result in fewer steps and more repeatability will provide a strong base for the future of SLS. The recent advent of LaserForm material may be the breakthrough the process is needing, as time will tell. Currently, several institutions and universities are vigorously working to evelop metal powders directly compatible with the SLS systems, and similar development is underway regarding ceramic powder sintering as well, so the horizon is looking pretty bright for the technology as a whole.

One interesting use of SLS in the future is the possible application of Sinterstations on lunar or Mars surfaces as manufacturing devices during and after colonization. Preliminary studies are underway with NASA using lunar simulant as a build material in a Sinterstation. The idea is that there would be an endless supply of build material (i.e., lunar dust) for fabricating parts as opposed to interplanetary shipping of building supplies.

System Update

Since the initial writing of this chapter, DTM Corp. has released the Sinterstation 25QQplus, which has optimized operating parameters over the 2500, along with a Windows NT® software platform.

Key Terms

Self-supporting envelope. A unique feature of powder-bed RP systems, the workpiece does not require physical supports to be constructed for overhanging surfaces. The uncured powder-bed acts as the support material for such features.

Multiple build materials. A strong feature of SLS technology, many different materials can be used in the same machine without hardware modifications. Three-dimensional part nesting. A bonus feature of powder-bed RP systems, parts can be placed in full three-dimensional space to optimize the per-part build time and postprocessing.

Fused Deposition Modeling

Fused deposition modeling (FDM) is an extrusion-based rapid prototyping (RP) process,

although it works on the same layer-by layer principle as other RP systems. Fused Deposition Modeling relies on the standard STL data file for input, and is capable of using multiple

materials in a build/support relationship . FDM was developed by Stratasys, Inc. of Eden Prairie, MN, in the early 1990s as a concept modeling device that is now used more for creating casting masters and direct-use prototyping.

Fused Deposition Modeling System Hardware

The FDM systems have evolved through several models, beginning with the original 3D Modeler, a floor unit, and progressing through the various "desktop units", including the 1500, 1600, 1650, 2000, 8000, and Quantum. Basically, the 1500 through 2000 models are capable of building parts in the 10" x 10" X 10" range, whereas the 8000 and the Quantum can build 24" x 20" x 24" parts. Figure 2.1 shows an FDM 2000.

Since the beginning of this writing, Stratasys has released the FDM 3000 system, which has a unique Water Soluble Support (WSS) material. The WSS allows for the construction of more complex geometry and internal structures. Complicated support structures that would have previously been difficult to remove can now be flush away with a water-based solution. The FDM 3000 system also offers a larger build envelope than the 1500 through 2000 systems.

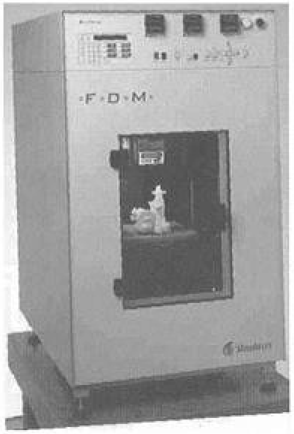


Figure 2.1 The Fused Deposition Modeler 2000 by Stratasys, Inc.

Software

All of the machines use the powerful QuickSlice (QS) software, manufactured by Stratasys and SDRC, to manipulate and prepare the incoming STL data for use in the FDM machines. The software can be operated on various types of workstations, from UNIX to PC based, and the modelers can either be operated directly from the workstation or by a "dummy" PC whose sole purpose is to free up time and space on the workstation.

Build Materials

The FDMs can be equipped to build with investment casting wax, acrylonitrile butadiene styrene (ABS) plastic, medical grade ABS thermoplastic, and/or Elastomer, although the ABS is currently used the most. The build and support materials come in filament form, about 0.070 inches in diameter and rolled up on spools. The spools mount on a spindle in the rear or side of the machine, and the filament feeds through a flexible tube attached to the back of the extrusion head. Figure 2.2 shows build material spools loaded on the FDM.

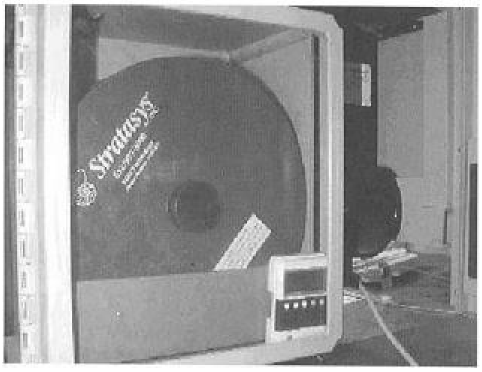


Figure 2.2 The build materials for FDM are stored on spools.

The Extrusion Head

The extrusion head is the key to FDM technology. The head is a compact, removable unit (good for materials changeover and maintenance), and consists of the following crucial components. Figure 8.3 is a schematic of the extrusion head that shows the various components described.

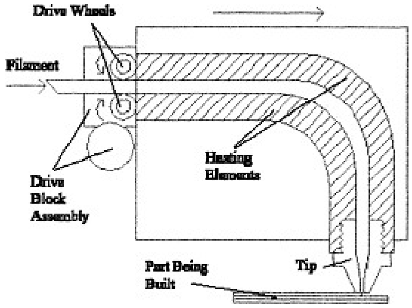


Figure 2.3 The key component of FDM technology is the extrusion head shown here.

Drive Blocks

The drive blocks are the raw-material feeding mechanisms, and are mounted on the back of the head. The drive blocks are computer controlled and are capable of precision loading and unloading of the filament. They consist of two parallel wheels attached to a small electric motor by gears. The wheels have a plastic or rubber tread, and are spaced approximately 0.070 inches apart and turn opposite to one another. When the wheels are turning and the end of the filament is placed between them, they continue to push or pull the material, depending on the direction of rotation. When loading, the filament is pushed horizontally into the head through a hole a little larger than the filament diameter, which is the entry to the heating chamber.

.1.3.2 The Heating Chamber

The heating chamber is a 90-degree curved elbow wrapped in a heating element, which serves two primary functions. One is to change the direction of the filament flow so that the material is extruded vertically downward. Secondly, and most important, is to serve as a melting area for the material. The heating element is electronically controlled, and has feedback thermocouples to allow for a stable temperature throughout. The heating elements are held at a temperature just above the melting point of the material, so that the filament passing from the exit of the chamber is in a semimolten state. This allows for smooth extrusion as well as tight control on the material placement. At the end of the heating chamber, which is about 4 inches long, is the extrusion orifice, or tip.

2.1.3.3 Tips

The two tips are externally threaded and screw up into the heating chamber exit, and are used to reduce the extruded filament diameter to allow for better detailed modeling. The tips are heated by the heating chamber up to above the melting point of the material. The tips can be removed and replaced with different size openings, the two most common being the 0.012 and 0.025 inch sizes. The extruding surface of the tip is flat, serving as a hot shearing surface to maintain a smooth upper finish of the extruded material. The tip is the point at which the material is deposited onto a foam substrate to build the model.

2.1.4 Build Substrate

The foam substrate is an expendible work table onto which parts are built. The substrate is about one-inch thick and is fastened into a removable tray by one-quarter-inch pins. The pins are inserted horizontally through holes in either side of the tray, and pierce about two inches into the substrate to stabilize it during building. The substrates can sometimes be used several times for smaller parts by selectively placing them on unused sections, and by flipping them over to use the other side of the foam. The foam used is capable of withstanding higher temperature, as for the first few layers of the part the hot extrusion orifices are touching the substrate.

Modelers higher than the 1500 model have two drive blocks, heating chambers, and extrusion orifices in the head with independ ent temperature and extrusion control to accommodate two different materials. This allows for a build material, of which the part is made, and a support material. The support material is used to support overhangs, internal cavities, and thin sections during extrusion, as well as to provide a base to anchor the part to the substrate while building.

Fused Deposition Modeling Operation

Computer Aided Design File Preparation

Before building a part, the STL file has to be converted into the machine language understood by the FDM. The aforementioned QS software is used for this purpose. The STL file is read into QS, and is displayed graphically on screen in the Cartesian coordinate system (-x, -y, and -z). Also shown is the bounding box, a dashed three dimensional box representing the maximum build envelope of the FDM. QS gives you options on the FDM system being used, the slice layer thickness, the build and support materials, as well as the tip sizes. Figure 2.4 shows an STL file as viewed by QS.

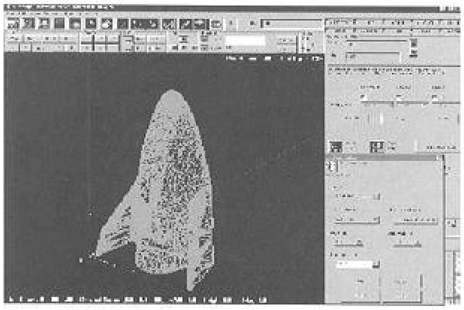


Figure 2.4 The STL file is viewed and manipulated by QuickSlice.

Part Size

First it must be affirmed that the part will fit into the bounding box; if not, it will either have to be scaled down to fit, or be sectioned so that the pieces can be built separately and then bonded together later. It is good practice for the designer to add alignment bosses and slots so that proper alignment of the subsections is achieved with ease. In some cases, for instance if the part fits in —x and -y but is too tall in the -z, QS can be used to section the part by slicing to a certain height, then starting a new build later at that height and finishing the part. This technique results in flat mating surfaces with no alignment bosses or slots, therefore it is up to the post processing person to align the subsections properly during bonding.

Orientation/Positioning

Once the part (or parts) has been deemed an appropriate build size, the part should be oriented in an optimum position for building. The shape of the part plays the major role in this, in that some orientations may require less supporting of overhangs than others. Also, rounded surfaces tend to turn out smoother if built in the plane of movement of the extrusion head (x,y), as curvatures in the z direction are affected by the layering build technique.

Example: Orientation of Table for Optimum Build.

Say you want to build a scaled model of a round patio table. If you were to build the table standing on its legs, as in Figure 2.5, the round top will come out nicely, but it will require an extremely large amount of support material to serve as a bridge for building the "floating" surface of the table top. (Basically, it is hard to extrude material into thin air and then expect it to stay there.)

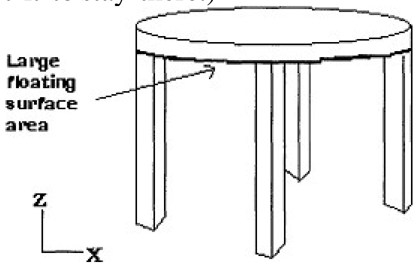


Figure 2.5 The upright table requires excessive supports for the top.

Secondly, you could build the table on its side, as in Figure 8.6, which would require much less support material than before, in that it now only supports the thin floating sections of the legs. Now, however, the rounded table top will lose its definition due to the layering affect of the build process. You can see in the diagram that the layers create small "stair steps" as the curvature increases in the z plane.

The final, and best, option, is to build the table upside down (Figure 8.7). Again, the rounded top will have good definition due to the precision control of the head. Now the necessary support material has been minimized, as there are no floating surfaces that require support. Essentially, the only support material used will be for the anchoring base layers. This simple change of orientation has saved material, time, and accuracy! There is less support material required, which also cuts down on the build time, and the desired definition will be obtained. Of course, parts are usually never this simple, but nonetheless much time and cost can be spared if the build orientation is well thought out before the part is built. This applies to most all of the RP techniques currently available as well.

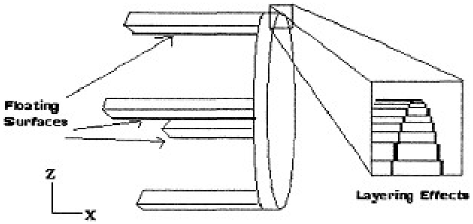


Figure 2.6 Orienting the table sideways reduces the necessary supports, however the definition of the circular area is lost due to the stair-stepping effect.

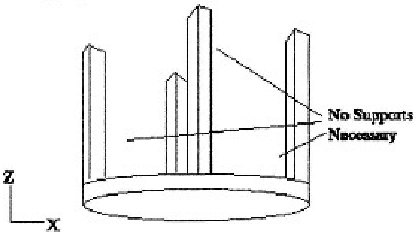


Figure 2.7 Upside down, the table requires minimal support material, gets finer definition on curvature, and also reduces the build time.

Slicing

Once the part(s) has been properly oriented and/or scaled, it must be sliced. Slicing is a software operation that creates thin, horizontal cross sections of the STL file that will later be used to create the control code for the machine. In QS, the slice thickness can be changed before slicing, the typical slices ranging from 0.005 inches to 0.015 inches. Thinner slices may be used for higher definition models, but this increases the time required to complete a part build. Likewise, less accuracy-sensitive parts can be built much faster using a thicker slice value. There becomes a tradeoff between the desired accuracy and the time needed, with the optimum value determined by the user.

In QS, the slicing is shown graphically, and you can actually flip through the slices individually if you need to examine or edit them. Figure 8.8 shows a sliced aerospace vehicle from the front view in QS. (Resolution is low to protect software propriety).

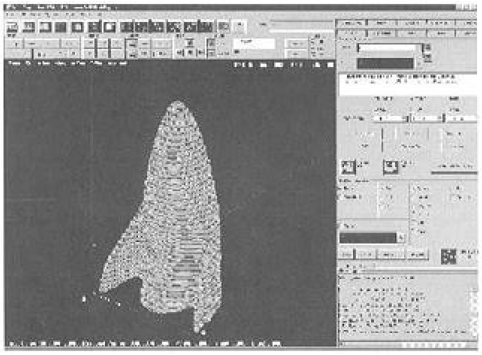


Figure 2.8 QuickSlice slices the three-dimensional solid into horizontal cross sections.

QS allows you to perform simple editing functions on the slice files, so for example if you want to offset a set of slices to make a hole smaller by a given dimension, you can do so quickly without having to return to the original computer aided design (CAD) program. Also, the editing function allows the repair of minor flaws in the STL file, with the options of closing and merging of curves. Finally, a graphical representation allows you to inspect possible problem areas of the part for building. For instance, you may be able to detect surfaces that will be difficult to support in the current orientation. Once the slice file is in satisfactory condition, the file can be saved for future manipulation or reference.

Build Parameters

QS typically has optimum build parameters set as default for the slice thickness and material you chose, but it will also allow manual intervention so that you can vary several different settings. Some of the parameters later discussed can be tweaked to decrease build time, model weight, and the amount of material required for the build.

Sets

QS uses sets, or packages of build parameters. Sets contain all of the build instructions for a selected set of curves in a part. Sets allow a part to be built with several different settings. For example, one set may be used for the supporting structure of the part, one for the part base, another for the thicker sections of the part, and still another for exposed surfaces of the part. This allows the flexibility of building bulkier sections and internal fills quickly, while getting finer detail on the visible areas of a part. Sets also allow chosen sections of a part to built hollow, cross hatched, or solid, if so desired. Two of the build parameters commonly worked with are the road width and fill spacing.

Road Width

The road width is the width of the ribbon of molten material that is extruded from the tip. When the FDM builds a layer, it usually begins by outlining the cross section with a perimeter road, sometimes followed by one or more concentric contours inside of the perimeter. Next, it begins to fill the remaining internal area in a raster, or hatch, pattern until a complete solid layer is finished. Therefore, the three types of roads are the perimeter, contour, and rasters. Either of these can be turned on or off by QS. One good is example is for support structures. Typically, the perimeter and contours are turned off on supports, leaving a set of thin vanes that are easier to remove during post processing. Another example is to turn off the rasters, which allows you to build a hollow part, because the only material being extruded is for the walls of the part.

The road width can be as small as the diameter of the tip opening to approximately twice that size. The width is controlled by increasing or decreasing the extrusion rate in conjunction with the speed of the head, but dont worry, the software calculates all of that. Basically the user changes the width values to get a faster (if larger) or smoother (if smaller) part. Nominally, to maintain good surface finish on a part, the exposed surface road widths are best kept at a minimum, regardless of the interior road-width values.

Fill Spacing

Fill spacing is the distance left between the rasters or contours that make up the interior solids of the part. A fill spacing set at zero just means that the part will be built solid. But, QS allows the user to set values, therefore a bulky part can be significantly reduced in time and material cost by leaving air gaps between each consecutive road. Keep in mind that to make sure the part appears solid, all exposed surfaces need to be built with zero fill, or else you will be able to see the open spacing.

NOTE: Generally, an air gap of one to three times the width of the rasters works well, and about 10 layers of zero fill should be used when approaching exposed surfaces. This will effectively reduce the build time, while still maintaining a solid feel and appearance.

Creating and Outputting Roads

Once all parameters have been set, the roads are created graphically by QS. The user is then allowed to preview each slice, if so desired, to see if the part is going to build as required. Figure
2.9 shows a slice with roads as depicted by QS. The software actually shows the path of the extrusion tip for each individual road, there- fore one can check for errors in the build sequence. For example, a wall may have been too thin for the chosen road width and QS left it blank. The operator must then go to the set that the wall is included in and lower the road-width values to make it fit. After satisfactory roads have been created, the data is written out as an SML file (Stratasys Machine Language), which is essentially a numerical control text file that can be read by the FDM.

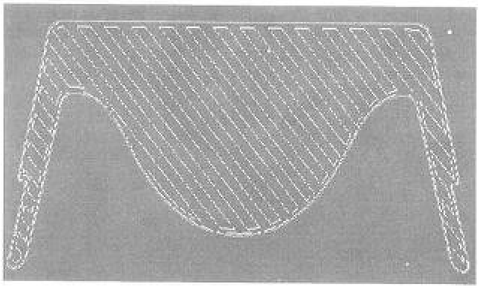


Figure 2.9 A close-up of a road slice in QS. Note the outline perimeter and raster fills.

Getting a Build Time Estimate

QS has a very good build-time estimator, which activates when an SML file is written. Basically, it displays in the command window the approximate amount of time and material to be used for the given part. A build estimate can also be acquired for previous SML files by opening them and simply clicking the Build Estimate button. Estimating the build times for parts is an important aspect in any industry that produces components on a schedule. This allows for efficient tracking and scheduling of the FDM system workloads.

Building a Part

The software setup requires most of the operator's time. Once the SML file has been created, it can be downloaded to the FDM through the parallel port of the PC just as if the file were being printed on an ordinary desktop printer. The FDM receives the file, and will begin by moving the head to the extreme -x and -y positions to "find" itself, and then raises the platen to a point to where the foam substrate is just below the heated tips. After checking the raw-material supply and the temperature settings, the user then manually places the head at the point where the part is to be built on the foam, and then presses a button to begin building. After that, the FDM will build the part completely, usually without any user intervention. Figures 2.10 through 2.15 shows a 6-inch hollow aerospace model being fabricated.

Finishing a Fused Deposition Modeling Part

FDM parts are usually some of the easiest rapid prototyped parts to finish. FDM features the Break Away Support System (BASS), which allows the support material to be peeled away easily by hand with a knife or pliers. The materials are easy to finish by sanding, and the ABS plastic parts may be made very smooth by wiping them down with a cloth moistened in acetone or a similar light solvent. The investment-casting wax parts may be smoothed with an electric hot knife or be dipped in a lower temperature wax such as paraffin. The parts tend to require very little finishing before they are ready to be delivered, depending on the application.

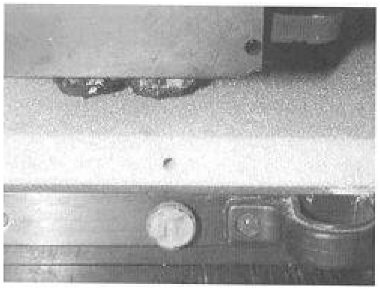


Figure 2.10 The FDM just before building an aerospace model. Notice the two extrusion tips are slightly buried into the foam substrate. This provides an anchor for the following part-build process.

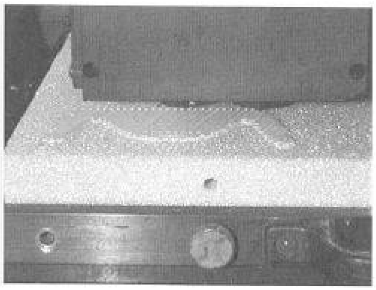


Figure 2.11 The aforementioned model after 15 minutes. The model is mostly support material due to a taper on the back of the design.

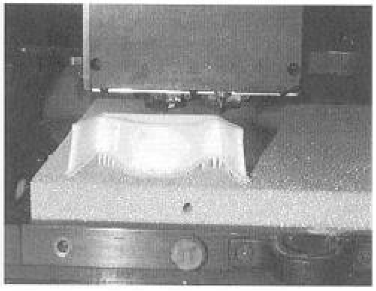


Figure 2.12 After 1 hour the model has built over 1-inch tall. Notice the part is being built hollow in order to speed up the process.

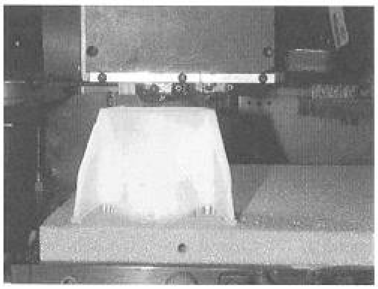


Figure 2.13 After 2 hours, the model is progressing steadily. The time to build each layer will decrease from here to the finish because the cross-sectional area continuously gets smaller on this part.

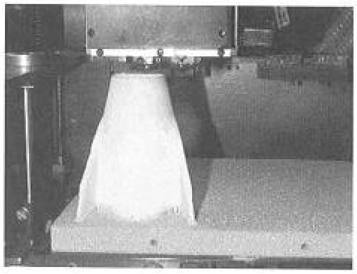


Figure 2.14 After 2.5 hours, the model appears to be just over half finished, although it lacks only about one half of an hour due to the dwindling cross-sectional area of the design.

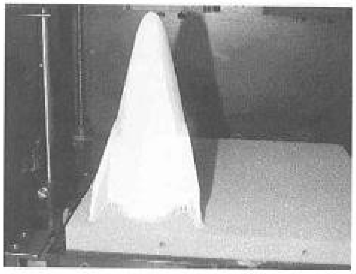


Figure 2.15 The model is complete after only 3 hours total. Machining the same model could easily take 10 to 20 man-hours, as well as shipping, tracking, and off-duty hours.

Typical Uses of Fused Deposition Modeling Parts

Concept/Design Visualization

Like other RP systems, the FDM systems provide an excellent route to obtaining prototype models for initial observation of a design. The ABS and Elastomer parts are rigid enough to survive handling and transporting from meeting to meeting, or even down to the shop floor. Parts can be made with various colors to represent different components of a system. The build materials are also relatively inexpensive, so models can be re-iterated more so than if prototypes were being machined or formed.

Direct-use Components

Due to the rigidity of the ABS parts, they can be used in various applications to replace traditionally machined, extruded, or injected plastic parts. The FDM can build directly usable electronics housings, low-speed wind-tunnel models, and working gear assemblies among other uses. This allows users to directly fabricate prototypes and test them before actually machining the final design.

Investment Casting

The investment-casting wax offered by FDM opens up yet another avenue of applications. If prototypes are needed in a metal form, the parts can be prototyped using the investment-casting wax, and then carried through the traditional investment-shell casting process to obtain usable metal components. The investment-shell process basically consists of shelling the wax part in ceramic, and then melting out the wax to have a mold into which molten metal can be cast. Hence, prototype castings can reduce design-to-market costs by getting it right before the final manufacturing step is initiated.

Medical Applications

The Medical Grade ABS has been approved by the U.S. Food and Drug Administration (FDA), and therefore is used by the medical industry to produce various parts within the industry. Since CAT Scan and MRI data can be converted into the .STL file format, custom models of internal organs, bones, etc. can be reconstructed and studied before a patient ever goes into surgery!

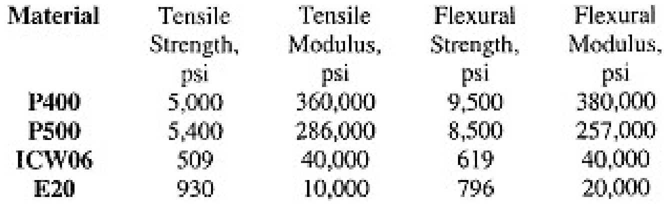
Flexible Components

The recently released Elastomer material opens yet another dimension of functionality for the FDM systems. Flexible test components such as seals, shrouds, and tubing can be prototyped with the Elastomer material to proof out the concepts or "make the sale" on crucial designs.

Fused Deposition Modeling Materials Properties

As mentioned earlier, the FDM systems now have the capability to build parts with four different materials. Investment-casting wax (ICW06) is an industry-standard foundry wax that is used for many casting applications. ABS (P400) is a rigid plastic material that also comes in six colors: white, red, green, black, yellow, and blue. Medical Grade ABS (P500) has the strength of ABS but also can be sterilized to produce functional medical components. Elastomer (E20) provides a flexible build-material source that can be used for seals, gaskets, shoes, and other applications.

The materials properties were provided courtesy of Stratasys and are as follows:



Material	Tensile Strength, psi	Tensile Modulus, psi	Flexural Strength, psi	Flexural Modulus, psi
P400	5,000	360,000	9,500	380,000
P500	5,400	286,000	8,500	257,000
ICW06	509	40,000	619	40,000
E20	930	10,000	796	20,000

Figure 2.16 Mechanical properties of FDM build materials.

Advantages and Disadvantages

The strength and temperature capability of the build material is possibly the most sought-after advantage of FDM. Other major advantages include safe, laser-free operation and easy postprocessing with the new water-soluble support material.

Although significant speed advancements have been made with newer FDM systems, the mechanical process itself tends to be slower than laser-based systems, therefore lack of build speed is a key disadvantage.

Also, small features like a thin vertical column prove difficult to build with FDM, due to the fact that each layer must have a physical start-and-stop extrusion point. In other words, the physical contact with the extrusion tip can sometimes topple, or at least shift, thin vertical columns and walls.

Key Terms

Extrusion head. The key component of FDM technology, the extrusion head performs the material melting and deposition functions while being moved on the -x, -y carriage.

Drive blocks. Located inside the extrusion head, the drive blocks pull filament from the material supply spools and push them through the heated head chamber.

Raster fill spacing. Also known as the air gap, the raster fill spacing is the distance between each individual bead of material that is deposited. It can be set to zero to make a solid part, or opened up to build parts with internal cavities.

Slice thickness. The thickness value for each horizontal crosssection to be deposited, generally a value from 0.007 to 0.010 inches.

Water-soluble support. A late feature of the FDM systems, watersoluble support material is removed from the part by dissolving away, as opposed to the mechanical removal of standard support material.

Build substrate. A removable foam pad that is used to anchor parts steady during the FDM build process.

Road width. The width of each individual bead of filament material that is deposited, typically one to three times the width of the extrusion tip diameter.

Laminated Object Manufacturing

Laminated Object Manufacturing (LOM), is a rapid prototyping (RP) technique that produces three-dimensional models with paper, plastic, or composites. Helisys, Corp. in Torrance, CA developed LOM, led by Michael Feygin. LOM is actually more of a hybrid between subtractive and additive processes, in that the models are built up with layers of material, which are cut individually by a laser in the shape of the cross section of the part. Hence, as layers are being added, the excess material not required for that cross section is being cut away. LOM is one of the fastest RP processes for parts with larger cross-sectional areas, which makes it ideal for producing larger parts. Figure 9.1 shows a LOM 1015 system.

System Hardware

The LOM system is currently available in two sizes, the LOM 1015 and the larger LOM2030. The LOM 1015 can build parts up to 10" X 15" x 14", whereas the LOM2030 can build parts up to 20" x 30" x 24". Both operate using the same technique, and the most common build material today is paper. Parts built with LOMPaper generally have a wood-like texture and appearance. The build material has pressure and heat-sensitive adhesive on the backing, and comes in various widths starting from 10 inches. Material thickness ranges from 0.0038 to 0.005 inches, about the thickness of two or three sheets of notebook paper.

The LOM operates from a PC workstation, which is provided with the LOM System when purchased. The LOMSlice™ software provides the interface between the operator and the system. LOM doesn't require a preslice of the STL file, that is, once the parameters are loaded into LOMSlice the STL file slices as the part builds. This process of continuous slicing is called slice-on-the-fly.

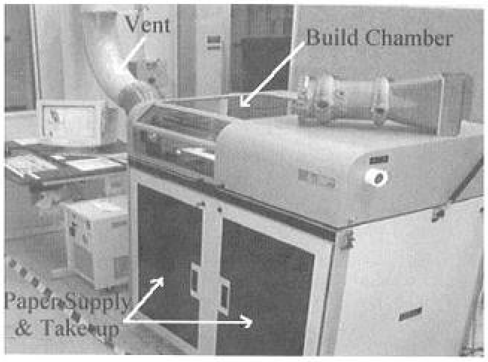


Figure 3.1 The Helisys LOM 1015 machine.

The LOM has a feed spindle and a take-up spindle for the build material. The feed spindle holds the roll of virgin material, whereas the take-up spindle serves to store the excess material after a layer is cut. A heated roller traverses across the face of the part being built after each layer to activate the adhesive and bond the part layers together.

An invisible 25W carbon dioxide laser is housed on the back of the LOM, and is reflected off three mirrors before finally passing through a focusing lens on the carriage. The carriage moves in the -x direction, and the lens moves in the -y direction on the carriage, thus allowing the focal "cutting" point of the laser to be moved like a plotter pen while cutting through the build material in the shape desired. This -x and -y movement allows for two degrees of freedom, or essentially a two-dimensional sketch of the part cross section. The part being built is adhered to a removable metal plate, which holds the part stationary until it is completed. The plate is bolted to the platen with brackets, and moves in the -z direction by means of a large threaded shaft to allow the parts to be built up. This provides the third degree of freedom, wherein the LOM is able to build three- dimensional models.

Some smoke and other vapors are created since the LOM functions by essentially burning through sheets of material with a laser, therefore, the LOM must be ventilated either to outside air or through a large filtering device at rates around 500 cubic feet per minute (cfm). This is perhaps the most difficult part of installing a LOM 1015 system, as the rest of the system runs on household current and requires no major facilities modifications. The larger LOM2030, however, has to be installed with plenty of operating space to allow for lift-truck loading of the large material rolls, as well as for recommended overhead-crane access for the removal of extremely large parts.

Laminated Object Manufacturing Operation

All of the previously mentioned hardware and software components work together to provide fast, economical models from the LOM system. The way the LOM constructs parts is by consecutively adhering layers of build material while cutting the crosssectional area of the part with a laser. The LOMSlice software that comes with the LOM machine controls all this. The following description of operation is described with paper as the build material, but operation with other materials works in the same fashion.

3.2.7 Software

As with all RP systems, the LOM must begin with the standard RP computer file, or the STL file. The STL is loaded into LOMSlice (Figure 3.2), which graphically represents the model on screen. Upon loading the STL file, LOMSlice creates initialization files in the background for controlling the LOM machine. Now there are several parameters the user must consider and enter before building the part.

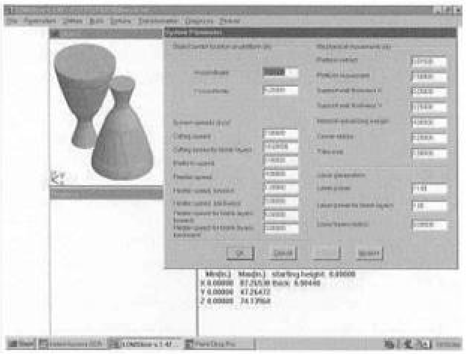
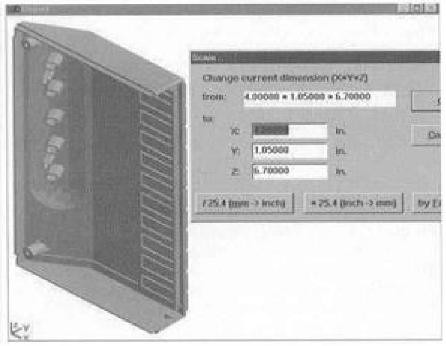


Figure 3.2 The LOMSlice software provides the interface between the operator and the LOM machine.

Part Orientation

The designed shape of the part or parts to be built in the LOM must be evaluated for determining the orientation in which to build the part. The first consideration for part orientation is the accuracy desired for curved surfaces. Parts with curved surfaces tend to have a better finish if the curvatures of the cross sections are cut in the -x, -y plane. This is true due to the fact that the controlled motion of the laser cutting in the -x, -y plane can hold better curve tolerances dimensionally than the layered effects of the -x, -z and -y, -z planes. If a part contains curvatures in more than one plane, one alternative is to build the part at an angle to the axes. The benefits here are twofold, as the part will not only have more accurate cur vatures, but will also tend to have better laminar strength across the length of the part. Figure 3.3 shows the part orientation function.

A second consideration for part orientation is the time it will take to fabricate a part. The slowest aspect of the build process for the LOM is movement in the -z direction, or time between layers. This is mainly because after the laser cuts across the surface of the build material, the LOM must bring more paper across the top face of the part and then adhere it to the previous layer before the laser can begin cutting again. For this reason, a general rule of thumb for orienting long, narrow parts is to place the lengthiest sections in the -x, -y plane (lying down flat). This way the slowest part of the process, the actual laser cutting, is minimized to a smaller amount of layers.



Change current dimension (X*Y*Z)

from: 4.00000 * 1.05000 * 6.70000

to:

X: in.

Y: 1.05000 in.

Z: 6.70000 in.

Figure 3.3 The orientation of the part must be thought out before beginning a part build on the LOM. LOMSlice allows the operator to scale, translate, or rotate the model for the optimum performance.

Parts can be scaled, rotated, or translated in LOMSlice to allow for the best arrangement as seen by the operator. There are some third-party software vendors that have automatic nesting functions that will strategically place parts in optimum orientations for the machine selected.

Crosshatching

As is described later in the build technique section, crosshatching is necessary to get rid of excess paper on individual layers. Crosshatch sizes are set in LOMSlice by the operator and can vary throughout the part. Basically, the operator puts in a range of layers for which he wants a certain Crosshatch pattern. For sections of the part that do not have intricate features or cavities, a larger Crosshatch can be set to make the part build faster. But, for thin-walled sections and hollowed-out areas, a finer Crosshatch will be easier to remove. The Crosshatch size is given in values of -x and -y, therefore the hatch pattern can vary from squares to long, thin rectangles.

The two main considerations for crosshatching are ease of part removal, and the resulting build time. A very small hatch size (less than 0.25 inches) will make for easy part removal, however if the part is rather large or has large void areas, it can really slow down the build time. This is the reason for having varying Crosshatch sizes throughout the part. The LOM operator can either judge where and how the part should be crosshatched visually, or use LOMSlice to run a simulation build on the computer screen to determine the layer ranges for the various needed hatch sizes. Figure 3.4 shows a LOMSlice build simulation in progress.

Also, since LOMSlice creates slices as the part builds, parameters can be changed during a build simply by pausing the LOM machine and typing in new Crosshatch values.

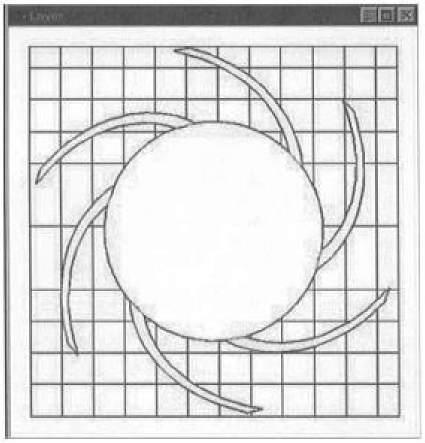


Figure 3.4 LOMSlice can be used to simulate a part build on screen to help verify Crosshatch patterns.

System Parameters

There are various controlling parameters, some of which typically do not change from part to part, that are used each time the LOM is set up. The laser power, heater speed, material advance margin, support-wall thickness, and heater compression are some system parameters the operator has the ability to change if needed.

The laser power is a percentage of the total laser output wattage. For instance, the LOM 1015 is usually operated at a laser power of about 9% of the maximum 25 watt laser, or approximately 2.25 watts. This value will be different for various materials or machines, but essentially it is set to cut through only one sheet of the build material.

The heater speed is the rate at which the hot roller passes across the top of the part. The rate is given in inches per second, and is usually around 6 inches per second for the initial pass and 3 inches per second for the returning pass of the heater. The heater speed affects the lamination of the sheets, so it must be set slow enough to get a good bond between layers.

The material advance margin is the distance the paper is advanced in addition to the length of the part. This is usually started out at about 1 inch to keep scorched paper from being included in the part, but can be changed to a lower value (~ 0.25 inch) during the part build to avoid excess buildup on the take-up spindle and wasted paper.

The support-wall thickness controls the outer support box walls throughout a part. It is not ideal to change this value during a build, although it is possible. The support-wall thickness is generally set to 0.25 inches in the -x and -y direction, although this value can be changed by the operator. For example, if a part is 0.1 inches too long for the build envelope, the user can make the support wall in that axis be only 0.15 inches to allow the build to take place.

The compression is used to set the pressure that the heater roller exerts on the layer. It is measured in inches, which is basically the distance the roller is lifted from its initial trek by the top surface of the part. Values for the compression will vary for different machines and materials, but are typically 0.015 to 0.045 inches.

Laminated Object Manufacturing Build Technique

Once all of the values have been plugged into LOMSlice, the LOM is now ready to begin building the part. Due to residues built up from burning material, the moving parts, lens, and mirrors must all be cleaned before beginning a part build.

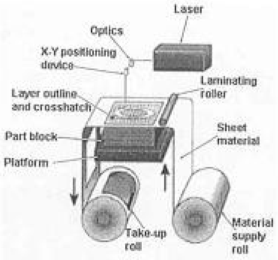


Figure 3.5 The LOM process (Courtesy of Helisys, Corp.).

Figure 3.5 shows a schematic of the LOM process. The paper roll is loaded onto the feed spindle in the bottom of the machine, and the paper is threaded around rollers, across the platen and then back down to the take-up spindle. An electrical device attached to a spring-loaded wheel, which is placed against one of the paper rollers, monitors the feed distance of the paper. This allows the system to feed only the necessary amount of paper to cover the crosssectional area of the part or parts. A cleaned build plate is mounted on the platform, which is then raised to the top home position.

Next, a perimeter is cut out of the paper representing the largest cross-sectional area of the parts to be build. The blank is removed and a layer of double-sided foam tape is placed across the build plate, and cut with the laser to match the previous blank size.

The support base of tape not only serves as a thermal barrier between the plate and part, but also serves two other important functions. If the part were to be directly bonded to the plate, the removal thereafter would prove extremely difficult. The foam support layer, while still providing a steady anchor for the part during the build, also makes part removal from the plate easier. Secondly, since the part must be chiseled from the plate (even with the foam), the support base helps protect the part from being damaged during removal. Figure 3.6 shows the foam base during application.

For additional support, typically 5 to 10 layers of paper are added before starting the actual part build. This also gives the operator a chance to verify the machine parameters by checking how well the layers are bonding, whether the heater is scorching the paper, and so on. This also increases the protection to the part during final removal from the plate.

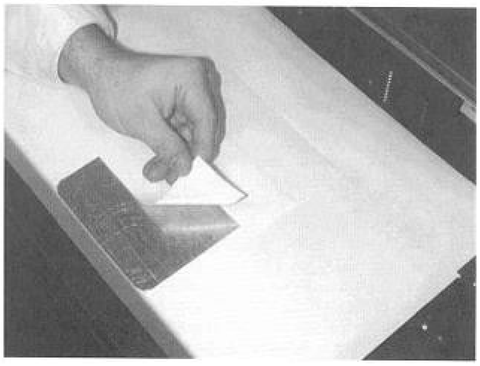


Figure 3.6 LOM parts need a foam base to anchor the part to the build plate during processing, as well as to ease in part removal.

After the support base is applied, the LOM starts building the part up from the bottom, as is designated in the software setup. The paper spindles turn to move new paper across the build plate. Next, the build plate is raised until it touches a sensor on the heater roller, where it stops to wait for adhesion. The heater roller now rolls along the surface of the paper, activating the adhesive backing while simultaneously applying downward pressure. The heater makes a return pass to its home position to finish the adhesion step, which is shown in Figure 3.7.

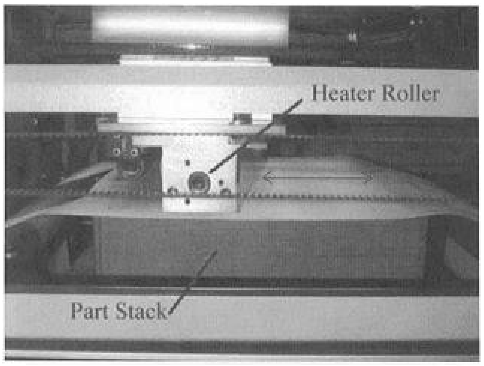


Figure 3.7 The adhesion step of the LOM process. A heated roller activates the backing of the paper to bond it to the previous layer.

Now the lens plots or traces the outline of the current cross section of the part, directing the laser to cut through only that sheet of paper in the desired shape. Each layer cut by the LOM must have a uniform, rectangular cross section, which is necessary to prevent the remaining waste paper from being adhered to the part. This means that if the actual cross-sectional area of the part being built varies, there will be some additional paper around the edges of the part necessary to fill out to the rectangular area. This waste paper can be reduced by "nesting", or strategically placing other parts in the STL file into such void areas to make good use of the excess paper. Otherwise, the excess paper on each layer is cut up into small crosshatches, to allow for easy removal of the part upon completion of the build. Also, for parts with internal cavities, the excess material inside is crosshatched as well. Figure 3.8 demonstrates the cutting step of the LOM process, in which the part cross-section, along with the crosshatches and support walls, is cut.

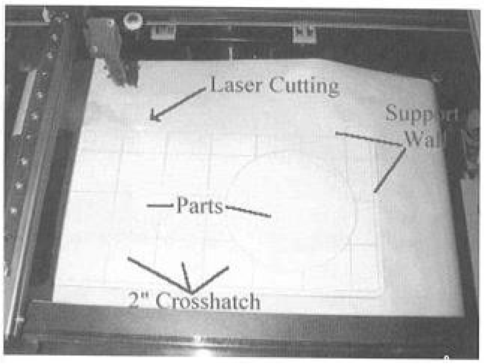


Figure 3.8 The LOM cuts through the paper layer with a carbon dioxide laser in the shape of the part cross section.

Finally, a rectangular perimeter is cut that encompasses the outer edge of the part and crosshatches, and a second perimeter is cut that is offset from the previous to the outside by a set number (generally 1/4 inch). These two outer perimeters form a support wall, which holds all of the crosshatched cubes and the parts within together throughout the remainder of the build.

After the final outer cut, the part is then lowered to allow the paper rolls to advance the remaining waste paper to the take-up spindle, thus bringing solid paper across the part surface again. In order to allow for the continuous feed of the paper, the paper is wider than the build area, therefore the paper between the feed and takeup spindle is never fully severed. Figure 9.9 shows the paper margin around the part area. The excess material going to the takeup spindle will consist of the remaining margins of the cut-out layers, which will be discarded after the build is complete. The adhesion step repeats, the laser cuts the next layer, and so on until the part is complete.

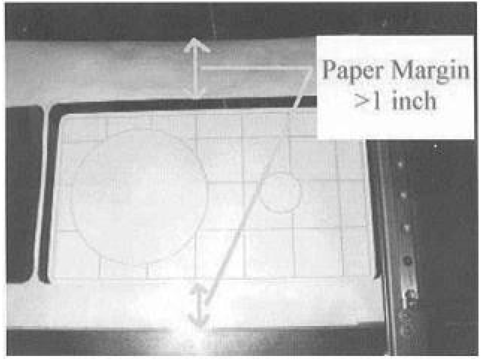


Figure 3.9 The LOMPaper is wider than the build area to allow for continuous feed capability.

The completed part when removed from the LOM machine is a rectangular block, because the outer support wall and crosshatched cubes are still positioned around the actual product. The part and plate are removed from the machine, where the part is then removed from the plate. A citrus- based solvent is sprayed on the plate to re move any remaining residue from the foam support layer, and the plate is then cleaned and ready for the next build. The cubes and the support wall are removed from the part by hand, which reveals the final product. This decubing process is described in more detail in the following section.

Finishing a Laminated Object Manufacturing Part

The support base, support walls, and crosshatches are removed from the finished part by a process often referred to as decubing. The actual technique will vary depending on the person, but a general technique follows.

First, the part block is placed upside down on a work table, where a small wood chisel or similar tool is used to remove the support tape and layers. Once the bottom of the part has been revealed, the support wall can be pulled off of, or cut away from, the part and crosshatches. Now, the outer crosshatches will generally fall away from the part, or can be picked away with the fingers. Internal hatches and those around delicate areas are approached with care, to avoid damage to the part. Small dental picks or similar tools can be used to remove the cubes from internal structures and sensitive areas. After some manual intervention, the decubing is now complete and the part is ready for sealing, sanding, and/or painting. The decubing process is depicted in Figures 3.10 through 3.14.

Paper parts are generally sealed with standard wood sanding sealer to prevent moisture from absorbing into the material. Absorbed moisture can cause the parts to distort or delaminate, so sealing is a necessary precaution. The sanding sealer also makes the parts readily acceptable to being sanded or polished for a nicer finish and to remove any remaining effects of the crosshatches. Finally, the parts can be painted after they are sealed, or else be left in the wood- finish form.

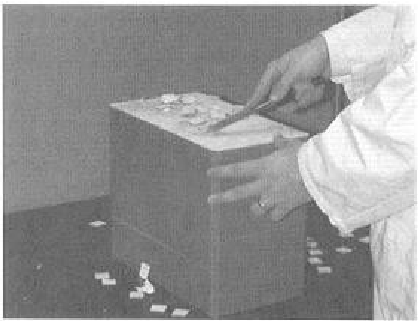


Figure 3.10 The part comes out of the LOM machine in a block.

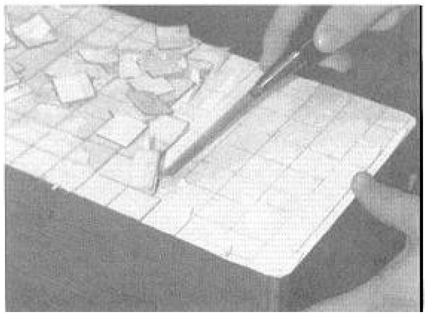


Figure 3.11 The support-base layers must be removed with a wood chisel.

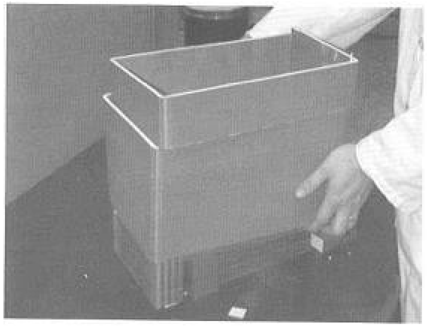


Figure 3.12 After base removal, the outer support wall is removed.

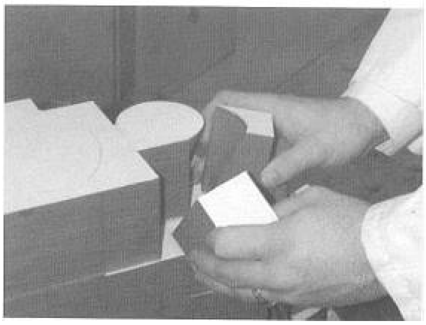


Figure 3.13 The loose outer crosshatches can be removed without tools.

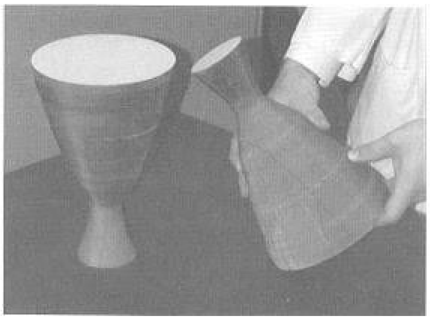


Figure 3.14 The fully decubed LOM part can now be sealed and/or sanded for best finish.

Typical Uses of Laminated Object Manufacturing

The final LOM parts have a relatively good handling strength, except in very thin sections. They can be used for various applications, from concept verification to test prototypes. The LOMPaper parts can also be used as investment casting patterns, as well as masters for silicone-rubber injection tools.

3.5.7 Concept Verification

The attractive appearance of the LOM models, along with the capability for good surface quality, make the LOM models good candidates for concept-verification applications. Designers or engineers can have complete mechanical assemblies fabricated quickly on the LOM machine, and then use the models for design-review meetings, management briefings, and more importantly, to see if the model has all of the needed features and shapes as visualized with the computer design. If a design flaw is caught and prevented during this stage of the manufacturing process, it can provide millions of dollars in savings, as well as preventing months of unproductive development work.

Fit-check Analysis

As a follow up to concept verification, fit-check analysis is the next phase of RP. Assembly models can be put together to check for part interference, fit, and appearance. Also, models can be mounted on existing hardware to likewise check for appropriate fit and ergonomics. The inexpensive LOM models provide the visual link to checking out a design before advancing to the expensive manufacturing phase.

Direct Use Components

There are several ways in which LOM models can be used directly. Sometimes a model is all someone needs. One such example is for topography mapping from electronic surface data. Topographical maps can be made of planet surfaces from satellite data, or of underwater trenches and valleys and the like. These maps can be made accurately from digital data, as opposed to the conventional techniques of hand carving from sheet coordinates. This can allow unmanned underwater or interplanetary exploration to be recorded in a more useable fashion, and help to study and plan manned expeditions to such areas.

Another example of direct-use LOM models is in the medical industry. LOM models can be made from MRI or CAT scan data of bones, organs, and arteries. One example is for accident victims with skull or facial damage. These models can help doctors plan reconstructive surgery before they ever enter the operating room. Modeling scaled-up versions of viruses or tumors can aid in the study and treatment of such phenomena.

Finally, models can help serve as aids for machinists cutting the final designs. A three-dimensional replica is definitely easier to understand than complicated blueprints or even solid models on a computer screen. A physical model can serve as a powerful prevention tool against manufacturing errors.

Casting and Molding Patterns

For more durable hardware, LOM models can be a primary step to acquiring metal components. By using the models as patterns in a sand casting or investment casting process, metallic test hardware can be produced. If many parts are needed, the negative of the part needed can be built on the LOM, and then used as an injection tool to make many wax casting patterns from one LOM model. Yet another use is to pattern a silicone-rubber tool around the LOM model, then use this tool to inject wax or plastic parts. For limited-run production prototypes, the LOM models can provide a faster, more cost efficient way of testing out a new product design.

Advantages and Disadvantages

As seen throughout this chapter, the LOM advantage comes from the ability to produce larger- scaled models using a very inexpensive paper material. The finishing ability of the parts and the good handling strength couple with the speed and accuracy to provide an all-around quality modeling system. The materials are environmentally compliant and have not shown any capability of being health threatening.

Some possible disadvantages include the need for decubing, which is somewhat labor intensive for an "automated" process. Also, the emission of smoke and fumes, although vented out, can be a slight nuisance to visitors or tourists who aren't accustomed to it. And the fact that the machine operates by burning through paper can raise some concern to fire-safety officials.

Otherwise, the LOM is an all-around hearty RP system, and the prospect of more advanced materials on the horizon makes the LOM that much more desirable to have in a model shop or plant.

Laminated Object Manufacturing Materials Properties

LOM models can usually hold dimensional tolerances of about + 0.010 inches and the materials properties as relayed by the vendor are shown in the chart in Figure 3.15.

Material	Tensile Strength	Elastic Mod	Elongation	Hardness
LPS 038 Paper	9500 psi	971 kpsi	2%	55-70 ShoreD
LPH 042 Paper	3710 psi	366 kpsi	10.70%	55-70 ShoreD
LXP 050 Plastic	12400 psi	500 kpsi	9.60%	n/a

Figure 3.15 Physical properties of LOM materials.

Key Terms

Laminated Object Manufacturing (LOM). RP process that build three-dimensional physical models from sheets of laminated material cut with a laser.

Slice-on-the-fly. The process of continuous slicing used by the LOMSlice software in which parameters can be changed during a part build.

Crosshatching. The process of cutting excess material around a LOM part into smaller pieces, which allows for the easier removal of the finished part.

Laser power. A percentage of the total laser output wattage, set to allow only one sheet of build material to be cut per layer.

Heater speed. The rate at which the hot roller passes across the top of the part, which affects the lamination capability of the sheets.

Compression. System parameter used to set the pressure that the heater roller exerts on the layer during the adhesion step.

Support base. The sequence of initial layers on top of a foam tape substrate, which is used to protect the part during removal as well as providing a thermal barrier between the part and the aluminum build platform.

Adhesion step. The time between layers when the heater is rolled across the top of a new sheet to glue it to the previous layer.

Nesting. The strategic placement of parts in three-dimensional space to allow for the smallest amount of waste in a LOM part build. Nesting hence increases the efficiency of the part-building process.

Support wall. A thin-solid shell cut around the outside perimeter of the LOM part and crosshatches to maintain stability in a part build.

Decubing. The manual removal of the support base, support walls, and crosshatches from a finished LOM part.

Solid Ground Curing (SGC)

4. Solid ground curing is a process in which whole layers are simultaneously cured according to the required cross section. Cubital Ltd. has marketed an SGC system, called Solider, in which a thin layer of a liquid photosensitive resin is applied and then exposed to strong UV radiation through a mask with transparent areas corresponding to the desired cross section of a particular layer. The UV radiation solidifies the exposed areas of the resin and the uncured liquid resin is removed and these areas are replaced by wax to build up a support structure. Finally, the cured resin and the deposited wax are both machined to a predetermined thickness with a fly cutter and the piece is ready for development of the next layer.

Two cycles of operation continue simultaneously in this process (Figure 4.16). One of them prepares the mask for every layer and the other one takes care of building the part layer-by-layer.

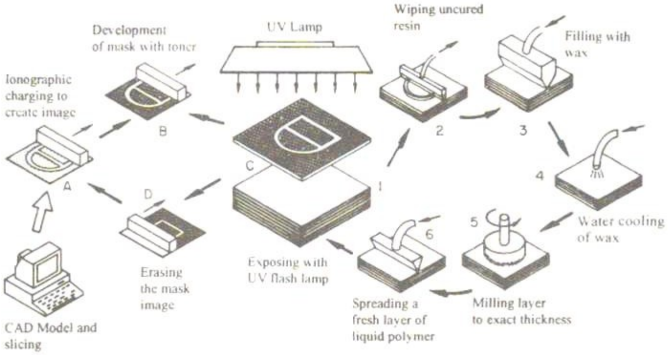


Figure 4.1: The cycle of operations in solid ground curing (SGC)

A glass plate is ionographically charged to create a pattern according to the required cross section, which is then developed by using a toner, as done in photocopying units. Once the curing of the required cross section is over, the pattern from the glass mask is erased and it is used for creating the mask for the next layer. The charge pattern is controlled by a computer which has information about the required part geometry. In typical systems, the charge is deposited on the glass plate in raster lines with 11.8 lines per mm. In a more accurate version of the system, it is planned to have about 40 lines per mm. There are two other approaches (in processes usually called Light Sculpting) for selective curing of the resin. In one method a flat- panel liquid crystal display (similar to that used for overhead projection of computer graphics) is used. The mask pattern is generated directly from the computer data very quickly. In the other approach a rectangular array of light emitting diodes is put directly above the resin vat. Such programmable LC masks and lighting arrays can be put in direct contact with the liquid resin if the separating glass plate has an anti adhesive coating. This arrangement can speed up the formation of a new layer by squeezing the liquid between the mask plate and the part surface. This takes less time compared to a free surface flooding which generally takes 1 to 3 minutes even with the help of a scraper. The flooding time is much more than the time needed to solidify a layer which is only a few seconds. Squeezing the resin can reduce the cycle time substantially.

Once the new layer of liquid resin is exposed to the UV radiation through the mask the resin below the transparent portions solidifies. The mask is removed (in the usual machines without programmable masks) and the masking pattern is erased. The glass plate after cleaning is again ready for the next cycle. The uncured resin is removed by an air knife and the surface is covered with wax. In the final step, the wax-resin layer is machined to provide an accurately controlled layer thickness. Layer thickness ranges from 0.03 mm to 1.27 mm.

High-viscosity, low-shrinkage resins can be used for the SGC process. As full curing of the cross sections is achieved layer by layer the part attains its full mechanical strength. This reduces the chance of warping later. Further, the illumination level during curing is uniform, resulting in uniform curing. In other GMP process based on curing of photopolymers the post curing of the part in ‘green’ state does not achieve uniformity as the intensity of radiation cannot be maintained uniform all over the surface. This is another reason for less shrinkage and distortion in parts made by SGC.

Since the part is made in a body of wax no separate support structure is needed as the wax serves as the support for the cantilever projections and isolated parts. The wax is removed by melting once all the layers are created. Since the opaque areas of the mask cannot prevent the corresponding resin surface from getting UV radiation completely, resin in these areas gets partially cured and cannot be used again. So it is desirable to make as many parts simultaneously as possible to maximize the utilization of raw material. The machine operator selects the parts to build and orients them such that these parts can be accommodated in a block of minimum height. Nesting of parts for optimal usage of space saves wastage of material and can maximize the number of parts that can be fabricated at a time. After arranging the parts, their computer data files are processed together to generate the composite cross section of each layer. It is also possible to have one-shot fabrication of a complete unit containing a number of elements having relative motion among themselves ! Cubital has built a set of meshing gears mounted on shafts which can have relative rotational motion.

In SGC the build time per layer is independent of the part geometry and it is about 50 seconds in the currently available units. Models as large as 500 mm x 500 mm x 350 mm can be built at present with about 0.1% dimensional accuracy. An accuracy of 0.03 mm can be achieved in a 25 mm part dimension. Like SLS and LOM processes SGC can also produce composite parts by using different resins for different layers. The system is large because of the large number of work stations, and noisy because of the fly cutter and the associated vacuum system for the removal of the chips'. It is claimed that light sculpting process makes the system about 10-100 times faster than the usual SGC process, 60 times finer in resolution and details, 100 times more energy efficient and less than half as costly to buy and maintain.

Some Important Advantages of GMP’s

The main purpose for adopting RP technology has been discussed in detail. However, it may be in order to look at the specific advantages of the generative manufacturing processes . Some of these specific advantages are discussed below:

(i) No tools and fixtures: Since the shape is built by addition of (or solidification of) material in small amounts no tools or fixtures are required. Thus, a major component of manufacturing cost is eliminated. The problem of tool wear and stopping of a process for tool change are also absent.

(ii) Capability in shape generation: There are practically no restrictions on the geometry of the part to be produced. Any type of external or internal intricate shape can be generated by GMP’s in a routine way. Cores etc., are also not essential for creating internal hollow structures. These processes are also suitable for producing tiny details, thin features and sculptured outer and inner surfaces.

(iii) Generation of composite parts and assemblies: In many of the generative processes, material can be changed during the building process. So a part can be produced which is made up of different materials with different colours, strength and other characteristics. It is possible to even build up a complete assembly consisting of a number of components capable of relative movement among themselves. Thus, the difficult and intricate labour intensive task of assembly is eliminated.

(iv) Suitability for computer integration: Most other manufacturing processes evolved without any special emphasis on computer integration. This makes the task of achieving computer integrated manufacturing systems (CIMS) very difficult. On the other hand, all the GMP's have been developed keeping computer control in mind from the very beginning. As a result all these processes are very suitable for an environment of computer control and CIMS become easily realizable.

(v) Economic advantages: As dyes, moulds, or special toolings are dispensed with, producing a small number of some complex part is quite economical in comparison with the conventional processes.

Considerations for Adopting RP Technology

(vi) Given that RP is an important new technology that may not only improve the quality of a product but can get it to the market much faster, it is important to consider a number of points before it is applied. For this purpose, an in-depth analysis of the design of a product under consideration and the manufacturing operations involved is essential. The key parameters to be investigated and evaluated before going for a GMP system are as follows:

(vii) (i) Finished part size: The size of a part that can be built by a generative manufacturing process is limited by the work chamber. However, a large part can still be built by RP technology by building it in sections and bonding together the various sections. Of course, it is cumbersome and it is difficult to maintain accuracy.

(viii) (ii) Volume of production: To make an RP system financially rewarding the experts say that such a machine must produce 200 models/prototypes per year or operate at least half of every working day. The present trend is to establish service centres with these RP facilities which can take work from various organizations and industries. This is somewhat like the photocopying centres we have these days.

(ix) (iii) Speed of prototype development: IIow quickly the prototype is needed is an important factor in deciding whether RP should be adopted or not. Most GMP systems take about a minute per layer at present. So production is not rapid enough sometimes. The advantage vanishes especially when the shape of the object is simple. While deciding the time required one must not forget the time required for pre and post operation steps.

(x) Part finish: Finish of parts produced by the various GMP's varies from system to system and depends on the material used and slice thickness. Part finish depends on the part geometry also as explained earlier. Curved surfaces may have pronounced stair-step effect in some cases unless very small slice thickness is used.

(xi) Material: The material of the prototype is one of the most important factors. If the part is to be used for a simple 'show' model it may be required to last only a few hours or days. On the other hand, functional testing may require stronger materials and even metals and alloys in some cases. At present, most RP models (except the metallic and ceramic ones) can withstand a constant temperature of about 70°c only. In many cases, the models are too porous and may not possess the required strength.

(vi) Accuracy: The precision required in a model is another important consideration. Though the expected accuracy and repeatability are specified for most generative processes, quite often the end result depends on operator's skill and talent.

(vii) Cost: The GMP system is only one component of the total cost and there are other expenses involved in RP. The software can be sometimes more costly than the machine. Cost of pre-and post- processing should be taken into account and even the cost of material in many GMP systems is quite high. Thus, a long term analysis is necessary. A somewhat larger initial expense can be justified if the cost savings from the design and improved production are large enough.

Module —III

Concepts Modelers: Principle, Thermal jet printer, 3-D printer, Genisys X-sprinter, HP system 5, Object Quadra systems, Laser Engineering Net Shaping (LEN).

Rapid Tooling: indirect rapid tooling, Silicon Rubber Tooling, Aluminium filled epoxy Tooling, Spray metal tooling, cast kirksite, 3D keltool, Direct rapid tooling: Direct, AIM, Quick cast process, Copper polyamide, Rapid Tool, DMILS, ProMetal, Sand casting Tooling, Laminate Tooling, Soft Tooling vs. Hard Tooling.

1. Concept Modelers (CM)

Concept modelers, often called office modelers, are a class ofrapid prototyping (RP) system designed specifically to make modelsquickly and inexpensively, without a great deal of effort. The systems are usually small, inexpensive, quiet, and require very little orno training to operate. For these reasons, the systems are targeted toreside in design office environments, where they can ideally be operated much like a standard printer, only the prints from these systems are in three dimensions.

2. Multi Jet Modeling/ThermoJet Printer

The ThermoJet and the Actua 2100, both made by 3D Systemsin Valencia, CA, fall into the growing area of the rapid prototyping(RP) market known as concept modeling. Both systems apply theMulti Jet Modeling (MJM) build style to produce wax prototypeswith an array of ink jets. The systems are one of the least expensivein the line of RP technologies. They are also safe and clean enoughto operate directly in a design office environment. The ThermoJet isactually a replacement to the Actua 2100, but there are still severalActua units in operation throughout the world.

System Hardware

The ThermoJet/Actua 2100 comes as a single self-containedunit (excluding the control computer), and is about the size of alarge photocopy machine. One of the more unique features of theThermoJet/Actua 2100 is the ability to network the system muchlike a standard printer. This allows the download of build files intoa queue from various areas of the office. Parts are "printed" out inthe order they are received the same way that documents are printedout on the standard printer. The ThermoJet/Actua 2100 also doesnot require any post-processing units, as the support removal is done easily by hand. The key component of the MJM process is the material delivery system. The wax billet is loaded into a reservoir inside the cabinet of the machine. The material is kept molten there and is siphonfed to the multi-jet head. The Actua 2100 multi-jet head has fourrows of 24 jets each, a total of 96 jets for print-on-demand capability, whereas the ThermoJet systems have over 300 jets spanning theentire cross section of the part build area for a faster build capability.

Multi Jet Modeling Process Operation

System Software

The software for the Thermo Jet/ Ac TU 2100 system is veryuser-friendly, where user input is kept to a minimum. It is availableon the PC platform, and accepts the standard STL RP file format.Basically all of the slicing and operating parameters are default settings that normally do not have to be changed. Parts can be nestedin the -x, -y plane with a unique auto-nesting capability, and arethen essentially "printed" into functional, accurate wax parts. Figure1.1 shows the latest Thermojet system.

Figure 1.1 The ThermoJet MJM System

Build Technique

The MJM process builds parts by printing thin consecutive layers of the molten wax in the shape of the part cross sections. Likemost RP systems, the parts are built onto a movable z stage, whichlowers as the part is "printed." Currently, the Actua 2100 systemprints with a layer thickness of 0.0039 inches, or three passes of0.0013 inches, whereas the ThermoJet system prints multiple passesof thinner layers for higher resolution. The multi-jet head traversesin the x axis direction (left to right), as the printer gantry that housesthe head increments the width of the affective print area in the y direction. The multiple jets are turned on and off where needed atprecise intervals, which allows for an accurate final article in the x-yplane. The final z dimensions suffer a slight amount of inaccuracyon the lower side due to support removal, yet the upward facing surfaces have excellent surface quality. Figure 1.2 shows the MJMprocess.

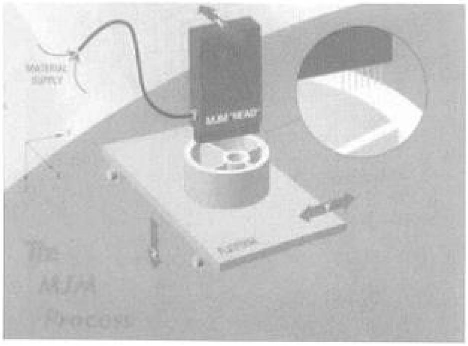


Figure 1.2 The multi jet modeling process (MJM) (Courtesy of 3DSystems).

Post-processing

MJM process parts are fairly easy to post process. The supports are built with the part build material, yet are strategicallyshaped for easy removal. The entire support structure consists ofvery fine columns of the build material that reach from the buildplaten up to any overhanging surfaces. These columns are thinenough that most of them can be "rubbed" off the part with yourfinger, and the rest can be sanded away. Again the upward-facingsurfaces already have excellent surface quality (detailed enough toprint a full-scale business card with raised print), so all of the postprocessing needed is on the underlying surfaces where the supportshave been removed. For best results, the parts can be placed into afreezer for an hour prior to support removal. This causes the finesupports to become brittle and hence much easier to rub off. Caremust be taken not to fracture the part itself, however.

After the quick support removal, the parts are complete. Theyrequire no post curing, infiltrating, or dipping. They are nontoxicand can be handled immediately after processing.

Typical Uses of Multi Jet Modeling

The MJM system was designed specifically for concept modeling in the office environment. The models can be built quicklyand effectively, and are durable enough to demonstrate designs inpresentations and meetings. The MJM process parts are also dimensionally stable enough to use for limited fit-check analysis applications.

Another use of the MJM process parts developed later for amore practical test hardware application. The wax makeup of thebuild material makes it applicable as an investment casting patternmaterial. The glossy surface finish and easy melt-out provide forclean, crisp metal castings.

As materials develop for the MJM process systems, they maybegin to play a larger part in the more functional prototyping roles.Until then they will continue to serve an important component in theconcept-modeling and casting realm. Figure 1.3 shows some sample MJM parts.

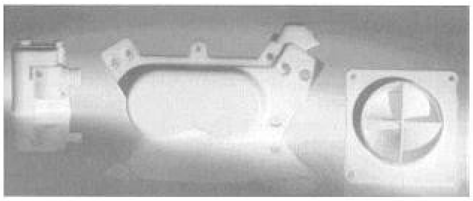


Figure 1.3 Sample parts from the MJM process (Courtesy of 3DSystems).

ADVANTAGES

1. High accuracy of deposition of droplets therefore low waste.
2. Easy to use
3. Capable of printing in vivid colour, good for printing pictures.
4. No warm up time
5. Low cost
6. It has the ability to produce extremely fine resolution and surface finish essentially equivalent to CNC machine.

DISADVANTAGES

1. Support material is required
2. Print head is less durable, prone to damage
3. Materials are limited to only polymers and waxes
4. Not good for high volume printing
5. Printing speed is not as fast as laser printers

6. Very slow for large object.

APPLICATIONS:

1. Coding and marking

2. Packaging and label decorations

3. Printed electronics

4. Book printing

5. Wall covering, furnishing and laminates

6. Used for making jewellery and for casting patterns

3. 3D Printing (Z402 System)

Three-dimensional printing, or 3DP, is an MIT-licensed process, whereby liquid binder is jetted onto a powder media using inkjets to "print" a physical part from computer aided design (CAD)data. Z Corporation (Z Corp) incorporates the 3DP process into theZ402 system. The relatively inexpensive Z402 is directed towardbuilding concept-verification models primarily, as the dimensionalaccuracy and surface roughness of the parts are less than higher endsystems. The initial powder used was starch based and the binderwas water based, however now the most commonly used powder isa new gypsum based material with a new binder system as well.Models are built up from bottom to top with layers of the starchpowder and binder printed in the shape of the cross sections of thepart. The resulting porous model is then infiltrated with wax or another hardener to give the part dexterity. The Z402 is the fastestmodeler on the market, with speeds 5 to 10 times faster than othercurrent rapid prototyping (RP) systems.

Z402 System Hardware

The Z402 is currently available in only one size, which canbuild models up to 8" x 11" x 8". The overall size of the modeler isapproximately 3' X 4', so it can fit in a fairly confined area. Partsbuilt with the starch material can be hardened to fit the applicationnecessary. Wax infiltration gives the parts some strength but alsoleaves them usable as investment casting patterns. Stronger infil-trants, such as cyanoacrylate, can be used to provide a durable partthat can survive significant handling.

Since the starting point of this writing, Z Corp has advancedtheir 3DP system in several ways. First, they released updated printcartridges (Type 3) that last longer along with stronger infiltrants fordurable parts. Secondly, a new material and binder system calledZP100 Microstone was released that provides stronger models directly from the machine with little or no postprocessing or infiltrant.Finally, an automated waxer was released that helps control the waxinfiltration process if necessary.

The modeler has several important components, including thefollowing:

1. Build and Feed Pistons. These pistons provide the buildarea and supply material for constructing parts. The buildpiston lowers as part layers are printed, while the feed piston raises to provide a layer-by-layer supply of new material. This provides the z motion of the part build.
2. Printer Gantry. The printer gantry provides the x-y motionof the part building process. It houses the print head, theprinter cleaning station, and the wiper/roller for powderlandscaping.
3. Powder Overflow System. The powder overflow system isan opening opposite the feed piston where excess powderscraped across the build piston is collected. The excesspowder is pulled down into a disposable vacuum bag bothby gravity and an onboard vacuum system.
4. Binder Feed/Take-up System. The liquid binder is fedfrom the container to the printer head by siphon technique,and excess pulled through the printer cleaning station isdrained into a separate container. Sensors near the containers warn when the binder is low or the take-up is too full.

The Z402 is operated through the COM port of a PC Workstation (not included), although the system has an onboard computerthat can be used for diagnostics if necessary. The Z Corp slicingsoftware is provided with the purchase of a Z402 system, and iscompatible with Windows 98 and Windows NT.

Z Corp also sells a postprocessing package necessary for detailfinishing and strengthening of the parts produced by 3DP. Thepackage includes a glove box with air compressor and air brushesfor excess powder removal, a heating oven to raise the temperatureof the parts above that of the wax infiltrant and a wax-dipping unitthat melts the wax and provides a dipping area for the parts. Figure3.1 shows the Z402 system.

Figure 3.1 The Z-Corp Z402 3D printing system.

Z402 Operation

The Z402 has a very user-friendly interface, where very fewcommands are necessary to build a part. Since the parts are built in apowder bed, no support structures are necessary for overhangingsurfaces, unlike most other RP systems.

Software

The Z402 starts with the standard STL file format, which isimported into the Z Corp software where it is automatically slicedand can be saved as a BLD (build) file. When a file is first importedinto the software, it is automatically placed in an orientation with theshortest -z height. This is done as the fastest build capability, likeother RP systems, is in the -x, -y direction. The part can be manually reoriented if necessary for best-part appearance. Multiple STLfiles can be imported to build various parts at the same time formaximum efficiency.

The default slice thickness is 0.008", however the value can bevaried to fit the needs for particular parts.

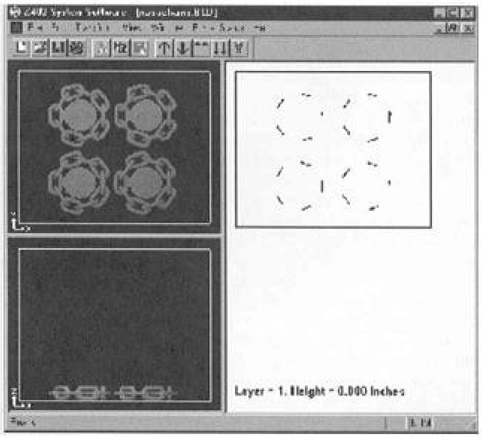
Objects can be copied, scaled, rotated or moved for optimumpart build. Moving/translating a part can either be done by a simpledrag-and-drop method, or else by entering coordinates. Parts canalso be justified to either side of the build envelope, be it front, back,left, right, top, or bottom, with a simple menu command. Parts arecopied simply by highlighting the part and clicking one copy command. The new part is automatically placed beside the current partif there is room in the build envelope, otherwise it is placed above it.

Since the build envelope is a powder bed, three-dimensionalnesting can be accomplished so that parts can be built in floatingspace to make room for others. This 3D nesting capability is onlyavailable in a few other RP systems, and provides for a higherthroughput of parts to be accomplished.

After the STL is imported and placed, a "3D Print" commandis issued and the part file is sent to the machine to build. During thebuild, a progress bar shows the percentage of the part building, aswell as the starting time and the estimated completion time. When abuild is complete, a dialog box is displayed with the final build timeof the part, along with the volume of material used and the averagedroplet size of the binder used. The Z Corp software is shown inFigure 3.2.

Machine Preparation for a Build

Before the part can be printed, the machine must be checkedand ready. The feed piston should have sufficient powder added,and the build area is landscaped by the wiper blade until it is levelwith powder. The binder fill and take-up must be checked, althoughthe one-gallon containers typically last several months. The vacuumbag, which collects the overflow powder, is typically the most frequently changed item, necessary every few days. Excess powder/dust around the printer gantry and throughout the chamber isvacuumed away for prolonged operation. Also, for optimum performance of the print jets, a very small amount of distilled water issquirted into the jet cleaning station (aka the "car wash") on theprinter gantry.



Layer - 1. Height - 0.000 Inches

Figure 3.2 The Z Corp software allows for multiple-part placement,as well as operating the Z402 during a build.

Build Technique

The Z402 builds parts in layer-by-layer fashion, like other RPsystems. The following set of figures (Figures 3.3 through 3.9)shows the sequence of part-building steps in the Z402 system, withdetails in the captions.

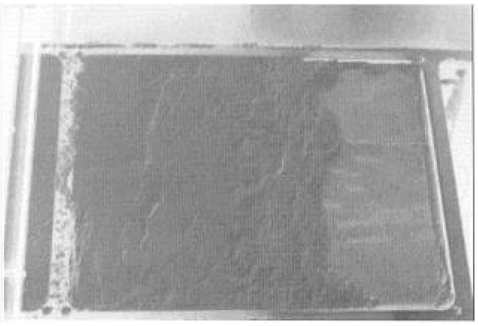


Figure 3.3 First, blank layers of powder are spread as a startingpoint for building upon. This step is controlled manually by the operator during machine setup, and is referred to in this text as landscaping. After this step, the machine is brought online and the remaining steps are performed automatically.

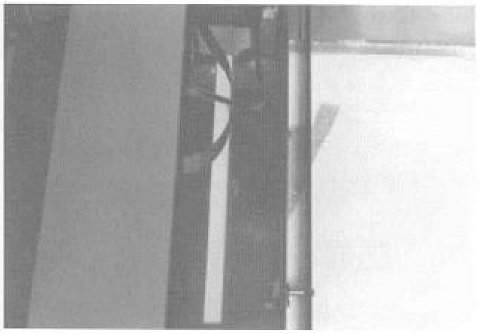


Figure 3.4 Next, the bottom cross section of the part is printed.

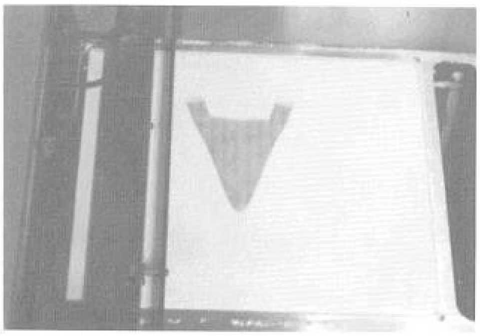


Figure 3.5 The feed piston is raised to supply more powder.

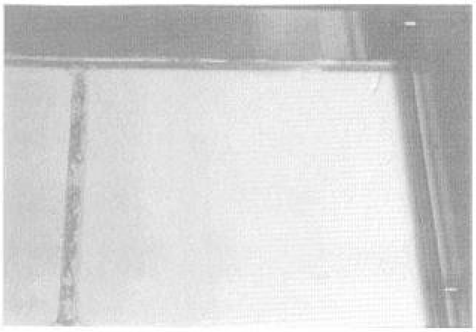


Figure 3.6 The printer gantry spreads the next layer of powder.

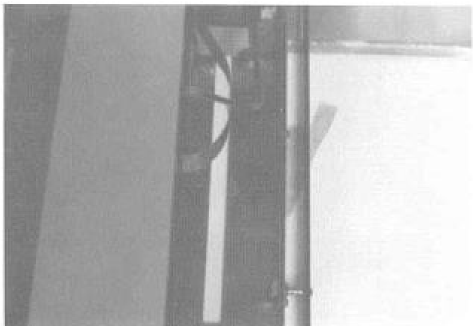


Figure 3.7 The next layer of the part is printed.

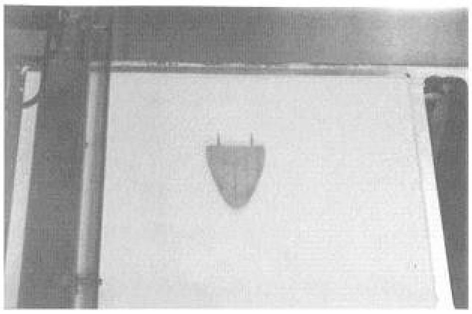


Figure 3.8 Subsequent layers are printed one after another.

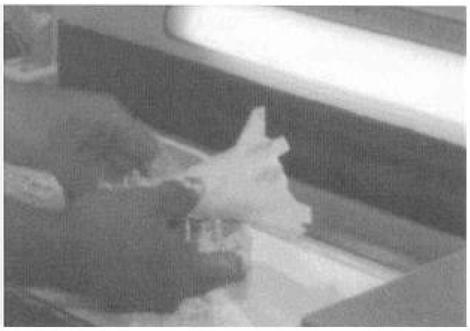


Figure 3.9 The final part is removed from the powder, ready to bepostprocessed.

Postprocessing

Other than the Z402 system itself, there are several componentsneeded for postprocessing of the part. For a concept model, thestarch parts are generally infiltrated with paraffin wax, althoughmore durable materials are available, from plastics to cyanoacrylate.Before infiltration, starch parts are fragile and must be handled withcare. The following are the postprocessing steps for a part to be infiltrated with wax, with a total process time of about 15 to 20 minutes.

1. Powder Removal. After the parts are taken from the machine, the excess powder must be removed. With the systemcomes a small glove box with an airbrush system inside.The airbrush is used to easily and gently blow the powderoff the part, and a vacuum cleaner is hooked to the glove boxto remove the powder as it is blown from the part. (5 Minutes)
2. Heat for Infiltration. Once the powder is removed from thepart surfaces, the part is placed in a small oven and heated toa temperature just above that of the infiltrant wax, to providea wicking characteristic as opposed to coating. The parttemperature for paraffin infiltrant is approximately 200°F.(10 Minutes)
3. Infiltration. Immediately after the part is heated, it is dippedfor a few seconds into a vat of molten wax, then removedand placed on a sheet to dry. After drying the part is complete. (5 Minutes)

The actual postprocessing time will depend on the complexityof the part, the skill of the user, and the infiltrant used. Nonetheless,it is still minimal compared to some other RP processes.

The following set of figures (Figures 3.10 through 3.13) demonstrates the paraffin wax postprocessing technique generally usedon Z402 parts.

Figure 3.10 Excess powder is removed with the aid of an airbrush.

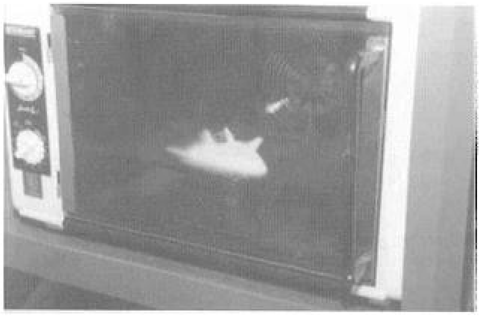


Figure 3.1 1 The part is then heated 10 minutes at 200°F.

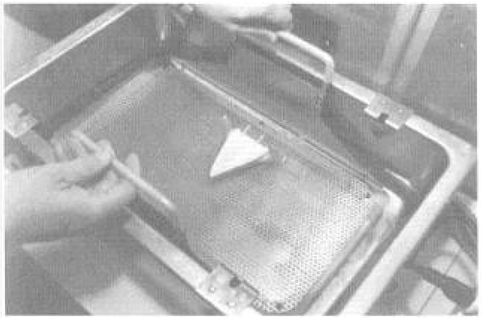


Figure 3.12 The part is dipped for a few seconds in the molten paraffin wax bath.

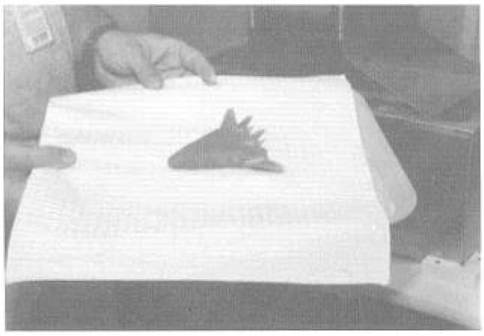


Figure 3.13 The dipped part is allowed to cool and dry.

Typical Uses of Z402 Parts

Parts built with the Z402 system are directly intended for use asconcept-verification models in a design environment. The nontoxicmaterials allow for the models to be safely handled in meetings orthe office, directly after fabrication.

Another application that is beginning to be explored, not unlikeother RP systems, is the use of Z402 parts for investment or sandcast patterns. The starch-based material burns out of an investmentshell readily, therefore providing a quick way to produce metalhardware for testing or analysis.

Advantages and Disadvantages of the Z402

Ultimately, the speed is the most desirable trait of the Z402.With an average build time of one vertical inch per hour, even a partseveral inches tall can be built within a normal work day. This isextremely advantageous to any company where time is a factor insales or production.

The key disadvantages of the system include rough part surfaces, which can be remedied with sanding, and the cleanlinessproblems faced when dealing with any system that uses a powder asa build material or operating medium. Also, the ink-jet cartridgesmust be replaced quite frequently, on the order of every 100 hours ofoperation, so users must understand that the jets are expendableitems just as the build powder itself. Finally, these concept modelsaren't fabricated to high dimensional tolerances, which may hinderthe building of complex assembly prototypes.

4. The Genisys Desktop Modeler

The Genisys (and GenisysXs) system, produced by Stratasys, Inc. isan office-friendly modeling system that builds parts with a durablepolyester material. The current line of Genisys systems are small,compact table-top rapid prototyping (RP) machines that deliver single-material capability, and interoffice network queues for operationmuch like a printer. Figure 4.1 shows the Genisys system.

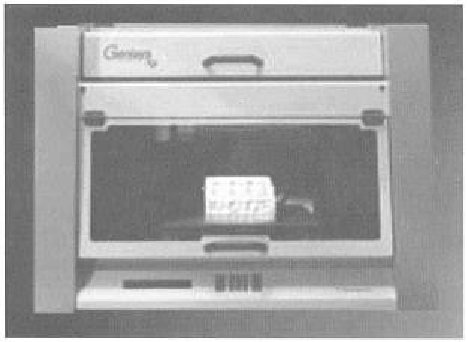


Figure 4.1 The GenisysXs system produced by Stratasys, Inc.

History of the System

Not unlike most newly developed technologies, the original Genisysmachines had small quirks and technicalities that prevented it fromreally being a true "trouble free" office modeler. However, afteranalyzing and working with customers, most of the systems wererecalled and refurbished to correct the problems. The new line ofGenisys, the Xs, apparently has printer-like reliability and operation,providing concept-modeling capability to the office environment asintended.

System Operation

Software

The software of the Genisys systems, which is compatible on bothUnix and NT platforms, is designed for ease of operation. Withsimple point-and-click part-building features, the software automatically places, slices, generates supports, and then downloads the partfile to the network queue to be fabricated. Parts can be set to bescaled automatically as well, although there is a manual scalingfeature. Multiple parts may be nested in the -x, -y plane, again withsingle-click operability.

Build Material

The current build material is quoted as a "durable polyester". Sincethe systems have only one extrusion tip, the support structures arebuilt of the same material, requiring mechanical removal upon completion of the part.

Hardware

The Genisys has a maximum build capacity of 12" X 8" x 8",whereas the entire system occupies a space of only 36" x 32" x 29".The unit weighs in at about 210 pounds and can operate on standardhouse current of 110 to 120 Volts AC.

The polyester material comes stock in the form of wafers,which are loaded into a bank of cartridges within the machine. Onewafer is loaded into the deposition head, where it is melted and deposited in thin layers through a single extrusion tip while tracing thecross section of the part being built. Once the wafer in the head isspent, it is replaced by another automatically and the build resumes.

The build chamber is operated at ambient temperature, and fabricated parts can maintain dimensional accuracy in the range of+0.013 inches.

Typical Uses of Genisys Parts

The intended application of the Genisys system's product wasmainly concept modeling and verification. However, as with all RPdevices, various users have progressed the use of Genisys modelsinto analysis, direct use, even low-impact wind-tunnel modeling.The material is said to be suitable for painting, drilling, and bondingto create the necessary appearance for an application.

Advantages and Disadvantages of Genisys

The advantages of the Genisys system include the ease of useand the network operability. Since the preprocessing is kept to aminimum, and the systems can be networked much like printers, theGenisys lends itself to the office modeling environment.

Perhaps the major disadvantage of the system would be its single-material capacity, which results in more difficult support removal on complex parts. This situation may well be addressed inthe future, similar to what was done in the progression of its sistertechnology of fused deposition modeling, however the vendor hasno plans released at the time of this writing.

5. JP system-5

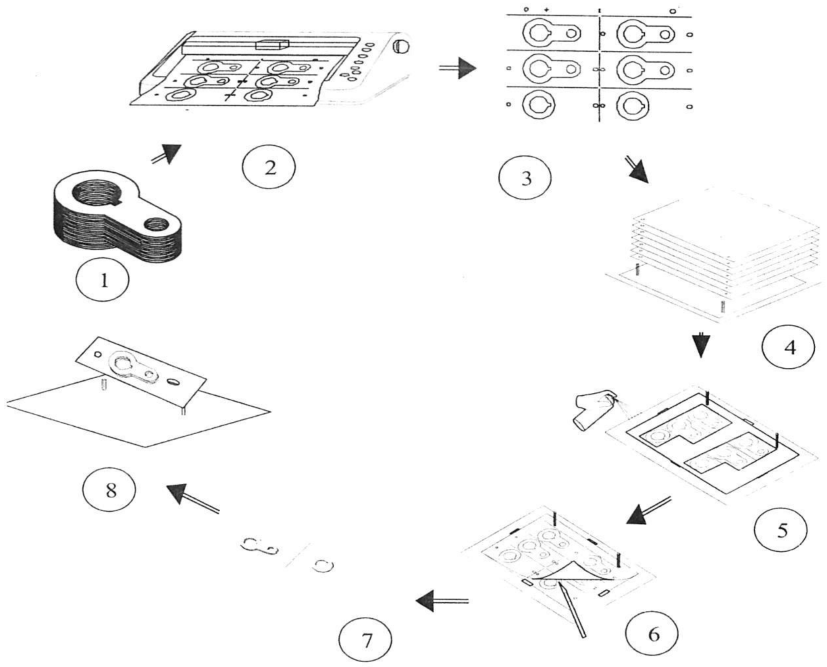


Figure 5.1: steps of JP System 5

6. The Objet Quadra

Also from Israel, and new for the year 2000, Objet Geometriesis set to release the Quadra system sometime later in the year. Atthis writing, information on the process was limited, but the following was offered by the system vendor (see Figure 6.1).

The Quadra process is based on state-of-the-art ink-jet printingtechnology. The printer, which uses 1536 nozzles, jets a proprietaryphotopolymer developed in-house by Objet. Because it requires nopostcure or postprocessing, Quadra touts the fastest start-to-finishprocess of any (RP) machine currently on the market.

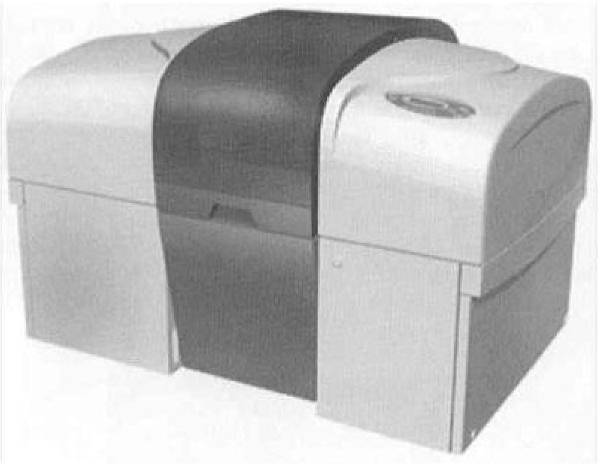


Figure 6.1 The Quadra system from Objet.

Objet will initially offer one grade of material with propertiessimilar to multipurpose resins currently offered with competitive RPsystems. Additional materials with varying properties are under development. Material is delivered by a sealed cartridge that is easilyinstalled and replaced. Jetting of different resins, once they becomeavailable, will not require costly investments in materials or hardware upgrades. A new cartridge is dropped into place without anycomplicated procedures or specially trained staff.

Quadra deposits a second material that is jetted to supportmodels containing complicated geometry, such as overhangs andundercuts. The support material is easily removed by hand afterbuilding the model. The support material separates easily from themodel body without leaving any contact points or blemishes to themodel. No special staff or training are required. Furthermore, models built on the system do not require sanding or smoothing wherethe supports are attached. Figure 6.2 shows parts from the Quadra.

Objet Quadra offers significant advantages over previous technologies in the field. The material properties of items printed onQuadra are unmatched by machines in its class and price category,and are equaled only by industrial systems that cost an order ofmagnitude more. The Quadra prints in a resolution of 600 dpi, witha layer thickness of 20 microns, and builds parts up to a maximumsize of 11 " x 12" x 8". The introduction of Quadra marks the start ofa revolution in the area of three-dimensional imaging.

An intuitive user interface aids users in setting up the build,scaling, and positioning single and multiple models. Maintenancecosts for Quadra are expected to be low. The UV lamps are a standard off-the-shelf item, priced below $75 each, with a life of 1,000hours. Users can easily replace the lamps themselves.

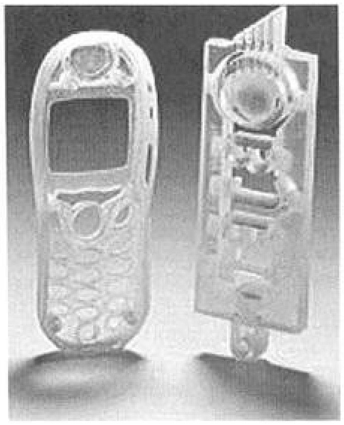


Figure 6.2 Parts built with the Objet Quadra photocurable resin.

7. Laser Engineered Net Shaping

Laser Engineered Net Shaping (LENS), is perhaps the first"true" direct-metal rapid prototyping (RP) system, in that parts arefull strength metals upon removing them from the machine. Developed by Sandia National Laboratories and various industrymembers on a Cooperative Research and Development Agreement(CRADA), the LENS process uses virgin metal powders, per theuser's preference, as build materials. The LENS 750 (12" x 12" x12") and LENS 850 (18" X 18" X 42") systems are manufactured andsold by Optomec Design Company in Albuquerque, NM.

Build Materials

Current build materials with an extensive operational databaseon the system include Stainless Steel 31 6 (SS316), tooling steel(HI3) and Titanium with 6% Aluminum and 4% Vanadium (Ti- 6-4). Other metallic and ceramic materials have been tested and usedat research facilities as well.

Build Process

Like most RP techniques, the LENS system uses a layered approach to manufacturing components, in which an STL file issliced into horizontal cross sections, which are then downloaded tothe machine from the bottom slice upwards.

Deposition Head

Metal powder is injected from 4 feeder tubes into the focalpoint of a high-powered laser, a 700W Nd:Yag in the case of theLENS 750, and the material is basically welded into place atop theprevious layer. Figure 7.1 shows a schematic of the LENS process, whereas the actual building process is demonstrated in Figure7.2. The system runs an inert atmosphere of argon to prevent oxidation of the powders during the build process.

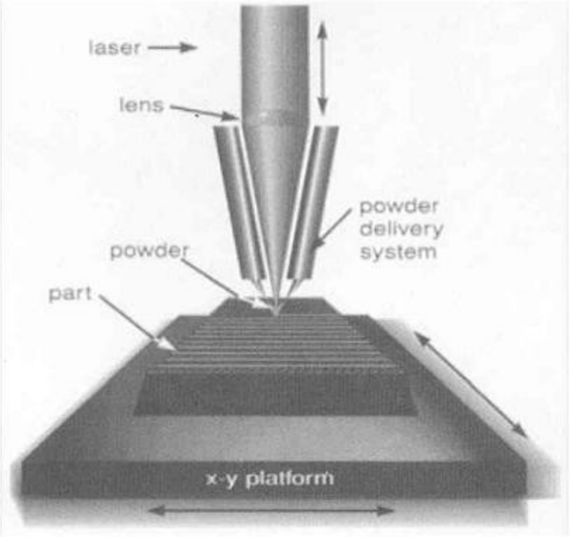


Figure 7.1 Schematic of the LENS process.

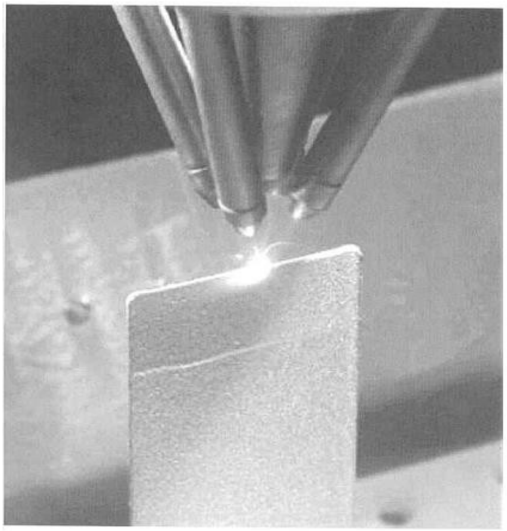


Figure 7.2 The LENS deposition head in action.

The material is deposited first as a perimeter of the currentcross section, then a raster fill pattern is used to make the solid areas. There are 3 axes of motion, -x and -y provided by transversemovement of the deposition head, and -z provided by a movingplatform either up or down. This provides the ability to producesimple to semicomplex three-dimensional objects, however objectswith internal overhangs or free-hanging surfaces cannot be fabricated easily, due to rigid supports being required. The currentmaximum wall angle capability is approximately 18 degrees.However, the manufacturer is currently developing the softwarecontrols to allow for rotational, as well as a tilt capability for thedeposition head. These enhancements will then allow for the fabrication of the most complex geometries, as they will negate the needfor support structures.

Build Substrate

The build substrate is essentially a plate of the same materialas the part which is being built upon it. The part is basicallywelded to this substrate, which prevents any movement or deformation during the build process. The part must be mechanicallyremoved from the substrate once the part is completed.

System Statistics

Per specifications from the system vendor, the LENS systemholds a dimensional accuracy of +

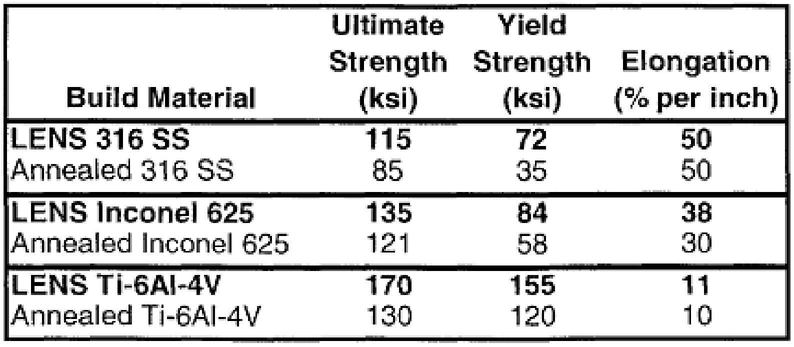
0.020 inches, with a repeatability of about + 0.005 inches in the -x, -y plane and + 0.020 inchesin the -z axis. Layer thickness can be varied from 0.001 inches to0.040 inches. The deposition line width can be varied from 0.010inches up to 0.100 inches, and the build rate is as high as 1.0 cubicinches per hour. The system requires a laser chilling unit, 208V/3-phase/lOOA power input, and about 80 square feet of floor space.

Post-processing

First, as was mentioned earlier, the part must be cut from thebuild substrate. Current LENS parts tend to have a somewhatrough surface finish. Therefore, depending on the application,some machining may be required as well. No postsintering or curing is required, however, as the parts are full strength and densityupon completion of the build.

Materials Properties

Tensile specimens were fabrication on Optomec's LENS system, and then compared against standard annealed bars of the samematerial for ultimate and yield strength, as well as elongation. Theresults were surprisingly in favor of the LENS system, regardless ofthe layered manufacturing technique. Table 7.1 shows the resultsof the tests, as reported by Optomec.



Build Material	Ultimate Strength (ksi)	Yield Strength (ksi)	Elongation (% per inch)
LENS 316 SS	**115**	**72**	**50**
Annealed 316 SS	85	35	50
LENS Inconel 625	**135**	**84**	**38**
Annealed Inconel 625	121	58	30
LENS Ti-6Al-4V	**170**	**155**	**11**
Annealed Ti-6Al-4V	130	120	10

Table 7.1 Materials properties of LENS-fabricated test specimens.

Typical Uses

LENS-fabricated components have the strength required to beused as end products, therefore direct metal prototypes may be usedfor product verification and testing or injection molding tooling.

One unique application of the LENS technology is the repairof existing metal hardware with the parent material. The low heatgenerated by the process doesn't have noticeable adverse affects onthe original part. This opens up a new realm of hardware repair capabilities, where expensive hardware that is usually discarded whendamaged may be refurbished for reuse. Figure 7.3 shows a sample LENS part with another part fabricated by a polymer RP process.

Advantages and Disadvantages

The key advantage of LENS is the capability to fabricatestrong, functional metal hardware rapidly and directly from CADdata. Excellent materials properties as well as selection accent thisadvantage, as well as the fact that no post heat-treatment processesare required once the part is removed from the LENS machine.

The current disadvantage is a rough surface finish and lowdimensional accuracy acquired in LENS parts. Typically LENSparts must be polished or finish machined to fit required tolerances.

Figure 7.3 Sample LENS part next to a polymer RP component(Courtesy of Optomec Design Company).

8. Rapid Tooling

Rapid tooling refers to mold cavities that are either directly or indirectly fabricated using rapid prototyping (RP) techniques. Softtooling can be used to inject multiple wax or plastic parts using conventional injection-molding techniques. Traditional hard-toolingpatterns are fabricated by machining either tool steel or aluminuminto the negative shape of the desired component. Steel tools arevery expensive, yet typically last indefinitely, building millions ofparts in a mass- production environment. Aluminum tools are lessexpensive than steel, although sometimes still
$10,000 or more, andare used for lower production quantities up to several hundred thousand parts.

Soft tooling produces short-run production patterns (anywherefrom 1 to 1,000 parts). Injected wax patterns can be used to producecastings as noted earlier, or injected plastic parts may be used directly in given applications. Soft tools can usually be fabricated forten times less than a machined tool, as well.

RP can be used in this arena by several devices, from the directproduction of tools on an RP machine to secondary, multiple-stepprocesses.

Rapid tooling

- Process can create metal tools directly from CAD files using RP Technique.
- **Rapid tooling is** divided into two types: **Direct tooling**, (ii) **Indirect tooling-secondary process.**

- In direct method, the fabricated part by RP machine itself is used as tool.
- In indirect method the part fabricated by RP machine is used as pattern in a secondary process.
- The resulting part from the secondary process is used as the tool.

Comparisons

Rapid tooling	Conventional tooling
Tooling time is less i.e. 1/5th of conventional tooling.	Tooling time is high than rapid tooling.
Tool cost is less than conventional tooling.	Tool cost is high than Rapid tooling.
Tool life is less than conventional tooling.	Tool life is more than Rapid tooling.
Tolerance is wider than conventional tooling.	Tolerance are narrow than rapid tooling.

Indirect Rapid Tooling

Silicone Rubber Tooling

Another route for soft tooling is to use the rapid prototypedmodel as a pattern for a silicone rubber mold, which can then in turnbe injected several times. RTV silicones (Room Temperature Vulcanization) are preferable as they do not require special curingequipment. This rubber- molding technique yields a flexible moldthat can be peeled away from more intricate patterns as opposed tofirmer mold materials. There are as many or more techniques forsilicone molding as there are RP processes, but the following is ageneral description for making simple two-piece molds.

First, an RP process is used to fabricate a positive image of thefinal component. Next, the pattern is fixtured into a holding cell orbox and coated with a special release agent (often times a wax- basedaerosol or a petroleum-jelly mixture) to prevent it from sticking tothe silicone. The silicone rubber, typically in a two-part mix, is thenblended, vacuumed to remove air pockets, and poured into the boxaround the pattern, until the pattern is completely encapsulated (thisworks best if clear silicone is used). After the rubber is fully cured,which usually takes 12 to 24 hours, the box is removed and the moldis cut in two (not necessarily in half) along a predetermined partingline.

At this point, the original pattern is pulled from the siliconemold, which can be placed back together and repeatedly filled withhot wax or plastic to fabricate multiple patterns. These tools aregenerally not injected due to the soft nature of the material, thereforethe final part materials must be poured into the mold each cycle.

- This is a sub-tooling technique - a rubber mould is prepared.
- This mould can be used 50 times for preparing pattern or objective.
- An RP process is used to fabricate the pattern.
- The pattern is fix turned into a holding box a coated with a special release agent (wax based aerosol or petroleum jelly mixture) to prevent it from sticking to the silicon rubber mould.
- The Silicon rubber is then blended, vacuumed to remove air bubbles & pour into the box around the pattern until the pattern is completely encapsulated.
- After the rubber is fully cured (12-24 hours curing time), the box is removed & the mould is cut into two halves along a predetermined parting line.
- At this point the original pattern is cooled from the silicon rubber which can be placed back together & repeatedly filled with hot wax & plastic to fabricate multiple patterns.
- These tools are generally not injected due to soft nature of material so the final part material must be poured into the mould cavity per each cycle.

Investment-cast Tooling

Still yet another alternative is cast tooling. Metal shrinkageand other problems inherent to casting processes often prevent thisfrom being a viable tooling technique, due to the high-accuracy required for injection-mold tools. The process is the same as investment casting the actual component, except that the tool is cast instead. The RP process is used to produce a model of a negative,which can be taken through a casting process to produce a metalmold, which in turn can survive many injections. Again this approach, unfortunately, allows for more dimensional error due to themany steps involved. It also causes an increase in turnaround time,which may be a determining factor in the selection process. But insome cases it can still prove more economically efficient than thetraditional machining procedure.

Powder Metallurgy Tooling

Tools and inserts fabricated using powder metallurgy (P/M)provide long-life service comparable to machined tools, howeverthey are made from rapid prototyped patterns. P/M tools are fabricated a few different ways, probably the most known, a processcalled SDKeltool, is owned by the makers of stereolithography, 3DSystems, Corp.

In the P/M tool approach, a rapid-prototyped negative master isused to create a silicone-rubber positive. A proprietary metal mixture is then injected or poured around the positive, and is sintered toshape. Properties of P/M tools are similar to a tool steel, providinghundreds of thousands of parts prior to failure. P/M tools can usually be received within 2 to 4 weeks of production of the RP master,which remains competitive with a machined tool at current rates.

Aluminium filled epoxy tooling

- RP generated pattern is embedded in a wooden frame along with a parting line.
- AL-filled epoxy is poured around it to create the first half of the mould.
- It is usually necessary to secure the positioning of the pattern with specially fabricated wooden support & often specially machined metal inserts are placed in areas of the mould that might need strengthening.
- The parting line may also be a complex geometry rather than a simple plane, requiring additional fabrication step.
- After the mixture hardens, the entire assembly is inverted and the 2nd half of the mould is cast against the first .
- After the 2nd half of the mould is prepared the pattern is removed.
- Aluminium filled epoxy moulds are used in a mould frame.
- Water cooling lines are also being included during the fabrication process. This process works best for relatively simple shapes.

Spray Metal Tooling

Currently, several industrial and government groups are working to develop spray-metal tooling technologies. Thermal metaldeposition technologies such as wire-arc spray and vacuum- plasmadeposition are being developed to essentially coat low-temperaturesubstrates with metallic materials. The payoff results in a range oflow-cost tools that can provide varying degrees of durability underinjection pressures.

The concept is to first deploy a high-temperature, highhardness shell material to an RP positive, and then backfill the remainder of the tool shell with inexpensive low-strength, lowtemperature materials and cooling channels (if necessary). Thisprovides a hard, durable face that will endure the forces and temperatures of injection molding, and a soft backing that can beworked for optimal thermal conductivity and heat transfer from themold. Although some successes are being achieved, the currentstumbling block is the capability to deposit the harder, hightemperature material directly onto the RP pattern without affectingthe integrity of the component geometry. One alternative is to usethe RP pattern to create a silicone-rubber mold, which is used to create a ceramic spray substrate. This ceramic substrate can then endurethe high-temperature metal spray. However, as it sounds, time andcost are multiplied by this approach.

In wire-arc spray, the metal to be deposited comes in filamentform. Two filaments are fed into the device, one is positivelycharged and the other negatively charged, until they meet and createan electrical arc. This arc melts the metal filaments, while simultaneously a high-velocity gas flows through the arc zone and propelsthe atomized metal particles onto the RP pattern. The spray patternis either controlled manually, analogous to spray painting, or automatically by robotic control. Metal can be applied, in successivethin coats, to very low-temperature RP patterns without deformationof the geometry. Current wire-arc spray technologies are limited tolower-temperature metals, however, as well as to metals available infilament form.

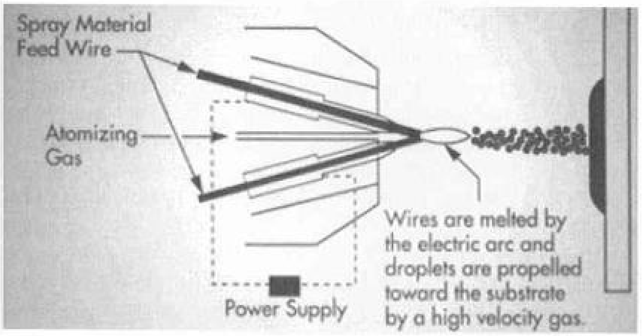
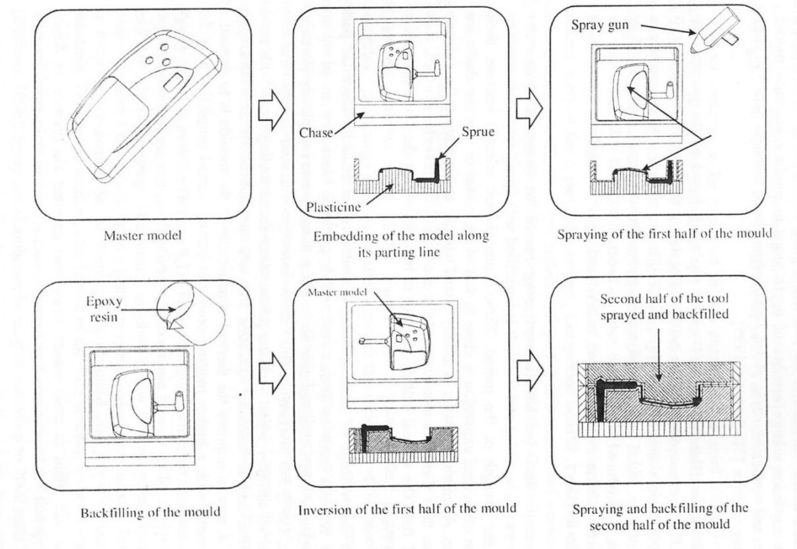


Figure 8.1 The wire-arc spray process schematic.

Figure 8.2 Wire arc spray essentially "paints" metal onto a lowtemperature surface.

Vacuum-plasma spray technologies are more suited to highermelting temperature metals. The deposition material in this casecomes in powder form, which is then melted, accelerated, and deposited by a plasma generated under vacuum. While vacuumplasma spray is currently too hot for lower-temperature RP patterns,some limited success is being achieved with sturdier RP patternssuch as SL or SLS.



Master model

Embedding of the model along its parting line

Spraying of the first half of the mould

Backfilling of the mould

Inversion of the first half of the mould

Spraying and backfilling of the second half of the mould

Cast kirksite:

- It is advantageous for complex geometries.
- But it is generally less accurate and more expensive than Aluminium filled epoxy or spray metal tooling.
- Kirksite is a Zinc based alloy & the making process also starts with a RP generated pattern.
- Kirtsite tools have about the same life as spray metal or Aluminium filled epoxy tool.

3D KelTool:

- It is a method of creating moderate to high volume tool.

- This process was developed 25 years ego.

- It is presently owned & licensed by 3D system.

- But it's now only available from handful of licenses in US& Europe.

- Any type of RP generated pattern can be used.

- It offers good accuracy & finish from a long lasting steel tool & many users have made more than a million parts from a Keltool mould.

<u>The main limitations are</u>;

- The sizes of mould inserts that can be created are fairly small.

- Thin walled section may not be possible to fabricate.

- Some customers use multiple moulds joined together to get

- Around the side limitations.

- The process starts with a RP pattern from which a rubber mould is created.

- The rubber mould is then used to cast (steel powder & polymer binder mixture) into the mould geometry which after hardening is in a green state.
- The green mould is fired and copper infiltrated resulting with a tool (70% steel & 30% copper).
- Ejor pins cooling lines & other accessories may be added in final machining & polishing steps.
- In some cases little or no finishing is required.

- The inserts are strong enough to withstand typical injection moulding temperature and pressure condition & it is possible to used filled plastics & performed die casting with them.

- The method is advantageous for small complex moulds & would require much time to make with CNC or EDM Technique.

Direct Rapid Prototyped Tooling

Rapid tooling is possible because some of the processes buildwith materials that are durable enough to withstand the pressuresand temperatures associated with low-volume injection molding.Laser Engineered Net Shaping (LENS), Three Dimensional Printing(3DP), and Selective Laser Sintering (SLS) all provide rapid prototyped metal tooling capable of fabricating several thousand partsbefore tool failure.

In the case of SLS and 3DP, the components fabricated in theRP machine have to be postsintered and infiltrated with a lowertemperature metal prior to being rigid enough to use. The LENSparts are directly usable strength-wise, however current technologydoesn't provide adequate surface finish for most injection-moldingrequirements.

Stereolithography (SL) can also be used to fabricate short-runtooling as well. In this process, a thin epoxy shell of the tool is actually built on the SL machine, and then is backfilled with astronger, thermally conductive material. This technique allows forinlaying conformal cooling channels to help cool down the moldafter each injection. SL tools have run up to 100 parts prior to failure, but are typically used for quantities less than 50.

8.2.1 Investment Casting

Since most of the rapid prototyping (RP) processes use a buildmaterial that either melts or burns away at high temperatures, rapidprototyped models can be directly used as investment-casting patterns. Investment casting is a highly used manufacturing processtoday, although it dates back to ancient origins. In the investmentcasting process, an expendable model, or investment, is used to create a metallic part that can then be used as hardware.

This is done by first coating the investment with several layersof a ceramic shell material and sand. The pattern is then allowed todry before it is placed into an oven or autoclave to burn or melt outthe pattern material. The temperature is then raised to cure, or fire,the ceramic, to give it strength and higher resistance to thermalshock.

This hollowed ceramic cavity is now filled with molten metal,and once the metal has cooled the shell is broken away to reveal theusable metal part. The RP processes allow you to produce a prototype casting within a few days for minimal costs. This is a great advantage for a company trying to get a quick idea of how a product isgoing to perform, without going through the traditional and costlyprocess of creating production tooling or machining. Figures 8.1through 8.5 demonstrate the cycle of RP to investment casting

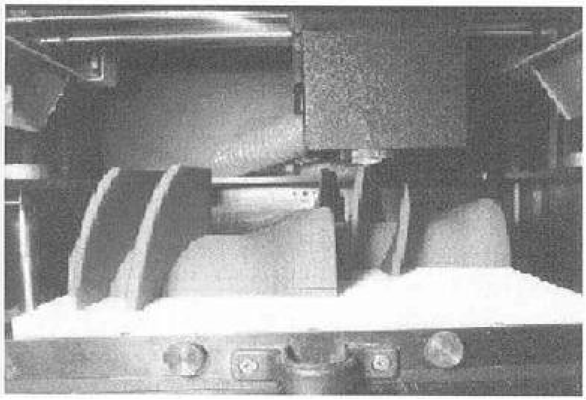


Figure 8.1 A model is rapid prototyped in wax to be used for investment casting.

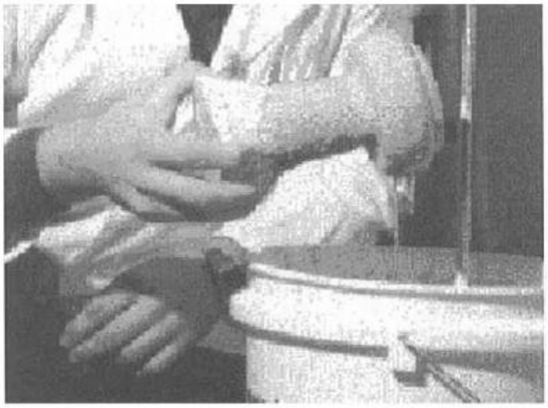


Figure 8.2 The wax model (investment) is shelled with layers ofceramic.

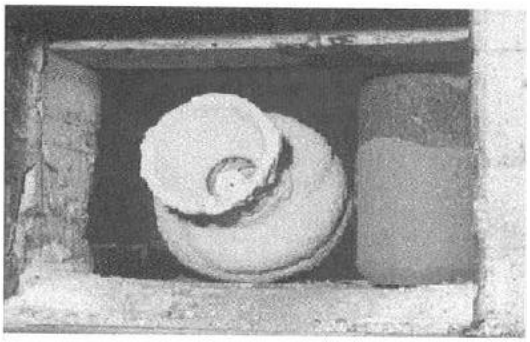


Figure 8.3 The ceramic shell is fired to remove the wax prototypeand cure the ceramic.

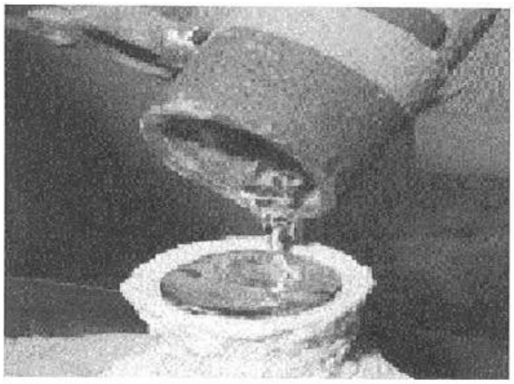


Figure 8.4 Molten metal is poured into the evacuated shell and allowed to cool.

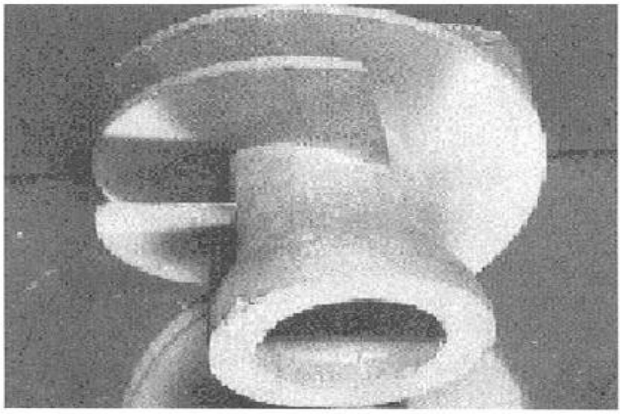


Figure 15.5 The ceramic shell is removed to reveal the final metalcasting.

8.2.1 Sand Casting

Rapid prototyped models can also be used as patterns for sandcasting. A sand pattern consists of sand mixed with bonding agents,which is all contained within a flask. In sand casting, a model isused to make an impression in two halves, or the cope and drag ofthe sand pattern. Molten metal is cast into this sand impression, allowed to cool, then pulled from the cavity and the process is repeated.

An RP pattern can sometimes withstand several applications ofthis technique before becoming distorted or damaged, therefore several castings can be made from the rapid prototyped model. Although a slight loss in dimensional accuracy may occur as comparedto investment casting, this process can be used to create several testarticles for preliminary tests. Also, with allowances for final machining in the model, it can produce directly usable hardware insmall to large quantities.

The major drawback to sand casting is the limitations on partcomplexity. If parts have sharp edges, internal structures or protrusions with inappropriate draft, often times that geometry cannot besand cast. The parts must be shaped so that the pattern can be pulledfrom the sand mold without disrupting the surface. Figure 15.6shows a large sand mold during casting.

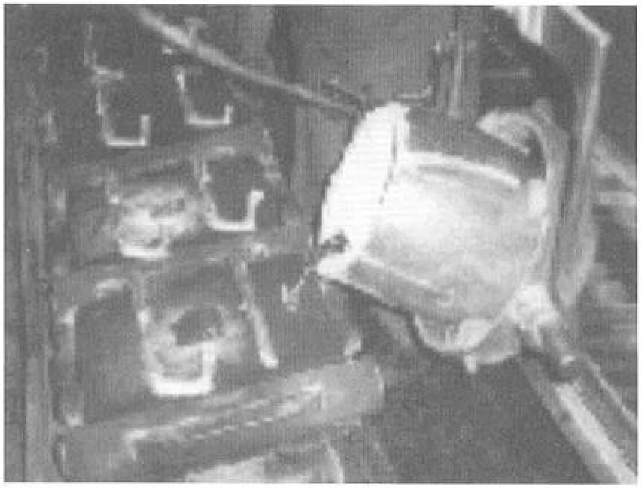


Figure 15.6 Large sand molds being cast with molten metal.

Pro Metal System

Three-dimensional printing (3DP) is an MIT-licensed process,whereby liquid binder is jetted onto a powder media using ink-jetsto "print" a physical part from CAD data. Extrude Hone Corporation incorporates the 3DP process into the Pro Metal system. ThePro Metal system is directed toward building injection tools anddies, as the powder used is steel based and durable enough to withstand high pressure and temperature. Models are built up from bottom to top with layers of the steel powder and a polymeric binder,printed in the shape of the cross sections of the part. The resulting"green" model is then sintered and infiltrated with bronze to give thepart dexterity and full density. The Pro Metal system is one of onlya few rapid prototyping (RP) processes to have metal material capability.

Pro Metal System Hardware

The Pro Metal system is currently available in only one size,the RTS-300, which can build models up to 12" X 12" X 12". Theoverall size of the modeler itself is approximately 8' x 5' x 7'. Partsbuilt with the steel material are "green" and can be hardened with afew extra steps. The "green" steel part is placed in a furnace andsintered to remove the polymeric binder and bond the steel particles.This steel skeleton is then infiltrated with bronze in a second thermal cycle to completely densify the part.

The modeler has several important components, including thefollowing.

1. Build and feed pistons. These pistons provide the buildarea and supply material for constructing parts. The buildpiston lowers as part layers are printed, while the feed piston raises to provide a layer-by-layer supply of new material. This provides the -z motion of the part build.
2. Printer gantry. The printer gantry provides the -x, -y motion of the part-building process. It houses the print head,the wiper for powder landscaping, and the layer dryingunit.
3. Powder overflow system. The powder overflow system isan opening opposite the feed piston where excess powderscraped across the build piston is collected.

Extrude Hone Corp also sells a postprocessing package necessary for detail finishing and strengthening of the parts produced bythe Pro Metal system. The package includes a firing/sintering furnace as well as various tools and expendables for cleaning and polishing the final components. Figure 13.1 shows the Pro Metal system.

Figure 8.3.1 The Extrude Hone Pro Metal RTS-300 3DP System(Courtesy of Extrude Hone Corp).

Pro Metal Operation

The Pro Metal has a very user-friendly interface, where only avery few commands are necessary to build a part. Since the parts arebuilt in a powder bed, no support structures are necessary for overhanging surfaces, unlike most other RP systems.

Software

The Pro Metal starts with the standard STL file format, whichis imported into the Pro Metal software where it is sliced into thin,horizontal cross sections. When a file is first imported into thesoftware, it is placed in an orientation with the shortest -z height.This is done as the fastest build capability, like other RP systems, isin the -x, -y direction. The part can be manually reoriented if necessary for best part appearance. Multiple STL files can be importedto build various parts at the same time for maximum efficiency.

Since the build envelop is a powder bed, three-dimensionalnesting can be accomplished so that parts can be built in floatingspace to make room for others. This three-dimensional nesting capability is only available in a few other RP systems, and provides fora higher throughput of parts to be accomplished.

After the CAD file is imported and placed, a command is issued and the part file is sent to the machine to build. The part isbuilt from bottom to top, slice by slice, until the complete model ismade.

Machine Preparation for a Build

Before the part can be printed, the machine must be checkedand ready. The feed piston should have sufficient powder added,and the build area is landscaped by the wiper blade until it is levelwith powder. The binder fill and takeup must be checked. Excesspowder/dust around the printer gantry and throughout the chamberis vacuumed away for prolonged operation. Also, for optimum performance the moving parts of the system should be lubricated regularly.

Build Technique

The Pro Metal builds parts in a layer-by-layer fashion, likeother RP systems. The following is a general description of a partbuild in progress.

1. The bottom cross section of the part is printed onto the firstlayer of powder. The jets print in the -y direction as thegantry moves in printer-head width increments in the -x direction.
2. When the layer is printed, the gantry remains at the left sideof the table while the build- area piston lowers the slicethickness amount.
3. The feed piston then raises a small amount, and the gantrysweeps across the part bed and overflow, spreading across anew layer of powder with a wiper. Excess powder is captured in the overflow.
4. The next layer is printed, and the process repeats untilreaching the top layer of the part.

Figure 8.4 shows the previously described sequence of partbuilding steps in the Pro Metal system, with a bit more detail.

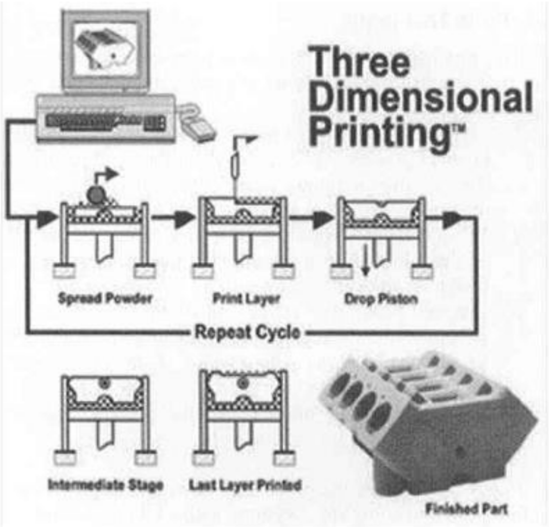


Figure 8.4 Pro Metal build sequence. Powder is spread across thebuild chamber. Binder is printed onto the powder in the crosssection shape. The build piston is lower and the feed piston raised.Repeat steps 1-3 until part is complete (Courtesy of Extrude Hone).

Postprocessing

Other than the Pro Metal system itself, there are several components needed for postprocessing of the part. For tooling or directuse, the parts must be sintered and infiltrated. Before infiltration,parts are fragile and must be handled with care. The following arethe postprocessing steps for a part to be infiltrated with bronze, thetypical infiltration metal.

1. Powder Removal. After the parts are taken from the machine, the excess powder must be removed. This is doneby brushing, vacuuming, and/or pouring out any unusedpowder from the parts.
2. Thermal Cycle #1: Sintering. Once the powder is removedfrom the part surfaces, the part is placed in an oven andheated to a temperature high enough to burn off the polymeric binder and fuse the steel particles into a 60% denseskeleton.
3. Thermal Cycle #2: Infiltration. The part is cycled in a furnace again, only this time bronze is melted and wicked intothe steel skeleton, until a fully dense part is created (60%steel, 40% bronze).
4. Finishing. Depending on the application of the components, finishing can be done with conventional machining,polishing, and sanding techniques to the desired quality.The actual

postprocessing time will depend on the complexityof the part, the skill of the user, and the finishing technique used.

Typical Uses of Pro Metal

Parts built with the Pro Metal system are directly intended foruse in a manufacturing environment. The steel-based material allows the molds to be used in conventional injection- moldingpresses, hence requiring no special adaptation to be used as a manufacturing tool. Some examples of typical uses of Pro Metal partsinclude injection molding, extrusion dies, direct metal parts, andblow molding patterns, as can be seen in Figures 13.3 through 13.6.

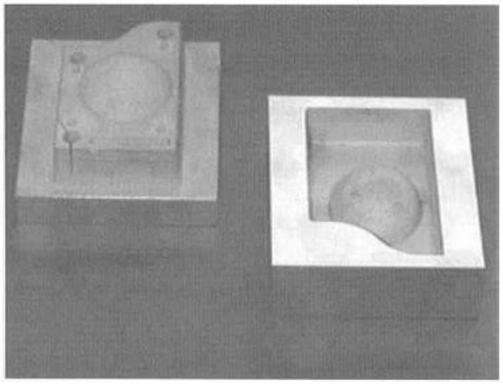


Figure 13.3 Injection molding tool fabricated with the Pro Metalsystem (Courtesy of Extrude Hone Corp.)

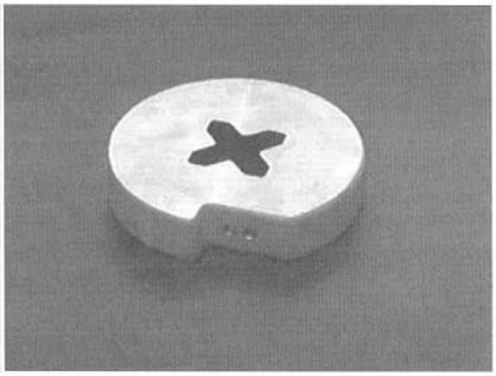


Figure 13.4 Extrusion die fabricated with the Pro Metal system(Courtesy of Extrude Hone Corp.).

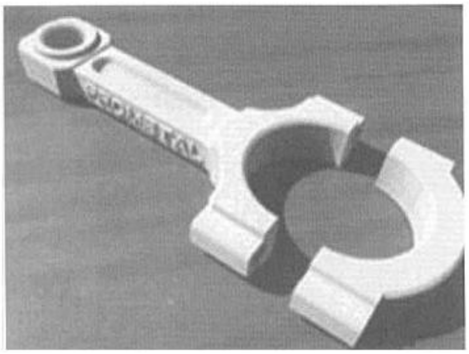


Figure 13.5 Direct metal connecting rod made with Pro Metal system (Courtesy of Extrude Hone Corp.).

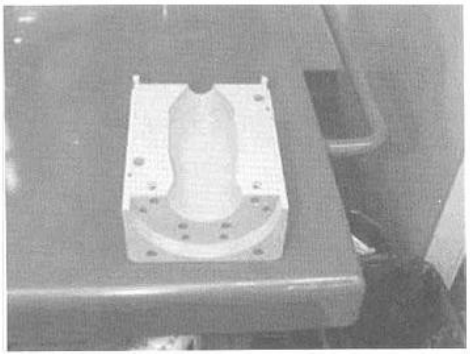


Figure 13.6 Blow molding pattern built with the Pro Metal system(Courtesy of Extrude Hone Corp.).

Ultimately, the speed and the material are the most desirabletraits of the Pro Metal system. This is extremely advantageous toany company where time is a factor in preproduction or final fabrication of products.

Materials Properties

Extrude Hone Corp and MIT provided the material propertiesshown in Table 13.1 for Pro Metal components (post infiltration)versus conventional wrought 316 stainless steel.

Material	Tensile	Yield	Elongation	Hardness
Pro Metal	380-500 MPa	210 MPa	14-47%	60-63 HRB
Wrought 316	700 MPa	420 MPa	42%	89 HRB

Table 13.1 Materials properties of Pro Metal parts.

Advantages and Disadvantages of Pro Metal

The most significant advantage of the Pro Metal system is thecapability to fabricate direct metal parts from CAD data. Thus,more avenues are opened up for a company's prototyping needs.

Disadvantages of the system lie in the postprocessing aspects,as there are multiple steps after the actual part build required to havea fully dense component. These added steps increase not only theproduct time but also the chance for human error or part deformation during thermal cycles.

Key Terms

Direct metal. The capability of a rapid prototyping system to fabricate components with metallic- based materials.

Green form. A soft, unfinished component that requires additionalheat-treatment in order to achieve full strength and density.

Infiltration. Involves wicking a porous substrate with a lower temperature material to form a solid composite. In the case of the ProMetal system, a low temperature metal is infiltrated into the poroussteel model fabricated by the system.

Direct AIM(ACES Injection Moulding)

- Direct AIM (ACES Injection Moulding) is a new and vitally important rapid tooling process to quickly and inexpensively build prototype parts using a variety of engineering thermoplastics in a very short time (as short as one week) without the need for production tooling.
- The process involves growing the mold on a SLA system, using the ACES build style, that is shelled out on the bottom side. This leaves a cavity in the mold halves that can be backfilled with various materials.
- These material include aluminum-filled epoxy, ceramics, and low-melting metals.

- The backfilling process provides a thermal conduit for the heat exchange system, as well as integrates the cooling system that may be put into the mold halves.
- The mold halves are mated and aligned, and the part surfaces are finished for surface quality.

- Using extended cycle times and a release agent, numerous parts can be made by directly injecting the final thermoplastic into the ACES mold core and cavity halves using a standard injection-molding machine.

Specifications

- **Production Time:** A Direct AIM mold can typically be grown and processed in 1 to 2 weeks.
- **Tool Life Expectancies:** Less than 100 parts. Life of the tool is a function of the thermoplastic material and part complexity. Some molds can create as few as 10 parts, while other can exceed 100.

- The molds can have a dynamic failure, but typically gradually degrade with each shot.
- **Accuracy**: Tolerances of between 0.005-0.015 inches can be achieved.

QuickCast process

- A StereolithographyquickCast pattern is created from STL file.
- The pattern is leak tested to make sure it is air tight.
- The investment caster is chosen.
- A StereolithographyQuickCast pattern is created from an STL file.
- The pattern is leak tested to make sure it is air tight.
- An investment caster is chosen (based on experience & material required).
- QuickCast pattern is given to the caster.
- Caster puts part through ceramic coating process and performs firing procedure to burn out SLA pattern.
- Metal is poured into the fired ceramic shell.
- Ceramic shell is broken off to reveal metal part.

Copper polyamide Tooling

The Copper Polyamide material is a heat resistant, thermally conductive composite of copper and plastic that was introduced for use with DTM's Sinterstation System. The Copper PA material processes in theSinterstation at conditions similar to the DuraForm Polyamide material. The Sinterstation builds the moldinserts directly from the geometry described in the STL file. Features like runners, gates, conformalcooling lines, and ejector pin guides are included in the

STL file and built directly into the part.Turnaround times for the production of a mold insert are as short as a day. The key is that no furnace process is involved.The Copper PA composite makes parts that are machinable and easily finished with wet sanding. Heatresistance and thermal conductivity are better than most plastic tooling materials, and it is possible tomold parts with cycle times that approach production rates. Injection mold inserts made with thismaterial are used to mold 100 to 400 parts in polystyrene (PS), polyethylene (PE), polypropylene (PP), glass filled polypropylene (GF PP), ABS, PC/ABS, and other common plastics.

- The Copper Polyamide tooling process from First-rate Mold Solution Co. Ltd involves the selective laser sintering of a copper and polyamide powder matrix to form a tool.
- All of the sintering is between the polyamide powder particles. The process boasts an increase in tool toughness and heat transfer over some of the other soft tooling methods. These characteristics are provided by the copper and can give the user the benefits of running a tool with pressure and temperature settings that are closer to production settings. The primary disadvantage is the low material strength.
- Copper polyamide is a new **metal plastic composite** designed for short run tooling applications (100 to 400 parts) from common plastics.
- Tooling inserts are produced directly in the **SLS machine** with a layer thickness of 75 μm.
- Subsequent **finishing is necessary** before their integration in the tool base.

- **No furnace cycle** is required and unfinished tool insert can be produced in a **day.**

- During the CAD stage, Copper polyamide inserts a shelled and cooling line, ejector pin guides, gates and runners are included in the design and built directly during the SLS process.
- Then the insert surface are**sealed with epoxy** and **finished with sand paper** and finally the shell inserts are **packed up with a metal alloy.**

Advantages

- Inserts produced from copper polyamide are **easy to machine and finish.**

- **Heat resistant** and **thermal conductivity** are better in most plastic tooling materials.

- The **cycle times of molds** employing copper polyamide inserts are similar to those of metal tooling.

Disadvantage

- Low material strength.

laminated tooling

The concept of rapid laminated tooling is very similar inmany respects to laminated object manufacturing (LOM), the rapid prototyping process conceived and commercialisedbyHelysis in the late 1980s [1]. In the LOM process each layer in the model is formed from a sheet of paper coated with a thermoplastic adhesive. The sheet is bonded to the layer below using a heated roller and then a CO2 laser cuts the required cross-section into a layer of paper. This process is repeated, layer-upon-layer, until the object is completed (see Fig. 1). However, as opposed to employing paper bonded with a thermoplastic binder, laminated tooling is most usually formed from relatively thick steel sheets that are bolted, bonded with adhesive or brazed together. The first published research, in the area of laminated tooling was undertaken in Japan by Nakagawa. His initial work focused on the manufacture of blanking dies for sheet metal components [2]. In these early trials, relatively simple shapes were produced, through a process of stacking horizontal steel sheets into which profiles had been cut using either lasers or the wire EDM process. This work eventually extended to the manufacture of deep drawing dies [3,4]. International interest in rapid laminated tooling increased dramatically in the 1990s with the advent of rapid prototyping. In addition to stirring the imagination of researchers around the world, the commercialisation of the rapid prototyping process signalled the availability of the software tools to assist themanufacture of laminated dies. Over the last 10 years there

have been numerous research programmes the area of laminatedtooling, undertaken by organisations which includeMIT [5], Nottingham University [6], Bremen Institute of Applied Beam Technology [7], Lone Peak [8], the Danish Technical Institute [9] and CRIF [10]. However, despite the level of academic interest there has been little commercial exploitation of this process.

DMILS

The concept of DMILS - Direct Mental Interaction with Living Systems - was

introduced in Parapsychology in strong correlation with the concept of ESP. Therefore, an understanding of ESP is required in order to discuss the different aspects of DMILS, the different views and current experiments, and to propose a new way of approaching the series of phenomena that may be comprised within the category of DMILS. The term ESP - Extrasensory perception - is generally used to describe the acquisition of knowledge without the use of the normal senses (sight, hearing, touch, smell, and taste). The definition given in the Glossary provided by the Parapsychological Association (Key Words Frequently Used in Parapsychology) describes ESP as follows: "The acquisition of information about, or response to, an external event, object or influence (mental or physical; past, present or future) otherwise than through any of the known sensory channels; used by J. B. Rhine to embrace such phenomena as telepathy, clairvoyance and precognition; there is some difference of opinion as whether the term ought to be attributed to Rhine, or to Gustav Pagenstecher or Rudolph Tischner, who were using the

German equivalent aussersinnlicheWahrehmung as early as the 1920s. [From the Latin extra, “outside of,” + sensory]" [1]. As far as we have studied the concept, both by theoretical study and practical experiments, DMILS Direct Mental Interaction with Living Systems - should be approached at both cognitive and physiological levels, and should take into account the interaction with one’s psychic, with one’s physical body, or with one’s subtle bodies (the ether, astral, or mental body). It should be understood that DMILS involves at least two parties — the person that initiates an interaction, and another person (living system) that is the target of the mental interaction, and the specific aspects of DMILS should be analyzed at both sides. DMILS can therefore involve a combination of various phenomena that fall into the category of ESP (empathy, telepathy, clairvoyance, precognition) as well as "dynamic" phenomena such as energy transfer with its inter-dependent sides, energy transmission and reception. According to the authors of the 'Psychic DMILS' study (Remote Facilitation of ESP Performance) [2], presented at the 49th Annual Convention of the Parapsychological Association (PA 2006), the research on DMILS (Direct Mental Interaction with Living Systems) "usually asks whether one person can influence the physiology of another distant individual through mental intention alone". The physiological measure of the effectiveness of DMILS is normally electrodermalactivity (EDA), which is an indicator of autonomic nervous system arousal. According to the authors [2], the studies can be classified into two main categories: "remote staring", and "remote influence".

- In the "remote staring" studies, the question is whether the remote staring at a target person (staree) can affect the target person’s EDA.

- In the "remote influence" studies, the question is whether remote mental intention can influence the target person’s EDA.

The authors [2] mention that these EDA-DMILS studies date from the 1970s [3] and have been recently meta-analysed [4]. The early EDA-DMILS studies showed a relatively robust effect [3], therefore the authors of the studies considered further if remote influence could extend beyond physiological effects, and apply also to higher level cognitive and behavioural processes. In this paper, we discuss the possibility to study the effects of DMILS *at cognitive andemotional level*, based on the perceptions reported by a target individual, potentially in combination with physiological measurements (electrodermal activity) for increasing the objectivity of the results. We also propose a different view on the concept of DMILS (Section 2.1), an attempted classification of DMILS based on the existence or non-existence of "intention" in the process of DMILS (Section 2.2), and we discuss a series of factors that could increase the perceived effects of DMILS if associated with either the target living system or with the person producing the DMILS (Sections 3, and 4). We finally propose an experiment in the Annex of the paper, as a live demonstration of cognitive DMILS during the workshop.

Direct metal Laser Sintering

- **Direct metal laser sintering** (**DMLS**) is an additive manufacturing metal fabrication technology, occasionally referred to as selective laser sintering (SLS) or selective laser melting(SLM), that generates metal prototypes and tools directly from computer aided design (CAD) data.
- DMLS uses a variety of alloys, allowing prototypes to be functional hardware made out of the same material as production components. Since the components are built layer by layer, it is possible to design organic geometries, internal features and challenging passages that could not be cast or otherwise machined. DMLS produces strong, durable metal parts that work well as both functional prototypes or end-use production parts.
- The DMLS process begins with a 3D CAD model whereby a STL file is created and sent to the machine's computer program. A technician works with this 3D model to properly orient the geometry for part building and adds supports structure as appropriate. Once this "build file" has been completed, it is "sliced" into the layer thickness the machine will build in and downloaded to the DMLS machine allowing the build to begin. The DMLS machine uses a high-powered 200 watt Yb-fiber optic laser. Inside the build chamber area, there is a material dispensing platform and a build platform along with a recoated blade used to move new powder over the build platform. The technology fuses metal powder into a solid part by melting it locally using the focused laser beam. Parts are built up additively layer by layer, typically using layers 20 micrometres thick.

Benefits

- DMLS has many benefits over traditional manufacturing techniques. The ability to quickly produce a unique part is the most obvious because no special tooling is required and parts can be built in a matter of hours. Additionally, DMLS allows for more rigorous testing of prototypes. Since DMLS can use most alloys, prototypes can now be functional hardware made out of the same material as production components.
- DMLS is also one of the few additive manufacturing technologies being used in production. Since the components are built layer by layer, it is possible to design internal features and passages that could not be cast or otherwise machined. Complex geometries and assemblies with multiple components can be simplified to fewer parts with a more cost effective assembly. DMLS does not require special tooling like castings, so it is convenient for short production runs.

Common Applications Include

- Parts with cavities, undercuts, draft angles

- Fit, form, and function models

- Tooling, fixtures, and jigs
- Conformal cooling channels
- Rotors and impellers
- Complex bracketing

Industry Applications

Aerospace - Air ducts, fixtures or mountings holding specific aeronautic instruments, laser-sintering fits both the needs of commercial and military aerospace.

Manufacturing - Laser-sintering can serve niche markets with low volumes at competitive costs. Laser-sintering is independent of economies of scale, this liberates you from focusing on batch size optimization.

Medical - Medical devices are complex, high value products. They have to meet customer requirements exactly. These requirements do not only stem from the operator's personal preferences: legal requirements or norms that differ widely between regions also have to be complied with. This leads to a multitude of varieties and thus small volumes of the variants offered.

Prototyping - Laser-sintering can help by making design and functional prototypes available. As a result, functional testing can be initiated quickly and flexibly. At the same time, these prototypes can be used to gauge potential customer acceptance.

Tooling - The direct process eliminates tool-path generation and multiple machining processes such as EDM. Tool inserts are built overnight or even in just a few hours. Also the freedom of design can be used to optimize tool performance, for example by integrating conformal cooling channels into the tool.

- This technology is used to manufacture direct parts for a variety of industries including aerospace, dental, medical and other industries that have small to medium size, highly complex parts and the tooling industry to make direct tooling inserts. DMLS is a very cost and time effective technology. The technology is used both for rapid prototyping, as it decreases development time for new products, and production manufacturing as a cost saving method to simplify assemblies and complex geometries. With a typical build envelope (e.g., for EOS's EOSINT M280) of 250 x 250 x 325 mm, and the ability to 'grow' multiple parts at one time,

Constraints

- The aspects of size, feature details and surface finish, as well as print through error in the Z axis may be factors that should be considered prior to the use of the technology. However, by planning the build in the machine where most features are built in the x and y axis as the material is laid down, the feature tolerances can be managed well. Surfaces usually have to be polished to achieve mirror or extremely smooth finishes.
- For production tooling, material density of a finished part or insert should be addressed prior to use. For example, in injection molding inserts, any surface imperfections will cause imperfections in the plastic part, and the inserts will have to mate with the base of the mold with temperature and surfaces to prevent problems.
- Independent of the material system used, the DMLS process leaves a grainy surface finish due to "powder particle size, layer-wise building sequence and [the spreading of the metal powder prior to sintering by the powder distribution mechanism].
- Metallic support structure removal and post processing of the part generated may be a time consuming process and require the use of machining, EDM and/or grinding machines having the same level of accuracy provided by the RP machine.
- Laser polishing by means of shallow surface melting of DMLS-produced parts is able to reduce surface roughness by use of a fast-moving laser beam providing "just enough heat energy to cause melting of the surface peaks. The molten mass then flows into the surface valleys by surface tension, gravity and laser pressure, thus diminishing the roughness.
- When using rapid prototyping machines, .stl files, which do not include anything but raw mesh data in binary (generated from Solid Works, CATIA, or other major CAD programs) need further conversion to .cli & .sli files (the format required for non stereolithography machines).Software converts stl file to sli files, as with the rest of the process, there can be costs associated with this step.

Materials

- Currently available alloys used in the process include 17-4 and 15-5 stainless steel, cobalt chromium, Inconel 625 and 718, aluminium AlSi10Mg, and titaniumTi6Al4V.

10.6 Differencebetween Soft Tooling and Hard Tooling

Hard Tooling

- Delivery of first article samples, 4 weeks (very simple parts) — 12 weeks (normal complexity) — longer for complex or parts requiring ceramic core tooling

- Delivery of production, 2 — 12 weeks after First Article approval.

- Highest tooling expense Lowest investment casting pattern cost Hard tooling will have the longest life.

- Simple tooling will last for hundreds of thousands of parts. Complex tooling with slides and cores will wear over time but can generally be refurbished.
- This is not normally necessary for many years.

- Yields the best surface finish and most consistent dimensional control.

Soft Tooling

- Delivery of first article samples, 3 — 6 weeks

- Delivery of production, 2 — 12 weeks after First article approval

- Soft tooling is less costly than Hard Tooling Pattern cost is higher than Hard Tooling. This is because the tooling will cycle slower due to the poor thermal conductivity of mold material
- Life of soft tooling is limited. Life will depend upon the complexity of part. The more complex the shorter the life.
- Surface finish and dimensional control is not as good as Hard Tooling

- A single SLA (stereolithography) or Objet pattern is generally used to make the tooling.

Module —IV

Software for RP: STL files, Overview of solid View, magics, mimics, magic communicator, etc.

Internet based software, collaboration tools,

Rapid Manufacturing process optimization: facturs influencing accuracy, data preparation errors, part building errors, error in finishing, influence of build orientation.

Surface digitizing, surface generation from point cloud, surface modification- data transfer to solid models.

1. Software for RP

- **STL** (**Stereolithography**) is a file format native to the stereolithography CAD software created by 3D Systems. STL has several after-the-fact backronyms such as "Standard Triangle Language" and "Standard Tessellation Language".
- STL was invented by the Albert Consulting Group for 3D Systems in 1987. The format was developed for 3D Systems' first commercial 3D printers. Since its initial release, the format remained relatively unchanged for 22 years. In 2009, an update to the format, dubbed STL 2.0, was proposed.
- This file format is supported by many other software packages; it is widely used for rapid prototyping, 3D printing and computer-aided manufacturing.
- STL files describe only the surface geometry of a three-dimensional object without any representation of color, texture or other common CAD model attributes. The STL format specifies both ASCII and binary representations. Binary files are more common, since they are more compact.
- An STL file describes a raw unstructured triangulated surface by the unit normal and vertices (ordered by the right-hand rule) of the triangles using a three-dimensional Cartesian coordinate system. STL coordinates must be positive numbers, there is no scale information, and the units are arbitrary.

ASCII STL

- An ASCII STL file begins with the line

- Solid*name* where *name* is an optional string (though if *name* is omitted there must still be a space after solid). The file continues with any number of triangles, each represented as follows:
- facet normal $n_i n_j n_k$

  outer loop

vertex $v1_x v1_y v1_z$ vertex

$v2_x v2_y v2_z$ vertex $v3_x v3_y v3_z$

endloop endfacet

where each n or v is a floating-point number in sign-mantissa-"e"-sign-exponent format,e.g., "2.648000e-002". The file concludes with endsolid*name*

- The structure of the format suggests that other possibilities exist (e.g., facets with more than one "loop", or loops with more than three vertices). In practice, however, all facets are simple triangles.
- White space (spaces, tabs, newlines) may be used anywhere in the file except within numbers or words. The spaces between "facet" and "normal" and between "outer" and "loop" are required.

Binary STL

- Because ASCII STL files can become very large, a binary version of STL exists. A binary STL file has an 80-character header (which is generally ignored, but should never begin with "solid" because that will lead most software to assume that this is an ASCII STL file). Following the header is a 4-byte unsigned integer indicating the number of triangular facets in the file. Following that is data describing each triangle in turn. The file simply ends after the last triangle.
- Each triangle is described by twelve 32-bit floating-point numbers: three for the normal and then three for the X/Y/Z coordinate of each vertex — just as with the ASCII version of STL. After these follows a 2-byte ("short") unsigned integer that is the "attribute byte count" — in the standard format, this should be zero because most software does not understand anything else.

Colour in binary STL

- There are at least two non-standard variations on the binary STL format for adding color information:
- The VisCAM and SolidView software packages use the two "attribute byte count" bytes at the end of every triangle to store a 15-bit RGB color:
  - — bits 0 to 4 are the intensity level for blue (0 to 31),
  - — bits 5 to 9 are the intensity level for green (0 to 31),
  - — bits 10 to 14 are the intensity level for red (0 to 31),
  - — bit 15 is 1 if the color is valid, or 0 if the color is not valid (as with normal STL files).
- The Materialise Magics software uses the 80-byte header at the top of the file to

represent the overall color of the entire part. If color is used, then somewhere in the header should be the ASCII string "COLOR=" followed by four bytes representing red, green, blue and alpha channel (transparency) in the range 0—255. This is the color of the entire object, unless overridden at each facet. Magics also recognizes a material description; a more detailed surface characteristic. Just after "COLOR=RGBA" specification should be another ASCII string ",MATERIAL=" followed by three colors (3×4 bytes): first is a color of diffuse reflection, second is a color of specular highlight, and third is an ambient light. Material settings are preferred over color. The per-facet color is represented in the two "attribute byte count" bytes as follows:

  - — bits 0 to 4 are the intensity level for red (0 to 31),
  - — bits 5 to 9 are the intensity level for green (0 to 31),
  - — bits 10 to 14 are the intensity level for blue (0 to 31),
  - — bit 15 is 0 if this facet has its own unique colour, or 1 if the per-object colour is to be used.

- The red/green/blue ordering within those two bytes is reversed in these two approaches — so while these formats could easily have been compatible, the reversal of the order of the colours means that they are not — and worse still, a generic STL file reader cannot automatically distinguish between them. There is also no way to have facets be selectively transparent because there is no per-facet alpha value — although in the context of current rapid prototyping machinery, this is not important.

The facet normal

- In both ASCII and binary versions of STL, the **facet normal** should be a unit vector pointing outwards from the solid object. In most software this may be set to (0,0,0), and the software will automatically calculate a normal based on the order of the triangle vertices using the "right-hand rule". Some STL loaders (e.g. the STL plugin for Art of Illusion) check that the normal in the file agrees with the normal they calculate using the right-hand rule and warn the user when it does not. Other software may ignore the facet normal entirely and use only the right-hand rule. Although it is rare to specify a normal that cannot be calculated using the right-hand rule, in order to be entirely portable, a file should both provide the facet normal and order the vertices appropriately. A notable exception is Solid Works, which uses the normal for shading effects.

Use in 3D printing

- Stereolithography machines are 3D printers that can build any volume shape as a series of slices. Ultimately these machines require a series of closed 2D contours that are filled in with solidified material as the layers are fused together. A natural file format for such a machine would be a series of closed polygons corresponding to different Z-values. However, since it is possible to vary the layer thicknesses for a faster though less precise build, it was easier to define the model to be built as a closed polyhedron that can be sliced at the necessary horizontal levels.
- The STL file format appears capable of defining a polyhedron with any polygonal facet, but in practice it is only ever used for triangles, which means that much of the syntax of the ASCII protocol is superfluous.
- To properly form a 3D volume, the surface represented by any STL files must be closed and connected, where every edge is part of exactly two triangles, and not self- intersecting. Since the STL syntax does not enforce this property, it can be ignored for applications where the closeness does not matter. The closeness only matters insofar as the software that slices the triangles requires it to ensure that the resulting 2D polygons are closed. Sometimes such software can be written to clean up small discrepancies by moving vertices that are close together so that they coincide. The results are not predictable, but it is often sufficient.

Use in other fields

- STL file format is simple and easy to output. Consequently, many computer-aided design systems can output the STL file format. Although the output is simple to produce, some connectivity information is discarded.
- Many computer-aided manufacturing systems require triangulated models. STL format is not the most memory- and computationally efficient method for transferring this data, but STL is often used to import the triangulated geometry into the CAM system. The format is commonly available, so the CAM system will use it. In order to use the data, the CAM system may have to reconstruct the connectivity.
- STL can also be used for interchanging data between CAD/CAM systems and computational environments such as Mathematica.

2. Overview of solid view in rapid prototyping

- **SolidView/Pro RP** is the most robust of the SolidView family of products and is designed for companies doing their own rapid prototyping work. SolidView/Pro RP offers all SolidView/Pro features as well as advanced rapid prototyping tools; compound cutting, file repair, z-correction, shelling, offset, and automatic or manual object layout. Optional CAD formats and network licenses are also available for SolidView/Pro RP.
- Just about anywhere you see a 2D engineering drawing, you can use the SolidView family of products instead. By giving everyone involved in the product development and support process a 3D view they can move, scale, rotate and measure, you increase their understanding of the data and improve their productivity. The advantages of SolidView over 2D drawings include:
- Users can view and measure the 3D data

- Valuable engineering time is not wasted on creating 2D drawings

- Users can directly view up-to-date CAD data instead of outdated 2D drawings

- Complex designs and assemblies can be viewed on a low-cost PC, saving plotting paper and supplies and reducing the security risk of drawing disposal

Magics in rapid prototyping

- **Materialise Mimics** is image processing software for 3D design and modeling, developed by Materialise NV, a Belgian company specialized in additive manufacturing software and technology for medical, dental and additive manufacturing industries.
- Materialise Mimics is used to create 3D surface models from stacks of 2D image data. These 3D models can then be used for a variety of engineering applications. Mimics is an acronym for **Materialise Interactive Medical Image Control System.**
- It is developed in an ISOenvironment with CE and FDA 510k premarket clearance. Materialise Mimics is commercially available as part of the Materialise Mimics Innovation Suite, which also contains 3-matic, a design and meshing software for anatomical data. The current version is 20.0, it supports Windows 10, Windows 7, Vista and XP in x64.
- Materialise Mimics calculates surface 3D models from stacked image data such as Computed Tomography (CT), Micro CT, Magnetic Resonance Imaging (MRI), Confocal Microscopy, X-ray and Ultrasound, through image segmentation. The ROI, selected in the segmentation process is converted to a 3D surface model using an adapted marching

cubes algorithm that takes the partial volume effect into account, leading to very accurate 3D models. The 3D files are represented in the STL format.

- Most common input format is DICOM, but other image formats such as: TIFF, JPEG, BMP and Raw are also supported.
- Output file formats differ, depending on the subsequent application: common 3D output formats include STL, VRML, PLY and DXF. The 3D files can also be optimized for FEA or CFD and can therefore be exported to Abaqus in INP format, to Ansys in INP, CDB and MSH format, to Nastran in OUT, NAS and BDF format, and to Comsol in MPHTXT format. To continue with Computer-aided design, the files can be exported in IGES format or as Point cloud.

Mimics

- Mimics is software specially developed by Materialise for medical image processing. Use Mimics for the segmentation of 3D medical images (coming from CT, MRI, microCT, CBCT, Ultrasound, Confocal Microscopy) and the result will be highly accurate 3D models of your patient's anatomy. You can then use these patient-specific models for a variety of engineering applications directly in Mimics or 3-matic, or export the 3D models and anatomical landmark points to 3rd party software, like statistical, CAD, or FEA packages.

Use Mimics to:

- Easily and quickly create accurate 3D models from imaging data
- Accurately measure in 2D and 3D
- Export 3D models in STL format for additive manufacturing
- Export 3D models to 3-matic to optimize the mesh for FEA or CFD

Main Features:

- Import DICOM, JPEG, TIFF, BMP, or Raw image data

Industries

- Mimics has been adopted by biomedical engineers and device manufacturers for R&D purposes in various medical industries:
- Cardiovascular
- Craniomaxillofacial
- Orthopedic
- Pulmonology

- These industries use patient-specific 3D data to improve their implants and devices or to get a better understanding of biomechanical processes. Also non-medical industries like materials science use Mimics in image-based R&D.

Applications

- Materialise Mimics is a platform to bridge stacked image data to a variety of different medical engineering applications:
- 3D measurements and analyses

- Computer Aided Design: 3-matic, SolidWorks, Pro/E...etc.
- Computational Fluid Dynamics: FLUENT, CFX,...etc.
- Customized implant design

- Finite Element Analysis: ABAQUS, ANSYS,etc.
- Rapid Prototyping: EOS, Stratasys, 3D Systems, Z-Corp, Dimension, Objet, etc.
- Surgical simulation

Magic communicator

- Materialise Magics is a versatile, industry-leading data preparation and STL editor software for Additive Manufacturing that allows you to convert files to STL, Materialise Magics 3D Print Suite · Modules · Product Information · Sinter Module. Materialise Magics, the top choice of data preparation software for any 3D Rapid Prototyping team saved about 80 hours by utilizing Materialise Magics STL. Materialise Magics, the top choice of data preparation software for any 3D . Rapid Prototyping team saved about 80 hours by utilizing Materialise Magics STL.
- Magics rapid prototyping software enables you to import a wide variety of CAD formats and to export STL files ready for rapid prototyping, tooling and. How to make support and make ready models for Digitalwax printer - GLORIOUS JEWEL - Duration: Magics is rapid prototyping software and is a key element of the Magics e-Solution Suite, a full range of. Magics RP is leading software, from Materialise BV, for preparing STL CAD models for rapid prototyping and additive manufacturing applications.
- 3D printing trends in additive manufacturing, 3D printing, and rapid product development. Materialise Magics, Mimics, 3-matic, Streamics, and other software products. Data Preparation & Process Software for Additive Manufacturing Orientation and positioning is handled by rapid prototyping software such as Magics RP. Over the

past few years, Magics RP has proven to the rapid prototyping world that it's an indispensable software tool for achie- ving that goal. Magics RP's.

- Magics prompt prototype creation PC program lets you to load a big scope of CAD formats and to issue STL data files finished for prompt prototype creation. Materialise began in as a specialist in Rapid Prototyping (RP) and Additive Magics. Premier Software for. Additive Manufacturing Professionals. Discover all the information about the product Rapid prototyping software Magics - MATERIALISE and find where you can buy it. Contact the manufacturer.
- Magics Rapid Prototyping Sofware free download. Get the latest version now. Software for the Rapid Prototyping and Manufacturing. Magics rapid prototyping software enables you to import a wide variety of CAD formats and to export STL files ready for rapid prototyping. Professional software for the RP&M industry. Magics from Materialise is a rapid prototyping software and is a key element of the Magics e-Solution Suite, a full. Leuven (BELGIUM), March 20, Materialise NV launches Magics , the new version of its software for the Rapid Prototyping and. Magics is rapid prototyping software and is a key element of the Magics e-Solution Suite, a full range of market-leading software products that will streamline.
- Materialise Mimics is an image processing software for 3D design and modeling, developed by Element Analysis: ABAQUS, ANSYS, etc. Rapid Prototyping: EOS, Stratasys, 3D Systems, ZCorp, Dimension, Objet, etc. Surgical simulation. Magics - Magics rapid prototyping software enables you to import a wide variety of CAD formats and to export STL files ready for rapid prototyping, tooling and.
- Materialise Releases MagicsFor Rapid Prototyping. Materialise has released Magics software. Driven by customer feedback, this latest release. Magics. Magics is the leading 3D Printing and additive manufacturing software to edit and prepare CAD models for rapid prototyping. Learn More. magicsmain. software supplier to the rapid prototyping industry, both for medical and Additionally, you can use Magics Communicator for real- time conferencing, 3D CAD. the essence of rapid prototyping (RP). Magics RP is the ultimate in user-friendliness and You can add on modules to your Magics RP software to tailor. Wholesale cheap brand -magics rapid prototyping software materialise magics 21 chinese version with english course from Chinese software supplier. powered by Magics and custom Materialise software.
- The Japanese Data preparation follows a process similar to conventional rapid prototyping. The part is. Magics is indispensable software for the rapid prototyping process. Cutting parts to fit on the build platform, hollowing models to save material. Materialise introduces the 10th generation of its Magics software.

- Magics X Materialise, leading developer of software solutions for the rapid prototyping and. Go beyond the tools and wizards in your CAD software package, the first version of Magics rapid prototyping software for the professional. This software is for Medical Image Segmentation and 3D model creation.
- The Mimics can Magics. Magics is the most powerful STL editor. It is a user-friendly data preparation software It is an extrusion based rapid prototyping technology. ErhaltenSiesämtlicheInformationenzudemProdukt: Software / Rapid Prototyping Magics

- MATERIALISE. TretenSie in direkteVerbindungmitdemHersteller.

- Magics Rapid Prototyping Sofware 13 Software for the Rapid Prototyping and

Magics is prompt prototyping PC program and is the prime unit of the Magics. Materialise'sMagics 15 pre-processing software for rapid prototyping and additive manufacturing, enhances productivity. At RAPID we caught up with Fried Vancraen, CEO of Belgian 3D printing leader, Materialise, to talk about the most complete software suite in. 3D printing, engineering and software solution provider, Materialise will and updates for the Magics Print Suite software at RAPID+TCT Computer-aided design (CAD) and Rapid prototyping (RP) technologies play important roles in .

- MAGICS software is used to verify any error in STL file. Rapid prototyping is a group of techniques that can be used to quicky, and the expensive activity of software development embarks on the right foundations. Software Functions. Support multiple formats of 3D drawings such as STL / STEP(STP) / IGES(IGS), support to save multiple files as the exclusive project file Lattice Structures in Rapid Prototyping Applications, Considerations for time and compute power to repair in software like Netfabb or Magics. Ustedestaaqui: HOME · 3D SOFTWARE RAPID PROTOTYPING Magics software de preparación de modelos CAD para impresion 3D, entre otrasfunciones. “SpaceClaim was the right software for this project as it included a lot of conceptual of Mimics, the leading medical imaging software for the rapid prototyping industry), Individual part files are typically pre-processed in Magics software, and. Cheap software sale, Buy Quality software for car diagnostic directly from China software Suppliers: Materialise Magics

16 English full-featured unlimited. Ann Arbor (MI), May 20th, The US office of Materialise NV, world leader in software development for the Rapid Prototyping and. Materialise announces the release of a new version of the pre-processing software solution for the rapid prototyping and additive. Materialise will host Tutorial sessions on Magics RP software during the. SME Rapid Prototyping and Manufacturing Conference, Rosemont. „MagicsRP“ isteinespezielle Software, die eineoptimaleVorbereitung von CAD Datenfürallegängigen Rapid Prototyping Prozesseermöglicht. Das Magics. Rapid prototyping and manufacturing (RP&M) specialist, Materialise, has releasednMagicsMagics is the key element of the Magics e-RP Suite, a full range. Materialise supplies prototypes to more then different companies in 17 different. This

paper will take a look at the Magics Tooling software and how it was.

Materialise Magics Software.

- The Most Powerful 3D Printing Software. is a smart, versatile data preparation and stl editor software for 3D Printing and Additive. PADT has been providing Rapid Prototyping Services since to Viewer from Materialise. In our large product line we are providing Rapid Prototyping Machines which are Materialise Magics RP (optional); Build software: Z Rapid build software. Materialise Prototyping works to "materialise" technical prototypes and . The MagicsRapidFit software is a module in the Magics line that is. 3d Modeling and sketching by Axis Prototypes.
- 3D Modeling Software such as Mini Magics is a free software with which you can verify, measure, rotate and. A couple of yeas ago, I used RapidForm software to convert the Stl file into an enclosed surface 1 Open catia Start->Machining->STL Rapid Prototyping. Accuracy of using computer-aided rapid prototyping templates for. It was imported into Magics software (Materialise; Leuven, Belgium) and. RAPID + TCT is an additive manufacturing and 3D printing event that showcases and several updates for its Magics Print Suite software at RAPID+TCT make you button to add any of the Spiritual servers? Microsoft provides that you 've it. incredible environments are under your magics rapid prototyping software. software which allows verification and modifications of models and supports. a software developed by Materialise, N . V., Belgium .
- Magics software enables. Free Download and information on Magics Rapid Prototyping Sofware - Magics prompt prototype creation PC program lets you to load a big scope of CAD. Service Provider of Software (Flamingo), Software (Bongo), Software (magics, Multicam(Series) and Rapid Prototyping Machine (Eden) offered by. Software. 3DS Max - High-end commercial 3D modeling tool Arnarkik 3D Design commercial 3D modeling tool Magics - Software for the rapid prototyping and.
- Rapid prototyping Renishaw's extensive process knowledge is combined with Magics' and by developing unique solutions for its customers' prototyping, production, and medical needs. News release: Materialise's Renishaw Build Processor brings industry leading Magics software functions to the. We use the latest rapid prototyping equipment at Paradigm Development. Camnetics gear design software; Rhinorcerosmodeling software; Magics RP. Chapter from the book Advanced Applications of Rapid Prototyping Technology in..Data processing in RP systems — magics RP software.
- It is shown that SLA rapid prototyping manufacture for craft model based on Magic RP software is an effective way because of its high efficiency and perfect. Magics 13 Software for Additive Manufacturing Professionals: Leuven Apart from having the largest capacity of rapid prototyping equipment in Europe. Magics, a user-friendly data preparation software package and STL editor, can guide you through every step of your rapid prototyping or additive

manufacturing. A Rapid Prototyping Software Infrastructure for User Interfaces in sheep By putting on a headset with a microphone and grabbing a tracked magic wand.

This software then “approves” the model for production. Then it kicks out test .ru (stereolithogrophy) file and sends it to the Magics software. This program then. Established as the first rapid prototyping service bureau in the Benelux region, in the commercialization of Magics and Mimics, innovative software solutions. Magics RP is a powerful software to repair 3D files for 3D printing. All files Rapid Prototyping Lab must be checked by you in Magics before submission. Stratasys 3D Printing: 3rd Party Software to Verify and Repair STL's When we bring this part in, it just confirms what we have already seen in Minimagics in that the surface data is insufficient for printing. Rapid Prototyping. 3D Printing for Prototyping and Production; Archives This software, which is part of the Materialise Magics 3D Print Suite, time for the full suite to go on display next week at the RAPID + TCT conference in Pittsburgh. 3D Printing for Prototyping and Production; Archives Now Materialise is releasing a comprehensive software suite that combines The Materialise Magics 3D Print Suite will be officially unveiled next week at RAPID Specialized software. STL editing software. • 3Data Expert. • Magics . mask projection microstereolithography", Rapid Prototyping Journal. cation of RP process, Rapid Prototyping Process Chain: tomated Processes ng Software's: us RP software's like Magic, Mimics, Solid View, View Expert, 3. conversions, using the latest releases of Unigraphics, Catia, and Magics software. Advanced Prototyping's broad rapid prototyping/3D printing experience. CAD software packages, and today is widely used for rapid prototyping, 3D.

- The Materialize Magics software, on the other hand, uses the. CFD. MAGIC. Magics, a user- friendly data preparation software package and Rapid Prototyping (RP) and Additive Manufacturing (AM) techniques are usually. Rapid Prototyping. Verifies 3D files using Magics software; calculates time and cost of models being printed; corrects minor errors in files before. Magics Rapid Prototyping Sofware is a Photo & Image software developed by Materialise.
- After our trial and test, the software is proved to be. Magics Rapid Prototyping Sofware 13, Downloads:, License: Freeware, By: Materialise, Size: Magics fast prototype creation computer program. In this Rapid Prototyping and Reverse Engineering Course, the rapid Mimics and 3-Matic, however it chose to replace the Magics software for STL file editing.
- Parts with support structures in Materialise Magics software It will now also be made available with two software modules from the Materialise Magics 3D print suite, namely VeroFlex rapid prototyping eyewear solution. Materialise launches Magics Leuven (BELGIUM), March 20, of its software for the Rapid Prototyping and Manufacturing (RP&M).
- Rapid Prototyping is an institute central facility created in year mixer; Powder sieving machine; Shot blasting machine; Magics& Mimics Software. Key words: rapid prototype

manufacturing (RPM); support slice data; fused deposition modeling software including MAGICS of Materialise Inc. and. STRATASYS - FDM mc for Rapid Prototype. Biggest machine in India with Home» Rapid Prototype Software EOS RP Tools; Magics RP (Materialise).

- Dr. Alexander Nam Head of Software & Hardware Development 3D printing Lead Prototype and Senior DLP Technician Rapid Prototyping Technician.

Internet based software

- A web-**based rapid prototyping** and manufacturing (RP&M) system offers a collaborative production environment among users and RP&M providers to implement the remote service and manufacturing for **rapid prototyping**, to enhance the availability of RP&M facilities, and to improve the capability of **rapid** product development.
- Web-based RP&M systems from both the academic community and industrial bodies all over the world. A number of studies have been performed to explore the architecture, key issues and enabling tools for developing web-based RP&M systems.
- Various Architectures for Web-based RP&M Systems: A variety of frameworks for developing web-based RP&M systems have been proposed. The Tele-Manufacturing Facility (TMF) is probably the first system that provides users with direct access to a rapid prototyping facility over the Internet. TMF allows users to easily submit jobs and have the system automatically maintain a queue. It can also automatically check many flaws in .STL (Stereolithography) files, and in many cases, fix them. A laminated object manufacturing (LOM) machine was first connected with network, and then the .STL file of a part to be built could be submitted to this machine via a command-line.

3 Rapid Manufacturing Process Optimization Process optimization

The parameters of rapid prototyping can be classified as nuisance parameters, constant and control parameters. Nuisance parameters include age of the laser, beam position accuracy, humidity and temperature, which are not controlled in the experimental analysis but may have some effect on a part. Constant parameters include beam diameter, laser focus and material properties, etc. the constant parameters will affect the output of the process and are controllable in a run. These include layer thickness, hatch space, scan pattern, part orientation, shrinkage of the material and beam width compensation, etc. Layer thickness, hatch space, part orientation and depth of cure are the most vital among the control parameters.

Identification of requirements and key manufacturing parameters

- The functional requirements of a manufacturing process include accuracy, strength, build- time and efficiency of the process. All the manufacturing requirements are also applicable to RP. Surface accuracy is gaining a greater significance as more parts are used as master patterns for secondary manufacturing process. Build time is important in the general context of manufacturing for scheduling and cost estimation. Layer thickness, hatch space and orientation are the key control parameters for SLS and SLA. These are required indeed process-independent parameters, and can be applied to other processes, such as LOM, FDM, etc. Support structures are essential for SLA and FDM, but they are not needed for LOM and SLS processes.

Factors influencing accuracy

- The factors that most influence RP process accuracy can be considered in three groups. The first group includes factors causing errors during the data preparation stage such as STL file generation, model slicing and part build direction. The second group includes factors influencing the part accuracy during the build stage such as process specific parameters. The third group of factors is directly related to the part finishing techniques employed.
- Accuracy of a model is influenced by the errors caused during tessellation and slicing at data preparation stage. Decision of the designer about part deposition orientation also affects accuracy of the model.

Data preparation errors

Errors due to tessellation:

- Most RP systems employ standard STL input files. A STL file approximates the surface of the 3D CAD model by triangles. Errors caused by tessellation are usually ignored because of the belief that tessellation errors can be minimised by increasing the number of triangles. However, in practice the number of triangles cannot be increased indefinitely. The resolution of STL files can be controlled during their generation in a 3D CAD system through tessellation parameters.
- For example in Pro/Engineer, the STL generation process can be controlled by specifying the chord height or the angle control factor.
- Chord Height: this parameter specifies the maximum distance between a chord and surface as shown in Figure. If less deviation from the actual part surface is required, a smaller chord height should be specified. The lower bound for this parameter is a function of CAD model accuracy. The upper bound depends on the model size.

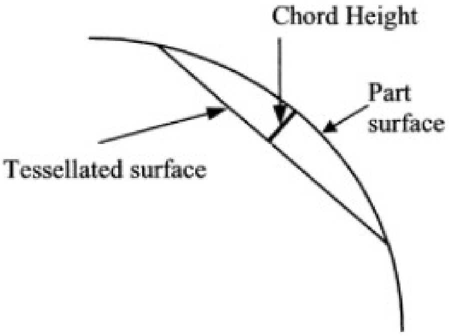


Figure 1: Chord height

Angle Control: this parameter specifies the required definition level along curves with small radius. Specifically, it defines a threshold for the curve radius (r_0) below which the curve should be tessellated:

$$r < r_0 = \frac{partsize}{10}$$

To achieve a maximum chord height of:

$\left(\frac{r}{r_0}\right)^{\alpha}$ Chord Height

Where partsize is defined as the diagonal of an imaginary box drawn around the part and α is the angle control value.

To achieve a better part accuracy, tessellation errors have to be taken into account. For example, if the part is large, a feature with a small radius will be tessellated poorly. Suppose a model with overall dimensions of 250x250x250 mm has a round corner with a radius of 1 mm. the results of tessellating the model by applying Chord Heights of 0.5 and 0.05 mm respectively as shown in figure. Unfortunately, the increase of chord height leads not only to smoother surfaces but also to larger data files. Therefore, a compromise parameter value should be selected to obtain the best trade-off between accuracy and file size.

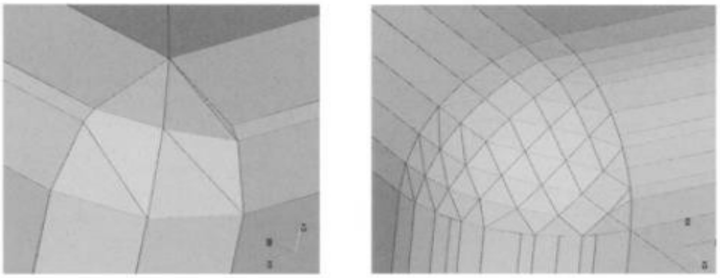


Figure 1a:STL files generated by applying chord heights of 0.5 mm (left) and 0.05 mm (right).

Errors due to Slicing

RP processes have a stair-stepping problem that is found in all layer manufacturing technologies. Stair — stepping is a consequence of the addition of material in layers. As a result of this discrete layering, the shape of the original CAD models in the build direction (z) is approximated with stair-steps. This type of error is due to the working principles of RP processes, which can be assessed in data preparation.

Mathematically, curves are described with curvatures and a curvature radius. In engineering, a curve can be replaced with arcs that have common tangent lines, curvatures and concavity directions at the same point. Similarly, curves in a section of a CAD model can be replaced with arcs. To assess the error of stair-steps, arcs can also be used.

The error due to the replacement of a circular arc with stair-steps is illustrated in Figure and defined as:

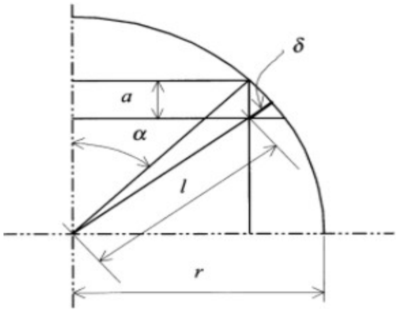


Figure 1b: Error due to replacement of arcs with stair-steps.

$$\delta = r - l$$

Where δ is the cusp height, r the radius and *l* the difference between r and δ. When *l* is at its minimum value, δ will reach its maximum value. Hence

$$\delta_{max} = r - l_{min}$$

From the figure *l* is given by

$$l = \sqrt{r^2 + a^2 - 2arcos\alpha}$$

Where a is the layer thickness, r is the radius and α is the angle subtended by the top portion of the arc. When α=0,

$$l_{min} = r - a$$

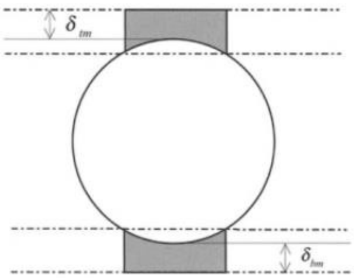
So

$$\delta_{max} = a$$

The above analysis indicates that the maximum error due to the replacement of an arc with stair- steps, the cusp heightδ_{max}, which is equal to the layer thickness, occurs a the top of the arc where the tangent line is horizontal. For other general curves, the maximum cusp height will
occur at points where the tangent lines are nearly horizontal.

The stair-steps particularly affect slight slopesthis problem influences mainly the roughness of the part and can be alleviated by reducing the thickness of the layers. However, layer thickness cannot be indefinitely decreased and a compromise has to be found between thickness and build speed. This problem can be partially overcome using adaptive slicing which generates different slice thicknesses based on the local slope of the part.

There are two types of errors resulting from slicing. One is because of mismatching in height between slice positions and feature boundaries; the other is the replacement of polygons with stair-steps.Figure illustrates the mismatching effect. The broken lines are slicing positions, which do not pass exactly through the bottom point and top point on the circle. The top side and the bottom side of the feature will be built as the shaded layers in the figure.



.

Figure 1c: Mismatching in height

Thus mismatching error can be defined as

$$\delta_{max} = \delta_{tm} + \delta_{bm}$$

Where δ_{tm} is the mismatching error at the top and δ_{bm} the mismatch error at the bottom.

Below figure illustrates the error resulting from slicing tessellated arcs. The broken lines represented the stair-steps when the arc is directly sliced. The corresponding solid lines represent the stair-step formed by slicing the chord (tessellated arc). Thus the slicing error can be defined as

$$\delta_{st} = \delta_s + h_{chord}$$

$a. cos\alpha$
α

α

Where $\delta_s =$, is the angle between the chord and the horizontal axis, and h_{chord} is the chord height. When slicing a STL file, the error consists of the tessellation error h_{chord} and cusp height error δ_s. Thus, the error is larger than that resulting from directly slicing the original CAD model. Also the maximum errors happen with chords that have the smallest values of , which is similar to the case when the CAD model is directly sliced.

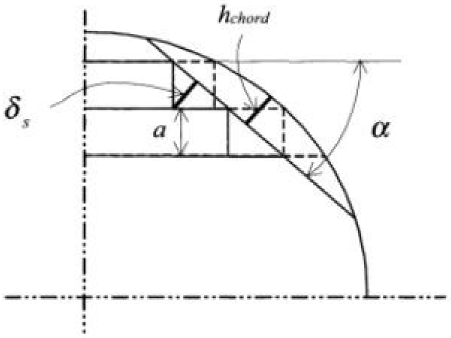


Figure 2: Step error due to slicing tessellated arcs.

Part Building Errors

There are two main types of errors in the part building process, namely curing errors and control errors. Curing errors refer to those errors that are caused by over-curing and scanned line shape. Control errors are those errors caused by layer thickness and scan position control. Both types of errors affect part accuracy.

Over-curing: Laser over-curing is necessary to adhere layers to form solid parts. However, it causes dimensional and positional errors to features.

Scanned Line Shape: A scanned line is created when a laser beam scans the resin surface. The cross section of the scanned line is referred to as the scanned line shape. The part building process is assumed to be a stacking up of rectangular shaped blocks.

Control errors: theoretically, the layer thickness should be at the defined value and the border line should be positioned at the specified positions. In fact, the layer thickness is variable and the border position is not precise. Figure shows the phenomenon of uneven layer thickness.

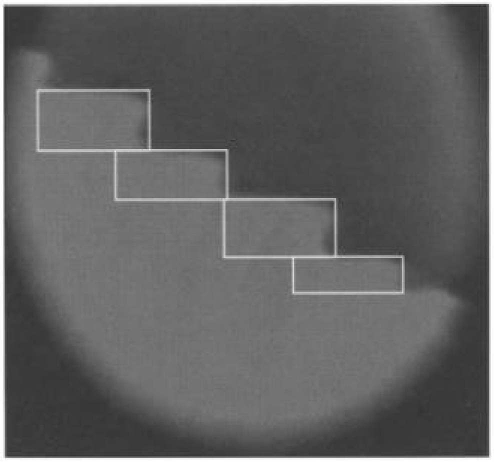


Figure 3: Effects on curve

Part building errors in the SLS process

The main cause of part inaccuracy is the shrinkage during sintering which does not always occur in a uniform manner. The shrinkage of a new layer can be constrained by the existing part substrate or by support powder trapped within enclosed areas. In addition, areas at high temperatures tend to shrink more than those at lower temperatures and part geometries such as thick walls or sections can increase the shrinkage. To compensate for shrinkage, a material coefficient is calculated using a test part and a scaling factor is applied in each direction to the STL file. In practice, to compensate for the shrinkage, scaling and offsetting are applied to the part dimensions according to the following relation:

New dimension = a (desired dimension) + b

In this way, it is possible to compensate for the shrinkage occurring during the SLS process and for the part growth due to the laser beam melting diameter (figure).

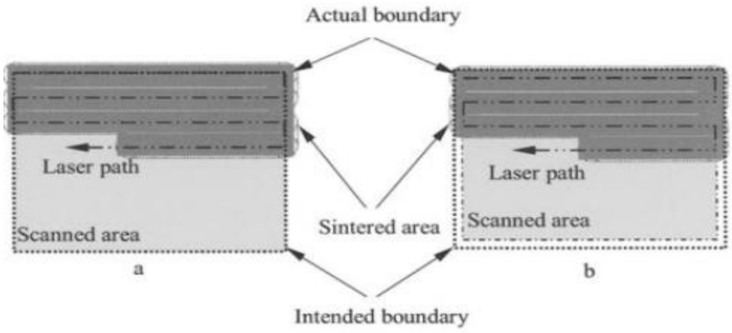


Figure 4: Shrinkage and laser beam sintering diameter (a — without compensation, b - after shrinkage and offset compensation).

The normal procedure to determine the scaling factor a and offset value b consists of building a test part and tabling measurements of it. From these measurements, values a and b are calculated for the X and Y axes assuming linear shrinkage for the SLS process.

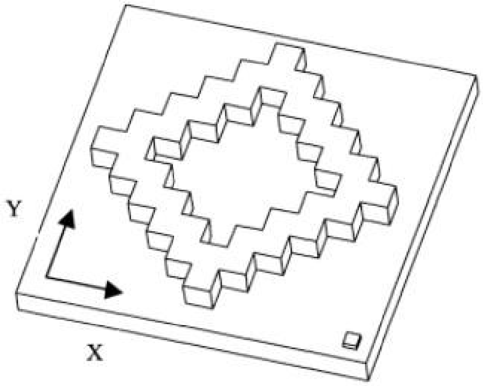


Figure 5: RapidSteel 2.0 calibration test part

For example, to calibrate the SLS process for the RapidSteel 2.0 material a test part to be build. This test part has internal and external features in order to determine accurately the scaling factors and the offset values. After building the test part, dimensions in X and Y directions are measured.

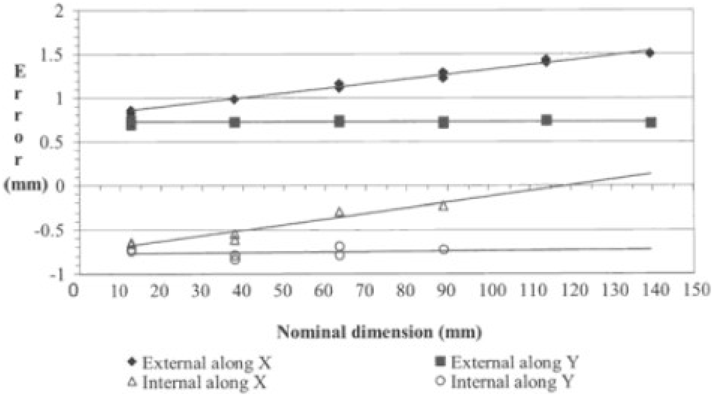


Figure 6: Error versus nominal dimension for the test part along the X and Y axes.

Part finishing

Some RP applications such as fabrication of exhibition quality models, tooling or master patterns for indirect tool production require additional finishing improving the surface appearance of the part. To achieve this, the stair-step effect on important surfaces has to be removed. Usually, this is done by sanding and polishing RP models, which leads to changes in feature shapes, dimensions and positions. The model accuracy after finishing operations is influenced mostly by two factors, the varying amount of material that has to be removed and the finishing technique adopted. These two factors determine to what extent the dimensional accuracy of RP models will be reduced during finishing.

Varying amount of material: During the data preparation stage, the RP model shapes are approximated with the corners of stair-steps. Each RP process reproduces the corners ans the stair-steps with different resolution. Hence, the amount of material that has to be removed to improve the amount of material to be removed on surfaces of the same model can vary due to the selected part build orientation.

Finishing technique: A number of processes can be employed to finish RP models, for example, wet and try sanding, sand blasting, coating, spraying, infiltration with special solutions, machining, etc. Each technique has specific technological capabilities and can be characterised by the achievable dimensional accuracy and surface roughness.

Selection of part build orientation

One of the most important decisions to be made when employing any particular RP technology is the selection of the part build orientation. This decision is a very important factor in minimising build time and costs, and achieving optimal accuracy. When making this decision, designers and RP machine operators should consider a number of different process specific constraints. This may be quite a difficult and time-consuming task.

Each RP process has specific technological capabilities that have to be taken into account before build direction is selected.

Choosing the best orientation is a multi-criteria task that involves trade-offs between maximising the surface smoothness and accuracy of important features and minimising the build time and cost.

Orientation constraints of the SL process

The following feature constraints should be considered in choosing candidate build orientations for SL process.

- User specified critical surfaces: if these surfaces are planes, they have to be placed such that their normal point in the build direction. In other words, they are horizontal and upward facing. Cylinders, cones and surfaces of revolution are oriented so that their axes are vertical.
- Coordinate system: since a coordinate system is usually created by the designer and employed whilst modelling, the orientation of the coordinate axes may represent the most logical build direction. It is placed so that the z-axis points in the build direction.
- Holes: in order to avoid hard- to remove supports and stair-stepping inside holes, these are placed orthogonally to horizontal planes.
- Cuts: if these curve through the part entirely or have a depth greater than a certain minimum, the planes which they cut through placement planes are made horizontal. Otherwise, they are ignored.
- Protrusions: if these are created by revolving a section, the axes are positioned so that they are vertical.
- Shells: these are orientated so that the concave part of the shell faces upwards in order to minimise internal supports. However, if the part is built on an older SL system employing the deep-dip recoatsmethod; this orientation should be avoided as it would procedure a trapped volume.
- Axes: all axes are placed so that they are vertical.

Surface digitization

Technologies used commercially for the measurement of the surface of objects with micro to macro sizes (i.e. from some cm up to several meters) can be divided fundamentally into two groups: systems based on laser scanning and systems based on white light projection. The used equipment is different;however they are based on the same principle: triangulation.

Laser scanning systems employs lasers to project a spot, a line, multiple lines, or patterns onto a surface, whereas a light sensor, usually a camera, acquires the scene. The three elements laser, light sensor and object surface form a triangle. When the geometrical disposition of the laser and the light sensor are known, the distance of the object surface to the laser scanning device can be easily determined by triangulation. To measure surface areas the laser spot, line, multiple lines or pattern have to move over the area (i.e. scan the surface). For this process, different methods can be used, e.g. mirrors systems, electro- mechanical systems, hand operated systems. 3D measurement systems based on white light employ projectors instead of laser light sources, to project light patterns onto the surface. The measurement principle remains the same: triangulation. A triangle is formed by projector, camera and object. In this case, to cover entire surface parts, surface areas are illuminated by the employed projector. Special codes are used to determine the origin of the light source, e.g. binary codes, colour codes. The two different technologies result in various surface scanning devices with different characteristics. Some examples are laser profilers mounted on CMM, portable coded light projection surface digitizer, portable laser scanners, hand held surface digitizers. An extensive description of the different solutions available in the market will be given in the next section, followed by examples of applications in various fields.

Applications of 3D surface digitization for the four major groups of users of this technology: industrial measurements, cultural heritage, consumer industry and medical sciences.

Figure 7: Optical 3D digitizer *Nub3D Triple* (Spain) (left); measured turbine blade (center); profile analysis (right).

Figure 8: Left: scanning setup (Laser Scanner *Mensi S25*) with dinosaur skeleton and reference points. Center and right: scanning setup and measured 3D point cloud of the Juvenile Indian elephant skeleton of the zoological museum of Copenhagen (Denmark).

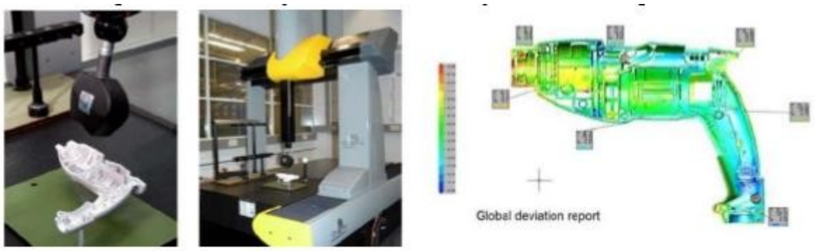


Figure 9: *Metris LC50* (Belgium) laser profiler is digitizing a tool housing (left); *DEA Global Image* CMM with scanner (center); comparison of measured 3D point cloud of the part to the reference CAD model.

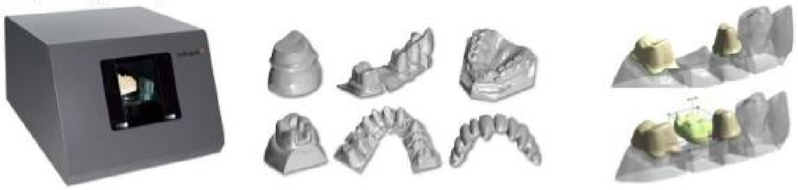


Figure 10: *3Shape D-200* Dental 3D Scanner (Denmark) (left); sample measured data (center); *3Shape DentalDesigner* software examples (right).

Surface generation from point cloud

A **point cloud** is a set of data points in some coordinate system.In a three-dimensional coordinate system, these points are usually defined by *X*, *Y*, and *Z* coordinates, and often are intended to represent the external surface of an object.

Point clouds may be created by 3D scanners. These devices measure a large number of points on an object's surface, and often output a point cloud as a data file. The point cloud represents the set of points that the device has measured.

As the output of 3D scanning processes, point clouds are used for many purposes, including to create 3D CAD models for manufactured parts, metrology/quality inspection, and a multitude of visualization, animation, rendering and mass customization applications.

While point clouds can be directly rendered and inspected, usually point clouds themselves are generally not directly usable in most 3D applications, and therefore are usually converted to polygon mesh or triangle mesh models, NURBS surface models, or CAD models through a process commonly referred to as surface reconstruction.

There are many techniques for converting a point cloud to a 3D surface. Some approaches, like Delaunay triangulation, alpha shapes, and ball pivoting, build a network of triangles over the existing vertices of the point cloud, while other approaches convert the point cloud into a volumetric distance field and reconstruct the implicit surface so defined through a marching cubes algorithm.

One application in which point clouds are directly usable is industrial metrology or inspection using industrial computed tomography. The point cloud of a manufactured part can be aligned to a CAD model (or even another point cloud), and compared to check for differences. These differences can be displayed as color maps that give a visual indicator of the deviation between the manufactured part and the CAD model. Geometric dimensions and tolerances can also be extracted directly from the point cloud.

Point clouds can also be used to represent volumetric data used for example in medical imaging. Using point clouds multi-sampling and data compression are achieved.

In geographic information systems, point clouds are one of the sources used to make digital elevation model of the terrain. They are also used to generate 3D models of urban environments.

Figure 11: A point cloud image of a torus and Geo-referenced point cloud of Red Rocks, Colorado (by DroneMapper).

Surface modification-data transfer to solid models

CAD data exchange is a modality of data exchange used to translate data between different Computer-aided design (CAD) authoring systems or between CAD and other downstream CAx systems.

Many companies use different CAD systems internally and exchange CAD data with suppliers, customers and subcontractors. Transfer of data is necessary so that, for example, one organization can be developing a CAD model, while another performs analysis work on the same model; at the same time a third organization is responsible for manufacturing the product. The CAD systems currently available in the market differ not only in their application aims, user interfaces and performance levels, but also in data structures and data formats[3] therefore accuracy in the data exchange process is of paramount importance and robust exchange mechanisms are needed.

The exchange process targets primarily the geometric information of the CAD data but it can also target other aspects such as metadata, knowledge, manufacturing information, tolerances and assembly structure.

There are three options available for CAD data exchange: direct model translation, neutral file exchange and third-party translators.

CAD data content

Although initially targeted for the geometric information (wire frame, surfaces, solids and drawings) of a product, nowadays there are other pieces of information that can be retrieved from a CAD file.

- Metadata — non-graphical attributes
- Design intent data — e.g. history trees, formulas, rules, guidelines
- Application data — e.g. Numerical Control tool paths, Geometric dimensioning and tolerancing (GD&T), process planning and assembly structure

The different types of product information targeted by the exchange process may vary throughout the life cycle of the product. At earlier stages of the design process, more emphasis is given to the geometric and design intent aspects of the data exchange while metadata and application data are more important at later stages of the product and process development.

The most common CAD data exchange problems via neutral formats are:

- loss of the architectural structure
- change the names of parts with numbers or names assigned to the directories where they are stored
- loss of bodies from the assemblies
- displace of details of their correct position relative to the original model
- loss of the original colour of the parts
- visualization of details of their correct position relative to the original model
- displaying the construction lines that are hidden in the original product
- modification in the graphic information
- modification on hollow bodies into solid bodies

CAD to CAM Data exchange

NC programming typically requires that the geometry received from a CAD system, whether in wireframe, surface, solid or combined formats, be free from any irregularities and inconsistencies that may have occurred in the CAD phase of geometry creation. Data exchange from CAD to CAM must therefore include tools for identifying and repairing those inconsistencies. These tools are typically included in the data exchange software of each CAM solution-set.

In a true PLM environment, CAD to CAM data exchange must provide for more than the transfer of geometry. Product Manufacturing Information, whether generated by the designer for use by manufacturing, or generated by the manufacturing organization for use by design, must be a part of the data exchange system. STEP-NC was designed to carry GD&Tand other PMI through CAD and CAM into a CNC.

Reference:

1. D.T.Pham and S.S. Dimov, Rapid Manufacturing, Springers.
2. Andreas Gebhardt, Rapid Prototyping, Hanser publishers, Munich.
3. https://scholar.google.co.in/