formed layer.

The packing density of particles during sintering affects the part density. In studies of particle packing with uniform sized particles [3] and particles used in commercial sinter bonding [4], packing densities were found to range typically from 50% to 62%. Generally, the higher the packing density, the better would be the expected mechanical properties. However, it must be noted that scan pattern and exposure parameters are also the major factors in determining the mechanical properties of the part.

Applications

The Vanguard™ si2™ SLS® system can produce a wide range of parts in a broad variety of applications, including the following:

(1) *Concept models*. Physical representations of designs used to review design ideas, form and style.

Functional models and working prototypes. Parts that can withstand limited functional testing, or fit and operate within an assembly

(3) *Polycarbonate (RapidCasting™) patterns*. Patterns produced using polycarbonate, then cast in the metal of choice through the standard investment casting process. These build faster than wax patterns and are ideally suited for designs with thin walls and fine features. These patterns are also durable and heat resistant.

(4) *Metal tools (RapidTool™)*. Direct rapid prototype of tools of molds for small or short production runs.

LAMINATED OBJECT MANUFACTURING (LOM)

Introduction

Laminated Object Manufacturing is a rapid prototyping technique that produces 3D models with paper, plastics or composites. LOM was developed by Helices Corporation, Torrance, California. LOM is actually more of a hybrid between subtractive and additive process. In that models are built up with layers of cross section of the part. Hence as layers are been added, the excess material is not required for that cross section is being cut away. LOM is one of the fastest RP processes for parts with longer cross sectional areas which make it ideal producing large parts.

System Hardware

1. LOM system is available in two sizes.

- LOM 1015 produces parts up to 10×15×14 inches
- LOM 2030 produces parts up to 20×30×24 inches

2. Common build material is paper
3. Build material has pressure and heat sensitive additive on the banking
4. Material thickness ranges from 0.0038 – 0.005 inches.

Softwares

LOM SLICES SOFTWARE

It provides interface between operator and the system. LOM does not require a pre slice of STL FILE i.e. once the parameters are loaded into LOM SLICE, the STL file slices as the part builds. The process of continuous slicing is called slice on the fly. 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 the layer is cut. A heated roller travels across the face of the part being after each layer to activate adhesive and bond the part layer together.

An invisible 25Watts CO_2 laser is housed on the back of the LOM and reflected off three mirrors before finally passing through a focusing lens on the carriage. The carriage moves in the X firection and the lens moves in the Y direction on the carriage, thus allowing focal cutting point of laser to be moved like a plotter pen while cutting through build material in the shape desired.

This X and Y movements allows for two degrees of freedom or essentially a 2-D sketch of 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 where in the LOM is able to build 3D models.

Some smoke and other vapors are created since the LOM functions by essentially burning through the sheets of materials with a laser, therefore LOM must be ventilated either to the outside air or through a large filtering device at rates around 500 cubic feet per minute.

LOM OPERATION

The way the LOM constructs the parts is by consecutively adhering layers of build material while cutting the cross section of the parts with a laser. The LOM SLICE software that comes with LOM machine controls all these. The following description of operation is described with paper as build material.

SOFTWARE

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

PART ORIENTATION

The designed shape of the parts to be built in LOM must be evaluated for determining the orientation in which to build the parts.

FIRST CONSIDERATION

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 XY plane. This is true due to the fact that the controlled motion of the laser cutting than the layered effects of XY and YZ planes.

If a part contains curvatures in more than one plane, one alternative is to build the Part at an angle to the axis. The benefits here are too full as the part will not only have more accurate curvatures but will also tend to have better laminar strength across the length of the part.

SECOND CONSIDERATION

Time taken to fabricate a part

The slowest aspect of build process for LOM is movement in Z direction or time between the layers. This is mainly because after laser cuts across the surface of the beam material, the LOM must bring more paper across the top face of the part and then adhere to the previous layer before the laser can begin cutting again.

For this reason, a general rule has come for orientation long narrow parts is to place the lengthiest sections in the XY plane. This way the slowest part of the process the actual laser cutting is minimized to a smaller number of layers.

These are some third-party software renders that have automatic testing functions that will strategically place parts in optimum orientations for the selected sections.

Cross hatching

Cross Hatching is necessary to get rid of excess paper on the individual layers. Cross hatch is set in LOM SLICE by the operator and can vary throughout the part. Basically, the operator puts in a range of layers for which we want a certain cross hatch pattern for sections of the part that do not have integrate features or cavities, a larger cross hatch can be set to make a part build faster but for thin walled sections and hollowed out areas, a finer cross hatch will be easier to remove. The cross-hatch size is given in values of X and Y. Therefore, the hatch pattern can vary from square to long thin rectangles.

The two main considerations for cross hatching are

- Ease of part removed
- Resulting build time

A very small hatch size will make for easy part removal. However, if the part is rather large or has large void area it can really slow down the build time. This is the reason for having varying cross hatch sizes throughout the part.

The LOM operator can either judge where and how the part should be cross hatched visually or use long slice to run a simulation build on the computer screen to determine layer ranges for the needed hatch sizes.

Also since the LOM SLICE creates slices as the part build parameters can be changed during a build simply by pausing a LOM machine and typing in new cross hatch values.

System Parameters

There are various controlling parameters such as laser powder, heater speed, and material advance margin and support wall thickness and heater compression.

Laser Power

It is the percentage of total laser output wattage.

For e.g. LOM 1015 is operated at a laser power of about 9% of maximum 25W laser or approximately 2.25 W. This value will be different for various materials or machines but essentially it is set to cut through only one sheet of build material.

Heater Speed

It is the rate at which hot roller passes across the top of the part. The rate given in inches/second. It is usually 6”/sec for initial pass and 3”/sec for returning pass of heater. The heater speed effects the lamination of the sheet so it must be set low enough to get a good bond between layers.

Material Advance

It is the distance the paper is advanced in addition to length of the part.

Support Wall Thickness.

It controls the outer support box walls throughout a part. The support wall thickness is generally set 0.25” in the Margin X and Y direction, although this value can be changed by operator.

Compression

It is used to set the pressure that the heater roller exerts on the layer. It is measured in inches which are basically the distance the roller is lifted from its initial track by the top surface of part. Values for compression will vary for different machines and materials, but are typically 0.015”-0.025”.

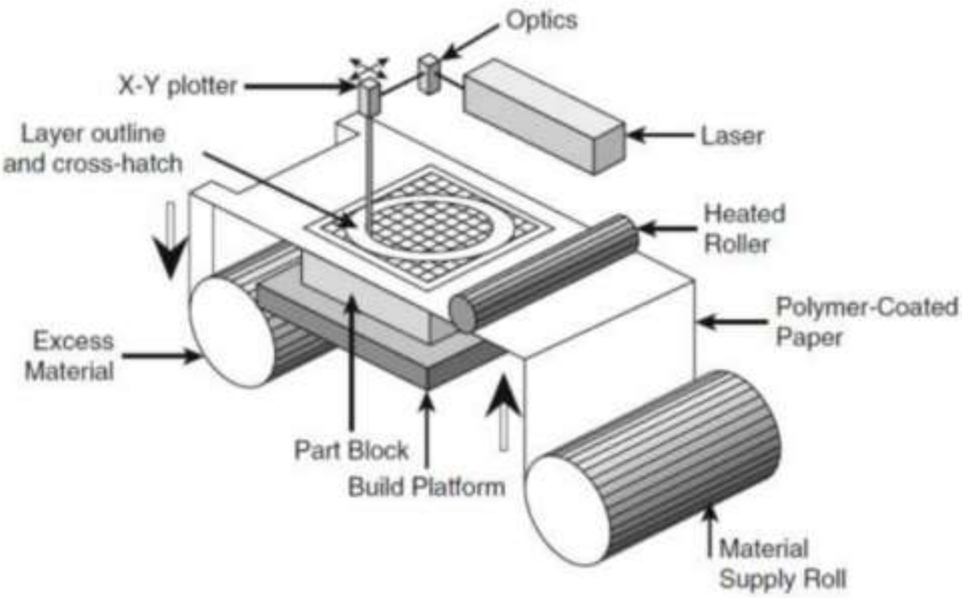

Fig 2.5: Laminated Object Manufacturing

Company

Cubic Technologies was established in December 2000 by Michael Feygin, the inventor who developed Laminated Object Manufacturing® (LOM^{TM}). In 1985, Feygin set up the original company, Helisys Inc., to market the LOM^{TM} rapid prototyping machines. However, sales figures did not meet up to expectations [1] and the company ran into financial difficulties. Helisys Inc. subsequently ceased operation in November 2000. Currently, Cubic Technologies, the successor to Helisys Inc., is the exclusive manufacturer of the LOM^{TM} rapid prototyping machine. The company's address is Cubic Technologies Inc., 100E, Domingnez Streets, Carson, California 90746-3608, USA.

Products

Models and Specifications

Cubic Technologies offers two models of LOM^{TM} rapid prototyping systems, the LOM-1015Plus^{TM} and LOM-2030H^{TM}. Both these systems use the CO_2 laser, with the LOM-1015Plus^{TM} operating a 25 W laser and the LOM-2030H^{TM} operating a 50 W laser. The optical system, which delivers a laser beam to the top surface of the work, consists of three mirrors that reflect the CO_2 laser beam and a focal lens that focuses the laser beam to about 0.25 mm (0.010"). The control of the laser during cutting is by means of a *XY* positioning table that is servo-based as opposed to the galvanometer mirror system. The LOM-2030H^{TM} is a larger machine and produces larger prototypes. The work volume of the LOM-2030H^{TM} is 810 mm x 550 mm x 500 mm (32" x 22" x 20") and that of the LOM-1015Plus^{TM} is 380 mm x 250 mm x 350 mm (15" x 10" x 14"). Detailed specifications of the two machines are summarized in Table

Process

The patented Laminated Object Manufacturing® (LOM^{TM}) process [2–4] is an automated fabrication method in which a 3D object is constructed from a solid CAD representation by sequentially laminating the part. cross-sections. The process consists of three phases: pre-processing; building; post-processing.

Pre-processing

The pre-processing phase comprises several operations. The initial steps include generating an image from a CAD-derived STL file of the part to be manufactured, sorting input data, and creating secondary data structures. These are fully automated by LOMSlice^{TM}, the LOM^{TM} system software, which calculates and controls the slicing functions. Orienting and merging the part on the LOM^{TM} system are done manually. These tasks are aided by LOMSlice™, which provides a menu-driven interface to perform transformations (e.g., translation, scaling, and mirroring) as well as merges.

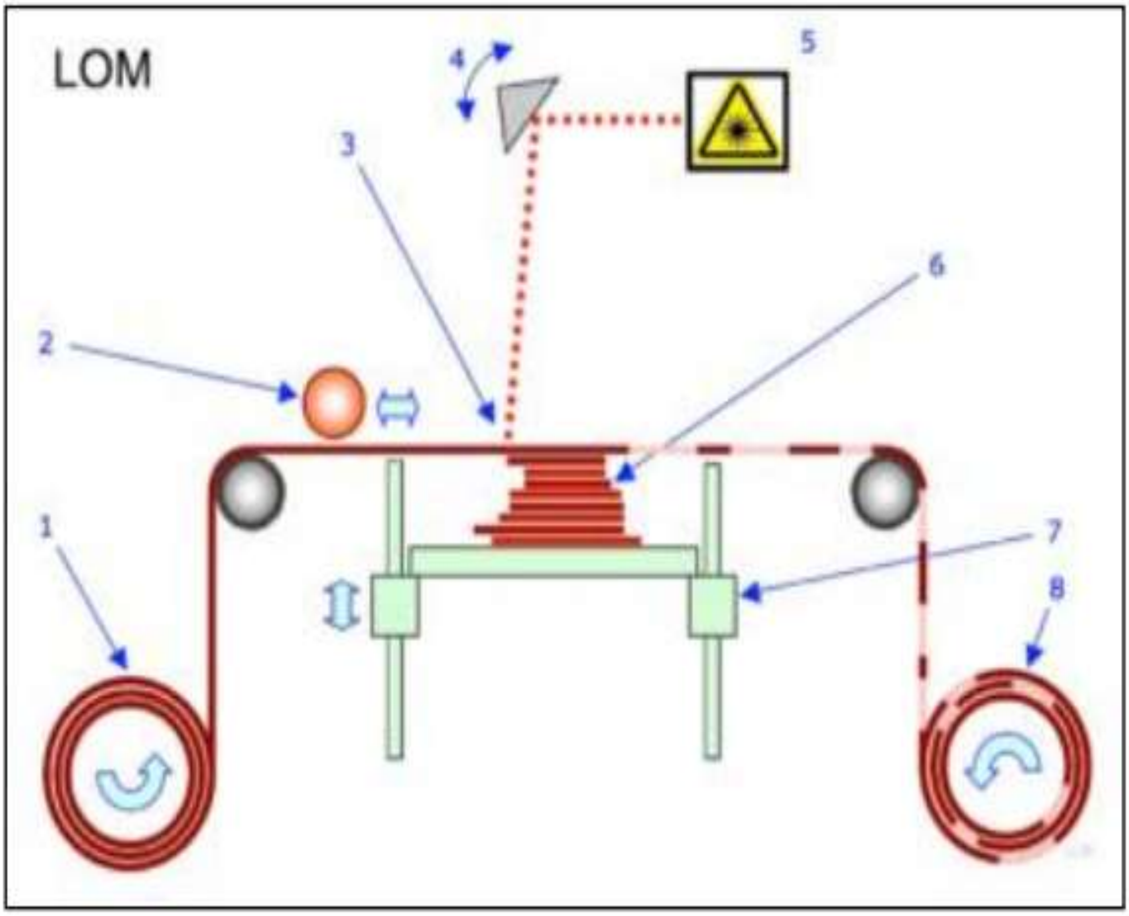

Fig 2.6: Laminated Object Manufacturing

Table 2.2: Specifications of LOM-1015Plus™ and LOM-2030H

Model	LOM-1015Plus™	LOM-2030H™
Max. part envelope	L381 x W254 x H356	L813 □ W559 □ H508
size, mm (in)	(L15 x W10 x H14)	(L32 □ W22 □ H20)
Max. part weight, kg (lbs)	32 (70)	204 (405)
Laser, power and type	Sealed 25 W, CO_2 Laser	Sealed 50 W, CO_2 Laser

Laser beam diameter, mm (in)	0.20–0.25 (0.008–0.010)	0.203–0.254 (0.008–0.010)
	Servo-based *X–Y* motion	Brushless servo-based *X–Y*
	systems with a speed up to	motion dystems with a speed
Motion control	457 mm/sec (18"/sec);	up to 457 mm/sec (18"/sec);
	Typical *Z*-platform	Typical *Z*-platform feedback
	feedback for motion system	for motion system
Part accuracy *XYZ* directions, mm (in)	±0.127 mm (±0.005 in)	±0.127 mm (±0.005 in)
Material thickness, mm (in)	0.08–0.25,	0.076–0.254,
Material size	Up to 356 mm (14") roll	Up to 711 mm (28") roll
Floor space, m (ft)	3.66 x 3.66 (12 x 12)	4.88 x 3.66 (16 x 12)
Power	Two (2) 110VAC, 50/60Hz, 20 Amp, single phase Two (2) 220VAC, 50/60 Hz, 15 Amp, single phase	220VAC, 50/60 Hz, 30 Amp,single phase
	LOMPaper® LPH series,	LOMPaper® LPH series,
Materials	LPS series LOMPlastics® LPX series	LPS series LOMPlastics® LPX series, LOMComposite® LGF series

Building

In the building phase, thin layers of adhesive-coated material are sequentially bonded to each other and individually cut by a CO_2 laser beam. The build cycle has the following steps:

(1) LOMSlice™ creates a cross-section of the 3D model measuring the exact height of the model and slices the horizontal plane accordingly. The software then images crosshatches which define the outer perimeter and convert these excess materials into a support structure.

(2) The computer generates precise calculations, which guide the focused laser beam to cut the cross-sectional outline, the cross-hatches, and the model's perimeter. The laser beam power is designed

to cut exactly the thickness of one layer of material at a time. After the perimeter is burned, everything within the model's boundary is "freed" from the remaining sheet.

(3) The platform with the stack of previously formed layers descends and a new section of material advances. The platform ascends and the heated roller laminates the material to the stack with a single reciprocal motion, thereby bonding it to the previous layer.

(4) The vertical encoder measures the height of the stack and relays the new height to LOMSlice™, which calculates the cross section for the next layer as the laser cuts the model's current layer.

This sequence continues until all the layers are built. The product emerges from the LOM™ machine as a completely enclosed rectangular block containing the part.

Materials

Potentially, any sheet material with adhesive backing can be utilized in Laminated Object Manufacturing. It has been demonstrated that plastics, metals, and even ceramic tapes can be used. However, the most popular material has been Kraft paper with a polyethylene-based heat seal adhesive system because it is widely available, cost-effective, and environmentally benign [

In order to maintain uniform lamination across the entire working envelope it is critical that the temperature remain constant. A temperature control system, with closed-loop feedback, ensures the system's temperature remains constant, regardless of its surrounding environment.

Principle

The LOM™ process is based on the following principles:

(1) Parts are built, layer-by-layer, by laminating each layer of paper or other sheet-form materials and the contour of the part on that layer is cut by a CO_2 laser.

(2) Each layer of the building process contains the cross-sections of one or many parts. The next layer is then laminated and built directly on top of the laser-cut layer.

(3) The *Z*-control is activated by an elevation platform, which lowers when each layer is completed, and the next layer is then laminated and ready for cutting. The *Z*-height is then measured for the exact height so that the corresponding cross sectional data can be calculated for that layer.

(4) No additional support structures are necessary as the "excess" material, which are cross-hatched for later removal, act as the support.

Advantages and Disadvantages

The main advantages of using LOM technology are as follows:

(1) *Wide variety of materials*. In principle, any material in sheet form can be used in the LOM^{TM} systems. These include a wide variety of organic and inorganic materials such as paper, plastics, metals, composites and ceramics. Commercial availability of these materials allows users to vary the type and thickness of manufacturing materials to meet their functional requirements and specific applications of the prototype.

(2) *Fast build time*. The laser in the LOM^{TM} process does not scan the entire surface area of each cross-section, rather it only outlines its periphery. Therefore, parts with thick sections are produced just as quickly as those with thin sections, making the LOM^{TM} process especially advantageous for the production of large and bulky parts.

(3) *High precision*. The feature to feature accuracy that can be achieved with LOM^{TM} machines is usually better than 0.127 mm (0.005"). Through design and selection of application specific parameters, higher accuracy levels in the *X*–*Y* and *Z* dimensions can be achieved. If the layer does shrink horizontally during lamination, there is no actual distortion as the contours are cut post-lamination, and laser cutting itself does not cause shrinkage. If the layers shrink in the transverse direction, a closed-loop feedback system gives the true cumulative part height upon each lamination to the software, which then slices the 3D model with a horizontal plane at the appropriate location.

The LOM^{TM} system uses a precise *X*–*Y* positioning table to guide the laser beam; it is monitored throughout the build process by the closed-loop, real-time motion control system, resulting in an accuracy of ±0.127 mm regardless of the part size. The *Z*-axis is also controlled using a real-time, closed-loop feedback system. It measures the cumulative part height at every layer and then slices the CAD geometry at the exact *Z* location. Also, as the laser cuts only the perimeter of a slice there is no need to translate vector data into raster form, therefore the accuracy of the cutting depends only on the resolution of the CAD model triangulation.

(4) *Support structure*. There is no need for additional support structure as the part is supported by its own material that is outside the periphery of the part built. These are not removed during the LOM^{TM} process and therefore automatically act as supports for its delicate or overhang features.

(5) *Post-curing*. The LOM^{TM} process does not need to convert expensive, and in some cases toxic, liquid polymers to solid plastics or plastic powders into sintered objects. Because sheet materials are not subjected to either physical or chemical phase changes, the finished LOM^{TM} parts do not experience warpage, internal residual stress, or other deformations.

The main disadvantages of using LOM are as follows:

(1) *Precise power adjustment*. The power of the laser used for cutting the perimeter (and the crosshatches) of the prototype needs to be precisely controlled so that the laser cuts only the current layer of lamination and not penetrate into the previously cut layers. Poor control of the cutting laser beam may cause distortion to the entire prototype.

(2) *Fabrication of thin walls*. The LOM^{TM} process is not well suited for building parts with delicate thin walls, especially in the *Z*-direction. This is because such walls usually are not sufficiently rigid to withstand the post-processing process when the cross-hatched outer perimeter portion of the block is being removed. such delicate parts are located in the model and take sufficient precautions so as not to damage these parts.

(3) *Integrity of prototypes*. The part built by the LOM^{TM} process is essentially held together by the heat sealed adhesives. The integrity of the part is therefore entirely dependent on the adhesive strength of the glue used, and as such is limited to this strength. Therefore, parts built may not be able to withstand the vigorous mechanical loading that the functional prototypes may require.

(4) *Removal of supports*. The most labor-intensive part of the LOM^{TM} process is its last phase of post-processing when the part has to be separated from its support material within the rectangular block of laminated material. This is usually done with wood carving tools and can be tedious and time consuming. The person working during this phase needs to be careful and aware of the presence of any delicate parts within the model so as not to damage it.

Applications

(1) *Visualization*. Many companies utilize LOM^{TM}'s ability to produce exact dimensions of a potential product purely for visualization. LOM^{TM} part's wood-like composition allows it to be painted or finished as a true replica of the product. As the LOM^{TM} procedure is inexpensive several models can be created, giving sales and marketing executives opportunities to utilize these prototypes for consumer testing, marketing product introductions, packaging samples, and samples for vendor quotations.

(2) *Form, fit and function*. LOM^{TM} parts lend themselves well for design verification and performance evaluation. In low-stress environments LOM^{TM} parts can withstand basic tests, giving manufacturers the opportunity to make changes as well as evaluate the aesthetic property of the prototype in its total environment.

(3) *Manufacturing*. The LOM^{TM} part's composition is such that, based on the sealant or finishing products used, it can be further tooled for use as a pattern or mold for most secondary tooling

techniques including: investment casting, casting, sanding casting, injection molding, silicon rubber mold, vacuum forming and spray metal molding. LOM^{TM} parts offer several advantages important for the secondary tooling process, namely: predictable level of accuracy across the entire part; stability and resistance to shrinkage, warpage and deformity; and the flexibility to create a master or a mold. In many industries the master created through secondary tooling, or even when the LOM^{TM} part serves as the master (e.g., vacuum forming), withstands enough injections, wax shootings or vacuum pressure to produce a low production run from 5 to 1000 pieces.

(4) *Rapid tooling*. Two part negative tooling is easily created with LOM^{TM} systems. Since the material is solid and inexpensive, bulk complicated tools are cost effective to produce. These wood-like molds can be used for injection of wax, polyurethane, epoxy or other low pressure and low temperature materials. Also, the tooling can be converted to aluminum or steel via the investment casting process for use in high temperature molding processes.

SOLID GROUND CURING (SGC) OR CUBITAL'S SOLID GROUND CURING (SGC)

The early versions of the system weighted several tons and required a sealed room. Size was made more manageable and the system sealed to prevent exposure to photopolymers, but it was still very large. Instead of using a laser to expose and harden photopolymer element by element within a layer as is done in stereolithography, SCG uses a mask to expose the entire object layer at once with a burst of intense UV light. The method of generating the masks is based on electrophotography (xerography)

Highlights

- Large parts of 500×500×350mm can be fabricated quickly
- High speed allows production of amny parts
- Masks are created
- No post curing required.
- Milling step ensures flatness of subsequent layers.
- Wax supports model, hence no extra support is required.
- Create a lot waste.
- Not as prevalent as SLA and SLS but gaining ground because of high throughout and large parts.