

LAMINATED OBJECT MANUFACTURING (LOM): A SIMPLER PROCESS

Michael Feygin
Helisys, Inc.

Brian Hsieh
Helisys, Inc.
Mechanical, Aerospace, and
Nuclear Engineering Department,
University of California,
Los Angeles

Introduction

Basic Concept

With Laminated Object Manufacturing (LOM) process, three dimensional objects are manufactured by sequentially laminating and cutting two-dimensional cross-sections. The medium used in LOM process is adhesive-coated sheet materials. As seen in Figure 1, the sheet material carries the adhesive either on one side or both sides, or it contains the adhesive in itself, like woven composite material impregnated with bonding agent. The adhesive, which can be pre-coated onto material or be deposited prior to bonding, enables layers of sheet material to be attached to each other so as to construct a three-dimensional object.

After one layer is deposited, peripheries of this layer's cross-section are cut by a laser beam based on the information from the CAD model. This bonding-before-cutting procedure is repeated until the full height of the part is reached. (Figure 2)

Advantages

Due to its simple and straightforward concept, the LOM process has several advantages:

- A variety of organic and inorganic materials can be used in the LOM process allowing the user to meet various requirements such as price range, environmental concerns, chemical and mechanical properties, color and appearance, secondary process durability, etc. Materials such as paper, plastic, ceramic, composite, and metal have been proved applicable to the LOM process. Virtually, any sheet-form material which can be bonded to itself and can be cut by a laser is suitable for this technique.
- The process is much faster than competitive techniques, since the laser does not have to scan the entire area of a cross-section. Instead it just has to go around its periphery. Layers are glued to the stack virtually instantaneously, substantially reducing layer formation time. The speed advantage of the process grows with the size of the manufactured part. The more volume of material is contained within the part the stronger is the speed advantage.
- The process produces virtually no internal stress and associated with it undesirable deformation. Also, because the in-process part is already solid, it is convenient to measure the actual height and perform real-time slicing on the fly. High precision (below .005") is achieved due to the absence of shrinkage and ability to perform real-time measurement and slicing.
- A finer surface definition is expected due to the availability of sheets, which could be as thin as 0.0005".

- No support structure is needed. Since exterior material remains surrounding the part while the LOM process proceeds, it naturally provides a support for overhang and undercut portions of the part. This eliminates extra design time required to create proper support structures.

Machine Structure

Figure 3 demonstrates a fundamental structure of a current LOM machine. The mechanical part of the system contains an unwinding and a rewinding roll connected by a ribbon of sheet material routed through several idler rollers. These rolls store and supply the material. The laminated part is grown on a platform capable of a vertical incremental movement under the action of a stepper motor. Above the platform is located a heated roller capable of heating and compressing the ribbon between itself and the stack of laminations on the platform. As a result of a single reciprocal motion of the heated roller the ribbon material is bonded to the top of the stack. An X-Y positioning table carries two mirrors which reflect a beam from a CO₂ laser and a lens which focuses the beam on the upper surface of the laminated stack so as to cut the very top layer. Scrap pieces remain on the platform as the part is being built. They are diced by the laser beam into crosshatched squares and serve as a support structure for the part. A picture of a LOM machine (model 1015) is shown as Figure 4.

The working cycle of an LOM machine is as follows:

- A computer which runs the system is capable of slicing a 3-D solid model into thin two-dimensional cross-sections. The thickness of each cross-section is equal to the thickness of the material used in the process. At first, the geometry of a cross-section is generated by the computer.
- The geometrical information is fed into the LOM system which guides the laser beam cutting around the periphery of the cross-section. The laser cuts to the depth of one layer of the material. The material which surrounds the cross-section is usually crosshatched by the laser beam into squares to facilitate separation at the completion of the process (Figure 5). In the areas where attachment of the material which belongs to the part to the material which surrounds it is undesirable the laser beam ablates the portions of the bottom layer to prevent bonding. Sometimes fine crosshatch of these portions can achieve virtually the same effect.
- Next, the platform moves down. The ribbon moves by an increment exceeding the length of a cross-section onto the rewinding roll. As the platform moves up, the heated roller moves across the stack while pressing the ribbon against the stack and bonding it to the upper layer.
- Meanwhile, the height of the stack is measured by the machine and fed back to the computer where the next layer is calculated according to the current measurement.
- Laser beam cuts a new cross-section. The process continues until all of the cross-sections have been deposited and cut.
- The product comes out of the machine as a rectangular block containing the part (Figure 6). The material surrounding the part has already been diced into small cubes due to a "crosshatch" cut by the laser, so they can be separated easily from the part (Figure 7 & 8).

Software

The control and slicing software for the LOM machines, called LOMSlice, takes files in the STL format as an input. After receiving a few parameters specified by an operator, the software supervises the LOM machine through out the unattended operation. Some features of the current version of the software are shown as follows:

- A proprietary algorithm enables LOMSlice to slice each layer "on the fly"; in other words, while the LOM machine is laminating and cutting one layer, LOMSlice is concurrently computing the next slice. Therefore, no extra computing time is required for slicing and simply an IBM-compatible PC is needed as the platform.
- By constantly receiving feedback of the current height of the stack from the LOM machine, LOMSlice applies dynamic height control procedure to eliminate hardware turbulence and adjust the slicing increment. Thanks to the real-time slicing capability, every layer is sliced precisely.
- LOMSLice has been developed under Microsoft Windows 3.0 environment (Figure 9). The Windows's popularity and user- friendliness itself makes it easy to learn and operate.
- LOMSLice possesses robust capacity of dealing with imperfect STL files. Not every STL-generating CAD system does a perfect jobs; some STL files are created with discontinuities which means that the surfaces of STL objects are not closed completely. LOMSlice can tolerate these cases and clarify these ambiguities to make a successful slice.
- LOMSlice has a beam compensation ability. Even having been described as a "zero-diameter tool," a laser beam still has a thickness of several thousandth of an inch. The software offsets the center path of the beam so as to cut a precise outline of each cross sections.
- Other utilities such as: translation, scaling, and rotation of the object; multi-layering, i.e., laminate more than one layer then cut once; build several objects in one production, run from different STL files or duplicate the same object; and so on.

Future Research and Development

Several categories where current research and development are conducted are described below.

- **Material:** A larger varieties of media and bonding agents will be tested. Various grades of paper, plastics, ceramics, composites, and metal are of major interest. Usage of UV- curable adhesive is also under evaluation.
- **Working envelope:** Due to the simplicity of the LOM process, it is relatively easy to scale up or down the structure of the system to make machines with a larger or smaller working envelopes. Other than two currently available sizes (10"x13"x15" and 20"x30"x20"), a even larger envelope version for industrial use is under development.

- **Process:** By utilizing floodlamp, photomask, and photo-activated adhesive, layer lamination can be done in a flash. A "remove-as-you-go" procedure and a laser "selective-bonding" tactic can dispose scrap media after each layer's cutting and then refill the void with material as which will be removed after the production is finished.
- **Software:** A more robust version will be delivered with capacities of automatic crosshatch size determination, near-horizontal surface burnout, and direct input of standard CAD format (like IGES). A UNIX-base package running under X-windows will also be available in near future.

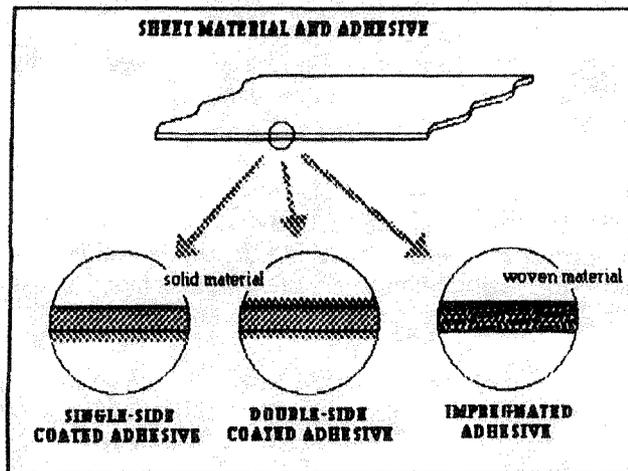


Figure 1: material combination

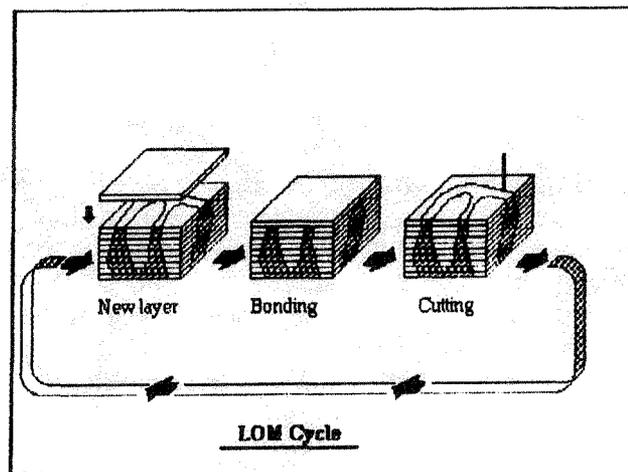


Figure 2: LOM cycle

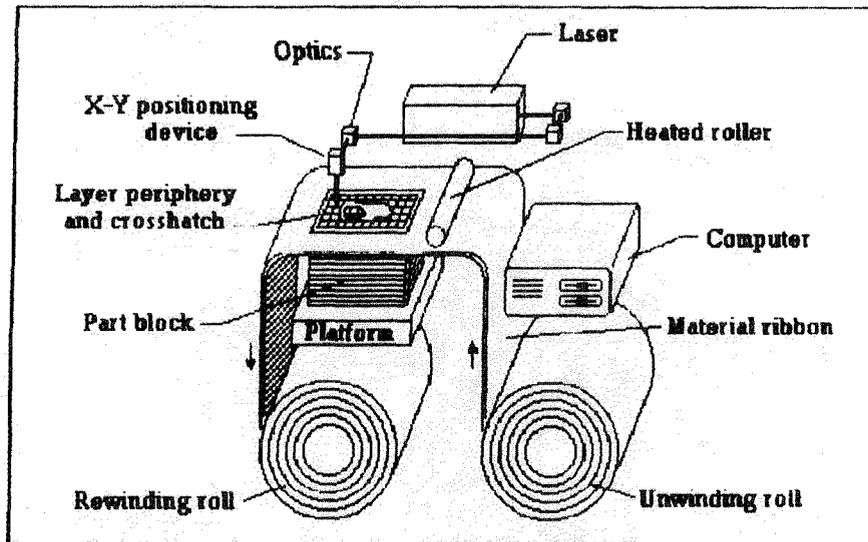


Figure 3: machine structure

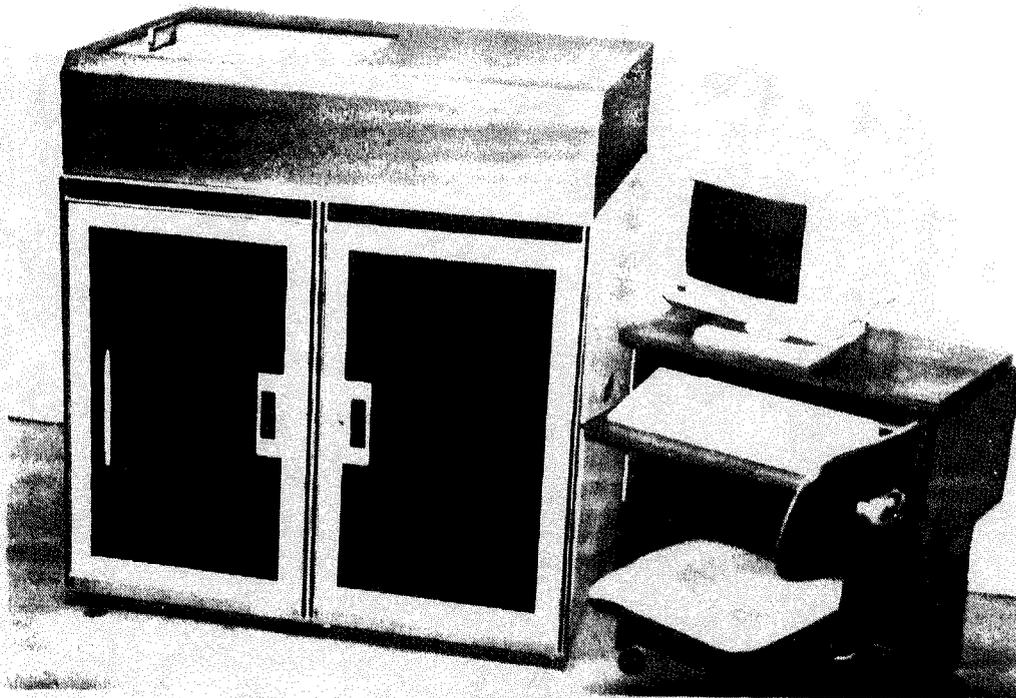


Figure 4: LOM machine (model 1015)

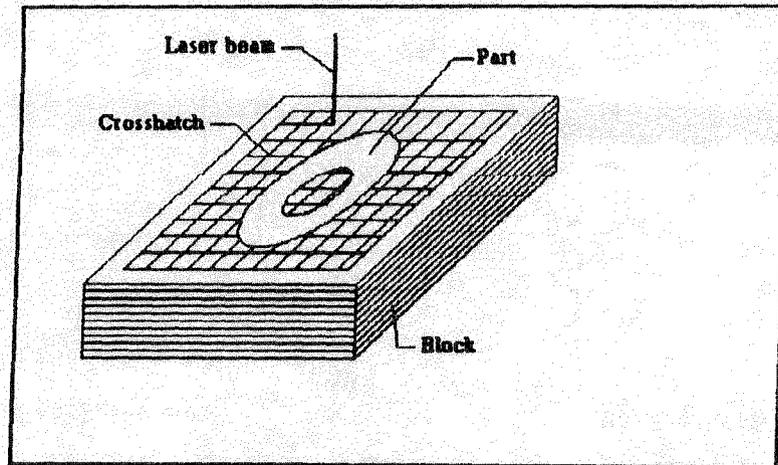


Figure 5: crosshatch

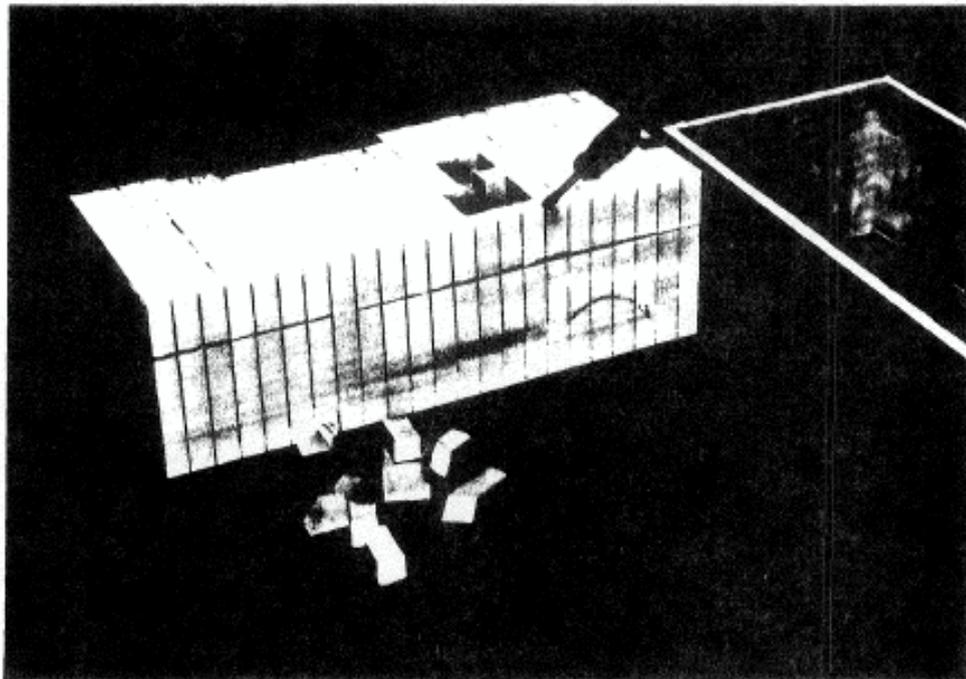


Figure 6: part block

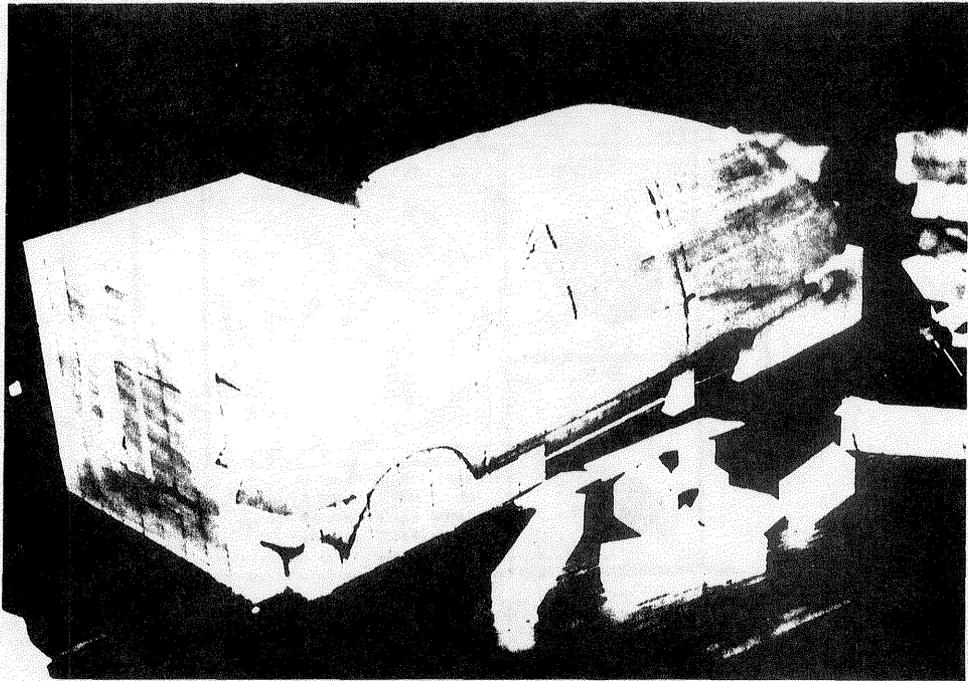


Figure 7: seperation

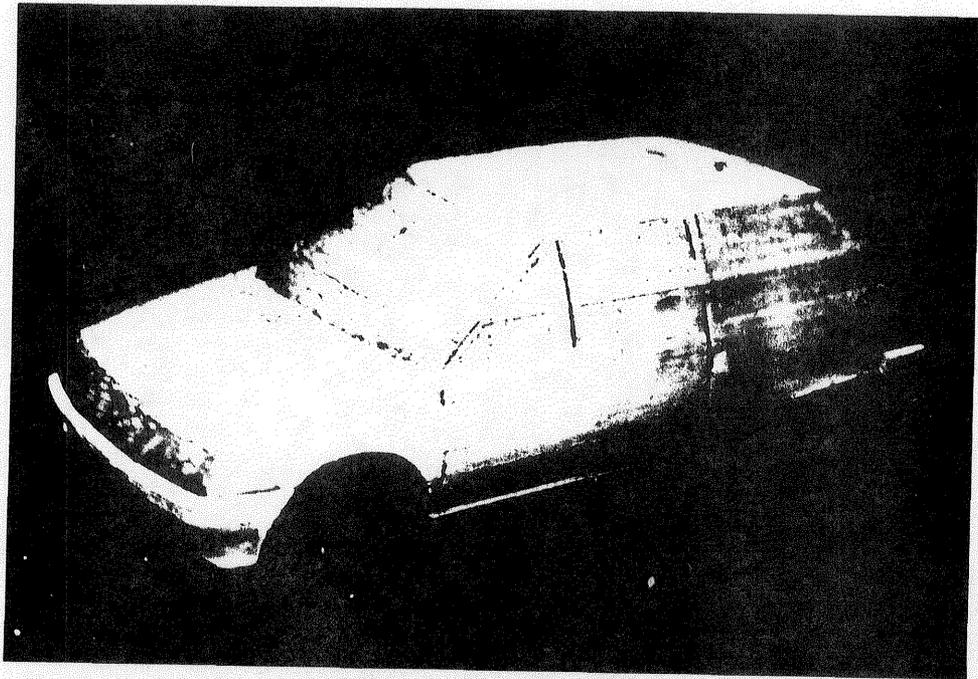


Figure 8: final part

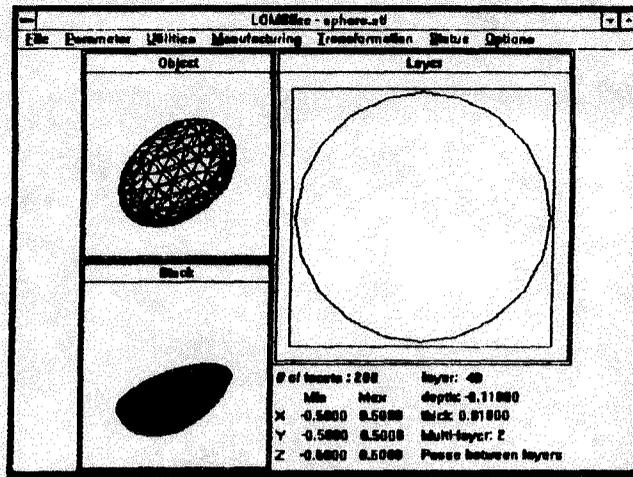


Figure 9: LOMSlice