

Fourth Industrial Revolution “Laminated Object Manufacturing”

Shreyas Kulkarni¹, Akshay Auti², Yogesh Kudale³, Suraj Sayare⁴

*Department of Mechanical Engineering
MCT's Rajiv Gandhi Institute of Technology
Mumbai University, Mumbai-400053, India
Corresponding Author- Shreyas Kulkarni*

ABSTRACT:- Today's global market has brought a fundamental change in the product development philosophy where there are multiple manufacturers who produce the same product of diverse quality. The manufacturer should be capable of developing a high quality, self-supporting, low cost product from recyclable material with the aim of customer satisfaction. For this, the product needs to be tested before manufacturing in a large scale. This is achieved with rapid prototyping method. Laminated Object Manufacturing is one of the types of rapid prototyping which is used to make 3-Dimensional physical object directly by using CAD data. This is done by loading thin layers of plastic one on another to create a solid model. This paper elaborates construction & working of laminated object manufacturing method to print a 3-Dimensional product.

KEYWORDS:- Product Development, Quality, Self-Supporting Object, Recyclable Material, Rapid Prototyping, Laminated Object Manufacturing.

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I. INTRODUCTION

Rapid prototyping is defined as the process of layer-by-layer creation of 3-Dimensional physical model from 3D CAD data. Various solid modelling softwares available to create a 3-Dimensional CAD object are SolidWorks, Inventor, Creo, Catia, Fusion-360. The modelled geometry is saved in STL file format which is accepted by most of the 3D printing platforms.

Laminated object manufacturing is a solid based rapid prototyping system. The object to be manufactured is modelled in a 3D modelling software. This CAD data is then sliced in a slicing software. In this process, the feed material is fed to the working table. A heated roller then passed over the working layer which bonds the working layer to the penultimate layer. Thin plastic sheet is made to cut in geometry as per sliced data to a depth of exactly 1-layer thickness. This cutting operation of material is done by movement of tool in X & Y direction. This motion of tool is controlled by an Arduino platform. separate stepper motors for X and Y axis are used which are mounted on the Arduino shield. The software then identifies the outer perimeter. The unused material between the outer perimeter and the part boundary is hatched by a rotating cutting tool using a cross hatch or parallel hatch platform into small four-sided pieces called slates. This cross hatched part acts as support during building of the part and it can be easily removed later once the build process is complete.

After cutting of one layer is complete, the build platform is lowered by the depth of one-layer thickness. This motion (Z-axis) is controlled by a stepper motor. The remaining portion of the sheet is then carried to the collecting bin and sheet for the next layer is supplied by the feed roller. The material sheet used is made from a recyclable material which can eliminate material wastage on a large scale. The process is repeated until the part is completely built. The last step in laminated object manufacturing is postprocessing or decubings which includes separating the part from its support material. Finishing is required wherever necessary.

II. LITERATURE SURVEY

▪ Material-

This technology is very versatile as almost any material which is available in the form of sheet can be used. Plastic and paper are the most widely used materials as they can be effortlessly cut. If a LASER cutter is provided instead of Mechanical Cutter, any metal can also be used. But metallic sheets are avoided because of the further complexity.

▪ Motors-

Stepper motors do not give as much torque as compared DC servo or DC geared motors. Stepper Motor's advantage over DC Servo and Geared motors is the positional control. Generally, the longer the motor

body, the more torque the motor has. The motor won't produce the manufacturer's rated torque, if a motor is rated to more amps or volts than the driver's capacity which are in use.

- **Temperature Controller-**

The W1209 is an economical yet highly practical thermostat controller. Employing this device, the user can control power to most types of electrical gadgets based on the temperature sensed by the high accuracy NTC temperature sensor. No programming knowledge is required for this module as it has microcontroller embedded in the system. Three tactile switches permit for constraining various parameters including ON and OFF trigger temperatures.

III. DESCRIPTION

Two wooden boxes of size 600x600x400 mm and 600x200x400 are made. First box is for the feeding mechanism, working area, flow bed roller arrangement and later is for the cutting tool motion and heated roller mechanism.



Fig. 1. Laminated Object Manufacturing Machine Prototype

A motor is connected to both two M8 screws (8mm diameter) which are connected to the working table and supported by Encoder flexible coupling. Four smooth shafts are used on either side of the lead screw for support, along which table moves in vertical direction. Two bearings are used to support each shaft. Movement of this table is controlled by a high torque stepper motor of 5.5 kgf torque (Nema 17). The working table is of size 200X200 mm.

PVC Clear material roll of 22 mm wide and 800 microns thick is used for prototype manufacturing. The material roll is fitted on the feed roller, such four rollers are used. These rollers are supported by two ball bearings each of 8mm internal diameter. Plastic sheet will pass through a set of two rollers which will guide the direction of the sheet to the precise position. These rollers will also maintain adequate tension in the material. When the cutting operation is done on the material, another set of two rollers will again guide the sheet towards the collecting bin. Flow bed helps to level the material to the height of working table. It also provides an additional support to the material.

A rotating type of cutting tool of HSS material (size 0.95mm diameter) is used for cutting operation. For the rotation of the tool, a high-speed DC motor of 6000 rpm, 6mm spindle diameter is used. The cutting tool and motor are interconnected by using a spindle which can accommodate variety of drill sizes from 0.5 to 3.0 mm. For motor holding purpose, a wooden box is made of appropriate size. This box moved entirely in vertical direction when gear connected to lead screw (M8 size) rotated manually. The entire tool assembly moves in x and y direction along guide rod and lead screw. Two motors are used for d movement of the Y direction and One motor is used for X direction. The motors used for the motion of tool is Nema 23 (Stepper Motor).

Heated roller is used for the adhesion of PVC material, tungsten filament lamp (230V – 750Watts) is used as a heating element. The temperature of heating element is maintained by temperature controller (W1209 – Range: -50 to 110). Rack and pinion mechanism is used for the movement of the heated roller, the pressure to roller is maintained by the tension spring.

IV. WORKING

First developed in the 90s decade, 3D printing or additive manufacturing refers to numerous different methods of building three-dimensional objects using computer-aided design (CAD) files. Engineers, designers and product development teams use 3D printing to rapidly and cheaply create prototypes that can be tested for their role & purpose. The manufacturer can improvise the object design before mass production.

Despite being one of the easiest and cost-efficient ways to create 3D products, LOM is not the most popular method of 3D printing used today. LOM system start out as CAD files to make models, like all 3D

printers. Prior to the printing operation, its CAD file must be converted to a format that a 3D printer can understand — usually STL or 3DS. This STL file is further converted into a G-code file using a software named Slic3r. slice3r provides wide variety of G-code flavors for different rapid prototyping machines. A marlin Firmware is used for g-code flavor. This G-code file is sent to the controlling device (Arduino) using pronterface. Pronterface is also used to control the tool motion manually.

Laminated object manufacturing apparatus uses a roll of material (PVC Soft) which is fed to the build platform by the feed rollers. To form a bond between two sheet layers, a heated roller is passed over the sheet of material on the build platform, which sticks the last layer of sheet to the penultimate layer after pressing it onto the platform. Temperature of heating roller is controlled using W1209 temperature controller which provides controlling range between -50 to 110 degrees Celsius. Lamp is used to heat the roller and a temperature of 90 degrees is used to stick the layer to adjacent bottom layer. The material is cut by a computer-controlled cutting tool conferring to the desired pattern. A pulley-belt assembly is used to provide motion to the x-axis and the y-axis 62 and the z-axis are driven by lead screw and guideways assembly which slices up any excess material in a hatched pattern, making it easier for decubing once the object is fully printed.

After one layer of the object is formed, the build platform is lowered by about 0.5 millimeters (the typical thickness of one layer). New material is then drawn across the platform using a DC motor and the heated roller again passes over the material, binding two layers. This cycle is repeated until the whole object is shaped.

WORKING MODEL -

- Design Input – Firstly, the object to be manufactured is drawn on any designing software (AutoDesk Inventor, SolidWorks). This file is saved as STL (.STL) file.
- Cavity Formation – A standard cube of 25cm³ size is made. The object to be manufactured is subtracted from the this standard mould. The desired product is the cavity and tool works around the extra peripheral part which also acts as support to the object.
- Hatching – Slicing software (Slic3r in this case) offers multiple hatching options – Concentric, Rectilinear, Hilbert Curve, Archimedean Chords, Octagram Spiral. Out of these variants, Rectilinear hatching technique is selected due to its less time consumption and ease of operation.
- Code Generation – Slic3r will generate G-codes according to the input design for cutting. This program is modified to accompany the Tool Home Position movement and Heated roller movement. These modifications are meant to be done for only once during entire course of operation.
- Code Transfer – All the G-codes generated by Slic3r are sent to the Arduino through a data transfer device or “Pronterface”. Arduino checks for the errors in the program. If the errors are detected, it does not send the code for operation. If the code is errorless, the program is uploaded to RAMPS to run the tool for cutting operation. Motor drivers (A4988 & DRV8825) are mounted on RAMPS to drive the stepper motors in X, Y and Z direction motion. A power supply of 12V is given to RAMPS will turn the motors on and guide the motors according to the program.
- Cutting – Tool spindle motor is connected to the power supply through a limit switch. So, the motor starts rotating as soon as it is switched on.

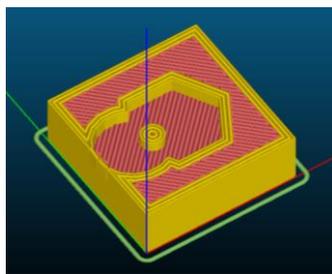


Fig. 2 (A) Rectilinear

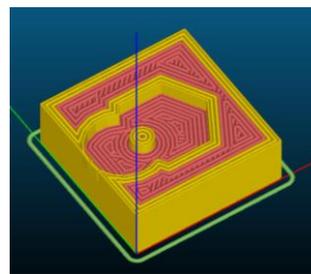


Fig. 2 (B) Concentric

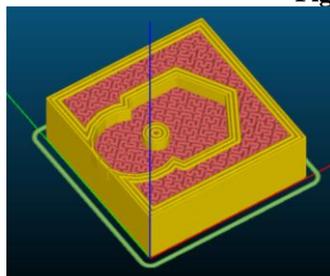


Fig. 2 (C) Hilbert Curve

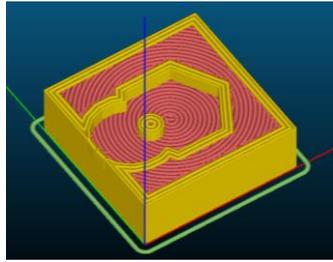


Fig. 2 (D) Archimedean Chords

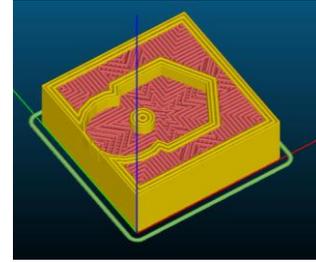


Fig. 2 (E) Octagram Spiral

Initial layer of material is by default placed on the working table. After reaching to home position, cutting operation for the first layer starts, here required geometry is cut along peripheral material which acts as support.

After completion of first layer, the work bed will index downward by thickness of one layer. Now the tool moves to a prefixed position where it hits a limit switch and remains stationary for preset delay time (5 seconds as per our program) after which it retracts to set distance (5 mm). Switch actuation turns on the feed roller DC motor which introduces fresh layer by pulling previously cut layer out through exit.

The new layer sticks to the previous layer using heated roller. The heat and pressure of the roller results in forming a good bond between two layers.

After the heated roller returns to its Home position RAMPS again turns on X and Y axis motors for tool motion and the procedure repeats itself from step to step to complete the entire geometry of object.

During operation if material roll finishes, another roll of material has to be feeded manually and set to its default position by extending it (over flow bed) to exit.

The provision is made to take the complete object out from machine after that the extra support material is removed to get the desired product.

V. CALCULATIONS

For X-motion of tool:

Smooth rod material,

Stainless Steel = C20

$\sigma_{yt} = 560 \text{ N/mm}^2$ (PSG 1.9)

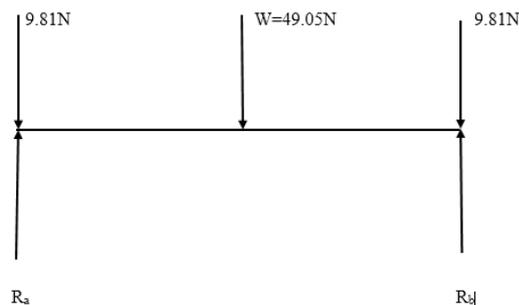
FOS = 3

$[\sigma_b] = 186.66 \text{ N/mm}^2$

For X- Motion rod:

Weight of tool post : $5\text{kg} = 50\text{N}$

$L = 350\text{mm}$



Σ of Moments at A=0

$$W \times 175 + 9.81 \times 350 - R_b \times 350 = 0$$

$$R_b = 34.33\text{N}$$

$$\Sigma F_y = 0$$

$$R_a + 34.33 = 9.81 + 9.81 + 49.05$$

$$R_a = 34.34\text{N}$$

$$M = 4292.75 \text{ N-mm}$$

$$M = \frac{\pi}{32} d^3 \times \sigma_b$$

$$d = 6.24$$

$$d_8 > d_6.24 \quad (\text{Safe})$$

For Y-motion of tool:

Checking smooth rod for bending failure,

$$W = 2 \text{ kg} = 20 \text{ N}$$

$$L = 300 \text{ mm}$$

$$M = \frac{WL}{4} = 1471.5 \text{ N-mm}$$

$$\frac{32M}{\pi d^3} = \sigma_b$$

$$d = 4.31 \text{ mm}$$

$$d_{10} > d_{4.31} \quad (\text{Safe})$$

Major diameter (D) = 8mm

Minor diameter (d) = 6mm

Pitch = 2mm

Load = 5kg = 50N

Length of screw = 350mm

$$\begin{aligned} \text{Number of threads (Z)} &= \frac{L}{p} \\ &= \frac{350}{2} \\ &= 175 \end{aligned}$$

Material of lead screw = C35

$\sigma_{yt} = 280 \text{ N/mm}^2$ (PSG 1.9)

FOS = 3

$$[\sigma_{yt}] = 93.34 \text{ N/mm}^2$$

$$[\sigma_{cr}] = 0.8[\sigma_{yt}] = 74.664 \text{ N/mm}^2$$

$$[\tau] = 0.5[\sigma_{yt}] = 46.67 \text{ N/mm}^2$$

Crushing failure of lead screw,

$$\begin{aligned} \sigma_{cr} &= \frac{W}{\frac{\pi}{4} \times (D^2 - d^2) Z} \\ &= \frac{50}{\frac{\pi}{4} \times (8^2 - 6^2) 175} \\ &= 0.013 \text{ N/mm}^2 \\ 0.013 \text{ ind} &< [74.664] \\ \sigma_{cr} &< [\sigma_{cr}] \quad (\text{Safe}) \end{aligned}$$

Check for Crushing failure of nut,

Major diameter (D) = 8mm

Minor diameter (d) = 6mm

Pitch = 2mm

Load = 5kg = 50N

Height of nut = 8mm

$$\begin{aligned} \text{Number of threads (Z)} &= \frac{H}{p} \\ &= \frac{8}{2} \\ &= 4 \end{aligned}$$

Material of lead screw = C35,

$\sigma_{yt} = 280 \text{ N/mm}^2$ (PSG 1.9)

FOS = 3

$$[\sigma_{yt}] = 93.34 \text{ N/mm}^2$$

$$[\sigma_{cr}] = 0.8[\sigma_{yt}] = 74.664 \text{ N/mm}^2$$

$$[\tau] = 0.5[\sigma_{yt}] = 46.67 \text{ N/mm}^2$$

Crushing failure of lead screw nut,

$$\begin{aligned} \sigma_{cr} &= \frac{W}{\frac{\pi}{4} \times (D^2 - d^2) Z} \\ &= \frac{50}{\frac{\pi}{4} \times (8^2 - 6^2) 4} \\ &= 0.56 \text{ N/mm}^2 \end{aligned}$$

$$0.56 \text{ind} < [74.664]$$

$$\sigma_{cr} < [\sigma_{cr}] \quad (\text{safe})$$

Check for direct shear failure of nut,

$$\tau = \frac{W}{\frac{\pi}{4} \times d^2}$$

$$= \frac{50}{\frac{\pi}{4} \times 6^2}$$

$$= 1.76 \text{N/mm}^2$$

$$[\tau] > \tau_{ind} \quad (\text{safe})$$

Calculation of lead screw (Table motion):

Major diameter (D) = 8mm

Minor diameter(d) = 6.466mm

Pitch = 1.25mm

Load = 20kg = 200N

Length of screw = 330mm

$$\text{Number of threads}(Z) = \frac{L}{p}$$

$$= 330/1.25$$

$$= 264$$

Material of lead screw = C35

$\sigma_{yt} = 280 \text{ N/mm}^2$ (PSG 1.9)

FOS = 3

$[\sigma_{yt}] = 93.34 \text{ N/mm}^2$

$[\sigma_{cr}] = 0.8[\sigma_{yt}] = 74.664 \text{ N/mm}^2$

$[\tau] = 0.5[\sigma_{yt}] = 46.67 \text{ N/mm}^2$

Crushing failure of lead screw,

$$\sigma_{cr} = \frac{W}{\frac{\pi}{4} \times (D^2 - d^2) Z}$$

$$= \frac{200}{\frac{\pi}{4} \times (8^2 - 6.466^2) 264}$$

$$= 0.04346 \text{ N/mm}^2$$

$$0.04346 \text{ind} < [74.664]$$

$$\sigma_{cr} < [\sigma_{cr}] \quad (\text{Safe})$$

Checking for buckling failure of lead screw,

$$P_{cr} = \frac{\pi^2 EI}{Le^2}$$

$$= \frac{\pi^2 \times 209 \times 10^8 \times \frac{\pi}{64} \times 6.466^4}{(115)^2}$$

$$= 13383.29 \text{N}$$

$$= 1338.3 \text{Kg}$$

$$[13383.29] > 200 \text{ind}$$

$$P_{cr} > P_{Load}$$

Checking for Crushing failure of nut,

Major diameter(D) = 8mm

Minor diameter(d) = 6.647mm

Pitch = 1.25mm

Load = 20kg = 200N

Height of nut = 8mm

$$\text{Number of threads}(Z) = \frac{H}{p}$$

$$= 8/1.25$$

$$= 7$$

Material of lead screw= C35
 $\sigma_{yt} = 280 \text{ N/mm}^2$ (PSG 1.9)
 FOS = 3
 $[\sigma_{yt}] = 93.34 \text{ N/mm}^2$
 $[\sigma_{cr}] = 0.8[\sigma_{yt}] = 74.664 \text{ N/mm}^2$
 $[\tau] = 0.5[\sigma_{yt}] = 46.67 \text{ N/mm}^2$

Crushing failure of lead screw nut,

$$\sigma_{cr} = \frac{W}{\frac{\pi}{4} \times (D^2 - d^2) Z}$$

$$= \frac{200}{\frac{\pi}{4} \times (8^2 - 6.647^2) 7}$$

$$= 1.83 \text{ N/mm}^2$$

$$1.835 \text{ ind} < [74.664]$$

$$\sigma_{cr} < [\sigma_{cr}] \quad (\text{safe})$$

VI. PROJECT OUTCOMES

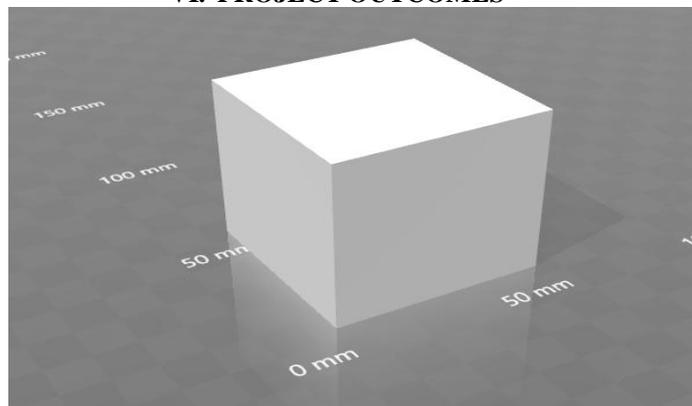


Fig. 3(A) Object to be printed

A cube of 120 X 120 X 120 mm³ is first created using 3D CAD modelling software (AutoDesk Inventor, SolidWorks, 3D Builder). The geometry can be anything (except hollow part) which is to be printed by the machine. The CAD model generated is later exported as .STL file which could be read by an open source rapid prototyping software. (i.e.Slic3r,CAMotics,etc)

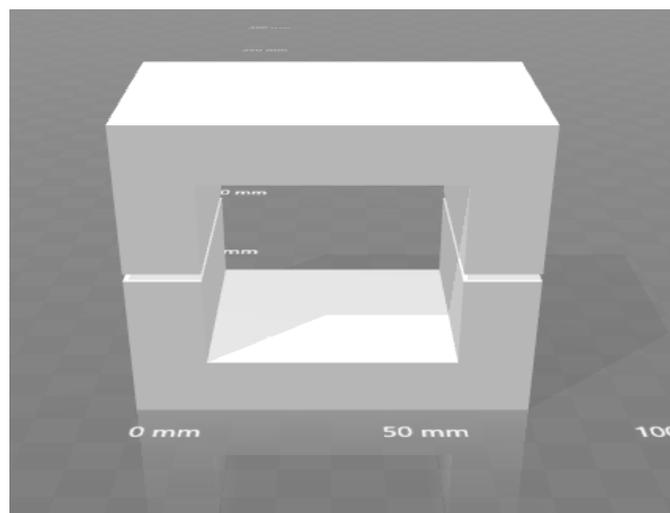


Fig. 3(B) Mould made on CAD CAM software by Substraction

The object is placed concentrically with the mould and the whole portion is eliminated from the mould. This results in forming the cavity which is the desired part. The cutting tool hatches throughout the material layer except the cavity formed.

The slicing software which is used for this printer (Slic3r) offers various options for hatching the layer. Rectilinear has been selected as a standard for every process due to its lack of complexities.

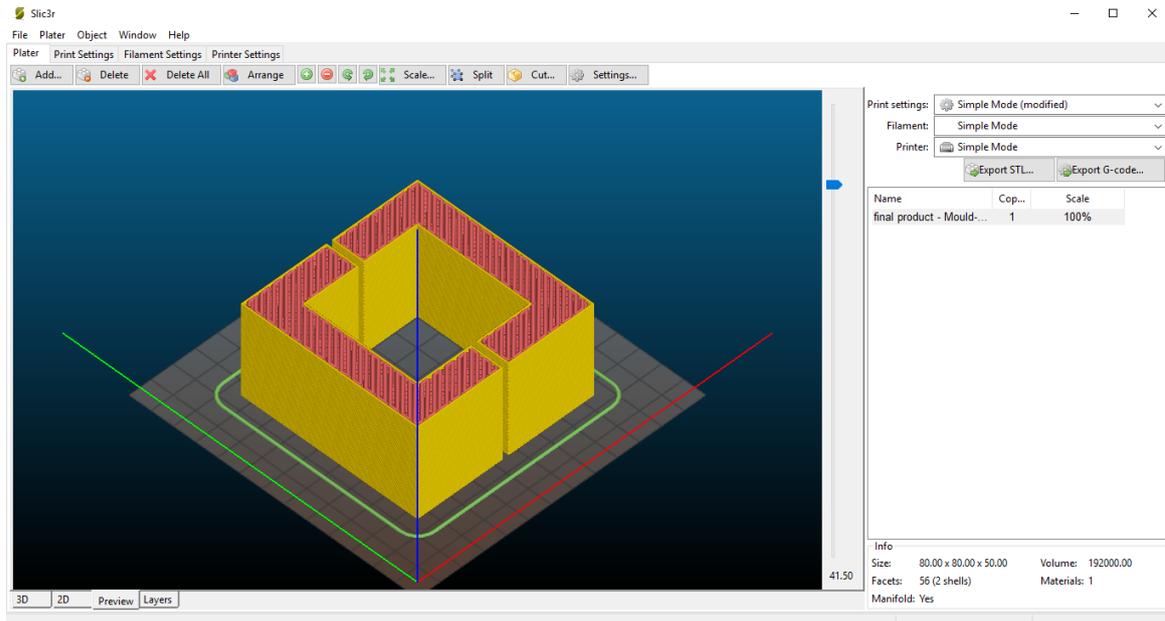


Fig. 3(C) Generation of GCode

Slic3r will generate G-codes according to the input design for cutting. This program is modified to accompany the Tool Home Position movement and Heated roller movement. Rectified codes are sent to Pronterface software.

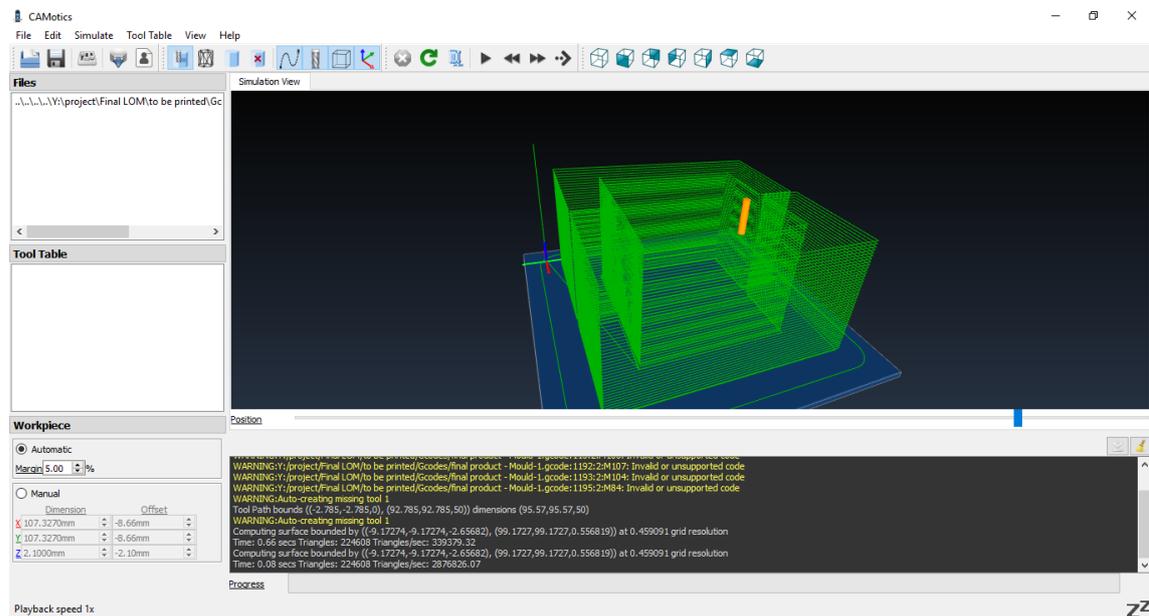


Fig. 3(D) Checking for the tool path

Due to rectilinear selection, the tool hatches in a straight line till it reaches to the maximum position. At maximum position, lateral movement equal to the diameter of the tool takes place and tool travels in opposite direction. Tool follows this process for the entire geometry of the object to complete hatching of one layer. Changing the type of hatching will change the movement as well as sequence of operation

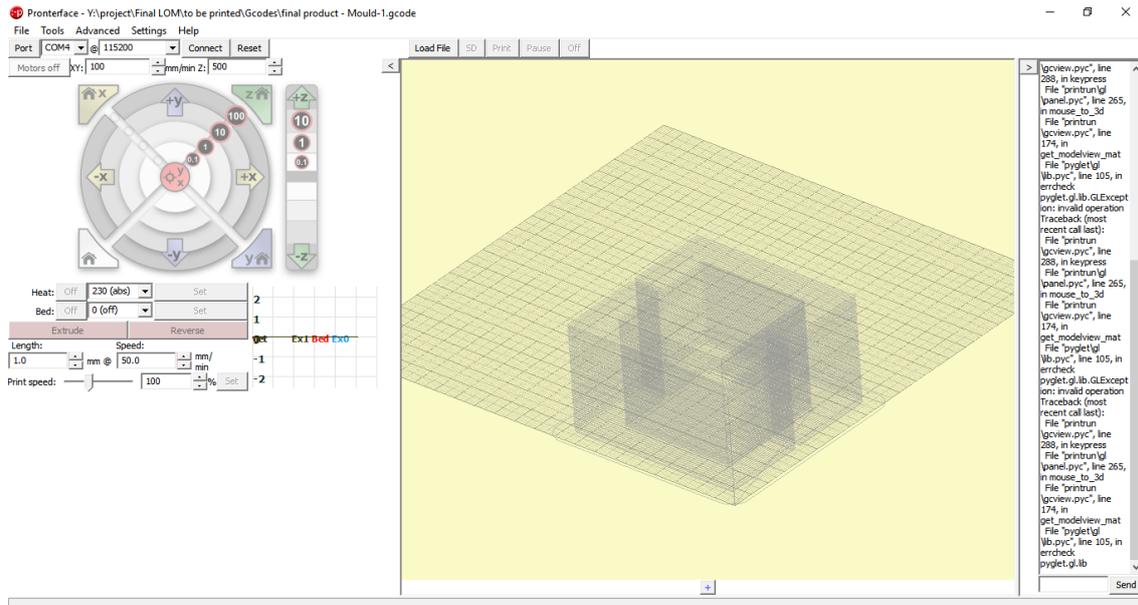


Fig. 3(E) Uploading to the Printer

Pronterface is the software bridge between design input and actual operation. The object is centrally placed and Pronterface allows modifications in the data such as distance to be travelled by the tool or heated roller, speed with which the roller will cover the total specified distance. The values for speed and feed of cutting tool are dependent on the program and operation is performed. The final object with peripheral material support is printed to get desired product the decubing of above printed object is done.

VII. CONCLUSION

Hence, by implementing this method, rapid prototypes of any solid objects can be created with virtually no wastage and wide range of material variety (from plastic to metal sheets and paper) with varying dimensions (material layer thickness and layer cross-section area) and in most effective way without compromising the quality. Our project also highlights a less popular 3D printing technology which could be an alternative to the widely used methods.

VIII. FUTURE SCOPE

LOM could provide extraordinary control over the shape, configuration and function of fabricated products as well as high degree of personalization for individuals.

It has the potential to modernize the cost-effective mass customization of intricate products that cannot be manufactured easily using conventional technologies.

It will not substitute conventional manufacturing methods in the foreseeable future. However, it may still bring ground-breaking advances to the manufacturing industries through its combination with conventional manufacturing technologies.

LOM could offer numerous benefits over conventional industrial technologies including reduced substantial waste and energy consumption.

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