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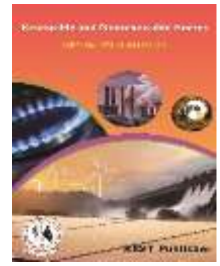


Structural and Motion Optimization of a High-Resolution Delta 3D Printing

***K Kalyani Radha, B Omprakash**

JNTUACEA, Ananthapuramu, Andhra Pradesh, India.

*Corresponding Author Email: radha.mech@jntua.ac.in

***Abstract**: The manufacturing process is an important phase and it's become the major concern in manufacturing industries. Many industries use the traditional manufacturing process for the product development which is time consuming, expensive and it requires skilled labour which in turn leads to huge investment for the development of product. These are the problems which originate due to the use of the current conventional methods. So keeping all these in observance, I have planned to study and develop the indigenous machine works on Rapid prototyping technique (3D printers). Mainly these 3D printers are devices that can create a three-dimensional object from a digital model. The product is manufactured by adding material layer by layer and fusing these layers together. These machines can capable of doing complex and difficult tasks in one long step and it only requires a 3D model of the object to be made with a defined set of parameters and scaling ratios, which can then be converted into G-code. This data is then used for controlling the motors and extruding plastic, based on the g-code generated. These G-codes guides the machine to produce the part according to the requisite Design. It's an easy, economic and doesn't require intense labour for processing. In this present work, a Multi material FDM based DELTA 3D printer is Designed, Developed and analysed for further development.*

***Keywords:** 3D Printer, FDM, Additive manufacturing, Rapid Prototyping*

1. INTRODUCTION

3D printing is a rapid prototyping methodology where a three dimensional object is made layer by layer addition of the raw materials used by executing the G-codes of a CAD designed model which is controlled by a computer. These objects can be of almost any shape or geometry where fabrication through the conventional methods will be challenging or impossible. These machines could be categorized into an industrial robot where they are already being used. This method is also known as Desktop Manufacturing or Freedom Fabrication.

Need of rapid prototyping:

- Objects can be formed with any geometric complexity or intricacy without the need for elaborate machine set-up or final assembly.
- Freeform fabrication systems reduce the construction of complex objects to a manageable, straightforward, and relatively fast process.
- These techniques are currently being advanced further to such an extent that they can be used for low volume economical production of parts.
- It significantly cut costs as well as development times.

Three-dimensional data from digitizing a physical part is not always straightforward. It generally requires data acquisition through a method known as reverse engineering, using a CMM or laser digitizer. The industry standard for rapid prototyping is the STL file, a file extension from Stereolithiography. The CAD software generates a tessellated object description. In STL format, the file consists of the X, Y, and Z coordinates of the three vertices of each surface triangle, with an index to describe the orientation ofthe surface normal. Normally, the support structure is generated before slicing to hold overhanging surfaces during the build. Most current CAD packages can export a CAD file in STL file format, and good STL files will assure a speedy quote turnaround, and good quality RP models. The STL format is an ASCII or binary file used in the RP process. It is a list of triangular surfaces that describe a computer generated solid model.

Classification of rapid prototyping techniques:

Rapid Prototyping Techniques have proven to be more convenient in building complex prototypes. This is because these processes are additive in nature unlike conventional subtractive processes. At least six different rapid prototyping techniques are commercially available, each with unique strengths. Rapid prototyping techniques can be basically classified in three categories, namely:

- Liquid Based Processes
- Solid Based Processes
- Powder Based Processes

2. LITERATURE REVIEW

Wei-chin Lee, Ching-chih Wei, Shan-Chen Chung [1] has proposed currently, two major processes are being used to produce prototypes, namely machining and rapid prototyping. Machining is generally more accurate and precise, but it is difficult to produce objects with certain complicated features. In contrast, rapid prototyping can produce objects with complicated features, which allows materials to be used more efficiently. However, due to the uneven shrinkage and residual stresses within rapid prototyping products, their accuracy is usually uncertain. This study attempts to integrate these two manufacturing processes and develop a hybrid rapid prototyping system in order to overcome the disadvantages associated with each process and to develop new applications. Fused deposition modeling (FDM) was used as the rapid prototyping process in this work. A spindle and a low-cost FDM extruder were designed to be placed on each end of a rotary axis in a five-axis machine tool. The proposed design allows the rotation of the axis on the five-axis machine to switch between machining and FDM, thus achieving the advantage of reducing costs for extra actuators without sacrificing working space. The case studies demonstrated that the proposed hybrid system can build FDM objects without using support materials and produce FDM parts with metal embedded to increase the stiffness. The system can also conduct five-axis machining on a completed FDM part or trim the freeform surface fabricated by FDM to achieve more accurate dimensions or better surface finish. S.H. Masood [2] he proposed that Fused deposition modelling (FDM) is one of the most widely used additive manufacturing processes for fabricating prototypes and functional parts in common engineering plastics. The process is based on the extrusion of heated feedstock plastic filaments through a nozzle tip to deposit layers onto a platform to build parts layer by layer directly from a digital model of the part. The simplicity, reliability, and affordability of the FDM process have made the additive manufacturing technology widely recognized and adopted by industry, academia, and consumers. The FDM process has also been widely used by research and development sectors to improve the process, develop new materials, and apply the FDM systems in a wide range of engineering applications. This chapter describes an overview of the basic process, materials, and capabilities of the Stratus's FDM technology, and also presents a comprehensive review of research and development work undertaken using the FDM process since its inception over the past two decades. Christian Weller, Robin Klee, Frank T. Pillar [3] described that Additive manufacturing (AM), colloquially known as 3D printing, is currently being promoted as the spark of a new industrial revolution. The technology allows one to make customized products without incurring any cost penalties in manufacturing as neither tools nor molds are required. Moreover, AM enables the production of complex and integrated functional designs in a one-step process, thereby also potentially reducing the need for assembly work. In this article, we discuss the impact of AM technology at both firm and industry level. Our intention is to discern how market structures will be affected from an operations management perspective. Based on an analysis of established economic models, we first identify the economic and technological characteristics of AM and distil four key principles relevant to manufacturers at firm level. We then critically assess the effects of AM at industry level by analyzing the validity of earlier assumptions in the models when these four principles apply. In so doing, we derive a set of seven propositions which provide impetus for future research. In particular, we propose that in a monopoly, the adoption of AM allows a firm to increase profits by capturing consumer surplus when flexibly producing customized products. Meanwhile in competitive markets, competition is spurred as AM may lower barriers to market entry and offers the ability to serve multiple markets at once. This should ultimately result in lower prices for consumers.

3. MATERIAL SELECTION

Frame: The base frame is designed in designing software called AUTOCAD and then it is fabricated through laser cutting technique using acrylic sheets, in VEDANT industries Bangalore. *The Base frame gives the printer its stiffness. The three axes of the machine will be added to this frame. The frame consists of threaded rods connected together with printed parts (these are called the vertices.)*

Linear plain bearings: *Linear plain bearings are based on extremely wear resistant polymers specially looped for the linear technology. The dimensions are compatible with standard ball bearings and the special geometry guarantees reliability to extreme environments. The IGUS INDIA PVT.LTD Company has sponsored these newly designed DRYLIN linear polymer bearings for the project purpose under young engineer development scheme. DRYLIN is a range of maintenance-free and lubricant-free linear bearings in four different type series. In addition, the range is complemented by complete linear units with spindle drive or toothed belt. Besides the freedom from maintenance and lubricants, the main features include ruggedness and the insensitivity to dirt, water, chemicals, heat or impacts.*

Print plate: Printed parts are printed on the print plate. The three axis move together so that the nozzle can move above the print plate in an area of bed. Warping is the main issue, caused by the uneven cooling of outer and inner sections of a printed part. The material at the outside of a part will cool and thus shrink faster than the material inside. This will cause the cooler material to warp or bend while the hot material won’t. This uneven shrinking will cause straight edges to bend and might cause structural failure in parts. Warping is especially a problem for the lower layers of a part since the print plate will cool those layers much faster than higher layers. The heat bed remains on for the entire duration of the print. Usually a glass plate is installed on top of the heat bed. If the heat would be turned off after a few layers the printed part would eventually come loose due to the temperature drop and the print would fail. A heat bed can either be bought or home-made. While installing a heat bed checking the temperature of the transistor on electronics board must be necessary.

Electronics

- Stepper motors: 4x NEMA 17 (3 positioning, 1 extruder).
- Stepper torque of atleast 4600 g/cm.
- Endstops : 3x ZM switch (pin plunger, no lever).
- Electronics : RAMPS 1.4, Arduino Mega.
- Power Supply : 12v 10A
- Firmware : Repetier Host.
- Software : CURA.

General electronic parts are

- Blower fan
- Heating resistor
- ATX power supply
- LCD smart controller
- LCD to ramps Adapter
- PCB heat bed
- Electronics controller
- Thermistor

4. DELTA 3D PRINTER FABRICATION

DESIGN METHODOLOGY:

The process of developing a 3D printer is categorized into 6 stages:

- Literature survey
- Design of 3D printer
- Developing of software and Programing
- Fabrication of outer casing and Designing of extruder
- Incorporation of electronics
- Testing and Interpretation

To develop the 3d printer, key segment is to focus on the existing different types of printers, their design specifications and their working methodologies concentrating on ABS and PLA extruders then it is easier to produce a conceptual design of the particular 3D printer and to perform any required design analysis. From the literature survey basis, a conceptual design of 3D printer is primed. The motion system comprises of the extruder assembly have both X and Y movement. It is operated by belts moving a double bar cross-beam in the y-direction whiles the extruded is moved up and down this crossbeam in the x-directions. The z-axis motion is produced by raising and lowering the printing plate. This is operated by use of a threaded rod. This greatly reduces printing errors due to the printing object having no lateral movement during the printing process and so is unlikely to be disturbed. This is an advantage over printers with lateral y- or x-axis movement of the printing bed which may cause problems. Building a 3D printer compels the arrangement of software, electronics, and mechanics, for a simple breakdown of the different technologies behind a 3D printer design. This flowchart can be used to visualize how all the components connect and interact with each other to make the device work together as a unit. Developing a software which interconnects with the 3D printers is the vital task. A host software is developed, allows communication to the printer electronics before and during the print works. It allows the operator to upload a. STL file and convert it to G-code to control the printer. The host software that will take input 3D drawings (. still files) and will geometrically breakdown the file into layers which are then converted into a series of paths in which the tool-head should move. This information is sent to the controller, via the firmware which will control the movement of the printer. The extruder is the crucial part of the 3D printer. It takes a filament input from above, and passes it through a heated channel, and squeezes it out through a nozzle. An extruder consists of a cold end and a hot end. The hot end is where the filament is heated and melted. The hot end can reach temperatures of approximately 240°C. The hot end specifically refers to the part that is the tip of the extruder. The hot-end design is very simple and is based on the J-head nozzle. It contains a heater block, a PEEK block, a brass nozzle, a PEEK insulator and a PTFE sleeve with an M4 brass nut. It also has a resistor running perpendicular to the filament flow and a thermistor for monitoring the temperature. Later, the fabrication of the outer casing is geared up. The fabrication majorly the 3D printed parts are utilized. After the fabrication, the casing is integrated with electronics such as Arduino boards and RAMPS. The electronics of the device ought to be more accessible and it permits the user to squeeze the rotation speeds in the stepper motors. Programmed the 3D printer using Firmware. Firmware is a program which resides on the printer's motherboard. The firmware is the link between software and hardware, it interprets commands from the G code file and controls the motion accordingly. Repeater host firmware is developed for use with 3D printer machines.

5. CONSTRUCTION PROCESS OF 3D PRINTER

To see how the DELTA 3D Printer is assembled, refer to the pictures available in the source files. Assembly is as follows:

- Begin by constructing each of the three towers, starting with the motor end, then the idler end, followed by the carriage, and then putting it all together to complete the tower.
- Complete the frame by attaching the motor ends of each tower to the lower frame before attaching the upper frame to the idler ends.
- Assemble the end effector platform, assembling and attaching the diagonal rods as you go.

- Attach the ends of each diagonal rod to the carriages on each tower to complete the mechanical assembly.
- Finally, install the electronics, mount the extruder, and complete the wiring.

Motor end:

- Begin the motor end assembly by taping the four mounting holes for the lower frame with an M4 tap.
- Drill each of the six M3 holes with a 7/64 or #35 drill bit.
- Insert six M3x12 screws using fender washers and nuts but do not tighten.
- Insert 8mm smooth rods into the top of the motor mount until just shy of the bottom of the opening.
- Once both rods are adjusted to the same length, tighten each M3 screw to secure the smooth rods.
- Mount the NEMA17 motor using four M3x10 screws with washers or M3x12 screws and washers with a cork gasket.
- Attach a 36-tooth timing pulley to the motor shaft**.**

FIGURE 1. Motor end

IDLER END:

1. Tap the two mounting holes for the upper frame with an M4 tap
2. Drill each of the four M3 holes with a 7/64 or #35 drill bit
3. Insert four M3x12 screws using fender washers and nuts but do not tighten
4. Insert M8x30 screw through two 608ZZ bearings and one M8 washer and thread through the idler end until tight
5. Tighten idler on the inside with a M8 washer and nut using a wrench and allen key

FIGURE 2. Idler end

Carriage:

- Cut out the supports in the timing belt retainer
- Tap the end stop screw hole with an M3 tap
- Thread an M3x10 flat or button head screw for end stop adjustment
- Drill each of the four M3 holes for the u-joints with a 3/32 or #40 drill bit
- Set four M3 nuts on the inside of each u-joint using a soldering iron to heat the nut to make it flush with the opening, shown here
- Insert four M3x12 screws using fender washers but do not tighten and leave the u-joint open
- Drill each of the four M3 holes in two u-joints with a 3/32 or #40 drill bit
- Lubricate the holes and bearing surfaces of each u-joint with PTFE grease or 3-in-One motor oil
- Insert both u-joints into the carriage and tighten the four M3 screws
- Insert two LM8UU linear bearings and secure with four 7/8"x4-1/8" zip ties

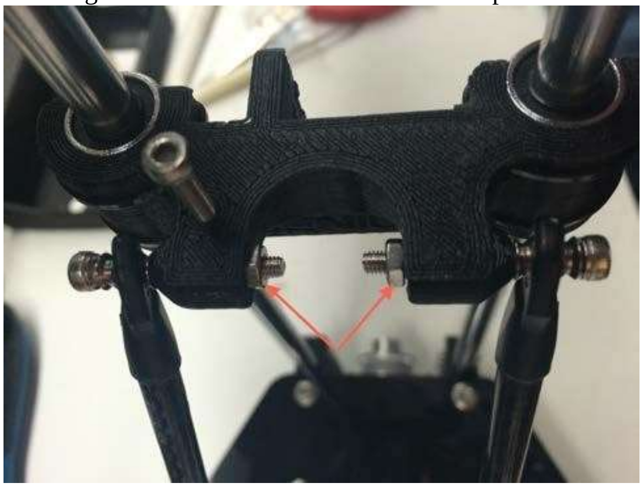


FIGURE 3. Carriage

FRAME

- Complete the towers by sliding the carriage on each pair of 8mm smooth rods
- Slide an idler end on top of each pair of rods making sure to align the top and bottom of the tower keeping the rods parallel
- Once each tower is assembled but before tightening the idler end, stretch a GT2 timing belt over the pulley, between the belt holder on the carriage, and over the idler
- Pulley upwards on the idler to tension the timing pulley, tighten all four M3 screws to finish the tower.
- Once the towers are complete, attach the lower frame to the motor ends of each tower using M4x16 screws and washers; three on each of the front towers and four on the rear tower
- Attach the upper frame to the idler ends of each tower using two M4x16 screws and washers on each tower.

Platform

- Drill each of the six M4 holes for the hot end with a 5/32 or #22 drill bit
- As with the carriage, drill each of the twelve M3 holes for the u-joints with a 3/32 or #40 drill bit
- Set twelve M3 nuts on the inside of each u-joint using a soldering iron to heat the nut to make it flush with the opening, shown here
- Insert twelve M3x12 screws using fender washers but do not tighten and leave the u-joint open
- Drill each of the twelve M3 holes in six u-joints with a 3/32 or #40 drill bit
- Lubricate the holes and bearing surfaces of each u-joint with PTFE grease or 3-in-One motor oil
- Insert all six u-joints into the platform and tighten the twelve M3 screws

- Attach 40mm fan to fan mount using two M3x12 flat-head screws and nuts, then attach mount to platform with two M3x12 socket-head screws, washers, and nuts

FIGURE 4. Frame

DIAGONAL RODS:

- Cut six pieces of .188" OD rigid carbon fiber tube to lengths of 20mm short of the calculated diagonal rod length
- For this build, the diagonal rod length was calculated to be 186mm so the rods were cut to 166mm in length
- Use cyanoacrylate (super glue) or epoxy to glue a diagonal rod end (jaw) to each end of the carbon fiber tube
- Be sure to keep the rod ends flat to a table and all at the same distance
- Once the glue is dry, drill each of the twenty-four M3 holes for the u-joints with a 3/32 or #40 drill bit
- Attach each diagonal rod to each u-joint on platform using an M3x16 screw and washer
- Nuts were not used in this build because of clearance although M3x20 button-head screws and locknuts could be used instead
- Finally, attach the other end of the diagonal rods to the carriage u-joints, connect platform to carriages.

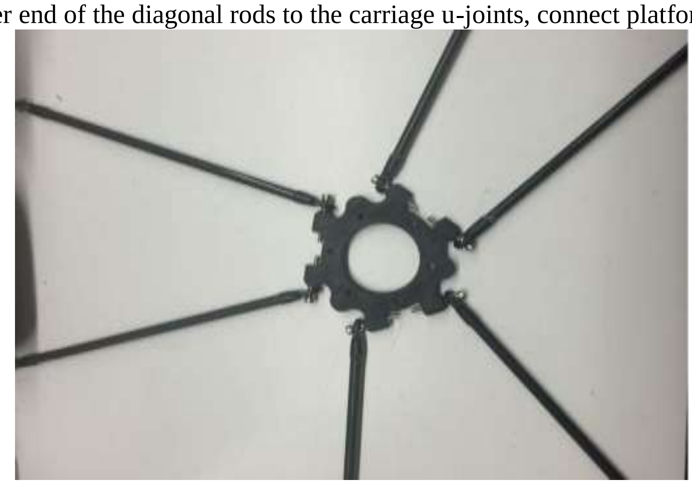


FIGURE 5. Diagonal rods

End stops:

- Solder two 26-22AWG wires to each switch, with lengths sufficiently longer than the vertical smooth rods
- Secure each end stop switch to the inside of each idler end using two M2.5x10 screws in the orientation shown
- Without M2.5 screws the switch mounting holes need to be drilled with a 7/64 or #35 drill bit and each hole in the idler tapped to M3 and secured with M3x12 screws

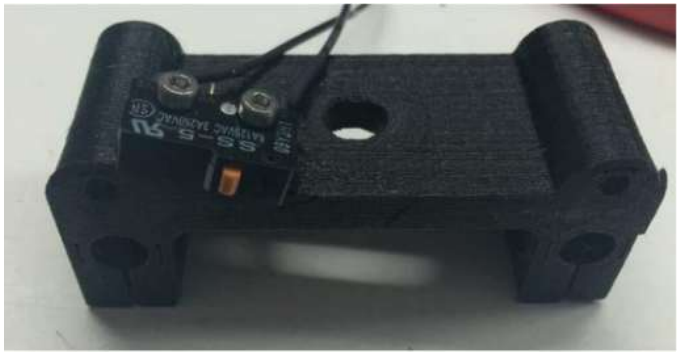


FIGURE 6. End stops

Wiring

- The default controller for the Portable Delta printer is the ramps 1.4 with an Adriano mega 2650
- With the printer right side up, the motor and end stop for the front left tower are connected to X, front right to Y, and rear to Z.

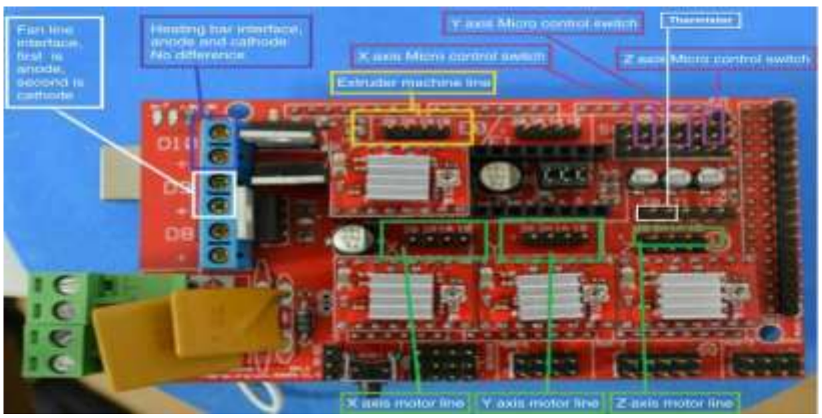


FIGURE 7. Wiring

Assembled delta printer:

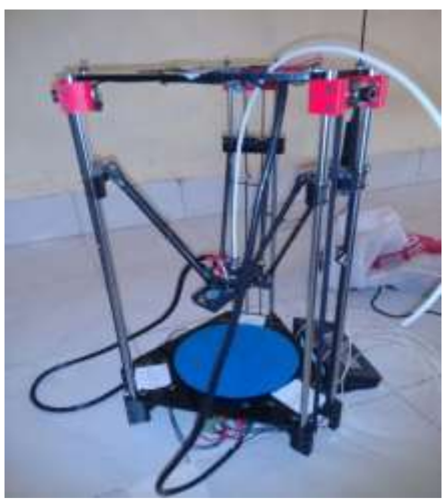


FIGURE 8. ASSEMBLED PRINTER

6. THERMAL ANALYSIS

A steady state thermal analysis is that in which thermal loads do not vary over time. A steady state thermal analysis using Any's workbench can be used to evaluate temperature contours, temperature gradients, heat fluxes, heat flows as well as thermal stresses over a body. These all occurs due to thermal loads acting on that body. A steady state thermal analysis can be linear or nonlinear. In linear analysis material properties are temperature independent while opposite condition occurs in nonlinear analysis. Continuing to any workbench tutorials, this current learning module focuses the steady state thermal analysis of heat sink using any workbench. Heat sink is a cooling component used to dissipate heat in many engineering applications like electronic devices, CPU, transformers and number of others. In current any workbench tutorials, a CPU heat sink is under observation. Run Any's Workbench from start menu and drag steady state thermal analysis from toolbox to project schematic window

Geometry of the nozzle: Import IGES file of the geometry. Right click Geometry>Import Geometry>Browse and give path of your downloaded file. Save the project now.

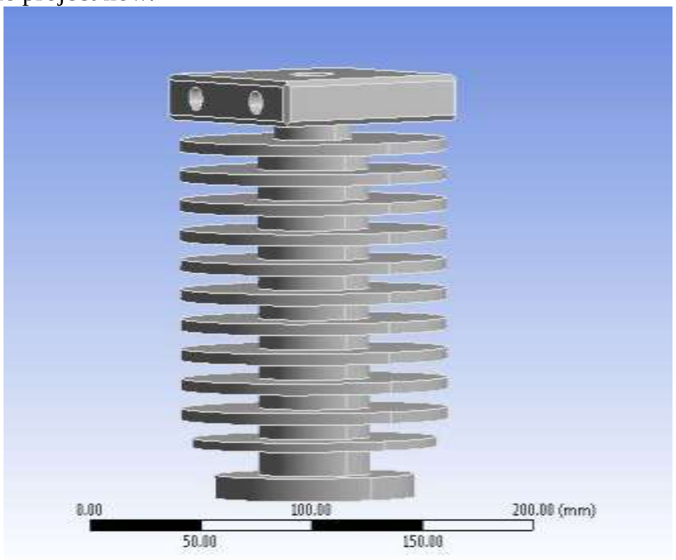


FIGURE 9. Geometry of the Nozzle

Meshing Of The Nozzle: From tree outline, Right click Mesh>Update, meshing will be created. You will see meshing is not fine, so results can't be precise. In order to get accurate results, we have to reduce mesh element size. To do that click on the Mesh in Outline tree, a "Details of Mesh" will open. Change element size from default to 5mm. Then Update Mesh again, final mesh will be the statistics of the nodes and elements.

Details of "Body Sizing" - Sizing

Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Type	Element Size
Element Size	5. mm
Behavior	Soft

FIGURE 10. Details of mesh

FIGURE 11. Meshed Nozzle Model

Statistics

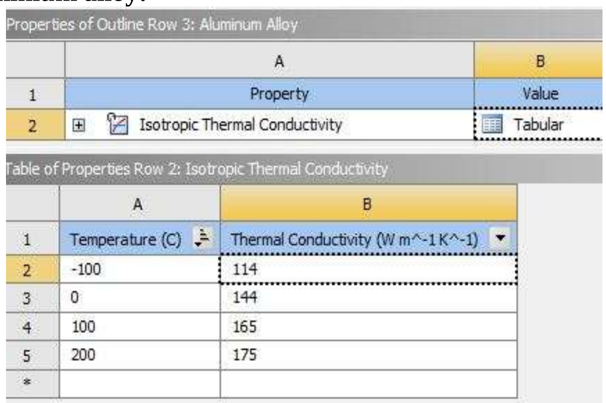
Nodes	125537
Elements	74757
Mesh Metric	None

FIGURE 12. Mesh statistics

7. TEMPERATURE ANALYSIS OF NOZZLE WITH DIFFERENT MATERIALS

Aluminium Alloy Nozzle Heat Flux-Temperature Distribution

Thermal conductivity of aluminium alloy:


Properties of Outline Row 3: Aluminum Alloy

	A	B
1	Property	Value
2	Isotropic Thermal Conductivity	Tabular

Table of Properties Row 2: Isotropic Thermal Conductivity

	A	B
1	Temperature (C)	Thermal Conductivity (W m^-1 K^-1)
2	-100	114
3	0	144
4	100	165
5	200	175
*		

FIGURE 13. Thermal conductivity

Boundary condition

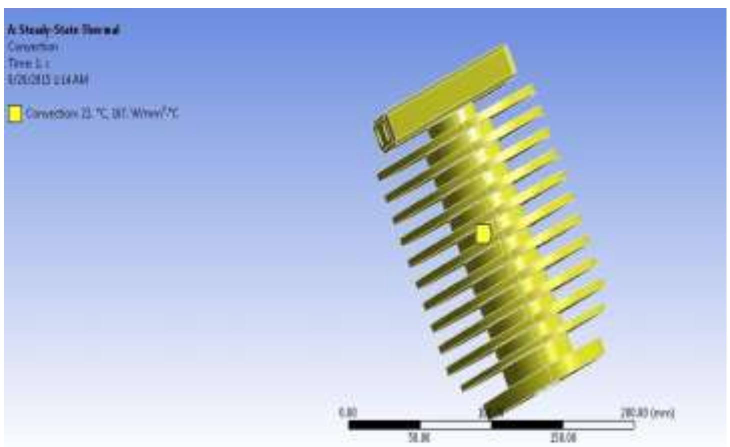


FIGURE 14. Boundary condition

Direction of heat flux in y axis

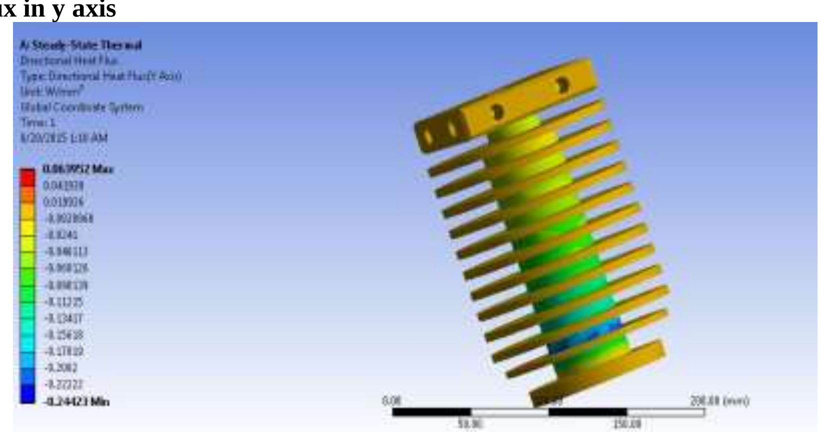


FIGURE 15. Direction of heat flux in y axis

Direction of heat flux in x axis

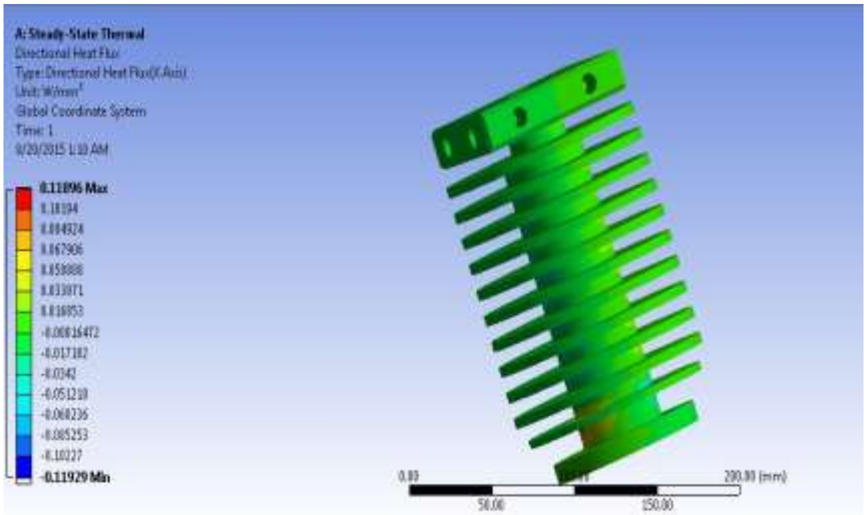


FIGURE 16. Direction of heat flux in x axis

Direction of heat flux in Z axis

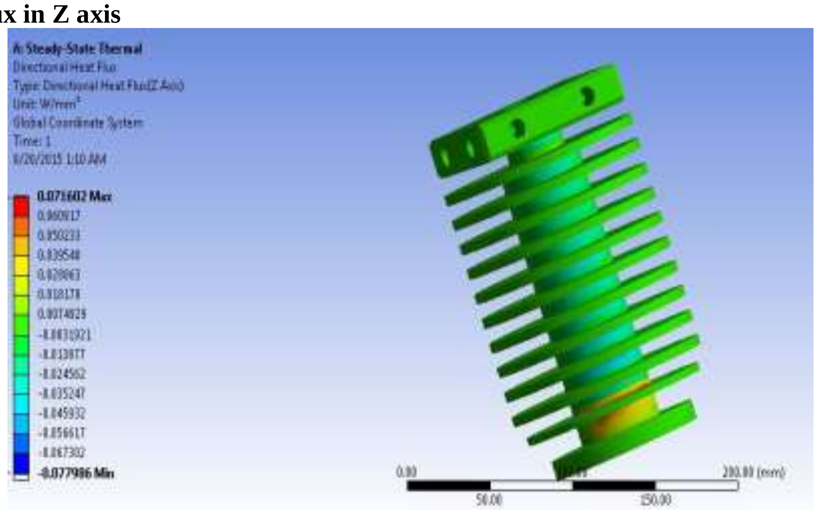


FIGURE 17. Direction of heat flux in Z axis

Temperature distribution

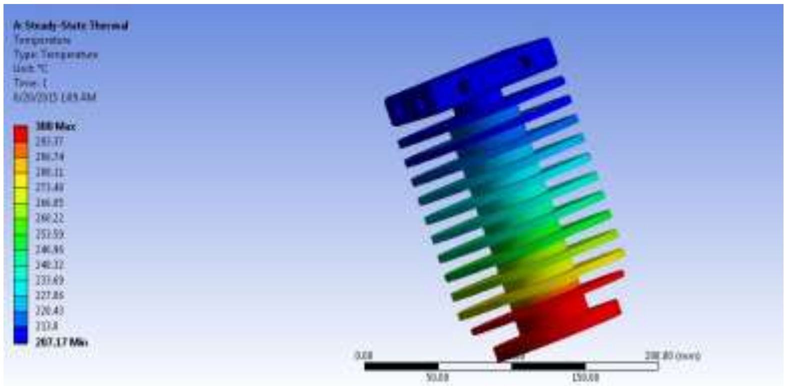


FIGURE 18. Temperature distribution

Total heat flux

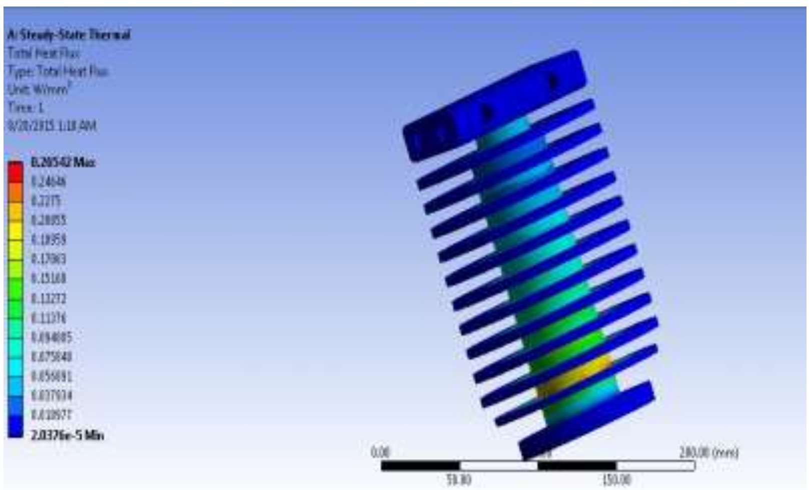
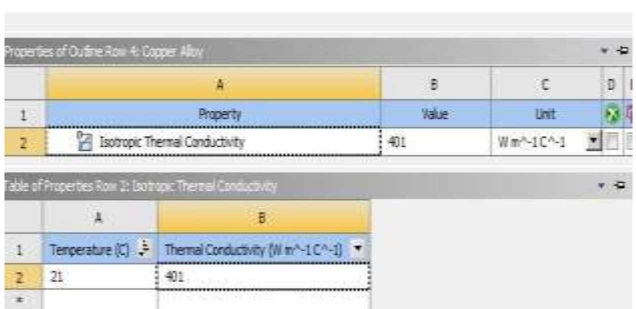


FIGURE 19. Total heat flux

8. COPPER ALLOY NOZZLE HEAT FLUX-TEMPERATURE DISTRIBUTION

Material Property



Properties of Outline Row 4: Copper Alloy

	A	B	C	D
1	Property	Value	Unit	
2	Isotropic Thermal Conductivity	401	W m^-1 C^-1	

Table of Properties Row 2: Isotropic Thermal Conductivity

	A	B
1	Temperature (C)	Thermal Conductivity (W m^-1 C^-1)
2	21	401
*		

FIGURE 20. Material Property

Boundary

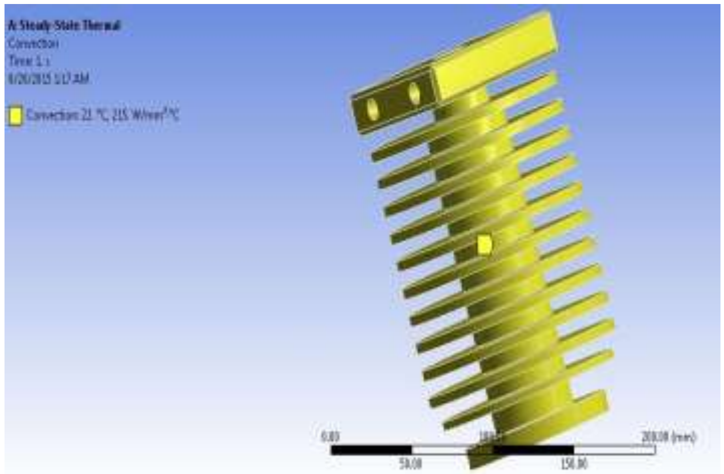


FIGURE 21. oundary conditions

Direction of heat flux at X axis

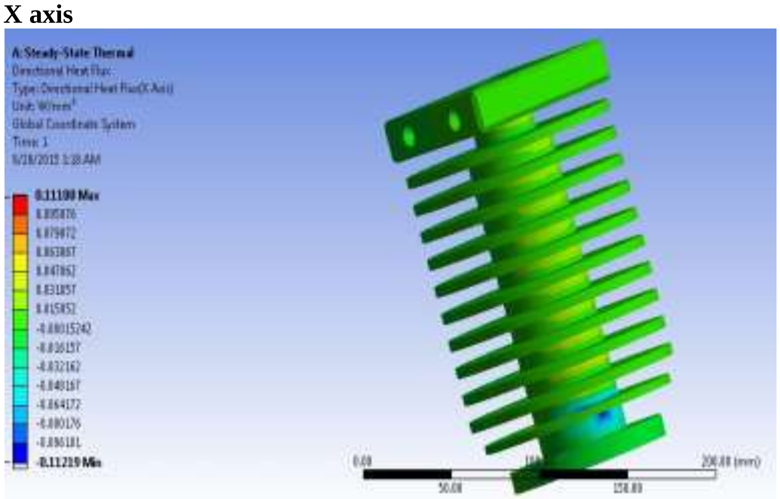


FIGURE 22. Direction of heat flux at X axis

Direction of heat flux at Y axis

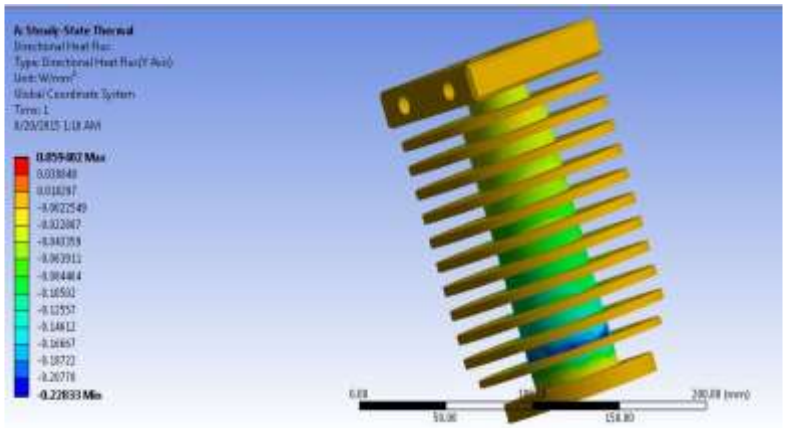


FIGURE 23. Direction of heat flux at Y axis

Total directional heat flux

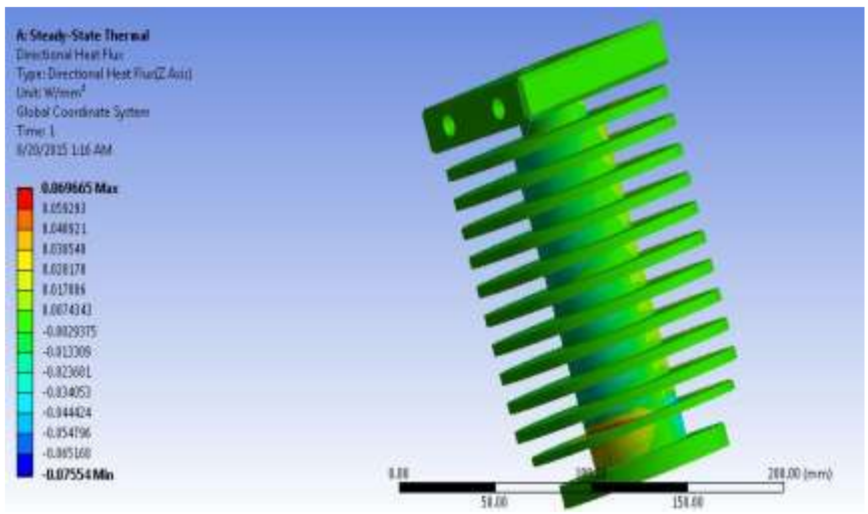


FIGURE 24. Total directional heat flux

Temperature distribution

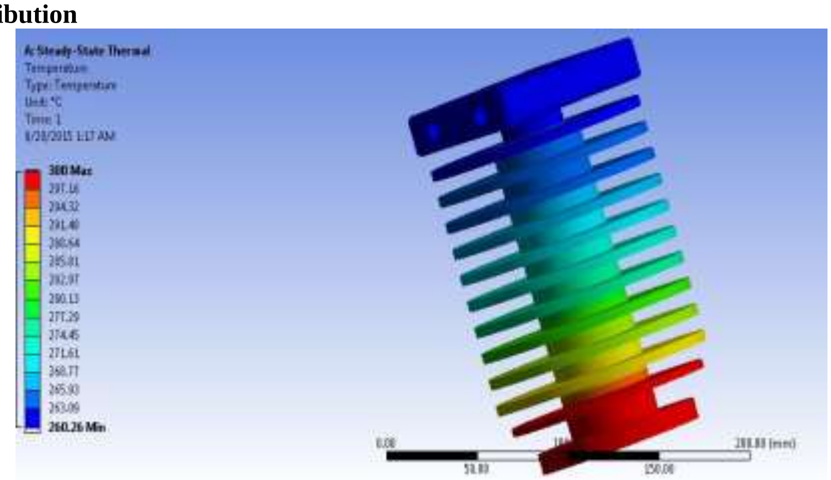


FIGURE 25. Temperature distribution

Stainless steel nozzle heat flux-temperature distribution:

Material properties

Properties of Outline Row 5: Stainless Steel

	A	B	C
1	Property	Value	Unit
2	Isotropic Thermal Conductivity	15.1	W m^-1 C^-1

Table of Properties Row 2: Isotropic Thermal Conductivity

	A	B
1	Temperature (C)	Thermal Conductivity (W m^-1 C^-1)
2	21	15.1
*		

FIGURE 26. Material properties

Boundary condition

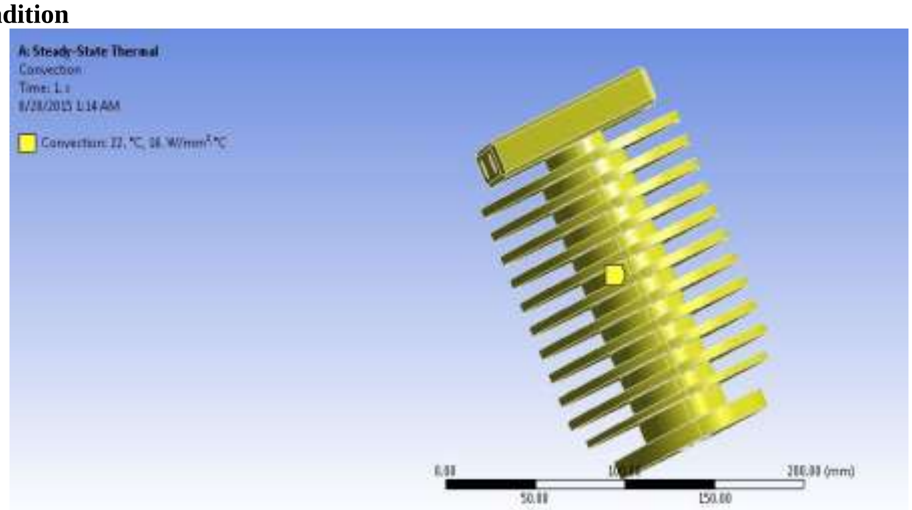


FIGURE 27. Boundary Condition

Direction of heat flux in Y axis

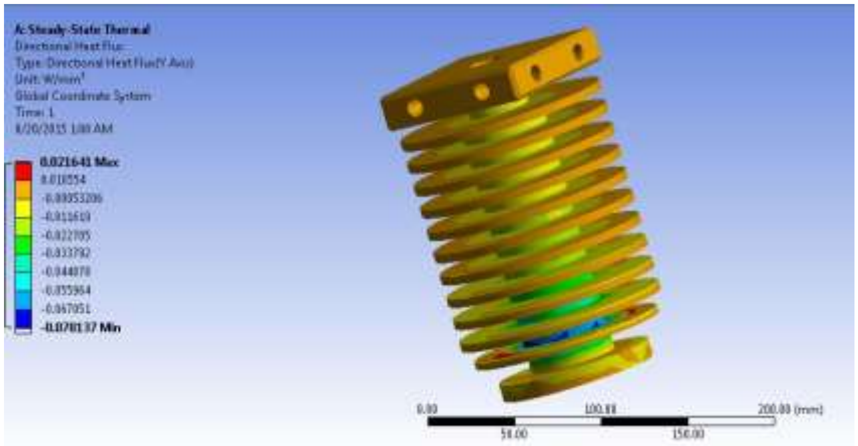


FIGURE 28. Direction of heat flux in Y axis

Directional heat flux at X axis

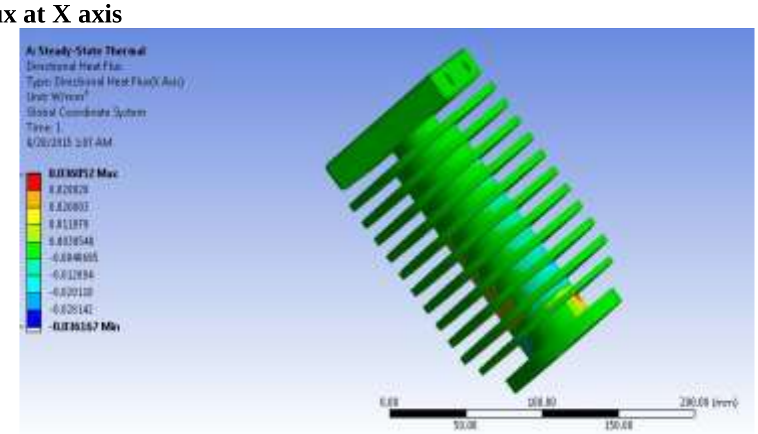


FIGURE 29. Directional heat flux at X axis

Total heat flux

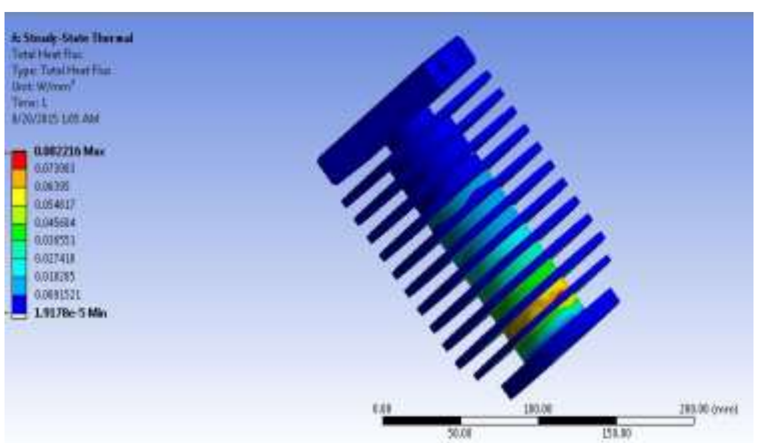


FIGURE 30. Total Heat Flux

Temperature distribution

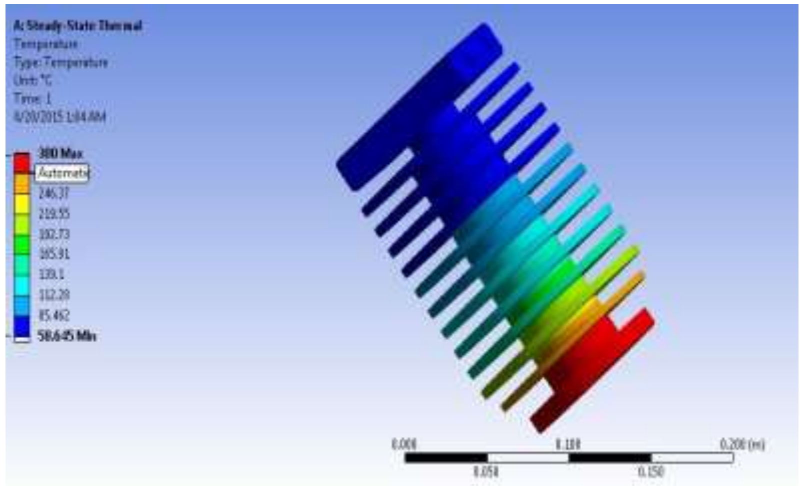


FIGURE 31. Temperature distribution

9. CONCLUSIONS

The DELTA 3D printer is designed and fabricated and also conclusion made on by performing analysis on nozzle of extruder by using different materials and the following results are drawn through analysis from the above analysis it is concluded to use either stainless steel or Aluminum Nozzle for optimum result. Due to the following reasons the above material is preferred for nozzle. Specific reasons are

COPPER: The second-most-electrically-conductive metal (after silver), and so used in practically all category: electronics PCBs and wires. Coefficient of Thermal conduction of 204 W/mike to 223 W/make

Aluminum (Final)
Advantages: Lighter than steel and much stronger than plastic. Does not corrode very much. Conducts electricity fairly well, 61% as well as copper. Easily machined.
Disadvantages: Heavier than plastic and weaker than steel. Has a thermal conductivity even higher (167 W/mK) than Brass (115 W/mike)? Often used in Hot End Heater Blocks.
Brass often used for the nozzle, or "Hot End" of extruders. Thermal conductivity is high, at 115 W/mK. Quote from Team Open **Air:** The reason that people started off with copper and brass is because they are excellent conductors of heat, and we want the heat from the chrome wire wrapped around the nozzle to be conducted inside to the plastic to melt it. However, with a thin, long cylinder it is very easy for the heat to move inward, even with an insulating material for the nozzle. But the copper and brass also carry it sideways a LONG way, requiring a long rod of PTFE or other high temp plastic to isolate the heat of the nozzle from the Stepper Motor and any electronics.
***Stainless Steel*:**Stainless steel was chosen for thermal characteristics. It favors heat to just the heated portions as opposed to aluminum which absorbs heat throughout while reducing efficiency.
High-efficiency integrated vertical heater block. Threads inhibit heat transfer in threaded heater blocks. No bulky heat sink.

Scope of Future Work: The present work can be extended for FDM technique for fabricating of many types of multi materials like wood, flexible material and many more. DELTA Type 3D printer isa quick, easy, cost effective fabrication that is considered and could have a promising future.From this project, it is evident that choosing good thermal characteristic material for extruder Nozzle can be used to enhance the performance of material extrusion from the nozzle to get better adhesion and finishing of parts. Hence it has a huge potential to be used for many advanced 3D printers.

REFERENCES

[1] Wei-chen Lee, Ching-chih Wei, Shan-Chen Chung, Development of a hybrid rapid prototyping system using low-cost fused deposition modeling and five-axis machining Journal of Materials Processing Technology, Volume 214, Issue 11, November 2014, Pages 2366-2374.
[2] S.H. Masood, Advances in Fused Deposition Modeling, Comprehensive Materials Processing, Volume 10, 2014, Pages 69-91.
[3] Christian Weller, Robin Kleer, Frank T. Piller, Economic implications of 3D printing: Market structure models in light of additive manufacturing revisited, International Journal of Production Economics, Volume 164, June 2015, Pages 43-56.
[4]] Erica Lin, Yaning Li, Christine Ortiz, Mary C. Boyce, 3D printed, bio-inspired prototypes and analytical models for structured suture interfaces with geometrically-tuned deformation and failure behaviour, Journal of the Mechanics and Physics of Solids, Volume 73, 15 December 2014, Pages 166-182.
[5] Dario Croccolo, Massimiliano De Agostinis, Giorgio Olmi, Experimental characterization and analytical modelling of the mechanical behaviour of fused deposition processed parts made of ABS-M30, Computational Materials Science, Volume 79, November 2013, Pages 506-518.
[6] Ben Ezair, Fady Massarwi, Gershon Elber, Orientation analysis of 3D objects toward minimal support volume in 3D-printing, Computers & Graphics, Volume 51, October 2015, Pages 117-124.