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Experimental Analysis on Optimization of Process Parameters in Fused Deposition Modelling

Mr. S. Hima Teja Reddy*, Mr. CH. Veera Yaswanth Kumar*, Mr. K. Manikya Chakradhar*, Mr B. Teja Sai Trinadh*, Mr M. Veera Venkata Sai Akhil*, Mrs. P Gayatri, Mr VVN Sarath****

***UG students, Department of Mechanical Engineering, Pragati Engineering College (A)**

****Faculty, Department of Mechanical Engineering College, Pragati Engineering College (A)**

ABSTRACT: The 3D printing process is a kind of additive manufacturing, that the basic principle of this process is adding material layer by layer to form a product. The purpose of this research was to study the effect of orientation and internal over hangs on micro heat exchanger. In this we are optimizing the printing orientation to avoid the warpage of micro heat exchanger printing and decreasing the ovality of the circular tube by orienting. In this case study we are optimizing the orientation with constant layer height of 0.1mm to achieve the dimensional accuracy of internal features of micro heat exchanger. By the end of the study, the orientation effect on the micro heat exchanger will be deduced. In addition to that effect of various process parameters can be calculated.

Key words: Optimization, 3D Printing, Slicing, Modelling

I. INTRODUCTION

3D printing or Additive Manufacturing (AM) is any of various processes for making a three-dimensional object of almost any shape from a 3D model or other electronic data source primarily through additive processes in which successive layers of material are laid down under computer control. A 3D printer is a type of industrial robot. Early Additive Manufacturing equipment and materials were developed in the 1980s. In 1984, Chuck Hull of 3D Systems Corp, invented a process known as stereolithography employing UV lasers to cure photopolymers. Hull also developed the Standard Triangular language file format widely accepted by 3D printing software, as well as the digital slicing and infill strategies common to many processes today. Also during the 1980s, the metal sintering forms of Additive Manufacturing were being developed (such as selective laser sintering and direct metal laser sintering), although they were not yet called 3D printing or Additive Manufacturing at the time. In 1990, the plastic extrusion technology most widely associated with the term “3D printing” was commercialized by Stratasys under the name Fused Deposition Modelling (FDM). In 1995, Z Corporation commercialized an MIT-developed additive process under the trademark 3D printing (3DP), referring at that time to a proprietary process inkjet deposition of liquid binder on powder.

Additive Manufacturing technologies found applications starting in the 1980s in product development, data visualization, rapid prototyping, and specialized manufacturing. Their expansion into production (job production, mass production, and distributed manufacturing) has been under development in the decades since. Industrial production roles within the metalworking industries achieved significant scale for the first time in the early 2010s. Since the start of the 21st century there has been a large growth in the sales of AM machines, and their price has dropped substantially

Applications are many, including architecture, construction, industrial design, automotive, aerospace, military, engineering, dental and medical industries, biotech (human tissue replacement), fashion, footwear, jewellery, eyewear, education, geographic information systems, food, and many other fields.

3D printable models may be created with a Computer-Aided Design (CAD) package, via a 3D scanner, or by a plain digital camera and photogrammetry software. 3D printed models

1.2 3D Printer

3D-Printer is a machine reminiscent of the Star Trek Replicator, something magical that can create objects out of thin air. It can “print” in plastic, metal, nylon, and over a hundred other materials. It can be used for making nonsensical little models like the over-printed Yoda, yet it can also print manufacturing prototypes, end user products, quasi-legal guns, aircraft engine parts and even human organs using a person’s own cells. We live in an age that is witness to what many are calling the Third Industrial Revolution. 3D printing, more professionally called additive manufacturing, moves us away from the Henry Ford era mass production line, and will bring us to a new reality of customizable, one-off production. 3D

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printers use a variety of very different types of additive manufacturing technologies, but they all share one core thing in common: they create a three-dimensional object by building it layer by successive layer, until the entire object is complete. It's much like printing in two dimensions on a sheet of paper, but with an added third dimension. The Z-axis. Each of these printed layers is a thinly-sliced, horizontal cross-section of the eventual object. Imagine a multi-layer cake, with the baker laying down each layer one at a time until the entire cake is formed. 3D printing is somewhat similar, but just a bit more precise than 3D baking. In the 2D world, a sheet of printed paper output from a printer was "designed" on the computer in a program such as Microsoft Word. The file - the Word document which contains the instructions that tell the printer what to do. In the 3D world, a 3D printer also needs to have instructions for what to print. It needs a file as well. Opensource files can be beneficial for the user as the printed object can be more cost effective than commercial counterparts. The file, a Computer Aided Design (CAD) file is created with the use of a 3D modelling program, either from scratch or beginning with a 3D model created by a 3D scanner. Either way, the program creates a file that is sent to the 3D printer. Along the way, software slices the design into hundreds, or more likely thousands, of horizontal layers. These layers will be printed one atop the other until the 3D object is done. Though the printer-produced resolution is sufficient for many applications, greater accuracy can be achieved by printing a slightly oversized version of the desired object in standard resolution and then removing material using a higher-resolution subtractive process.

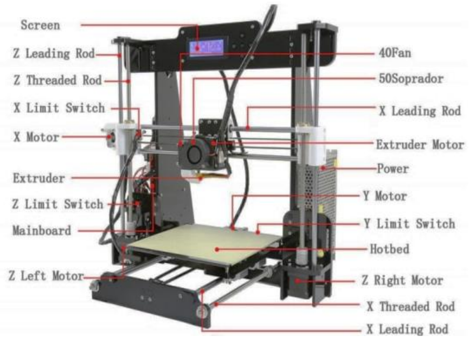

Fig 1.1: Construction of 3d printer

The picture shows the structure of a typical 3D printer. The print table is the platform where the objects for printing has been situated. It provides the basic support for manufacturing objects layer by layer. The extruder is the most important part of a 3D-Printer. As the extruders in the normal paper printers, this extruder is also used to pour ink for printing. The movement of extruder in various dimensions create the 3D print. For printing a 3d object, the extruder has to access X, Y and Z coordinates. For achieving this, many techniques are used according to the printer specification required for various applications. If the 3D-Printer is a desktop printer, the Z axis movement of the extruder can be avoided and that function can be transferred to the print table. This will avoid complexity in 3D printing as well as time consumption. When the file is input to the printer, the microcontroller extracts each layer from it and also extracts each line segment from each layer. Then it gives controls to the movement of the extruder at required rate. The X-direction movement of extruder is made possible by the X-motor. When the X motor rotates, the shaft also rotates and the extruder moves in X direction. The Y-direction movement of extruder is made possible by the Y-motor. When the Y motor rotates, the shaft also rotates and the extruder moves in Y direction. The X direction movement is made by the print table. In the case of desktop printers, the printing ink is usually plastic wire that has been melted by the extruder at the time of printing. While printing, the plastic wire will melt and when it falls down to the printing table. Consider printing larger objects like house using 3D printer. There will not be any X motor or Y motor in that case. An extruder which can pour concrete mix is fixed on the tip of a crane. The crane is programmed for the movement of extruder in X, Y and Z axis. The concept and structure of 3d printer changes according to the type, size, accuracy and material of the object that has to be printed. Generalizing the facts, the extruder needs to access all the 3 coordinates in space to print and object. The method used for that doesn't matters much.

1.3 Additive manufacturing

i. Extrusion deposition
ii. Granular material binding
iii. Photopolymerization
iv. Laminated Object Manufacturing
v. Selective Laser Welding
vi. Electron Beam Welding
vii. Beam Formation
viii. Beam Penetration
ix. Digital Light Processing
x. Material Jetting

1.4 Materials used in Fused Deposition Modelling Process:

a) Plastics

i. Nylon
ii. Acrylonitrile butadiene Styrene
iii. Polylactic Acid
iv. Lay Wood

b) Metals

c) Other Rapid Prototyping Materials

i. Ceramics
ii. Paper
iii. Bio Materials
iv. Food

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1.5 Advantages of AM

- 3D printing is an energy efficient technology.
- Additive Manufacturing use up to 90% of standard materials and therefore creating less waste.
- Lighter and stronger products can be printed.
- Increased operating life for the products.
- Production rate increases within short period.
- Production has been brought closer to the end user or consumer.
- Spare parts can be printed on site which will eliminate shipping cost.
- Wider adoption of 3D printing would likely cause re-invention of a number of already invented products.
- 3D printing can create new industries and completely new professions.
- Printing 3D organs can revolutionaries the medical industry
- Small production runs often prove faster

1.6 Disadvantages of AM

- Since the technology is new, limited materials are available for printing.
- Consumes more time for less complicated pats.
- Size of printable object is limited by the movement of extruder.
- In additive manufacturing previous layer has to harden before creating next layer.
- Curved geometry will not be much accurate while printing
- Actual printing process can be time consuming and most machines can only print one at a time
- No inspection can be done for product safety and consumer safety.
- Ability could belong to either the design producer or the person who printed the product.

B. M. Tymrak, M. Kreiger, J. M. Pearce [1] This aims at resultant uptake of 3-D printing technology enables for the first-time mass-scale distributed digital manufacturing. RepRap variants currently fabricate objects primarily from acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA). M. Sugavaneswaran, G. Arumaikkannu [2] The study has been utilized in a variety of engineering applications because of its desirable characteristic of mass customized manufacturing. Polyjet 3-Dimensional Printing (3DP) is one among the various AM techniques which is well known for fabrication of part with multiple materials. G. W. Melenka, B. K. O. Cheung, J. S. Schofield et al [3] The aim of this study is to evaluate the elastic properties of the fibre reinforced 3D printed structures and predict elastic properties using an Average Stiffness (VAS) method. Samples evaluated in this study were produced by varying the volume fraction of fibres within the 3D printed structures. M. Domingo, J. M. Puigriol, A. A. Garcia et al [4] This study aims to accomplish two purposes: finding a good model to simulate FDM parts and correlating a finite element analysis (FEA) simulation with physical testing. C. Casavola, A. Cazzato, V. Moramarco et al [5] The aim of this work is to describe the mechanical behaviour of FDM parts by the classical laminate theory (CLT). In order to reach this objective, the values of the elastic modulus in the longitudinal and transverse directions. B. Rankouhi, S. Javadpour, F. Delfanian [6] In this study, a comprehensive effort was undertaken to represent the strength of a 3D printed object as a function of layer thickness by investigating the correlation between the mechanical properties of parts manufactured out of acrylonitrile butadiene styrene (ABS) using fused deposition modelling J. M. Chacon, J. C. Bellido, A. Donoso [7] The present study describes a solution to a non-parametric shape optimization problem of a brake model to suppress squeal noise. The brake model consists of a rotor and a pad, between which Coulomb friction occurs. A. Donoso, J. C. Bellido, J. M. Chacon [8] This study states deposition modelling is a rapidly growing additive manufacturing technology due to its ability to build functional parts having complex geometries. The mechanical properties of a built part depend on several process parameters

II. METHODOLOGY

3.1.1 Designing using Computer Aided Design

Computer-Aided Design (CAD) is the use of computer systems to assist in the creation, modification, analysis, or optimization of a design. This software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing. Computer Aided Design output is often in the form of electronic files for print, machining, or other manufacturing operations. Computer Aided Design software for mechanical design uses either vector-based graphics to depict the objects of traditional drafting, or may also produce raster graphics showing the overall appearance of designed objects. However, it involves more than just shapes. As in the manual drafting of technical and engineering drawings, the output of software must convey information, such as materials, processes, dimensions, and tolerances, according to application-specific conventions. Computer Aided Drafting may be used to design curves and figures in two-dimensional (2D) space; or curves, surfaces, and solids in Three-Dimensional (3D) space. It is an important industrial art extensively used in many applications, including automotive, shipbuilding, and aerospace industries, industrial and architectural design, prosthetics, and many more. It is also widely used to produce computer animation for special effects in movies, advertising and technical manuals, often called Digital Content Creation. The modern ubiquity and power of computers means that even perfume bottles and shampoo dispensers are designed using techniques unheard of by engineers of the 1960s. Because of its enormous economic importance, This has been a major driving force for research in computational

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geometry, computer graphics (both hardware and software), and discrete differential geometry. The design of geometric models for object shapes, in particular, is occasionally called Computer-Aided Geometric Design (CAGD). Unexpected capabilities of these associative relationships have led to a new form of prototyping called digital prototyping. In contrast to physical prototypes, which entail manufacturing time in the design. That said, Computer Aided Design models can be generated by a computer after the physical prototype has been scanned using an industrial Computer Tomography scanning machine. Depending on the nature of the business, digital or physical prototypes can be initially chosen according to specific needs.

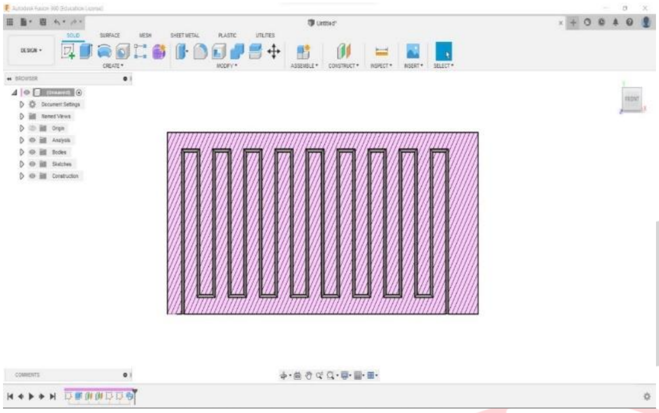

Fig 3.1: Front View of Micro Heat Exchanger

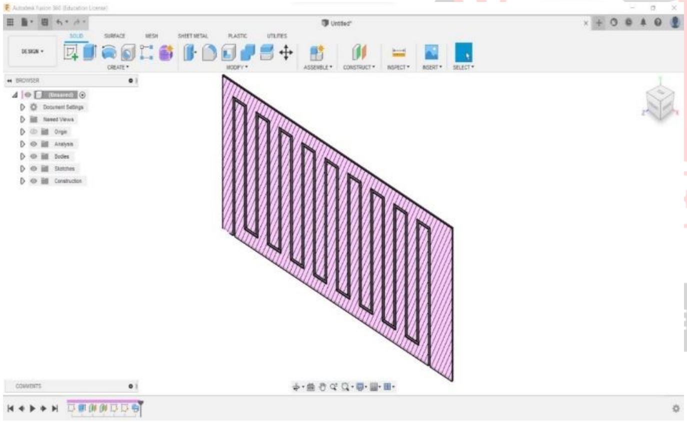

Fig 3.2: Isometric View of Milling Cutter

3.1.2 Conversion to Standard Triangular Language file format

Standard Triangular Language file is a triangular representation of a 3D surface geometry. The surface is tessellated logically into a set of oriented triangles (facets). Each facet is described by the unit outward normal and three points listed in counter clockwise order representing the vertices of the triangle. While the aspect ratio and orientation of individual facets is governed by the surface curvature, the size of the facets is driven by the tolerance controlling the quality of the surface representation in terms of the distance of the facets from the surface. The choice of the tolerance is strongly dependent on the target application of the produced file. In industrial processing, where stereolithography machines perform a computer-controlled layer by layer laser curing of a photo-sensitive resin, the tolerance may be in order of 0.1 mm to make the produced 3D part precise with highly worked out details. However much larger values are typically used in pre-production prototypes, for example for visualization purposes. The native format has to fulfil the following specifications. The normal and each vertex of every facet are specified by three coordinates each, so there is a total of 12 numbers stored for each facet.

(i) Each facet is part of the boundary between the interior and the exterior of the object. The orientation of the facets (which way is ``out'' and which way is ``in'') is specified redundantly in two ways which must be consistent. First, the direction of the normal is outward. Second, the vertices are listed in counter clockwise order when looking at the object from the outside (right-hand rule).

(ii) Each triangle must share two vertices with each of its adjacent triangles. This is known as vertex-to-vertex rule

(iii) The object represented must be located in the all-positive octant (all vertex coordinates must be positive).

(iv) However, for non-native applications, the Standard Triangular Language format can be generalized. The normal, if not specified (three zeroes might be used instead), can be easily computed from the coordinates of the vertices using the right-hand rule. Moreover, the vertices can be located in any octant. And finally, the facet can even be on the interface between two objects (or two parts of the same object). This makes the generalized the format suitable for modelling of 3D non-manifolds objects. There are various other formats in which the design software accepts and automatically creates a mesh format

3.1.3 Significance of Standard Triangular Language file:

Then convert the design into mesh file format file is mesh type file and STL stands for Standard Triangular Language. It means that the surface is divided into different geometric forms without overlapping and gaps. Standard geometries used for tasseling are triangles, square and hexagonal. For 3D printing we normally use triangular tessellation 3D printing method because of triangular geometry enables the faster printing speed and reduce the amount of material for a part to be print. Usually when the cad model converted to file, the surface of the cad model is divided into number no of triangles without overlapping and gaps. Smaller triangles are created near the edges to form fine edge and reinforce the model. The larger triangles are shape out the holes. The surface roughness of the printed part depends on the size of the triangles and layer height. If the triangle is large, the surface roughness will be high and the surface rough. If the size of the triangle is small, the surface roughness will be low and the surface shall be smooth. Different Computer Aided Design software saves the modelled files in different formats. To establish consistency, a standard format has been adopted which is known as Universal format for rapid prototyping industry. Increasing the number of triangles improves the approximation and result, but the file size gets bigger. Since the format is universal, this process is identical for all of the Rapid Prototyping build techniques.

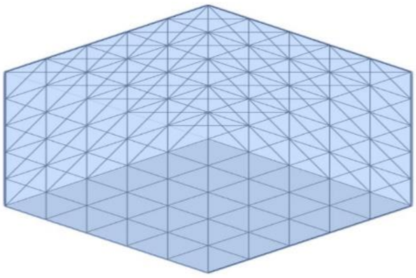

Fig 3.3: Typical Triangular Mesh View

Technical specification

Ultimaker Cura works by slicing the user’s model file into layers and generating a printer-specific g-code. Once finished, the g-code can be sent to the printer for the manufacture of the physical object.

The open-source software, compatible with most desktop 3D printers, can work with files in the most common 3D formats.

Parts are automatically more tightly packed, using the full available space of the build plate. This improves user experience, especially for batch production, saving time by minimizing the number of manual steps for build plate arrangement.

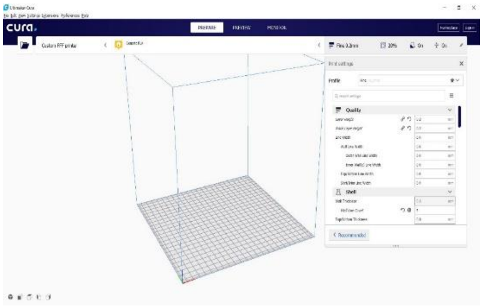

Fig 3.4: Slicing software Interface

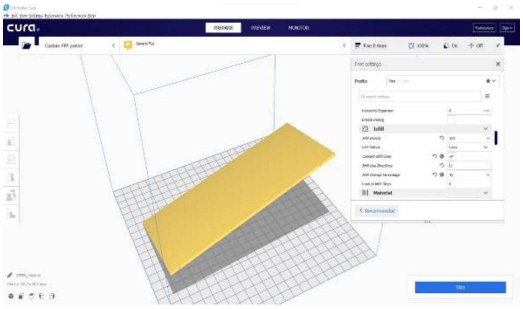

Fig 3.5: loading model

Quality	
Layer height (in millimeters)	0.1
Intial layer height (in millimeters)	0.1
Line width (in millimeters)	0.4
Outer wall line width (in millimeters)	0.4
Inner wall line width (in millimeters)	0.4
Top/bottom line width (in millimeters)	0.4
Wall line width (in millimeters)	0.4
Infill line width (in millimeters)	0.4

Table 3.1: Values Of Process Parameter Quality

Infill		Material	
Infill density (in percentage)	100	Printing temperature (in celsius)	205
Infill pattern	Lines	Plate temprature (in celsius)	60
Overlap (in percentage)	10	Flow (in percentage)	100
Infill steps	0	Retraction (in percentage)	100

Table 3.2: Values Of Process Parameters Infill And Material

Shell		Speed	
Wall thickness (in millimeters)	0	Print speed (in mm/s)	40
Top thickness (in millimeters)	0.8	Infill speed (in mm/s)	40
Bottom thickness (in millimeters)	0.8	Wall speed (in mm/s)	45
Top/bottom thickness (in millimeters)	0.8	Outer wall speed (in mm/s)	45
Horizontal expansion (in millimeters)	0	Top/bottom speed (in mm/s)	45

Table 3.3: Values Of Process Parameters Shell And Speed

Support	
Support overhang angle (in degrees)	50
Support pattern	Zig-zag
Support density (in percentage)	15
Infill line direction (in degrees)	0

Table 3.4: Values Of Process Parameter Support

3.1.9 Orientational Figures Of Micro Heat Exchanger

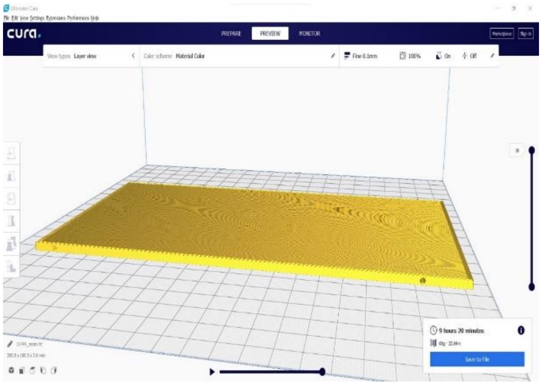

Fig 3.6: First Orientation Of Micro Heat Exchanger

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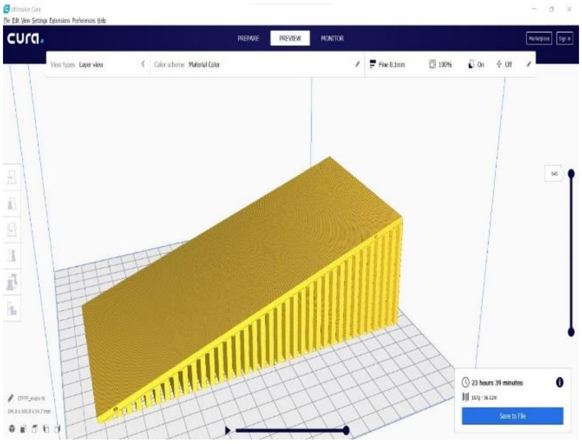


Fig 3.7: Secomd Orientation Of Micro Heat Exchanger

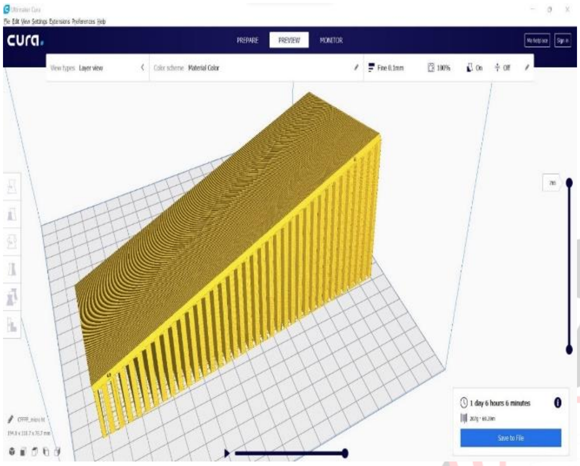


Fig 3.8: Third Orinetation Of Micro Heat Exchanger

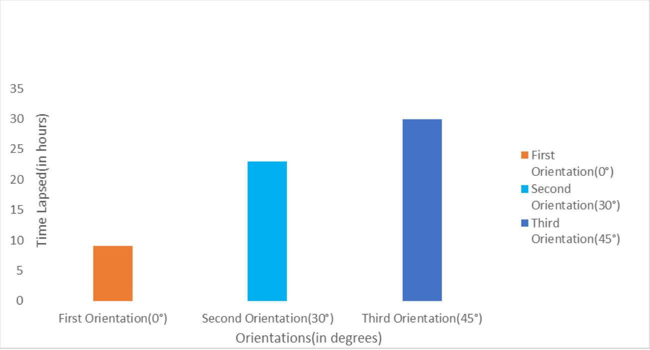
The effect of orinetatiom on the micro heat exchanger will be observed by chaning the angle of inclination of the heat exchanger in certain directions

In this study, we have applied three orientations to the micro heat exchanger and calculated the effect on slicing time, material consumed, length of the material consumed.

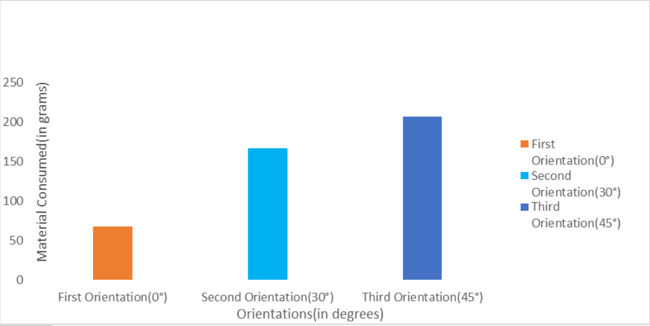
A heat exchanger is a system used to transfer heat between two or more fluids. Heat exchangers are used in both cooling and heating processes. + The fluids may be separated by a solid wall to prevent mixing or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, and sewage treatment.

The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant. Another example is the heat sink, which is a passive heat exchanger that transfers the heat generated by an electronic or a mechanical device to a fluid medium, often air or a liquid coolant.

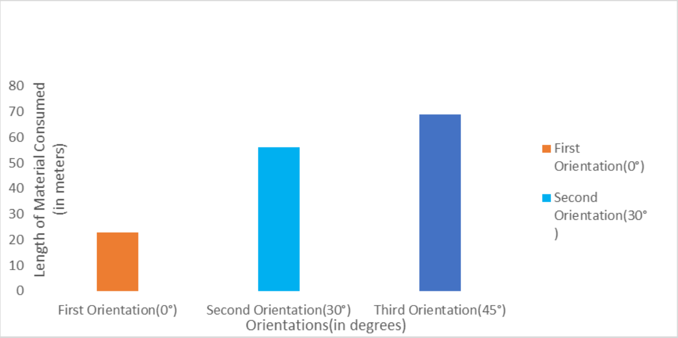
III. RESULTS AND CONCLUSION



Graph 4.1 Effect on Time Lapsed



Graph 4.2: Effect on Material Consumed



Graph 4.3: Effect on Length of The Material Consumed

IV. CONCLUSION

From the above results we can conclude that

Printing surface area is larger, more the chance of warpage and adhesion problems. When the micro heat exchanger is oriented in different directions printing time and material consumption is increasing. But in third orientation it gives better adhesion and heat transfer. It is concluded from the Ultimaker Cura software. The micro heat exchanger has 2mm hole inside it for flowing the fluid. Compare to three orientations in the first orientation ovality and blocking of internal contour is more when compare to other two orientations. In the third orientation it gives very less ovality of circular contour. In the first orientation the micro heat exchanger is in horizontal position and minimum height to the print direction and in the orientation. The contour does not need any support materials. In plastic printing up to 5mm do not need any support materials.

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