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Design and development of Hybrid 3D printer Extruder for Fused Deposition Modelling Printer

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Abstract:
3D printing technology is derivative of Additive manufacturing (AM) in which layers of build materials are processed and add to form a desired shape under computer control, which uses advanced information from a 3D Computer Aided Design data (CAD). Fused Deposition Modelling (FDM) is one of the major classifications in 3D printers which are used for constructing of prototype and production applications.The quality of 3D printed components is mainly depend on parameters like layer thickness, fill density, curing time etc. These Parameters are straight away influenced by 3D printer extruder's specifications like working temperature, nozzle diameter, amount of heat dissipating from body of extruder. Working temperature is a value of temperature at which build material starts to melt, and fusedwhen passes through the nozzle to build the component.The aim of this Design and Development of hybrid 3D Printer extruder is to increase the working temperature specification values which ranges between 120^{0}C -400^{0}C and cost of extruder should be economical ,and can be used in various FDM machines as standard extruder Design validations are carried out by FEA Finite element analysis method & numerical method, later Extruder is fabricated by Computer numerical control (CNC) machine.

Keywords: Additive manufacturing (AM), Fused Deposition Modelling (FDM), Computer Aided Design data (CAD), Hybrid 3d Printer Extruder, Computer numerical control (CNC).

1.Introduction

Fused Deposition Modelling (FDM) is one of the Additive manufacturing (AM) technology which is used for constructing of prototype and production applications. FDM basically deals on an "Additive" principle by laying down build material in layer by layer manner; A plastic filament or metal wire in wounded form, is unwounded and supplies material to feeder where wire is loosened up from a loop and supplies material to an extruder which can control the stream . A worm-drive is provided to push the fibre into the extruder at a controlled rate. The extruder is heated up to a working temperature at which material starts melt. The resins are heated above their glass transition temperature and made themto pass through small orifice called heat breakwhere resins get melted & then passes through Nozzle &deposited on printer bed to form the component. Classification of FDM printers are usually made on the basis of working volume, soft wares used and working temperatures. By literature surveys, it is found that there is lack of work done on various working temperatures in extruder.the range is limited till 300^{0}C.Some of the works are done beyond 300^{0}C but they are patented and are expensive also. The aim of this Design and development of hybrid extruder to achieve the working temperatures up to 400^{0}C.in which materials having melting temperature of 400^{0}C can be easily build.

1.1 Various process and performance parameters

The parameters which assume essential part in 3D printing or FDM are as per the following: Slice thickness, fabricate statement introduction, Air crevice, raster edge, raster width,build laydown design, wire-width remuneration, expulsion speed, filling speed, Porosity, compressive yield quality, compressive modulus,

Tensile quality, measurement precision and surface roughness, Liquefier temperature, working temperature,envelope temperature, convective condition.

1.2 Various 3d Printer Used

Various 3D printers utilized in industries arelisted below:

Stratasy's FDM-2000
Stratasy's FDM-3000
Statasy's Dimension BS1768
Zcorporation-Z450,
Makerbot replicator-2

1.3parts of 3d Printer Extruder

- Cold end consists of major parts like: Nozzle block, Heat sink, Heat dissipating Fins, Cooling Fans, worm wheels for feeding the materials, Guide for material flow.(TEFLON TUBE).
- Hot end consists of parts like: Heat block, Heat breaker, Heat cartridge, Thermistors and Nozzle

2. Literature Review

Some of the works are done and their investigations are Jerez-Mesaet al [1] have describes the another Design of liquefier, called Twist3D. A 3D printer liquefier must transmit temperature to the thermoplastic material so as to extrude it, achieving temperatures over 200^{0}C for a few materials like ABS on the tip of the hot end. The outline of the warming procedure must agree to keeping the balance between appropriate warming of the material and controlling the temperature along the expelling body,so that the printer itself is most certainly not hurt for over temperature. Then again, the plan must ensure that the liquefying front is situated in a moderate point between the hot end tip and the passage of the filament material, to limit weight drops in the system, thus diminishing pressure to the servos. An option outline of the warming framework is proposed in this paper and recreated with FEA apparatuses in a printing situation. The changes of the disseminating balances are determinant to the volume of warmth disseminated, and in this way, for the nature of the procedure and change of the printer's toughness.

Thomas W. Hughes, et al [2] explains that high temperature thermoplastic and thermoset polyimide resins as competitor materials for use in Additive Manufacturing (AM). Polyimides managable to a dissolvable free process were delivered through responsive expulsion in structures appropriate for added substance fabricating. High temperature polyimide gums were defined to yield shifted atomic weights with receptive and nonreactive end caps, for example, phenylethynylphthalic gathering (PEPA)to advance and avoid cross connecting, separately. This exertion effectively showed the suitability of utilizing responsive expulsion to deliver high temperature polyimides straightforwardly both as fibresmanageable to Fused Deposition Modelling (FDM) and as gum powders appropriate for Selective Laser Sintering (SLS) in added substance producing.

Ismail et.al.[3] this paper is to explain how parts produced by (FDM), with various part orientations and raster edges and angles, are analyzed tentatively and assessed to accomplish the coveted properties of the parts while shortening the assembling times because of upkeep expenses. out Comes about propose that the orientation has a more noteworthy impact than the raster edge on the surface roughness and mechanical behaviour of the resulting fused deposition part.

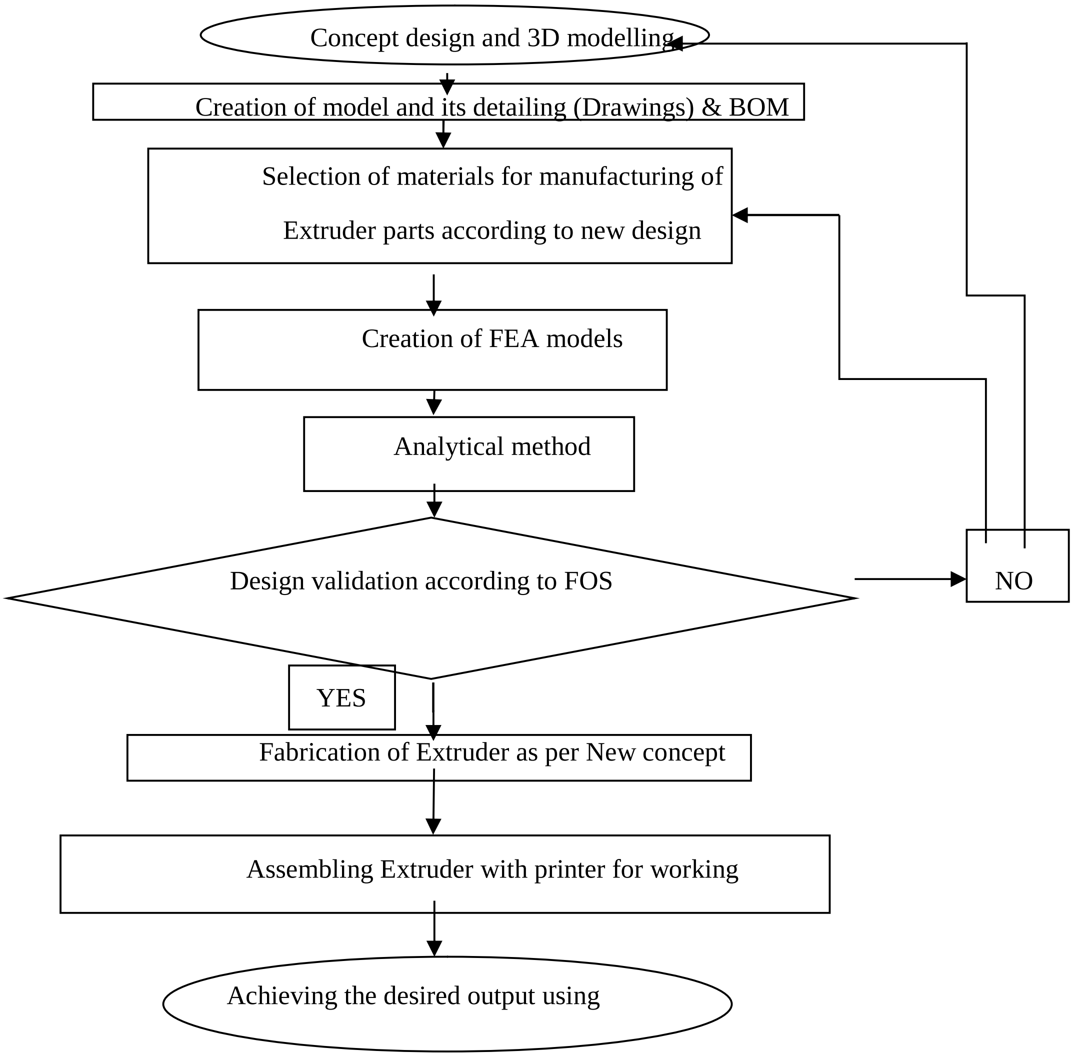
S.F. Costa et al [4] have proposed that analytical solution for the transient warmth conduction creating amid fibre statement in Fused Deposition Techniques (FDT), which is coupled to a normal that actuates or deactivates all applicable nearby limit conditions relying upon part geometry, working conditions and testimony methodology. Limit conditions incorporate contact between fibre sections, between fibre fragments and the support, and additionally warm exchange with the earth. The subsequent Mat Lab code involves a grip basis that is utilized to evaluate whether bordering fibre portions will stick satisfactorily to each other before cementing. Anticipated and trial information for the fibre surface temperature demonstrated great understanding. Additionally, bond forecasts were as per the aftereffects of genuine peel-like tests. The handy capability of this Figureuring apparatus is exhibited by an application illustration.

Karl-Heinz Herrmann et al [5] Studiedto assess less budget 3D printing innovation to make MRI good quality parts. We have exhibited that a low budget 3D printer can be utilized to rapidly advance from an idea to a

practical working machine at less manufacturing cost. While 3D printing innovation imposes a few confinements on model geometry, added substance printing innovation can make objects with complex structures that can generally not be made by traditional machine. Along these lines, we consider a 3D printer a profitable resource for MRI groups.

Jim Jose et al [6] Thisstudy concentrates on planning and manufacturing a convenient combined affidavit 3D printer with modest and effortlessly accessible parts. Among various sorts of 3D printers, intertwined deposition3D printers are thought to be the least expensive and they are impressively little in size. This is fundamentally because of its hub developments and kind of material utilized for 3D printing. It's a 4 hub machine whose x, y and z pivot make up the initial 3 pivot, and the extruder is the fourth hub. The crude material utilized for printing is plastic, for example, ABS, PLA or ninja flux, and so on. However a specific measure of alignment is expected to adjust the temperature sensor utilized for the extruder relying upon the fibre utilized. In this work, a FDM based 3D printer is created and broke down for further improvement.

3. Process Flow chart



BOM: Bill Of Materials.

FEA: Finite Element Analysis

FOS: Factor Of Safety

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4. Experimental Details

4.1 Concept Design And 3d-Modelling

By comparing various previous works it has been found that some lack of works in Basic design of Extruder parts like Nozzle block with respect to heat dissipating, Heat block fastening with nozzle block & Problem in guiding the Build/support material flow inside the nozzle block,Usage of single Build material per Extruder,working temperature is restricted up to temperature of 300^{0}C.

To overcome these issues some of the design changes are made along with new concept designs. They are as follows.

New concept:

- Design of Dual nozzle block, means two nozzles are provided for a single extruder for usage of two different Build materials or can be used as one for Build material and another for support material.
- Design of extruder is done in such a way that to achieve the working temperature by providing customised Heater cartridge & Thermocouples to attain working temperatures which ranges between 100^{0}C – 400^{0}C.
- Along with this extruder parts has to withstand the working temperature, so material selection for manufacturing of Extruder parts is taken care in design view.
- Heat blocks are fitted inside the nozzle block by means of fasteners, where heat blocks are provided with threads on its body and nozzle blocks are accommodated with internal threads, so while handling for maintenance, threads provided on heat block body and nozzles internal threads often undergoes damages.To avoid this and for ease handling of Heat block fastening with nozzle block is provided indirectly with help of Grub screws.
- Large area and large number of Heat dissipating fins are provided on the circumference of Dual nozzle block, so that it helps to maintain adequate working temperature at nozzle tip area.

4.2 3d-Modelling:

Concept modelling and 3D models are created using a modelling tool called CATIA V5 R20.

Models are individually created and assigned with their respective materials& properties and later all the part models are assembled together to form a product called “EXTRUDER”.

Manufacturing details (Drawings) are created using CATIA V5 R20.Bill of materials is created using Microsoft Excel-2007.

3D modelled, Printer Extruder assembly using CATIA V5 R20

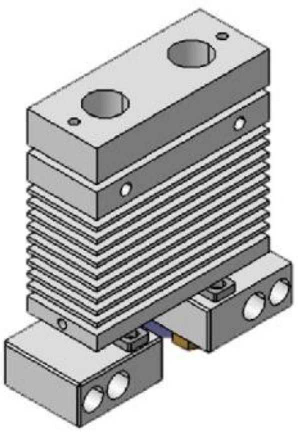

Fig 2:Isometric view of Extruder model.

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Section view of assembled Extruder

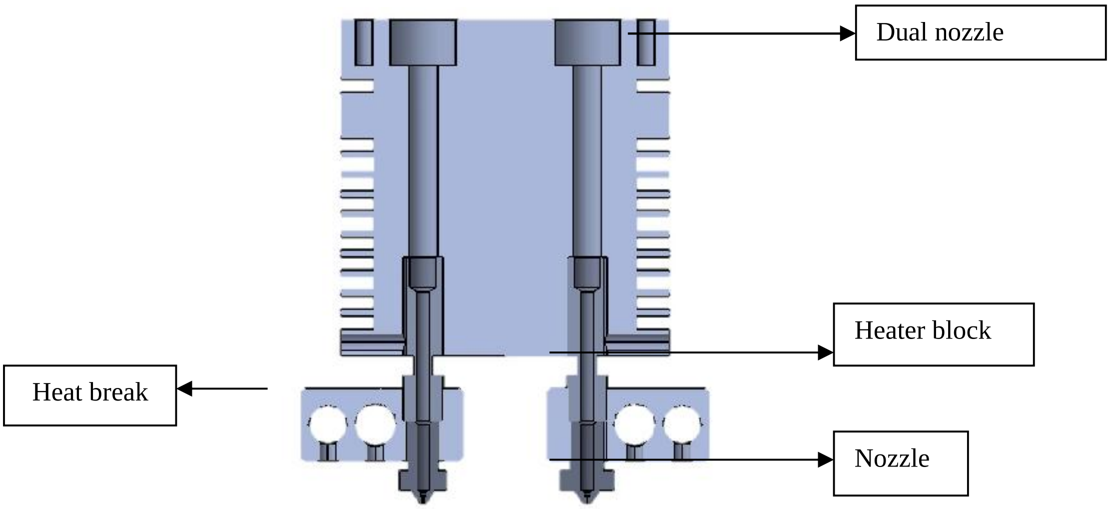

Fig 3: Sectional view of Extruder model.

Drafted details of manufacturing parts

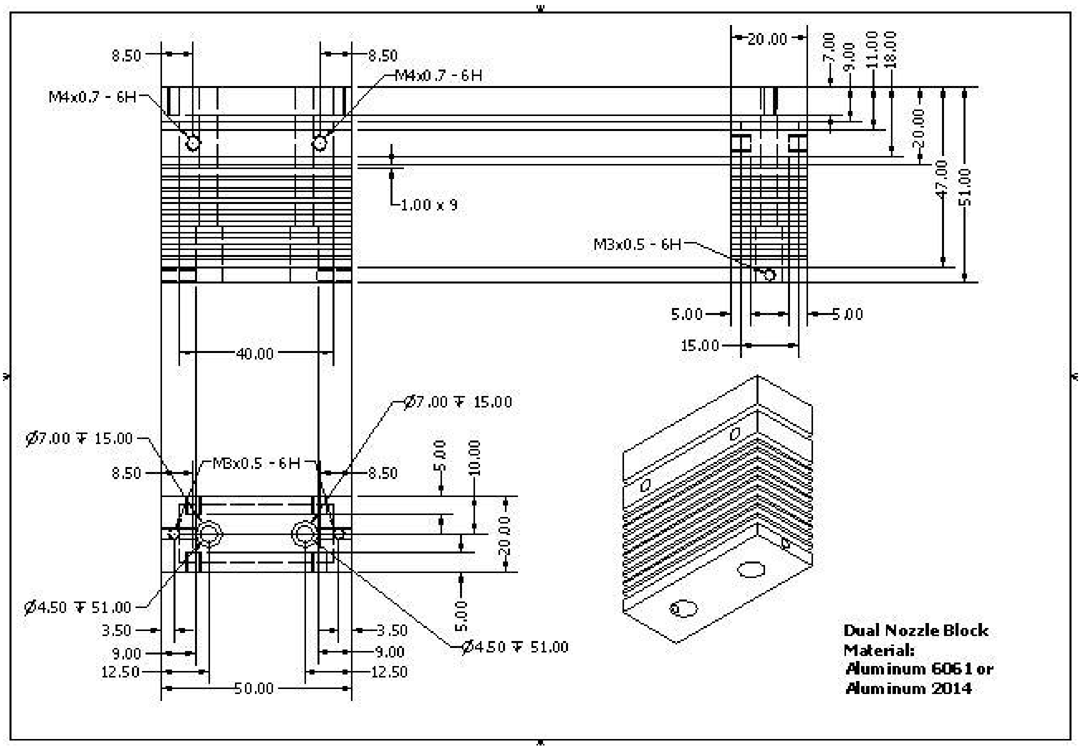

Fig 4: Drawings of parts done by CATIA V5 R 20

4.4Finite Element Analysis (FEA) for 3D-Concept Models.

Concept modelling and 3D models are created using a modelling tool called CATIA V5 R20.later the models are taken for analysis; models will undergo some pre-processing operation called “MESH”. Meshing is the technique where irregular shapes (infinite) are processed to get finite shapes by dividing the surfaces into uniform shapes like trihedral, tetrahedral, octahedral for analysis purpose.

Assembled Models are meshed and assigned with appropriate elements & nodes respectively and later all the meshed part models are subjected to Analysis. Meshing operations are carried out from the tool called HYPERWORKS-14.

In this study two variants of analysis are carried out, they are

1. Structural stress analysis
2. Thermal stress analysis.

The above 2 kinds of Analysis is carried out in a tool called ANSA-WORKBENCH.

Parts for analysis are having Technical -specs as follows:

- Mesh size : 0.5 mm
- Mesh type : Triangular shape
- Number of nodes generated : 5035276
- Number of Elements generated : 3543223
- Temperature : 400^{0}C
- Boundary condition : Fixed at top of Extruder, forced Conviction

3D-model of Extruder after MESHING operation in HYPER-WORKS

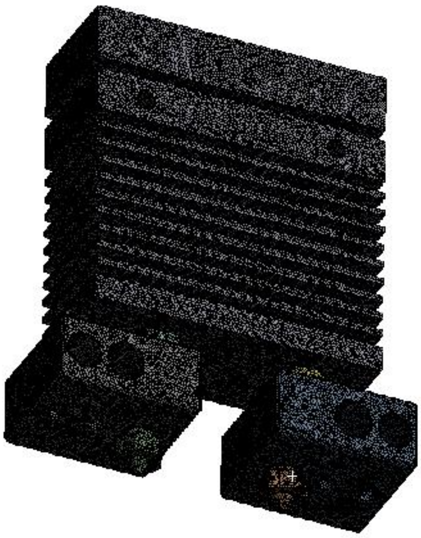

Fig 5: 3D modelled Extruder assembly with Mesh operation.

4.3 Selection Of Materials For Manufacturing Of Extruder Parts According To Design Requirements.

- Design of extruder is done in such a way that to achieve the working temperature which ranges between 100^{0}C – 400^{0}C.While achieving this specification, it is mandatory to keep the physical, mechanical &Thermal properties of the Extruder parts to be in safe design limit.
- According to design requirement temperatures at different parts of extruder are considered and various materials are selected according to their functionality.

Table.1: Materials selected for different parts of Extruder are as follows

Sl no.	Part Name	Material
1	Dual nozzle block	Aluminium-6061
2	Heater block	303-SS
3	Heat break	Aluminium-2014
4	Nozzle	Brass

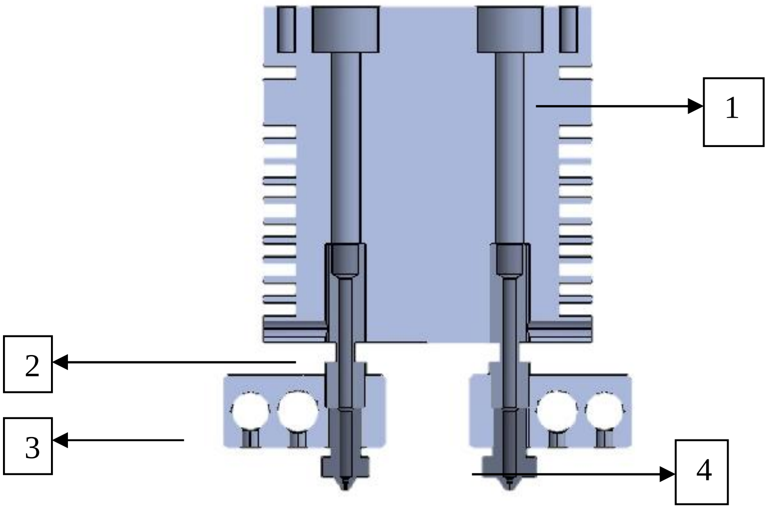

Fig 6: Sectional view of 3D printer extruder with materials details.

4.5 Analytical method:

Method of solving the problem by manual mathematical calculation by using some set of Formulae, where by considering boundary conditions & other environmental conditions.

FEA results are manually compared and verified for design validation purposes with the help of solving the above situation by numerical method.

Numerical method will results approximate outputs, whereas FEA method outputs almost near value to reality. Numerical methods are usually used for cross verifying the results with FEA outputs.

4.6 Design validation

Results of FEA & Numerical methods are compared among themselves to achieve the pre-set Benchmark value, which is set according to Design (concept).

The Benchmark value is the rate of output (result) beyond the expected or actual result value.

Essentially, Benchmark value is called asthe"Factor of Safety" **(FOS).**

FOS is how much stronger the system is than it usually needs to be for an intended condition.

FOS ≥ RESULT VALUE

4.7 Fabrication of Extruder after Design validation

Once the results are validated with respect to FOS, if the results are lying with FOS limit, then the work can be proceed to further stages like manufacturing of parts and assembling it with main system, fitments, accessories attachments.

If the results are not within the FOS limit then the process has to redirect to previous levels to identify at which area the problem exist, in some cases the process are redirected back to concept level and from there the entire operations will be reprocessed to achieve the required output(result).

Once the Results are matching the requirements, then the design is Freezed and manufacturing Drawings will be released for manufacturing and assembling of Extruder.

Fabrication of Extruder is taken care by CNC machine called V.M.C Vertical Milling Centre machine. A product of Jyothi-kirloskarCompany.

CNCM/C with technical specifications:

Bed length	:	1250x600mm
Height	:	700mm
Working on	:	Siemens-FANUC program

5. Result

3D models of FEA are assembled together are meshed and assigned with appropriate elements & nodes respectively and all the meshed part models are subjected to Analysis in ANSYS-WORKBENCH tool.

The FEA models are assigned with proper

- Boundary condition
- Temperature
- Material properties
- Heat flow etc..

FEA models are subjected under working temperature of 400^0C conditions results are as follows

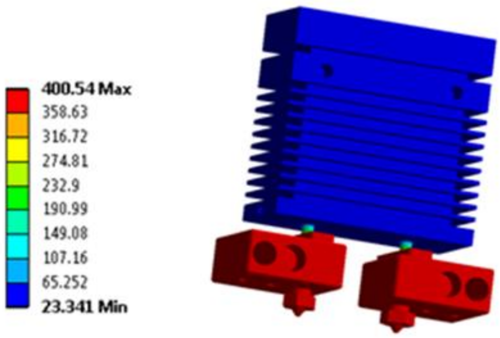

Fig 7: Shows the temperature distribution through the parts of Extruder

From the above result it is showing that Temperature at hot end is attaining the working temperature of 400^0C and the temperature at Heater block and nozzle is attaining maximum. The temperature is getting drop as it moves towards cold end.Cold end parts attain minimum temperature of 23.4^0C.Heat distribution along the Hot end and Cold end is recorded as shown.

FEA models are subjected under working temperature of 400^0C conditions the resultant stress developed are as follows.

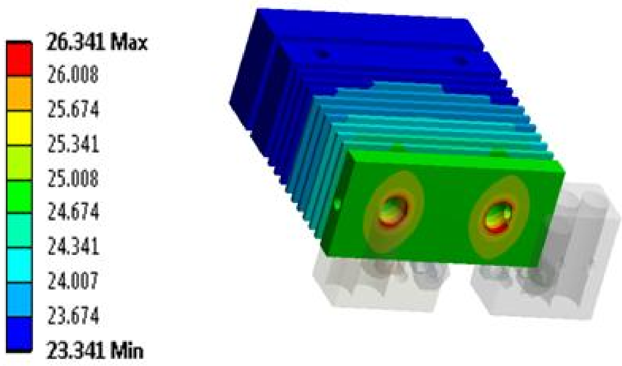

Fig 8:Shows the temperature distribution and Thermal stress through the parts of Extruder.

Above result is showing the Thermal stresses developed in the extruder when it is subjected to 400^0C temperature and with boundary conditions. The stresses induced in the Dual nozzle block exit area are260 Mpa. Nozzle block is made out of Aluminium-6061material which is having ultimate tensile strength value of 310 Mpa. Resultant stress is under safe limit.

FEA models are subjected under Analysis, the resultant Deformation developed are as follows

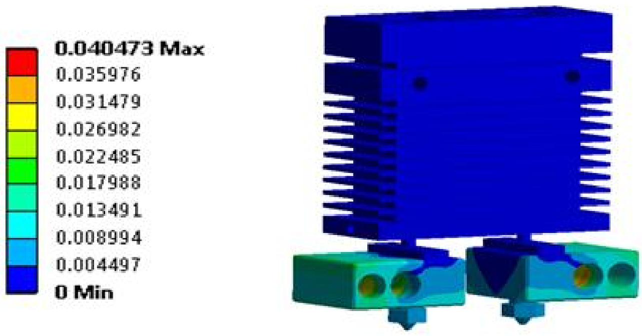

Fig 9: Shows Deformation developed through the parts of Extruder.

Above result is showing the Deformations in the extruder. Maximum deformation of induced at Heater block is $0.4x10^{-5}$ mm.Heater block material is made out of Aluminium-2014,its maximum deformation value is Nozzle block is made out of Aluminium-6061material which is having ultimate tensile strength value of 310 Mpa. Resultant stress is under safe limit.

FEA models are subjected under Analysis, the resultant Von misses Stresses developed in Dual nozzle block exit,are as follows

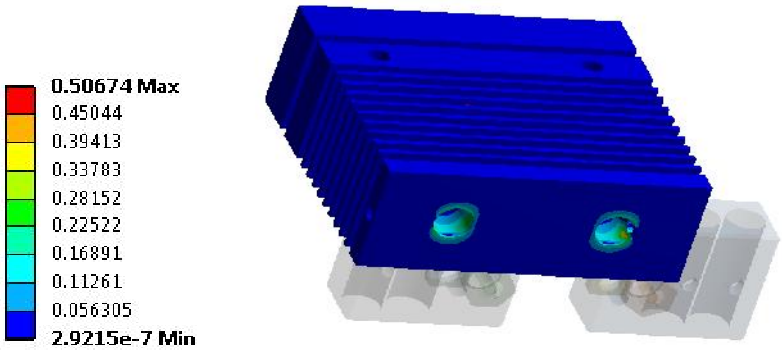

Fig 10: Shows Von misses Stresses developed through the parts of Extruder.

Above result is showing the Von misses Stresses in the extruder. Maximum stresses induced at Heater block is 50Mpa.Heater block material is made out of Aluminium-6061,its maximum deformation value is Nozzle block is made out of Aluminium-6061material which is having ultimate tensile strength value of 310 Mpa. Resultant stress is under safe limit.

FEA models are subjected under Analysis, the resultant Von misses Stresses developed at Heat break centre are as follows

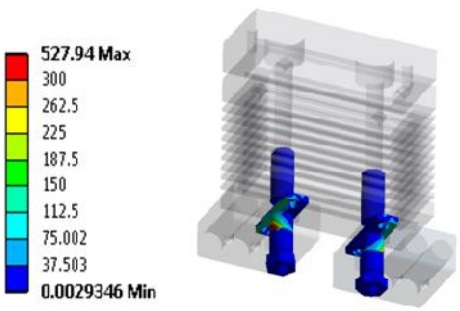

Fig 11: Shows Von misses Stresses developed through the parts of Extruder.

Above result is showing the Von misses Stresses in the extruder. Maximum stresses induced at Heater block is 527Mpa. Heater block material is made out of Stainless steel-303,its maximum deformation value is Nozzle block is made out of Stainless steel-303 material which is having ultimate tensile strength value of 690 Mpa. Resultant stress is under safe limit

FEA models are subjected under Analysis, With Boundary conditions.

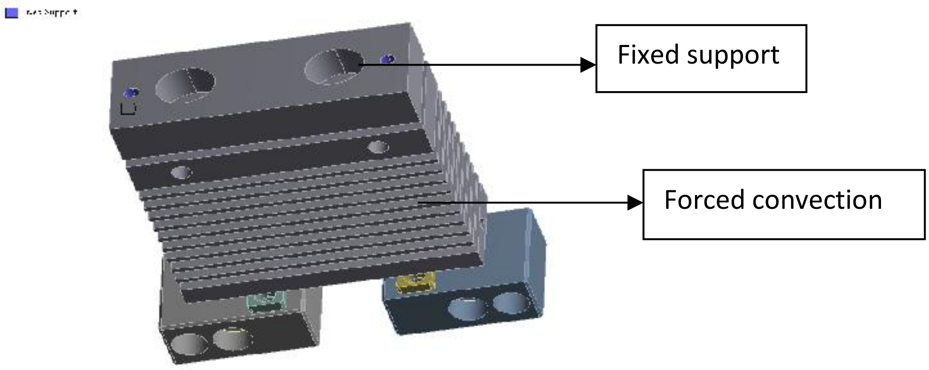

Figure 12: Shows boundary conditions applied to Extruder.

Above image is showing the Boundary conditions considered while analysis. Extruder is fixed with the help of Fasteners at the top as shown, This whole body is get attached with printer head movement carriage.

Extruder is facilitated with External fan for cooling purpose, In this region major amount of heat dissipate from the fins of the body by forced convection method with the help of exhaust fan.

6. Conclusion

FEA models are analysed using a tool called ANSYS WORKBENCH, Models underwent Thermal and structural analysis, The results after analysis are in safe range, The models which are designed and analysed are lying inside the Factor Of Safety level, Hence the design can be concluded as safe design.

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