Group ID: 48

A Project Stage-I
Report on

MANUFACTURING OF CONTINUOUS FIBER FILAMENT FOR 3D PRINTING.

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Pimpri Chinchwad College of Engineering

C E R T I F I C A T E

This is to certify that

has successfully completed the Project Stage – I entitled —

“Manufacturing of Continuous Fiber Filament For 3D Printing.”

under my supervision, in the partial fulfilment of Bachelor of Engineering Mechanical Engineering of University of Pune.

Date: 21-12-2020

Place: Nigdi, Pune.

Guide’s Name & Signature

Internal Examiner Name & Signature

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Head of the Department

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Principal

Seal

Acknowledgement

We wish to express our deep sense of gratitude and honor towards our respected guide Prof Amit Divekar for his inspiring guidance and constant encouragement. His committed devotion, dedication and encouragement with full faith on us were like a lamp in our path which keeps us constant throughout project work.

We also express our honor and gratitude to our Head of Mechanical Department Dr. P.A. Deshmukh for consistent encouragement for completing our project work successfully.

We are thankful to all Teaching and Non-Teaching staff member of the institute and our classmate who had directly or indirectly made me enthusiastic for the project work.

As we conclude, we would like to state that just as a positive attitude pays off our hard efforts to bring this project to successful end, would also pay off. We hope that this project would be one of the most significant steeping stones for our career and would fulfill our aspiration in every aspect.

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Abstract/Synopsis

Composite part manufacturing is labor-intensive, costly, and needs to perform complex methods such as vacuum bagging. Because of these composite applications are limited to only the high-end aerospace industries. On the other hand, 3D printed thermoplastic parts are weak to be used as structural components.

Because of COVID-19 product industries are most affected compared to software industries. Virtual development of products becomes impossible because of the need of prototyping.

This problem can be solved by continuous fiber 3d printing. In this project, the solution is proposed to solve the above problems. By printing continuous carbon fiber embedded in nylon and using it in 3d printing, the strength part should be significantly increased. By achieving merely 35%-40% of fiber fraction printed parts could have strength comparable to steel.

1. Introduction

The 3D Printing (Additive Manufacturing) Industry has experienced significant growth in the last few years, and it is predicted to bring revolution among the manufacturing industries for creating next-generation high-performance materials. Additive manufacturing primarily uses thermosetting plastic which is cheap but barely produces any strength at all.

In order to enhance the performance of the plastic composite, different reinforcement; for instance, carbon black, platelets, chopped fibers, polymer fibrils are mixed with thermoplastic matrix and then extruded together during printing. The performance of these composites significantly depends on the fiber orientation in the plastic and fiber volume fraction (FFV). However, they still show inferior mechanical performance compared to traditional fiber-reinforced composites. Therefore, to widen the application of 3D printed FMD technology for designing high-performance composites, is a need of the product industry. The technology available with this feature is known as continuous filament fabrication (CFF). In this project we are developing a CFF printer at very low cost so it can replace traditional composite manufacturing processes.

1.1 Problem Statement

To reduce the cost of composite part manufacturing by vacuum bagging or molding process, we are designing and manufacturing continuous fiber filament for 3D printing.

1.2 Objectives

- To produce a nylon embedded fibre used for 3D printing.
- To perform tensile strength test on the manufactured fibre.
- To print the generative or topologically optimized part with a continuous fiber 3d printer.

Continuous fiber-reinforced composite materials are now used in a wide range of applications including aerospace, automotive, industrial, and sports goods. The materials normally contain a thermosetting polymer matrix (usually an epoxy or polyester resin) reinforced with carbon, glass, or aramid fibers. These materials have higher strength and stiffness per unit weight and often have lower finished component costs than the metals they replace.

1.3 Scope

- Necessary Modifications on 3D printer should be designed, manufactured and tested on the 3D printer.
- The Continuous Carbon Fibre Filament should be 3D printable with desired properties.
- The Continuous Carbon Fiber filament (CFF) properties should be measured and compared with other 3D printing materials.

1.4 Methodology Planned

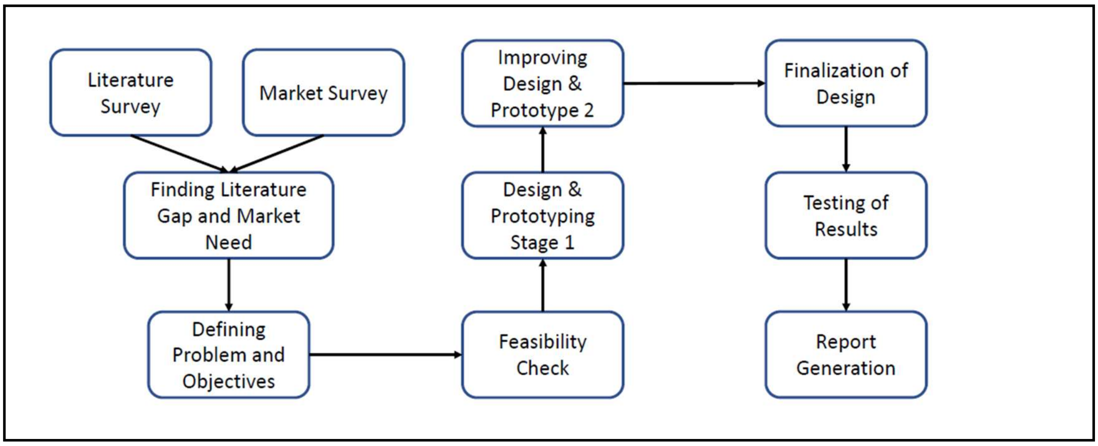


Figure 1 Flowchart of Methodology Planned to Solve the Problem

2. Literature Review

Title	Author	Year	Inference
Spread Tow Technology for Ultra Lightweight CFRP Composites: Potential and Possibilities	Hassan M. El-Dessouky	2017	Spreading module mechanism.
Forming low-cost, high quality carbon tows for automotive application	T Sharif, P Potluri, R S Choudhry, A Dodworth	2018	Cost effective manufacturing and proposed applications.
An Overview of Impregnation Methods for Carbon Fibre Reinforced Thermoplastics	Thomas Köhler, Tim Röding1, Thomas Gries and Gunnar Seide.	2017	Impregnation of nylon with fibre.
Fibre Damage and Impregnation during Multi-Die Vacuum Assisted Pultrusion of Carbon/PEEK Hybrid Yarns	Felix Lapointe, Louis Laberge Lebel	2018	Damages that can occur due to mistakes in procedure.
Preparation of carbon fibre-reinforced thermoplastics with high fibre volume fraction and high heat-resistant properties	Bing Liu, Anchang Xu and Limin Bao	2015	Preparation and actual impregnation of fibre.

3. Filament Properties Calculation:

The fiber-reinforced composite made by prepreg or vacuum bagging method has up to 60% of fiber volume fraction. However, such high fiber volume fraction may not work in 3d printing because porosity is generated by a gap between two diagonally adjacent filaments in print that need to be filled with thermoplastic material for good strength. We can observe in previous continuous fiber 3d printing a maximum of 40% of fiber fraction is achieved.

3.1 Tensile Strength and Modulus of Elasticity of Filament

For the selection of fiber, a comparison between different fibers is done. From the below comparison, carbon fibers are clearly the stiffest and strongest fiber and also *fibers and mild steel* comparatively stronger than steel.

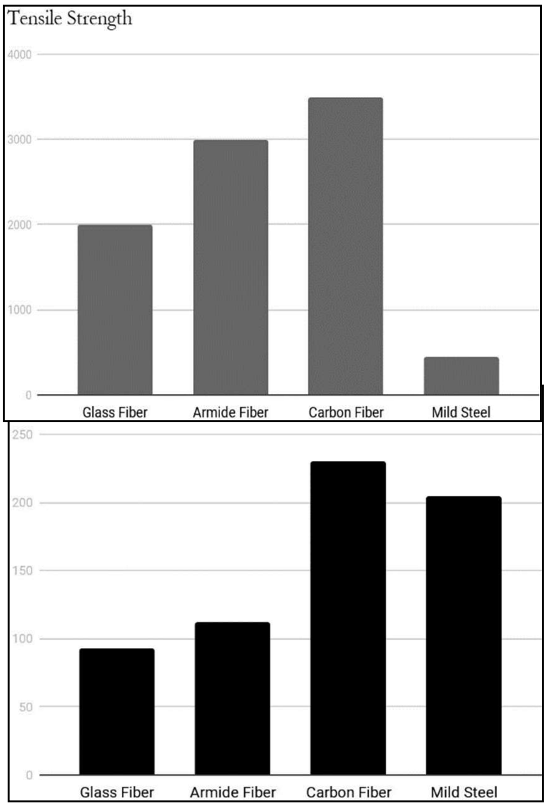


Figure 2 : Tensile strength (MPa) and modulus of elasticity (GPa) comparison between different materials

The Properties of the composite can be calculated as follows:

$$\mathbf{P_C = FVF \times P_f + (1 - FVF) \times P_m}$$

Where,

P_c = Property of Composite,

Pf =Property of Fiber,

P_m =Property of the Matrix,

FVF=Fiber Volume Fraction.

So, for 0.35 fiber volume fraction strength of carbon fiber is 1225 MPa, and the Modulus of Elasticity is 80.5 GPa with neglecting the properties of the thermoplastic matrix which are very small compared to reinforcement.

2.2 The Diameter of Filament

The Thickness of filament for a particular fiber count (nk) and fiber volume fraction (FVF) is as follows

Density of carbon fiber ρ= 1930 kg/m^3.

Weight of 1k carbon fiber per unit length; λ=66 × 10^{-6}

Fiber count = nk(k=1000).

So, Cross Sectional Area of filament… $A = n \times \frac{\lambda}{\rho} \times \frac{1}{FVF}$

Hence, Diameter of filament… D = 2 × $\sqrt{\frac{A}{\pi}}$

Sr. no	Fiber Count	FVF	Diameter of Filament (mm)
1	1k	0.35	0.3527
2	1k	0.40	0.3300
3	3k	0.35	0.6108
4	3k	0.40	0.5715
5	6k	0.35	0.8639
6	6k	0.40	0.8083
7	12k	0.35	1.2217
8	12k	0.40	1.1431

Table 1: Diameter of filament for different Fiber count and different Fiber volume fractions.

From diameter calculation, 1k and 3k fiber count is suitable for good print quality which is achieved between 0.1mm to 0.6mm of print nozzle. Furthermore, we also need to consider the cost and availability of fiber. 1k carbon fiber cost is around 200$/kg which is 4 times high compared to 3k fiber which is 48$/kg.

From this analysis, we have selected Carbon Fiber reinforcement with 3k fiber count and 0.6mm diameter of a nozzle for printing.

4. Pultrusion Setup:

Pultrusion is a process in which composite parts are manufactured by pulling of fibers that are impregnated with thermoplastic or thermosetting plastic with various methods. A general block.

For the manufacturing of Continuous carbon fiber-nylon filament, we manufactured a pultrusion setup.

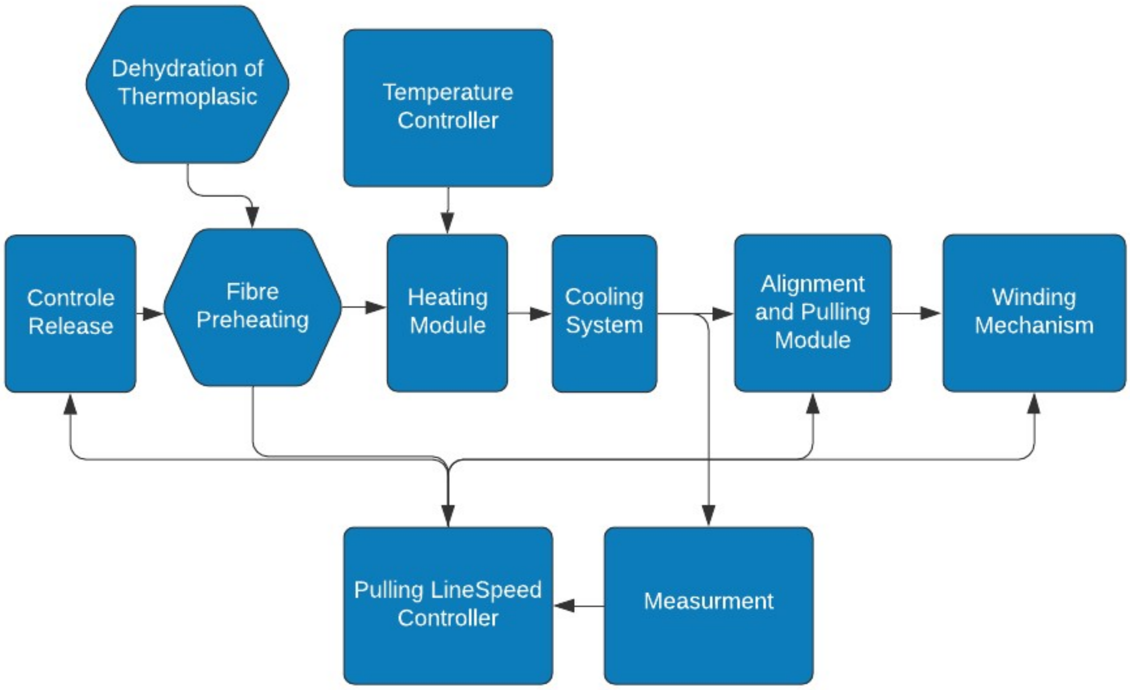


Fig. 2: Block diagram of the pultrusion process

which CF with nylon ensuring proper infusion and proportion. This mechanism is a combination of a Spreading module, heating module, pulling module, and winding module.

4.1 Pultrusion 1.0:

Design 1.0 is based on the extrusion process in 3D printing with additional protrusion of fibers.

4.1.1 CAD design:

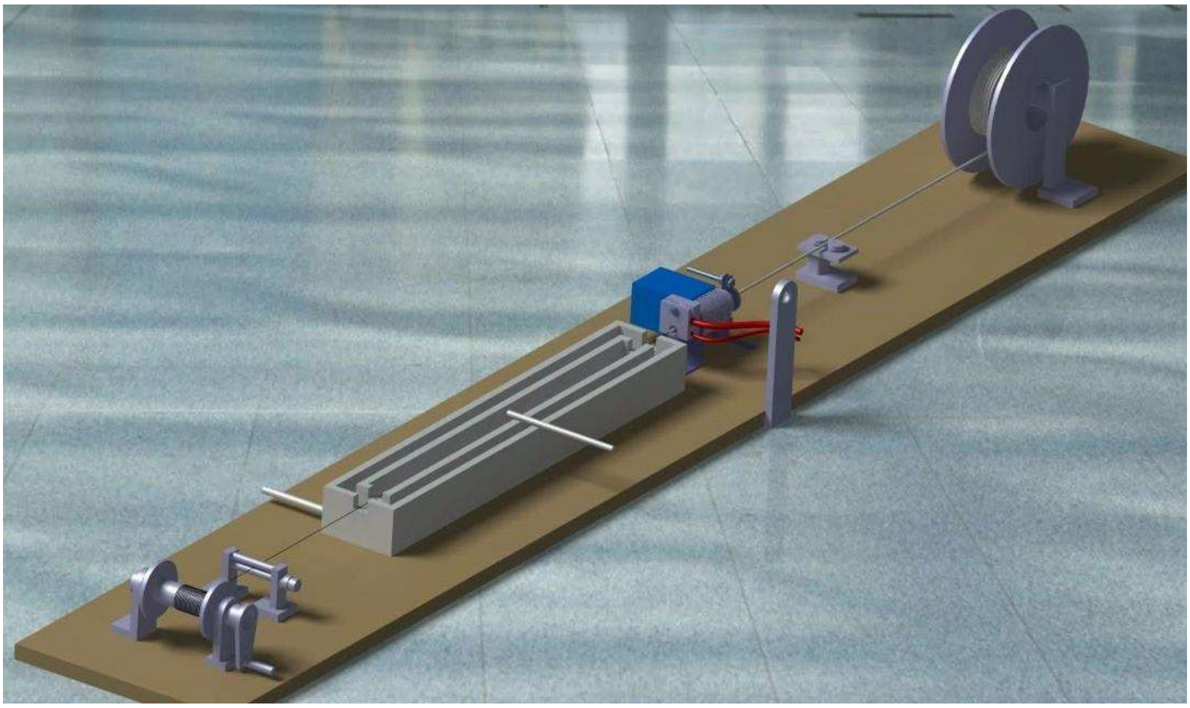


Fig.3: Complete pultrusion assembly.

In the above figure is a complete assembly of the first iteration of pultrusion. First, the fiber tow is placed on the left, passes through the heating nozzle. The heating element is nothing but 3d printing v6 nozzle with a hole at the end to pass the fiber as shown in fig below.

Thermoplast is passed by pushing filament of 1.75mm thermoplast from the rear end of the heating element similar to 3d printing. This coated filament is then passed through water to cool down the filament. This cooled down filament is then collected on a coil.

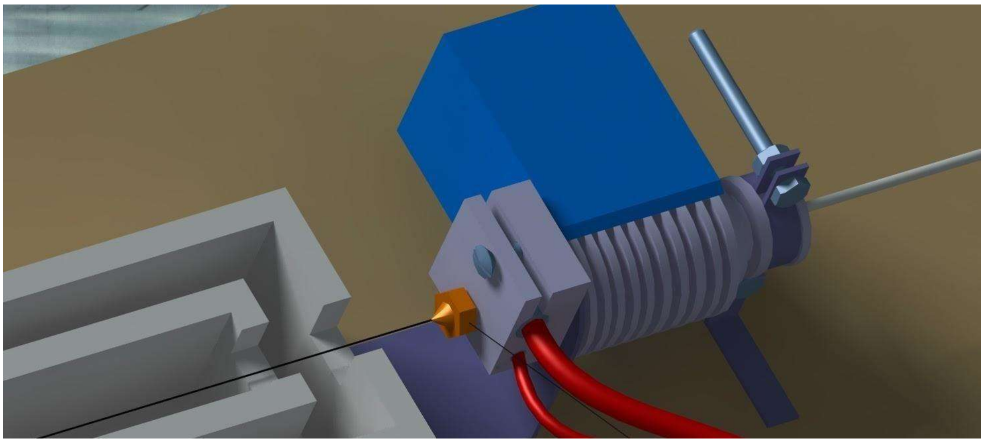


Fig 4: Heating module and fiber feeding system.

4.1.2 Prototype 1.0 test:

In this prototype the thermoplastic filament of PLA is fed by a feed mechanism. The rate of feed is adjusted manually through the motor controller. 12V supply is given to the heating cartridge.

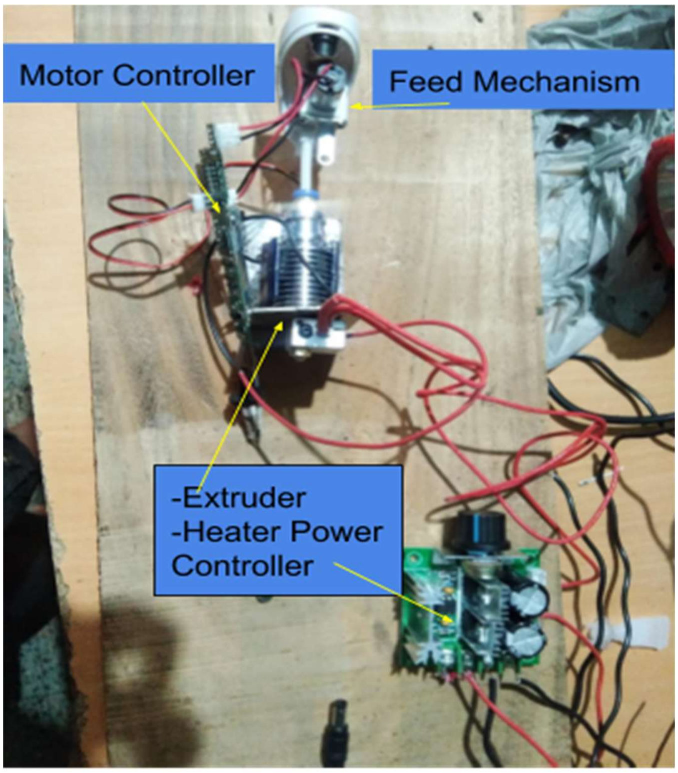


Fig 5: Pultrusion Design 1.0 Prototype.

4.1.3 Prototype 1.1

In this prototype spreading of the fibers is done by passing fibers through different holes, impregnating them in molten thermoplastic. Afterwards these fibers combine by passing through 0.7mm nozzle as shown in fig below.

Fig 6: Prototype 1.1

4.1.4 Results:

Fig 7: Prototype 1.0 filament

Fig 8: Prototype 1.1 filament

1. From prototype 1.0 only surface impregnation of filament is achieved.
2. Because of thermoplastic feed mechanism clogging was observed.
3. In prototype 1.1 complete impregnation of fibers is achieved.
4. Because of fiber separation by different holes fiber breakage occurred. These broken fibers become the reason for clogging further.

4.1.5 Conclusion

1. There is a need for a spreading module which can spread fibers uniformly without breakage or distortion.
2. Thermoplastic flow must not be forced but it should flow under gravity to avoid fiber distortion.
3. Fiber should not have a sharp turn in molten nylon to avoid clogging as it was in the first design.

4.2 Pultrusion 2.0:

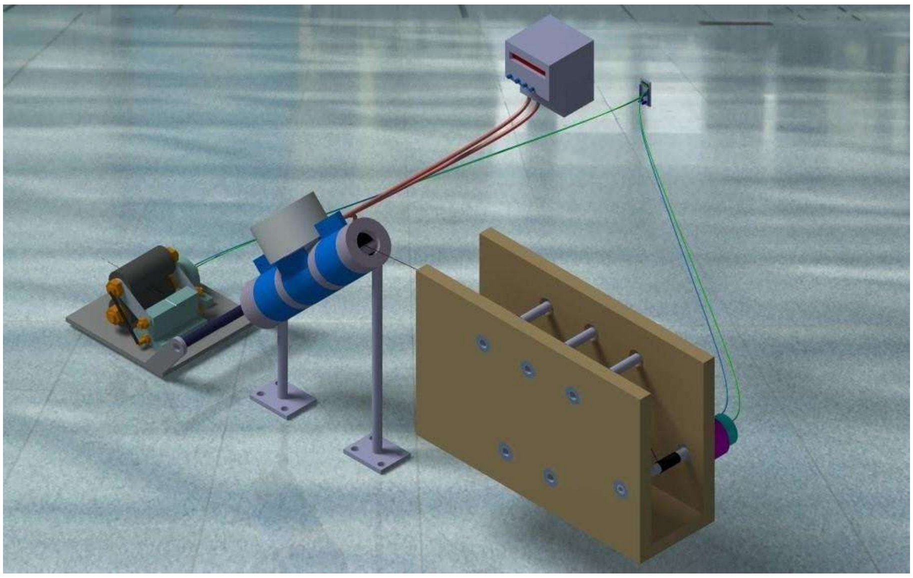


Fig 9: Pultrusion design 2.0

4.2.1 Spreading module:

To manufacture the filament of diameter 0.7mm from 3k CF, we use a spreading mechanism that spreads the 3k fibers of 2mm width to a width of 12mm. This is done via passing the 3k fibers under tension around 5 polished cylinders. These cylinders can rotate about their own axis and are mounted on the frame by using ball bearings as shown below.

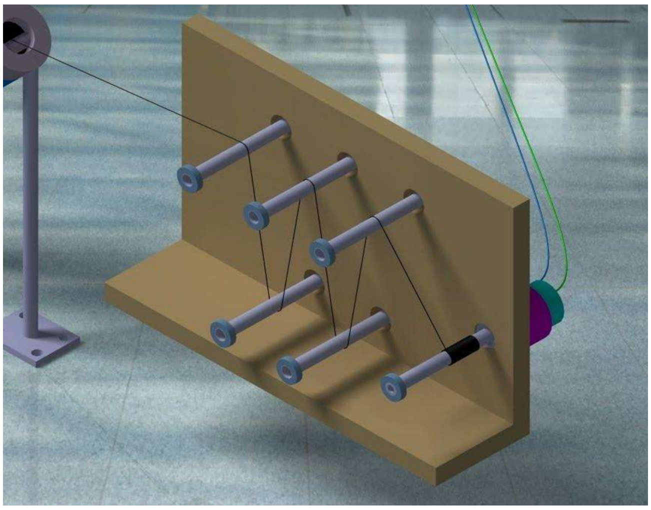


Fig 10: Spreading Module after removing a left section

In order to obtain the right number of cylinders and tension force to be applied, we carried out a number of iterations and selected 5 cylinders.

Fig 11: Spreading Module

4.2.2 Heating module:

After the spreading of fibers, the strands are pulled through a container containing molten nylon. The spread strands enter the heating module from the right side and the coated filament is pulled out from the left side of a module. Nylon pellets are added from the upper portion of a module. The module has a heater that maintains a temperature of 280 ^{0}C through the pipe. This temperature is above the melting point of nylon.

Fig 12: Heating Module

To avoid the solidification of nylon, we did a thermal analysis of this pipe and ensured uniform temperature across the pipe. The control module is used to maintain the required temperature. Given below are images of a prototype of the heating module.

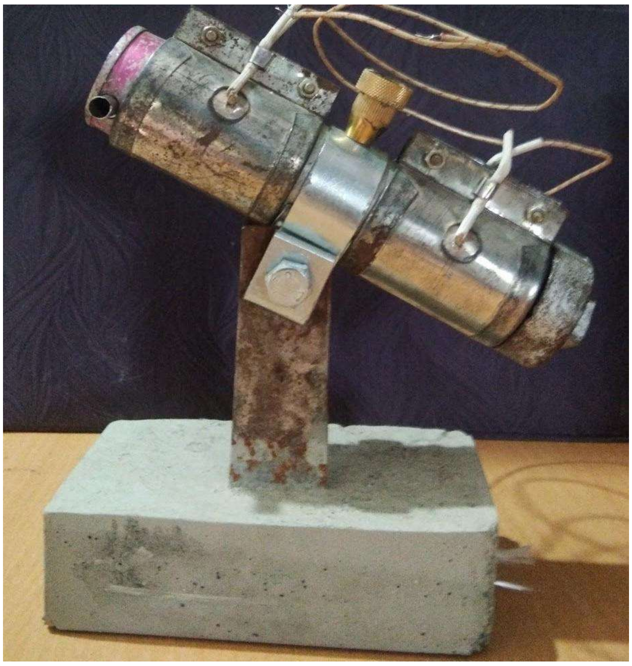


Fig 13: Heating Module without insulation.

4.2.3 PID Temperature Controller.

For the temperature controller, we have used an Arduino UNO. For temperature measurement k-type thermocouple for which can measure temperature up to 1020^{0}C. This recorded temperature is displayed on 16 × 2 I2C display.

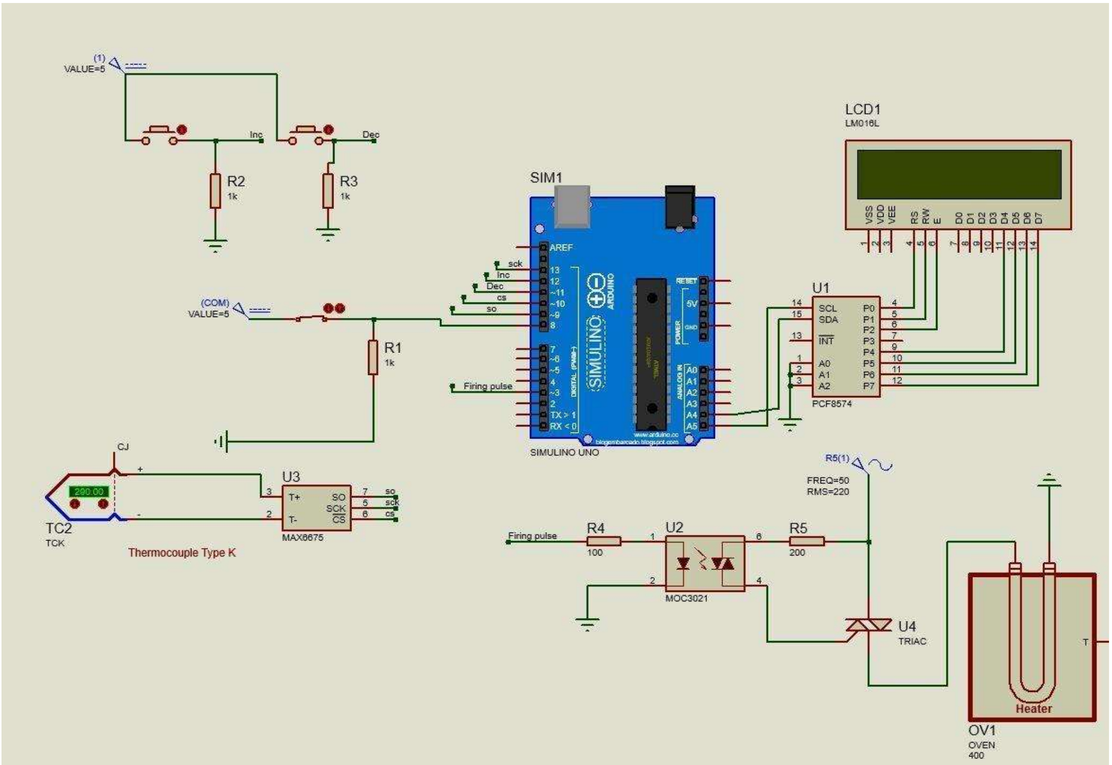


Fig 14: Temperature controller circuit diagram.

For controlling current flow TRIAC is used which is coupled with Arduino by Optocoupler MOC3021 for ensuring isolation of high voltage circuits from low voltage circuits.

The heating module is small and so it is prone to fluctuation in temperature if we use an ON/OFF type control system. For accurate control on temperature and to avoid overshoot of temperature PID controlling method is implemented. The tuning of PID is explained in the simulation chapter.

4.2.4 Pultrusion 2.0 test:

In this prototype a heating chamber and PID controller is introduced to uniformly heat the nylon present in the chamber to avoid fuming by higher temperature and solidification due to less temperature.

Fig 15: Pultrusion 2.0 test

The spreading module results in spreading of fiber to acquire better impregnation.

4.2.5 Results:

Fig 16: Pultrusion 2.0 result

1. In this prototype nylon impregnation was better.
2. No clogging was observed in this prototype.
3. Fiber was not at the center of the filament.
4. Surface finish was better than prototype 1.0 but still not satisfactory.

4.2.6 Conclusion:

1. The spreading module resulted in a better impregnation.
2. Heating module helped to solve the problem of clogging.
3. Fiber centering and surface finish needs to be improved.

4.3 Pultrusion 3.0:

In this prototype emphasis was given to ensure that the fiber is at the center of the filament. To achieve this a capsule was introduced.

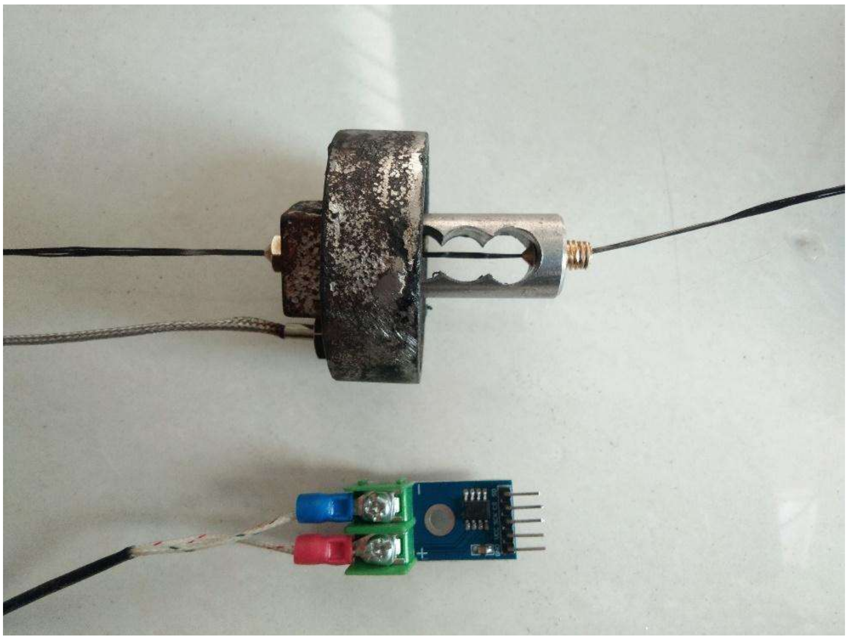


Fig 17: Capsule to ensure that fiber is at the core of the filament

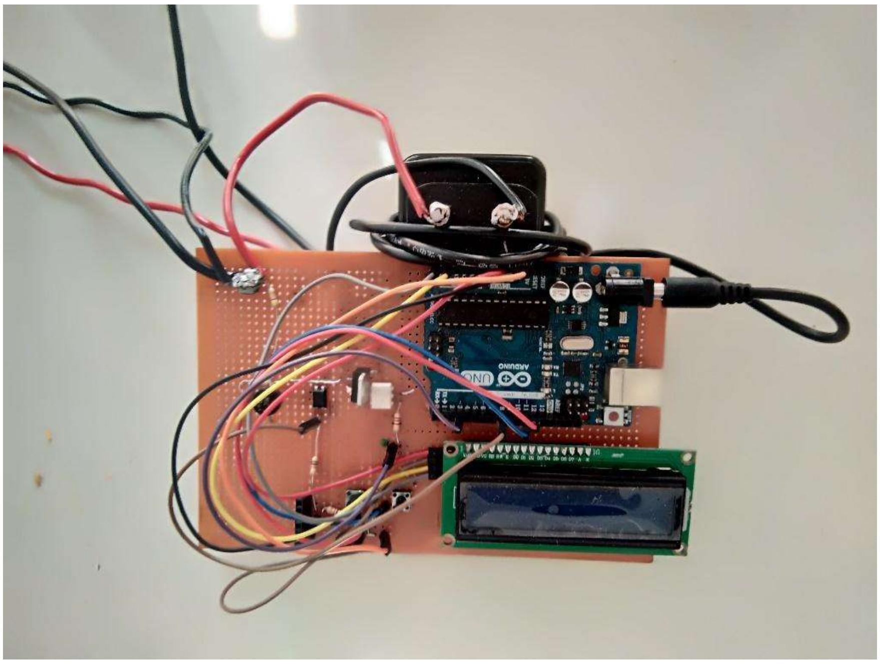


Fig 18: Updated temperature control unit

The spreading module was integrated into the heating module to achieve a compact assembly.

4.3.1 Pultrusion 3.0 test:

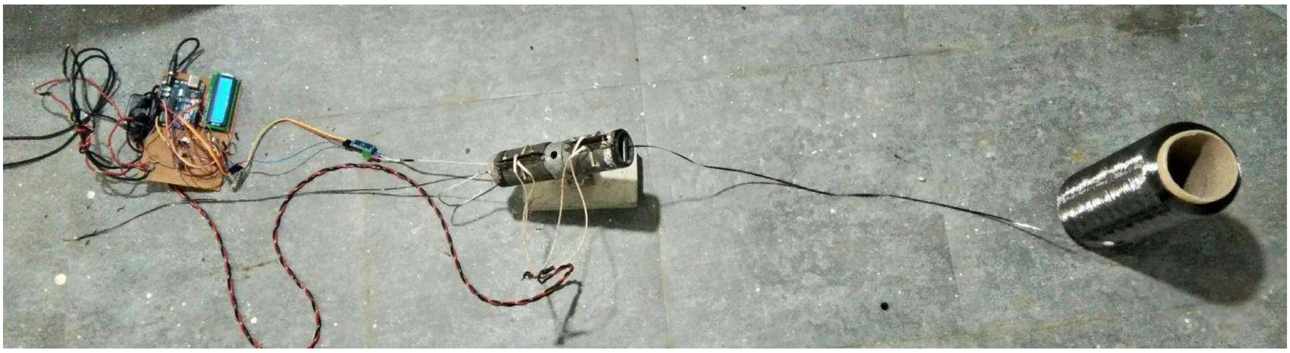


Fig 19: Prototype 3.0 testing

4.3.2 Results:

Fig 20: Prototype 3.0 obtained fiber

1. The filament manufactured was not dimensionally accurate.
2. The surface finish acquired was not up to standard.
3. The fiber is at the center of the filament.

4.3.3 Conclusion:

1. The problem of fiber centering was solved due to introduction of capsule.
2. Due to non-uniform pulling rate surface finish was not smooth.
3. The fiber needs to be measured continuously for quality control purposes.

4.4 Pultrusion 4.0:

In the previous prototype the capsule was introduced to maintain the coaxiality of the filament. But the capsule was preventing the nylon to completely impregnate the fiber. Hence a design change was made to introduce two dies that will maintain the coaxiality and will not hinder the impregnation process.

4.4.1 Heating Module:

In the last prototype there was solidification of nylon at the hooper site. In this prototype heater was introduced in the vertical pipe to ensure uniform heating of nylon.

Fig 21: Heating Module

Fig 22: Heating module exploded view

Fig 23: Manufactured heating module

4.4.2 Alignment Module:

Problem with earlier prototypes was that the fibre was not at the centre of the filament. Hence an alignment module was introduced to ensure that the fibre is at the centre if the filament. This module consists of slots for vertical and horizontal alignment which ensure that the filament exiting the heating module is straight.

Fig 24: Alignment Module

Fig 25: Alignment module exploded view

This design provides flexibility to set the filament to achieve fiber at the center of the filament.

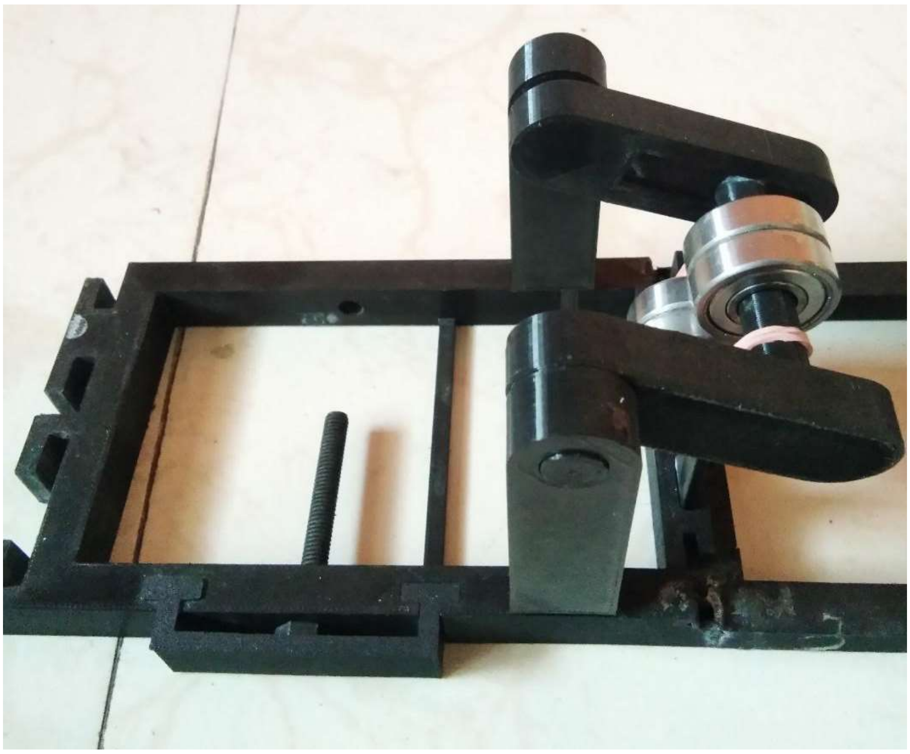


Fig 26: Manufactured alignment module

4.4.3 Measurement Module:

This 3D printable filament needs to be manufactured with a tolerance limit of 0.02mm. To check whether the manufactured filament is up to the required standard, a measurement module is introduced. It consists of two blocks that have tapered profile inside them to accommodate the vernier calliper. On the other side of these blocks are mounting measure for bearings that hold the filament. This then continuously measures the manufactured filament to check if its under tolerance limit.

Fig 27: Measurement Module

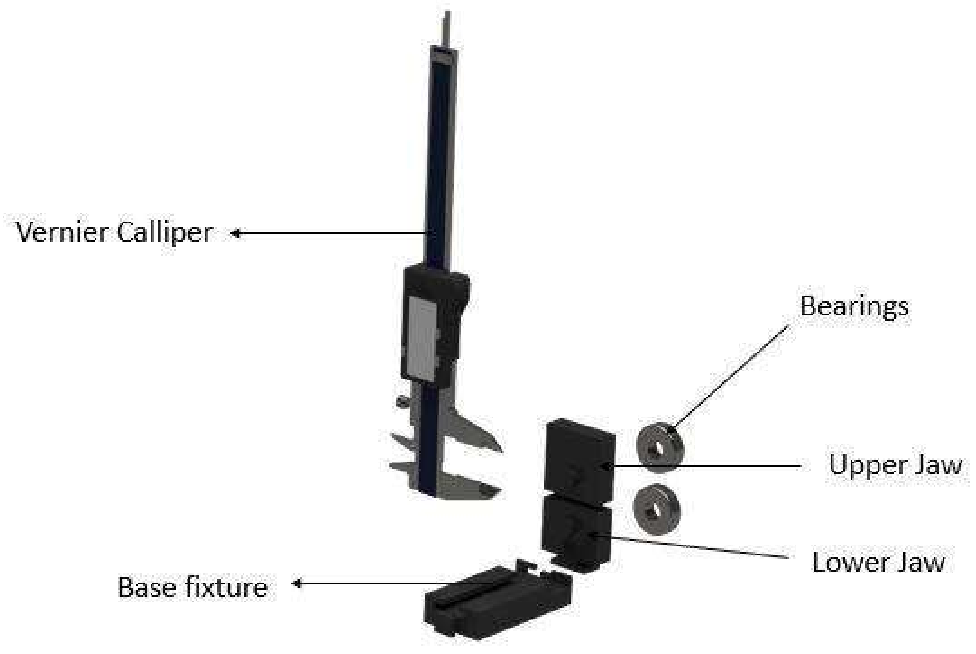


Fig 28: Measurement Module Exploded View

Fig 29: Manufactured measurement module

4.4.4 Pulling Module:

Pulling Module consists of a stepper motor that creates a uniform pulling rate which is important for the quality and expected dimension of the filament. The stepper motor is bolted on to a fixture that also consists of a shaft on which a bearing is placed. This bearing ensures that the filament is always in contact with the motor shaft and maintains its path. An external driver A4988 is used to drive the motor at a uniform rate.

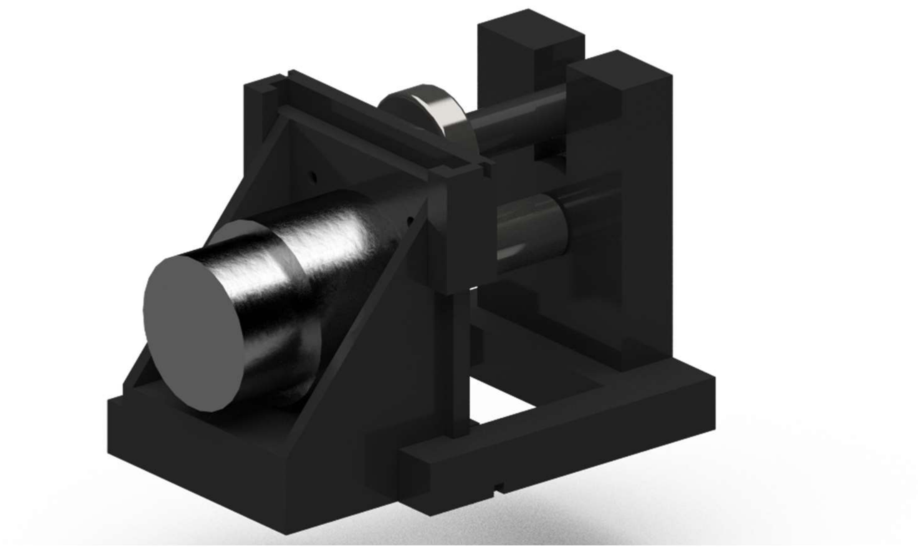


Fig 30: Pulling Module

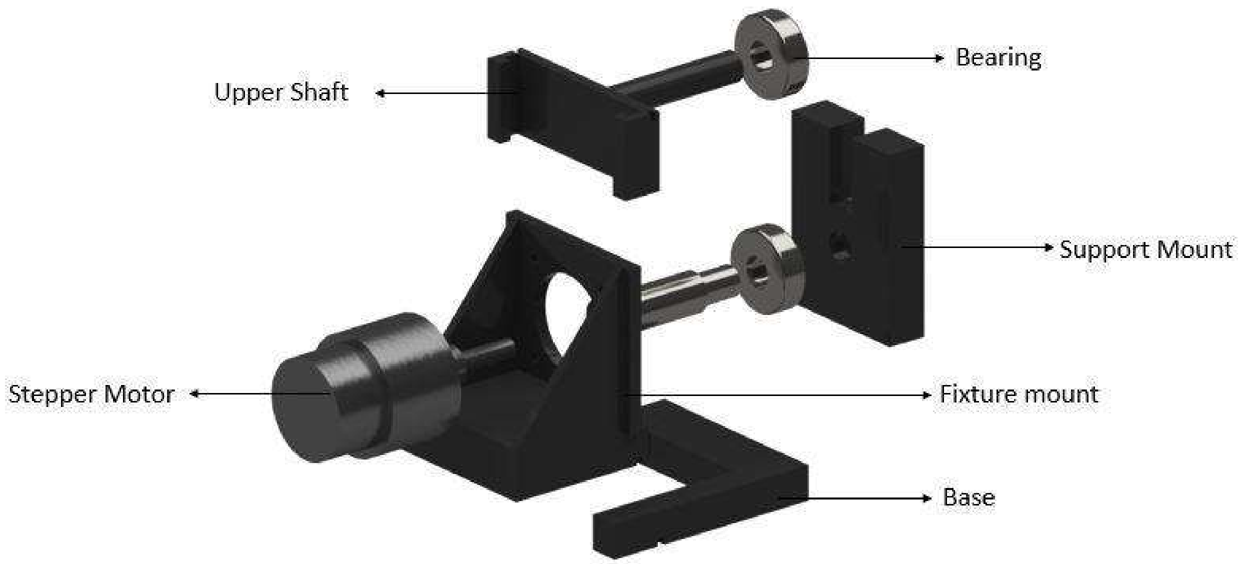


Fig 31: Pulling Module exploded view

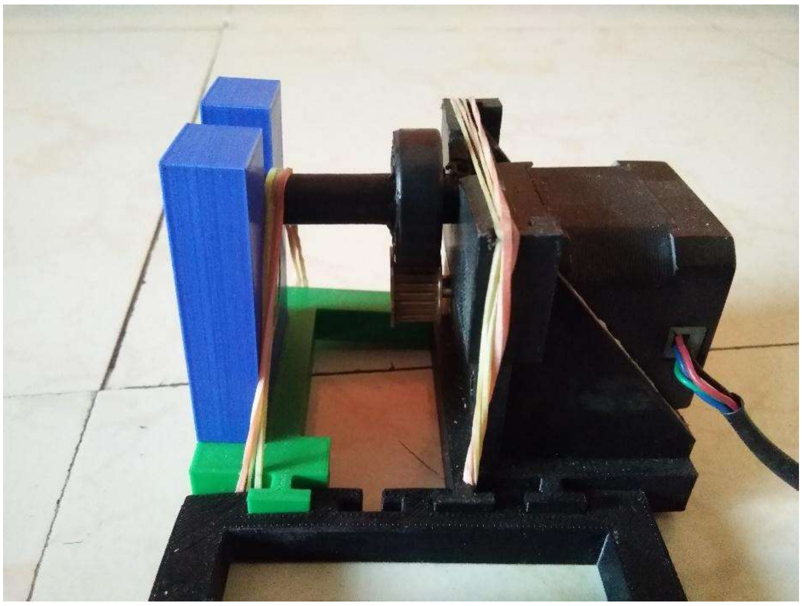


Fig 32: Manufactured pulling module

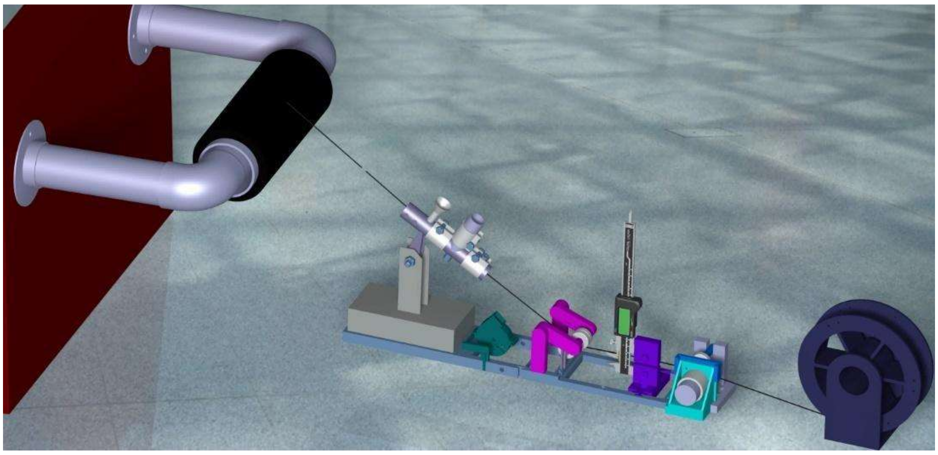


Fig 33: Prototype 4.0 Cad model

4.4.5 Prototype 4.0 test:

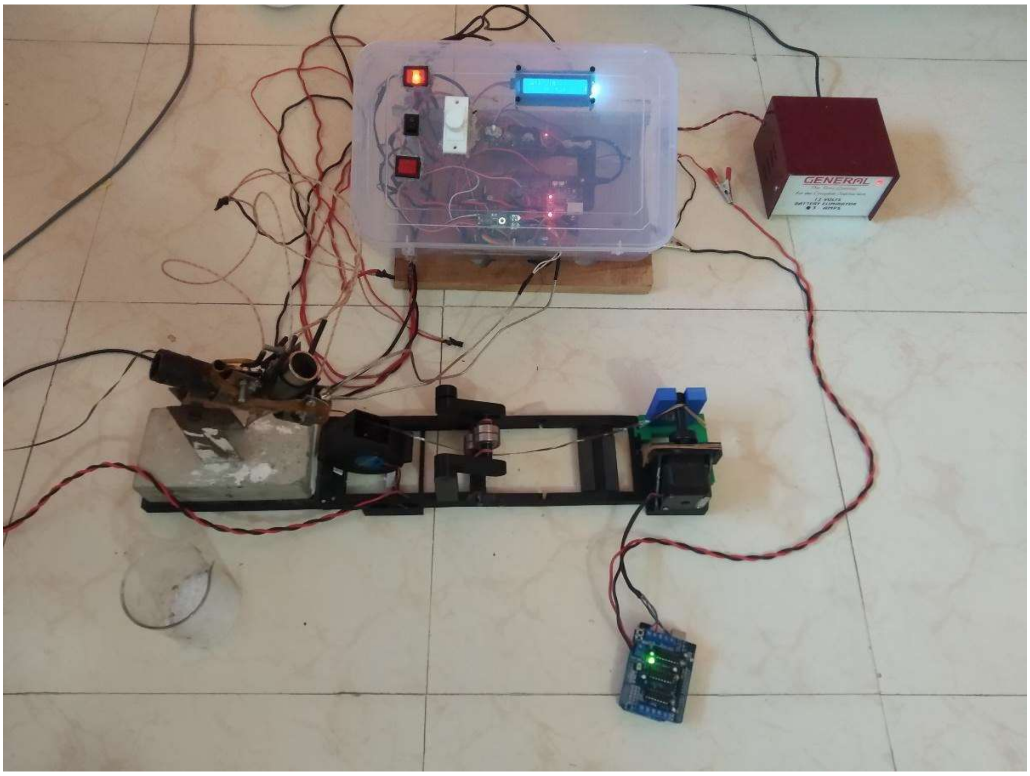


Fig 34: Prototype 4.0 Test

4.4.6 Results:

Fig 35: Prototype 4.0 result

1. The fiber obtained was in the tolerance limit $\pm$0.02mm.
2. The manufactured fiber had good surface finish.
3. The fiber was impregnated at the center of the filament.

4.4.7 Conclusion:

1. The quality of manufactured fiber in terms of dimension and surface finish is good to acquire 3d printable products.

5. Dry box and Dehydrator:

Since nylon is hydrophilic hence it absorbs moisture when exposed to the atmosphere. Hence a dry box is introduced to maintain the relative humidity near zero.

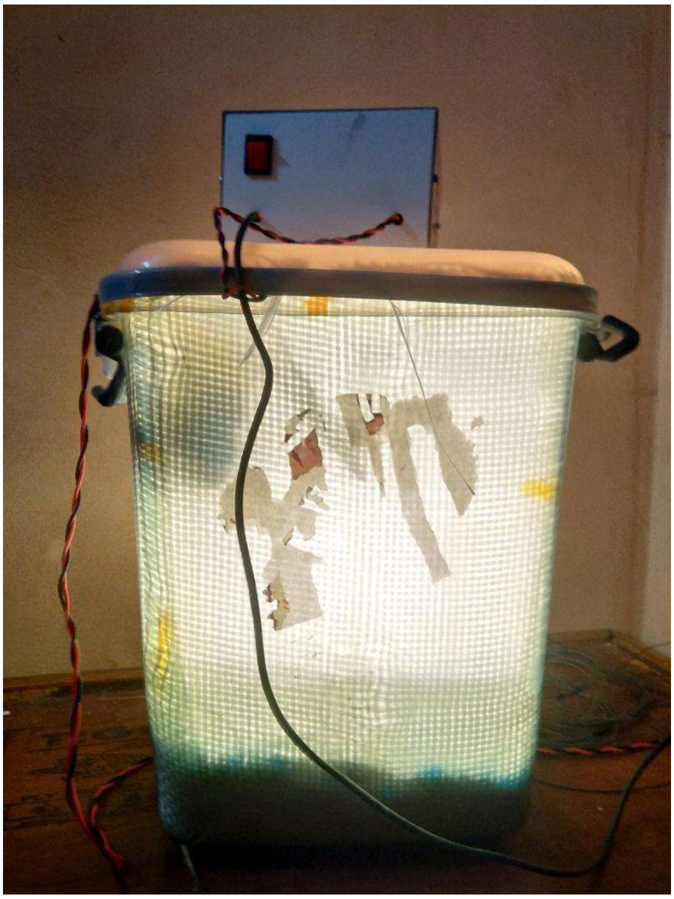


Fig 36: Dry Box

These consist of silica gel crystals and a light bulb to maintain the relative humidity as low as possible.
A fiber mat is coated on the sides of the box to maintain insulation.

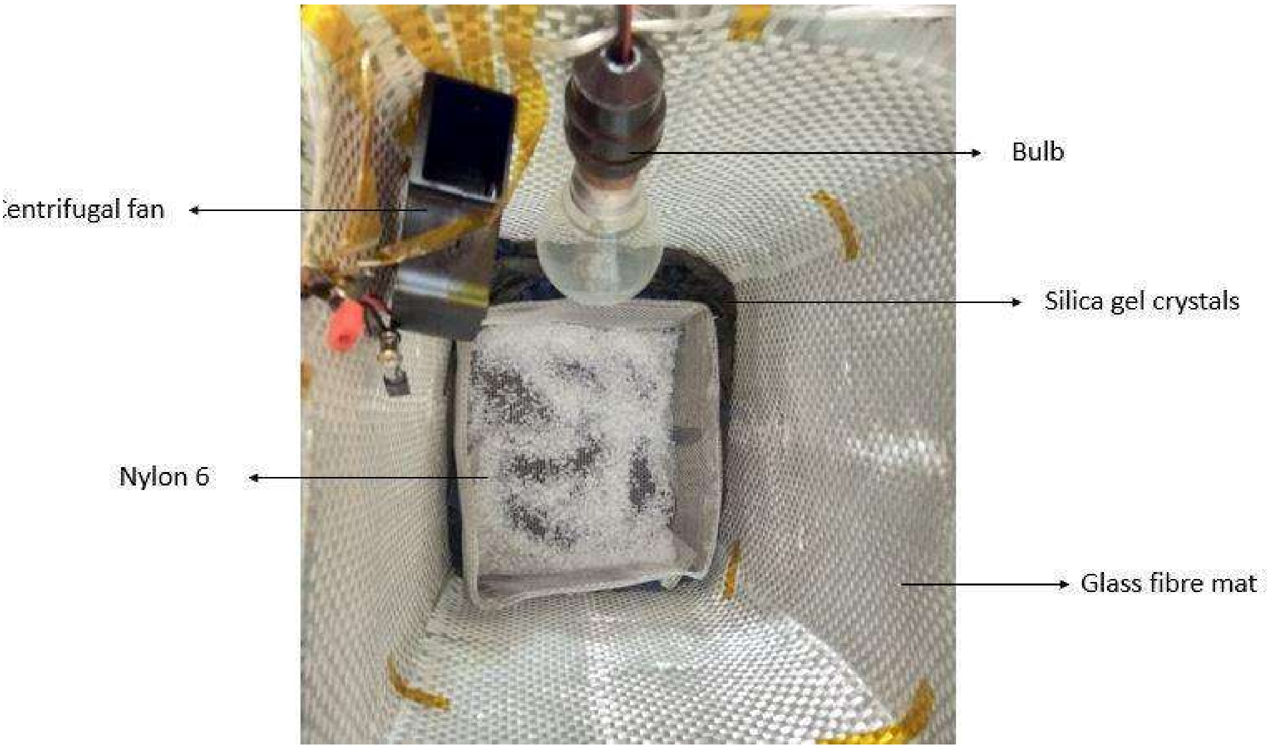


Fig 37: Dry box detailed view

Also, a dehydrator was manufactured to dehydrate any nylon which was in contact with atmosphere.

Fig 38: Dehydrator

6. Simulation & Analysis:

Thermal analysis was done to ensure temperature fluctuation is not high throughout and it maintains the melting temperature of nylon in the heating system and 3d printing nozzle.

6.1 Heating system:

A heating system is used to heat up and melt the nylon. But this should be maintained between 290-350 degrees. If the temperature is lower nylon won't melt and if it is higher it will start to fume. Hence thermal analysis is required for the same.

6.1.1 CAD of heating system:

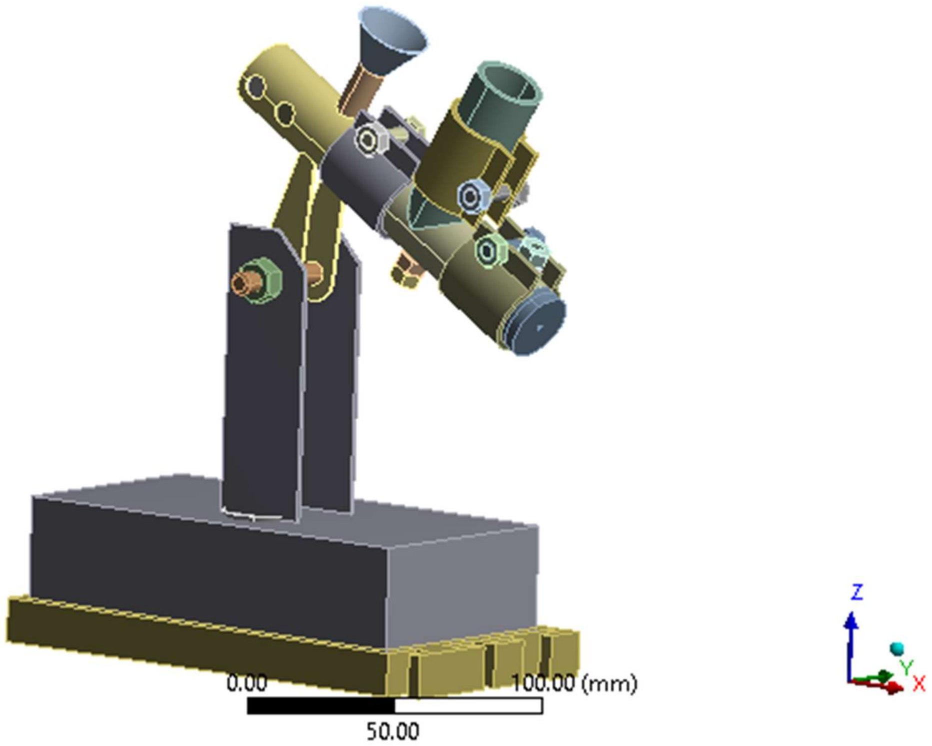


Fig 39: CAD of Heating Module.

This heating system consists of three heaters that are clamped to a one-inch pipe which contains nylon to be melted. From the upper region nylon beads, then these beads are melted and the fibre is passed through it.

The pipe material is stainless steel whereas the polymer inside is nylon 6.

6.1.2 Mesh:

The mesh used was a mix of hex and tetrahedron mesh. Mesh size used is 1mm.

Mesh quality check: quality check is done to ensure that the results obtained can be trusted.

ASPECT RATIO	1.9
SKEWNESS	0.75
No. OF ELEMENTS	50946
No. OF NODES	132556

Table 2: Mesh Specifications of Heating System

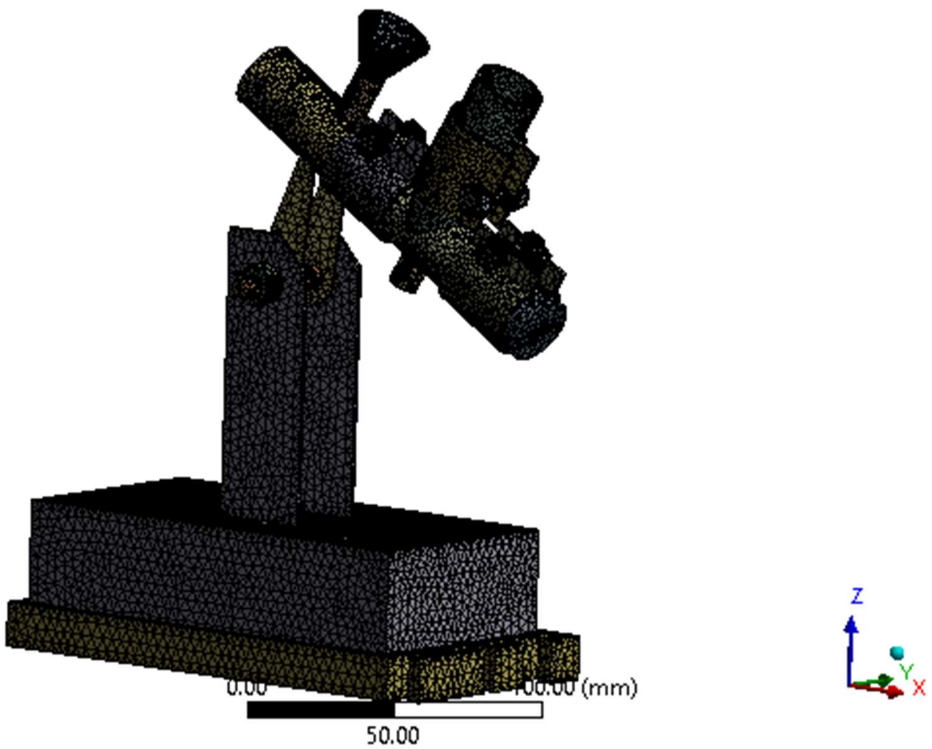


Fig 40: Heating module mesh

6.1.3 Thermal loading conditions:

The three heaters heat up the pipe with a heat flux value of $10W.mm^{-2}$. Also, there are heat losses due to convection considering room temperature is 22°C and coefficient is 1W/mm^2.

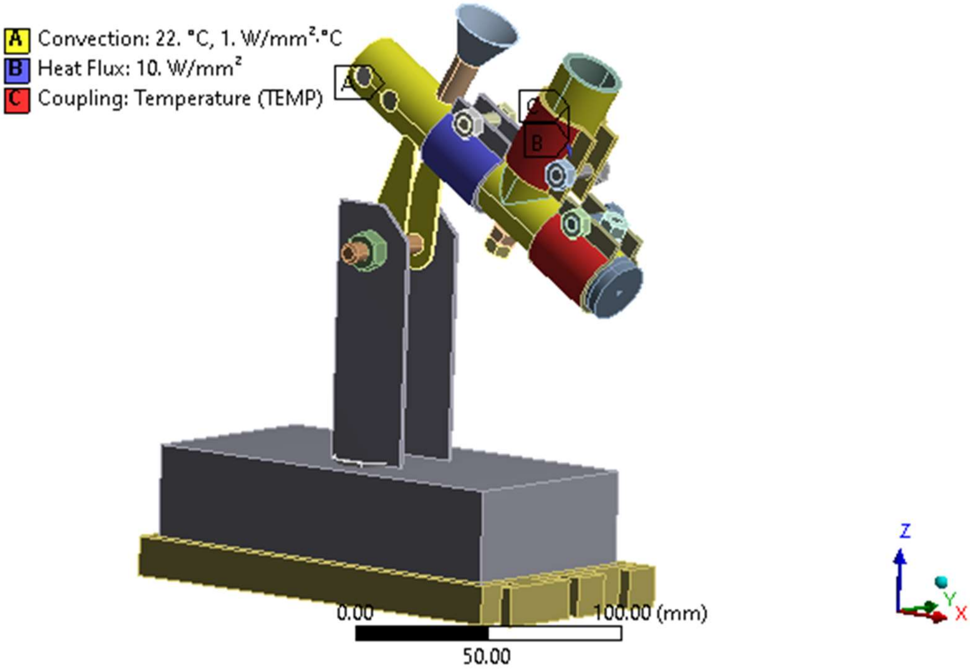


Fig 41:Thermal loading constraints.

6.1.4 Results:

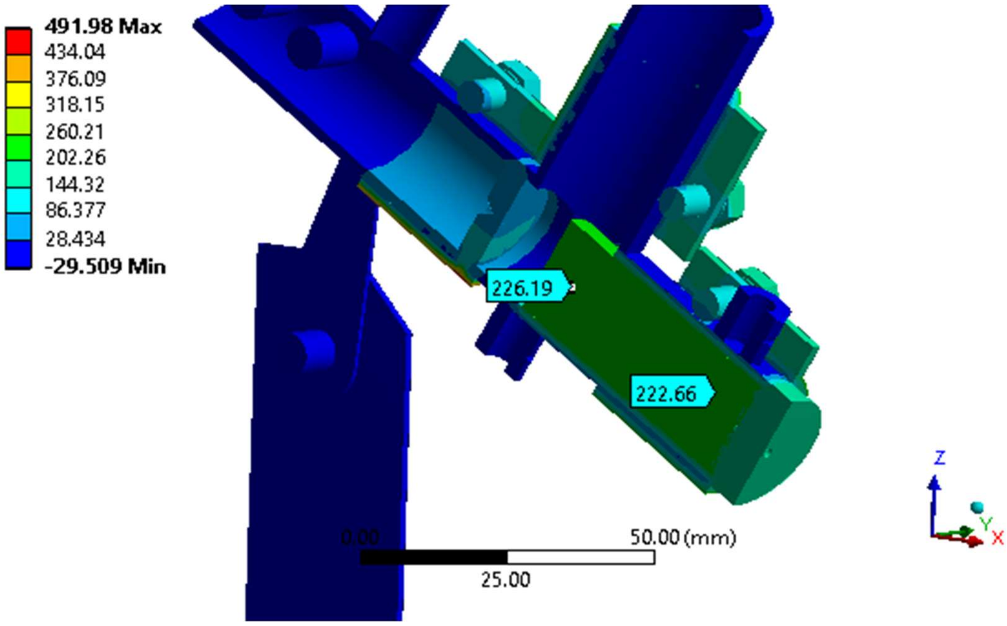


Fig 42: Temperature Gradient of Nylon..

6.1.5 Conclusion:

1. The temperature gradient for nylon is between 2220-230 degrees, therefore nylon is in liquid state but is also not fuming.
2. According to the analysis, the temperature gradient is between 220-230 degrees. This satisfies the requirement.

7. MATLAB-Simulink simulation of the heating module and PID controller:

For finding constants of PID controllers virtual thermal circuits are built in the matlab-simulink. Also this simulation determines time required to reach the required temperature and power requirement.

7.1 Thermal Circuit:

In the Simulink complete thermal circuit is built with a PID controller, for that the target temperature is kept 270^0C which is 543 K is given as constant in the below block diagram. Heater input varies between 0 W to 400W according to PID input.

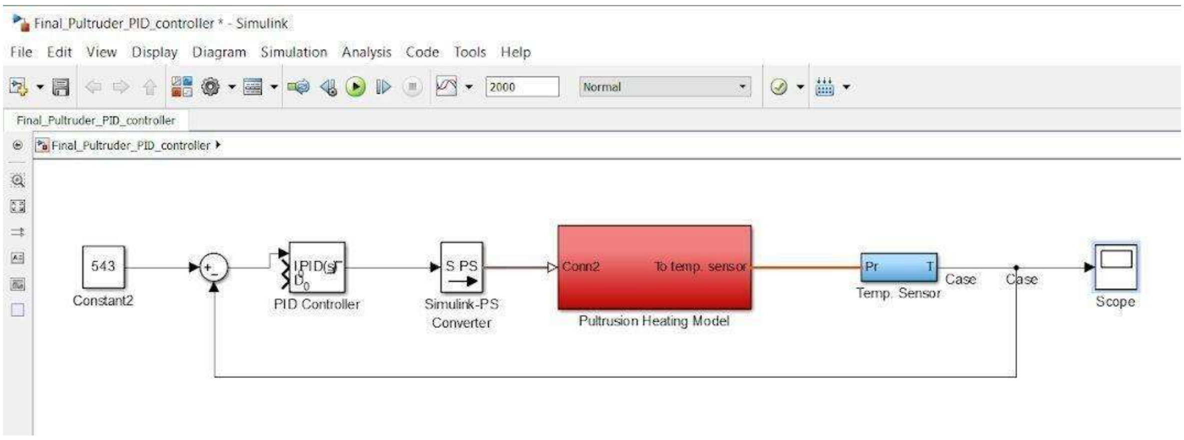


Fig 44: MATLAB feedback loop of PID controller.

As shown in the thermal circuit below two thermal masses were considered: one is mass of the iron pipe in which heating is done and 200g mass nylon in the heating module. Furthermore, conductance inside and between the pipe and nylon is considered. In the end loss to the atmosphere is considered to form an opening for the fiber insertion. The temperature of nylon mass is taken out as reading and for the PID feedback loop.

7.2 PID Tuning:

If only a proportional controller is used temperature fluctuates up to ± 20^0C.PID constants were tuned manually up to which fluctuation stops and the temperature is constant over time. Melting temperature reaches after 800s.

PID constants are,

$K_p = 200$,

$K_i = 1.2$,

$K_d = 0.2$.

7.3 Results:

Graph of temperature vs time is plotted as shown below.

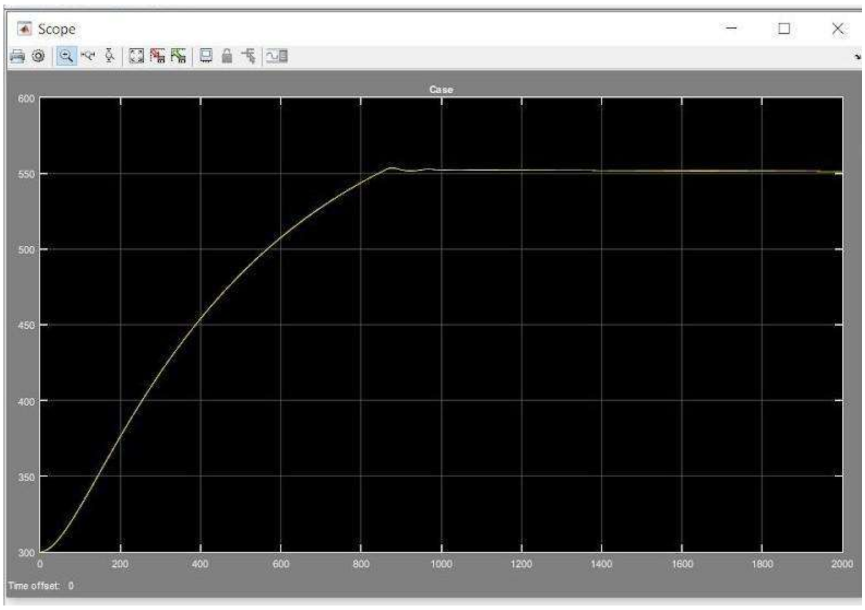


Fig 45: Simulated temperature reading of nylon inside heating module vs time(s).

7.4 Conclusion:

1. 400 W of heater power is required considering energy loss to the atmosphere.
2. The temperature reaches to 270^0C in around 800s.
3. PID constants are determined which are K_p =200, K_i =1.2, K_d =0.2.

8. 3D printing nozzle:

The nylon and fiber filament enters the nozzle at a temperature of 300°C which is ideal for 3D printing. Thermal analysis of the nozzle is done so as to check whether it is not losing that temperature to the environment due to losses.

8.1 CAD of 3D printing nozzle:

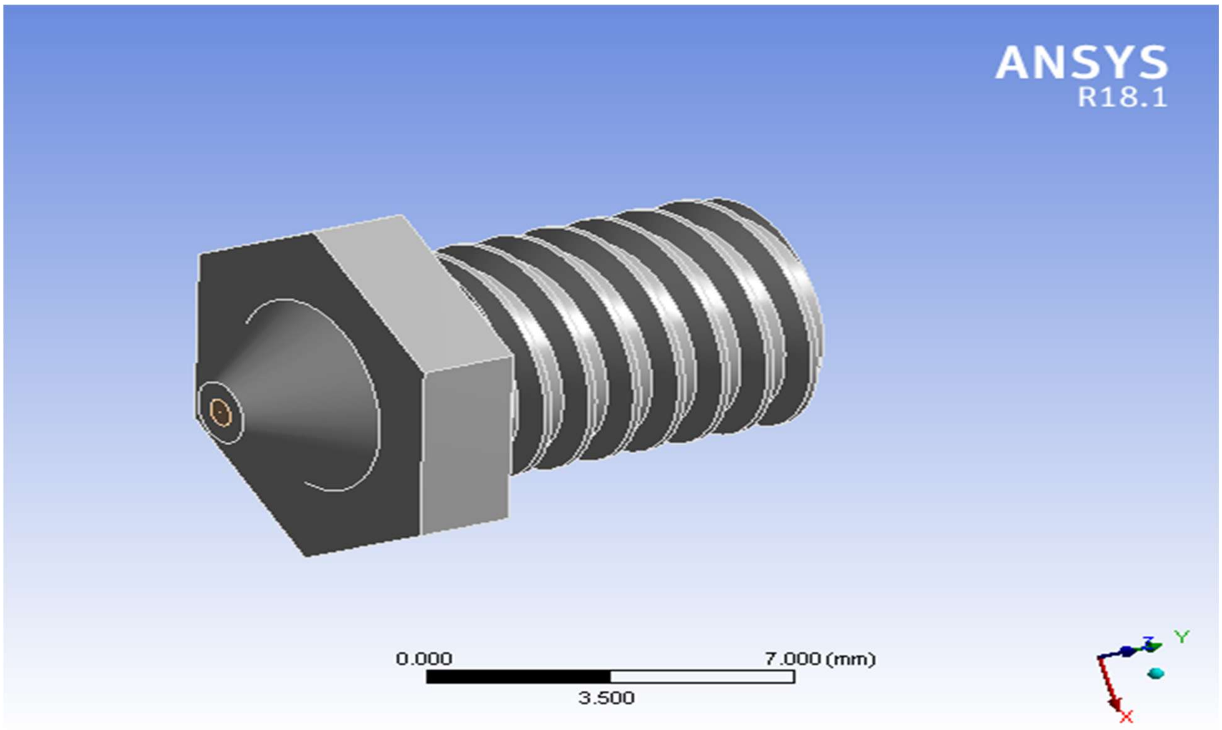


Fig 46: 3D Printing Nozzle

The nozzle contains threads which are used to thread in the nozzle. Nozzle contains a hole through which the filament passes for 3D printing.

8.2 Mesh:

The mesh used was a mix of hex and tetrahedron mesh. The Mesh size used is 1mm.

Mesh quality check: quality check is done to ensure that the results obtained can be trusted.

ASPECT RATIO	1.127
SKEWNESS	0.7
No. OF ELEMENTS	5877
No. OF NODES	16982

Table 4.2 Mesh Specification for Nozzle

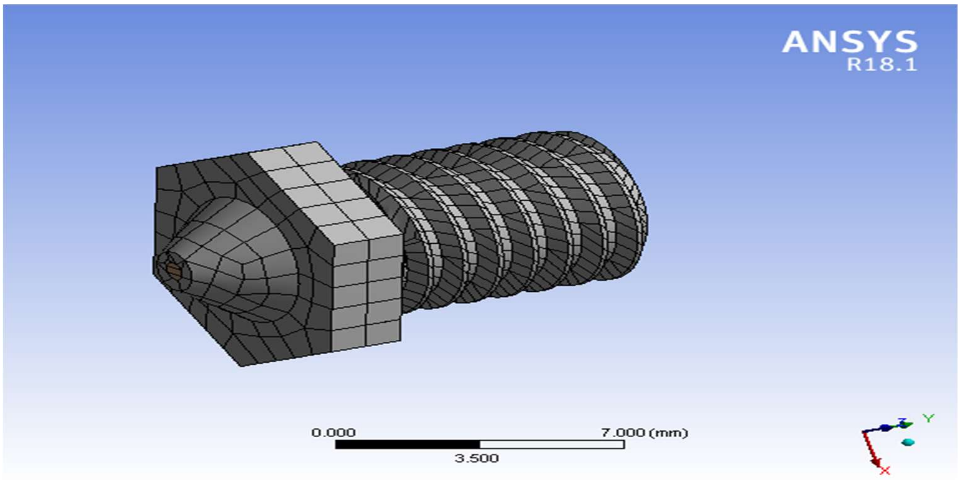


Fig 47: Mesh Illustration for Nozzle

8.3 Thermal loading constraints:
The thermal constraints are:

1. The temperature of a filament of 300°C
2. There are losses due to radiation with an emissivity of 0.8.

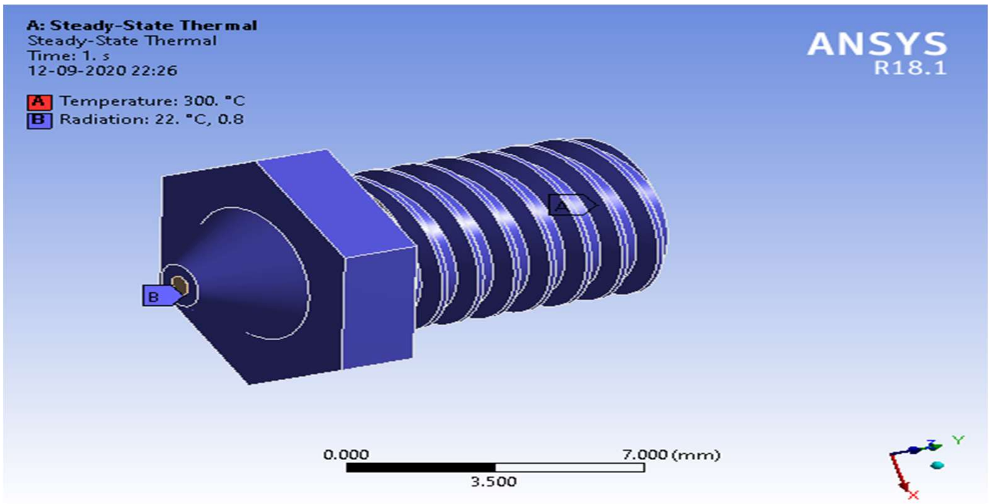


Fig 48: Thermal loading constraints for Nozzle

8.4 Thermal results:

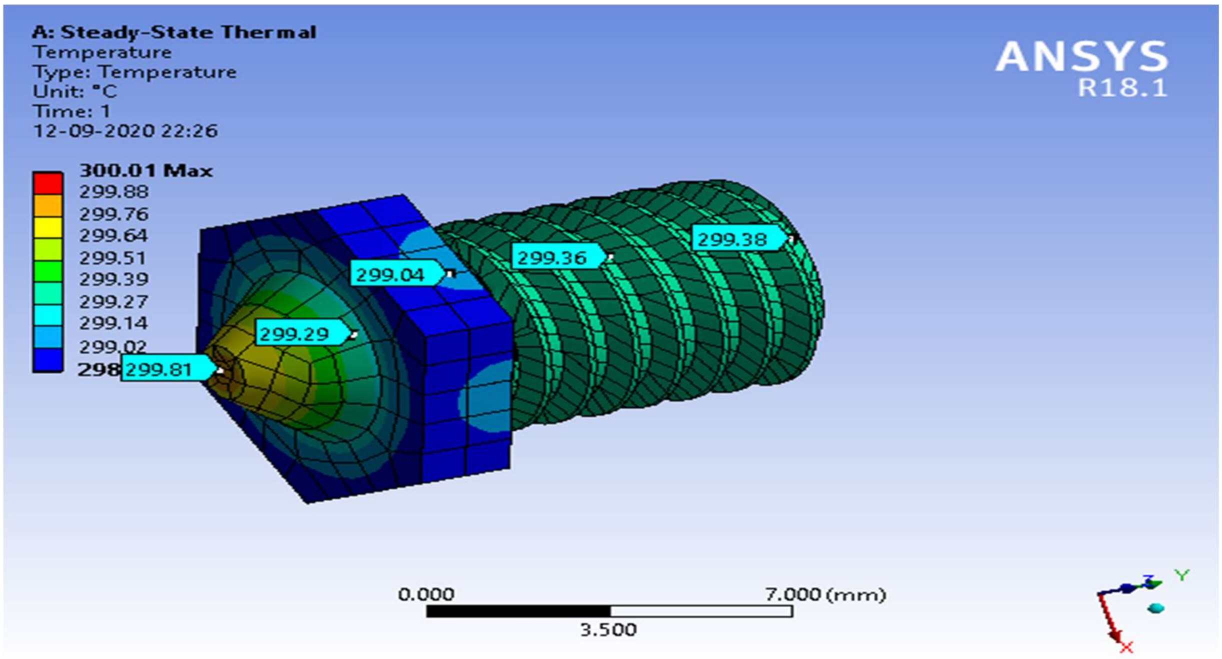


Fig 49: Thermal Results for Nozzle

The temperature is maintained at around 300°C throughout the nozzle.

8.5 The conclusion from Thermal Analysis of Nozzle:

The filament temperature is maintained around 300°C which is ideal for 3D printing of the filament

9. 3D printer:

Initial design stage of manufactured filament compatible 3D printer.

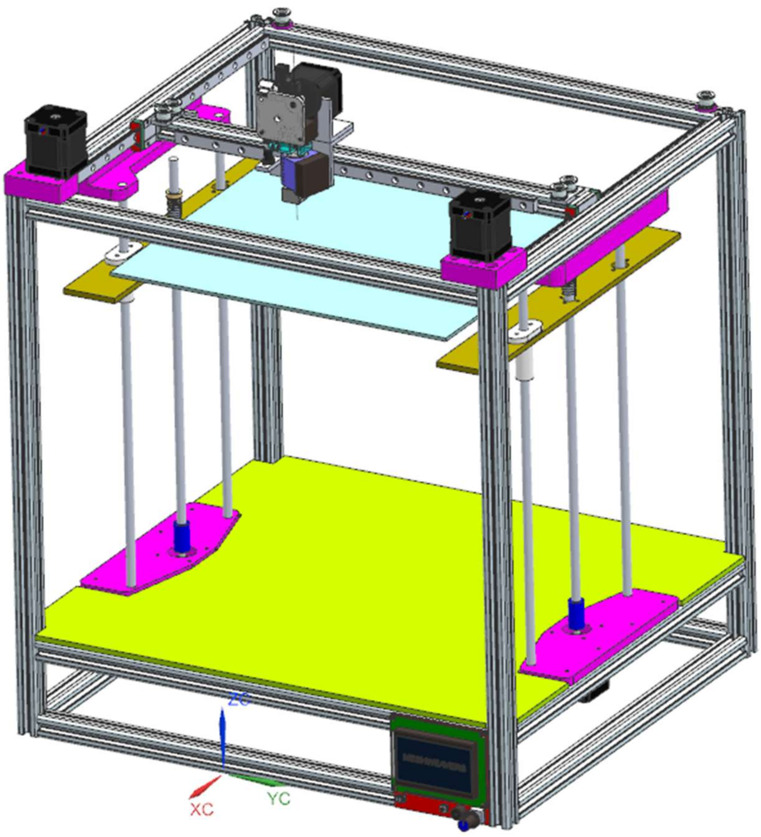


Fig 50: Initial design of 3d printer

.
The second iteration of 3D printers consists of dual nozzles to print manufactured filament for strength and nylon from others for surface finish. Filament used and nylon are hydrophilic hence it requires a drybox for long printing sessions. The printer consists of two supporting rails for support and timing belts for bed movement.

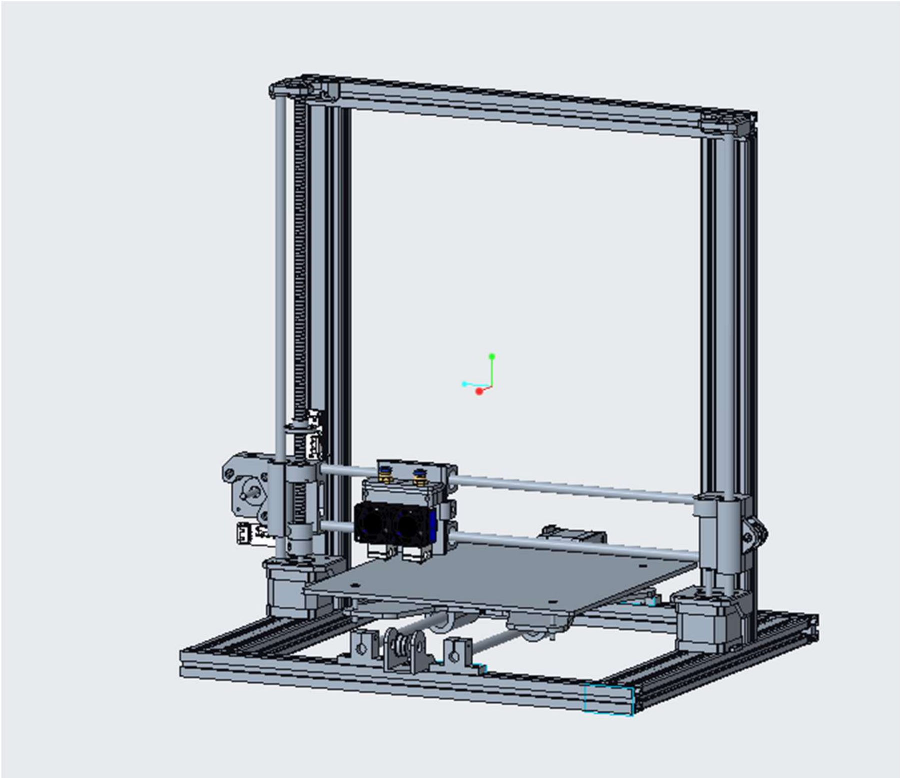


Fig 51: Cad model of 3D printer

After deciding manufacturing feasibility we fixed single horizontal beam design. Afterwards we designed all the supporting parts and procured the OEM parts required for the printer. Mounting components were designed according to OEM parts and 3D printed from manufacturers.

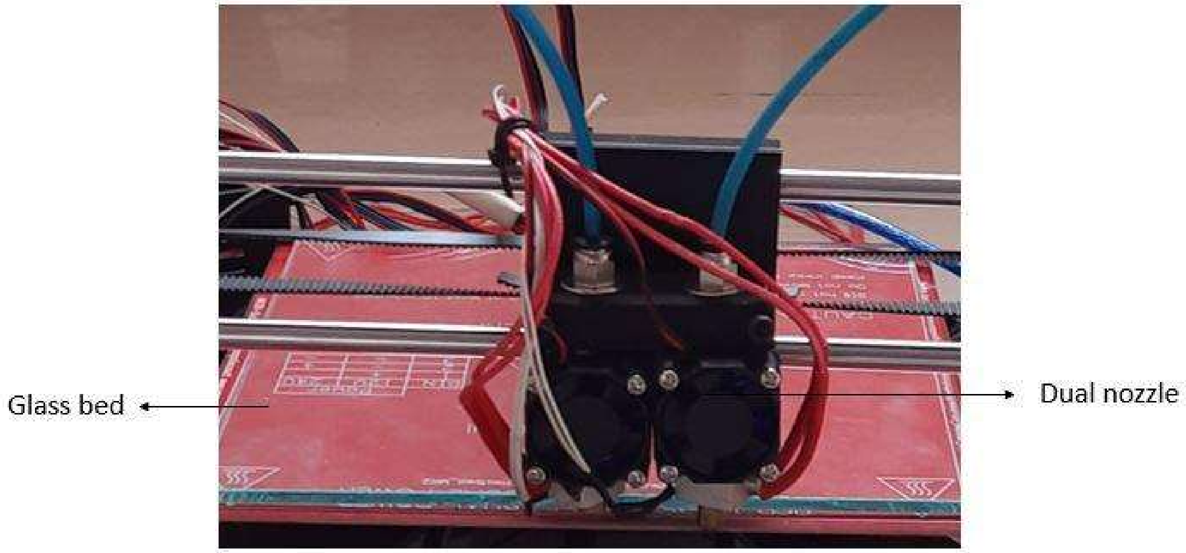


Fig 52: Printer modifications

The modifications used to make manufactured filament compatible 3D printer:

1. Dual Nozzle: Dual nozzle is used to print required components, one fiber prints manufactured filament for strength of a component. The second fiber prints nylon for external surface finish.
2. Bed Material: The bed material used to manufacture continuous fiber 3D printed components is glass. This was done as glass is compatible for printing of nylon components.
3. Linear bearings: Currently 3D printers use rollers which were replaced by linear bearings to achieve accurate printing.

9.1 Manufacturing process of 3D printer:

Fig 53: Printer support rail

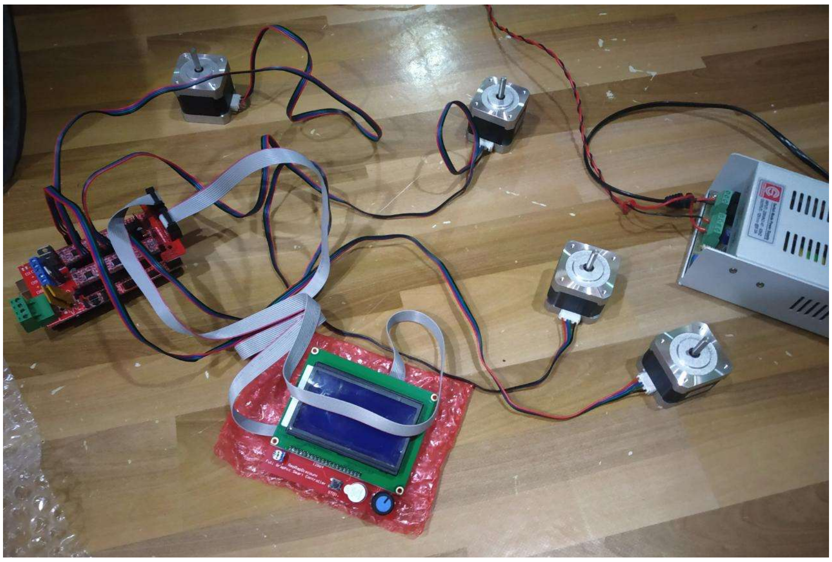


Fig 54: 3D printer electronics

To create a stl file for the printer Ultimaker Cura software.

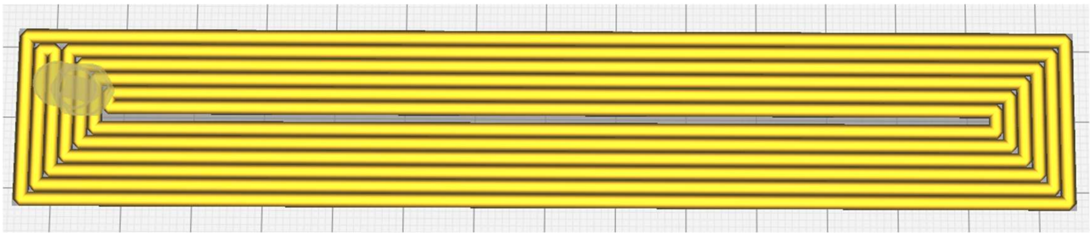


Fig 55: Ultimaker cura component visualization

Fig 56: Final printed product

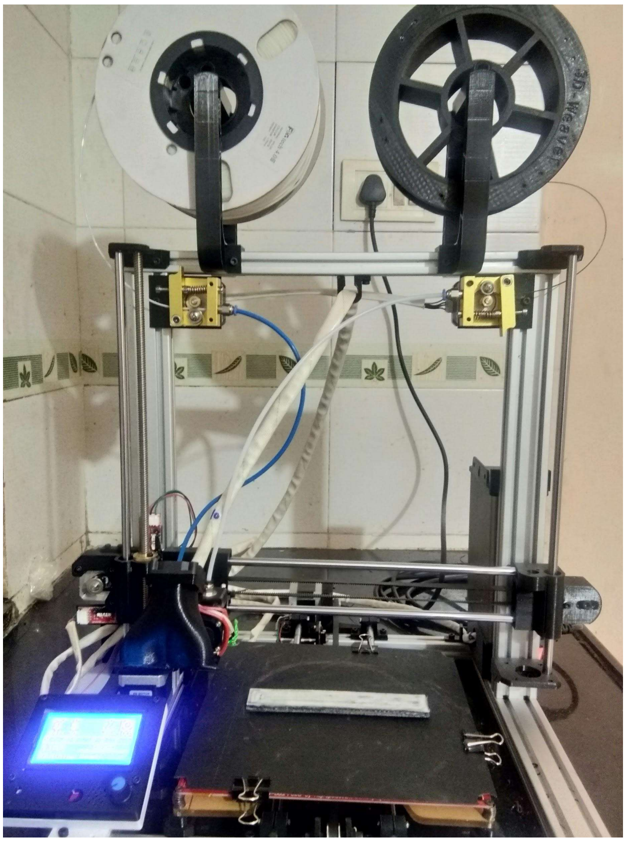


Fig 55: Final printer

9.2 Results and Impact on current industry:

A prototype was printed to be tested; this was done to find the specific strength.

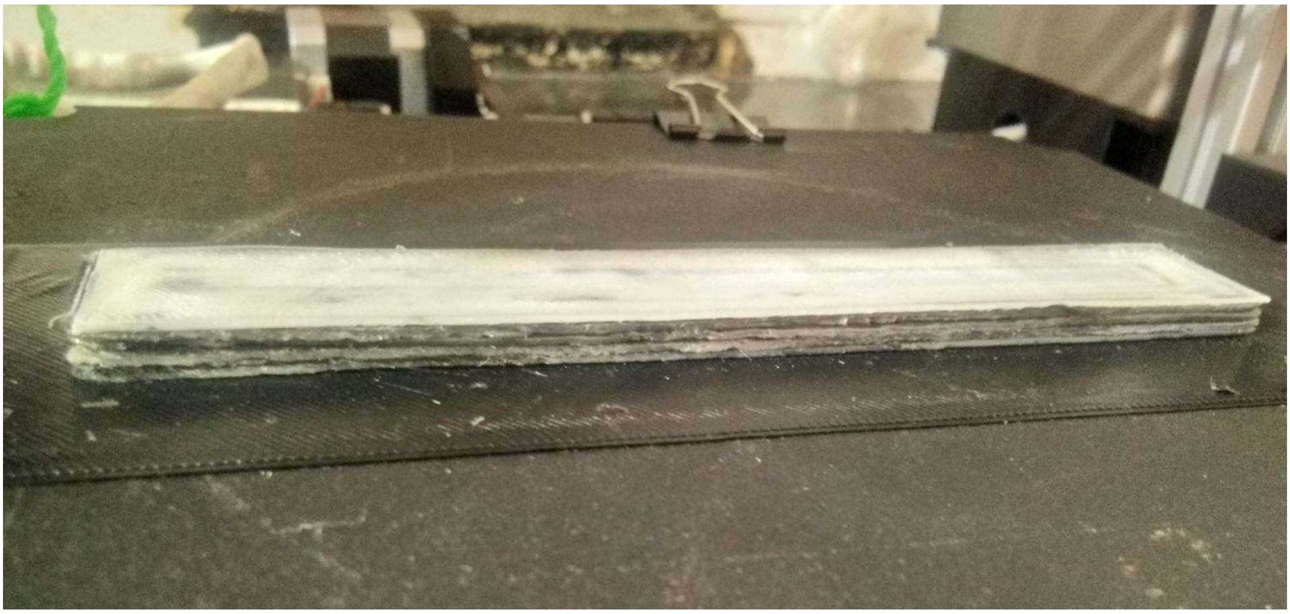


Fig 56: Printed component

This was put on UTM to perform destructive tensile strength tests.

Fig 57: Destructible tensile strength

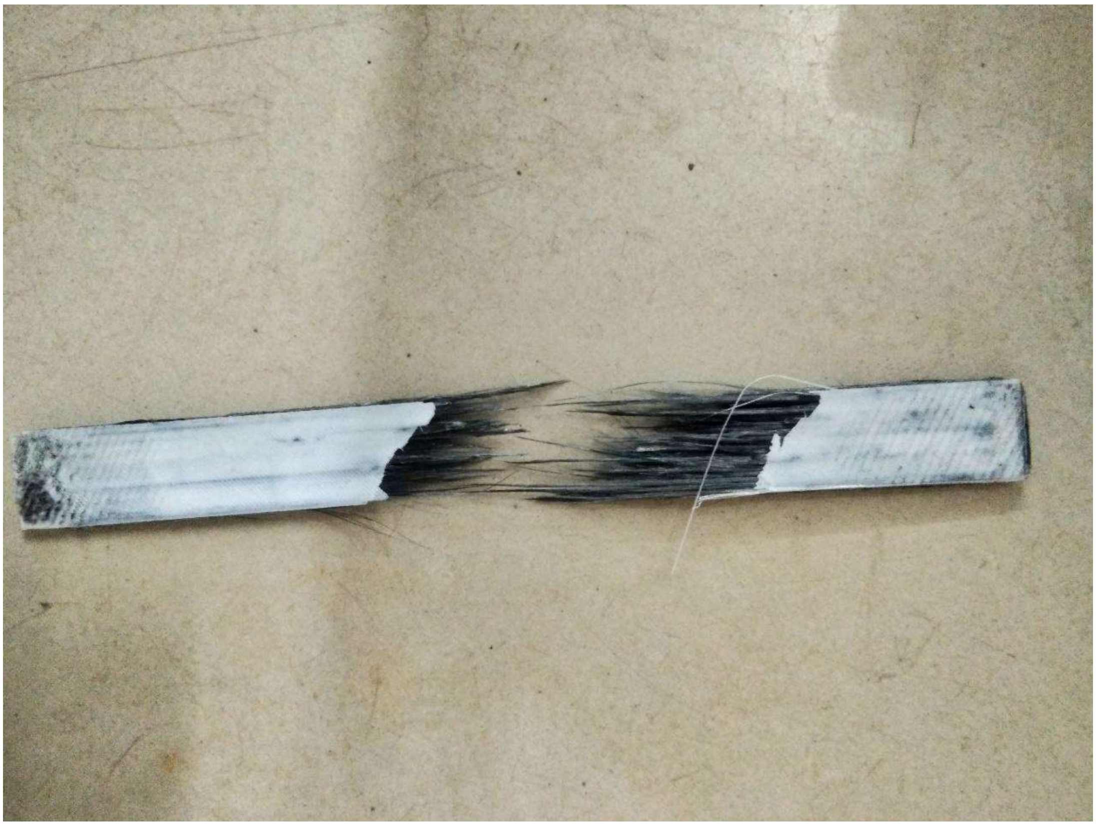


Fig 58: Tested component

9.3 Result:

TEST CERTIFICATE

Date : 31-01-2021

NDT METAL SOLUTION LABORATORY

PIMPRI PUNE-411018

To / Dept.	: PCCOE AKURDI
Address	: AKURDI PUNE
sample Identification	: NO30A2001-TEAM 3-D PRINTING
Part description	:
Part Number	:
Machine	: Universal Testing Machine , 600 kN

Input Data

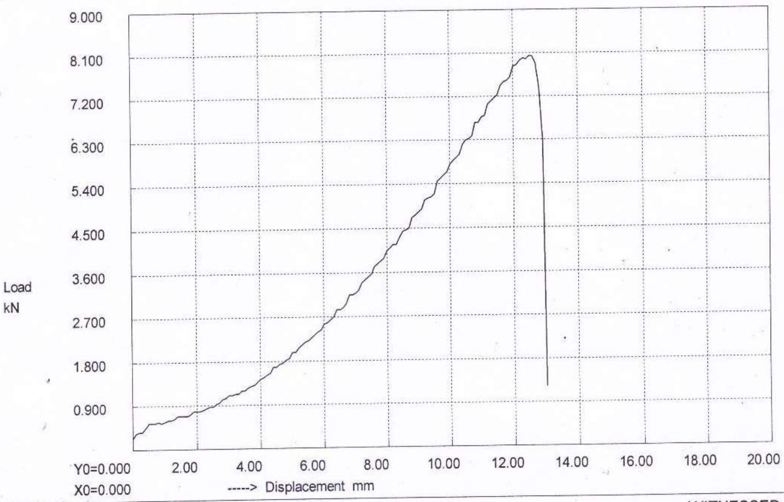
File Name : NO30A2001
Sample Type : Rectangular Bar
Width : 24 mm
Gauge Length : 0 mm

Record No. : 1
Area : 120.000 mm ²
Thickness : 5 mm

Results of Tension Test

Maximum Force (Fm)	: 8.040 kN
Disp. at Fm	: 12.400 mm
Max. Disp.	: 13.000 mm
Tensile strength (Rm)	: 67.000 MPa

Graph : Load Vs Displacement



TESTED BY

INSPECTED BY

WITNESSED BY

ndt metal solution laboratory Pimpri Pune-18

Fig 59: Test report

The printed part which was tested for the tensile test failed at 67 MPa. The dimension of printed part was 147 * 24 * 5. The weight of the part was 17gm. The specific strength of this continuous carbon fiber 3D printed part is 69.57 x 10^3 N.m/kg. The specific strength of mild steel is 44.58 x 10^3 Nm/kg. This proves that the manufactured component has a higher specific strength than mild steel which is widely used in industrial components.

9.4 Environmental Impact:

The use of carbon-fibre parts in various sectors has a great and long time effect on the environment. The greatest advantage of being resistant to rust and corrosion makes CF parts the best choice for parts to be used for long terms, over steel which requires frequent replacement to the effect of atmosphere.

Automotive Sector:

The greatest impact CFRP has made on the automotive sector is the reduction in kerb weight of the vehicle, increasing its fuel efficiency, which in turn helps reduce the carbon footprint. Approximately, 12% of the parts in the automotive sector can be replaced by CFRP. This includes: closures like, doors, lift-gates, hoods; seats, crash safety parts, structural components of the chassis.

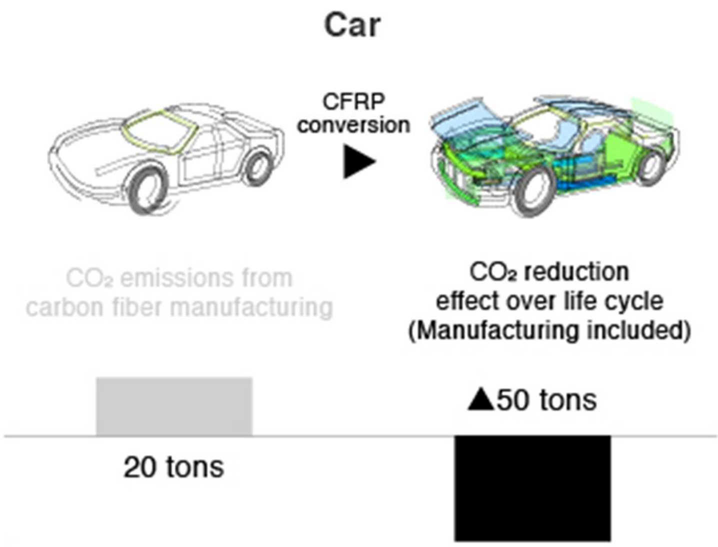


Fig 60: Environmental impact of automotive sector

Reference: Carbon Fiber and Global Environment | TORAYCA® | TORAY

Case Study of Formula Student Race car chassis:

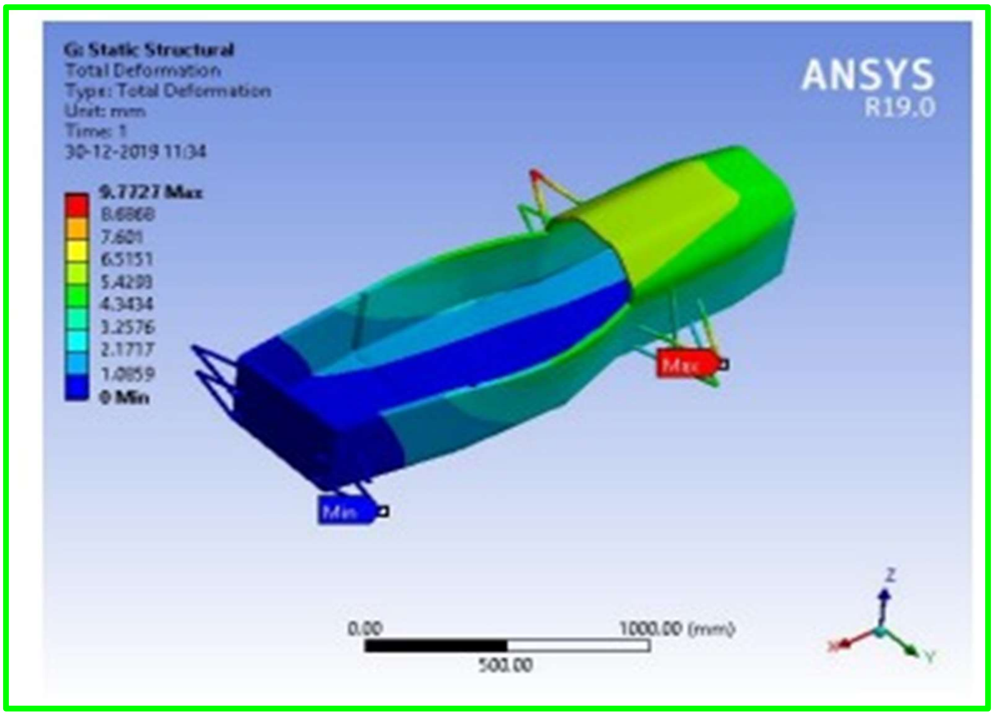


Fig 61: Tubular member Chassis:
Space frame chassis:
weight=42KG

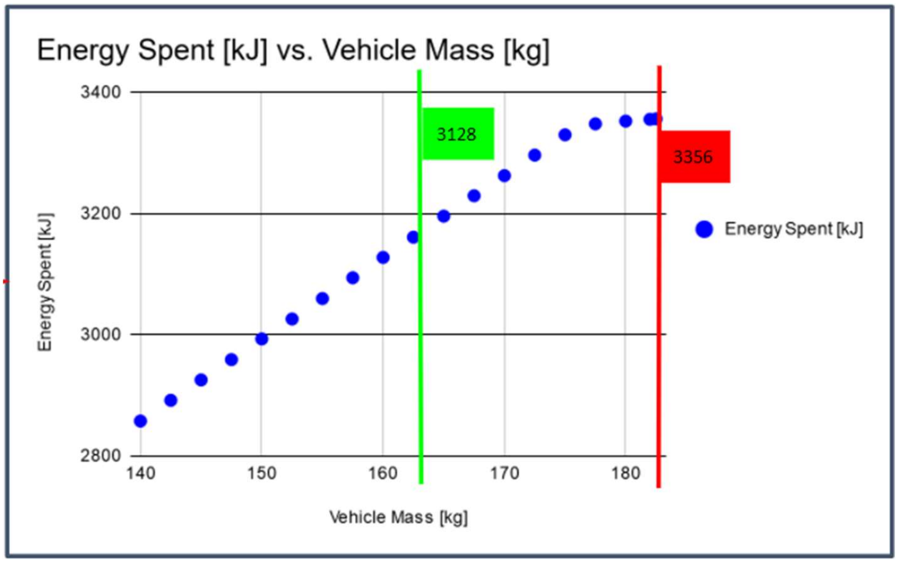


Fig 62: CFRP Monocoque Chassis
weight=20KG

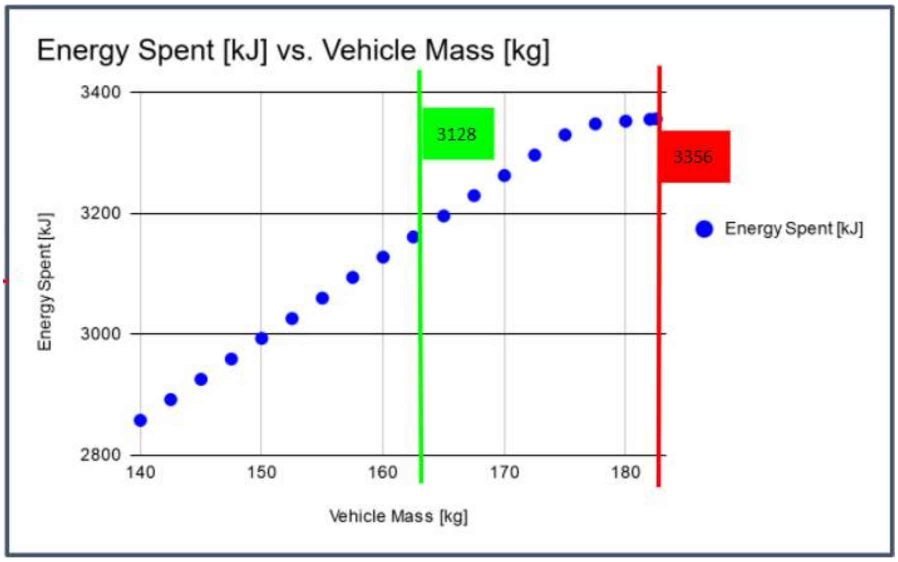


Fig 63: Energy required wrt vehicle mass

Approximately 6.7% of energy is saved by shifting from steel tubular chassis to carbon fibre monocoque chassis.

Aerospace Sector:

This sector has the highest percentage of usage of CFRP. It accounts for upto 42% of CFRP part replacement against the conventional materials. The parts that are replaced include: few parts of the main airframe, sections of wings and tails, fuselage, flaperons and rudder, aircraft seat components.

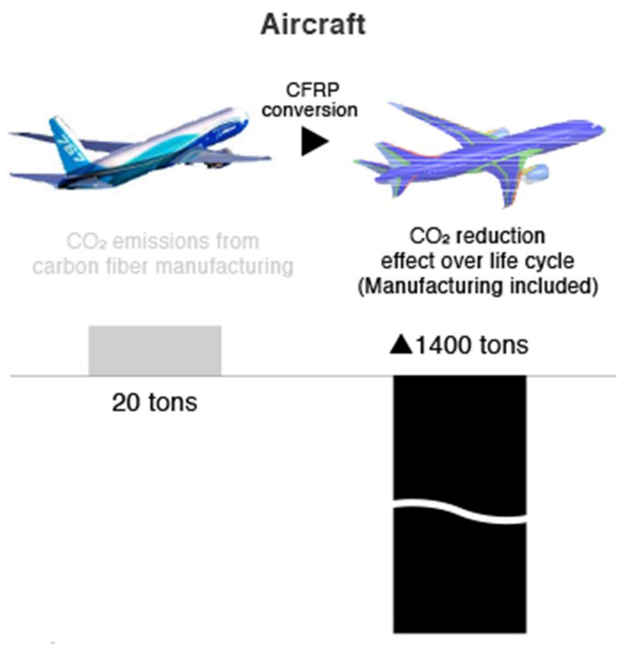


Fig 64: Environmental Impact of aircraft

Reference: [Carbon Fiber and Global Environment | TORAYCA® | TORAY]

If passenger cars (42 million vehicles owned, excluding light automobiles) and passenger aircraft (430 planes owned) in Japan adopt carbon fiber to reduce weight and therefore improve fuel economy, 22 million tons of CO2 will be saved. This corresponds to approx. 1.5% of total CO2 emissions in Japan in 2006 (1.3 billion tons), which clearly shows why this cutting-edge material is a "trump card" in reducing CO2 and contributing to the global environment.

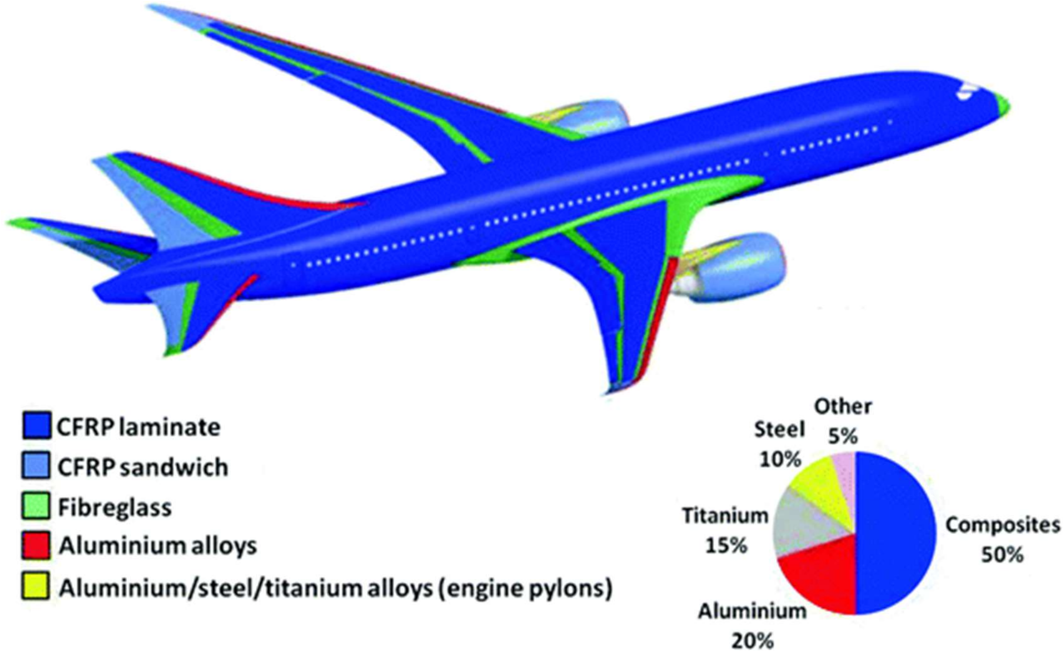


Fig 65: CFRP solution applied in Boeing 787

Sports and Medical goods:

These sectors comprise 5% and 2% of CFRP usage respectively. The sports goods include cricket bat springs, skis, shinty sticks, and it should not be too long before the racing bicycle, vaulting pole, javelin and ski stick benefit from a redesign in CFRP. The deepest penetration of carbon fiber in sports equipment can be seen in tennis rackets. Players can hit faster balls with the lighter racket and control the ball better with the larger area of the racket.

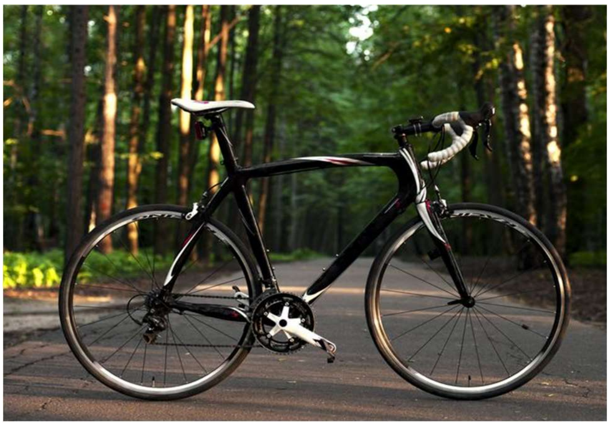


Fig 66: Competitive sports equipment

Fig 67: Competitive sports equipment

In the medical field, Carbon fiber offers several advantages over other materials in the medical field, including the fact that it is ‘radiolucent’ – transparent to X-rays and shows as black on X-ray images. It is used widely in imaging equipment structures to support limbs being X-rayed or treated with radiation. The use of carbon fiber to strengthen damaged cruciate ligaments in the knee is being researched, but probably the most well-known medical use is that of prosthetics – artificial limbs.

Military and Defense:

The applications in the military are very wide-ranging – from planes and missiles to protective helmets, providing strengthening and weight reduction across all military equipment. It takes energy to move weight – whether it is a soldier's personal gear or a field hospital, and weight saved means more weight moved per gallon of gas. Also, it is used in many impact resistant applications.

Other:

Other sectors where CFRP plays a major role is the wind energy sector. It consists of 29% use of CFRP parts. This reduces the energy footprint of this source of energy over years of use due to longer life of parts. The remaining applications include gas and pressure vessels, making material handling efficient.

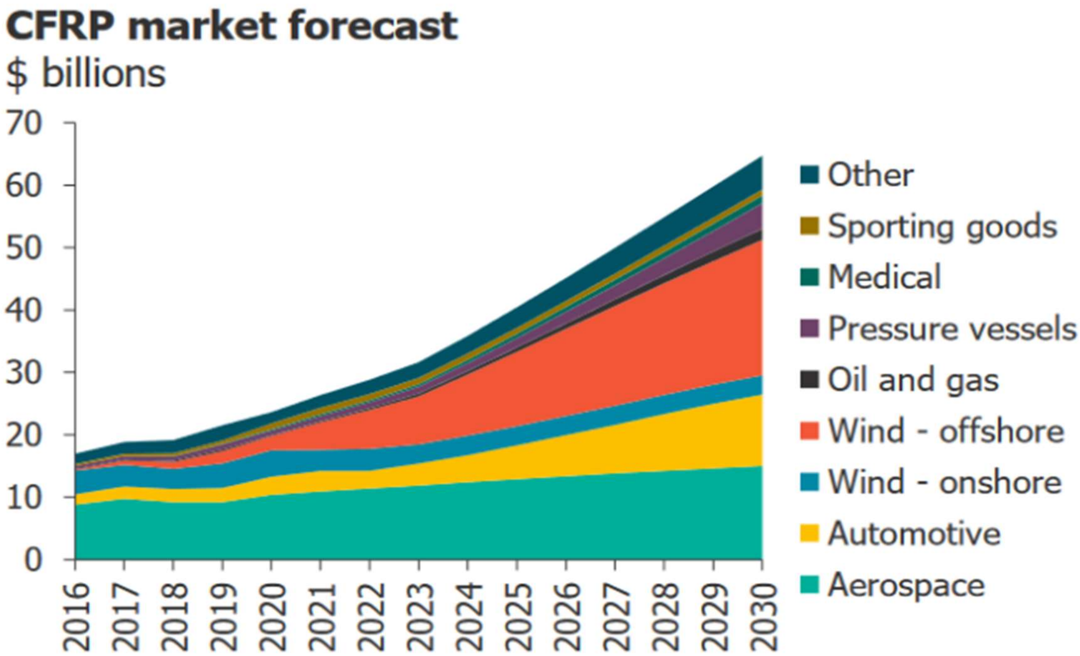


Fig 68: CFRP market forecast

10. Pultrusion Setup Cost:

Provisional Cost						
Sr .No		Item	Cost per Unit	Quantity	Unit	Total Cost of Items
1	Pultrusion Mechanical Line	Nozzle Heater(42mm)	150	4	unit	600
2		Nozzle Heater(24mm)	100	4	unit	400
3		Steel Axle(10mm)	200	1.5	m	300
4		Ball Bearings (10mm)	30	10	unit	300
5		Iron T joint(ID 1.75 inch)	100	2	unit	200
6		Iron Threaded Pipe(ID 1.75 inch)	75	4	unit	300
7		Threaded End Joint (1.75 inch)	50	3	unit	150
8		MS pipe (24mmx22mm)	40	1	ft	40
9		POP	30	1	Kg	30
10		Cement	20	1	Kg	20
11		V6 Nozzle 0.2 to 1mm with Cleaning kit	699	1	set	699
12		Heating Cartage	150	1	unit	150
13		J head Hot end Extruder	585	1	unit	585
14		3D printed Parts	2000	0.15	Kg	300
15		Machining Cost	400	1	unit	400
16		PVC pipe and bend joints	300	1	m	400
17	Temperature and Speed Controller	MAX 6675 and K Thermocouple	365	1	unit	365
18		MAX 6675 and K Thermocouple	808	1	unit	808
19		Electronic Components (Temperature Controller)	1100	1	unit	1100
20		Arduino UNO	259	3	unit	777
21		Motor Controller	600	1	unit	600
22		Stepper Motor Driver A4988	95	2	unit	190
23		Stepper Motor	450	1	unit	450
24		DC motor	272.5	2	unit	545
25	Consumable Materials	Glass Fiber	380	4	m^2	1520
26		PLA filament	51.8	5	m	259

27		ABS filament	12.7	30	m	381
28		Nylon 6 Plastic	210	2	Kg	420
29		Nylon Filament	2400	1	Kg	2400
30		3K Carbon Fiber Tow	14050	1	Kg	14050
		Total Provisional Cost				28739
		Total Estimeted Cost of Pultrusion				30041

11. Time Planning:

MANUFACTURING OF NYLON EMBEDDED CONTINUOUS CARBON FIBER FILAMENT											
WBS NUMBER	TASK TITLE	AUG	SEP	OCT	NOV	DEC	JAN	NOV	DEC	JAN	FEB
1	**Project Conception and Initiation**										
1.1	Project Charter										
1.2	Literature Review										
2	**Market Research**										
2.1	Project Initiation										
3	**Project Design and Planning**										
3.1	Scope and Goal Setting										
3.2	Budget										
4	**Prototype Manufacturing and Testing**										
4.1	Design Stage I										
4.2	Manufacturing Stage I										
4.3	Testing Stage I										
4.4	Design & Manufacturing Stage II										
4.5	Testing Phase II										
5	**Final prototype and testing**										
5.1	Final Design & It's Manufacturing										
5.2	Testing of the Final design										
6	**Documentation**										
6.1	Design report										
6.2	Presentation and Video preparation										

12. References

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