Brief Report

Design and Development of Portable ABS Filament Extruder for Desktop FDM Applications.

Harshal Pakhare [1] and Rashid Momin[2]

[1] Dept. of Mechanical Engineering, Bharati Vidyapeeth College of Engineering; pakharehs2022@gmail.com
[2] Dept. of Production Engineering, Veermata Jijabai Technological Institute; rashidmomin.2006@gmail.com

Abstract

The rapid adoption of fused deposition modeling has increased the need for affordable and flexible thermoplastic filament production systems, particularly for small-scale users, educational laboratories, and research environments. This study presents the design, fabrication, and experimental evaluation of a low-cost, portable ABS filament extruder intended for laboratory-scale filament production. The system is based on a single-screw extrusion mechanism driven by a NEMA 23 stepper motor, with thermal regulation achieved through PID-controlled band heaters and an air-based cooling strategy to reduce thermal shock–induced brittleness in ABS. Design calculations were performed to estimate material feed rate, screw rotational speed, torque requirements, and heating power demand. The fabricated prototype operates within a temperature range of 300–450 °C and achieves a steady-state material throughput of approximately 11 g/min under stable operating conditions. Experimental extrusion trials indicate continuous filament formation with acceptable dimensional stability after thermal equilibrium is established. The total system cost is approximately INR 20,000, corresponding to a cost reduction of about 50–60% relative to commercially available desktop filament extruders. The proposed system demonstrates the feasibility of low-cost filament extrusion and provides a basis for future work on closed-loop diameter control and multi-material extrusion.

Keywords: *ABS; filament extrusion; FDM; desktop extruder; polymer processing; low-cost manufacturing.*

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1. Introduction

Additive manufacturing, commonly referred to as 3D printing, has significantly transformed modern prototyping and small-scale production by enabling the fabrication of complex geometries with reduced material waste and shorter development cycles. Among the various additive manufacturing techniques, fused deposition modelling (FDM) remains the most widely adopted due to its relatively low cost, material versatility, and operational simplicity [1]. In FDM, thermoplastic filaments such as acrylonitrile butadiene styrene (ABS) are heated beyond their glass transition temperature and extruded through a nozzle to build components layer by layer [2]. The dimensional accuracy, mechanical performance, and surface quality of printed parts are strongly dependent on the consistency and quality of the filament used.

Conventionally, thermoplastic filaments are produced through industrial-scale extrusion processes involving controlled melting, extrusion, cooling, and spooling of polymer feedstock. While these systems ensure high throughput and dimensional precision, they are capital-intensive and unsuitable for small-scale users, educational laboratories, or research environments. In recent years, interest has grown in developing compact and portable filament extruders that allow end users to manufacture filaments from raw polymer pellets, thereby reducing material costs and enabling greater control over filament properties [3,4].

Despite their potential advantages, small-scale filament extrusion systems face several technical challenges that directly affect filament quality and process stability. Variations in extrusion temperature, screw speed, and cooling conditions can lead to inconsistent filament diameter, which adversely impacts print reliability. Accurate thermal control is particularly critical for ABS, as deviations from optimal processing temperatures can result in under-extrusion, overheating, or material degradation. Additional challenges include screw clogging due to material impurities or prolonged thermal exposure, insufficient torque delivery from the drive motor leading to irregular material flow, and improper cooling that can induce residual stresses or filament deformation before winding. Furthermore, sustained high-temperature operation introduces mechanical wear in critical components such as the screw, barrel, and nozzle, necessitating appropriate material selection for durability [5,6].

With the continued expansion of FDM-based applications, the demand for cost-effective and reliable filament production solutions has increased. Commercial filaments remain relatively expensive and may exhibit batch-to-batch variability, which can compromise print quality and process efficiency. In this context, a portable ABS filament extruder represents a practical and economical alternative for small-scale filament production using raw polymer pellets [7-9]. The present work aims to design, fabricate, and experimentally evaluate a compact and low-cost ABS filament extruder capable of producing filament with stable extrusion behaviour. The study focuses on mechanical design, thermal management, and motor-driven screw extrusion, demonstrating the feasibility of an accessible system suitable for laboratory and educational use.

2. Literature Review

The technology for making filaments to be used in 3d printing is under advancement and constant development. Effective strategies have been employed since early 90's for better production of the filaments [10]. Through extensive research done around the globe many problems like: Choice of Heating System, Power Transmission, Hopper Design and more were eliminated by using their specific material/component replacements [11].

In order to maximize the accuracy and tolerances this machine still has certain room for replacement or modifications such as [12]: Behavior of raw material (ABS), Effective Cooling Strategy, Power Distribution.

This literature review aims to identify the probable causes and effects associated with the listed modifications by reviewing existing research/industrial research conducted.

2.1 Material Properties

(**Fig. 1** ABS Granules) [13]

Acrylonitrile butadiene styrene (ABS) (chemical formula $(C_8H_8)_x\cdot(C_4H_6)_y\cdot(C_3H_3N)_z$ is a common thermoplastic polymer. Its glass transition temperature is approximately 105 °C (221 °F). ABS is amorphous and therefore has no true melting point. It is a terpolymer made by polymerizing styrene and acrylonitrile in the presence of polybutadiene. The proportions can vary from 15% to 35% acrylonitrile, 5% to 30% butadiene and 40% to 60% styrene. The result is a long chain of polybutadiene crisscrossed with shorter chains of poly(styrene-co-acrylonitrile). The nitrile groups from neighboring chains, being polar, attract each other and bind the chains together, making ABS stronger than pure polystyrene. The acrylonitrile also contributes chemical resistance, fatigue resistance, hardness, and rigidity, while increasing the heat deflection temperature. The styrene gives the plastic a shiny, impervious surface, as well as hardness, rigidity, and improved processing ease. The polybutadiene, a rubbery substance, provides toughness and ductility at low temperatures, at the cost of heat resistance and rigidity. [13-16]

For the majority of applications, ABS can be used between −20 and 80 °C (−4 and 176 °F), as its mechanical properties vary with temperature. The properties are created by rubber toughening, where fine particles of elastomer are distributed throughout the rigid matrix. When extruded into a filament, ABS plastic is a common material used in 3D printers, as it is cheap, strong, has high stability and can be post-processed in various ways (sanding, painting, gluing, filling and chemical smoothing). When being used in a 3D printer, ABS is known to warp due to shrinkage that occurs while cooling during the printing process [17]. The shrinking can be reduced by printing inside an enclosure on a heated print surface, using an adhesive such as a glue stick or hairspray to ensure the first layer of the print is well stuck to the print surface [18], or printing with a brim/raft at the base of the print to help increase adhesion to the print surface. ABS is only used in FFF/FDM 3D printers, as resin 3D printers cannot melt plastic.

Table 1. Mechanical Properties of ABS [15]

Property	Value
Notched IZOD (kJ/m)	0.203
Youngs Modulus (GPa)	2.28
Tensile Strength (MPa)	43
Heat Deflection Temperature (Celsius)	81
Flexural Modulus (GPa)	2.48
Flexural Strength (MPa)	77

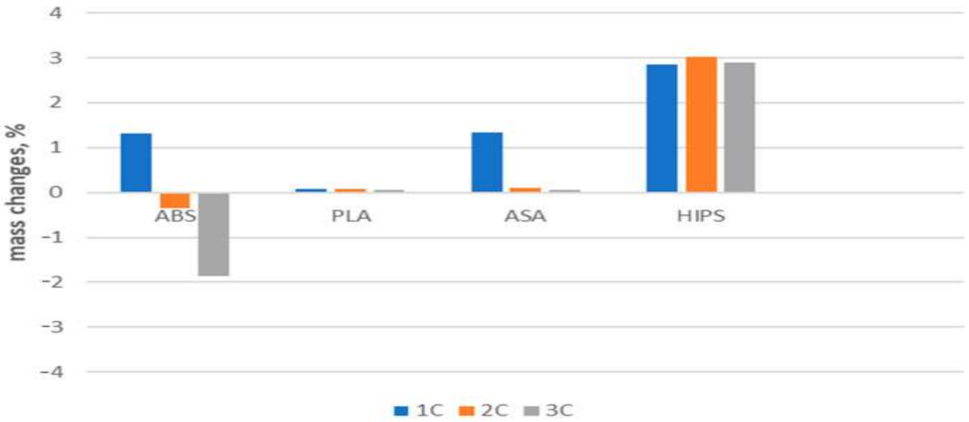
Yellowing in ABS plastic occurs when it is exposed to UV light or excessive heat, which causes photo-oxidation of polymers that breaks polymer chains and causes the plastic to yellow and become brittle [19].

Particular forms of ABS filaments are ABS-ESD (electrostatic discharge) and ABS-FR (fire resistant), which are used in particular for the production of electrostatically sensitive components and refractory prefabricated parts [20].

2.2 Cooling Techniques

The raw material i.e. ABS pellets is heated at or near about its melting temperature. Due to this the state of the pellets change, it transforms into a semi-solid form. This semi-solid material is then passed through a nozzle assembly where it attains its final shape and dimension. For the later stage the filament formed needs to be cooled in order to attain its shape and to reduce the temperature. [14]

From earlier metallurgy principles we know that sudden cooling via water channels may lead to increased brittleness in steel and other materials. As in the case of the project's raw material that is Acrylonitrile Butadiene Styrene (ABS) the material is a polymer and experiences the same phenomenon [21,22]. ABS (Acrylonitrile Butadiene Styrene) is a thermoplastic polymer known for its toughness and impact resistance. However, like many polymers, it can be susceptible to cracking under certain conditions, especially when subjected to thermal shock [23]



(**Fig. 2** Changes in mass of sample after successive cycles) [24]

Thermal shock occurs when the material experiences drastic change in temperature which leads to significant property change and demerits.

1. Rapid Temperature Change:
   - Thermal shock occurs when ABS is suddenly exposed to a drastic temperature change, such as being rapidly cooled in water after being at a high temperature.
   - ABS has a relatively low thermal conductivity, meaning it doesn't quickly equalize temperature across its entire volume. When exposed to sudden cooling, the outer surface of the material cools and contracts much faster than the interior [25].
2. Thermal Stress Development:
   - The rapid cooling of the outer layer leads to uneven contraction between the surface and the core of the ABS material.
   - Internal stress develops as the cooler, contracting outer layer tries to pull against the warmer, still-expanded inner layer. This difference in contraction rates creates tensile stress on the surface of the material.
   - Since ABS is a brittle material at lower temperatures, it cannot absorb or redistribute these stresses easily, making it more prone to cracking [14].
3. Crack Initiation and Propagation:
   - The tensile stress can lead to the formation of microcracks on the surface of the ABS. If the thermal shock is severe or repetitive, these microcracks can grow.
   - Once initiated, these cracks can propagate through the material, especially if the thermal cycling (repeated heating and cooling) continues, or if the material is subjected to mechanical stresses while cooling [27].
4. Water’s Role:
   - Water cooling exacerbates this problem because it provides a rapid and effective heat sink, increasing the rate of cooling and thus the severity of the thermal shock.
   - Additionally, water may seep into any existing microcracks or surface imperfections, causing further stress through processes like hydrostatic pressure buildup or freeze-thaw cycles (if the temperature is near freezing) [2].
5. Material Brittleness:
   - ABS can become more brittle at lower temperatures. As it cools rapidly, the ductility of the material decreases, making it less capable of withstanding the internal stresses caused by thermal shock, which increases the likelihood of crack formation. [13]

In summary, ABS cracks under thermal shock during water cooling due to the rapid and uneven temperature change, which induces internal stresses that the material cannot withstand, especially when it becomes more brittle at lower temperatures. This leads to the initiation and propagation of cracks. Gradual cooling stages using air only via electric fans after filament is extruded from the nozzle to further cool it. This gradualism enhances the control and provides less brittleness issues. [14]

2.3 Power Distribution

Every machine used for machining or production requires a stable power distribution to its grid for efficient working. The power required to run each electrical component needs to be stable and consistent [32]. In many existing designs of filament machines, the power input was much higher and, in some cases, unnecessary.

The following steps are included in order to give an effective power distribution system [26,27]:

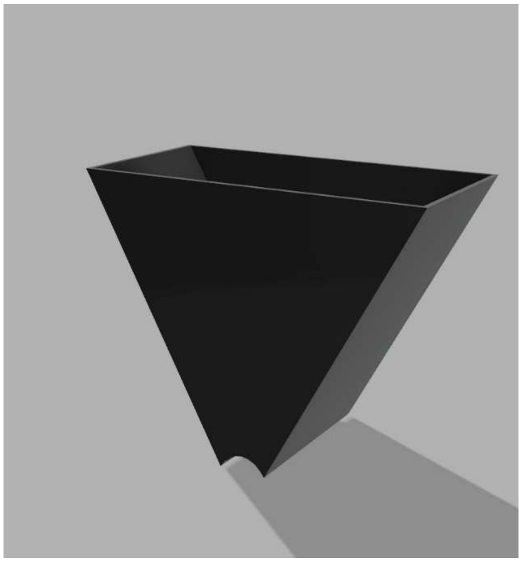
- Connecting the elements on the basis of their input power type. If some components work on Alternating (AC) current then these elements can be grouped together and connected to a single power source. Whereas, for components which work on Direct (DC) current like motors are grouped and provided power from a different source and distributed accordingly.
- In a much-detailed explanation the DC motors responsible for running the extruder screw and winding mechanism are powered separately. But in most cases like this the motor needs to be under a specified limit. The extruder screw motor requires more torque rather than speed for gradual and stable feed.
- Whereas, the winding wheel mechanism requires a motor with moderate speed enough to produce tensile stretch on the filament to wind it properly. In this scenario, instead of 2 different power sources we can distribute the power from a single source amongst these 2 motors at a certain ratio for their working.
- This not only eliminates a whole additional power supply but saves the energy going to waste as we are concerned more about the torque of the spindle rather than high speed.

3. Materials/Components

All component and their respective specifications are listed in this section. Each part has been selected based on mechanical strength, thermal resistance, and operational efficiency to ensure optimal performance and durability.

3.1 Hopper

- Material: Mild Steel (MS)
- Function: The hopper serves as the feeding unit, allowing ABS pellets to enter the extrusion system.
- Design Considerations: The shape and size are optimized to ensure a smooth flow of material without clogging or bridging.
- Bottom sheets were sheared off as per barrel’s outer diameter for proper sealing and seating arrangement.
- MS sheets welded together with 2.4 mm filler rods under controlled parameters.
- Coated with corrosion resistant paint.
- Inner welds were grinded with help of Tyrolt Grinding wheel to produce a uniform texture for minimum surface defects during raw material feed.



(**Fig. 3** Hopper Design).

(**Fig. 4** Barrel)

3.2 Barrel

- Material: Stainless Steel (AISI 304)
- Function: Houses the screw and serves as the primary heating and melting chamber.
- Design Considerations: High thermal conductivity ensures efficient heat transfer.
- Corrosion resistant material grade & polishing prevents contamination of molten polymer.
- Inner diameter (22 mm) and length are designed for optimal melting and extrusion pressure.

3.3 Screw

(**Fig. 5** Screw)

- Material: Stainless Steel (AISI 304)
- Function: Transports, compresses, and melts ABS pellets through the barrel.
- Design Considerations: Optimized screw pitch and flight geometry for uniform material flow.
- High wear resistance to withstand prolonged operation.

3.4 Nozzle

- Material: Stainless Steel (AISI 304)
- Function: Shapes and controls the diameter of the extruded filament (3 mm).
- Design Considerations: Precision-machined to ensure consistent filament dimensions.
- Heat-resistant to maintain flow stability at high temperatures.

3.5 Support

- Material: Mild Steel (MS) Angle Beams
- Function: Provides structural integrity and stability to the extruder assembly.
- Design Considerations:
    - Welded and bolted frame for durability.
    - Capable of withstanding vibrations and thermal expansion.

3.6 Heating Bands

- Material: Stainless Steel Sheathed Electrical Heating Elements
- Function: Provide uniform heating to the barrel to melt the ABS pellets.
- Design Considerations:
    - Capable of reaching 300-450°C.
    - Controlled by solid-state relays (SSR) and a PID controller for precise temperature regulation.

(**Fig. 6** Nozzle)

(**Fig. 7** Heating Band)

3.7 Coupling

- Material: Aluminum
- Function: Connects the NEMA 23 stepper motor to the screw shaft, transmitting torque for material extrusion.
- Design Considerations:
    - Lightweight and corrosion-resistant.
    - Provides secure and efficient power transmission with minimal backlash.

3.8 Solid-State Relays (SSR)

- Type: High-power electronic switching device.
- Function: Controls the heating bands, providing precise temperature modulation.
- Design Considerations:
    - Ensures rapid and reliable switching with no mechanical wear.
    - Works in coordination with the PID controller and thermocouples.

(**Fig. 8** Coupling)

(**Fig. 9** SSR)

3.9 Thermocouples

- Type: K-Type Thermocouple
- Function: Measures the barrel temperature and provides input to the PID controller.
- Design Considerations:
    - High temperature accuracy and response time.
    - Works under high thermal loads without degradation.

3.10 PID Controller

(**Fig. 10** PID Controller)

- Function: Regulates the temperature of the heating bands based on thermocouple feedback.
- Design Considerations:
    - Provides precise control over extrusion temperature.
    - Helps in maintaining consistent material flow and filament quality.

3.11 NEMA 23 Stepper Motor

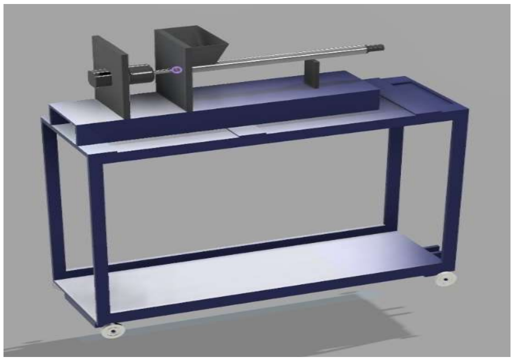
(**Fig. 11** Stepper Motor)

- Specifications:
  - Holding Torque: 25 kg-cm, Max Operating Speed: 450 RPM
- Function: Drives the screw rotation, ensuring controlled material flow through the barrel.
- Design Considerations:
  - High torque-to-weight ratio, making it ideal for extrusion applications.
  - Stepper motor driver ensures precise speed control for filament consistency.

3.12 Motor Controller

- Function: Regulates the speed and torque of the NEMA 23 stepper motor.
- Design Considerations:
  - Prevents overheating and stalling under high loads.
  - Allows adjustable extrusion speed to fine-tune filament output.

(**Fig. 12** Fine tune RPM controller)



(**Fig. 13** Frame)

3.13 Moving Frame Structure

- Material: Mild Steel (MS)
- Function: Provides portability and stability to the entire extruder assembly.
- Design Considerations:
  - Equipped with nylon wheels for mobility.
  - Right-angle brackets for mounting and easy disassembly.

4. Calculations

The calculations are based on standard extrusion theory [27], practical design considerations, and the desired output parameters such as feed rate, screw speed, and filament diameter.

4.1 Design Dimensions

Table 2. Dimensions

Component	Dimension	Remarks
Overall Frame Height	889 mm	Ergonomic and portable height
Frame Width	355.6 mm	Stable support base
Frame Depth	304.8 mm	Compact footprint
Barrel Length	420 mm	Effective melting and pressurization zone
Screw Diameter	25 mm	Suitable for small-scale extrusion
Screw Helix Angle	24°	Used for pitch calculation and machine setting
Barrel Outer Diameter	38 mm	For heat retention and strength
Nozzle Diameter	3 mm	Desired filament output
Hopper Height	152 mm	Easy top-loading of pellets
Hopper Inlet Diameter	76 mm	Large enough to avoid bridging
Support Plate Thickness	12 mm	For rigid mounting
Angle Welding Incline	53°	Optimal structural support

4.2 Material Feed Rate Calculation

To maintain a consistent filament output, the feed rate (mass flow rate) must match the thermal and mechanical capabilities of the extruder. The following assumptions are [20,23,26]

- Material: ABS
- Bulk density of ABS pellets: 1.04 g/cm^3
- Desired filament output rate: 1.5 m/min
- Filament diameter: 3 mm
- Cross-sectional area of filament (A): 0.0706 cm^2
- Volumetric flow rate (Q): 10.59 cm^3/min
- Mass flow rate ($\dot{m}$): 11.02 g/min

Therefore, the system is designed to process ~11 g/min of ABS pellets.

4.3 Screw Speed & Torque Estimation

Assumptions:

- Screw length = 420 mm
- Pitch = 30 mm
- One rotation = 1 pitch advancement
- Desired feed rate = 1500 mm/min
- Screw RPM = 50 RPM

Torque Requirement: Approx. 2.5–3 Nm

- NEMA 23 stepper motor: 4.2 A, 25 kg-cm = 2.45 Nm
- With gear reduction and coupling, effective torque is sufficient.

4.4 Heating Power Requirements

- Barrel Heating Zone Length = 420 mm
- Estimated power requirement per band heater = 150 W
- Number of heaters used: 2 Total Power = 150 × 2 = 300 W

Controlled via: Solid State Relay (SSR), PID Controller and K-Type Thermocouple. The heaters raise the barrel temperature to 300–450°C within 5–8 minutes and are regulated thereafter.

4.5 Structural Load Distribution

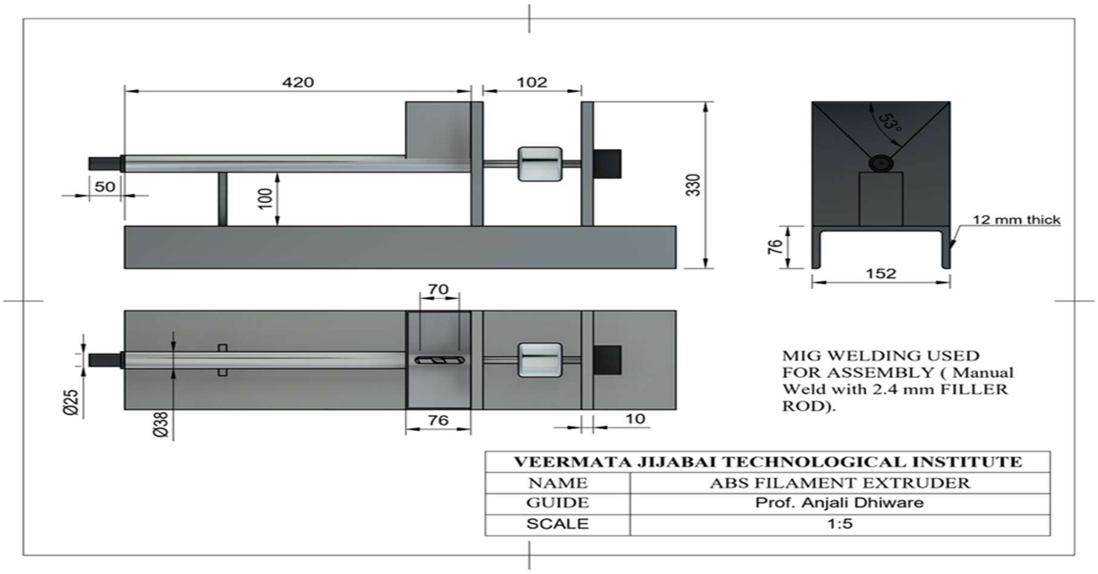
- MS frame supports entire assembly weight: estimated at ~25–30 kg
- Load-bearing components: 12 mm thick support plate and welded 53° MS angle beams
- Wheels (Nylon 6) rated for >10 kg each, allowing safe mobility of the unit.

Table 3. Summary of Calculations

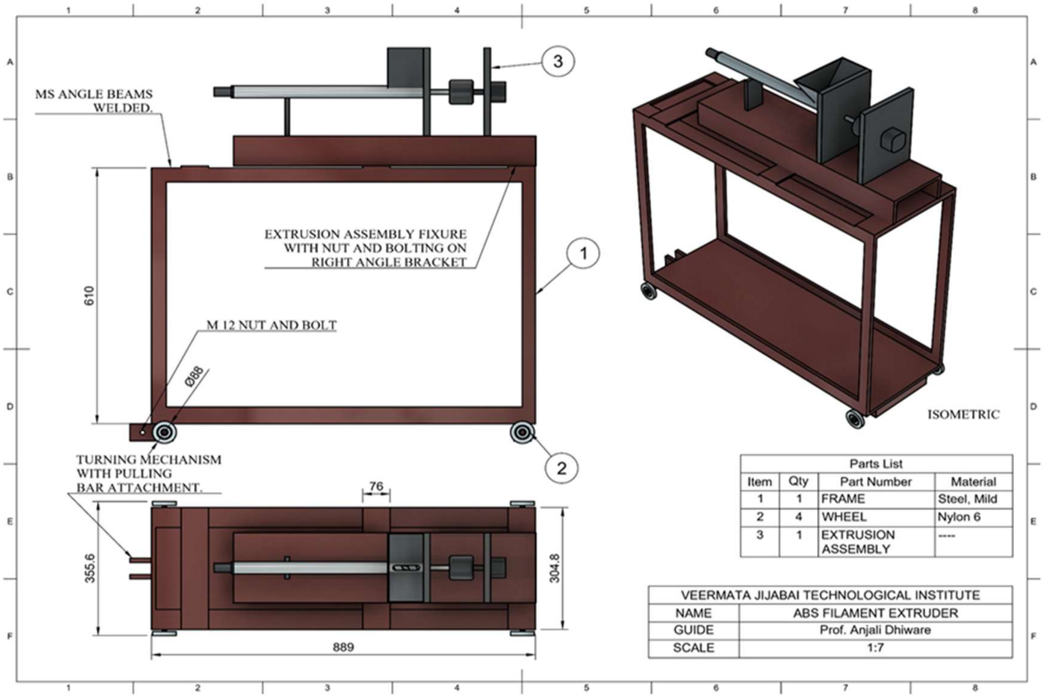
Parameter	Value
Desired filament output	1.5 m/min
Filament diameter	3 mm
Mass flow rate (ABS)	11 g/min
Screw RPM	50 rpm
Torque required	2.5 Nm
Heating power	300 W
Operating temperature	300-450°C

This design approach ensured that every selected dimension and component aligned with theoretical performance requirements, validating the practical dimensions chosen during fabrication.

5. Design & Cost



(**Fig. 14** Working Mechanism Draft)



(**Fig. 15** Full Assembly Draft)

Table 3. Cost

Component	Total Cost (INR)
EXTRUDER SCREW	543
MICA HEATERS	1,498
PID CONTROLLER	2,590
THERMOCOUPLE	760
STEPPER MOTOR	1,937
MOTOR CONTROLLER	1,999
POWER CONVERTOR	1,298
MECH. ELEMENTS (Barrel, Wheels, Blank, Bolting, Frame, C-Chanel, Coupling, Bearing)	4,868
FABRICATION	2,726
SOLID STATE RELAY	718

6. Conclusions

The successful design and fabrication of the Portable ABS Filament Extruder demonstrate the feasibility of developing an efficient, affordable, and modular system for in-house filament production. This project integrated traditional machining processes with precision electronic control, resulting in a robust assembly capable of consistently producing 3 mm ABS filament at a controlled rate. Key components such as the stainless-steel barrel, custom-machined nozzle, and NEMA 23 stepper motor were carefully selected and integrated to ensure mechanical stability and performance under prolonged operating conditions. The thermal control system, comprising band heaters, a PID controller, thermocouples, and SSRs, provides accurate temperature regulation across the barrel, ensuring uniform material flow and output quality. The system's design also supports compatibility with other polymers like PLA and blends, allowing for future material experimentation and sustainability initiatives, such as recycling failed prints. With its compact frame, portability via castor wheels, and ease of maintenance, the extruder is well-suited for academic labs, research institutions, and maker environments

Abbreviations

The following abbreviations are used in this manuscript:

ABS	Acrylonitrile Butadiene Styrene
AC	Alternating Current
DC	Direct Current
FDM	Fused Deposition Modelling
FFF	Fused Filament Fabrication
PID	Proportional–Integral–Derivative
SSR	Solid-State Relay
MS	Mild Steel
CRCA	Cold Rolled Close Annealed
AISI	American Iron and Steel Institute
NEMA	National Electrical Manufacturers Association
RPM	Revolutions Per Minute
CAD	Computer-Aided Design
ESD	Electrostatic Discharge

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