Modelling and 3d Printing of 4 - Cylinder Engine Block

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Abstract

The advancement of additive manufacturing has revolutionized the prototyping and fabrication of complex mechanical systems, including internal combustion engines. This study focuses on the design, Modelling, and 3D printing of a four-cylinder engine block, replicating its structural and functional features with high precision. Computer-Aided Design (CAD) software was employed to create detailed component models, ensuring accurate dimensions, proper assembly compatibility, and functional motion. The fabrication process utilized Fused Deposition Modelling (FDM) technology with high-strength thermoplastic materials to optimize durability, surface finish, and mechanical reliability. Post-processing steps such as sanding, support removal, and alignment adjustments were performed to enhance assembly quality and functional performance. The printed parts were subsequently assembled to evaluate fit, movement, and potential real-world applicability. This project demonstrates the feasibility of using 3D printing for educational models, mechanical design validation, and rapid prototyping. Additionally, it underscores the utility of 3D-printed engine models as effective tools in academic environments for teaching engine dynamics, kinematics, and thermodynamic concepts.

Key Words: 3D Printing, Four-Cylinder Engine, CAD Modelling, Additive Manufacturing, Rapid Prototyping, FDM Technology, Mechanical Assembly, Engine Design, Prototyping.

1. INTRODUCTION

The internal combustion engine (ICE) continues to be fundamental in powering the majority of vehicles and machinery worldwide. The engine block, as the main structural component, houses critical features such as cylinders, coolant and oil passages, and mounting points for the crankshaft, pistons, and cylinder head. Traditionally, engine blocks are produced using complex manufacturing methods like sand casting and machining, which are expensive, time-consuming, and restrict design flexibility. Advancements in additive manufacturing (AM), especially 3D printing, offer new possibilities for mechanical design and prototyping. Unlike traditional subtractive methods, AM builds components layer-by-layer directly from digital models, enabling the creation of intricate internal structures and precise, functional prototypes. This technology reduces the time and cost involved in early design validation, minimizes material waste, and provides valuable educational models for understanding complex systems. This project focuses on the Modelling and 3D printing of a four-cylinder inline engine block using SolidWorks for CAD design and Fused Deposition Modelling (FDM) for prototype fabrication. The design incorporates essential structural and functional features such as cylinder bores, crankcase geometry, oil galleries, and coolant channels. Printed using PLA material on a professional-grade FDM printer, this approach demonstrates how combining CAD and additive manufacturing can enhance the prototyping process in automotive engineering, making it more efficient and cost-effective. The study also evaluates the accuracy and feasibility of the printed prototype for educational and functional testing purposes, highlighting the growing potential of 3D printing in mechanical component development.

2. LITERATURE REVIEW

Bryant, A. [1] in 2020 investigated advancements in 3D printing materials for biomedical applications, highlighting the mechanical performance and customizability of PLA and biocompatible polymers. Her findings support the use of PLA for detailed prototypes in educational and research contexts.

Perez, S. [2] in 2021 applied machine learning techniques to optimize 3D printing parameters such as print speed, infill density, and layer thickness. His work underlines the importance of parameter tuning to improve surface quality and dimensional accuracy in complex mechanical parts.

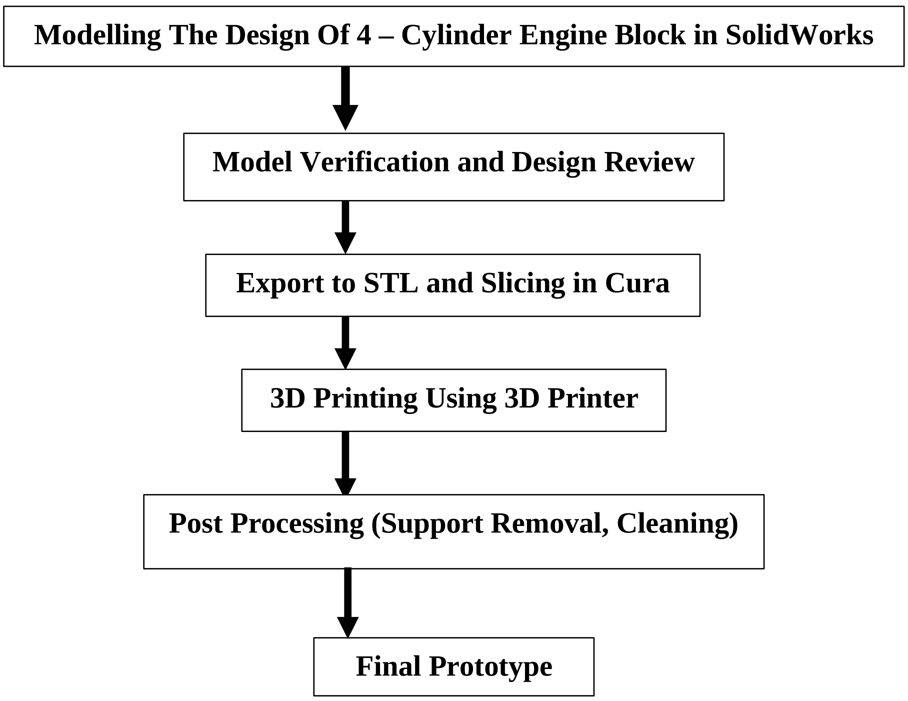
Scott, E. [3] in 2020 focused on post-processing techniques to improve the strength, surface finish, and dimensional stability of 3D-printed parts. His findings emphasize the role of sanding, vapor smoothing, and epoxy coating in enhancing prototype quality.

Caton, J.A. [4] in 2019 developed a thermodynamic simulation model for spark-ignition engines, including combustion chamber dynamics and heat transfer using the Wiebe function. His work provides a theoretical foundation for engine performance analysis during early design stages.

Mianzo, L. & Peng, H. [5] in 2020 created a cylinder-by-cylinder model of a variable valve timing (VVT) 4-cylinder engine. Their simulation incorporated pressure dynamics and combustion behavior, useful for validation of CAD-based engine block models.

Kodah et al. [6] in 2018 conducted reverse engineering and combustion pressure Modelling using the Wiebe approach. Their methodology supports accurate reconstruction of engine components for simulation or prototyping purposes.

3. METHODOLOGY



4. DESIGNING OF 4-CYLINDER ENGINE BLOCK IN SOLIDWORKS

The engine block serves as the fundamental structure of an internal combustion engine, housing critical components such as cylinders, coolant passages, oil galleries, and the crankcase. In this study, a 4-cylinder inline engine block was modeled using SolidWorks to accurately replicate real-world engine architecture with precise dimensions and geometrical features. The design aimed to develop a prototype suitable for 3D printing, while maintaining the mechanical integrity essential to engine operation.

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Fig - 4.1: **SolidWorks Default Page**

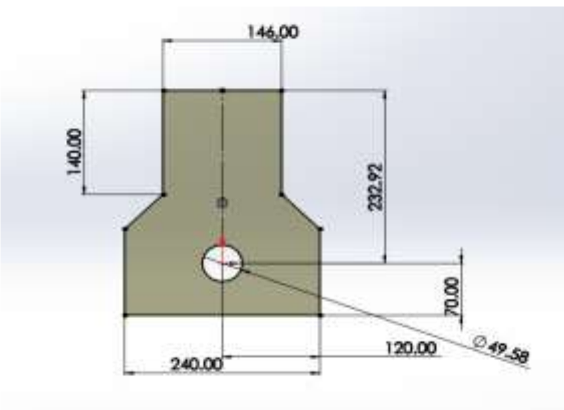
Fig - 4.2: **Parts of SolidWorks**

Software and Tools

- **Software:** SolidWorks
- **Modules Used:** Part Modelling, Assembly, Drafting, and Simulation
- **Design Methodology:** Bottom-up approach with parametric Modelling

4.1 Design Considerations

- **Cylinder Bore and Spacing:** Each cylinder was designed with a bore diameter of 86 mm, consistent with common passenger car engines. The centre-to-centre spacing between cylinders was maintained at 109.22 mm to ensure adequate wall thickness for structural strength and thermal stability.
- **Crankcase Dimensions:** The crankcase base was designed with dimensions of 240 mm width and 232.92 mm height, focusing on symmetry, stability, and proper mounting geometry. Variable wall thicknesses were incorporated to withstand mechanical stresses.
- **Cooling Jacket and Internal Flow Paths**: A cooling jacket was created around each cylinder bore with a radius of 6 mm to facilitate coolant flow and effective thermal regulation, essential for engine performance and durability.
- **Bolt Hole Placement:** Bolt holes of 12 mm diameter were symmetrically positioned 15 mm from edges to allow secure attachment of cylinder heads and sealing gaskets.
- **3D Printing and Scalability:** The model was designed considering 3D printing constraints, with the final prototype scaled to 105% of base dimensions, resulting in approximate dimensions of 80 mm (X) × 53 mm (Y) × 51 mm (Z).



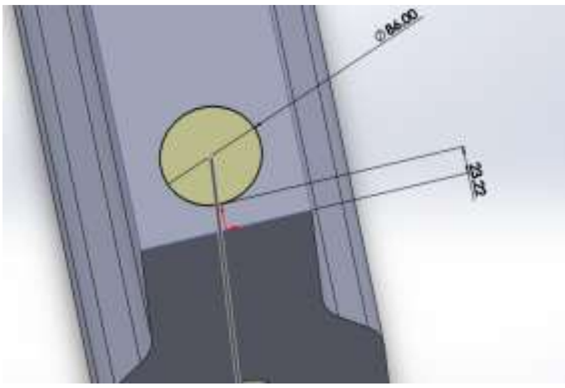


Fig – 4.3: **Crankcase Base Sketch Profile**

Fig – 4.4: **Cylinder Bore Sketch with Dimensions**

4.2 Design Specifications

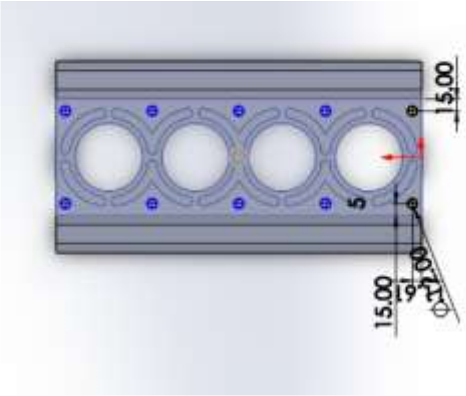
Parameter	Value
Number of Cylinders	4
Cylinder Bore Diameter	86.00 mm
Cylinder Spacing (C-C)	109.22 mm
Block Width	240 mm
Block Height	232.92 mm
Bolt Hole Diameter	12.00 mm
Cooling Channel Radius	6.00 mm

4.3 Modelling Workflow

1. **Base Plate Sketching:** A rectangular base plate was sketched as the foundational platform, including mounting and oil drainage holes.
2. **Cylinder Construction**: Cylinders were created using patterned extrusion to maintain precise bore placement and spacing.
3. **Crankcase Housing:** The lower block section was hollowed to accommodate the crankshaft, maintaining realistic clearance for moving parts.
4. **Cooling Passages:** Water jackets were modeled using shell features and lofted cuts to create continuous coolant flow channels around the cylinders.
5. **Bolt and Head Mounts:** Bolt holes for cylinder heads were designed using hole wizard tools and patterned to ensure uniform distribution.
6. **Assembly Interfaces:** Mates and reference geometry were incorporated to interface accurately with auxiliary components such as the oil pan and bearing caps.
7. **Rendering and Drafting:** The model was rendered with SolidWorks Visualize for presentation purposes, and detailed 2D drawings were generated for documentation.

4.4 Modelling Workflow

- **Initial Setup:** The model was created with metric units (mm), using standard reference planes to ensure symmetry.
- **Main Block Extrusion:** A 240 mm by 232.92 mm rectangle was extruded to form the engine block base, with draft angles applied where necessary.
- **Structural Ribs:** Vertical ribs of 8-10 mm thickness were added for reinforcement, aligned with cylinder centers.
- **Cylinder Bores:** Four Ø86 mm cylinders were extruded through the block with zero taper to replicate straight bore walls.



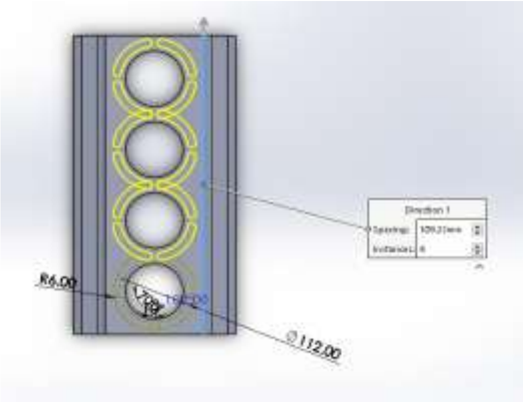


Fig – 4.5: **Top View with Bolt Hole Placements** **Fig – 4.6**: **Cooling Channel Pattern Design**

- **Cooling Channels:** Offset sketches with a 6 mm radius formed the water jackets, with inlet and outlet ports positioned near cylinder ends.
- **Crankshaft Supports:** Bearing saddles (Ø55 mm) were modeled at the block bottom, matching cylinder spacing, with separate bearing cap parts designed for assembly.
- **Oil Passages:** Oil galleries and feeds to bearings were created using swept cuts and vertical holes to simulate lubrication pathways.
- **Bolt Holes:** Cylinder head bolt holes were counterbored Ø12 mm holes arranged in a circular pattern, while oil pan mounting flanges were designed with precise bolt spacing.
- **Validation and Export:** Interference checks and section views verified internal clearances. The model was scaled appropriately and exported as STL files with fine resolution for 3D printing, followed by mesh repair to ensure printability.

5. 3D PRINTING PROCESS

The fabrication of the 4-cylinder engine block prototype using Fused Deposition Modelling (FDM) was carried out to verify the CAD model's dimensional accuracy and visualize complex internal features. The CAD model, created in SolidWorks, was exported in STL format, with mesh resolution adjusted to strike a balance between file size and surface detail.

Fig - 4.7: **RAISE3D N1 3D PRINTER** **Fig – 4.8**: **PLA FILAMENT (1.75 MM)**

- **Printer Used –** Raise3D N1
- **Material Used –** PLA (Polylactic Acid)

5.1 Pre-Printing Setup

Before initiating the print, the **Raise3D N1** 3D printer was prepared through a series of setup steps:

1. **Printer Calibration**: Auto-bed levelling was performed to ensure an even first layer across the build plate. The nozzle was also cleaned and purged to prevent clogging or filament residue from affecting print quality.

2. **Filament Loading**: 1.75 mm **PLA filament** was loaded into the extruder. The filament spool was mounted securely with minimal friction in the spool holder to avoid feeding interruptions.

Fig – 5.1: **Start of 3D Printing of Engine Block**

Fig – 5.2: **3D Printing of Engine Block**

3. **Slicing Configuration**: The STL file was imported into Cura, a slicing software, where essential print settings were configured. The nozzle temperature was set to 200°C, and the bed temperature to 60°C to ensure better adhesion with PLA. A layer height of 0.2 mm was chosen to achieve moderate detail, while a 25% infill density using a gyroid pattern provided strength without excessive material use. The print speed was set at 50 mm/s to balance quality and efficiency. Support structures were enabled specifically under overhangs and bolt holes to maintain print accuracy, and an 8 mm brim was added to help prevent warping on large flat surfaces. Once the slicing process was completed, the resulting G-code file was transferred to the 3D printer via USB.

5.2 Printing Execution and Real-Time Monitoring

Once the print job was initiated, several steps were taken to ensure a successful print:

- **First-Layer Inspection**: The first layer was closely monitored to confirm adhesion quality and bed leveling. Any lifting at the corners or gaps between lines was corrected by fine-tuning the Z-offset.

- **Extrusion Check**: The extruder's movement and filament feed were monitored for signs of under-extrusion, over-extrusion, or nozzle blockage. Manual pausing and filament retraction were ready.

- **Temperature Stabilization**: Internal chamber temperature was kept stable due to the enclosed design of the Raise3D N1. The print fan was activated only after the first layer to avoid warping.

- **Support Generation**: As the model progressed to overhanging features like cylinder bores and internal cooling passages, the generated support structures printed smoothly without detachment or sagging.

- **Intermittent Inspection**: Visual inspections were carried out at layer transitions (e.g., near bore areas and mounting flanges) to ensure dimensional fidelity and no shifting or warping had occurred.

5.3 POST-PROCESSING

After completion of the print, the model was allowed to cool before removal from the build plate to avoid warping. The following post-processing steps were applied:

1. **Support Removal**: Using needle-nose pliers and precision cutters, support structures were carefully detached without damaging detailed features.

2. **Sanding**: The surface was smoothed using 120 to 400+ grit sandpaper, especially around visible layer lines and support-affected zones.

3. **Dimensional Verification**: Callipers were used to verify key dimensions such as bore diameters, mounting hole spacing, and overall width.

4. **Finishing (Optional)**: Primer or epoxy resin could be applied to improve surface finish and minor durability for display or light handling.

6. RESULTS

The 3D printing of the 4-cylinder engine block using Polylactic Acid (PLA) material successfully demonstrated the capabilities of additive manufacturing for mechanical prototyping. While PLA's mechanical and thermal limitations restrict its use in functional engine components, it served well for visual representation and design validation.

Key aspects include:

- **Geometric Accuracy:** All major design features—cylinder bores, coolant jackets, and bolt holes—were captured accurately. No noticeable warping or deformation occurred.
- **Prototyping Outcome:** The printed model enabled clear visualization and supported effective communication of engine design concepts.
- **Educational Impact:** Served as a tangible aid for understanding engine part relationships and internal geometry.
- **Time & Cost Efficiency:** Achieved significant savings compared to traditional manufacturing techniques.
- **Post-processing Ease:** PLA allowed for smooth sanding and assembly.
- **Material Limitations:** PLA's brittleness and low heat resistance limited its use to static or educational applications.

7. DISCUSSION

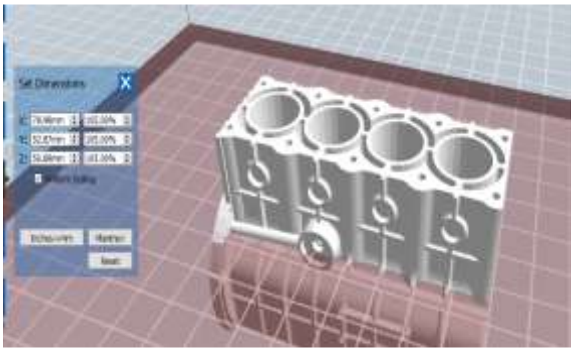
The process from design to finished prototype was executed in several structured steps:

Step 1: CAD Modelling

A detailed SolidWorks model was developed, considering bore alignment, wall thickness, and space for cooling jackets. The model was scaled down appropriately for the printer's build volume.

Step 2: STL Export and Validation

The model was exported as an STL file and checked for mesh integrity. Cura was used for slicing, applying optimal orientation and support strategies.



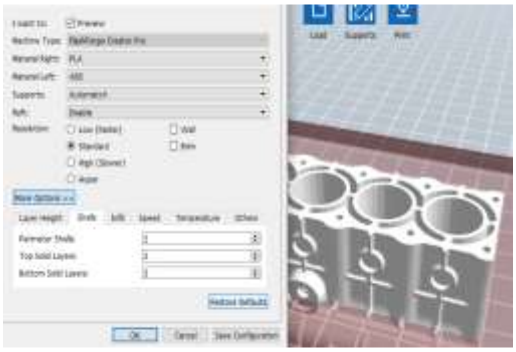
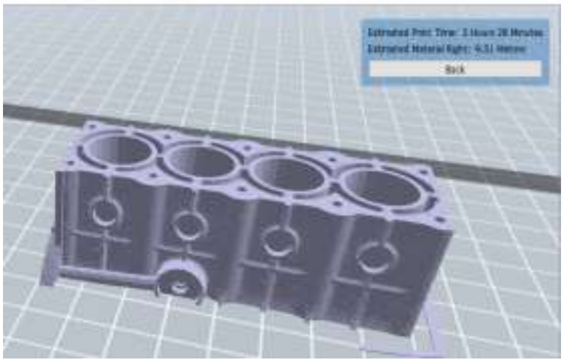


Fig – 7.1: 3D Printed Model in Slicer Software **Fig – 7.2: 3D Printer Configuration Settings**

Step 3: Material Selection

PLA was selected due to its cost-effectiveness and printability, with the trade-off of low strength and heat resistance acknowledged.



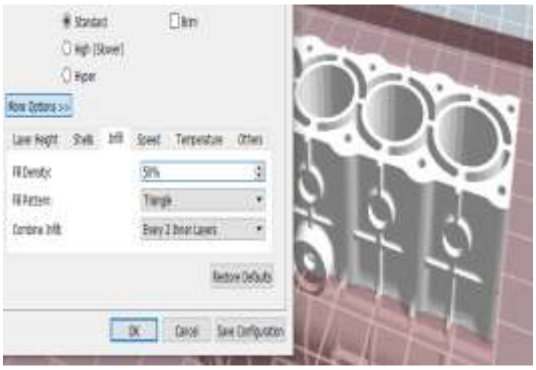


Fig – 7.3: Estimated Printing Time and Material Usage **Fig – 7.4: Infill Settings for Engine Block Model**

Step 4: Slicing Configuration

Slicing parameters included a 0.2 mm layer height and 20–40% infill. Support was enabled for overhangs, with an estimated print time of 12–15 hours.

Step 5: Printing Execution

The model was printed in two halves on an FDM 3D printer. Standard PLA settings were used, and regular monitoring ensured print success.

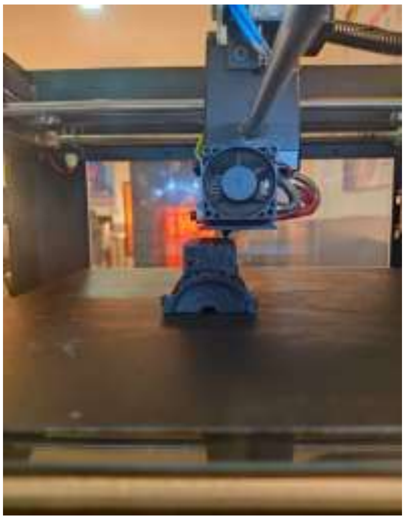


Fig - 7.5: Top view of Engine Block During 3D Printing **Fig - 7.6: Side view of Engine Block**

Step 6: Post-processing

- Support Removal: Carefully extracted with tools like flush cutters and tweezers.
- Cleaning: Stringing and blobs were removed; defects were touched up.
- Sanding: Multi-stage sanding gave a polished finish.

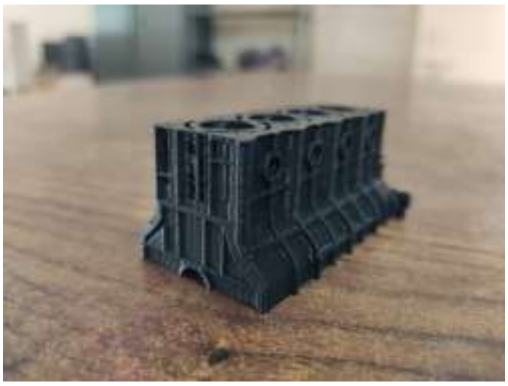


Fig – 7.8: Close-up View of Cylinder Detailing

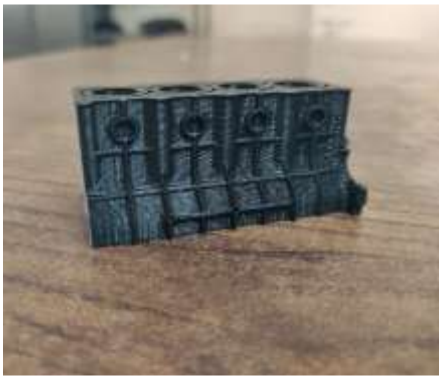


Fig – 7.9: Cross-Sectional View

- Dimensional Tuning: Callipers and files were used to correct tolerances.
- Optional Painting: Enhanced appearance with metallic colours.

Step 7: Assembly and Validation

Segments were aligned and glued using cyanoacrylate. Dowel pins ensured alignment. Final measurements matched CAD dimensions, validating the prototype's integrity.

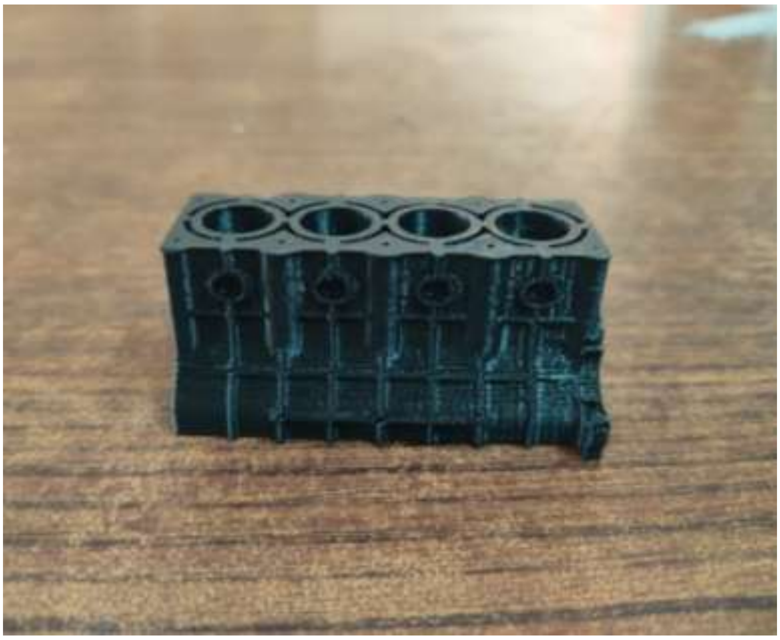


Fig – 7.10: Final Prototype

Step 8: Observed Limitations

- One edge cracked due to PLA brittleness.
- Visible layer lines remained unless extensively sanded.

- Internal cavity accuracy was constrained by nozzle limitations.

8. CONCLUSIONS

The Modelling and 3D printing of a 4-cylinder engine block offer significant advantages in design flexibility, rapid prototyping, and production efficiency. By utilizing CAD tools like SolidWorks, engineers can accurately visualize and optimize critical internal features such as coolant channels, cylinder alignment, and mounting points elements that can be precisely fabricated through additive manufacturing. 3D printing enables the creation of complex geometries that are often difficult or expensive to produce using traditional casting or machining methods. This not only reduces material waste but also opens up opportunities for lightweight design. Furthermore, the use of advanced 3D printing materials, including high-temperature polymers and metal composites, enhances the mechanical strength of the prototype, making it viable for functional testing and educational demonstrations. While challenges remain particularly in terms of surface finish and dimensional accuracy ongoing advancements in 3D printing technology are steadily addressing these limitations. Overall, this approach proves to be a highly innovative and cost-effective solution for prototyping, research, and training in automotive and mechanical engineering domains

FUTURE SCOPE

The future of 3D printing in engine block production is highly promising, offering lightweight, complex, and high-performance designs that are difficult to achieve with traditional methods. While PLA was used here for prototyping, future applications will adopt advanced materials like aluminum, titanium, stainless steel, Inconel, and CFRP for durable, heat-resistant parts. Technologies such as DMLS, SLM, EBM, and WAAM enable precise, scalable metal printing, supporting rapid prototyping and functional part manufacturing. Hybrid manufacturing, topology optimization, and recyclable powder reuse will improve efficiency and sustainability. Overall, 3D printing is set to revolutionize engine design with faster development, reduce waste, and on-demand production.

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