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Design and manufacturing of casting molds for the housing of a hand-operated sed grinding machine

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ABSTRACT

This study investigates the design and manufacturing of casting molds for the housing of a hand-operated seed grinding machine, aimed at delivering cost-effective and durable solutions for rural applications. The study began with comprehensive CAD modelling of the housing, segmented into five parts: inlet funnel, cylindrical chamber, vertical support bracket, reinforcement gusset, and mounting base. Mold geometry was optimized for cope and drag design, incorporating considerations such as parting lines, draft angles, cooling channels, gate area, clamping force, and shrinkage to minimize casting defects.CNC milling and EDM were employed to machine tool steel (H13/P20) m olds with high precision (±0.01–0.05 mm) and fine surface finishes (Ra 0.1–0.2 μm). Post-processing included heat treatment (~50 HRC) and polishing. Stainless steel 304 was chosen for the final part due to its corrosion resistance. Dimensional accuracy and surface integrity were verified using CMM and profilometry. Trial casting of the inlet funnel confirmed mold functionality. FEA was performed on the AISI 304 housing under fixed-base boundary conditions, internal pressure (12,000 N/m²), a 1000 N vertical load, and gravity. Results showed low stress (24.75 MPa), minimal displacement (0.0633 mm), and a high safety factor (8.35), confirming structural soundness. The optimized mold design enhances part quality and production efficiency, supporting sustainable, low-cost manufacturing of agricultural components.

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1. INTRODUCTION

Manual seed grinding machines must be durable and affordable, especially in rural areas where such equipment is vital for agriculture. Casting is an effective method for producing robust machine housings with minimal material waste and high consistency [1]. This study focuses on the design and production of casting molds for the housing of a hand-operated seed grinding machine, with the aim of optimizing performance without significantly increasing cost. Traditionally, housing parts may be made by machining or welding of cast components, which can lead to inefficiencies [2]. High production costs, poor durability, and suboptimal designs have been observed in conventionally manufactured housings, adversely affecting machine performance and lifespan. To address these challenges, this study seeks to develop improved die-casting molds for the housing, thereby enhancing cost-effectiveness, functionality, and durability [3].

The main objectives of the research are:

1. Develop a CAD model of the seed grinding machine, focusing on the housing assembly.
2. Determine the geometric parameters of the mold forms for the housing components, including parting lines, cores, and cavities.
3. Establish the manufacturing process for the upper mold (cope), including tool selection and machining strategy.
4. Establish the manufacturing process for the lower mold (drag), ensuring proper core-cavity alignment and finishing.

This research is significant because it provides a practical pathway to improve the production of housing components for manually operated seed grinders. By designing efficient casting molds and processes, the work promotes cost-effective manufacturing techniques, increasing the accessibility of reliable grinding machines in under-resourced communities. Improving the functionality and reliability of these small-scale grinders also supports sustainable farming practices in rural regions, where such machines are essential for processing seeds and grains [4].

2. CAD MODELLING AND MOLD GEOMETRIC DESIGN

The design process began with a detailed CAD model of the hand-operated seed grinding machine. The machine was represented as a manually-powered device comprising a material feed hopper, hand crank, and internal screw conveyor to drive the grinding mechanism.

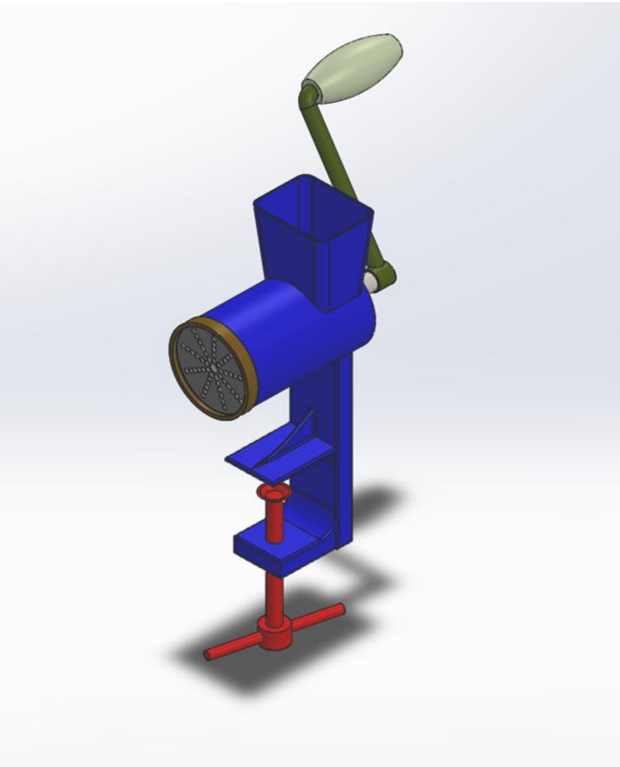

Fig. 1 *Seed Grinding Machine*

In SolidWorks, the housing assembly was created and subdivided into five distinct parts: the inlet funnel, cylindrical grinding chamber, vertical support bracket, reinforcement gusset, and mounting base. This subdivision allowed each component to be modeled independently, enabling more accurate definition of geometric constraints, draft angles, and surface transitions necessary for die-casting production. By separating the assembly into smaller functional units, it was also possible to optimize the mold design for each part individually and ensure proper alignment during the final assembly stage. The spatial arrangement and orientation of these components within the overall housing are illustrated in Figure 2, which provides a visual reference for their interaction and positioning.

Geometric parameters for the die-casting molds were carefully determined to satisfy manufacturing tolerances, ensure proper material flow, and minimize potential defects during casting.

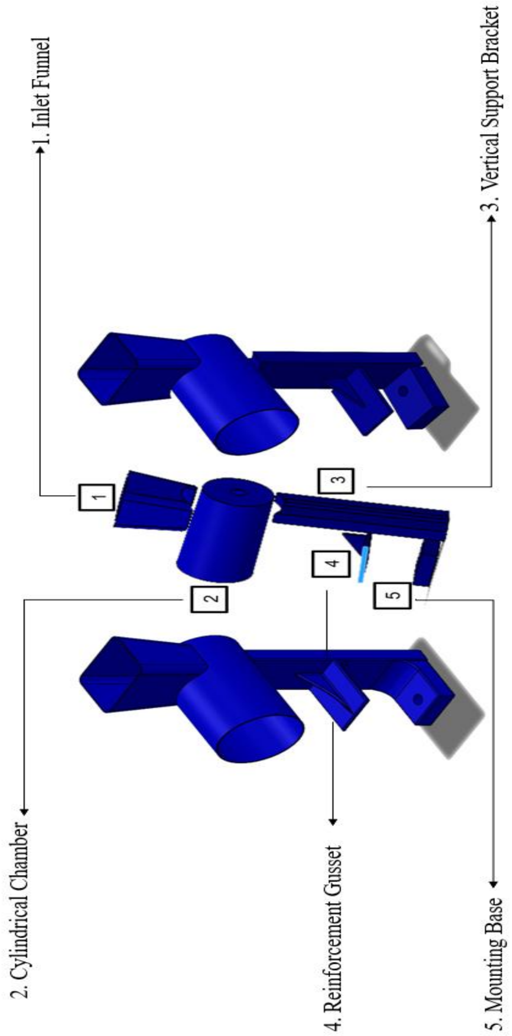

Fig. 2 *Housing Sub-divided into five (5) parts*

2.1 Mold Analysis and Manufacturing Technology

For each housing part, a core and cavity were defined to match the dimensional and draft angle requirements specified during the mold design stage. The inlet funnel core and cavity were designed to produce the tapered interior and exterior profile with uniform wall thickness, in accordance with the draft angle and shrinkage values listed in Table 1. These parameters ensured smooth part ejection and accurate reproduction of the intended geometry. Similarly, for all other sub-components, the core–cavity definitions were adjusted to reflect their respective dimensional characteristics, enabling consistent casting quality and adherence to the shrinkage allowances outlined in Table 1.

Table 1 – *Housing Sub-parts and their Draft Angle Selection* [2]

Part	Dimensions (mm)	Draft Angle	Shrinkage
Inlet Funnel	Custom profile	3°	2%
Cylindrical Chamber	Ø50 × 100	3°	2.50%
Vertical Support	40 × 20 × 140	3.5°	2%
Reinforcement Gusset	70 × 40 × 140	3°	2%
Mounting Base	73.7 × 73.7 × 20	3°	2%

2.1.1 Mold Geometric Designs for Housing Sub-Parts

Figures 3–7 show the mold designs for all five housing components, illustrating the core–cavity layout used for each part. Figure 3 presents the mold for the inlet funnel with a centered core forming the tapered interior.

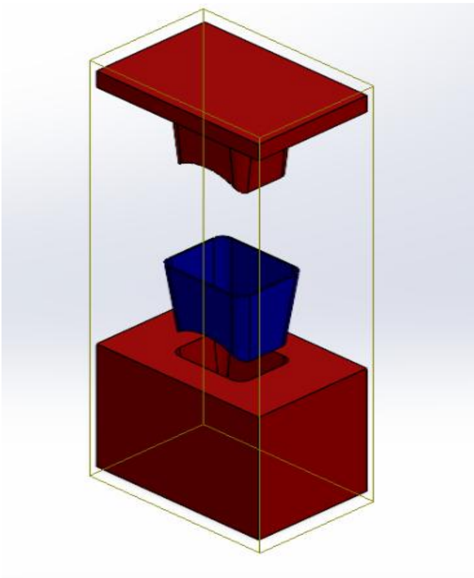

Fig. 3 *Mold Design for Inlet Funnel*

Figure 4 shows the cylindrical chamber mold, which uses an elongated core and split cavities for easy demolding. Figure 5 illustrates the vertical support bracket mold, designed with a vertically oriented core due to its height. Figure 6 shows the reinforcement gusset mold, requiring precise core placement because of its thin, angled geometry.
Figure 7 presents the mounting base mold, where a flat cavity and central core ensure uniform wall thickness. Together, these figures summarize the mold configurations developed for all sub-components in alignment with the parameters listed in Table 1.

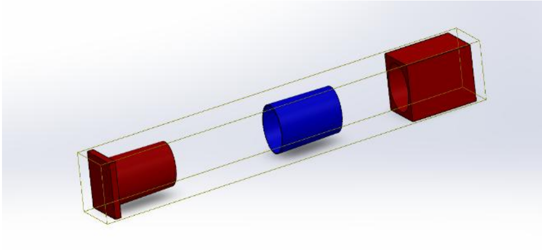

Fig. 4 *Mold Design for Cylindrical Chamber*

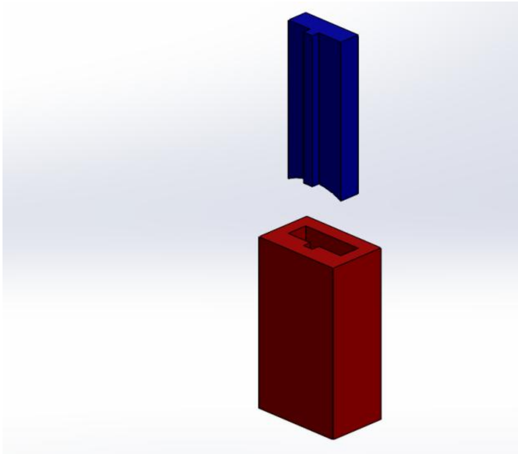

Fig. 5 *Mold Design for Vertical Support Bracket*

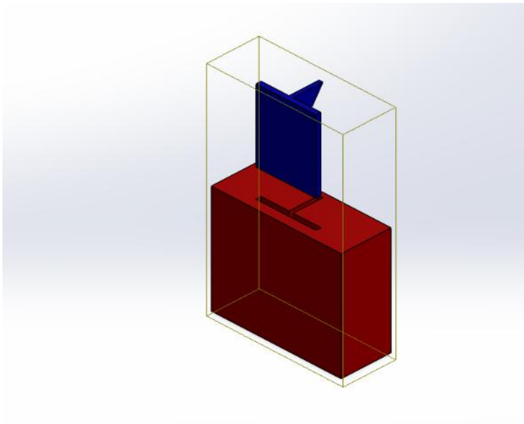

Fig. 6 *Mold Design for Reinforcement Gusset*

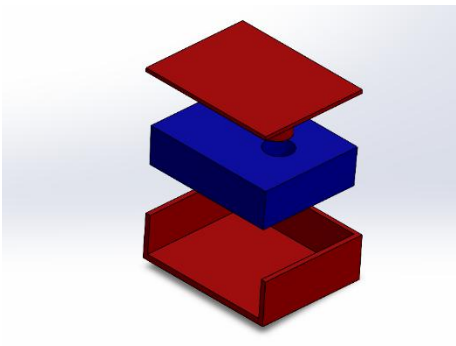

Fig. 7 *Mold Design for Mounting Base*

The cylindrical chamber mold was dimensioned to match the screw conveyor (approximately 80 mm diameter, 100 mm length) with smooth, curved walls and draft angles of about 2°–3° to aid ejection. The vertical support bracket, gusset, and base molds were shaped to ensure proper alignment and balanced support in the final assembly. In all cases, considerations such as parting lines, core insertion direction, cooling channel placement, and provision for ejector pins were incorporated into the mold designs [5].

2.1.2 Mold Geometric Designs for Housing Sub-Parts

Calculations for gate area, clamping force, and shrinkage allowances (typically 1.5%–2.5% for stainless steel 304) were performed to optimize the molds and accommodate material behavior during solidification [6].

Note: *CAM softwares (Edgecam, SolidWorks CAM or Mastercam) can accurately predict all these parameters and this calculation was done to show the Engineering behind how these parameters can be predicted.*

Calculations are Performed with the Vertical Support Bracket, Similar steps apply for other sub-parts of the housing.

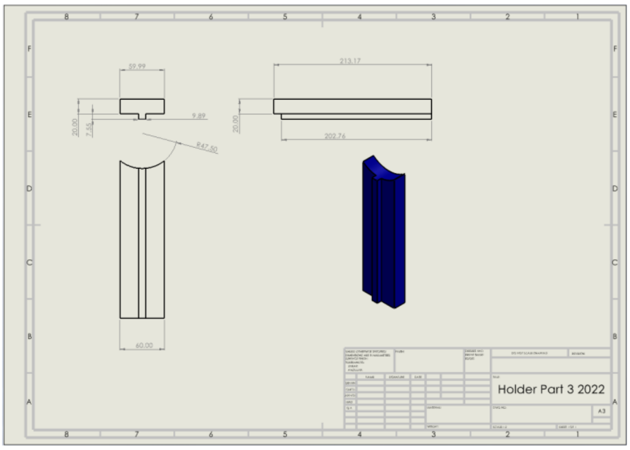

Fig. 8 *Engineering Drawing for the Vertical Support Bracket*

Based on the Dimensions and Material Properties, the following calculations can be made for the die casting process:

1. Cavity Box Volume and Weight:

- Dimension of Cavity Box: 50mm x 30mm x 150mm (Width X Depth X Height)
- Cavity Box Volume ($V_{cavityVB}$):

$$V_{cavityVB} = 50 \times 30 \times 150 = 225000\ mm^3 = 225\ cm^3$$

- Material: P20 tool steel ($Density = 7.8\ g/cm^3$)

2. Vertical Bracket Volume and Weight (Stainless Steel 304):

- Dimension of Vertical Bracket: 40mm x 20mm x 140mm (Width X Depth X Height)
- Vertical Bracket Volume (V_{VB}):

$$V_{VB} = 40 \times 20 \times 140 = 112000\ mm^3 = = 112\ cm^3$$

- Material: Stainless steel 304 ($Density = 7.93\ g/cm^3$)
- Weight of Vertical Bracket (W_{VB}):

$$W_{VB} = V_{VB} \times \rho_{304} = 112\ cm^3 \times 7.93\ g/cm^3$$
$$W_{VB} = 887.76g = 0.88776\ kg$$

3. Shrinkage Allowance:

- Stainless Steel 304 Shrinks during Cooling and Solidification (typically between 1.5 – 2.5%) and as such we assume a standard shrinkage allowance of **2%**
- $\text{Adjusted Dimensions} = \text{Original Dimensions} \times (1 + Shrinkage\ Allowance)$
- We shall adjust all dimensions to account for the shrinkage factor of 2%.

4. Clamping force for Die Casting:

- Casting Pressure (P_{cast}): We use $50MP_a$ which is in line with the standard for high pressure die casting of stainless steel
- Projected Area (A_{proj}):

$$A_{proj} = Width \times Height = 40\ mm \times 140\ mm = 5600\ mm^2 = 0.0056\ m^2$$

- Clamping Force (F_{clamp}):

$$F_{clamp} = P_{cast} \times A_{proj} = 50MP_a \times 5600\ mm^2 = 280000\ N = 280\ kN$$

This is the minimum force required to keep the mold closed during die casting.

5. Cooling Time:

- Cooling time is dependent on Thermal Properties and Thickness
- Formular for cooling time (t_{cool}) [7]:

$$t_{cool} = \frac{\rho \times c \times s^2}{k \times \Delta T}$$

Where:
ρ : Density
c : Specific Heat
s : Part Thickness
k : Thermal Conductivity
ΔT : Temperature difference

- Based on Software Predictions and Simulations, Cooling time is estimated to be 120 seconds

6. Cycle Time (t_{cycle}):

- Total Cycle time,
- $t_{cycle} = Filling\ time + Cooling\ Time + Ejection\ time$

$$t_{cycle} = 5s + 120s + 10s = 135\ s$$

7. Gate Area (A_{gate}):

- For die casting, gate area is crucial for metal flow, For a pin gate [7]:
- $A_{gate} = \frac{Q\ (Volumetric\ flow\ rate)}{v\ (velocity\ of\ molten\ metal)}$

$$A_{gate} = \frac{0.0004\ m^3/s}{1\ m/s} = 0.0004\ \ m^2$$

3. CAM MANUFACTURING PROCESSES WITH CNC MACHINING

The molds were fabricated using precision machining and post-processing. Mold cores and cavities were milled from high-grade tool steel (H13 or P20) using a multi-axis CNC milling machine.

Major Operations Done:

1. Roughing Operation

For the initial machining of the mold cavity, a roughing pass was performed to remove the bulk of material from the billet. After the workpiece (a tool steel block, as shown in Fig. 9: Tool and Solid Billet) was securely clamped in the CNC machine vise, a 20 mm diameter carbide flat-end mill was mounted in the spindle..

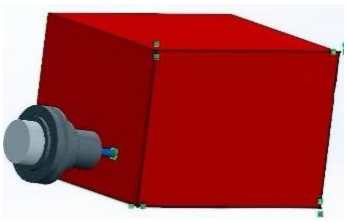

Fig. 9 *Tool and Solid Billet*

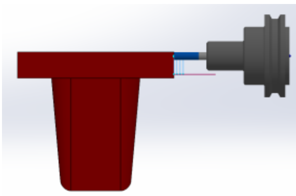

Fig. 10 *Roughing Operation*

The spindle was operated at 2500 rpm, providing a stable cutting speed suitable for the tool material and the hardness of the billet. The feed rate was set to 1000 mm/min, enabling efficient material removal while preventing tool chatter or surface burning.

For each pass, an axial depth of cut of 5 mm was applied, allowing the tool to penetrate 5 mm into the material per step. This depth was selected to balance rapid material removal with the avoidance of excessive load on the tool or spindle.

The radial stepover was set to 50% of the tool diameter, equivalent to 10 mm in this case. This value ensures optimal engagement with the material while preventing excessive tool load. It also contributes to smooth cutting and reduces the likelihood of tool deflection during the operation [8].

This first roughing operation successfully removed the excess material and shaped the basic cavity outline of the mold. The stock was now ready for finishing passes to achieve tighter tolerances and better surface quality.

2. Finishing Operation

After the roughing phase removed most of the excess material, the process continued with the finishing operation to achieve the final shape and surface quality of the mold cavity.

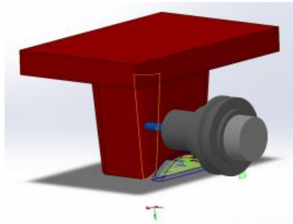

Fig. 11 *Finishing Operation on filleted edges*

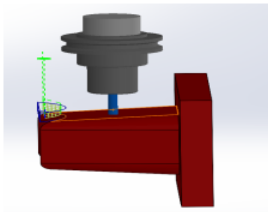

Fig.12 *Final Finishing Operation*

For this step, to a **12 mm ball-nose end mill with a 1 mm corner radius** was switched. This tool was chosen specifically for its ability to handle detailed surfaces and smooth internal transitions, especially around fillets and curved areas in the mold design.

The spindle speed was set to 1000 rpm, providing improved control and surface finish at the required level of precision. The feed rate was reduced to 500 mm/min to maintain surface accuracy and minimize tool vibrations during the fine cutting process.[8].

A very light axial depth of cut of 1 mm was applied. This shallow pass allowed the tool to follow the geometry contour with high precision while minimizing stress on both the spindle and the workpiece material..

To further refine the finish, a radial stepover of 10% of the tool diameter was applied, corresponding to 1.2 mm per pass.

This small stepover ensures that each cutting path slightly overlaps with the previous one, resulting in a smooth, uniform surface with minimal visible tool marks.

This finishing pass was mainly focused on the detailed internal surfaces of the cavity, especially corners, radii, and areas where a flat-end mill could not maintain full contact.

The result was a clean, well-defined surface that required minimal post-processing. In most areas, the surface finish achieved was visually smooth and suitable for polishing or direct casting use.

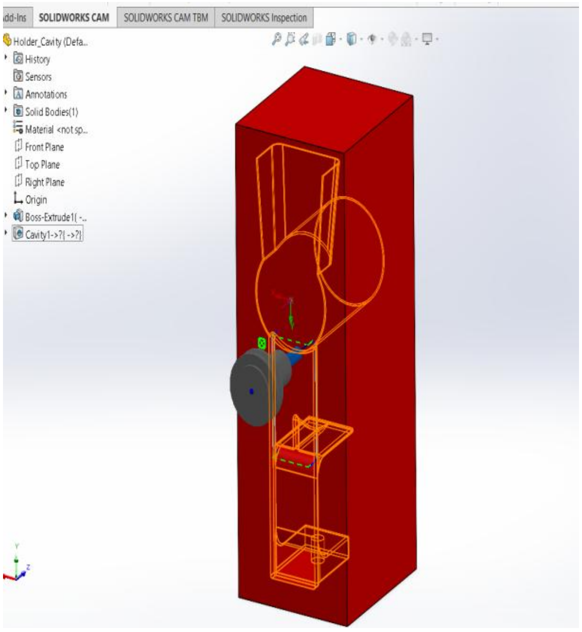

Fig. 13 *Tool Path Description on SolidWorks CAM*

3. Wall draft and Taper angles

i. Applied 2.5° – 3.5° draft to all vertical walls directly in the CAM part setup.

4. Surface finish Target

i. Ra 0.1–0.2 µm

5. Cycle time estimate

i. Roughing pass: ~7 minutes

ii. Finishing pass: ~ 33.38 minutes

iii. Total per core/cavity: ~41 mins

Note: This CAM process is typical for each Part of the Housing Machine.

3.1 Machine Selected for CNC Milling

During the CAM programming phase, SolidWorks CAM to simulate the entire machining process before actual manufacturing began was used. One of the key features utilized was the Machine Set-Up environment, which allowed the virtual definition of the machine type, including its travel limits, tool size compatibility, spindle speed range, and other operational capabilities.

As shown in Figure 14, the Machine Set-Up in SolidWorks CAM played a major role in helping me figure out what kind of CNC machine was required to execute the job efficiently. Based on the size of the billet, tool paths, and tool lengths needed, the simulation clearly indicated that we would need a machine with:

i. At least 457 mm of X-axis travel,

ii. A spindle capable of running up to 10,000–12,000 RPM,

iii. Compatibility with tools up to 20 mm in diameter,

And enough rigidity to handle both roughing and finishing operations on tool steel.

This virtual setup also highlighted the need for a machine with reliable coolant support, and ideally, the option for an Automatic Tool Changer (ATC) for future batch production. So, before even touching a real billet, this CAM-based planning helped me confidently select a machine that met all these criteria, saving time, avoiding mismatch errors, and ensuring smooth operation during actual machining [9].

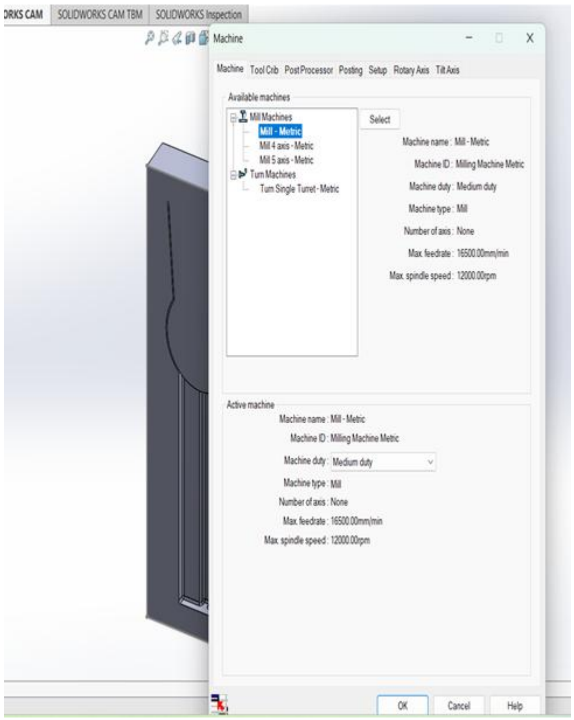

Fig. 14 *CAM predicted Machine specification*

Based on the CAM prediction, for the machining of the casting molds, we used a CNC mill that offered just the right mix of precision, speed, and reliability. Below are the key specifications that made it suitable for this project.

i. **Spindle Speed:** The machine runs at speeds up to 10,000–12,000 RPM, which is ideal for both roughing and finishing, especially when working with aluminum or tool steel.

ii. **Rapid Feed Rate:** It has a fast feed rate of 16,500 mm/min (or 650 inches per minute), which helped us reduce machining time while still keeping accuracy.

iii. **Travel Range:** The working envelope is quite practical: 457 mm on the X-axis, 279 mm on the Yaxis, and 406 mm on the Z-axis. This was enough to accommodate all the mold parts we had designed.

iv. **Spindle Power:** The spindle has a power rating of 1.5 kW (around 2 horsepower), with enough torque to handle light steel and aluminum without issues.

v. **Controller**: It uses a PathPilot control system. It's very intuitive, easy to learn, and still powerful enough to handle complex toolpaths and 3D contours.

vi. **Tool Changer:** While the basic model comes with manual tool changes, it supports an optional Automatic Tool Changer (ATC), which is helpful for production runs.

vii. **Coolant System:** The machine is compatible with both flood and mist coolant systems, which allowed us to manage chip removal and tool temperature effectively.

viii. **Machine Weight:** Weighing about 600 to 800 kg, it's a sturdy machine with a rigid frame, which helpedreduce vibrations and maintain accuracy during long cuts**.**

Workpiece Holding: A combination of vises, clamps, and custom fixture plates was used to secure the workpieces firmly during machining.

Fig. 15 *Tormach 1100MX CNC Mill [10]*

4. STATIC STRUCTURAL ANALYSYS OF THE HOUSING

Another important task of my study was to check the structural integrity of the Housing. To do this, the CAD model to a .STEP file and loaded it o ANSYS in preparation for the structural analysis was converted.

On ANSYS, a static structural, finite element analysis (FEA) was done to assess the strength of the cast housing under operating loads [11].

4.1 Meshing, Loading and Boundary Conditions applied

The assembled housing model, made of AISI 304 stainless steel (E = 190 GPa, ν = 0.29, yield strength = 206.8 MPa), was rigidly fixed at the mounting base to replicate operational constraints. The simulation applied a uniform normal pressure of 12,000 N/m² on the inner surface of the cylindrical chamber, a concentrated load of 1,000 N on the chamber interior, and accounted for gravitational acceleration (9.81 m/s²).

A high-quality solid mesh, consisting of approximately 262,664 tetrahedral elements, was employed to ensure precise capture of stress concentrations and deformation patterns. The finite element analysis computed key results, including equivalent (von Mises) stress, total deformation, equivalent strain, reaction forces at supports, and the factor of safety throughout the housing.

These results were then used to verify compliance with design strength requirements, evaluate structural performance under combined loading conditions, and identify potential areas for reinforcement or design optimization.

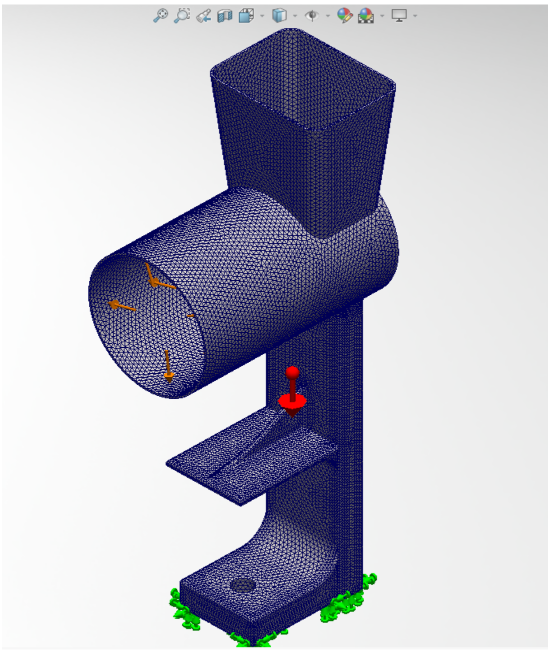

Fig. 16 *Loading and Meshing the Housing on ANSYS*

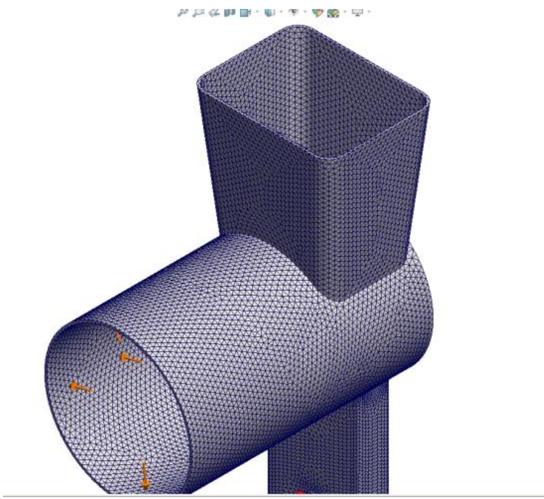

Fig. 17 *Mesh Close-up view*

Table 2 - *Mesh Description for the Structural Analysis*

Mesh Details	Technique Used
Mesher Type	Solid mesh
Mesher Used:	Blended curvature-based mesh
Jacobian points for High quality mesh	16 Points
Number of Elements	262,664 elements
Number of Nodes	413,193 nodes
Maximum element size	3 mm
Minimum element size	0.259 mm
Computation Time	1320 seconds (22 minutes)
Mesh Quality	High, with 99.8% of elements having an aspect ratio below 3 and only 0.0179% exceeding an aspect ratio of 10

4.2 Results Obtained from Static Structural Analysis

In this part of the work, a static structural analysis was conducted to evaluate how the grinder housing would behave under operational loads. Based on the previously described setup, the obtained results were highly promising.

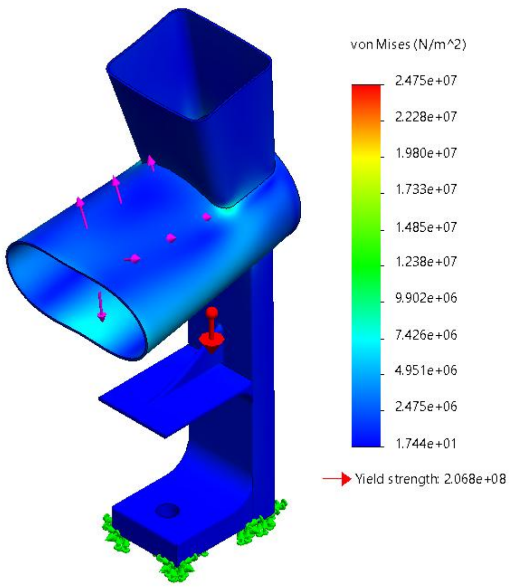

Fig. 18 *Equivalent Stress Result*

The analysis showed that the maximum stress in the housing was about **24.75 MPa.** Since the material for the housing is AISI 304 stainless steel was used, which has a much higher yield strength **206.8 MPa**, this means the structure is well within safe limits, there is no risk of it failing under normal operating conditions.

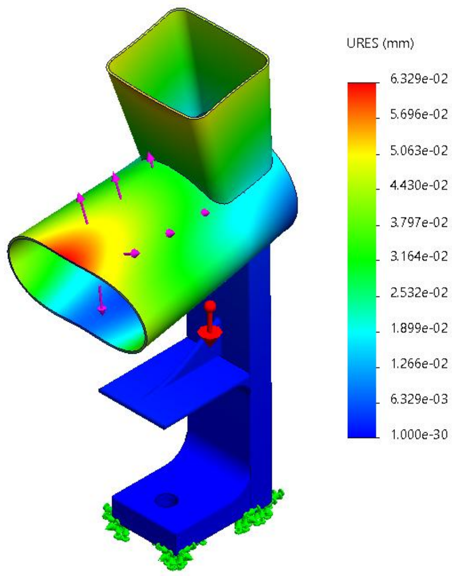

Fig. 19 *Total Deformation Results*

The deformation of the housing was also evaluated. The maximum displacement was found to be only 0.0633 mm, indicating that the housing remains dimensionally stable and does not exhibit flexural behavior that could affect machine operation.

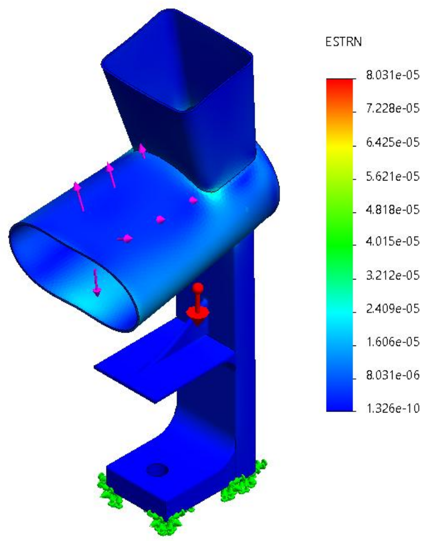

Fig. 20 *Equivalent Strain Distribution Results*

Now, looking at **strain**, the simulation recorded a **maximum equivalent strain** of around **8.031 × 10⁻⁵**, which is very low. This makes sense, because if the stress is within limits and the displacement is minimal, the strain, which is a measure of how much the material stretches, should also be small. This confirms that the structure isn't being overworked or pushed to its limits.

This result is also reassuring from a design standpoint. It means that the chosen material, wall thickness, and overall geometry of the housing were appropriate and effectively distributed the stresses throughout the structure. No region is overstressed or locally strained beyond what the material can tolerate. This adds confidence that the component can handle not just the simulated load, but also real-world variations in use, such as uneven seed loading, manual force fluctuations, or minor shocks during handling, without compromising performance or safety.

In summary, the low equivalent strain confirms that the housing design is both mechanically sound and conservative. It is not only strong enough to withstand the required forces, but it also maintains its shape and dimensional integrity over time, which is critical for proper assembly and function of all mating parts in the grinding machine.

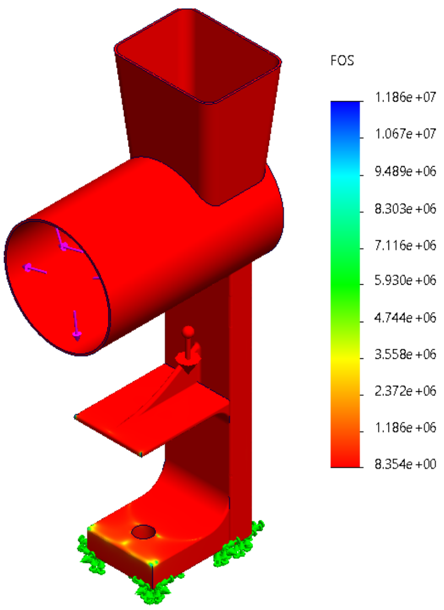

Fig. 21 *Factor of Safety*

Lastly, the safety factor came out to be around 8.35, which is more than enough. This gives me confidence that the design can handle much higher loads than what it was designed for, making it reliable even if conditions change slightly during use.

So overall, this simulation gave me solid proof that the design is strong, stable, and ready for real-world operation.

5. Conclusions

The development of precision casting molds for a hand-operated seed grinding machine using a CAM-based manufacturing approach has demonstrated significant benefits in terms of part quality, production efficiency, and mechanical performance. The successful trial casting of stainless-steel components, alongside the finite element analysis confirming low stress and displacement levels, validates the effectiveness of the process. These outcomes directly align with the project's aim of producing durable and affordable agricultural equipment tailored to rural manufacturing capabilities.

The use of CNC guided by CAM toolpaths has proven advantageous in achieving tight tolerances and complex geometries, which are critical for reliable die performance. Compared to conventional or manual mold-making methods, this digitally driven approach enhances reproducibility, reduces waste, and shortens lead times. These results are consistent with trends in the literature that emphasize the value of integrated CAD/CAM workflows in precision toolmaking [12].

However, the process does have limitations. It requires access to high-end CNC equipment, skilled operators, and upfront software investment, which might limit immediate adoption in low-resource settings. Despite these barriers, its application in small-scale foundries or regional machine shops remains highly promising, especially where quality and consistency are critical.

The broader significance of this work lies in its scalability and adaptability. The design framework and tooling strategy can be extended to similar agricultural devices or small mechanical systems, fostering localized manufacturing solutions. Furthermore, the integration of simulation and CAM not only optimizes current designs but also lays the groundwork for automation and real-time quality control in future applications.

Follow-up research could explore hybrid manufacturing methods (e.g., additive + subtractive tooling), automation of toolpath optimization using AI, or material substitution using biodegradable alloys [9] [13]. Experimental validation of casting thermal cycles and analysis of long-term performance in field conditions are also proposed to enhance the robustness of future designs.

In summary, this work contributes meaningfully to sustainable manufacturing by combining digital precision with practical rural needs, and it opens new avenues for high-quality, low-cost production in underserved regions.

Acknowledgements

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