

Curing Rocket Motor Grains Under Pressure

System Justification, Design Considerations, and Material Selection

1 Design Justification Based on Nakka's Method

The design ensures the grain is cured under consistent pressure throughout the cooling and solidification process. The scientific reasoning for this selection rests primarily on the material behavior of KNSB propellant during phase change. When the sorbitol fuel component is melted and mixed with potassium nitrate, the resulting slurry must be cast into molds to cool and solidify into propellant grains. However, during cooling, shrinkage occurs due to thermal contraction and crystallization. Without an applied force to counteract this shrinkage, internal voids and surface cracks are likely to form. These defects compromise the structural integrity of the propellant grain and lead to uneven burning, inconsistent thrust, and a high risk of grain fracture or detachment inside the combustion chamber. Applying pressure during curing ensures that the grain remains densely packed, minimizing porosity and stabilizing the internal structure. A spring mechanism applies this pressure consistently in a passive manner. Each part of the curing device serves a specific and essential function.

The central cylindrical chamber holds the molten propellant mixture and defines the final shape of the grain. It is designed to withstand moderate internal pressure and retain thermal energy to support uniform cooling. Inside this chamber, a piston or plunger is vertically placed on top of the propellant mass. This piston is directly connected to a compression spring located in the upper portion of the assembly. The spring is preloaded when assembled, exerting a downward force through the piston onto the grain. This constant force counteracts the internal tension produced during cooling and maintains material contact with the mold walls, effectively eliminating the formation of air pockets.

The bottom plate is a critical structural element. It acts as a counter-support to the spring's force, preventing the chamber from lifting or deforming under compression. It is firmly screwed into place to resist both vertical and lateral loads, ensuring the entire assembly remains stable during curing. The base is mounted on a wooden platform.

After the curing process, the expected implications of this method are highly favorable. The grain produced will have improved mechanical strength due to better internal bonding and higher packing density. This translates into greater reliability during motor ignition and burn, as the grain is less likely to crack or erode irregularly. Combustion efficiency is also enhanced because the fuel-oxidizer ratio is preserved consistently throughout the grain's structure, minimizing localized hot spots or incomplete burning. Furthermore, this method allows for reproducibility in batch manufacturing, which is essential in the context of rocket production, where standardization and safety are paramount.

The choice of using a spring-loaded press instead of hydraulic or pneumatic alternatives was based on practical engineering trade-offs. Springs offer a low-cost, low-maintenance solution that is self-regulating and compact. They require no external power supply, making them suitable for field use or remote fabrication setups. Additionally, the restoring force of a spring follows a predictable linear behavior, which allows the curing pressure to be engineered precisely based on spring selection and compression distance.

2 Spring Constant and Force Calculations

Hooke's Law:

$$F = kx \quad \Rightarrow \quad k = \frac{F}{x}$$

Pressure Range: 170–275 kPa

Area of annulus:

- Outer diameter = 92 mm $\Rightarrow R = 46$ mm
- Inner diameter = 86 mm $\Rightarrow r = 43$ mm
- $A = \pi(R^2 - r^2) = \pi(2116 - 1849) = 838.8 \text{ mm}^2$

Force Range:

- $F_{max} = 0.275 \text{ MPa} \times 838.8 \times 10^{-6} = 230.7 \text{ N}$
- $F_{min} = 0.170 \text{ MPa} \times 838.8 \times 10^{-6} = 142.6 \text{ N}$

This defines the necessary spring force for uniform pressure during curing.

3 CAD Design and Slicing Preparation

The curing mold includes a spring-loaded top plate and a stationary bottom plate, designed using CAD software and exported as STEP files. These include:

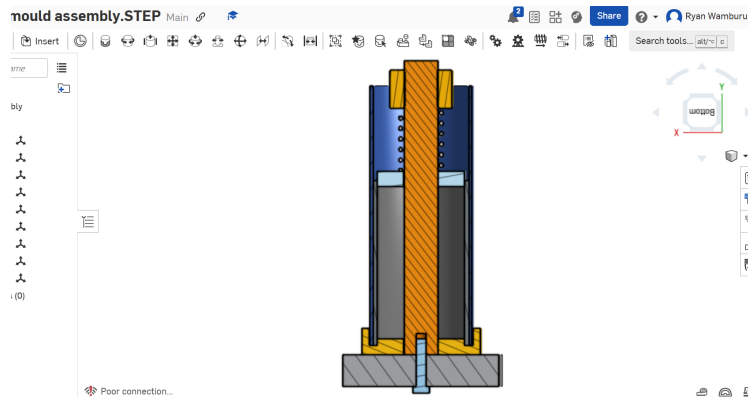


Figure 1: Mold assembly in Onshape

These parts were prepared for 3D printing in PrusaSlicer to ensure strength, proper infill, and optimal layer bonding.

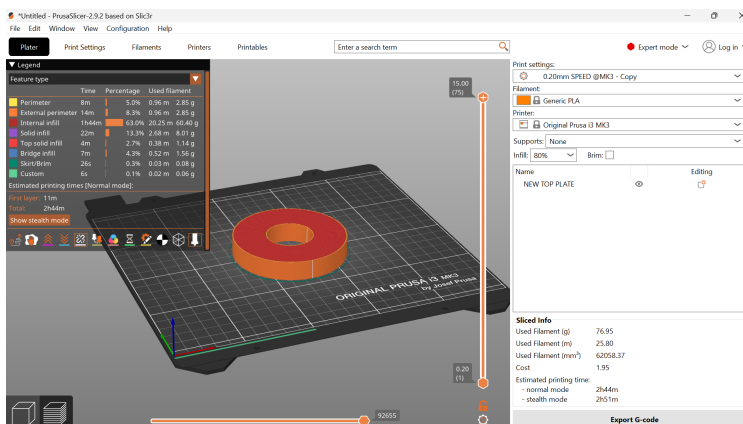


Figure 2: Top Plate Prepared in PrusaSlicer

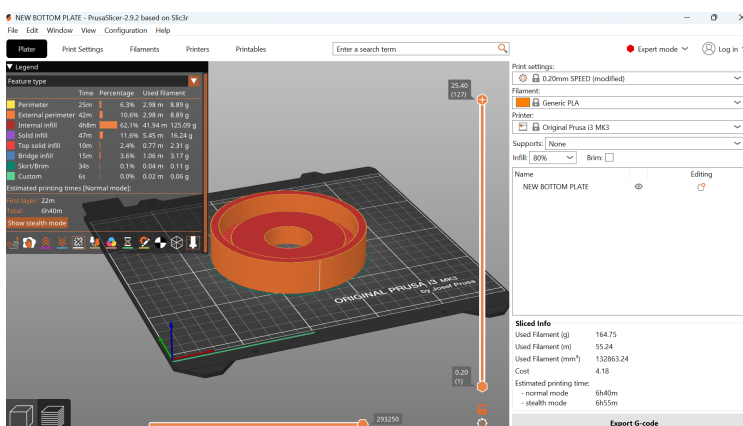


Figure 3: Bottom Plate Prepared in PrusaSlicer

4 Material Justification: PETG , PLA, and ABS

Evaluating the appropriate material for 3D printing the structural plates of a spring-loaded curing device designed to hold the potassium nitrate sorbitol slurry at a curing temperature of approximately 60°C, it is essential to select a polymer that balances thermal resistance, dimensional stability under load, mechanical strength, and print-ability.

Comparison of Printable Materials

Property	PLA	PETG	ABS
Glass Transition (°C)	60	80–85	105
Printability	Very Easy	Moderate	Needs Enclosure
Strength	Brittle	Tough	Tough
Thermal Resistance	Low	Moderate	High
Layer Adhesion	Moderate	Good	Fair
Warping Risk	Low	Low	High
Best Use Case	Prototypes	Functional Parts	Mechanical Fixtures
Print Difficulty	Low	Medium	High

Table 1: Comparison of 3D Printing Materials

Why PETG?

- $T_g \approx 80\text{--}85^\circ\text{C}$, ideal for curing temperatures around 60°C
- Strong and durable, good layer adhesion