A High-Temperature Valve Design for Lunar Regolith Aluminum Extraction

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I. Introduction

Previous work on high-temperature regolith processing focused on oxygen as the main product or looked at iron and titanium that would be extracted from mare regolith at equatorial landing sites.

With the current goal of building up infrastructure at the lunar south pole in highlands terrain, **aluminum is a much more viable metal** and has diverse applications in **power transmission, radiators, and structures.**

The MAGMA project (Molten Aluminum Generation for Manufacturing Additively) is a LuSTR23 selection to mature technology for extracting aluminum from regolith at the lunar south pole and turning it into an additive manufacturing feedstock. Given the 1500°C or above nature of extracting the aluminum from highlands regolith, a need for the development of a high temperature valve is necessary. Here, we provide an update on the progress of the project and future plans.

II. MAGMA Overview

MAGMA is led by the Colorado School of Mines, with Lunar Resources acting as the sole industry partner. The team has expertise in lunar geology, In Situ Resource Utilization (ISRU) hardware, metallurgy, materials science, and additive manufacturing.

The main technology pursued is Molten Regolith Electrolysis (MRE), which operates directly on raw regolith of any composition **without the need for an electrolyte or other consumables shipped from Earth**. This process occurs at temperatures where metals, such as aluminum, are molten. When extracting aluminum from the reactor, its flow must be precisely regulated to successfully form additive feedstock.

While transport of multiple melt compositions are required, aluminum is the focus of this poster.

III. Design Requirements

Several requirements were imposed on the system that affected design choices. These are outlined below to provide background.

- Interface: The valve must integrate with an MRE reactor using a **10" CF vacuum flange**.
- Material Compatibility: The design materials must **survive** prolonged exposure of **corrosive molten regolith** and **extreme heat** without degrading.
- Working Fluid Constraints: The design must be **compatible** with molten aluminum's **viscosity** and **density**.

IV. Final Design Concept – The Lensing Valve

- The selected final design concept features a plunger assembly constructed from two graphite pipes joined together in a Y shape.
- A motorized actuator linearly drives a **barbed graphite plunger** backwards and forwards within the top pipe.
- The valve precisely regulates the flow rate of the molten material by partially covering or uncovering the opening of the Y joint.
- To prevent the unwanted flow of molten aluminum toward the actuator, **machined barbs trap the aluminum and block its path using surface tension**.
- Graphite was chosen as the primary valve material because it provides desirable material compatibility with the molten regolith and demonstrates superior ease of machinability.

Guess Values

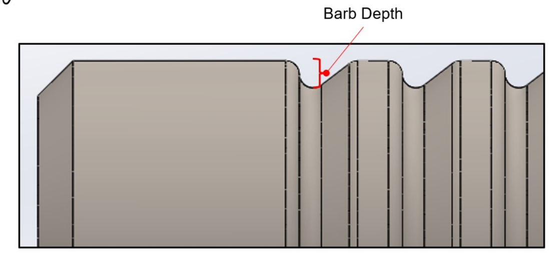
$$\gamma := 0.868\ N \cdot m^{-1} \qquad \theta := 19\ deg$$
$$D_{pipe} := 1\ in \qquad \rho := 2700\ \frac{kg}{m^3}$$
$$g := \frac{9.81}{6}\ \frac{m}{s^2} \qquad X := 5\ in$$
$$h := X \cdot \sin(\theta) \qquad D_{barb} := -.975\ in$$

Constraints

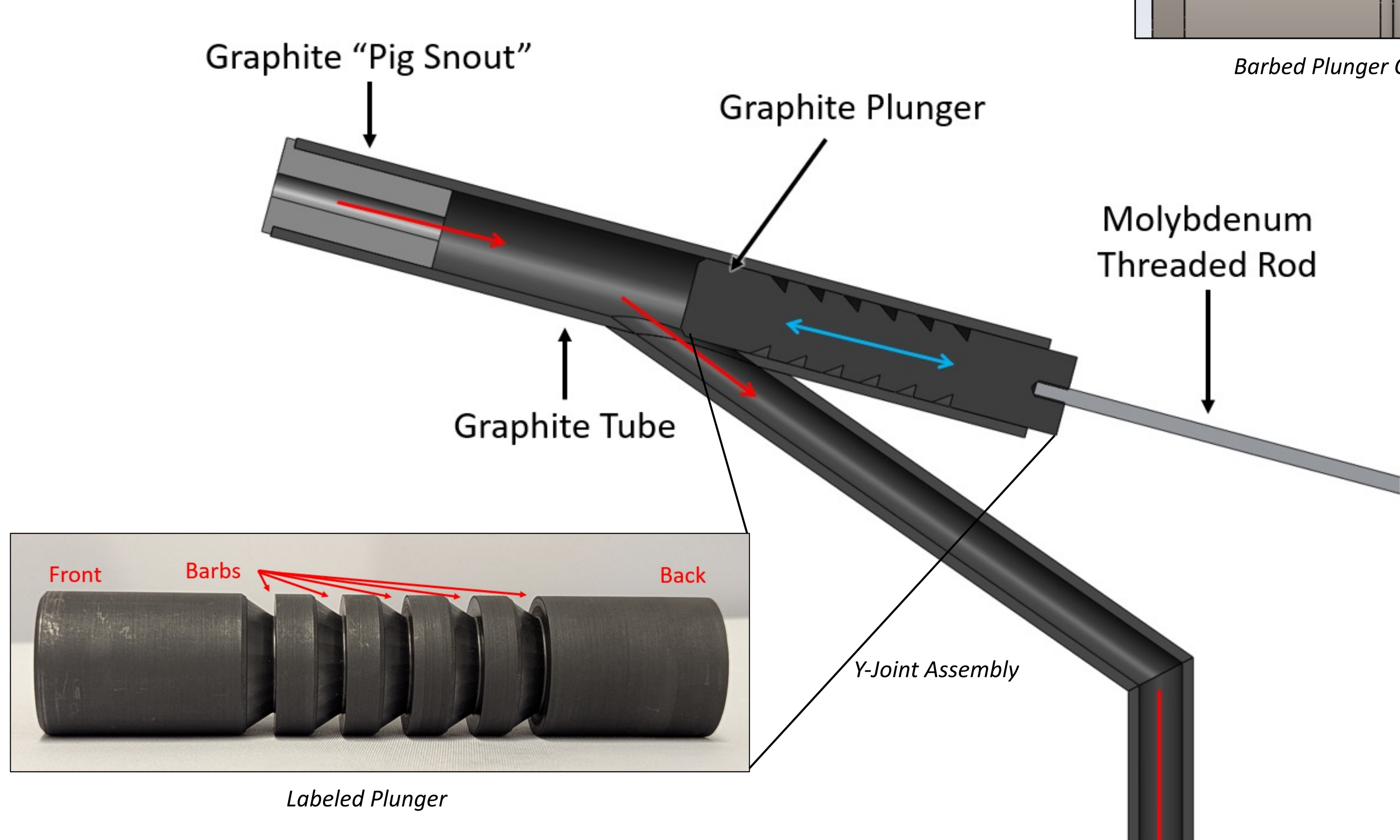
$$\pi \cdot D_{barb} \cdot \left(D_{barb} - \frac{\gamma}{\rho \cdot g \cdot h}\right) = 2.954\ in^2$$

Solver

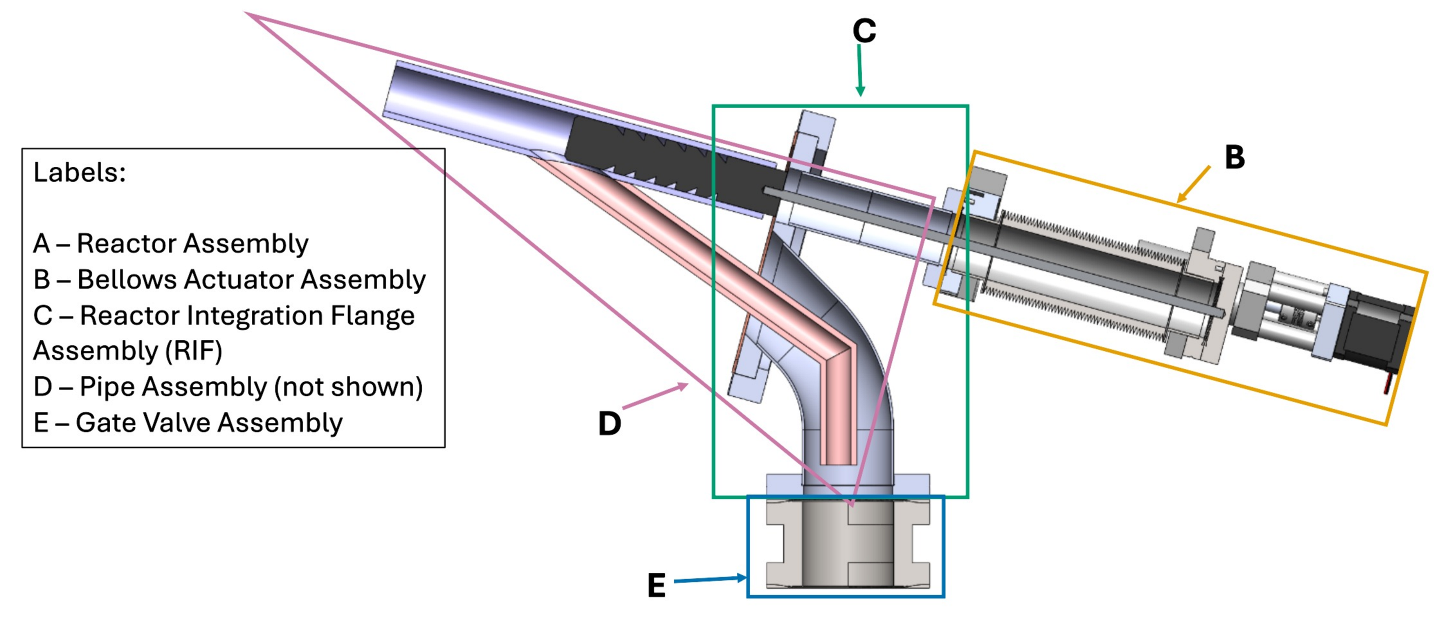
$$sol := \text{find}\left(D_{barb}\right) = -0.881\ in$$



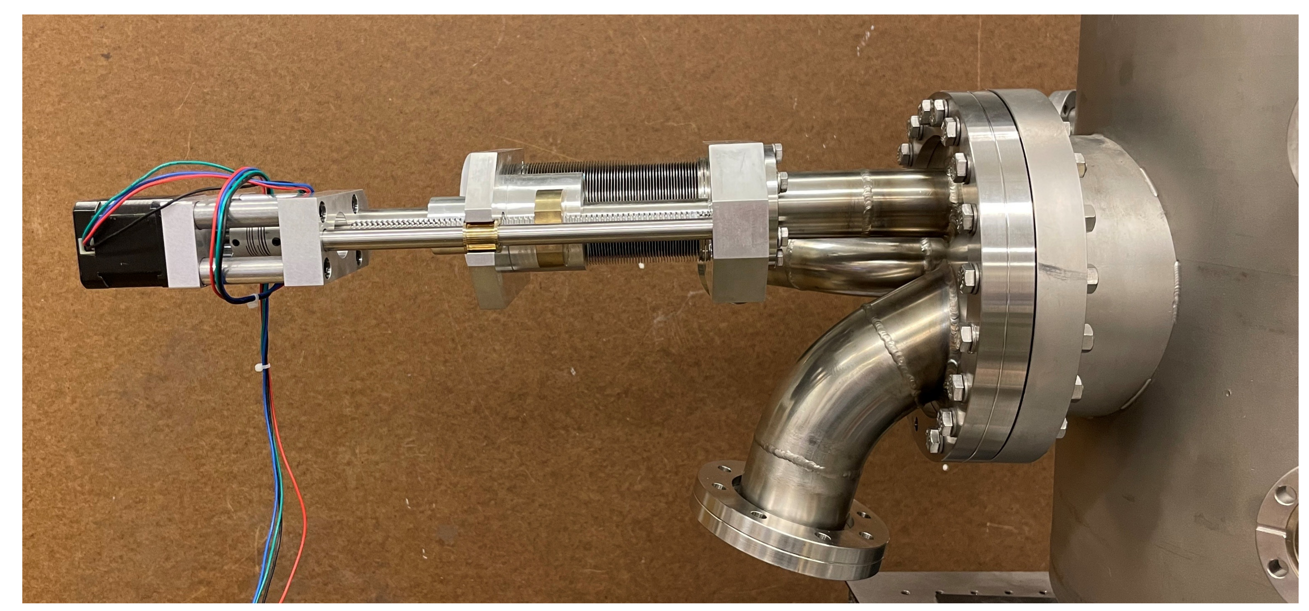
Barbed Plunger Concept



Labeled Plunger



Y-Joint Assembly



Integrated Valve Assembly with a Vacuum Chamber

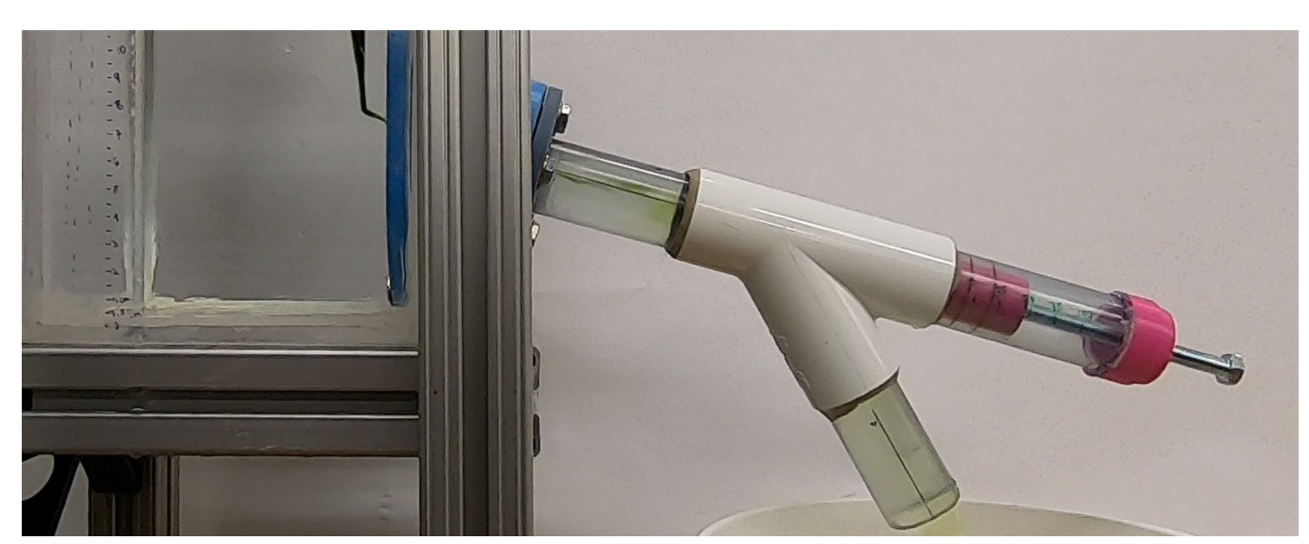
Material Compatibility Decision Matrix

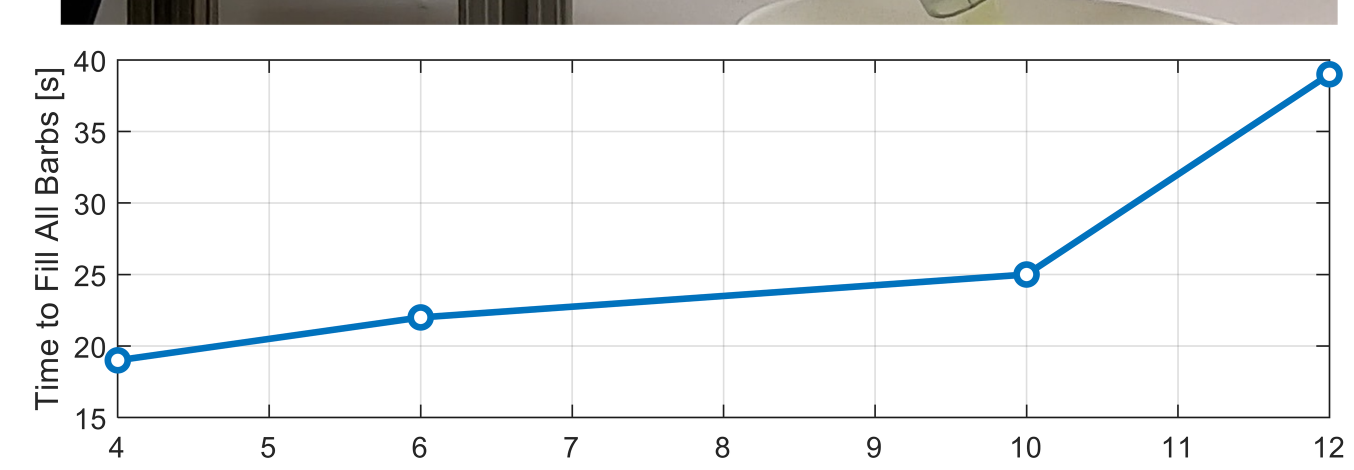
Criteria	Graphite	Alumina	Boron Nitride
Resistant to high temperatures (660°C)	High	High	High
Machinable	High	Medium	High
Non-wetting	High	High	High
Resistant to thermal shock	High	Low	High
Affordable	High	Low	Low

VI. Analogous Environment Testing

To **evaluate** the **performance** of varying designs, an analogous test setup was created to accommodate different valve prototypes. These prototypes were tested using water as the working fluid, given its viscosity is highly comparable to that of molten aluminum.

From these preliminary tests, a controllable flow rate **range of 1 – 4 cc/s** was successfully achieved with the final plunger design with 6 barbs.



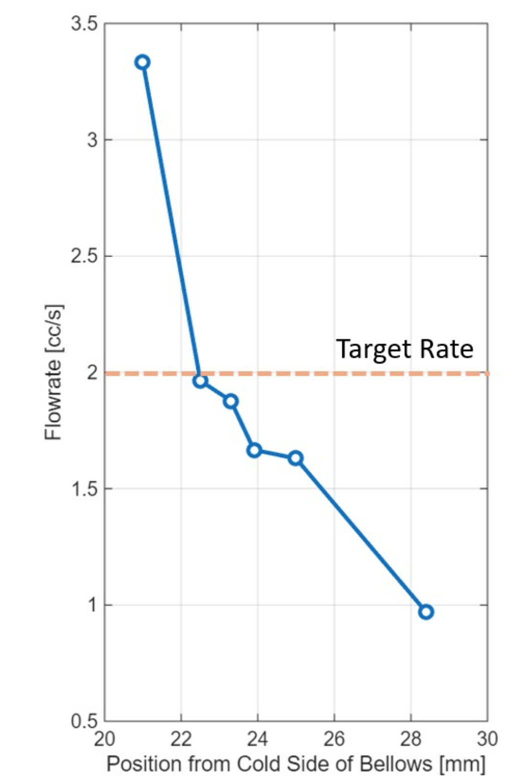


Flow Time as a Function of the Number of Barbs

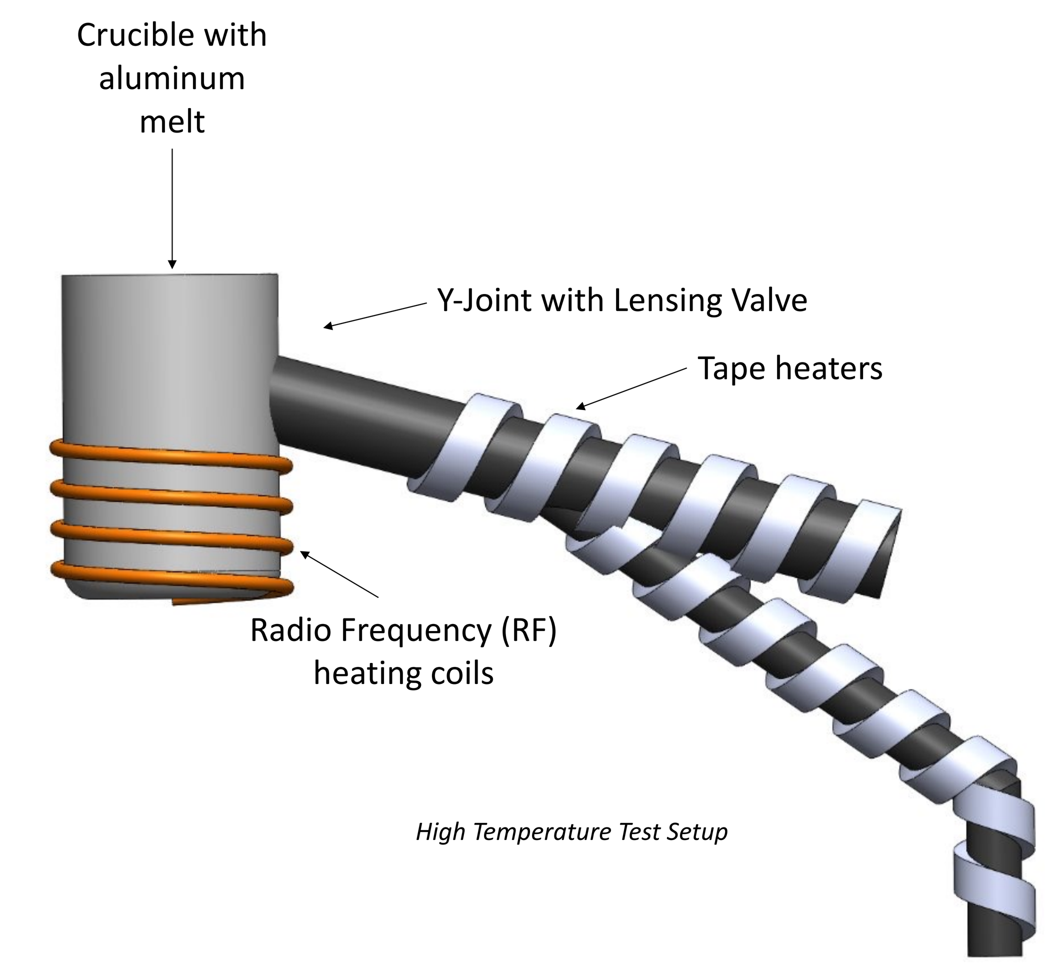
VII. High Temperature Testing

Objectives:

- Verify the tap can **actively** and **reliably control flow** of molten aluminum.
- Investigate the **aluminum leak rate** past the plunger over an extended time period.
- **Prove the concept**.



Flow Rate Calibration of Y-Joint

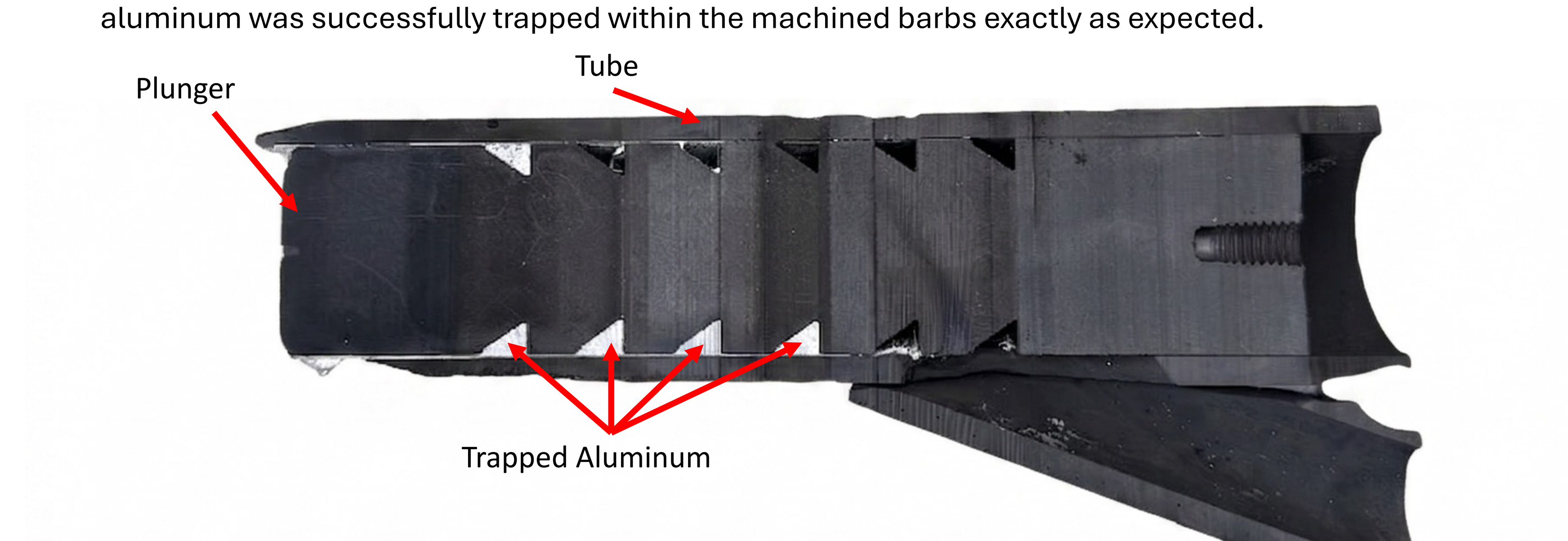


High Temperature Test Setup

Due to unforeseen circumstances, the test had to be conducted in ambient air rather than in vacuum.

- This exposure caused the graphite components to oxidize, become brittle, and ultimately fracture, ending the test prematurely.
- The components were hot for 6 hours during the test.

Despite this, the **core operational concept of the valve was validated**, as the molten aluminum was successfully trapped within the machined barbs exactly as expected.



Post-Test Cross-Section of Plunger in Y-Joint

VIII. Conclusion

- The Lensing Valve concept was successfully proven as a **versatile blueprint** for **regulating** multiple molten **working fluids**, highly adjustable via the number and depth of the plunger barbs.
- The integration of machined barbs **effectively utilizes surface tension to trap molten material** and completely block unwanted flow.
- By successfully demonstrating this flow control application in a relevant environment, the Lensing Valve has achieved **Technology Readiness Level 4**.

IX. Future Work

This technology is critical to a cislunar economy. Therefore, future work should aim to increase the Technology Readiness Level (TRL). Testing should include:

- A **high temperature test** within a **vacuum environment**.
- An **integrated** test with a **MRE reactor** undergoing an **MRE process**.

X. Acknowledgements

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