Extensive Testing, Standardization and Formalization of KNSB-Based Solid Rocket Motor

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INTRODUCTION

In the field of amateur and experimental rocketry, getting reliable and efficient propellant formulations is one of the major objectives among the rocketeers. Potassium Nitrate and Sorbitol (KNSB) with oxidizer to fuel (O:F) ratio of 65:35, a popular choice among hobbyists and researchers, offers a unique combination of accessibility, cost-effectiveness, and performance. However, despite its widespread usage, the KNSB-based solid rocket motors (SRMs) lack standardized manufacturing and formalized performance metrics, which are critical for their consistency and safety. This paper aims to bridge this gap by introducing a comprehensive study on the extensive testing, standardization, and formalization of KNSB-based SRMs. With series of methodical experiments and rigorous evaluations, we seek to propose a method to reliably manufacture KNSB-based SRMs and KNSB propellant with minimal errors and variants. As the baseline is established, modern KNSB data can be beneficial to the rocketry community as the interests keep growing more and more.

ENGINEERING FOR SAFE, FAST AND REUSABLE ASSEMBLY

Normally the structure of most sugar-based SRMs is a metallic casing with radially bolted metallic bulkhead and nozzle. The material of the nozzle can vary across many designs. To ensure maximal thermal safety and reusability, a combination of material with special properties and ablative materials is designed to serve rocket's internal ballistics requirements. The nozzle throat uses standard high-density graphite due to its high thermal conductivity, high melting point, low thermal expansion, erosion resistance, and machinability. This choice is obvious, but for nozzles and bulkheads, there are many variations to it: aluminum, graphite-only, stainless steel, etc. One of the materials we looked into was "linen phenolic," which is an ablative material with low thermal conductivity and high melting point. It can be paired perfectly with graphite throat to reduce surface erosion of standard metallic nozzles or graphite-only nozzles. Linen phenolic is also added to our bulkhead design to prevent heat from directly transferring to the motor structure made of aluminum, which can cause serious structural strength reduction when the temperature is sufficiently high. Standard paper liner with zero gap is also used to prevent any gas's direct contact with aluminum structure.

When assembling the SRM to the rocket, normally, there will be a size adapter and assembling them with radially bolted SRM can be tricky and uses more time. Risks when handling rocket motor with loaded explosive can increase over time. To achieve faster motor assembly, a single thread design is used in place of traditional radially bolted design. This reduces the number of threads/bolts required to assemble the nozzle, bulkhead and casing together as tightening threads can increase risk of heat from prolonged friction. Direct thread design can also increase strength because it does not introduce shear load onto radial bolts as it does not have one. This single thread design can also be extended to mounting the motor itself to the rocket using another single-thread mount adapter. The adapter and the rear of the airframe are "clamped" together by tightening the bulkhead with the mount adapter.

Nevertheless, single thread design can pose some risk of "decoupling" or motor/parts detaching from each other under fast and unpredictable rotational motion. This can be solved with gluing threads together with thread lock, but it defeats the purpose of parts reusability. High-temperature RTV silicone can be used in place to temporarily lock the threads together. It can be easily dissolved after launch while is sufficiently strong enough to adhere with metallic threads.

To ensure maximal performance with correct burn rate and thrust curve. A urethane plug is used to plug the nozzle to help build up the chamber pressure to its nominal operation pressure before ejecting the gas through the nozzle.

EXPERIMENTATION AND PROBLEMS WITH KNSB

KNSB can provide on-par performance compared to Potassium Nitrate and Sucrose (KNSU) and is safer to handle in the melting process while manufacturing. Despite being in the rocketry community for so long, many rocketeers may not have any problems with KNSB regarding its performance expectations. However, when we tried to experiment with KNSB, several problems were observed in many testing procedures. In one of our static firing test with BATES grain KNSB in 6-inch-diameter SRM, we observed the mountain-shaped thrust curve like the one Richard Nakka observed in the past. Extensive testing was conducted to determine the source of the mismatch curve. First, we increased the spacing between the grain as suggested, but the thrust curve was still mountain-shaped. Then, a thin layer of primer (dough-like black powder) is coated onto the forward and rear planar surfaces of all propellant grains inside the SRM. Most of the thrust curves observed in the static firing tests after modification were "textbook-correct," but a few batches still showed similar thrust curves. In the post-firing check, we noticed that the paper liner of some propellant grains were ripped off and some are burnt differently from other grains. The surface "debonding" or "disbonding" effect was the most probable cause of the observed inconsistencies.

The debonding effect of KNSB-paper can be resolved in many ways. Spring compression to the propellant casting mold during its cool down phase can help bonding the grain with the paper; however, as we have directly encountered the problem, it can make the propellant grain "sink" which makes one of the surfaces curve. Another solution is to coat the paper liner with polymeric isocyanate, which is commonly found in polyurethane foam as it can help adhering KNSB and paper together.

STANDARDIZATION OF MANUFACTURING KNSB

After experimenting with parameters affecting the quality and consistency of KNSB propellant grain, we came up with step-by-step to manufacture KNSB-based propellant with very high consistency across different batches. This includes chemical grade, grain mixing, propellant casting mold design, temperature control, humidity control, edge trimming, surface coating with primer, and compression considerations. Each of these steps can potentially affect the product in some way, so they all must be controlled.

RESULTS, CONCLUSIONS, AND FOLLOW-ON WORK

Our results demonstrate that by adhering to a standardized process, the performance of KNSB-based SRMs can be predicted more accurately and consistently. This predictability is crucial for safety and performance in amateur rocketry. Through our extensive testing, we have identified key factors that influence the quality and consistency of the propellant. By addressing these factors, the variability in performance can be significantly reduced, leading to safer and more reliable rocket launches.

The comprehensive study and experiments conducted on KNSB-based solid rocket motors have confirmed that systematic manufacturing processes and rigorous testing protocols can greatly enhance the reliability and safety of these motors. The implementation of standard manufacturing processes for KNSB propellant and SRMs is essential in achieving the desired performance and safety standards in amateur rocketry.

Future work will observe more on debonding effect and focus on refining the standardization processes and exploring new materials and techniques that could further improve the performance and safety of KNSB-based SRMs. Additionally, long-term stability studies and field tests under various environmental conditions will be conducted to ensure the robustness and reliability of the propellant over time. Further research into the environmental impact and disposability of SRM components will also be necessary to promote sustainable practices in rocketry.

REFERENCES

KNSB Propellant, Richard Nakka