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Analysis and Study of the Effects of Pre-Damage and Deformation on the Burning Rate of HTPB Propellants

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Extended Abstract

With the rapid advancement of strategic missile weapons and space launch vehicles, solid rocket motors (SRMs) are growing in size and complexity. This trend has led to increasingly intricate propellant grain structures. Throughout various stages—casting, curing, transportation, storage, and eventual launch—these solid propellant grains inevitably endure a combination of external mechanical and thermal loads. These loads can cause internal damage and deformation, which may alter the combustion behavior of the propellant. Such changes can, in turn, affect the internal ballistic performance of the motor. In the worst cases, these alterations might lead to the motor's inability to operate properly, compromising the mission's success. While extensive research has been conducted on how environmental pressure and the initial temperature of propellants influence burning rates, the impact of pre-existing damage (pre-damage) and mechanical deformation on burning rates has received relatively little attention. Yet understanding these effects is crucial. The development of a reliable formula to describe how pre-damage and deformation influence the burning rate of solid propellants would provide valuable insights for improving the reliability and safety of SRMs, offering significant engineering benefits.

In this study, an improved experimental apparatus was developed based on the "line-of-sight method." This new setup was specifically designed to measure the burning rate of composite solid propellants under conditions of transverse compressive deformation. The researchers measured the burning rates of HTPB propellants under varying conditions of axial tensile pre-damage and transverse compressive strain. By analyzing the collected data, they derived a formula that quantifies the relationship between pre-damage, deformation, and burning rate. In addition to measuring burning rates, the study employed scanning electron microscopy (SEM) to observe the internal damage of propellant samples. These observations revealed the microscopic changes within the propellant caused by different levels of axial tensile strain and transverse compressive strain. By correlating these SEM observations with the experimental data, the researchers uncovered the underlying mesoscopic mechanisms that explain how pre-damage and deformation affect burning rates. Using the derived formula, the study also conducted a two-dimensional numerical simulation to model how deformation impacts the movement of the combustion surface during burning. This simulation provides a more detailed understanding of the interaction between mechanical deformation and combustion dynamics, yielding practical insights for motor design and performance optimization.

The findings from this research are both specific and significant: At lower levels of transverse compressive strain, deformation did not generate new cracks. Instead, it caused existing micro-cracks to close, which prevented flames from penetrating into these cracks. As a result, the burning rate was slightly reduced. When the transverse compressive strain reached the propellant's failure strength, the propellant's internal structure was crushed in certain areas. This led to the formation of additional cracks, which increased the burning rate. However, the extent of internal damage varied, causing considerable fluctuations in the burning rate at higher strain levels. Axial tensile pre-damage had minimal direct impact on the burning rate. However, it influenced the propellant's failure strength, thereby altering how burning rates changed in response to deformation. By providing a comprehensive analysis of the effects of pre-damage and deformation on HTPB propellant burning rates, this study offers a valuable foundation for future research and the design of more reliable solid rocket motors.