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Author: Dr. Ch Paravan
Politecnico di Milano, Italy, christian.paravan@polimi.it

Mr. Alam U. Garciduenas Correa
TU Delft, The Netherlands, A.U.GarciduenasCorrea@tudelft.nl

GREEN SOLID FUELS WITH ENHANCED MECHANICAL PROPERTIES: USE OF SUSTAINABLE WAXES AND SCALE-UP ANALYSIS OF ARMORED GRAINS.

Abstract

Marketability of hybrid rocket engines is hampered by trade-offs between solid fuel grain mechanical properties and ballistic response. The most promising solutions for fast regression rates of the solid fuels are the use of liquefying formulations and non-conventional oxidizer injection methods. Liquefying fuels, as paraffin wax, provide fast regression rates offering the perspective of high thrust levels with relatively simple grain geometries (i.e., single, central port configurations). The low mechanical properties of liquefying fuels cancel the advantage of their fast regression. Stronger mechanical properties are achieved blending the liquefying fuel with thermoplastics. Reinforcing polymers hinder the fuel liquefying behavior, thus reducing the regression rate. Non-conventional vortex injection provides enhanced regression rate and combustion efficiency, but its application is limited to relatively short grain geometries to prevent flow viscous dumping and non-uniform regression of long grains.

Recently, new reinforcing strategies exploiting 3D-printing are emerging. This includes the hereby presented armored grain in which a printed cellular reinforcing structure is embedded.

In this paper, lab-scale testing of wax-based armored grains is discussed by pre-burning analyses and combustion testing. Scale-up of the armored grain is presented. The feasibility of greener and more sustainable liquefying fuels with reinforcing armor is discussed based on experimental data.

First, effects of reinforcing structure geometry and mass on the regression rate and mechanical response of the grains are identified by lab-scale testing. With simple, standard flow injection, grains embedding a reinforcing structure show faster regression rates than pure paraffin wax (with +90% increase under reference conditions). This performance is combined with increased mechanical properties. Cellular structure reinforcement yields grains exhibiting plastic behavior while waxes typically show frail and brittle behavior. The possible interplay of the 3D-printed reinforcing structure with the oxidizer injection implementation (standard/vortex) is discussed based on relative grading of firing tests. Grains embedding cellular structure offer fast regression rates independently from the injection method. The scale-up of the armored grain solution is presented exploiting a test-bench realized by Skyward Experimental Rocketry, a student-association of Politecnico di Milano. Achieved results show the scalability of the armored grain solution and the benefits in terms of regression rate enhancement. Given this working base, the possibility of using waxes and 3D-printing polymers from sustainable sources is discussed. Achieved results show how the proposed solution may disclose new opportunities for the exploitation of the low cost, environmentally friendly hybrid propulsion.