Real-Time X-ray Radiography Diagnostics of Components in Solid Rocket Motors

A.C. Cortopassi, H.T. Martin, E. Boyer, and K.K. Kuo
The Pennsylvania State University, University Park, USA

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Solid rocket motors (SRMs) typically use nozzle materials which are required to maintain their shape as well as insulate the underlying support structure during the motor operation. In addition, SRMs need internal insulation materials to protect the motor case from the harsh environment resulting from the combustion of solid propellant. In the nozzle, typical materials consist of high density graphite, carbon-carbon composites and carbon phenolic composites. Internal insulation of the motor cases is typically a composite material with carbon, asbestos, Kevlar, or silica fibers in an ablative matrix such as EPDM or NBR. For both nozzle and internal insulation materials, the charring process occurs when the hot combustion products heat the material intensely. The pyrolysis of the matrix material takes away a portion of the thermal energy near the wall surface and leaves behind a char layer. The fiber reinforcement retains the porous char layer which provides continued thermal protection from the hot combustion products. It is of great interest to characterize both the total erosion rates of the material and the char layer thickness. By better understanding of the erosion process for a particular ablative material in a specific flow environment, the required insulation material thickness can be properly selected.

The recession rates of internal insulation and nozzle materials of SRMs are typically determined by testing in some sort of simulated environment; either arc-jet testing, flame torch testing, or subscale SRMs of different size. Material recession rates are deduced by comparison of pre- and post-test measurements and then averaging over the duration of the test. However, these averaging techniques cannot be used to determine the instantaneous recession rates of the material. Knowledge of the variation in recession rates in response to the instantaneous flow conditions during the motor operation is of great importance. For example, in many SRM configurations the recession of the solid propellant grain can drastically alter the flow-field and effect the recession of internal insulation and nozzle materials. Simultaneous measurement of the overall erosion rate, the development of the char layer, and the recession of the char-virgin interface during the motor operation can be rather difficult. While invasive techniques have been used with limited success, they have serious drawbacks. Break wires or make wire sensors can be installed into a sufficient number of locations in the charring material from which a time history of the charring surface can be deduced. These sensors fundamentally alter the local structure of the material in which they are imbedded. Also, the location of these sensors within the material is not known precisely without the use of an X-ray. To determine instantaneous recession rates, real-time X-ray radiography (X-ray RTR) has been utilized in several SRM experiments at PSU.

The X-ray RTR system discussed in this paper consists of an X-ray source, X-ray image intensifier, and CCD camera connected to a capture computer. The system has been used to examine the ablation process of internal insulation as well as nozzle material erosion in a subscale SRM. The X-ray source is rated to 320 kV at 10 mA and has both a large (5.5 mm) and small (3.0 mm) focal spot. The lead-lined cesium iodide X-ray image intensifier produces an image which is captured by a CCD camera with a 1,000 x 1,000 pixel resolution. To produce accurate imagery of the object of interest, the alignment of the X-ray source to the X-ray image intensifier is crucial. The image sequences captured during the operation of an SRM are then processed to enhance the quality of the images. This procedure allows for computer software to extract data on the total erosion rate and the char layer thickness. Figure 1 **Error! Reference source not found.**shows a sequence of images captured during the operation the subscale SRM with the X-ray RTR system. The X-ray RTR system, alignment procedure, uncertainty determination, and image analysis process will be discussed in detail in the full manuscript.

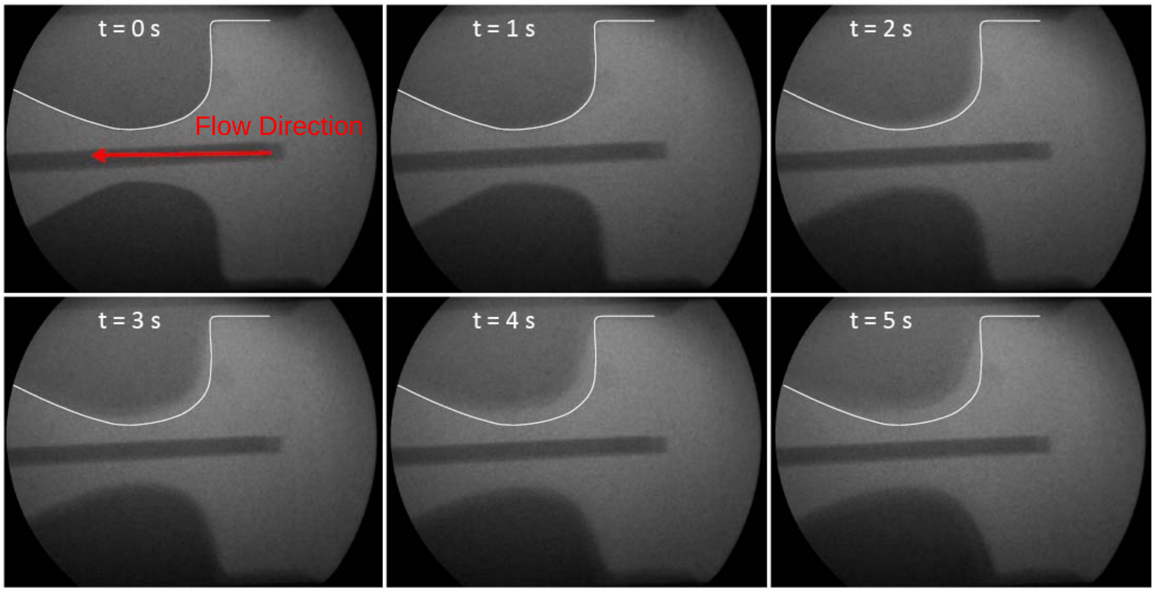

Figure 1. A typical set of X-ray images showing the erosion of a SRM nozzle from its initial contour