Vid. Proc. Adv. Mater., Volume 2, Article ID 2111245 **(2021)**

Modeling Charring Ablation of Ablative Composites using Finite Element Analysis in ABAQUS

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DOI: 10.5185/vpoam.2021.11245

Abstract

Modeling charring ablation is of critical importance to the design of ablative thermal protection systems for atmospheric entry/re-entry spacecraft and high-speed vehicles. The objective of such modeling effort is to predict the evolutions of the temperature and material recession in the charring ablation process. The predictions will be used for the initial screening of new designs of ablative materials or structures for thermal protection systems. Modeling charring ablation involves solving mass, momentum, and energy conservation equations considering the heat losses due to the surface chemical reactions and the liberation of pyrolysis gases, as well as the moving boundary condition caused by the progressive material removal. Such models are complex and typically cannot be achieved using commercial, general purpose finite element analysis (FEA) software. They are often achieved through developing custom-written codes, such as FIAT and CHAR developed by NASA and HERO developed by ATK Orbital. However, these codes show less capabilities in terms of usability, pre- and post-processing, mesh generation, flexibility, and ability to couple with CFD codes. Additionally, using these codes adds additional cost of software purchase and adds additional time in software training. Moreover, they are often ITAR restricted and not available in the public domain. To address this challenge, we have developed user subroutines that allow us to model charring ablation using the commercial, general purpose FEA software, ABAQUS. The model has been successfully verified for a benchmark 1D charring ablation problem with the Theoretical Ablative Composite for Open Testing 3.0 test case. Our predictions of the thermal and ablative responses agree well with those predicted using NASA FIAT (a well-validated charring ablation code). Moreover, we have assessed the predictive capability for modeling the charring of a phenolic impregnated carbon ablator subjected to oxygen-acetylene torch ablation. The comparison between our predictions and the experimental data provides us future possible directions in improving the design of torch ablation tests.

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