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PERIDYNAMIC MODELING OF CRACKING AND DEGRADATION IN CHARRING AND NON-CHARRING MATERIALS DURING ABLATION

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Abstract
Polymers and ceramics are preferred materials for ablative Thermal protection systems (TPS) owing to their superior thermal and mechanical properties. Based on their degradation mechanism in the presence of heat, they can be classified as non-charring and charring. In non-charring materials, the material degradation is limited to the surface and can be caused due to chemical reactions or thermomechanical erosion. During this process, the volume of the initial material changes; however, the density of the material remains constant. However, a charring ablative undergoes internal decomposition leading to the formation of char, release of pyrolysis gases, and deterioration in material properties. This study presents a 3D coupled thermo-chemo-mechanical peridynamic (PD) model to simulate the pyrolysis process and crack propagation of charring materials and degradation in non-charring materials due to aerodynamic heating.

1. Introduction

Peridynamics (PD) introduced by Silling [1] is a nonlocal continuum theory without requiring spatial derivatives. The material response in PD includes damage. This feature allows damage initiation and propagation at multiple sites, with arbitrary paths inside the material. In PD, internal forces are expressed through nonlocal interactions between the material points within a continuous body, and damage is a part of the constitutive model. It can propagate when and where it is energetically favorable for it to do so. The nucleation and propagation of a crack are simulated by breaking a PD bond (interaction). The PD theory can also model complex phenomena, such as flow and thermal diffusion, hydraulic fracture, thermo-mechanical behavior, thermal oxidation damage, and so on. Based on the PD concept, Madenci et al. [2-3] developed a PD differential operator (PDDO) which can convert the local differential equation to its nonlocal integral form regardless of the presence of discontinuities. This study presents a 3D PD model for the thermal response and crack propagation in a charring material during the process of thermal decomposition and degradation in non-charring materials. The PD temperature predictions recover the available experimental and simulation results.

2. Results

Formation and progression of surface cracks in a charring material are demonstrated by considering a block of material. It is insulated from the surrounding medium while being subjected to a uniform heat flux on its top surface. Also, its bottom surface is constrained from deformation with the remaining surfaces free of tractions. During the ablation process, the pyrolysis of phenol-formaldehyde resin leads to mass loss and shrinkage. Non uniformity in shrinkage leads to the initiation of surface cracks. During the pyrolysis process, deformation of the material can be attributed to the combined effect of thermal expansion and shrinkage due to decomposition. Figure 1 shows the initiation and propagation of surface cracks along with the density distributions at various time steps. The values of local damage and the density distribution are indicated in the undeformed and deformed configurations, respectively. The materials points with local damage value greater 0.2 are also shown in Fig. 1 to reveal the crack growth into the material. The crack growth, branching and interaction in simulations are autonomous without any guidance. The preliminary results from the coupled PD thermo-chemo-mechanical model to simulate the dynamic response of ceramic plates under thermal shock are shown in Fig. 2. The left and bottom boundaries of the plate are constrained, and the top and right boundaries are subjected to thermal shock loads.

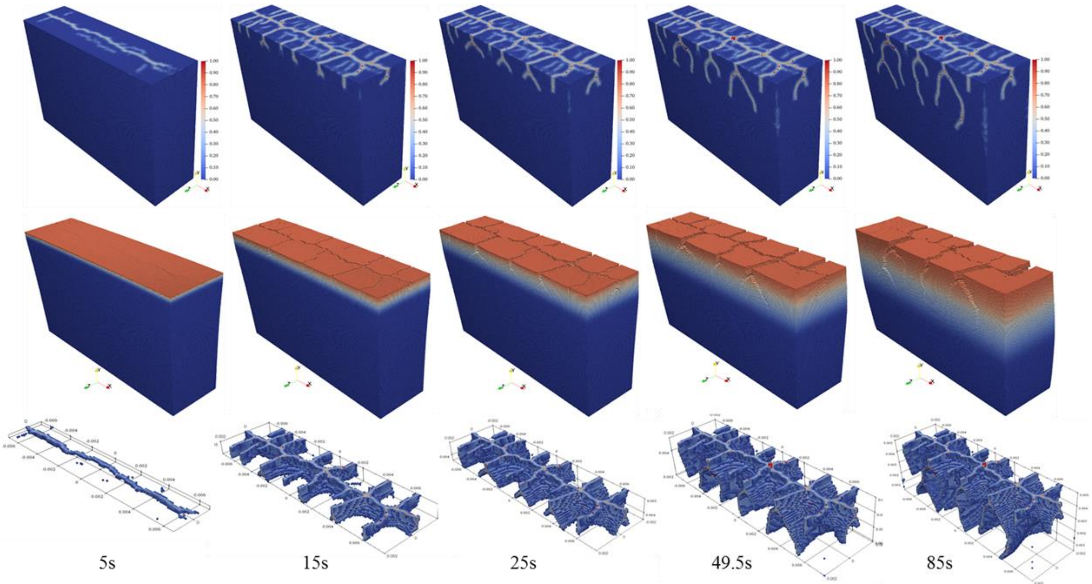

Fig. 1 - Crack propagation and density distributions at different times

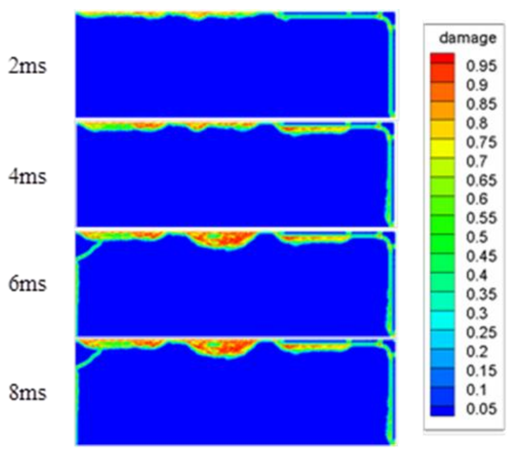

Fig. 2 - The degradation patterns in a ceramic plate under thermal shock

3. Conclusions

The numerical simulations indicate that the PD approach in extremely suitable in predicting deformation and crack propagation and degradation in materials during ablation. The robustness of PD makes it a suitable approach to investigate charring and non-charring ablation in new materials for TPS.

References

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