

OXIDATION OF CARBON AT HIGH TEMPERATURES

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Gas-surface interactions at high temperatures are of great importance to atmospheric re-entry of spacecraft. Hypersonic flows generate the most extreme thermal conditions experienced by any flight vehicle. For a flight vehicle to survive in this environment, it requires a thermal protection system (TPS) composed of materials that can function at extreme temperatures under harsh oxidizing conditions. Most TPS materials are based on carbon, either in pure form or in a composite. During atmospheric re-entry, these materials are exposed to partially oxidized air at temperatures that can exceed 2000 K. The fundamental reactive and non-reactive dynamics between carbon and atomic or molecular oxygen strongly impact the thermal load on these TPS materials, but they have not been studied in extreme environments such as re-entry.

Hyperthermal interactions of ground-state atomic oxygen, $O(^3P)$, from both highly oriented pyrolytic carbon (HOPG) and vitreous (or glassy) carbon surfaces were investigated with a broad range of surface temperatures from 800 K to approximately 2200 K. Beams of 5 eV O atoms were directed at surfaces, and angular and translational energy distributions were obtained for inelastically and reactively scattered products using a rotatable mass spectrometer detector. Inelastically scattered O atoms exhibited both thermal and non-thermal components. Surprisingly, an increasing fraction of inelastically scattered O atoms was observed as the surface temperature was increased, which corresponded to a significant increase in thermally scattered O atoms and a concomitant shift in the angular distribution of the scattered atoms toward the surface normal. Although CO and CO_2 were produced at lower temperatures, the primary reaction product was carbon monoxide (CO), which was formed through direct (nonthermal) and indirect (thermal) mechanisms, with the nonthermal mechanisms dominating at the highest temperatures. The flux of CO produced reached a maximum at surface temperatures between 1500 and 1900 K, depending on heating rate, and decreased with increasing temperature. Similar non-Arrhenius behavior was observed decades ago in the oxidation of carbon with thermal O and O_2 , but we have explained it for the first time. The increasing thermal desorption of O atoms with temperature signifies a decrease in surface oxygen coverage, and with fewer reagent O atoms to react with carbon the reactivity of the carbon surface is limited even though the surface is being constantly bombarded with highly reactive (hyperthermal) O atoms.

