From Structure to Space Environment: C-PEEK thermoplastic material and AO protective coating in VLEO

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Purpose: Spacecraft operating in Very Low Earth Orbit (VLEO), at altitudes between 200 and 400 km, encounter high fluxes of atomic oxygen (AO), reaching densities up to 10^8 atoms/cm³, impacting
surfaces at velocities near ~7.5 km/s. This environment induces significant surface erosion and degradation, particularly in polymer-based materials. To address this challenge, we investigated carbon-PEEK (C-PEEK), an advanced thermoplastic composite produced by additive manufacturing, alongside a TiO_2-coated variant designed to enhance AO resistance. Both uncoated and TiO_2-coated
samples were exposed to AO in a controlled ground-based beam facility at the ENEA SSPT-TIMAS-MCC Laboratory, following ASTM E2089. The study aims to evaluate the durability of these materials under simulated VLEO conditions and support the development of more resilient spacecraft
surfaces for future missions.
Methods: Comprehensive characterization was performed to assess morphological and chemical changes induced by thermal and oxidative stress. Thermal cycling tests were conducted under controlled oxygen flux to simulate AO-induced degradation. Surface morphology and microstructural
features were examined using optical microscopy and scanning electron microscopy (SEM). Three-dimensional surface mapping and roughness measurements quantified topographical changes. Additionally, X-ray Photoelectron Spectroscopy (XPS) and X-ray Absorption Spectroscopy (XAS) were utilized to analyze surface chemical composition and identify oxidation-related modifications.
Results: Thermal cycling and the impact of an oxygen flow resulted in detectable outgassing during
the initial heating phases, stabilizing in subsequent cycles. A slight mass loss and decreased apparent
density suggested alterations in the internal structure of uncoated C-PEEK. Surface analyses revealed
localized erosion and formation of oxidized microstructures. Despite minimal changes in surface roughness, optical and SEM imaging showed increased surface irregularities, fiber exposure, and more pronounced morphological changes in the uncoated samples compared to coated ones.
Conclusions: C-PEEK samples were tested under AO exposure according to ASTM E2089. While reference sample confirmed expected erosion behavior, the C-PEEK results required correction for outgassing effects. Once adjusted, the material showed erosion resistance consistent with literature
data, confirming its suitability for VLEO applications. The TiO_2 coating demonstrated improved surface stability, highlighting its potential to enhance material durability in harsh low Earth orbit environments.
Keywords: VLEO, C-PEEK, AO resistance, TiO2 coating, Surface erosion, Additive manufacturing, XPS, XAS