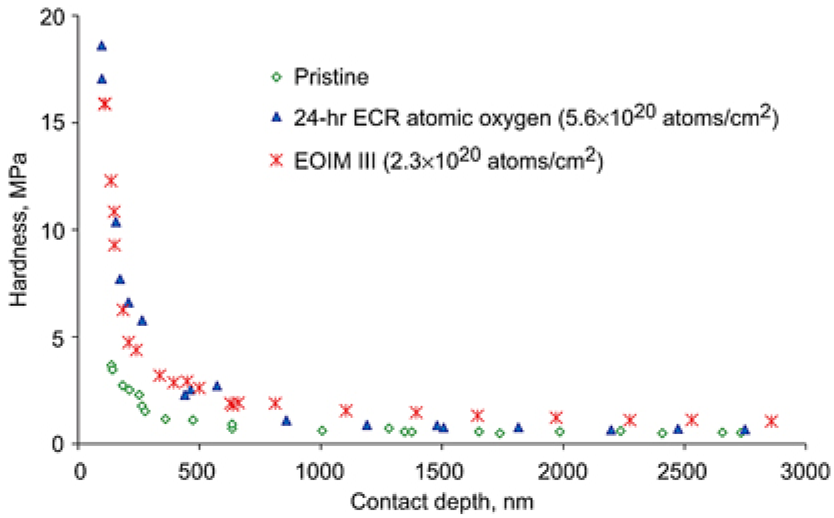
Ground-Laboratory to In-Space Effective Atomic-Oxygen Fluence Determined for DC 93-500 Silicone

Surfaces on the leading edge of spacecraft in low Earth orbit (e.g., surfaces facing the velocity direction), such as on the International Space Station, are subject to atomic oxygen attack, and certain materials are susceptible to erosion. Therefore, ground-based laboratory testing of the atomic oxygen durability of spacecraft materials is necessary for durability assessment when flight data are not available. For accurate space simulation, the facility is commonly calibrated on the basis of the mass loss of Kapton (DuPont, Wilmington, DE) as a control sample for effective fluence determination. This is because Kapton has a well-characterized atomic oxygen erosion yield (E_y, in cubic centimeters per atom) in the low Earth orbit (LEO) environment.

Silicones, a family of commonly used spacecraft materials, do not chemically erode away with atomic oxygen attack like other organic materials that have volatile oxidation products. Instead, silicones react with atomic oxygen and form an oxidized hardened silicate surface layer. Often the loss of methyl groups causes shrinkage of the surface skin and "mud-tile" crazing degradation. But silicones often do not lose mass, and some silicones actually gain mass during atomic oxygen exposure. Therefore, the effective atomic oxygen fluence for silicones in a ground-test facility should not be determined on the basis of traditional mass-loss measurements, as it is with polymers that erode. Another method for determining effective fluence needs to be employed for silicones.

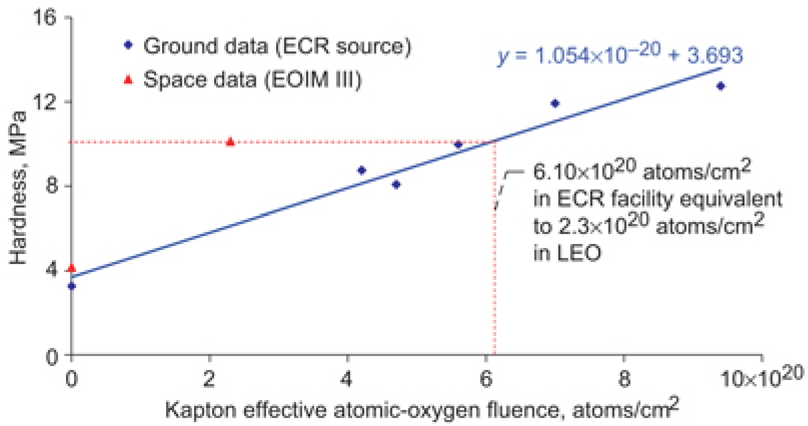
A new technique has been developed at the NASA Glenn Research Center for determining the effective atomic oxygen fluence for silicones in ground-test facilities. This technique determines the equivalent amount of atomic oxygen oxidation on the basis of changes in the surface-oxide hardness. The specific approach developed was to compare changes in the surface hardness of ground-laboratory-exposed DC93-500 silicone with DC93-500 exposed to LEO atomic oxygen as part of a shuttle flight experiment. The on-the-ground to in-space effective atomic oxygen fluence was determined on the basis of the Kapton effective fluence in the ground-laboratory facility that produced the same hardness for the fluence in space.



Hardness versus contact depth for pristine, 24-hr ECR-exposed, and LEO space-exposed DC93–500 silicone.

Because microhardness measurements need to be obtained on the very surface layer of a rubber substrate (with primarily elastic deformation), traditional techniques for microhardness characterization, which apply relatively large forces and characterize hardness on the basis of plastic deformation, could not be used. Therefore, nanomechanical testing, using ultralight load indentations and continuous load-displacement monitoring, was used to determine the surface hardness of the silicones. Hardness versus contact depth were obtained for five DC93-500 samples exposed to atomic oxygen in an electron cyclotron resonance (ECR) thermal energy source facility (exposed for 18 to 40 hr, corresponding to Kapton mass-loss effective fluences of 4.2×10^{20} to 9.4×10^{20} atoms/cm^2, respectively) and for a space-exposed DC93-500. The in-space exposed DC93-500 sample was exposed to LEO atomic oxygen as part of the Evaluation of Oxygen Interactions With Materials III (EOIM III) shuttle flight experiment flown on STS-46. This sample was exposed to directed ram atomic oxygen from within the shuttle bay and received a LEO atomic oxygen fluence of $2.3\pm0.3\times10^{20}$ atoms/cm^2. Pristine controls for the ECR tests and for the EOIM III flight sample were also measured. The preceding graph provides the hardness versus contact depth for pristine DC93-500, the EOIM-III flight sample, and DC93-500 exposed to the ECR atomic-oxygen source for 24 hr.

Values obtained from the curve-fit equations for each data set of hardness versus contact depth were used to produce plots of hardness versus Kapton effective atomic oxygen fluence at contact depths of 150, 200, 250, and 300 nm. These depths represent the “near surface” data. The 150-nm contact depth plot is provided in the following graph.



Hardness versus Kapton atomic-oxygen effective fluence at a contact depth of 150 nm.

Long description of figure 2. Graph of hardness in megapascals versus fluence in atoms per centimeter squared for ground and space data. Figure shows that 6.10×1020 atoms per centimeter in the ECR facility is equivalent to 2.3×1020 atoms per centimeter squared in LEO.

The ECR Kapton effective fluences that provided the same hardness as for the EOIM III sample for depths of 150, 200, 250, and 350 nm were determined to be 6.10, 6.00, 6.04, and 6.16×10^{20} atoms/cm^2, respectively. Averaging these values provides 6.08×10^{20} atoms/cm^2; therefore, the Kapton effective atomic oxygen fluence in the ECR facility needs to be 2.64 times higher than in LEO to produce exposure damage in the ground test silicone equivalent to what occurred in the space-exposed silicone.

This technique has been directly correlated with silicone pressure-sensitive adhesive (PSA) samples that have been ECR exposed for International Space Station solar-array diode tape blocking assessment. The DC93-500 samples were ECR exposed simultaneously with silicone PSA samples. On-orbit, the silicone PSA surface will eventually convert to a hardened silicate glass layer, changing from a sticky surface to a glassy nonblock surface. By using the correlation of ground and space DC93-500 data, one can deduce the ground-test effective fluence of the silicone PSA and can more accurately determine the degree of blocking versus atomic oxygen exposure that can be expected on-orbit for the space station diode tape.

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