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Preliminary Assessment of Potential Habitat Composites' Durability When Exposed to a Long-Term Radiation Environment and Micrometeoroid Impacts

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NASA's exploration goals include extending human presence beyond low earth orbit (LEO). As a result, habitation for crew is a critical requirement for meeting this goal. However, habitats are very large structures that contain a multitude of subsystems to sustain human life over long-durations in space, and one of the key challenges has been keeping weight to a minimum in order to reduce costs. Thus, light-weight and multifunctional structural materials are of great interest for habitation.

NASA has started studying polymeric composite materials as potential lightweight and multifunctional structural materials for use in long-duration spaceflight. However, little is known about the survivability of these materials when exposed to the space environment outside of LEO for long durations. Thus, a study has been undertaken to investigate the durability of composite materials when exposed to long-duration radiation. Furthermore, as an addition to the primary study, a secondary preliminary investigation has been started on the micrometeoroid and orbital debris (MMOD) susceptibility of these materials after radiation exposure. The combined effects of radiation and MMOD impacts are the focus of this paper.

When polymeric materials are exposed to ionizing radiation, there are typically two outcomes. Either the material becomes embrittled due to enhanced crosslinking of the polymer, or the material weakens and becomes ductile as a result of polymer chain scission occurring (Al-Sheikhly, 1994, O'Donnell, et al., 1977, Otaguro, et al., 2010, and Coulter, et al., 1986). In polymeric composites, the fibers are typically not affected by the radiation, but rather it is the matrix which governs how the material will respond to a large radiation exposure. These potential material changes due to radiation exposure could affect the performance of composites when encountering an MMOD hit.

Previous research on the MMOD impacts of composites has focused on carbon fiber and PEEK materials or carbon fiber and epoxy materials. A study by Christiansen (1990) shows that graphite/epoxy composites with higher modulus fibers have larger impact holes than those with lower modulus fibers. In addition, low modulus fibers exhibit peeling whereas high modulus fibers do not. Furthermore, there were comparable amounts of internal damage to external damage. Additional studies (Tennyson, et al., 1997 and Tennyson, et al., 2000) have investigated graphite/PEEK laminates. In these studies, linear correlations were made between an energy impact parameter and crater diameter, entry damage, internal damage, and exit damage. In addition, a relationship was found between the projectile diameter and crater diameter. The results of these MMOD studies were used as the basis for analyzing the data of this investigation.

In this preliminary examination, two materials were used: a carbon fiber/toughened epoxy (CF) system and a carbon fiber/boron fiber/toughened epoxy (BF-CF) system. Both materials had identical layups of $[+60/-60/0]_s$. Both materials were subjected to 200 MeV protons at a total dose of 500 Gy (500 krad), but some of the samples were exposed at a fast dose rate (135.9 cGy/s or 0.1359 krad/s) and others were exposed at a slow dose rate (13.9cGy/s or 0.0139 krad/s). The dose amount was calculated by assuming a mission lifetime of 30 years on the lunar surface, with three large solar particle events and a constant background galactic cosmic ray exposure. It was also assumed that the habitat was not buried underground, but rather exposed to the radiation in a worst-case scenario. In addition to the radiation, some of the samples were held under bi-axial tension during the radiation exposure to simulate the internal pressure forces of a habitat pressure vessel on the material.

After radiation exposure, the samples were sent to White Sand Test Facility to be impacted. There were a total of 26 shots, where 12 of the shots were without a bumper in front of the material and 14 shots were with a bumper to the material. The average projectile (aluminum) velocity used was 7.03 km/s and the projectile diameter was 0.40 mm for the samples without bumpers and 1.0 mm for the samples with bumpers.

At the conclusion of the hypervelocity impacts, data was collected on hole sizes, delaminations from the holes, crater dimensions, and internal damage. This data was then used to compare samples exposed to radiation vs. controls, fast vs. slow dose rates, and tension vs. no tension. In addition, this data was compared with previous hypervelocity studies of composite materials (Christiansen, 1990, Tennyson, et al., 1997 and Tennyson, et al., 2000).

Overall, the data was consistent with the material becoming more ductile or weakening as a result of radiation and further weakening with a slow dose rate exposure when compared with a fast dose rate exposure. There was good agreement with the results of Christiansen, 1990 in that the BF-CF material had higher modulus fibers (boron fibers) and exhibited larger damage areas when compared with the CF material which only contained carbon fibers at a lower modulus than the boron fibers. However there was less consistency when comparing the data with the models of Tennyson, et al., 1997 and Tennyson, et al., 2000. This discrepancy could be a result of different materials being used. In the models described by Tennyson, et al., 1997 and Tennyson, et al., 2000, the primary material being investigated was graphite/PEEK, whereas in this study the materials are carbon fiber/epoxy and carbon fiber/boron fiber/epoxy. Further investigation will need to be completed to validate the results shown in this preliminary study.

In summary, a preliminary investigation was undertaken to investigate the durability of potential habitat composite materials when exposed to a long-term space radiation environment and then impacted with simulated MMOD. It was found that the materials exhibited weakening of the material with radiation exposure and further weakening when exposed to a slow dose rate vs. a fast dose rate. Furthermore, the results showed good agreement with previous results pertaining to MMOD impacts of graphite/epoxy composites, but had some discrepancies when compared with graphite/PEEK composites. Further investigation will need to be completed to increase the data set and validate the results shown here.

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