Robust Materials for Next-Generation Spacecraft

Mostafa Moataz

Abstract

Having reached an advanced level in space technology, humanity has begun to seriously consider large-scale missions, such as mining of space resources, space travel, and even colonization of other celestial bodies such as Mars and the Moon. Nevertheless, it still requires far more dependable technologies to carry out such missions. Knowing that the materials used in manufacturing spacecrafts play a pivotal rule in their efficiency and reliability, researchers aim to foster the materials in three main characteristics: multi-functionality, adaptivity, and self-healing.

Background

If we are to conquer space exploration, we need to rethink how we design spacecraft to provide them with the necessary capacities. Indeed, when the success of an entire 40-year mission rests on proper operation of a single unit, with no ability for service or repair when millions of kilometers away from Earth, reliability becomes paramount. Such a prospect may seem incredibly out of reach, however, recent progress in material synthesis and self-assembly say otherwise.

The nanotech revolution has produced electronics and robotics with an unprecedented level of miniaturization and while retaining a respectable level of functionality. It has also provided material systems and device components that are lighter, stronger, and more robust than ever before, notably reducing the cost of their production and assembly. These achievements will definitely help us navigate vital barriers in the space industry and significantly expand the variety of our space assets.

Needed Characteristics

There are three major features that could be attained by enhancing the materials of our spacecraft; namely: self-restoration, adaptivity, and multi-functionality. The properties of materials required for the realization of the aforementioned features smoothly flow into one another. For instance, adaptivity could be considered as a case of "extreme" self-healing, where the property of a system is changed to another function; multi-functionality may be interpreted in the same way, i.e., as an ability of a system to change to the point of acquiring several functions, as shown in figure 1.

Figure 1: A "life ring" of novel materials for future space technology

Dynamic material properties are agility, strength/rigidity, healing, adapting, and the ability to transform, in contrast to "inanimate" structural materials that could decay by fatigue, cracks, degradation of an internal structure and composition, and de-shaping. The major physical, chemical, and structural properties that impart a "dynamic character" to materials are:

- Presence of reversible bonds and dynamic covalent bonds, capable of forming networks and supramolecular assemblies.
- Intense diffusion of specific elements and bonds.

- Reversible formation of crosslinkers. Capacity of the free radicals generated as a result of mechanical damage to re-establish covalent bonds.

Many of these features could be found in metallic materials, metal alloys, and compositions, including metal-frame systems and more complex architectures and metamaterials.

The materials for electronic devices can also possess the dynamic character and can self-heal and adapt. Nanostructured electronic compositions and graphene-based smart materials for micro and nanoelectronics also feature self-healing ability, thus laying a cornerstone for long-lasting, self-healing electronics.

Satellite Parts and Used Materials in Manufacturing Them

The materials used in manufacturing satellites are crucial when it comes to navigating the severe environment of space. Firstly, the external protection of the satellite is made of nanocrystalline diamonds. It has printable electronics for cheap, fast mission adaptation. Besides, it has solar cells which are highly efficient and nanostructure-based power system composed of metamaterial-based supercapacitors and power cells, and a thruster made of novel material for service life, efficiency, and adaptivity. The satellite body is custom-designed, mission-adaptable satellite chassis equipped with multi-metal and advanced polymer 3D-printed parts with high rigidity and high heat, ultraviolet, and radiation resistance. A satellite also contains strong, light design parts made of carbon nanotube fibers and advanced self-healing materials for chassis, antennas and other critical parts. Carbon nanowires and graphene are highly efficient, light-weight electronics. The propellant tank is made of composite propellant tanks made of thin metal layers and carbon nanotube-based fibers.

Challenges & Conclusion

Most of the mechanisms rely on integration of several distinct materials within a single system, which brings challenges of maintaining desirable material properties and structural integrity. Indeed, introduction of nonstructural components, e.g., encapsulated healing agents or catalysts, may undermine mechanical strength and chemical stability of the composite system. Furthermore, certain areas of the material may be subject to more extensive load and as a consequence experience damage more frequently or to a greater degree.

More dedicated research efforts will be required to deeply understand the numerous chemical and physical mechanisms and effects that contribute to the behavior of self-healing and other adaptive materials, to make them robust, reliable, and safe for human health. This is apparently one more significant issue critically important for long-lasting space travel and living in the interiors of Moon or Mars bases and stations, as well as in long-term orbital systems.

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