Titanium dioxide foams created using 3D - printing have been subjected to testing in extreme environmental conditions characteristic of Low-Earth Orbit (LEO).

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Abstract

This research article focuses on integrating studies in materials science, the physics of liquid foams, and 3D printing technologies to enhance robotic fabrication of titanium dioxide (TiO_2) foams and analyze their degradation behavior under Low Earth Orbit (LEO) space conditions. These TiO_2 foam structures hold significant promise for a variety of space applications, including efficient solar cells, advanced batteries, and radiation shielding. The experimental investigations are proposed to utilize the MISSE–FF platform aboard the ISS, where Earth-printed foam samples will be exposed to LEO environmental conditions. Upon their return, a comprehensive range of characterization techniques will be employed to examine potential degradation mechanisms. This evaluation will provide critical early insights into the suitability of TiO_2 foam materials for targeted space applications, facilitating further exploration of their manufacturing under microgravity conditions. By the conclusion of this study, a broader understanding of how TiO_2 foams degrade in LEO is anticipated. This includes identifying erosion mechanisms impacting the foams' organic components due to high atomic oxygen flux. Additionally, the research aims to evaluate how carbon-based materials such as graphene and carbon nanotubes (CNTs) might contribute to reinforcing these printed structures, enhancing their performance and durability for space missions. [1-70]

Keywords: Fluid physics, Titanium dioxide (TiO_2) foam, CNT's (carbon nanotubes), Low Earth Orbit (LEO), 3-D printing, Zero gravity, International Space Station (ISS), Drying, UV, Heat Treatment

Introduction

The research aims to integrate advancements in materials science and 3D printing with the fluid physics of sprays and foams to enhance the 3D printing process of TiO_2 foams and examine their degradation behavior under the space environment of Low Earth Orbit (LEO). These foams hold significant promise for space applications, including efficient solar cells, batteries, and radiation shielding. The project will utilize the Materials International Space Station Experiment Flight Facility (MISSE-FF) aboard the International Space Station (ISS) to expose Earth-printed TiO_2 foam samples to LEO conditions. After their return to Earth, potential degradation mechanisms will be analyzed using various characterization techniques (Figure 1). This data will provide valuable initial insights into the suitability and performance of TiO_2 foam materials for the proposed space applications. [1-70]

Figure 1: General framework of the experimental concept. [1-70]

The research team plans to 3-D print a variety of foam specimens, including TiO_2 foams on polymer substrates and small 3-D printed TiO_2 foam structural mesh shapes, all fabricated under Earth gravity conditions. These foam specimens will be mounted onto backing plates for installation on an external payload rack aboard the ISS, where they will undergo testing to evaluate the effects of extended space exposure on the performance of the 3-D printed TiO_2 foams. Specifically, the study will analyze how factors like atomic oxygen, radiation, vacuum, zero gravity, and low-Earth orbit (LEO) debris impact the specimens' properties. To achieve optimal results, the MISSE-FF platform will be used instead of the NanoRacks external platform. This choice allows for extended exposure to the space environment and ensures that the specimens maintain a zenith orientation. The primary objective is to observe degradation over time and assess the foams' viability for envisioned space applications. Following their return to Earth, the exposed specimens will undergo in-depth materials characterization and mechanical testing, with results compared to control specimens that were not exposed to space. These findings will provide preliminary, cost-effective insights into whether the fabricated TiO_2 foams are suitable for space applications before committing to the more complex and expensive process of printing similar foams in microgravity (μ-G) conditions. The project proposes a fully passive MISSE-FF payload experiment that aligns with existing time and budget constraints. It requires no crew involvement beyond deployment, installation, and removal of the specimens, has minimal power and space requirements, and promises a relatively short time to flight readiness. The long-term goal of this research is to eventually conduct 3-D printing of TiO_2 foams under μ-G aboard the ISS. This follow-up work would allow for a detailed comparison of the microstructural and mechanical properties between foams printed on Earth and those printed under μ-G conditions. Additionally, it would help assess the feasibility of manufacturing 3-D printed TiO_2 foams in microgravity within a space environment. [1-70]

Material, Method, and Discussion

Foam Design and Synthesis Process The proposed TiO_2 foam systems comprise multi-phase material composites suitable for various advanced applications. These lightweight foams can act as UV shielding coatings in spacecraft and space equipment, particularly in the harsh radiation and oxidative conditions of low Earth orbit (LEO). Moreover, they present a promising solution as scaffold materials in third-generation solar cells, such as dye-sensitized and perovskite devices, and as components in Li-ion batteries for energy storage. Formulated using non-toxic oil-in-water emulsions, the aqueous phase of these TiO_2 foams is composed of TiO_2 nanoparticles, a Ti-organic complex, and water serving as a solvent. The oil phase stabilizes the foam, consisting of fatty acids and surfactants that enable temporary entrapment of the gas phase (air), generating the characteristic macroporous structure of the foam. The design allows for the incorporation of additional materials, such as carbon nanotubes (CNTs) or graphene, which can be introduced into the aqueous or oil phases during preparation. These materials enhance the mechanical strength and thermal and electrical properties of the foams, making them adaptable for more demanding applications. TiO_2 particles are particularly valued for their exceptional performance as UV-protective materials and their chemical and thermal stability. When forming these foams, slurry dispersions involving TiO_2 particles and Titanium(IV) bis(ammonium lactato) dihydroxide (TALH), an organic complex with water solubility, are prepared. TALH hydrolyzes very slowly at neutral pH without external energy input. However, under UV or heat exposure, it facilitates the formation of nanocrystalline anatase TiO_2 structures, which integrate with the initial TiO_2 particles. These structures act as interconnections between particles to form a continuous yet mesoporous TiO_2 network when used in the foam's aqueous phase. Complementing this, the oil phase employs abundant, non-toxic fatty acids combined with surfactants to maintain stability. As illustrated in Figure 2, the foam preparation involves mixing the aqueous and oil phases followed by frothing to produce a flowable foam. This foam can then be applied to desired surfaces for UV protection or utilized as scaffolds in solar cells and Li-ion batteries. [1-70]

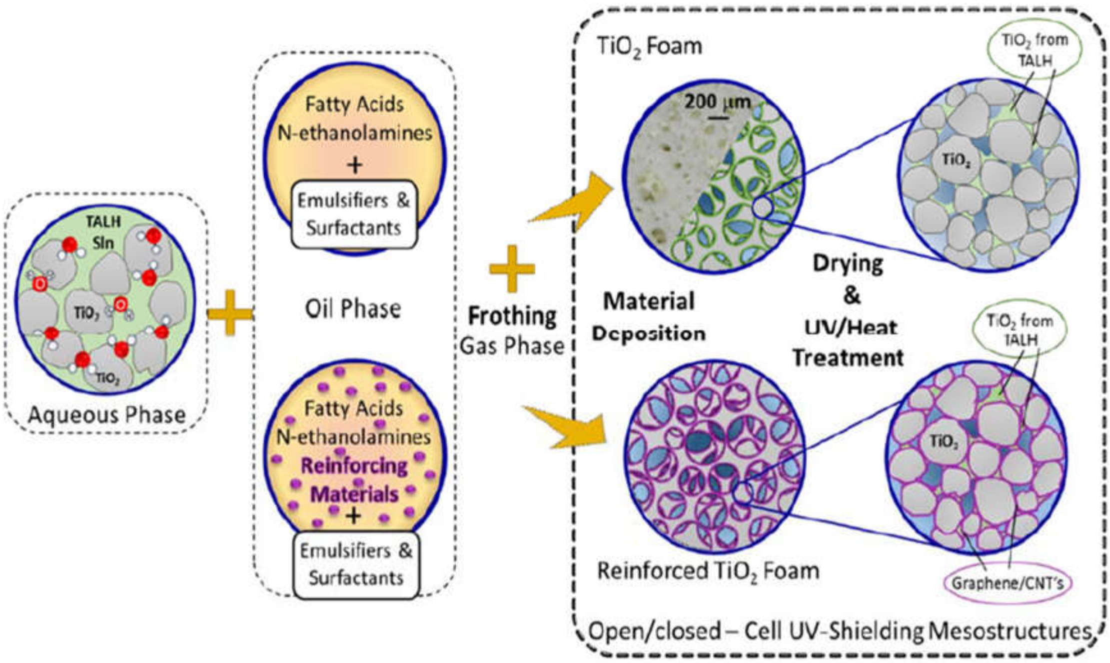

Figure 2: Diagram illustrating the preparation process of TiO_2: TALH Reinforced and baseline UV-shielding foams. [1-70]

Conclusion

This research project seeks to integrate materials science and the physics of liquid foams with 3D printing to advance robotic fabrication of TiO2 foams and analyze their degradation behavior when exposed to the low Earth orbit (LEO) space environment. These advanced printed foams hold considerable promise for various space applications, including efficient solar cells, batteries, and radiation shielding. The experimental phase of this study can utilize the MISSE–FF platform aboard the International Space Station (ISS) to expose Earth-printed foam samples to LEO conditions. Following their return to Earth, a comprehensive range of characterization techniques will be employed to investigate potential degradation mechanisms. This analysis will provide valuable early insights into the feasibility and durability of TiO2 foam materials for intended space applications before moving to explore their 3D printing capabilities in microgravity. By the conclusion of this research, it is anticipated that a deeper understanding of TiO2 foam degradation under LEO conditions will be achieved. Specifically, the study aims to uncover potential erosion processes impacting the organic components of the foams due to high atomic oxygen flux. The investigation will also assess the contribution of carbon-based materials like graphene and carbon nanotubes (CNTs) in enhancing the structural integrity of these printed materials. [1-70]

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Asst.Prof. Dr. Emin Taner ELMAS is a Mechanical Engineer having degrees of B.Sc., M.Sc., Ph.D., and was born in Sivas in 1974. He completed his doctorate at Ege University, Graduate School of Natural and Applied Sciences, Mechanical Engineering Department, Thermodynamics Science Branch, and his master's degree at Dokuz Eylül University, Mechanical Engineering Department, Energy Science Branch. He also completed his undergraduate education at Hacettepe University, ZEF, Mechanical Engineering Department and graduated from the faculty with honors in 1995 and became a mechanical engineer. He was awarded a non-refundable scholarship by the Turkish Chamber of Mechanical Engineers in his

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Asst. Prof. Dr. Emin Taner ELMAS is also a musician, saz (baglama) virtuoso player and ney (Nay, Turkish Reed Flute) performer. He plays also cümbüş instrument and performs darbuka rhythm instrument. He has a YouTube Music Channel (Emin Taner ELMAS) which includes some of his sound recordings of him playing the saz-baglama and blowing the ney. He composed the poem written by the great poet Âşık Veysel ŞATIROĞLU under the name of

“Raşit Bey” in memory of his father Judge (Hâkim) Raşit ELMAS as “Raşit Bey Türküsü”, wrote it down, notated and published it as an academic article and broadcasted this song on his own music channel. He wrote the poems entitled “Canım Babam” and “Geldim Babam” which he wrote also in memory of his father and published in an academic literature journal, and composed instrumental musics for these poems. He also composed an instrumental song called “Annem Annem Türküsü” and gave it to his mother, Lawyer Tuna ELMAS, as a gift on Mother’s Day, 11.05.2025. He also has a poem titled "Ney and Neyzen." He also wrote and presented a poem titled "Esra Kardeşim" to his sister, Esra ELMAS, an archaeologist and English teacher. He has published books including "Saz-Bağlama Tuning System Method" (“Saz- Bağlama Akort Sistemi Metodu”) and "Ney and Neyzen; Ney's Pitches, Frets, Sound Stages, Octaves, Structure, Performance, Ney Maintenance and Basic Music Theory" (Ney ve Neyzen; Ney’de Perdeler, Ses Devreleri, Oktavlar, Yapısı, İcrası, Ney Bakımı ile Temel Musiki Nazariyatı). He continues his artistic studies by writing various articles, books, poetry, lyrics and also realizing musical composition and repertoire works.

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