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Lightweight, Cost-effective, and Multi-functional Bio-based Composite Laminate Design for Satellite Applications

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Abstract
As the number of space launches and satellites placed in orbit continues to increase every year [1], the environmental impact of space missions becomes a pressing concern. The production of traditional satellite materials, which are typically petroleum-based, involves energy-intensive processes that contribute to a significant environmental footprint. Therefore, the development of sustainable and bio-based materials for space applications becomes increasingly essential. In this paper, we present a study on the development of a multi-functional bio-based material for space satellite applications. The project's first stage is to identify a suitable application for the intended material design. Various applications are considered, and a trade-off analysis is conducted to identify a solar array substrate for a Cube-Sat in Low Earth Orbit (LEO) as the best suitable application. After the selection of the application, an extensive study is performed to identify state-of-the-art and bio-based materials suitable for the solar array substrate. Several combinations of fiber and resin composites are analyzed, and a second trade-off analysis is carried out to select the best combination of matrix and fiber. The results show that the best option is a composite made of a Poly-Furfuryl-Alcohol (PFA) matrix with a 50% volume ratio of Ramie fibers. To ensure the material's performance in the operational environment, a series of design parameters are chosen and altered, and the material is subjected to Finite Element Method (FEM) analysis for thermal, mechanical, thermo-mechanical, and vibrational simulation. Due to the lack of information about PFA material properties, the models for the analysis have been created using Epoxy resin instead of PFA, as they have similar characteristics [2]. The results are incorporated into another trade-off analysis to determine the final laminate composition. A sensitivity analysis is performed considering the potential degree of uncertainty in the material properties. In addition to the operational performance of the material, a cost analysis is also conducted to evaluate the effectiveness of the laminate with respect to existing materials used in the industry. In conclusion, the PFA-Ramie composite with a 50% fiber volume is best suited for the design of a solar array substrate. The simulation results show that the material can withstand the operational conditions of a solar panel's substrate in LEO. Moreover, the material is lightweight, cost-effective, and has a large margin between the operational requirements and its performance, making it suitable for other space-related applications as well. This preliminary study demonstrates the feasibility and effectiveness of employing bio-based composite materials in space applications. The findings of this paper could have far-reaching implications for the development of sustainable materials for space applications and could pave the way for the further exploration of the use of bio-based materials in satellites' components.

References
[1] Witze, A 2023, *'2022 was a record year for space launches'*, Nature, vol. 613, 426.
[2] Granta (2022), Granta Library.