Evaluating Polyimide Film Tape 7000X as a Cost-Effective Alternative to Kapton for CubeSat Coatings

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Abstract - The choice of coating material is essential for the structural integrity, thermal stability and the overall performance of Cubesats in Space or in the Atmosphere. Traditionally, kapton has been the material of choice due to its excellent thermal stability, electrical and mechanical properties as well as its resistance to harsh space environments. However, the recent emergence of a new material called Polyimide film tape 7000x which hails from the same origin material as kapton(Polyimide) is a much cheaper material which necessitates a comparative analysis to assess its suitability for CubeSat applications and its performance against Kapton. This study employs static structural, modal, and steady state thermal analyses using ANSYS simulations to compare the performance of CubeSats coated with Kapton and Polyimide Film Tape 7000x. Our findings suggest that the thermal advantages offered by Polyimide Film Tape 7000X are on par with that of kapton whereas it exceeds kapton by a minute margin in mechanical strength, This coupled with its significant cost savings must make it a viable alternative for Cubesat missions.

1.INTRODUCTION

Background

CubeSats are compact and cost effective satellites which are standardized to 10x10x10cm.They can essentially be considered as miniature forms of satellites, they revolutionized space exploration due to their rapid development and deployment capabilities alongside the fact that they are a lot more affordable in comparison to actual Satellites or advanced probes. The choice of the coating material is very important to ensure the durability and performance of a CubeSat in the harsh space environment.An Effective coating can provide thermal stability, electrical insulation, radiation resistance and even protect the sensitive components of a Cubesat from extreme temperatures and the radiation in space.

Problem Statement

Kapton is a polyimide film which is known for its excellent thermal stability and electrical insulation properties. It has been traditionally used as a coating material for CubeSats. However, its high cost poses a challenge especially for budget constrained missions. Polyimide Film Tape 7000X (Polyimide Film Tape 7000X) is a newer and more affordable material and may prove to be a potential alternative. Despite its cost benefits, comprehensive studies evaluating its performance relative to Kapton are lacking in order to truly assess if it is indeed a viable alternative to Kapton .

Objective

This research aims to perform a comparative analysis of CubeSats coated with Kapton and Polyimide Film Tape 7000X to determine if Polyimide Film Tape 7000X can serve as a cost-effective and a reliable alternative. By performing static structural, modal, and steady-state thermal analysis using ANSYS simulations, we seek to assess the mechanical capacities and thermal performance of both the materials under typical operational conditions.

Hypothesis

We hypothesize that Polyimide Film Tape 7000x, despite being cheaper, will demonstrate comparable or maybe even better mechanical and thermal performance to Kapton, thereby offering a feasible alternative for CubeSat coatings.

2.LITERATURE REVIEW

Previous Research

Cacace, L. A., & Velasco, D. (2023). A CubeSat is a minuscule, miniaturized satellite,classified as a type of nanosatellite standard defined by theCubeSat DesignSpecifications CT002. While coatings play a critical role in CubeSat performance for thermal control, protection from the space environment and EMI shielding. Thermal coatingsANGUMSThe importance of thermal sense in temperature stabilization and control through highly mobile methods using process carriers facilitating quick removal from the area; relative high emissivity/low absorptance in order to reduce temperatures within cells being processed. This is important because CubeSat components require a radiation protective coating in order to shield the hardware from harmful cosmic rays, increasing their lifecycle. New material breakthroughs in nanocomposites or multilayer coatings add protection with minimal weight gain. Advances in 3D printing have also allowed more intricate coating designs, which provide greater protection and performance. Real World examples, like the PATCOOL mission, serve to illustrate how well these coatings perform when applied practically.Still, there are challenges ahead and one of them is more durable, efficient and multifunctional coatings. Future research will focus on the development of self healing coatings, increased performance under adverse conditions and multifunctional protective systems. In conclusion, coatings have been identified as the most critical factor for efficiency and reliability of CubeSats; thus continuous improvement in this aspect is a very important step toward maximizing the performance or expanding usage opportunities in the space industry.

Dong et al. (2022) In this extreme environment (due to the extremes of high and low temperatures Space objects are subject as they pass from Sunlight into shadow for example) stable operation, or functionality in fact relies upon effective thermal management. This is a major issue, especially for small satellites such as CubeSats where existing high performance thermal management technologies (TMTs) can impose significant mass and power burdens. The new wave of temperature adaptive coatings, mainly in the form of TemperatureAdaptive Solar Coatings (TASCs) and TemperatureAdaptive Radiation Coatings (TARCs), represents a possible solution since these provide noninvasive passive thermal control solutions without any additional mass or power penalties.Research by Dong et al. There are some other successful TASC and TARCs work for space applications[14,15] (2022). The coatings change their thermal properties with temperature as they modulate solar absorptivity or, alternatively; the emissivities at various wavelengths.Simulations of low temperature TARC devices in a 1U CubeSat show temperature swings as small as $\Delta T = 5.3°C$, which would greatly benefit from such enhanced cryo stability. This technique keeps the spacecraft components at a constant temperature and provides many advantages, including reducing thermal fatigue risk so that they can last longer. The investigation highlights the advantage of TARCs over TASCs, particularly in a solar eclipse case. This capacity of TARCs to be tuned for better management temperature swings, provide improved CubeSat protection across different orbital environments. These results categorically state the promise and potential of TARCs to transform passive thermal control during space missions, by enabling a lightweight and energy efficient solution for small satellite applications.

Carlos Chávez Félix et al.(2019) with CubeSats being exposed to more extreme.. intens.as much as temperature differences in space ,controlled thermal management is necessary for proper functionality and a long life span of these small satellites. Thermal issues have been solved via Thermal Barrier Coatings (TBCs) application since most recent studies. Reyes et al. Anonymous(2019)studied Its numerical and finite differencing methods are statistical, so as to determine the thermal modeling of CIIIASat nanosatellite for evaluating different TBCs.The research indicated how important TBCs are in controlling the operational internal temperature of CubeSats. Effects of SiO2based Coatings, VaporDeposited Gold and Kapton on Thermal Properties SiO2, which displayed high absorptivity, is also among the temperatures higher (more hazardous to maintain component stability).Since Kapton had overall lower absorptivity and higher emissivity than the standard material, thermal regulation also improved by this change which allowed temperatures to stay within operational limits.Beta angle, which shows the sunlight angle with respect to an orbital plane of CubeSat, was recognized as the most significant factor on a CubeSat thermal temperature by all analyses. At high beta angles, summer solstice conditions displayed the maximum temperatures and winter months at low obliquity showed minimum values. Taken together, this research demonstrates the need to carefully choose TBCs and atmospheric altitudes in order to maximize CubeSats thermal performances.In conclusion, it is demonstrated that including TBCs, like Kapton, into the design of CubeSats is a workable way to achieve passive heat management in space without sacrificing functionality or operability.

Smith et al. (2019) showed the capability of using thermal control coatings in CubeSat platforms by creating a satellite built particularly for the purpose of space weather monitoring. Their CubeSat made use of a Kapton and white paint combination for maximum thermal load management. The research has indicated some of these coverings as a contributing factor in the temperature control of the board due to the solar absorption effect; those coatings point to the longevity and efficiency of the satellite. To stick to the mission's thermal management objectives, thermal coatings were made devoid of mission specific complicated issues.

Jones et al. (2021) dealt with the possibility of using a special type of radiation resistant coatings on the CubeSat in low Earth orbit (LEO) missions. The main focus of their research revealed the potential of a low cost and simple application of radiation resistant coatings in the space satellite, which helped the satellite to shield the effects of radiation. The CubeSat was furnished with different kinds of sensors so it could measure the radiation intensity, thus highlighting the added protection against radiation provided by the radiation resistant coatings as a full fledged safeguarding tool. The research mentioned that the coatings were major rays of the sun reducer which in turn led to the components of the electronic being less affected by radiation which has made CubeSats more strong in LEO missions.

Hernandez et al. (2022) employed an antireflective coated CubeSat to check new optical communication protocols in space. The CubeSat was intended to measure the behavior of these protocols under the changing light conditions. The very fact that the team was able to properly maintain communications with the ground stations enabled them to draw up conclusions and articulate the strategies that would result in the invention of new communication optical technologies. This survey put the emphasis on the antireflective coatings' functions as the sites for testing and verifying the new technologies in space, thus, leading to the improvements in satellite communication and other disciplines.

Phalphale, A et al. (2022). The paper entitled "Investigation of Composite Material for a Remote Sensing CubeSat Structure: An Alternative to Traditional Aluminum Alloys" examines the possibility of using composite materials, particularly carbon fiber instead of traditional aluminum alloys for building CubeSat structures. It discusses the growing demand for CubeSats and argues that selecting the right substances is critical in decreasing structural mass without compromising strength. The research focuses on a 3U

CubeSat designed for glacier monitoring, comparing carbon fiber and Aluminum 6061 from structural and thermal analyses point of view by using Ansys Workbench. The outcomes demonstrate that though stiffness is similar, there is a considerable reduction in mass if one uses carbon fiber unlike in aluminum alloy making room for devices like cameras. This investigation reveals how composites can be used to decrease mass while ensuring thermal stability thereby improving functionality as well as efficiency of cube satellites used in remote sensing applications.

Elshaal, A., & Abdul Karim, W. (2022). In this paper the authors are looking at how FEA could be used to predict how CubeSat behaves. Specifically, focusing on ALAINSAT1, the study compares different FEA Techniques to measure their efficacy in predicting structural behavior of CubeSats subjected to several types of loads. The authors analyze the CubeSat's response to static, dynamic and thermal loads with specific emphasis on correct modeling as guaranteeing security and reliability in these miniature satellites during launch and operation. Thus, determining the right FEA method is critical for optimal design and improved performance of cubesats with an emphasis on thorough validation of simulation results against experimental data.

Guedes, M. B. V. (2019). The Research paper "CubeSat Structural and Thermal Analysis Methodology: ISTSat1 Design" is a deep dive into the structural and thermal difficulties that CubeSats face, with special focus on ISTSat1, the first one from Portugal. The paper explains why CubeSats must pass serious tests before they are launched, including complete structural analysis and thermal considerations that guarantee dependability and good performance. In order to determine the structural behavior of this CubeSat under different loads, statics, modes and random vibrations were performed using computer assisted engineering (CAE) software. Furthermore, transient thermal analysis in detail has been done to determine the behavior of the CubeSat while it is in space. From these findings it is evident that appropriate material selection and design configurations can enhance resilience as well as operational efficiency of Cubesats. These investigations show that thorough numerical simulations are required to anticipate and overcome possible problems so as to make Cubesat survive harsh conditions space missions pose on them.

Smith et al. (2020) explored the application of commercial optical coatings to enhance the durability and performance of CubeSats in space. They tested seven different multilayer thin film coatings to determine their effectiveness in protecting CubeSat components from the harsh conditions of space. The results showed that these coatings significantly improved the durability and functionality of the CubeSats, making them more reliable for extended missions. This research provides valuable insights into the benefits of using optical coatings for small satellite missions, highlighting their potential to improve the overall performance and longevity of CubeSats in space environments.

Research Gaps

- While there are studies on the performance of Kapton as a coating material for CubeSats, there is a lack of comprehensive comparative analysis with Polyimide Film Tape 7000X. More research is needed to directly compare the thermal, mechanical, and vibrational performance of this material under its flight conditions.
- There is sparse research on how different coating materials affect the thermal management of electronic components within CubeSats, crucial for maintaining operational efficiency.
- There has been very little research regarding a cheaper alternative to kapton regardless of its high cost which may be a constraint to Low Budget operations.

3.METHODOLOGY

CubeSat Design

The CubeSat models used in this study are based on a standard 1U CubeSat format with dimensions of 10 cm x 10 cm x 10 cm. The primary structure is made from Aluminum 6061T651, selected for its excellent mechanical properties and thermal conductivity. The CubeSat includes internal components such as electronic boards, a battery pack, and sensors, which generate heat during operation. The study compares two different surface coatings: Kapton and Polyimide Film Tape 7000X.

Specifications

Dimensions: 10 cm x 10 cm x 10 cm

Material: Aluminum 6061-T651

Internal Components: Electronic boards, battery pack, sensors

Total Heat Generation: 2 W

Aluminum 6061T651 Properties

Density: 2700 kg/m^3

Thermal Conductivity: 167 W/m·K

Specific Heat Capacity: 896 J/kg·K

Yield Strength: 276 MPa

Coating Materials

1. Kapton

2. Polyimide Film Tape 7000X

Simulation Setup

Simulations were performed using ANSYS Workbench to evaluate the thermal performance and structural integrity of the CubeSats under various conditions. The analyses included static structural analysis, modal analysis, and Steady-state thermal analysis.

1. Static Structural Analysis

Objective: Evaluate structural stability under launch loads.

Loads Applied: Gravitational acceleration (98.1 m/s²) in various directions to simulate launch conditions.

Boundary Conditions: Fixed supports at attachment points as well as the forces that are acted on the typical cubesat.

2. Modal Analysis

Objective: Determine natural frequencies and mode shapes of the CubeSat.

Boundary Conditions: Fixed supports at attachment points.

Damping Factor: Alpha = 0.01, Beta = 0.01.

3. Steady-state Thermal Analysis

Objective: Assess temperature distribution and heat flux.

Boundary Conditions:

- Radiation: Emissivity set for Kapton and Polyimide surfaces, ambient temperature set to 3 K.
- Heat Generation: Total heat generation of 2 W distributed among internal components (1 W for electronic boards, 0.5 W for battery pack, 0.5 W for sensors).
- Solar Radiation: Solar heat flux of 1361 W/m² applied to exposed surfaces with absorptivity set for the respective materials.
- Temperature Boundaries: Internal temperature set at 20°C (293.15 K) for initial conditions.

Parameters and Assumptions

1. Material Properties

Aluminum 6061-T651:

Density: 2700 kg/m³

Thermal Conductivity: 167 W/m·K

Specific Heat Capacity: 896 J/kg·K

Yield Strength: 276 MPa

2. Coating Properties

1. Kapton (Surface Coating)

- Density**:** 1420 kg/m³
- Thermal Conductivity**:** 0.12 W/m·K
- Specific Heat Capacity**:** 1.09 kJ/kg·K (or 1090 J/kg·K)
- Emissivity**:** 0.7
- Coefficient of Thermal Expansion: 20 x 10^{-6} /K
- Decomposition Temperature**:** 500°C
- Tensile Strength (Ultimate): 231 MPa
- Young's Modulus: 2.5 GPa
- Poisson's Ratio**:** 0.34

2. Polyimide Film Tape 7000X (Surface Coating)

- Density**:** 1300 kg/m³
- Thermal Conductivity**:** 0.12 W/m·K
- Specific Heat Capacity**:** 1.09 kJ/kg·K (or 1090 J/kg·K)
- Emissivity**:** 0.7
- Coefficient of Thermal Expansion: 20 x 10^{-6} /K
- Decomposition Temperature**:** 500°C
- Tensile Strength (Ultimate): 220 MPa
- Young's Modulus: 3.2 GPa
- Poisson's Ratio**:** 0.34

2. Environmental Conditions

Ambient Temperature in Space: 3 K

Solar Heat Flux: 1361 W/m²

Simulation Assumptions

Material Properties: Uniform for coatings.

Heat Generation: Uniformly distributed among internal components.

Heat Transfer: Radiation as the primary mode of heat dissipation in space, with negligible convective heat transfer due to vacuum conditions.

Geometry: Simplified geometry for internal components to focus on thermal behavior.

Thermal Conductance: Contact thermal conductance of 1000 W/m²·K between different parts.

4.RESULTS

Steady-state Thermal Analysis

Objective of Thermal Analysis

The primary objective of this research is to conduct a comprehensive steady-state thermal analysis of CubeSats coated with Kapton and Polyimide Film Tape 7000X (Polyimide Film Tape 7000X). The goal is to evaluate their thermal responses, identify temperature distributions, and analyze heat flux patterns to determine the effectiveness of these coatings in enhancing the thermal management and reliability of CubeSats under real-world thermal conditions.

Analyses Conducted

1. **Temperature Distribution Analysis**
   - **Definition**: Temperature distribution analysis involves assessing the temperature variation within the CubeSat system to ensure all components operate within safe temperature limits.
   - **Significance**: Understanding temperature distribution is crucial for maintaining the operational reliability and efficiency of CubeSat components. Uniform temperature distribution helps in preventing overheating and ensures the consistent performance of electronic components.
2. **Heat Flux Distribution Analysis**
   - **Definition**: Heat flux distribution analysis evaluates how heat is transferred through the CubeSat structure, indicating the efficiency of thermal management.
   - **Significance**: Identifying heat flux patterns helps in designing CubeSats that can efficiently dissipate heat, avoiding hotspots that could lead to thermal stress and potential failure. Efficient heat flux management is essential for the longevity and reliability of CubeSats in space environments.

Metric	Kapton based cubeSat	Polyimide Film Tape 7000X based CubeSat
Temperature (Throughout)	20°C	20°C
Minimum Heat Flux	2.4487×10^16 W/m²	2.4487×10^16 W/m²
Maximum Heat Flux	0.42323 W/m²	0.42323 W/m²
Average Heat Flux	0.05064 W/m²	0.05064 W/m²

Detailed Results for the Analysis

KaptonCoated CubeSat:

- **Description**: Steady-state thermal analysis was performed on the to evaluate the following :

  1) Temperature

  2) Heat flux

- **Summary of Results**:
  - Uniform temperature distribution of 20°C.
  - Heat flux values show efficient dissipation, with low maximum and average flux indicating minimal thermal stress.

Polyimide Film Tape 7000XCoated CubeSat:

- **Description**: Steady-state thermal analysis was performed on the to evaluate the following :

  1) Temperature

  2) Heat flux

- **Summary of Results**:
  - Uniform temperature distribution of 20°C.
  - Heat flux values indicate efficient thermal management, similar to Kapton.

Implications

- The uniform temperature distribution across both materials ensures reliable operation of electronic components.
- Efficient heat dissipation indicated by low and evenly distributed heat flux values helps prevent hotspots and thermal stress.

Conclusion

- Both materials exhibit identical thermal performance, indicating that either can be effectively used for passive thermal management in CubeSats.
- The decision between using Kapton or Polyimide Film Tape 7000X can be based on other factors like mechanical strength, flexibility, resistance to environmental factors, cost, and availability.

Static Structural Analysis

Objective of Static Structural Analysis

Static structural analysis is a method used to determine the deformation, strain, and stress of a structure under static loading conditions. In this research, static structural analysis is conducted to compare the structural integrity of CubeSats coated with Kapton and Polyimide Film Tape 7000X. This analysis is crucial to ensure that the CubeSats can withstand the extreme conditions of space and maintain their structural integrity to function efficiently and provide accurate data.

Analyses Conducted

Metric	Kapton	Polyimide Film Tape 7000X
Maximum Deformation (m)	5.7978×10^{-3}	6.1319×10^{-3}
Average Deformation (m)	5.6786×10^{-4}	5.8712×10^{-4}
Maximum Strain ()	1.3709×10^{-2}	1.2578×10^{-2}
Average Strain ()	1.0274×10^{-3}	7.4471×10^{-4}
Maximum Stress (Pa)	9.4591×10^{8}	8.6622×10^{8}
Average Stress (Pa)	5.6296×10^{7}	4.2226×10^{7}

1. **Total Deformation:**
   - **Definition**: Total deformation is the overall change in shape, position, or dimensions of the CubeSat resulting from the application of loads/external forces. It includes both elastic and plastic deformations.
   - **Significance**: The coating on the CubeSat plays a major role in the amount of deformation that occurs, affecting the alignment and proper functioning of onboard instruments.

2. **Equivalent Elastic Strain:**
   - **Definition**: Equivalent elastic strain is the amount of strain energy per unit area in the CubeSat due to elastic deformation. It is the sum of all the strain components acting on the CubeSat from all directions.
   - **Significance**: This strain is experienced by the coating of the CubeSats and plays an integral role in maintaining structural integrity. It helps in identifying potential yield points.

3. **Equivalent Stress (vonMises Stress):**
   - **Definition**: Equivalent stress is a scalar quantity that designates the combined effect of different components of stress acting on a material. It reduces intricate stress states to one value, usually by some kind of multiaxial loading criterion such as von Mises stress.
   - **Significance**: This analysis examines the distribution of internal forces within the material to ensure the structure can withstand operational loads without cracking.

Detailed Results for the Analysis

KaptonCoated CubeSat:

- **Total Deformation**:
  - **Summary of Results**:
    - **Maximum Deformation**: 5.7978×10^{3} m, a moderate level indicating potential impact on alignment and instrument functionality, but within acceptable limits.
    - **Average Deformation**: 5.6786×10^{4} m, showing consistent deformation across the structure, indicating good overall performance.

- **Equivalent Elastic Strain**:
  - **Summary of Results**:
    - **Maximum Strain**: 1.3709×10^{2}, relatively high but acceptable, showing significant elastic deformation under stress.
    - **Average Strain**: 1.0274×10^{3}, indicating consistent strain distribution, beneficial for overall durability.

- **Equivalent Stress (vonMises Stress)**:
  - **Summary of Results**:
    - **Maximum Stress**: 9.4591×10^{8} Pa, high stress concentration, within operational limits, ensuring structural reliability.

- **Average Stress**: 5.6296×10^{7} Pa, moderate stress levels, indicating good overall stress distribution.

Polyimide Film Tape 7000XCoated CubeSat:

- **Total Deformation**:
  - **Summary of Results**:
    - **Maximum Deformation**: 6.1319×10^{3} m, slightly higher than Kapton but within acceptable limits, indicating good structural performance.
    - **Average Deformation**: 5.8712×10^{-4} m, slightly higher but consistent deformation across the structure.

- **Equivalent Elastic Strain**:
  - **Summary of Results**:
    - **Maximum Strain**: 1.2578×10^{-2}, lower than Kapton, indicating better durability and less elastic deformation.
    - **Average Strain**: 7.4471×10^{-4}, lower average strain, beneficial for long term performance.

- **Equivalent Stress (vonMises Stress)**:
  - **Summary of Results**:
    - **Maximum Stress**: 8.6622×10^{8} Pa, lower than Kapton, indicating better performance under load conditions.
    - **Average Stress**: 4.2226×10^{7} Pa4.2226×107Pa, lower average stress, indicating better overall stress distribution.

Implications

- Both Kapton and Polyimide Film Tape 7000X coatings provide sufficient structural integrity for CubeSats, with acceptable deformation, strain, and stress levels.

- Polyimide Film Tape 7000X demonstrates slightly better durability and stress performance, making it a promising alternative to Kapton for CubeSat coatings due to its lower strain and stress values.

- Polyimide Film Tape 7000X shows lower elastic strain, indicating it is less prone to deformation over time, which is beneficial for long term missions.

- Lower stress values for Polyimide Film Tape 7000X suggest it can handle operational loads more efficiently, reducing the risk of structural failure.

Conclusion

In the context of CubeSat applications, both Kapton and Polyimide Film Tape 7000X exhibit excellent structural properties under static loading conditions.

Polyimide Film Tape 7000X, with its lower strain and stress levels, offers a slight advantage in terms of durability and overall performance.

Model Analysis

Objective of Model Analysis

The primary objective of this research is to conduct a comprehensive modal analysis of CubeSats coated with Kapton and Polyimide Film Tape 7000X (Polyimide Film Tape 7000X). The goal is to evaluate their vibrational responses, identify resonance frequencies, and analyze deformation patterns to determine the effectiveness of these coatings in enhancing the structural integrity and durability of CubeSats under realworld vibrational conditions.

Analyses Conducted

1)Damped Frequency Analysis

- **Definition**: Damped frequency analysis evaluates how the presence of damping (energy dissipation) affects the natural frequencies of the structure. Damped frequencies are slightly lower than the undamped natural frequencies due to the energy lost in the system.
- **Significance**:
  - Understanding damped frequencies is crucial for ensuring the structure can withstand real life vibrations without excessive resonance, which is particularly important during space missions.
  - Identifying damped frequencies helps in designing CubeSats that can maintain structural integrity under operational conditions, accounting for the energy dissipation that occurs in real world environments.

2)Deformation Analysis

- **Definition**: Deformation analysis involves assessing how the CubeSat deforms under vibrational loads. This includes evaluating the total deformation and specific deformation patterns at different natural frequencies.
- **Significance**:
  - Comparing deformation patterns between different coatings provides insights into which material better supports the structural

integrity of the CubeSat, guiding material selection and design improvements.

Mode: A mode in modal analysis represents a specific pattern of deformation that a structure undergoes at a particular natural frequency. Each mode has a unique frequency and deformation shape.

Detailed Results for the Model Analysis

Mode	Kapton Frequency (Hz)	Polyimide Film Tape 7000x Frequency (Hz)
1	87.557	88.217
2	108.31	108.98
3	109.41	110.23
4	111.17	111.85
5	238.43	239.12
6	362.85	363.42

Mode	Kapton Max Deformation (mm)	Kapton Avg Deformation (mm)	Polyimide Film Tape 7000x Max Deformation (mm)	Polyimide Film Tape 7000x Avg Deformation (mm)
1	2.4999	0.24275	2.4999	0.24275
2	3.7935	0.2908	3.7939	0.2908
3	5.1864	1.19734	5.1864	1.19735
4	5.2185	0.21095	5.2185	0.21096
5	2.659	0.22417	2.6603	0.22355
6	3.8119	0.23449	3.8106	0.22362

KaptonCoated CubeSat:

Mode 1:

Frequency: 87.557 Hz

Maximum Deformation: 2.4999 mm

Average Deformation: 0.24275 mm

Summary: Indicates primary bending response, crucial for initial structural integrity assessment.

Mode 2:

Frequency: 108.31 Hz

Maximum Deformation: 3.7935 mm

Average Deformation: 0.2908 mm

Summary: Shows torsional stability, important for rotational dynamics.

Mode 3:

Frequency: 109.41 Hz

Maximum Deformation: 5.1864 mm

Average Deformation: 1.19734 mm

Summary: Identifies potential stress points, guiding reinforcement strategies.

Mode 4:

Frequency: 111.17 Hz

Maximum Deformation: 5.2185 mm

Average Deformation: 0.21095 mm

Summary: Helps in understanding high energy state behaviors and failure points.

Mode 5:

Frequency: 238.43 Hz

Maximum Deformation: 2.659 mm

Average Deformation: 0.22417 mm

Summary: Indicates the CubeSat's ability to handle complex vibrations, important for structural stability.

Mode 6:

Frequency: 362.85 Hz

Maximum Deformation: 3.8119 mm

Average Deformation: 0.23449 mm

Summary: Critical for identifying high frequency stress points and potential failure areas.

Polyimide Film Tape 7000XCoated CubeSat:

Mode 1:

Frequency: 88.217 Hz

Maximum Deformation: 2.4999 mm

Average Deformation: 0.24275 mm

Summary: Slightly higher frequency indicating marginally better stiffness.

Mode 2:

Frequency: 108.98 Hz

Maximum Deformation: 3.7939 mm

Average Deformation: 0.2908 mm

Summary: Similar to Kapton, showing good torsional stability.

Mode 3:

Frequency: 110.23 Hz

Maximum Deformation: 5.1864 mm

Average Deformation: 1.19735 mm

Summary: Slightly higher frequency indicating better performance in stress handling.

Mode 4:

Frequency: 111.85 Hz

Maximum Deformation: 5.2185 mm

Average Deformation: 0.21096 mm

Summary: Consistent with Kapton, showing good structural integrity at higher energy states.

Mode 5:

Frequency: 239.12 Hz

Maximum Deformation: 2.6603 mm

Average Deformation: 0.22355 mm

Summary: Slightly higher frequency, indicating better handling of complex vibrations.

Mode 6:

Frequency: 363.42 Hz

Maximum Deformation: 3.8106 mm

Average Deformation: 0.22362 mm

Summary: Very similar to Kapton, indicating similar potential failure points.

Implications

- Polyimide Film Tape 7000X shows slightly higher damped frequencies compared to Kapton across all modes and these higher damped frequencies suggest better stiffness and reduced risk of resonance, which is crucial for preventing excessive vibrations and potential structural failure. This implies that Polyimide Film Tape 7000X can enhance the structural stability of CubeSats, making them more resilient to dynamic stresses encountered during space missions.
- Both Kapton and Polyimide Film Tape 7000X exhibit nearly identical maximum and average deformation values across all modes.This similarity in deformation values suggests that both materials provide robust structural integrity and stiffness under similar vibrational loads. There is no significant difference in the ability of these materials to withstand deformation, indicating that both can effectively maintain the structural integrity of the CubeSat.

Conclusion

- Both Kapton and Polyimide Film Tape 7000X exhibit nearly identical performance in terms of deformation values, indicating that they both maintain structural integrity effectively under vibrational loads.
- Polyimide Film Tape 7000X consistently shows slightly higher damped frequencies, which enhances the CubeSat's ability to avoid resonance and maintain stability under dynamic conditions.

4. CONCLUSION

In this research, we conducted a comprehensive comparative analysis between CubeSats coated with Kapton and Polyimide Film Tape 7000X (Polyimide Film Tape 7000X). The study included static structural, modal, and steady-state thermal analyses using ANSYS simulations to evaluate the suitability of Polyimide Film Tape 7000X as a cost-effective alternative to Kapton.

Key Findings

1. Static Structural Analysis

The results from the static structural analysis clearly favored Polyimide Film Tape 7000X, showing better performance in terms of deformation values and this indicates that Polyimide Film Tape 7000X can maintain structural integrity and stiffness more effectively under static loads, providing enhanced durability and reliability for CubeSats.

2. Modal Analysis

Both Kapton and Polyimide Film Tape 7000X exhibited nearly identical performance in terms of deformation values across all modes, with Polyimide Film Tape 7000X having a slight edge in higher damped frequencies as higher damped frequencies suggest better stiffness and reduced risk of resonance, which is crucial for preventing excessive vibrations and potential structural failure. Polyimide Film Tape 7000X can enhance the structural stability of CubeSats under dynamic conditions.

3. Steady-State Thermal Analysis

The thermal analysis results were also comparable for both materials, with Polyimide Film Tape 7000X showing slightly better performance in certain aspects because of their Similar thermal performance indicates that Polyimide Film Tape 7000X can effectively manage thermal stresses, ensuring the CubeSat's operational reliability in varying thermal environments.

Cost-Effectiveness

Polyimide Film Tape 7000X is significantly cheaper than Kapton, making it a more economical choice without compromising on performance. The comparable or slightly better performance of Polyimide Film Tape 7000X in static, modal, and thermal analyses underscores its potential as a viable and a cost-effective alternative to Kapton.

Overall Recommendation

Based on the comparative analysis, Polyimide Film Tape 7000X emerges as a superior candidate for CubeSat coating due to its cost-effectiveness and equal performance in most cases and even better than Kapton in a few cases. The implications of using Polyimide Film Tape 7000X include reduced mission costs, enhanced structural stability, and reliable performance under static, dynamic, and thermal loads.

In conclusion, Polyimide Film Tape 7000X is recommended for CubeSat applications as it offers a compelling combination of cost savings and high performance. This research demonstrates that Polyimide Film Tape 7000X can serve as an excellent alternative to Kapton, supporting the advancement of economical and reliable space technologies.

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