National Aeronautics and Space Administration

High Precision Thermally Stable Flexures for Large Deployable Antennas in SmallSats

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Objective

The objective of this project is to explore the viability of using high strain composites [1] (HSC) to design elastic flexures that could serve as a substitute to traditional mechanical spring-loaded hinges. This could help reduce the parasitic weight of the spacecraft, utilize stored strain energy for deployment, and improve the thermal stability of the antenna. At the end of the project, we hope to develop a novel flexure architecture and assess suitable materials for the design. The group at CU Boulder is quite familiar with high curvature bending and failure of composites, hence are best suited for this task. The collaboration between JPL and CU Boulder has enhanced JPL knowledge and expertise in HSC. In addition, this collaboration has provided an opportunity for a student to make a significant contribution to this field of research.

Significance/Benefits to JPL and NASA

This project develops a novel flexure that will be thermally stable and have lower weight compared to a mechanical hinge. If this project proves to be a success, the flexures in Figure 6 could be used for any future missions involving deployable panels. The analytical tools consider the size/mass factors of the panels, hence a suitable flexure design could be provided based on each mission parameters. Current results show favorable signs of achieving a high stiffness while maintaining a reasonable compaction level. Furthermore, this project focuses on high strain composites whose behavior is still not fully understood. Material testing on HSC will be a useful addition of knowledge to JPL to understand their behavior and failure.

Acknowledgments

The authors would like to acknowledge PhD student Yasara Dharmadasa for his great research work and dedication in developing cutting-edge capabilities for the infusion of High Strain Composites (HSC) into spaceflight hardware. The authors would also like to thank Dr. Francisco Lopez Jimenez in the area of HSC at the Aerospace Mechanics Research Center (AMRC), University of Colorado Boulder. His skills and expertise were fundamental in enhancing JPL's existing capabilities in advanced composites, leading to more efficient and lightweight flight hardware.

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Background

CubeSats such as Mars Cube One (MarCO, Figure 1) are low-cost solutions to be used for communication missions and they use X-band frequency to transmit data to earth. The reflectarray panels are folded around the CubeSat body during launch and later deployed to achieve maximum antenna size. One Meter Reflectarray Antenna (OMERA) is a technology demonstration mission that was able to fold a one-sq meter reflectarrray around a 6U CubeSat. The panels are folded using mechanical hinges made from Aluminum and the mismatch in thermal coefficient between the Al and composite panels decrease the thermal stability of the satellite. Replacing the mechanical hinges with HSC hinges would increase the thermal stability while reducing the weight of the hinge. The project aims at finding a new flexure architecture and suitable materials to replace mechanical hinges. In this project we will take OMERA as the baseline and attempt to design a HSC flexure that provides a precise deployment. We also investigated the application of similar flexures for other missions with different panel size and mass.

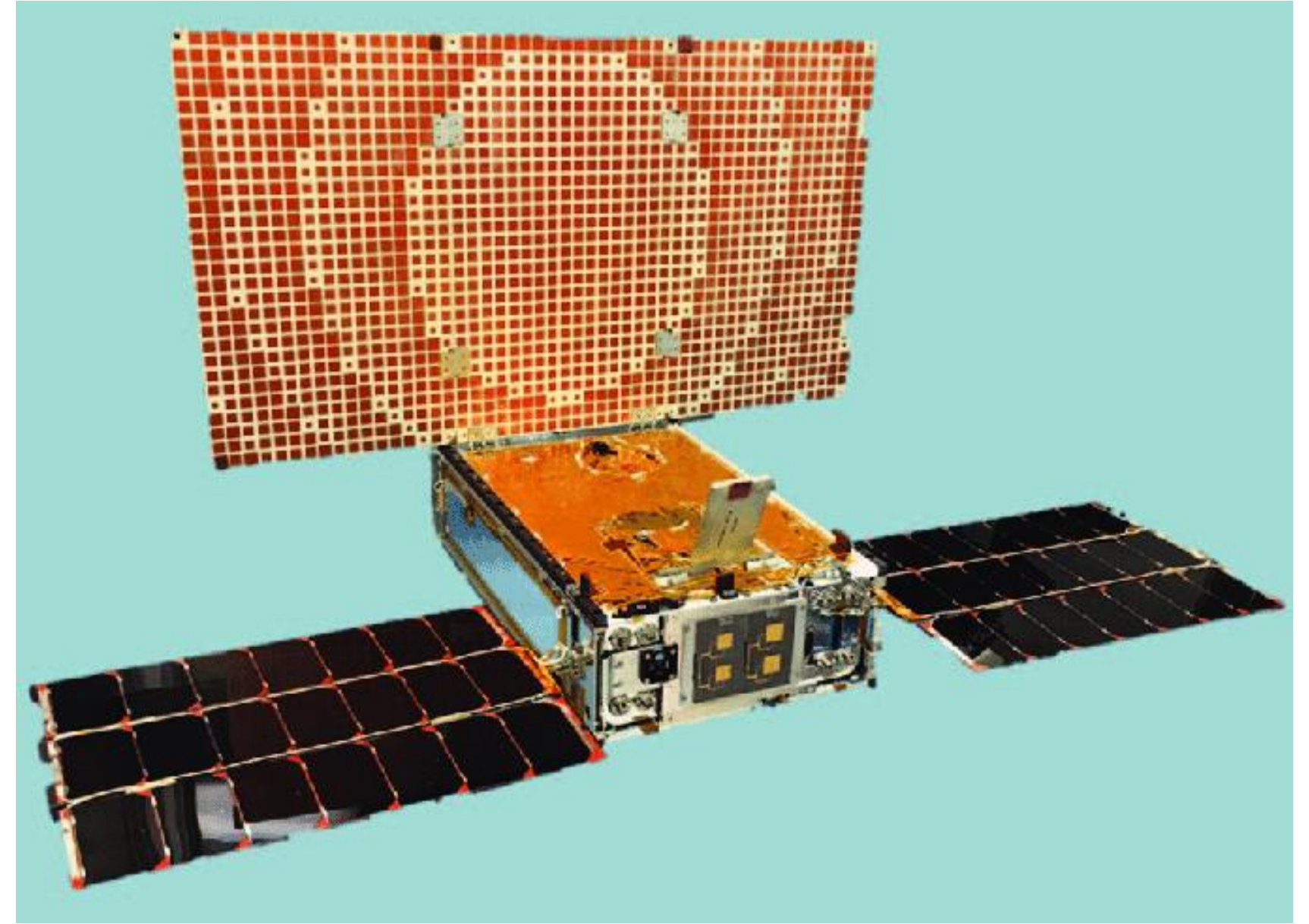

Figure 1, Mars Cube One (MarCO) reffectarray

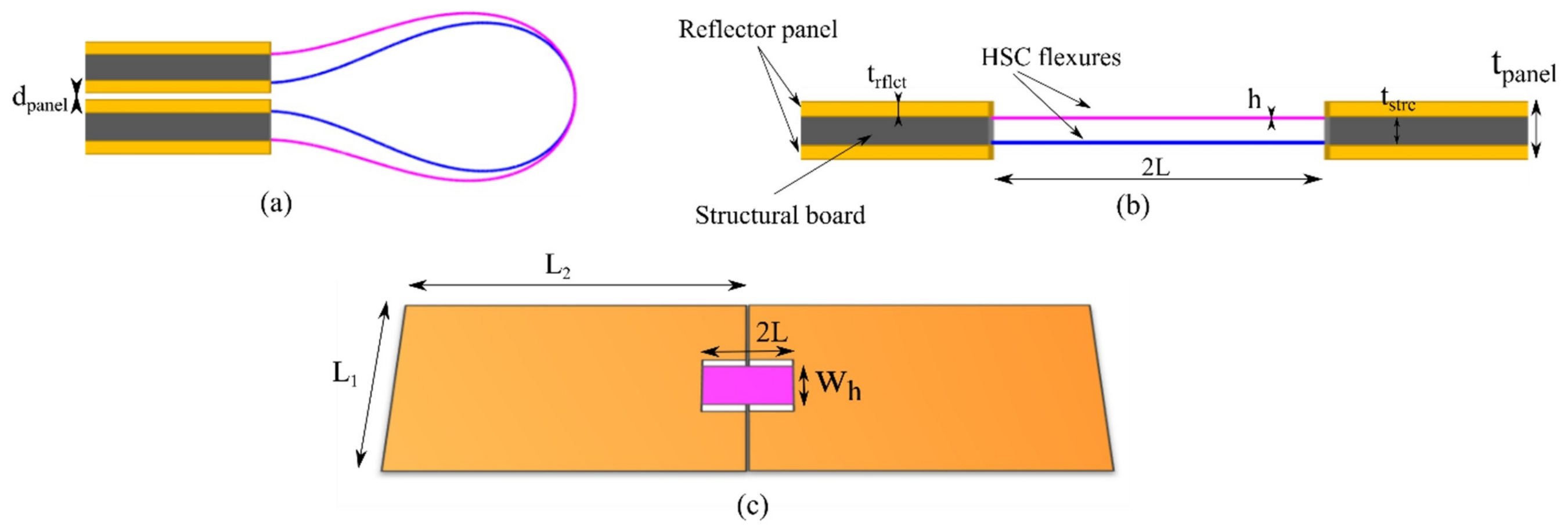

Figure 2, Proposed flexure design (a) when folded, (b) when deployed and (c) 3D view with the reflector panels

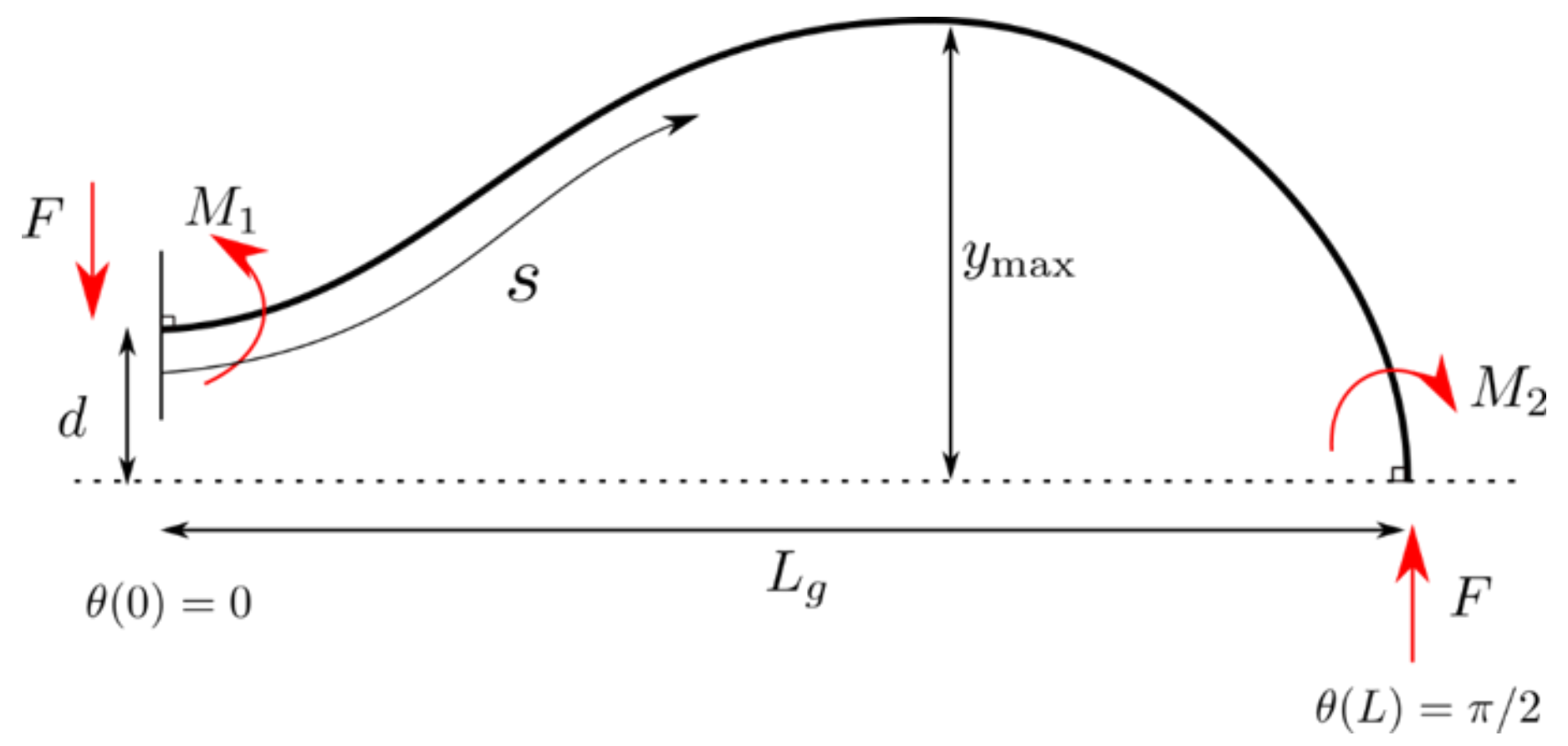

Figure 3, Elastica solution for the bending geometry of the flexure

Approach and Results

The ideal hinge design for a folding reflectarray should meet the following criteria: (a) the hinge should be able fold the panels on top of each other providing a good stowage; (b) the hinge should have sufficient stiffness in the deployed configuration; (c) the deployment path should be simple and easy to predict; and (d) the hinge should not plastify or undergo failure during stowage. We consider doubly flat HSC flexures, a hinge composed of two flat HSC strips that is able to elastically bend, Figure 2.

First, we carry out a geometric analysis on the folded state to ensure material does not fail. We make use of the elastica solution on the bending of a slender beam to estimate the deformed geometry of the flexure, Figure 3. From this analysis we can obtain the strain levels of each of the HSC strips for a given thickness(h), length(L), and compaction level (d). By superimposing the effect of both flexures, we can obtain relations between the length(L), HSC gap(Δ) and thickness(h) that satisfies a given failure strain, Figure 4.

We also need to carry out a dynamic analysis to ensure the stiffness of the hinge is not too low resulting in unnecessary vibrations of the spacecraft. For this purpose, we estimate stiffness of the hinge at the deployed configuration and compare the natural frequencies of the panel. We derive analytical tools that can provide a first order estimation of the natural frequencies using Timoshenko beam theory. Comparisons were carried out using finite element software Abaqus, Figure 5, and the analytical model was able to predict the first mode with a 96% accuracy.

Combining the analytic tools derived from the geometric analysis and the vibration analysis, we are able to optimize the hinge geometry such that it has maximum stiffness while maintaining the required compaction for a given failure strain. HSC coupons manufactured at JPL are being tested at CU Boulder to characterize their properties. The samples will be characterized through the Column Bending Test [2, 3], which is the most common experimental technique currently used to study the high curvature behavior of HSC. The test will provide the bending stiffness and the failure curvature of the samples; the latter is particularly important, since traditional failure theories significantly under-predict the failure properties of HSC under bending [4].

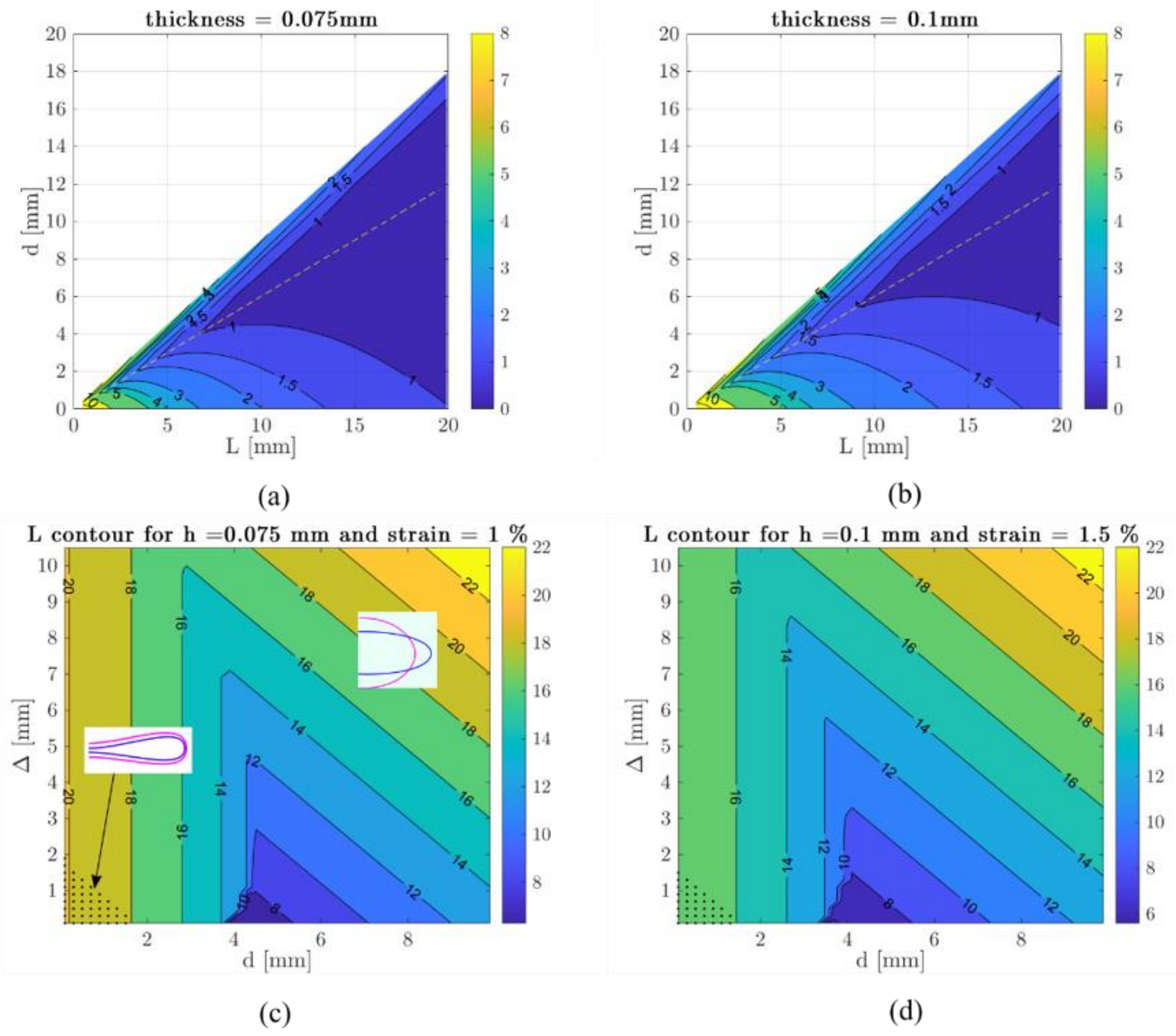

Figure 4, Maximum strain contours for hinge half length L and various d configurations for (a) h=0.075 mm and (b) h=0.1 mm. (c) Length contours for a pair of HSC strips satisfying 1% and (d) 1.5% failure strain.

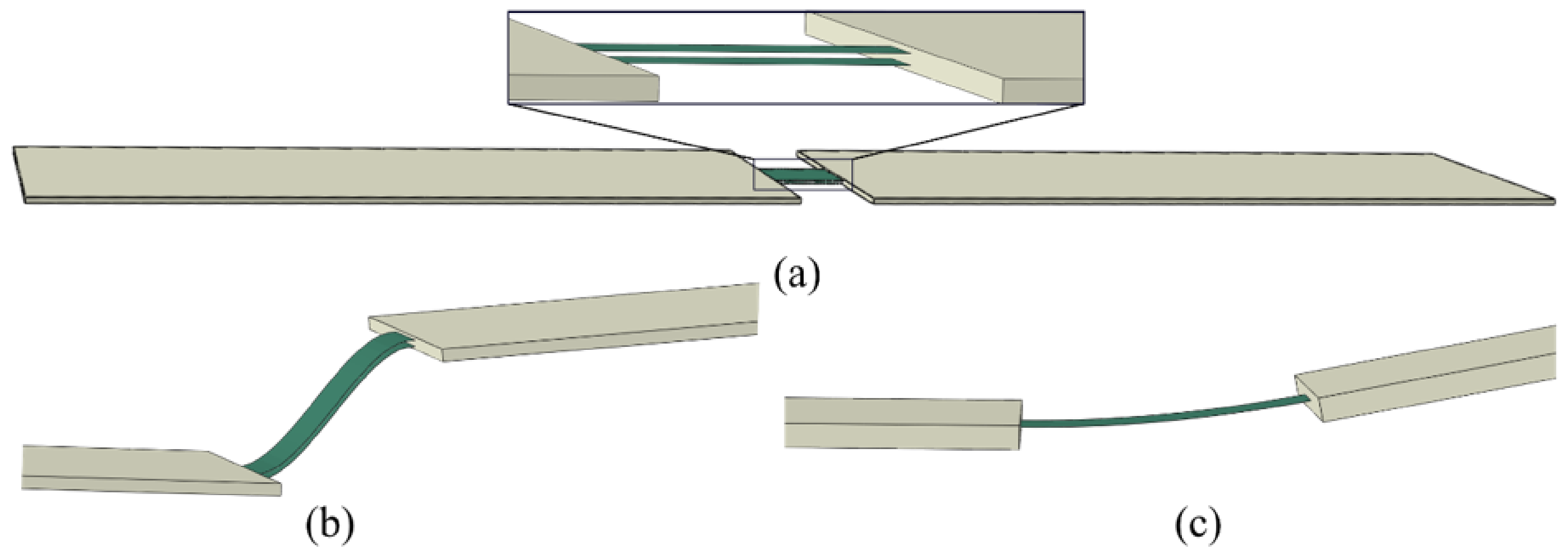

Figure 5, (a) Finite element model of the HSC flexure hinge, showing (b) first mode of deformation and (c) first mode of deformation for a single HSC strip

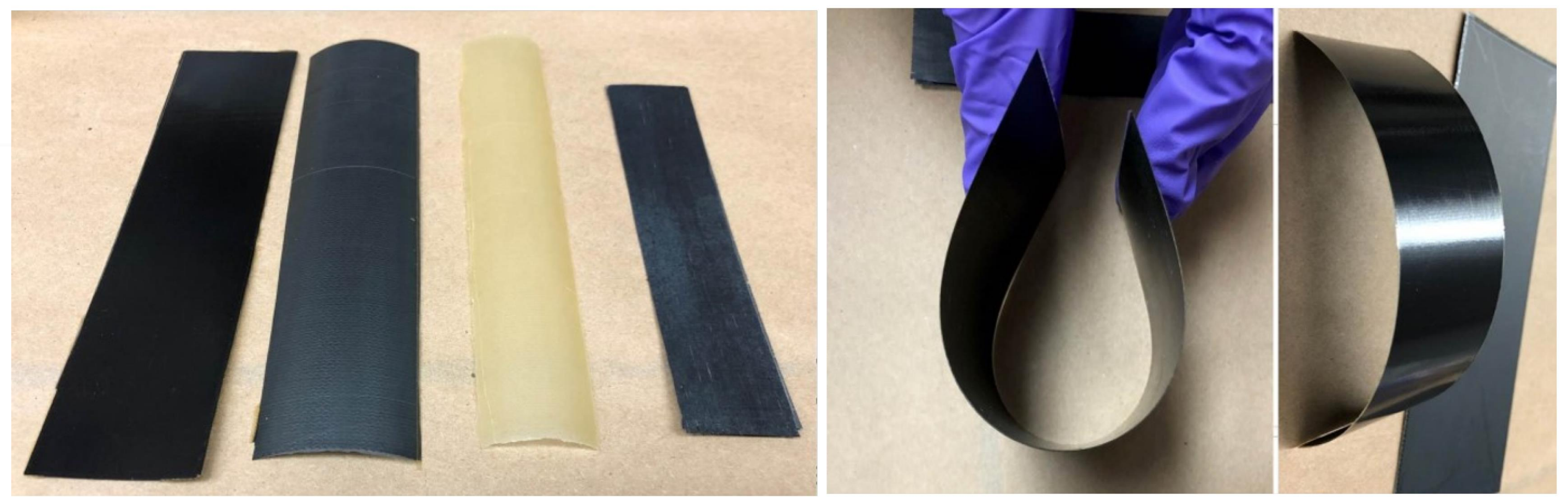

Figure 6, Carbon/Glass Fibers, High Strain Composites made at JPL

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