Deployment Testing of Flexible Composite Hinges in Bi-Material Beams

Extended Abstract

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Composites have excellent properties for strength, thermal stability, and weight. However, they are traditionally highly rigid, and when used in deployable structures require hinges bonded to the composite material, which increases complexity and opportunities for failure. Recent research in composites has found by adding an elastomeric soft matrix, often silicone instead of an epoxy, the composite becomes flexible. This work explores the deployment repeatability of silicone matrix composite hinges which join rigid composite beams. The hinges were found to have sub-millimeter deployment repeatability. Also, an interesting creep effect was discovered, that a hinges deployment error would decrease with time.

I. Introduction/Background

COMPOSITES have excellent strength characteristics, are lightweight, and thermally stable. Unfortunately, they are usually highly inflexible and require hinged joints when used in deployable structures. This is a challenge for CubeSats/SmallSats as the hinges and actuation mechanisms get very small and require multiple custom precision parts. On larger sattelites, hinges are not desireable as it increases piece part count, introduces a potential weakness as hinges must be bonded, and often the metals used in hinges are not thermally stable. A new field of research, high strain composites, which is a subset of deployable space structures[1], provides solutions for complaince which may eliminate the need for hinges in deployables. Specifically of interest in this paper are elastomeric soft matrix composites. Thus far, there have been advances in elastomeric soft matrix flat sheets and flexible rods[1]. However, as of yet, composite beams which have rigid section with flexible hinges in between have not been developed.

While there are a large number of flexible composites, like those used in rigidizing inflatable structures[2], our interest is in composites which remain flexible, enabling constant hinge-like characteritics, which limits the materails under consideration to elastomeric soft matrix flexible composites. Prior research have identified three types of elastomeric flexible composites, UV cured silcone matrix in composites sheet[3], FLASH materail by L'Garde which is a silicone infused carbon fiber rods[1], and triaxially woven carbon fibre reinforced silicone (TWF CFRS) developed in Europe[4]. While flexible sheets would be convenient for the development of sunshades, solar panels, and relfective surfaces, the interest of this work was beams. Therefore, the L'Garde FLASH materail was the best candidate for research.

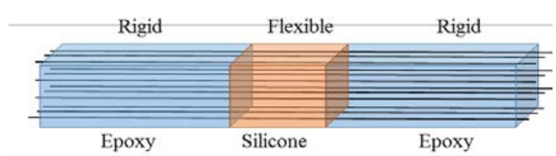

Figure 1: Concept for a Flexible Composite Hinge in a Bi-Material Beam

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II. Research Objective

The objective of this research was to build and test a proof-of-concept flexible composite hinge. The hinge consists of a two rigid beams joined by a flexible section. The hinge decreases the number of parts required for joints, which consequently lessens the likelihood of failure. Cost and weight are also reduced by using a one-piece hinge, as the use of precisely machined metal parts is avoided. Composite flexible hinges store strain energy which means they are self-actuating. Hinges with these properties may be especially useful in enabling origami based deployed. Developing a proof of concept flexible composite hinge would establish a foundation for future proposals in Flexible Material Systems with applications towards innovative antennas, booms and solar arrays.

III. Construction of a Flexible Composite Hinge

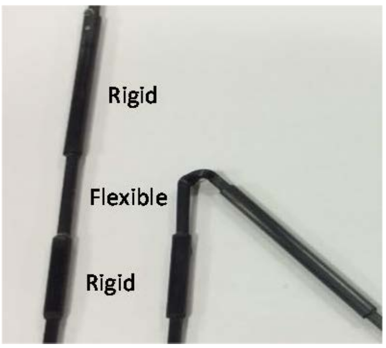

Figure 2: Flexible Composite Beam

Research by L'Garde Inc. and Caltech has investigated using a silicone matrix with carbon fiber to make a composite flexible[1,3]. This work extends their work by developing a rigid composite beam with a flexible section in the middle acting as a hinge. To start, we collaborated with L'Garde and Caltech to determine the best approach for building a flexible composite hinge. Originally, there were two concepts for creating a rigid composite beam with a flexible section in the middle acting as a hinge. The first was to layup the fibers lengthwise, and then apply a rigid epoxy to either end and apply silicone in the middle (as seen in Figure 1). This was the most desirable method, as the long fiber strands running through both the rigid and flexible hinge portions of the beam would add strength. A second option was to build the hinge by first laying up a small piece of flexible silicone composite as a hinge, and then bonding rigid carbon fiber beams to either side of the hinge. L'Garde provided JPL with ten 1.5 mm diameter rods of the Ultra-FLASH material and one 3 mm diameter rod of the FLASH material. In collaborating with L'Garde, it was learned while there are continuous fibers impregnated with epoxy and silicone in different sections in the 1.5 mm Ultra-FLASH material, the epoxy does not impregnate the fibers well and fatigue occurs at the epoxy-silicone joint. Therefore, the best approach was to build a flexible composite hinge by bonding rigid carbon fiber tubes to a flexible epoxy rod. As the 3 mm FLASH material had a greater cross-sectional area, it was decided to use these rods in constructing the flexible composite hinges. Two prototypes of flexible composite hinges were built by butting the 3mm FLASH material to 3mm composites rods and then overlapping the rods with a 3.2mm ID composite tube (4.75mm OD). Loctite 401 was used to bond the rods and tube.


Figure 3: Flexible Locking Mechanism, Concept and Prototype

One of the challenges with a flexible composite hinge, is that in order to deform up to 180 degrees, a significant length of the hinge (up to a half inch) is required to be flexible. This results in the hinge being "soft" in all directions except for when in tension, which means the beam can no support a bending load. To provide resistance to bending, a locking mechanism for the flexible composites was developed, where rigid section of tubing would slide over the composite. The rigid tube was spring loaded, automatically locked the beam in place when the flexible composite deployed the beam and the two rigid sections became aligned. The locking mechanisms still provided two interesting degrees of freedom. The first was rotational about the beams center axis, as the locking mechanism did not resist torsional loads, and the flexible composite allowed movement up to 120 degrees. The design also provide a small amount of freedom for compression, as the flexible composite would buckle inside the tube. The compression degree of freedom only occurred

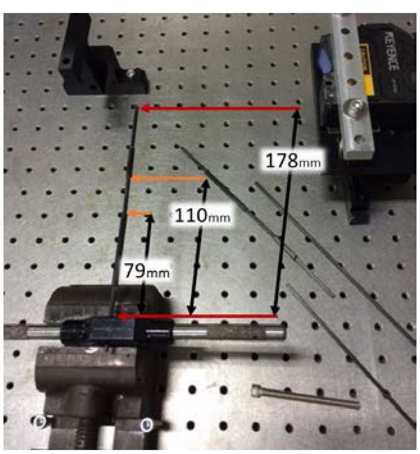

Figure 4: Deployment Test Set-Up

because the diameter of the flexible composite was about half the diameter of the locking tube.

IV. Deployment Testing of the Flexible Composite Hinge

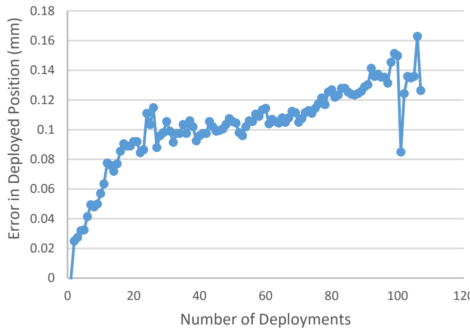

Figure 5: Deployment Error Initially Grows Quickly

One of the key properties of interest for the flexible composite hinge was deployment repeatability. Deployment repeatability is a critical property for deployable structures, especially when they support RF or optical instruments. The key are of interest, is after each deployment, how closely does the hinge return to its previous position? Second, how do multiple deployments influence deployment repeatability?

To test deployment repeatability, the prototype beams with flexible composite hinges were secured in a vice. A Keyence LK-G152 head with a LK-G3001 readout was used to measure the position of the deployed position of the beam. The laser measurements were taken 178mm away from the where the beam was clamped in the vice, with the flexible composite hinge beginning at 79mm to and ending at 110mm from the vice (Figure 4).

A total of 107 deployments were conducted sequentially, where the hinge we bent back to approximately 160 degrees and then allowed to freely deploy. After each deployment, the hinge was allowed 2-3 seconds to damp out vibrations, at which point the Keyence system produced a consistent reading. Deployment repeatability tests found that initially the error in deployed position increased rapidly (up to 0.02mm per deployment), but after 25 deployments the error in deployed position grew much more slowly

Another fascinating result, occurred on the 100th deployment, where instead of 2-3 seconds of time between deployments, a total of 45 seconds was allowed to pass. During this time, it was observed that the composites error in deployed position decreased by almost fifty percent (Figure 6). This reduction in error with time implies the flexible composites have internal strain energy which is slowly released with time.

V. Conclusion

While preliminary the results from a preliminary test have been completed, there are a number of tests the authors plan on completing before final paper submission. First, additional investigation on the time dependent shape restoration of flexible composites will be explored. Tests will be improved and time scales will be increased to explore if more time would result in greater shape restoration, and thus better deployment repeatability. Also, the experiment will be modified to account for any error occurring by the way the composite beam is held in the vice. A second area of investigation will be time dependent stowage on deployment repeatability. If flexible composite is held in the fully strained state for several hours, days, or weeks, how does deployment error compare to occurrences when the composite is only held for several minutes? Finally, a comparison will be completed on the deployment accuracy of the flexible composite hinge with and without the locking mechanism, to determine if it has any positive effects other than allowing the beam to withstand bending loads.

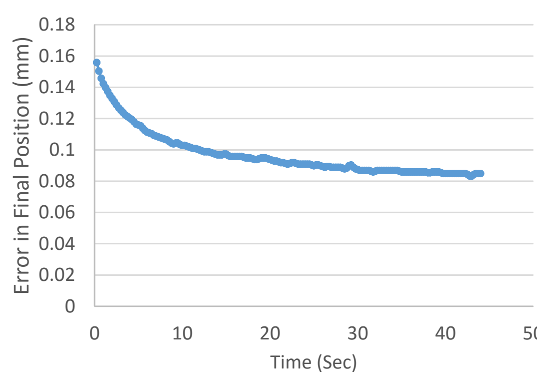

Figure 6: Flexible Composites Restore to Original Position Overtime

High strain composites are a new exciting field, especially in the area of spacecraft structures. It stands enable novel deployable structures which consist would consist of fewer parts. Thus far, flexible composites appear to provide the accuracy that would be required of RF structures, with sub-millimeter errors in deployment repeatability, and the deployment error decreases with time.

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