Single Motion Actuated Shape Memory Alloy Coupling

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Abstract

The objective of the single-motion-actuated-shape-memory-alloy coupling (SMA^{2}C) is to produce a small, single motion actuator used to secure and then release the solar panels on a CubeSat, or other very small satellite, upon command. The SMA^{2}C consists of a nickel titanium (NiTi) cylindrical shape memory alloy (SMA) press-fit into a stainless steel bushing, surrounded by a Kapton foil heater, a spring, a holding bolt, and a polyethermide isolation washer all in a structural housing. Heating the SMA above its activation temperature causes it to contract, permitting the spring to push the SMA, and therefore the holding bolt, out of the stainless steel bushing. This releases whatever the holding bolt is attached to from the CubeSat structure.

Introduction

In the past, CubeSats, very small satellites of about one to four kilograms, have used various ways to secure their solar panels while in their CubeSat launchers. Some have been simply held closed by the walls of the launcher itself. The CubeSat's solar panels would slide along the walls of the launcher and, when fully released, the solar panels would deploy. Sometimes the solar panel is secured by tying fishing wire around the solar panel and having a mechanism burn the wire for a controlled release. When this method is successful, it is quite simple and effective, but there have been premature releases occurring during vibration tests. In addition, there is a limit to the amount of force that the fishing wire can withstand, restricting its application to other types of deployments. SMA^{2}C is a release mechanism that addresses both control of deployment and capacity of holding force, which can be scaled for many applications.

SMA^{2}C Background

NiTi is a shape memory alloy with particular properties for our application. Shape memory alloys are a class of materials that exhibit a mechanical change in property with a non-mechanical input such as a temperature change. SMAs undergo three types of transformations; Austenite, Twinned Martensite, and Detwined Martensite. In its natural state, SMA begins in its memory state also known as the Austenite phase. Once cooled it enters into the Twinned Martensite phase in which the crystal structures realign and produce a minimal change in overall expansion. If stress is not introduced during the Twinned Martensite phase and heated back up, the SMA's crystal structure returns back to its Austenite phase and a minimal amount of overall contraction occurs. On the other hand, when stress (σ) is added in the cooled Twinned Martensite phase, an increase in strain (ε) (expansion) of the Shape memory alloy brings it to the Detwinned Martensite phase wherein its crystal structure has been further modified. In order to go from the Detwinned Martensite phase back to Austenite phase, all that's needed is an increase in temperature. This will cause the crystal structure to return to its original memory state (contraction). The amount of overall expansion is closely related to the amount of stress added during the Twinned Martensite phase. Figure 1 is a visual representation of this process.

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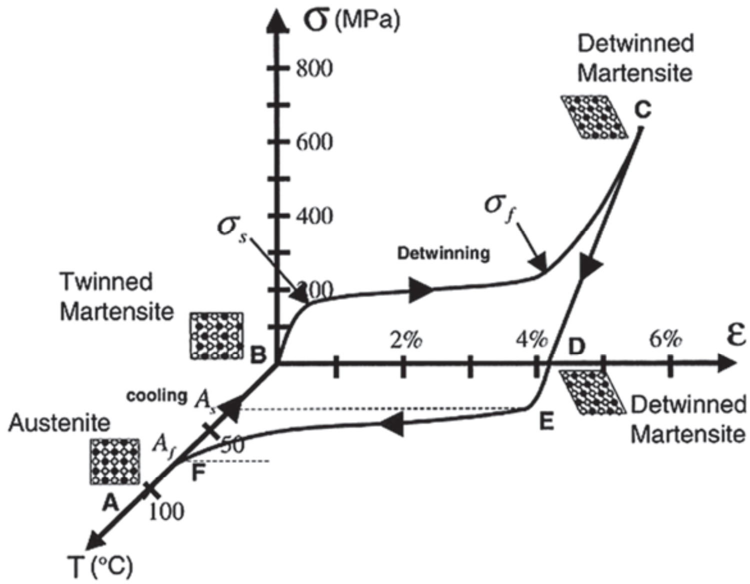

Figure 1. Shape Memory Alloy phases [1]

SMA^{2}C press fitting

Assembly begins with a load cell in order to measure the amount of stress incurred on the NiTi during press fit. The outer bushing is placed inside the cradle and a little Isopropyl alcohol is dropped inside in order to clean and act as a lubricant during the press fit. The remaining cradle is then placed on top followed by the NiTi ring on the press pin. The press pin is then forced down causing the NiTi ring to be forced into the steel bushing as the load cell records the amount of force being asserted by the press pin. Figure 2 depicts the press fit assembly.

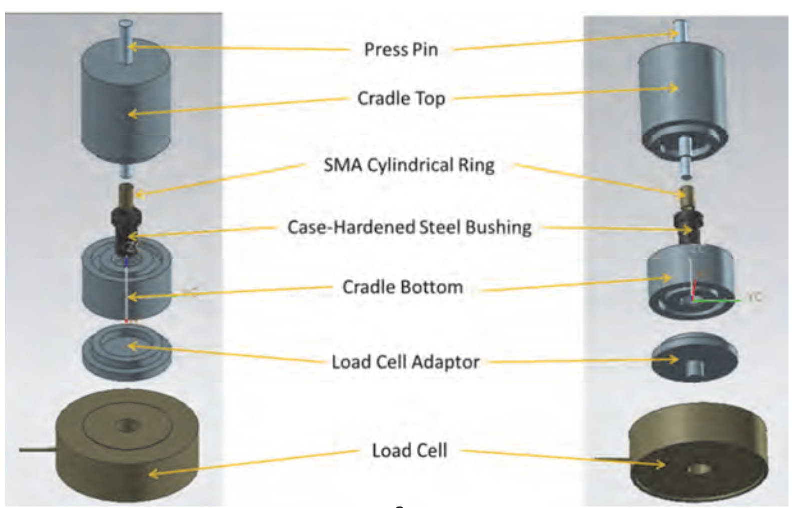

Figure 2. SMA^{2}C Press fit [2]

SMA^{2}C holding force

As mentioned above, the amount of stress induced between the Twinned and Detwinned Martinsite phase is directly correlated to the the amount of strain (expansion) that the NiTi undergoes. This expansion affects the amount of holding force when inside the bushing. In order to demonstrate this relationship, four different sample sets of NiTi rings were used with different outer diameters. They were each press fitted into a bushing of a certain diameter. The outcome was four sample sets, each with different interference measurements (difference between the outer radius of the NiTi ring and inner radius of the bushing). The sample with the greatest interference required greater force when press fitting the two pieces together, therefore increasing the stress induced. Because of this increased stress, the NiTi expands, leading to a greater force required to separate the two. Figure 3 plots the four different samples with varying interference and the amount of force needed to separate the NiTi ring from the bushing.

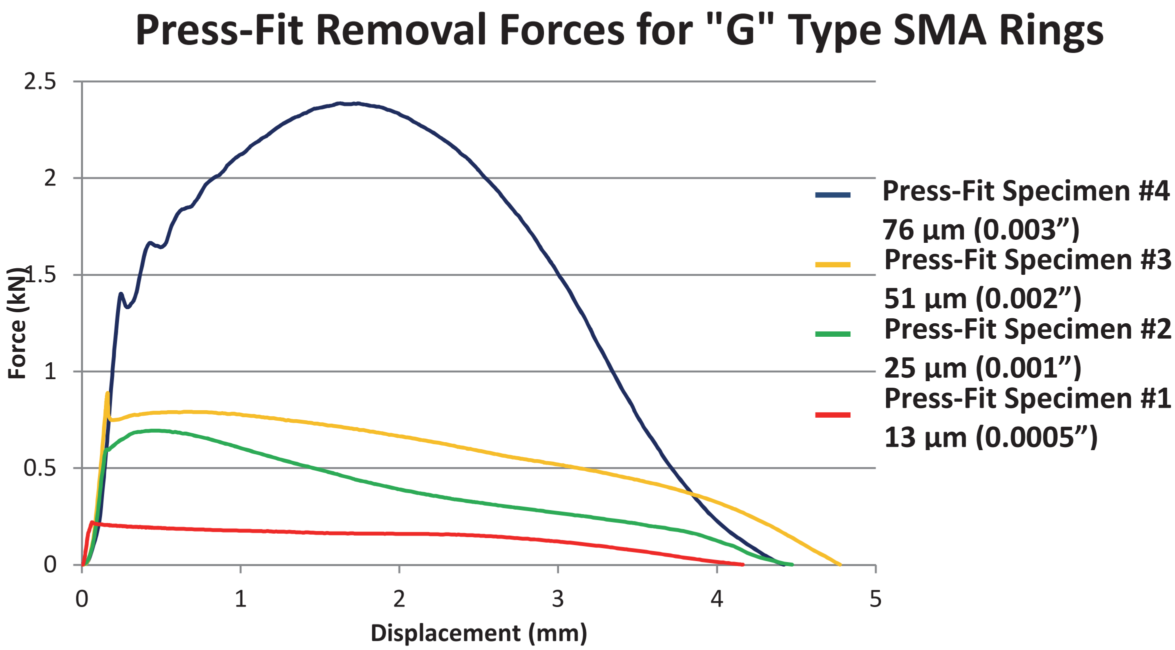

Figure 3. SMA^{2}C holding force [2]

<u>SMA^{2}C assembly</u>

After the NiTi ring has been press fitted into the bushing, a polyethermide isolation washer is placed through the bushing in order to thermally isolate it from the remaining assembly and the CubeSat. The bushing is wrapped with a Kapton foil heater and this assembly is then inserted into the outer housing. A push plate and spring are inserted on the other end. This push plate will provide the little push required to separate when the NiTi is heated in a zero gravity environment. Figures 4 and 5 depict the final assembly.

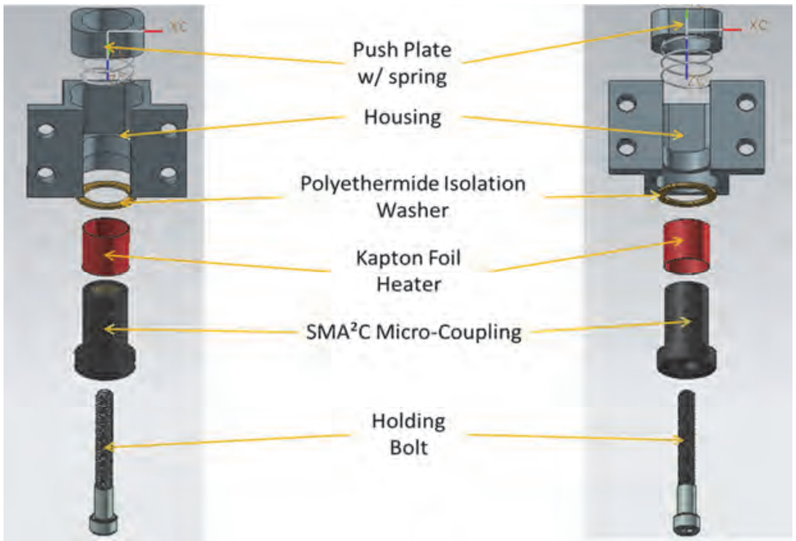

Figure 4. SMA^{2}C final assembly [2]

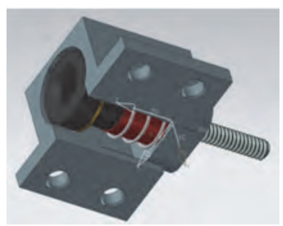

Figure 5. SMA2C assembled [2]

SMA^{2}C release

The SMA^{2}C housing would be secured to the bottom of the CubeSat. A retaining bolt would be inserted through the bushing and NiTi ring with the head of the bolt resting on the NiTi ring, and the other end secured to the solar panel. When commanded, current is sent to the Kapton foil heater, which then heats the SMA^{2}C micro coupling. Once heated, the NiTi will shrink allowing it to be released from the steel bushing. The push plate and spring would help nudge the NiTi ring along with the bolt out of the bushing.

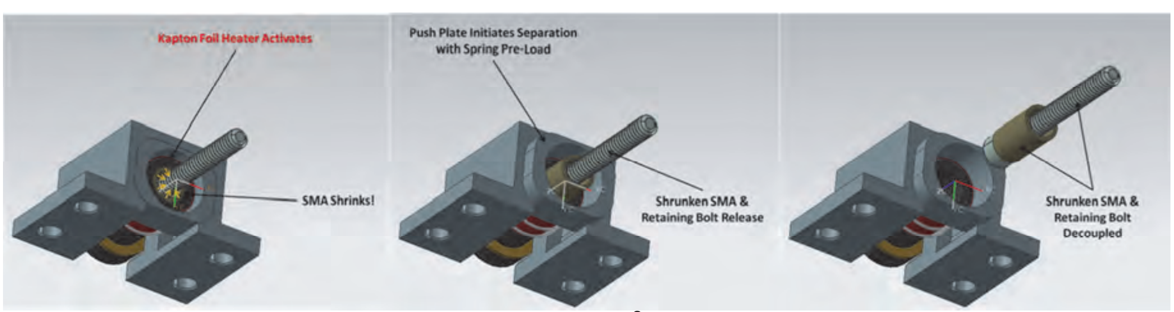

Figure 6. SMA^{2}C release [2]

Conclusion

CubeSats, and other small satellites, require a mechanism to secure and to control the release of their solar panels and other deployables. One common practice is to use fishing wire to secure the deployable and cut it thermally at the desired time on-orbit to release it. Due to the limitation of the fishing wire's strength and reliability, especially during vibration testing, other release methods may be useful.

SMAs, when pressed fitted into another metal, provide a strong holding force which can be released with the addition of heat. The amount of holding force can be modified by simply adjusting the difference between the outer diameter of the SMA ring and the inner diameter of the bushing. Once heat is added to the bushing, the SMA contracts allowing the SMA and the bolt to release from the bushing.

References

[1] D. C. Lagoudas – Editor, Department of Aerospace Engineering Texas A&M, *Shape Memory Alloys Modeling and Engineering Applications*; Published by Springer Science + Business Media, LLC © 2008.

[2] Crane, William Mike. *Development of a Nano-Satellite Micro-Coupling Mechanism with Characterization of a Shape Memory Alloy Interference Joint.* MS thesis. Naval Postgraduate School, Monterey, 2010. Print