＜様式 11＞（受入引受教員用）

共同研究成果報告書

提出日：2023 年 10 月 4 日

名城大学　学長　殿

<table>
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（共同研究者）</td><td>所属・職名</td><td>理工学部交通機械工学科・准教授</td></tr>
<tr><td>氏　　名</td><td>仙場淳彦　㊞</td></tr>
<tr><td>研究員氏名</td><td colspan="2">Jon Dewitt Dalisay　（国籍：フィリピン　）</td></tr>
<tr><td>共同研究期間</td><td colspan="2">2023 年 7 月 5 日～2023 年 8 月 31 日（　2 ヶ月間）</td></tr>
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共同研究要旨	次世代の宇宙工学ミッションに有望視される宇宙構造物の一つとして、形状記憶樹脂を用いた自己展開構造がある。本共同研究では、当方の近年の研究成果に基づき、Jon Dewitt Dalisay 氏の数値解析技術の知見を活かして、形状記憶樹脂を用いた宇宙構造物の数値シミュレーション技術の構築を目指すものである。特に、自己展開過程における材料加熱と形状回復の関係性を高精度に予測できるモデルの導出を行う。本モデルは、温度・力・変位関係の非線形性を表現できるモデルを検討する。その結果に基づき、次世代の応用ミッションに向けた基盤技術として、新しい構造様式を提唱できるものと考える。
共同研究成果	形状記憶樹脂を用いた宇宙構造物の数値シミュレーション技術の構築のため、汎用有限解析ソフトウェアである ANSYS Mechanical を用いて非線構造解析を行うことを議論した結果、まず受け入れ教員側の近年の研究対象であった、形状記憶樹脂を用いた自己展開シェルを解析対象とすることになった。このシェルは、輸送時はロケットに小さく折りたたまれ、宇宙空間で大面積に展開させる新展開技術の基礎となる構造要素ある。Dalisay 氏の研究結果において、形状記憶樹脂の特性を形状記憶合金の構成式で近似的に表す解析手法の提案内容と数値解析結果が示されている。要点は形状記憶合金の構成モデルのみ使用できることを考慮し、形状記憶樹脂製の構造特性表現に応用したものである。今回、同氏の 2 ヶ月という短期滞在にも関わらず、過去の実験結果を妥当に表現可能な解析モデルが得られたことは期待以上の成果と言える。今後は、形状記憶合金と樹脂の相違点を考慮した精度改善について共同研究していく。

＜様式 12＞（外国人研究員用）

共同研究終了報告書

提出日：2023 年 10 月 4 日

名城大学　学長　殿

研究員氏名	Jon Dewitt Dalisay	
研究期間	2023 年 7 月 5 日～2023 年 8 月 31 日（　2 ヶ月間）	
受入引受教員（共同研究者）	所属・職名	理工学部交通機械工学科・准教授
	氏名	仙場淳彦　㊞

研究課題名	形状記憶樹脂を用いた宇宙展開構造物の非線形挙動の数値シミュレーション
研究結果	The original research plan for the 2-month stay was to develop increasingly complex finite element (FE) models of shape memory polymer (SMP) structures so that the experimental structure presented in [1] can eventually be simulated. Unfortunately, we found during our literature review that there are no available SMP constitutive models ready for implementation in our chosen FE solver (Ansys Mechanical) [2]–[7]. Consequently, we pivoted from immediate application to more basic research with two primary directions: 1. establish the feasibility of simulating the shape memory characteristics of SMP patches and 2. identify a constitutive model and initialize the implementation in Ansys Mechanical. Majority of the activity during the 2-month stay was towards the first direction. Due to the unavailability of an SMP constitutive model, we used the shape memory alloy (SMA) constitutive model available in Ansys Mechanical, which enables pseudoelasticity and shape memory by virtue of a temperature-dependent pseudoelastic limit. The primary limitation of the current work is the use of nitinol-like properties (quite different from the actual material, a polyurethane SMP). Nevertheless, this allowed us to embark on activities of the first direction and acquire promising results.

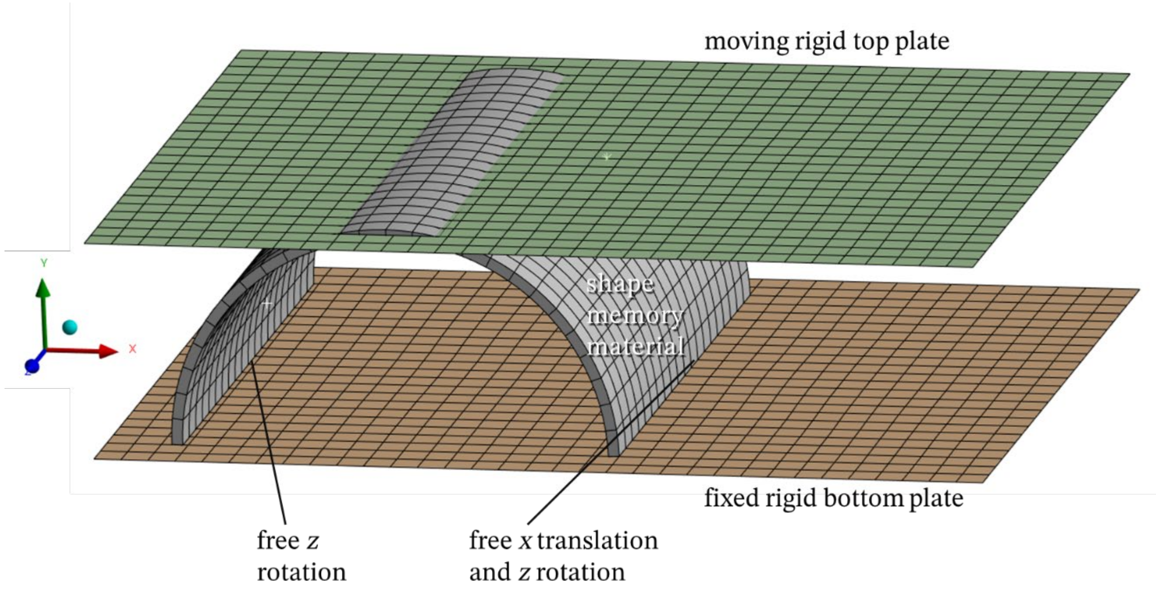

Figure 1. Computational model with boundary conditions.

Figure 1 shows the computational model with its boundary conditions. Since this work directly expands on the preliminary computational results in [8], the permanent boundary conditions of the SMP patch in [8] are employed. Improving upon the previous work, rigid plate boundary conditions are additionally employed here, very much like the experimental conditions in [8]. This enabled us to properly simulate an imposed strain on the material.

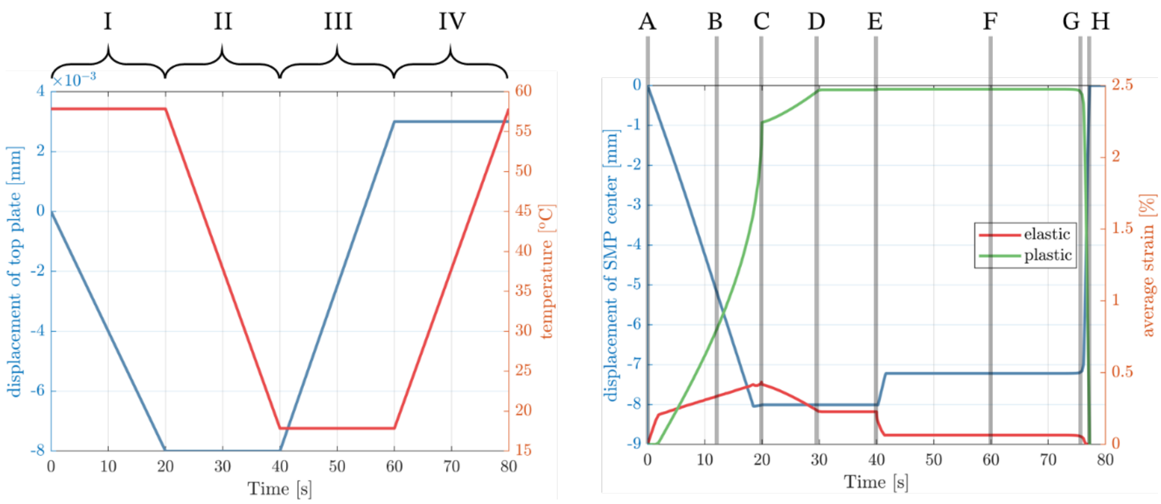

Figure 2. (a) thermomechanical cycling and (2) response of the shape memory material.

Figure 2a shows the thermomechanical cycling imposed on the computational SMP patch. The conditions are divided into 4 regions: (I) compression at high temperature (rubbery state, or austenitic state in the case of SMAs), (II) constant strain cooling passing through glass transition or phase change in the case of SMAs, (III) decompression, leading to elastic springback at low temperature (glassy state, or martensitic state in the case of SMAs), and (IV) zero-strain heating passing through glass transition or phase change in the case of SMAs. Figure 2b shows the resulting displacement of the SMP patch's center, as well as the average elastic and “plastic” (transition to glassy or phase change to martensitic) strains, which corresponds to states A-H in Figure 3. State A is the start of the computational simulation, where there is no displacement and initial contact with the top plate is established. State B is the intermediate state from zero to full compression. It is important to note that due to the pseudoelasticity submodel presuming 7% maximum strain for transition from austenitic to martensitic in the current constitutive model, phase change is already observed at this point even without heating. This will not happen (in the future constitutive model) to an SMP, which can exhibit highly dissimilar moduli for the rubbery and glassy states. State C is full compression while process C to D is where the glass transition (phase change) happens. The cooling doesn't end until state E which is the start of decompression. State F represents a fully decompressed SMA, where there is little elastic springback, as compared to what is expected if there were no temperature change. The process from state F to H is the heating process, where G is an intermediate state during shape recovery.

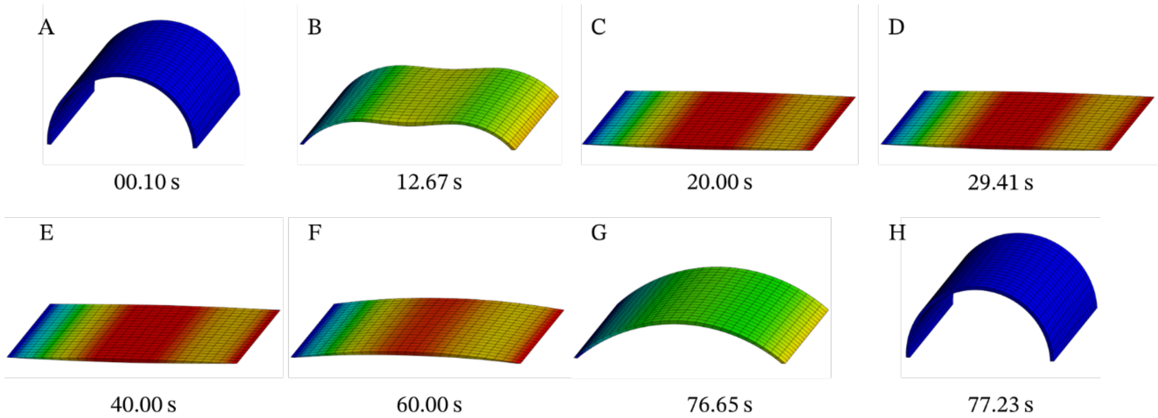

Figure 3. Total deformation of the shape memory material at different times.

With these results, we were able to establish the feasibility of simulating the shape memory characteristics of SMP patches, preparing us for continuing research on this matter. Towards the second direction, the authors are writing research proposals for funding of future collaborative research work. The second direction will involve a little bit more time and resources to produce experimental results needed for data assimilation, as well as computational model development efforts.

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