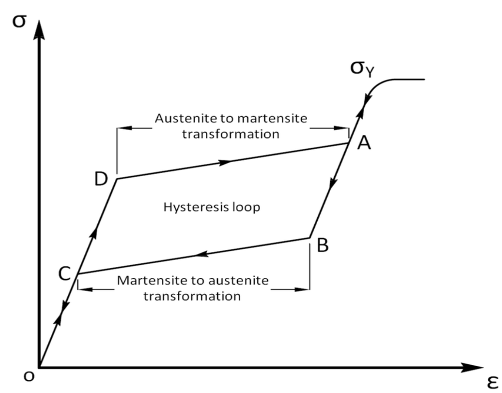
ANSYS Simulation for SMA Wire and bias Compressive Spring

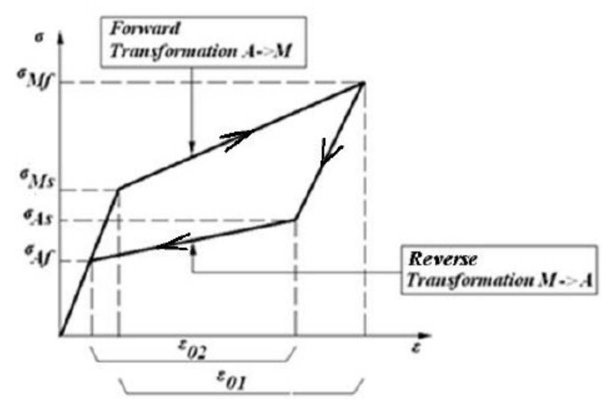
1. Introduction

Shape memory alloys (SMA) are smart materials having distinctive behavior such as shape memory effect and pseudoelasticity. A reversible solid-state displacive phase transformation from austenite to martensite is the reason behind the smart behavior. SMAs are metallic alloys and categorized as NiTi-based alloys (NiTi, NiTi Cu), copper-based alloys (CuZnAl, CuAlNi), and iron-based alloys (FeNiCoTi, FeMnSi). The SMAs exhibit high actuation energy densities and have the capabilities to recover their shape under large applied loads. SMAs can exist in two phases having three different crystal structures viz. twinned martensite, detwinned martensite, and austenite. The martensite is a low-temperature phase while the austenite is stable at high temperatures. The phase transformations have characteristic start and finish temperatures and give information about the operating range of an alloy. Ms, Mf, As, and Af are the characteristic temperatures of the martensite and austenite transformations.

Nickel-Titanium or Nitinol alloys are widely used SMA due to their exhibition of excellent mechanical properties, thermomechanical behavior, pseudoelasticity, and biocompatibility. They have the highest work density and large deformation recovery among other SMA compositions. It is the most studied SMA alloy system and has been applied in a variety of commercial applications. In addition to mechanical properties, the transformation temperatures are one of the most important characteristics which decide the applicability of the SMA.

The Figures below highlight the Shape Memory effect and the Pseudoelecticity effect in NiTi.





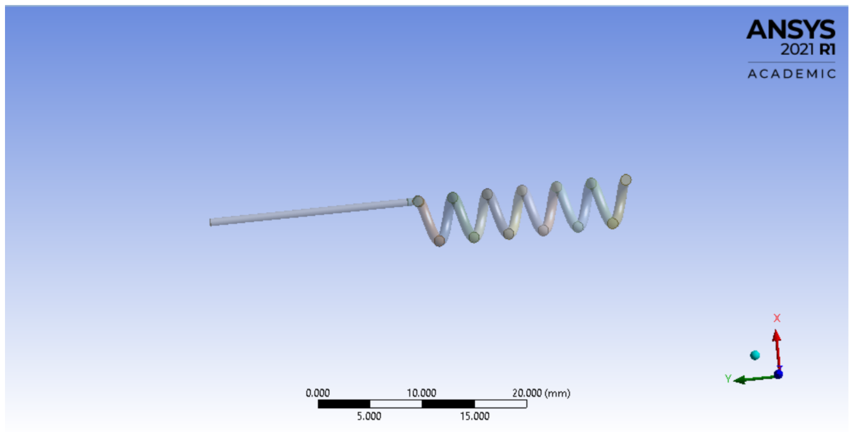
2. Engineering Data

Density, Isotropic Elasticity & Shape Memory effect Parameters were applied in the software from the relevant literature.

Density	6450 kg m^{-3}
Isotropic Elasticity	
Young’s Modulus	51700 MPa
Poisson’s Ratio	0.33
Bulk Modulus	43083 MPa
Shear Modulus	19884 MPa
Shape Memory Effect	
Hardening Parameter	1000 MPa
Reference Temperature	22 C
Elastic limit	140 MPa
Temperature Scaling Paramtere	5.6 MPa C^{-1}
Maximum transformation strain	0.1 mm mm^{-1}
Martensite Modulus	51700 MPa
Load Dependency parameter	0

3. Geometry

The geometry of the wire spring bias is modeled with a diameter of 10mm via a sweeping command in the ANSYS Design modeler, the wire design is assigned the NiTinol material while spring is assigned Structural steel material.

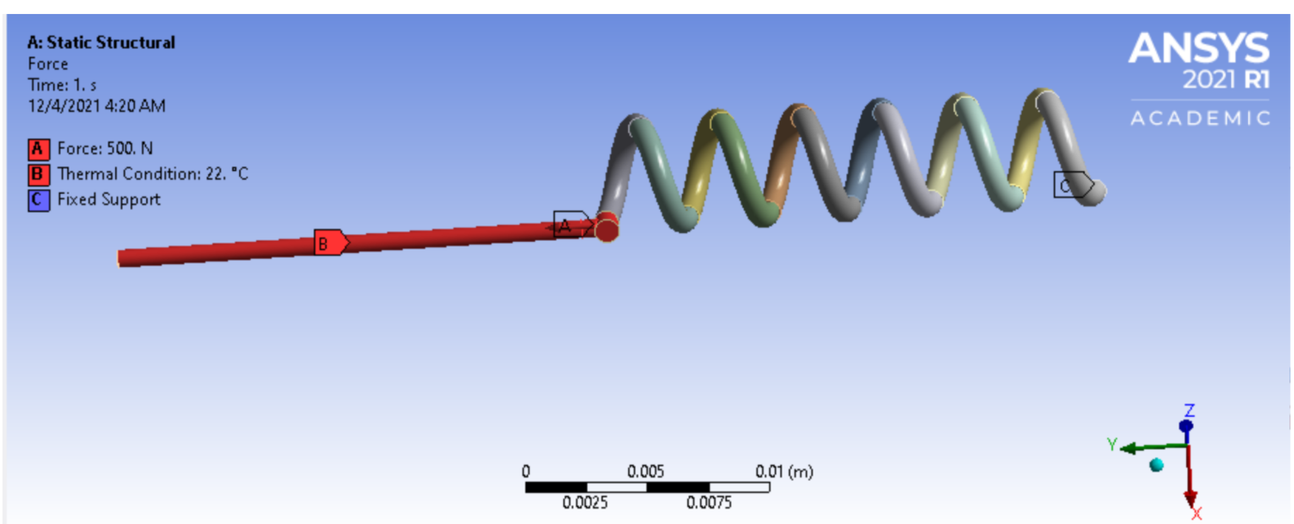


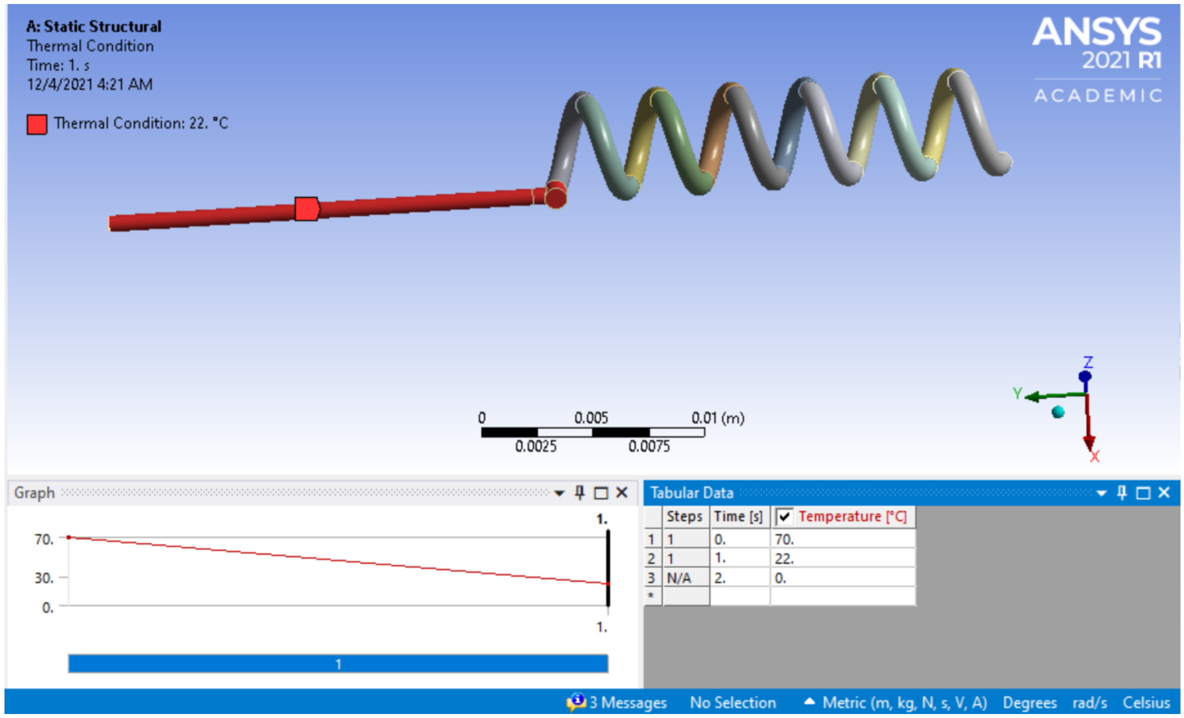
4. Analysis

Initial Conditions: Thermal Condition of step tabular size degrees Celcius (from 22 to 70 Cecluis in 3 steps) (Includes both heating and cooling cycle).

Boundary Conditions: Fixed supports at the extreme ends of the wire and spring.

De-twinning force: 500 N for the wire





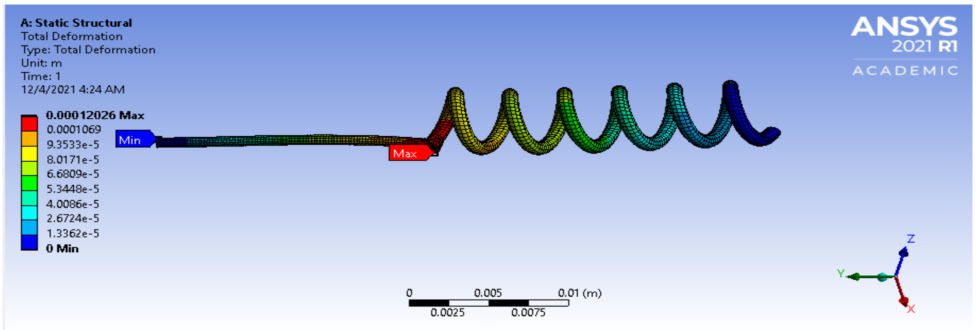
The analysis is performed to determine the total deformation (contraction) of the wire during the heating cycle and retraction during the cooling cycle.

5. Results

Wire activates initially due to the de-twinning of the structure because of the applied force. After the activation, the wire contracts and produces actuation as the temperature reaches austenite start (As) for NiTinol. This expands the biased spring.

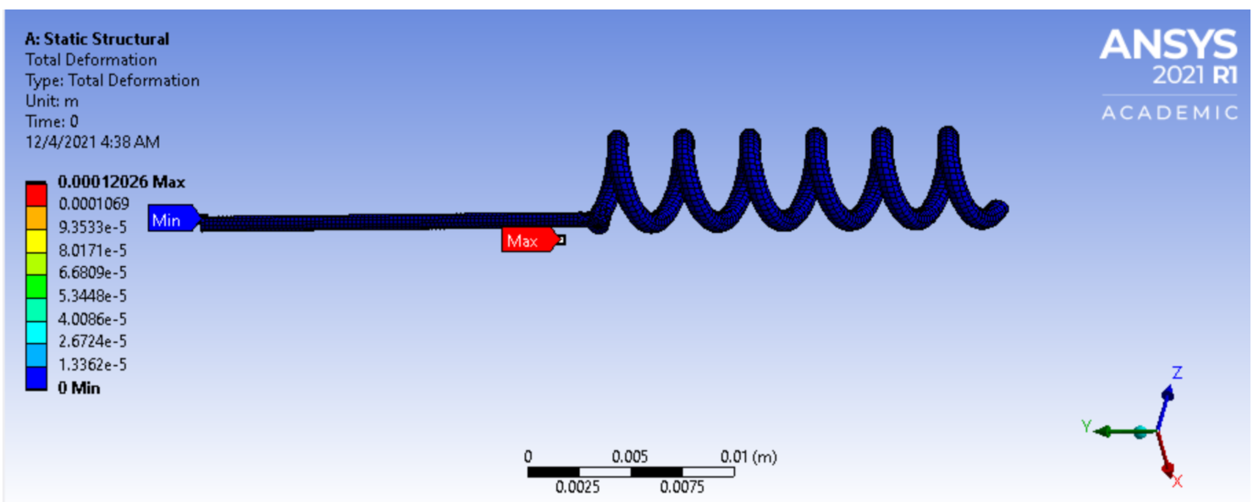
During the cooling process (Austenite to Martensite), the wire expands back to the initial state, this in turn contracts the biased spring.

Heating cycle (Contraction):



Max Deformation of the wire during heating: 0.012026 cm.

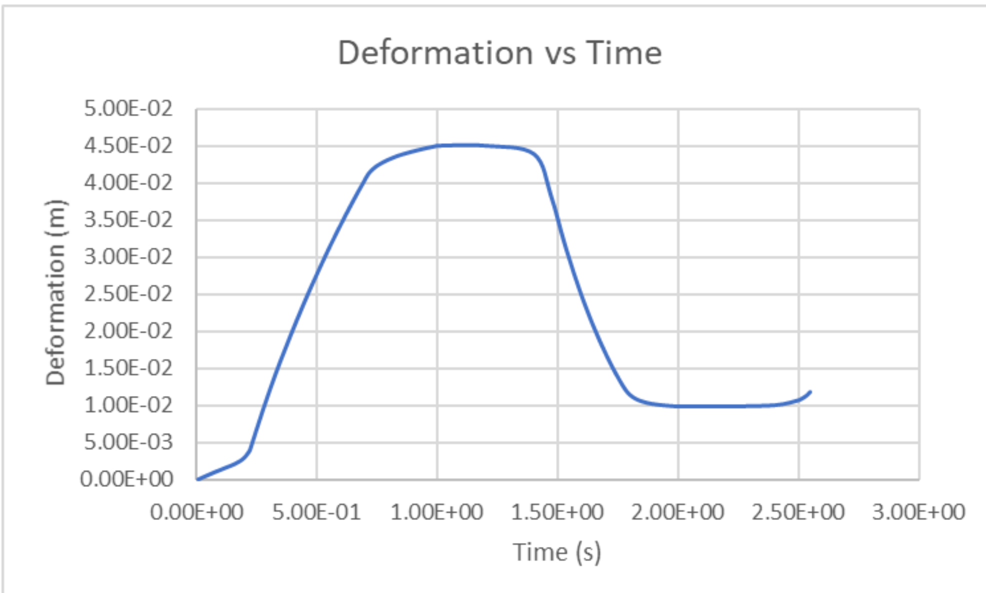
Cooling Cycle (Expansion):



SMA Wire returns to the original state (twinned Maternsite).

6. Post-Processing

We obtain the following plot:



The plot obtained shows two cycles of the process namely: Heating contraction (actuation, which increases the deformation) and cooling expansion (which decreases the deformation).

7. Results and Discussions

An SMA wire and mechanical spring bias actuator have been developed and its thermomechanical behavior has been investigated. The actuation characteristics with respect to temperature have been investigated. A maximum surface temperature of 70 degrees celsius has been found through simulation. Through thermal (joule heating) actuation, the developed actuator shows a max displacement of 0.012026 cm.