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Development of a Shape-Memory-Alloy-Based Overheating Protection System †

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Abstract: Shape Memory Alloys (SMAs) are a class of metallic alloys that have the ability to return to their original shape after being deformed. NiTi (nickel–titanium) alloy a type of shape memory alloy that possesses unique properties such as remembering its shape, biocompatibility, and super-elasticity. These SMAs have the ability to deform when heated and regain their original shape when allowed to cool. The disadvantage of a fuse is that it can only be used once. By replacing a wire that melts with a NiTi shape memory alloy, we can turn it into a switch that opens when an excessive current (which leads to an increase in temperature of the wire) is applied. Magnets keep the circuit closed. When the wire heats up, the spring-shaped coil shrinks, which opens the circuit. The circuit can then be closed manually once the problems are rectified.

Keywords: shape memory alloys (SMAs); overheating; deformation; electricity conductance analysis

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1. Introduction

Shape memory alloys (SMAs) are metallic materials with strong thermomechanical driving forces and the capacity to undergo significant reversible deformations under loading and heat cycles. The behaviour of SMAs is due to their innate propensity to experience temperature- and stress-induced reversible changes in their crystallographic structures. These alterations can be described as reversible martensitic transformations from the crystallographically less-ordered martensite (M) parent phase to the more-ordered austenite (A) parent phase. Furthermore, an SMA disconnects the connector in our design more effectively due to its high strain rate [1].

Super elasticity (also known as pseudo elasticity) and the shape memory effect are two distinct properties that describe how SMA wires behave when they try to regain their original shape [2]. When a metal is heated over a specific transition temperature, a phenomenon known as the form memory effect occurs, wherein the metal returns to its original size and shape. The shape memory effect is the ability of a specimen to change from a martensite phase to an austenitic phase, upon change of temperature. The two-way shape memory effect, also referred to as the "reversible" shape memory effect, occurs independently of external stress [3–5]. When the material temperature is higher than the austenite start temperature, the superelasticity behaviour of a SMA is visible; however, in order to fully recover a shape without residual deformation, the material temperature needs to be higher than the austenite finish temperature.

Ni-Ti is thought to be the most widely used and readily available material for purchase. W.J. Buehler and his research teams found Ni-Ti in 1962 while searching for an intermetallic compound that was ductile, creep-resistant, and fatigue-resistant [6]. Nitinol, which refers to Nickel Titanium Naval Ordnance Laboratory, is the name that was given to this alloy. This intriguing discovery sparked a plethora of ongoing studies on the potential of Ni-Ti SMA materials. Superelastic behaviour, reversible stresses during heating or cooling, low stiffness, practically bone-comparable mechanical behaviour, and exceptional corrosion resistance are just a few of the intriguing characteristics of NiTi alloys.

An electrical fuse is a type of electronic component used in electrical circuits to protect the circuit from overcurrent, hence safeguarding the electrical equipment and machinery that use the circuit. A low-melting-point metal melts when there is excessive current flow, breaking the circuit. We developed a self-actuating fuse using a NiTi-shaped memory alloy as an alternative to changing the fuse every time it breaks [7]. It functions by compressing the NiTi coil to cause the circuit to open when its temperature rises over the transition temperature. Because the coil we utilized was a one-way shape memory alloy [6], it had to be manually moved back to its starting position in order for it to activate again. Here, the heat dissipated from the wires causes the SMA to be thermally burdened [8].

Superelastic behaviour, shape memory effect, and exceptional corrosion resistance are only a few of the distinct qualities that NiTi alloys display [9]. The thermoelectric properties of NiTi SMAs primarily contribute to our problem statement. They result in significant deformation at the specified voltage, thereby triggering the fuse. In comparison to other shape memory alloys, they exhibit a high level of fatigue resistance and corrosion resistance. Because they are lightweight and compact, the fuse weighs less overall. Even though they are more expensive than other SMAs, the aforementioned benefits increase the thermal fuse's efficiency and may lengthen its lifespan.

2. Experimental Setup

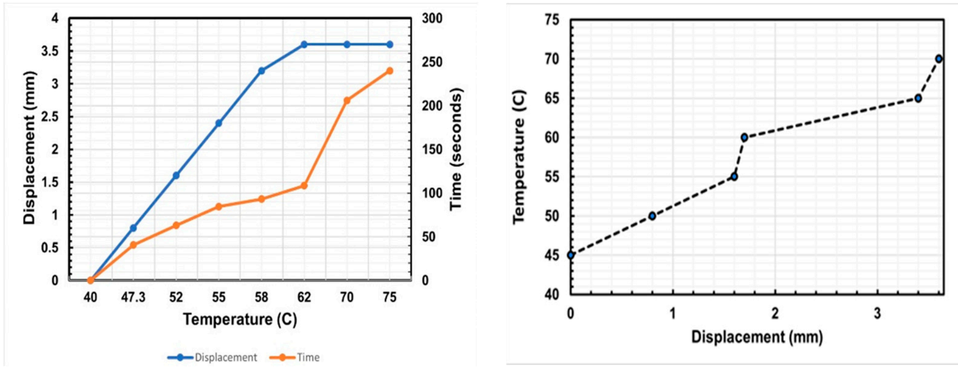
To test the SMA spring's actuation, a setup was devised using a base made of PLA material to hold the SMA spring. Water was selected as the testing medium due to its controlled heating and cooling properties, which are unlike those of an electrical circuit, wherein temperature control is difficult and risky. The austenitic temperature of the SMA was fixed at 348 K, the point at which full deformation occurs. Figure 1a depicts the temperature reader, and Figure 1b shows the SMA coil in the fully extended state.

(**a**) (**b**)

Figure 1. (**a**) Temperature reader; (**b**) SMA coil in fully extended state.

3. Results and Discussion

The experiments were carried out in non-uniform and uniform heating scenarios. In non-uniform heating, the SMA coil began to compress at 50 °C, with the compression increasing as the temperature increased. The contraction behavior was not uniform along the coil's length, resulting in uniform and non-uniform curves on the temperature–displacement graph, as shown in Figure 2a,b. The results are shown in Table 1.



(**a**) (**b**)

Figure 2. (**a**) Graph of uniform heating; (**b**) Graph of non-uniform heating.

Table 1. The SMA spring's behaviour at different temperatures.

S. No.	Temperature (°C)	Length of the Coil (cm)	Displacement (cm)
1	45	6	-
2	50	5.2	0.8
3	55	4.4	1.6
4	60	4.3	1.7
5	65	2.6	3.4
6	70	2.4	3.6
7	75	No Changes	-
8	80	No Changes	-
9	85	No Changes	-
10	90	No Changes	-

The SMA spring exhibited uniform contraction under uniform heating, commencing at 40 °C. This behavior contrasted with non-uniform heating, where contraction began at 50 °C. The study also revealed that heat transfer within the coil was not entirely uniform, with only five coils contracting by 0.5 cm between 52.2 and 62.2 °C. The main disadvantage is the ageing effect, in which the SMA will deform only for a certain number of cycles. But according to our design, the SMA will only deform very rarely [10]. It is activated only when an electric vehicle needs to be protected. Figure 3 provides a 3D image of the SMA spring being acted on by a compression force.

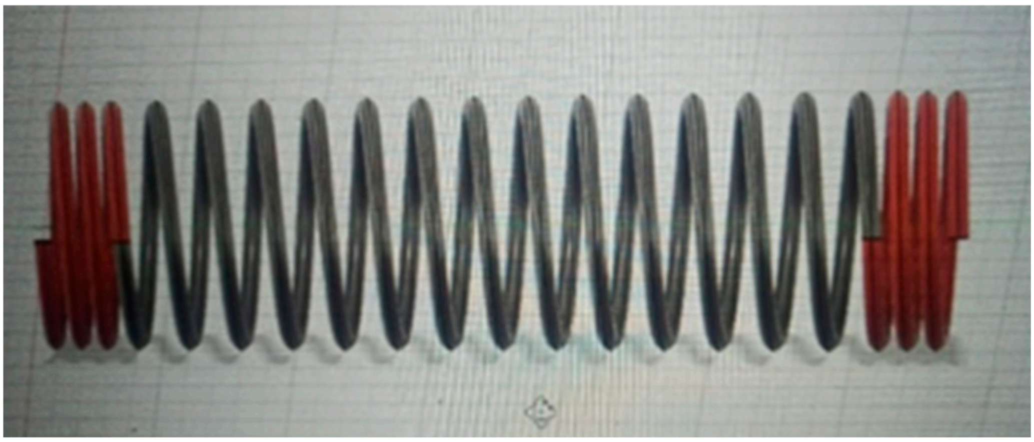


Figure 3. A 3D image of a compression force acting on the SMA spring, where the force is higher at the ends.

4. Conclusions

The goal of this ambitious research was to create a new preventive electrical switch system based on NiTi smart wires. When there is an observable temperature variation, the proposed SMA wire can detect and monitor electrical switch systems. This study allows for the addition of an SMA wire that acts as an electrical switch via serving as a spring between two connectors with non-uniform and uniform conditions at a temperature of 50 °C. According to this investigation, SMA springs increase displacement as the compression and temperature of the spring increase. This research also found that heat transfer within the coil was not completely uniform, with only five coils contracting by 0.5 cm between 52.2 and 62.2 °C. SMA spring fuses are suitable for use with electrical actuators.

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References

1. Nemat-Nasser, S.; Choi, J.-Y.; Guo, W.-G.; Isaacs, J.B. Very High Strain-Rate Response of a NiTi Shape-Memory Alloy. *Mech. Mater.* **2005**, *37*, 287–298. [CrossRef]
2. Santosh, S.; Sampath, V.; Mouliswar, R.R. Hot Deformation Characteristics of NiTiV Shape Memory Alloy and Modeling Using Constitutive Equations and Artificial Neural Networks. *J. Alloys Compd.* **2022**, *901*, 163451. [CrossRef]
3. Santosh, S.; Kevin Thomas, J.; Pavithran, M.; Nithyanandh, G.; Ashwath, J. An Experimental Analysis on the Influence of CO2 Laser Machining Parameters on a Copper-Based Shape Memory Alloy. *Opt. Laser Technol.* **2022**, *153*, 108210. [CrossRef]
4. Šittner, P.; Iaparova, E.; Kadeřávek, L.; Chen, Y.; Tyc, O. Tensile Deformation of NiTi Shape Memory Alloy Thermally Loaded under Applied Stress. *Mater. Des.* **2023**, *226*, 111638. [CrossRef]
5. Wang, X.; Van Humbeeck, J.; Verlinden, B.; Kustov, S. Thermal Cycling Induced Room Temperature Aging Effect in Ni-Rich NiTi Shape Memory Alloy. *Scr. Mater.* **2016**, *113*, 206–208. [CrossRef]
6. Bhargaw, H.N.; Ahmed, M.; Sinha, P. Thermo-Electric Behaviour of NiTi Shape Memory Alloy. *Trans. Nonferrous Met. Soc. China* **2013**, *23*, 2329–2335. [CrossRef]
7. Arun, A.; Rajkumar, K.; Santosh, S. Fiber Laser Cutting Study on Ternary NiTiV Shape Memory Alloy. *Mater. Manuf. Process.* **2023**, *38*, 1745–1754. [CrossRef]
8. Wang, B.; Kang, G.; Yu, C.; Gu, B.; Yuan, W. Molecular Dynamics Simulations on One-Way Shape Memory Effect of Nanocrystalline NiTi Shape Memory Alloy and Its Cyclic Degeneration. *Int. J. Mech. Sci.* **2021**, *211*, 106777. [CrossRef]
9. Costanza, G.; Tata, M.E.; Calisti, C. Nitinol One-Way Shape Memory Springs: Thermomechanical Characterization and Actuator Design. *Sens. Actuators A Phys.* **2010**, *157*, 113–117. [CrossRef]
10. Ezaz, T.; Wang, J.; Sehitoglu, H.; Maier, H.J. Plastic Deformation of NiTi Shape Memory Alloys. *Acta Mater.* **2013**, *61*, 67–78. [CrossRef]