Shape Memory Alloys and Their Applications

by Richard Lin

Shape memory alloys (SMAs) are metals that "remember" their original shapes. SMAs are useful for such things as actuators which are materials that "change shape, stiffness, position, natural frequency, and other mechanical characteristics in response to temperature or electromagnetic fields" (Rogers, 155). The potential uses for SMAs especially as actuators have broadened the spectrum of many scientific fields. The study of the history and development of SMAs can provide an insight into a material involved in cutting-edge technology. The diverse applications for these metals have made them increasingly important and visible to the world.

History

Nickel-titanium alloys have been found to be the most useful of all SMAs. Other shape memory alloys include copper-aluminum-nickel, copper-zinc-aluminum, and iron- manganese-silicon alloys.(Borden, 67) The generic name for the family of nickel-titanium alloys is Nitinol. In 1961, Nitinol, which stands for Nickel Titanium Naval Ordnance Laboratory, was discovered to possess the unique property of having shape memory. William J. Buehler, a researcher at the Naval Ordnance Laboratory in White Oak, Maryland, was the one to discover this shape memory alloy. The actual discovery of the shape memory property of Nitinol came about by accident. At a laboratory management meeting, a strip of Nitinol was presented that was bent out of shape many times. One of the people present, Dr. David S. Muzzey, heated it with his pipe lighter, and surprisingly, the strip stretched back to its original form. (Kauffman and Mayo, 4)

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Crystal Structures

Exactly what made these metals "remember" their original shapes was in question after the discovery of the shape-memory effect. Dr. Frederick E. Wang, an expert in crystal physics, pinpointed the structural changes at the atomic level which contributed to the unique properties these metals have. (Kauffman and Mayo, 4)

He found that Nitinol had phase changes while still a solid. These phase changes, known as martensite and austenite, "involve the rearrangement of the position of particles within the crystal structure of the solid" (Kauffman and Mayo, 4). Under the transition temperature, Nitinol is in the martensite phase. The transition temperature varies for different compositions from about -50 ° C to 166 ° C (Jackson, Wagner, and

Wasilewski, 1). In the martensite phase, Nitinol can be bent into various shapes. To fix the "parent shape" (as it is called), the metal must be held in position and heated to about 500 ° C. The high temperature "causes the atoms to arrange themselves into the most compact and regular pattern possible" resulting in a rigid cubic arrangement known as the austenite phase (Kauffman and Mayo, 5-6). Above the transition temperature, Nitinol reverts from the martensite to the austenite phase which changes it back into its parent shape. This cycle can be repeated millions of times (Jackson, Wagner, and Wasilewski, 1).

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Manufacture

There are various ways to manufacture Nitinol. Current techniques of producing nickel-titanium alloys include vacuum melting techniques such as electron-beam melting, vacuum arc melting or vacuum induction melting. "The cast ingot is press-forged and/or rotary forged prior to rod and wire rolling. Hot working to this point is done at temperatures between 700 ° C and 900 ° C" (Stoeckel and Yu, 3).

There is also a process of cold working of Ni-Ti alloys. The procedure is similar to titanium wire fabrication. Carbide and diamond dies are used in the process to produce wires ranging from 0.075mm to 1.25mm in diameter. (Stoeckel and Yu, 4) Cold working of Nitinol causes "marked changes in the mechanical and physical properties of the alloy" (Jackson, Wagner, and Wasilewski, 21). These processes of the production of Nitinol are described in greater detail in Jackson, Wagner, and Wasilewski's report (15-22).

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Properties

The properties of Nitinol are particular to the exact composition of the metal and the way it was processed. The physical properties of Nitinol include a melting point around 1240 ° C to 1310 ° C, and a density of around 6.5 g/cm³ (Jackson, Wagner, and Wasilewski, 23). Various other physical properties tested at different temperatures with various compositions of elements include electrical resitivity, thermoelectric power, Hall coefficient, velocity of sound, damping, heat capacity, magnetic susceptibility, and thermal conductivity (Jackson, Wagner, and Wasilewski, 23-55). Mechanical properties tested include hardness, impact toughness, fatigue strength, and machinability (Jackson, Wagner, and Wasilewski, 57-73).

The large force generated upon returning to its original shape is a very useful property. Other useful properties of Nitinol are its "excellent damping characteristics at temperatures below the transition temperature range, its corrosion resistance, its nonmagnetic nature, its low density and its high fatigue strength" (Jackson, Wagner, and Wasilewski, 77). Nitinol is also to an extent impact- and heat-resistant (Kauffman and Mayo, 4). These properties translate into many uses for Nitinol.

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Applications

Nitinol is being used in a variety of applications. They have been used for military, medical, safety, and robotics applications. The military has been using Nitinol couplers in F-14 fighter planes since the late 1960s. These couplers join hydraulic lines tightly and easily. (Kauffman and Mayo, 6)

Many of the current applications of Nitinol have been in the field of medicine. Tweezers to remove foreign objects through small incisions were invented by NASA. Anchors with Nitinol hooks to attach tendons to bone were used for Orel Hershiser's shoulder surgery. Orthodontic wires made out of Nitinol reduces the need to retighten and adjust the wire. These wires also accelerate tooth motion as they revert to their original shapes. Nitinol eyeglass frames can be bent totally out of shape and return to their parent shape upon warming. (Kauffman and Mayo, 6) Nitinol needle wire localizers "used to locate and mark breast tumors so that subsequent surgery can be more exact and less invasive" utilize the metal's shape memory property. Another successful medical application is Nitinol's use as a guide for catheters through blood vessels (Stoeckel and Yu, 9-10).

There are examples of SMAs used in safety devices which will save lives in the future. Anti-scalding devices and fire-sprinklers utilizing SMAs are already on the market. The anti-scalding valves can be used in water faucets and shower heads. After a certain temperature, the device automatically shuts off the water flow. The main advantage of Nitinol-based fire sprinklers is the decrease in response time. (Kauffman and Mayo, 7)

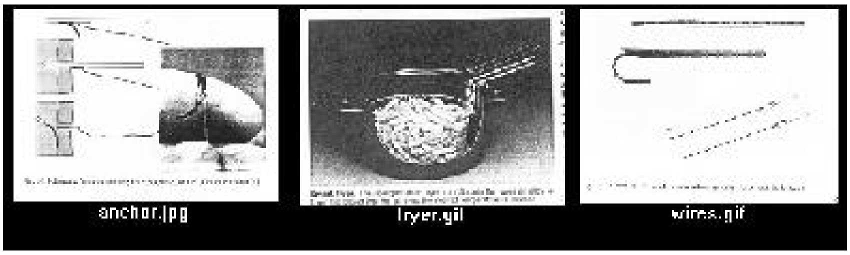
Nitinol is being used in robotics actuators and micromanipulators to simulate human muscle motion. The main advantage of Nitinol is the smooth, controlled force it exerts upon activation. (Rogers, 156)

Other miscellaneous applications of shape memory alloys include use in household appliances, in clothing, and in structures. A deep fryer utilizes the thermal sensitivity by lowering the basket into the oil at the correct temperature. (Falcioni, 114) According to Stoeckel and Yu, "one of the most unique and successful applications is the Ni-Ti underwire brassiere" (11). These bras, which were engineered to be both comfortable and durable, are already extremely successful in Japan (Stoeckel and Yu, 11). Nitinol actuators as engine mounts and suspensions can also control vibration. These actuators can helpful prevent the destruction of such structures as buildings and bridges. (Rogers, 156)

Other applications:

- European Space Agency
- SMA INC.

Here are some of the pictures available from this section:



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Future Applications

There are many possible applications for SMAs. Future applications are envisioned to include engines in cars and airplanes and electrical generators utilizing the mechanical energy resulting from the shape transformations. Nitinol with its shape memory property is also envisioned for use as car frames. (Kauffman and Mayo, 7) Other possible automotive applications using SMA springs include engine cooling, carburetor and engine lubrication controls, and the control of a radiator blind ("to reduce the flow of air through the radiator at start-up when the engine is cold and hence to reduce fuel usage and exhaust emissions") (Turner, 299).

SMAs are "ideally suited for use as fasteners, seals, connectors, and clamps" in a variety of applications (Borden, 67). Tighter connections and easier and more efficient installations result from the use of shape memory alloys (Borden, 72).

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Conclusion

The many uses and applications of shape memory alloys ensure a bright future for these metals. Research is currently carried out at many robotics departments and materials science departments. With the innovative ideas for applications of SMAs and the number of products on the market using SMAs continually growing, advances in the field of shape memory alloys for use in many different fields of study seem very promising.

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Works Cited

Borden, Tom. "Shape-Memory Alloys: Forming a Tight Fit." *Mechanical Engineering* Oct. 1991: 67-72.

Falcioni, John G. "Shape Memory Alloys." *Mechanical Engineering* Apr. 1992: 114.

Jackson, C.M., H.J. Wagner, and R.J. Wasilewski. *55-Nitinol- -The Alloy With a Memory: Its Physical Metallurgy, Properties, and Applications: A Report.* Washington: NASA, 1972.

Kauffman, George, and Isaac Mayo. "Memory Metal." *Chem Matters* Oct. 1993: 4-7.

Rogers, Craig. "Intelligent Materials." *Scientific American* Sept. 1995: 154-157.

Stoeckel, Dieter, and Weikang Yu. "Superelastic Nickel- Titanium Wires." Available from Raychem Corporation, Menlo Park, CA.

Turner, J.D. "Memory-metal Actuators for Automotive Applications." *Proceedings of the Institution of Mechanical Engineers* 208 (1994): 299-302.

An other bibliography

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Additional Information

To find out additional, detailed information about Nitinol and SMAs, look at these web sites:

Papers:

- Hodgson, Darel E., Ming H. Wu, and Robert J. Biermann. "Shape Memory Alloys." Online. Available SMA INC.
- Caron, M. and S. Dahl. "Magnetron Sputtering of TiNi Shape Memory Alloys for Microactuators."Online.

General references:

- Shape Memoy Alloy information from Mide Technology Corporation
- European Space Agency on SMAs
- NASA Langley Research Center on SMAs

Robots and Robot-related sites:

- Stiquito
- Mondo-tronics

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Searches

For the most recent developments in SMAs, use the terms "shape memory alloys" or "Nitinol" with the following search engines:

Google Ask.com

Webcrawler Yahoo

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Questions, comments, suggestions?

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