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Characterization of Binary Nitinol Actuators with Various Transformation Temperatures Employing Uniaxial Isobaric Loading

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Abstract

Binary nitinol wires of multiple transformation temperatures are characterized under isobaric uniaxial loading. Performance parameters are reported with analysis to highlight advantages and disadvantages of each temperature for design and application perspective.

Keywords: Nitinol, Shape Memory Alloy, SMA, Actuator

Introduction

Over the last several decades Shape Memory Alloys, more specifically binary nickel-titanium or nitinol, have become a dynamic design material for medical device engineers. Nitinol can exhibit Superelastic Effect (SE) or Shape Memory Effect (SME). To date, the medical device industry (activation temperatures at body temperature and below) has been the primary consumer of SE nitinol, enabling diverse applications. In contrast, most actuator applications seek to employ SME at elevated temperatures [1]. Loading a properly-tuned nitinol actuator in the low-temperature martensitic phase and driving the material to the high-temperature austenitic parent phase using any of a variety of heating methods can produce high force output. Nitinol's high work density makes it desirable for use in applications normally reserved for hydraulic, pneumatic, or electric actuators [2]. Additional benefits include reproducible force output, excellent component lifetime up to millions of work cycles, and a silent actuation [3].

Nitinol actuator properties can be tailored to attain optimal performance for specific applications. This work focuses on Ø0.305mm nitinol round wires with tailored austenitic start temperatures (A_s) near 50°C, 70°C and 90°C under constant tensile stress (σ) of 150 MPa, Figure 1.

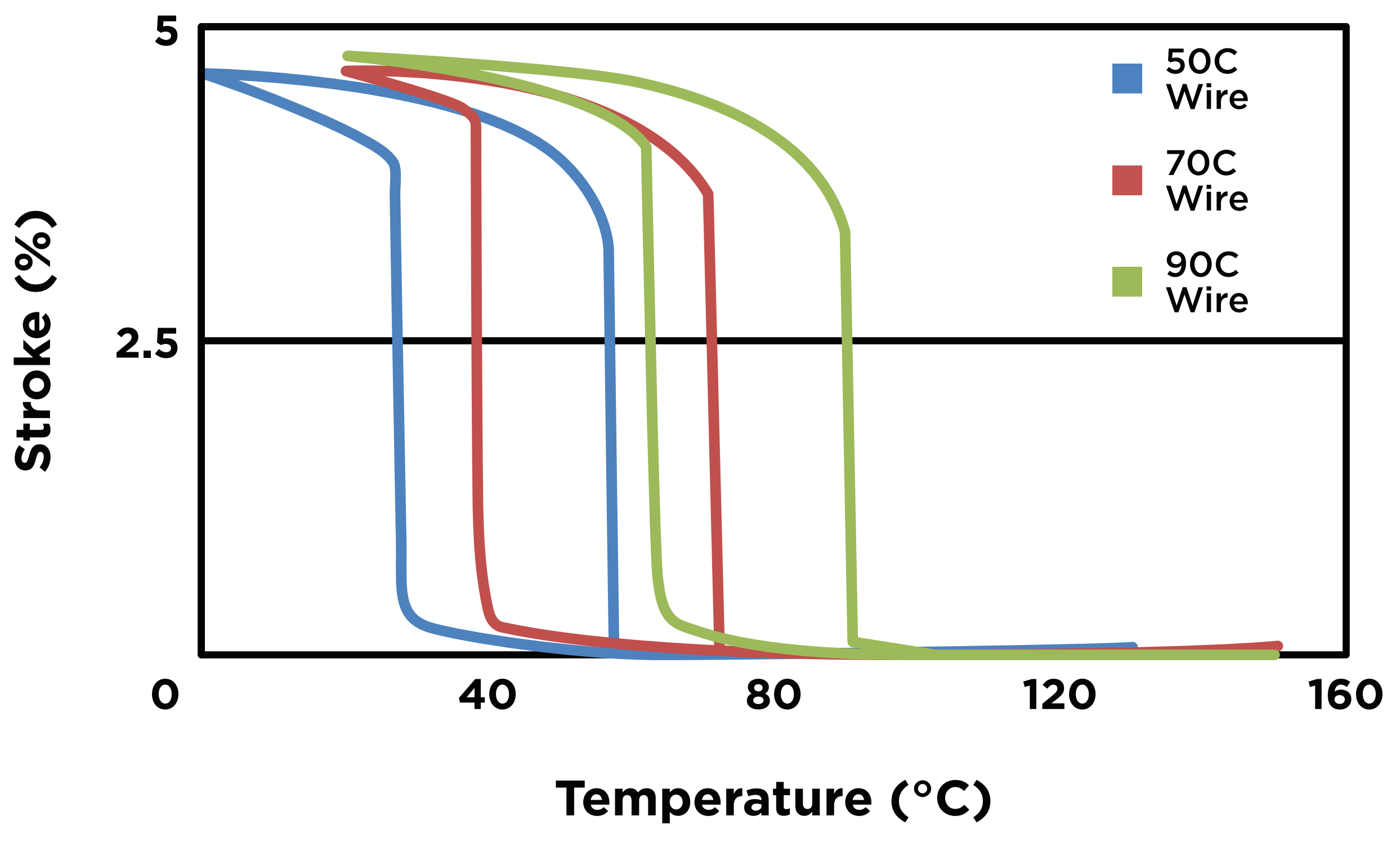

Figure 1. Thermal Characterization, σ = 150MPa.

Design

A thermal characterization of each actuator was performed where stroke (strain %) was measured as a function of temperature (°C), Figure 1. Additionally, an evaluation of reset time was performed. Per results of the thermal characterization, each wire was heated using joule heating to the strain corresponding to 20°C above A_f (complete actuation). Current was then removed and time was measured as the actuator cooled in a controlled environment of 22°C quiescent air to the reset position of initial strain. Results were normalized to show fraction reset as function of time (s), Figure 2. To demonstrate energy efficiencies, a one-watt pulse of varying duration was applied to each actuator to achieve complete actuation. Each energy input was measured, normalized against the 90°C actuator, and reported as an efficiency factor, Table 1.

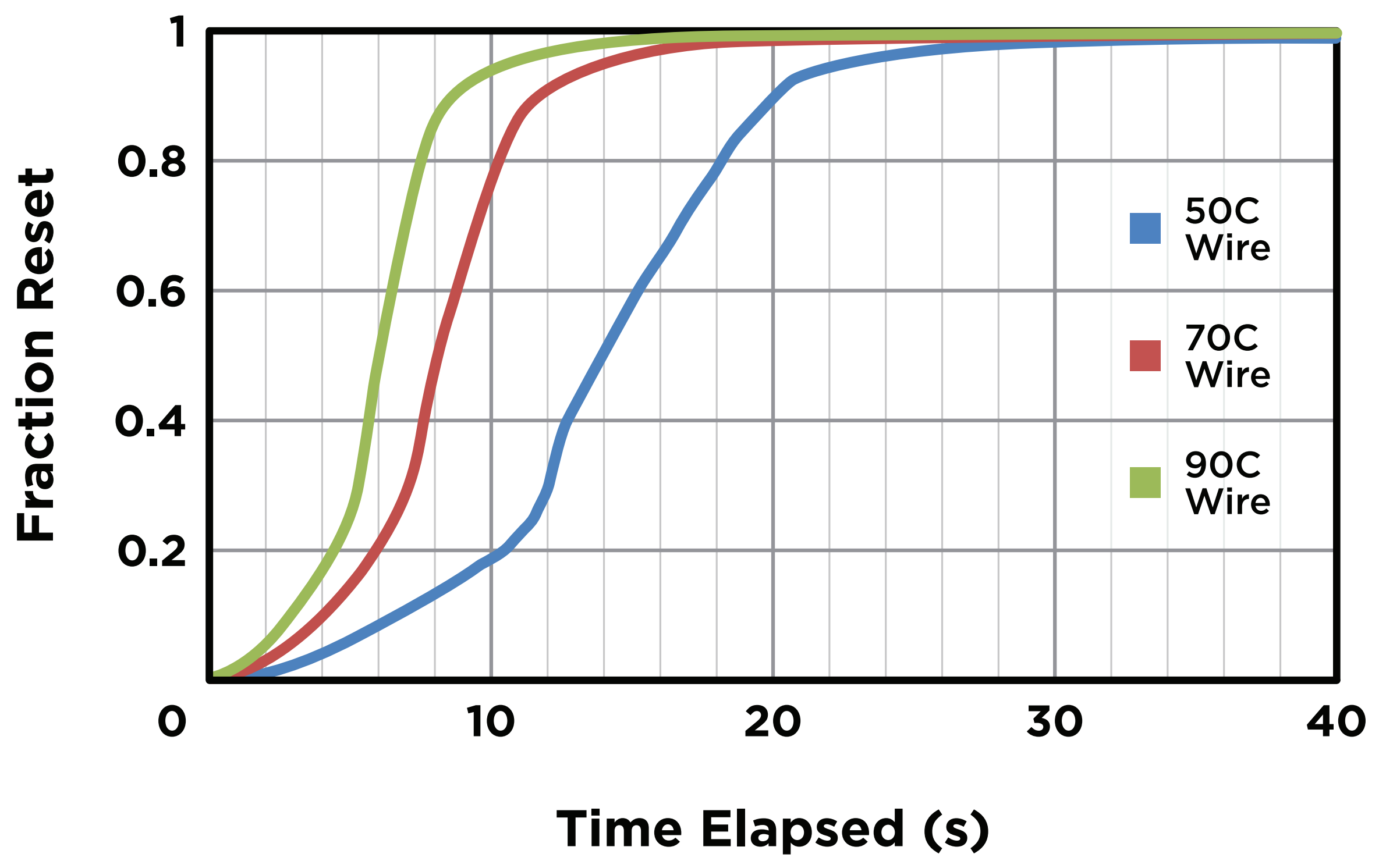

Figure 2. Time to reset after heating to complete actuation.

From the data above, it can be seen that the higher temperature actuator is better suited for rapid consecutive actuations due to its shorter reset time.

A_s (°C)	Efficiency Factor
50	2.12
70	1.48
90	1.00

Table 1. Energy efficiencies, relative to 90°C actuator.

While the higher temperature actuators provide potential for higher frequency actuation, there are significant energy savings available by utilizing lower temperature actuators.

Conclusion

When power consumption is of primary concern, the efficiency factor of the 50°C actuator demonstrates it to be the best-suited option. Conversely, should the application require faster cyclic rates, the 90°C actuator would be the most appropriate choice.

By identifying the critical performance parameters of an application, a nitinol actuator with optimal characteristics can be selected to most effectively incorporate Shape Memory Alloys into the design.

References

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