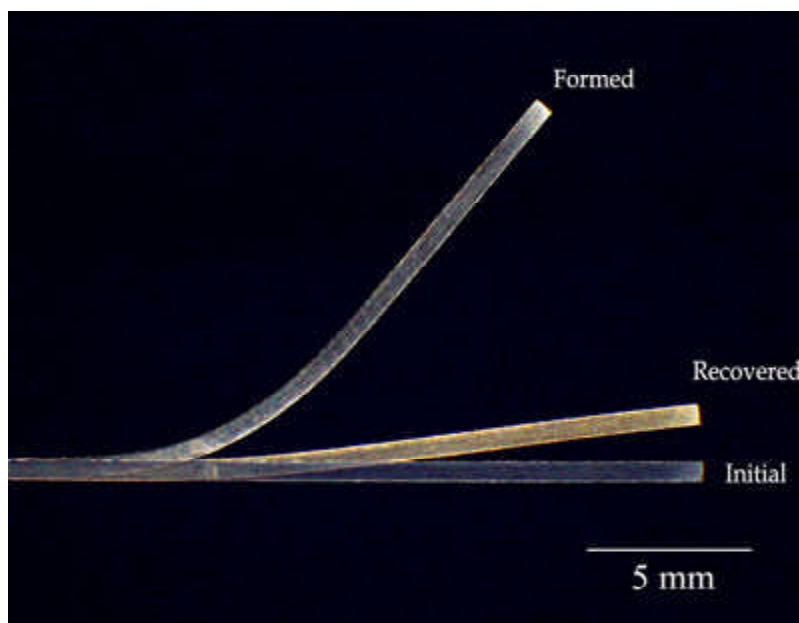


Potential High-Temperature Shape-Memory Alloys Identified in the Ti(Ni,Pt) System

"Shape memory" is a unique property of certain alloys that, when deformed (within certain strain limits) at low temperatures, will remember and recover to their original predeformed shape upon heating. It occurs when an alloy is deformed in the low-temperature martensitic phase and is then heated above its transformation temperature back to an austenitic state. As the material passes through this solid-state phase transformation on heating, it also recovers its original shape. An example of this behavior is shown in the photograph.



Demonstration of the shape-memory effect in a Ti(Ni,Pt) alloy. The super-imposed images are of Ti-30Ni-20Pt rolled sheet, bent 38° at room temperature, and recovered to 8° by heating to 350 °C, resulting in a displacement of the sheet end of almost 10 mm.

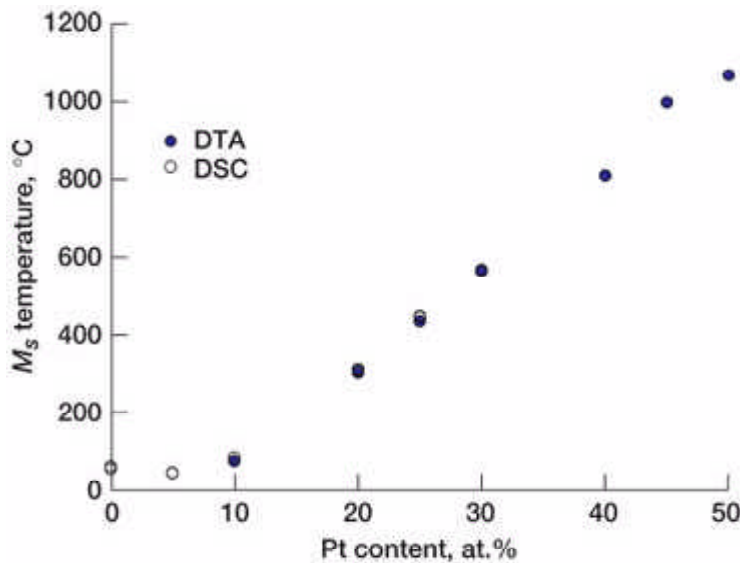
This behavior is widely exploited, near room temperature, in commercially available NiTi alloys for connectors, couplings, valves, actuators, stents, and other medical and dental devices. In addition, there are limitless applications in the aerospace, automotive, chemical processing, and many other industries for materials that exhibit this type of shape-memory behavior at higher temperatures. But for high temperatures, there are currently no commercial shape-memory alloys.

Although there are significant challenges to the development of high-temperature shape-memory alloys, at the NASA Glenn Research Center we have identified a series of alloy compositions in the Ti-Ni-Pt system that show great promise as potential high-temperature shape-memory materials. An example of the shape recovery achieved in one

of these alloys is shown in the preceding photograph. The following graph is a plot of the M_s temperature (a measure of the actuation temperature) as a function of Pt content from 0 to 50 at.%, when Pt is substituted for Ni in a series of $Ti_{50}Ni_{50-x}Pt_x$ alloys. There is a linear dependence of transformation temperature on Pt content for alloys containing 10 to 50 at.% Pt described by the following relation:

$$M_s (\text{°C}) = 25.2 (\text{at.}\% \text{ Pt}) - 182.7$$

with a correlation coefficient r^2 of 0.997. The alloys currently of most interest for aerospace applications (including combustor components, core exhaust chevrons, and other actuators) are those containing 15 to 35 at.% Pt.



Martensitic start temperature, M_s , for $Ti_{50}Ni_{50-x}Pt_x$ alloys as a function of Pt content. The initial region of focus for high-temperature actuators for aerospace applications includes alloys containing 15 to 35 at.% Pt for DTA, differential thermal analysis, and DSC, differential scanning calorimetry.

Pt additions ranged from 10 to 50 at.%, and temperatures varied between room temperature for $Ti_{50}Ni_{40}Pt_{10}$ and 1000 °C for binary $Ti_{50}Pt_{50}$

One of the major challenges in developing shape-memory alloys for high-temperature actuators is achieving the long-term stability of the alloy, including its microstructure, phase structure, and resistance to oxidation. The reason is that the shape-memory process depends on the diffusionless transformation of the martensitic phase to the higher temperature austenite phase. For materials such as NiTi, where this diffusionless transformation occurs near room temperature, alloy stability is not an issue. But when this transformation occurs at elevated temperatures where decomposition, recovery, recrystallization, and other thermal processes are prevalent, alloy and microstructural stability are major concerns as is environmental resistance. These diffusional processes can retard the material's shape recovery and can also affect its transformation temperature. Moreover, since these actuators could be highly loaded, relaxation and creep are also

concerns. Consequently, alloys in the composition range of interest are in the process of being fully characterized and optimized, and their potential as high-temperature shape-memory alloys demonstrated through subcomponent testing.

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