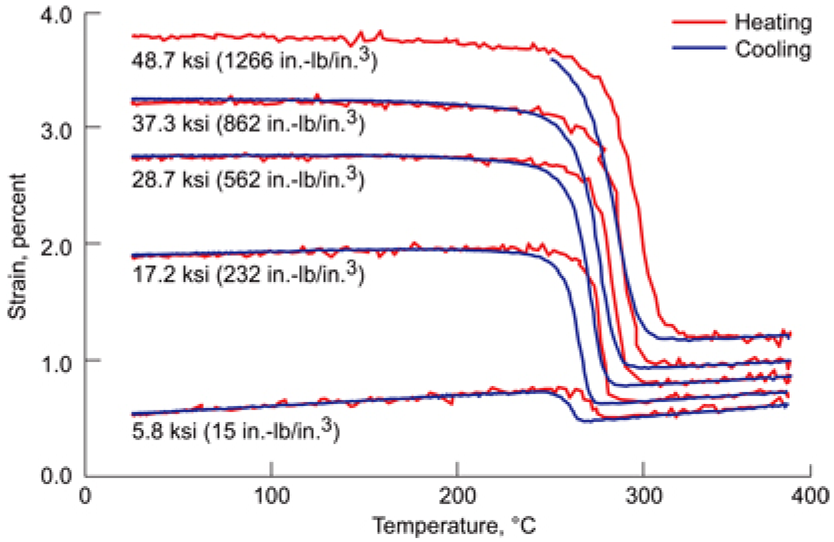
Potential High-Temperature Shape-Memory-Alloy Actuator Material Identified

Shape-memory alloys are unique “smart materials” that can be used in a wide variety of adaptive or “intelligent” components. Because of a martensitic solid-state phase transformation in these materials, they can display rather unusual mechanical properties including shape-memory behavior. This phenomenon occurs when the material is deformed at low temperatures (below the martensite finish temperature, M_f) and then heated through the martensite-to-austenite phase transformation. As the material is heated to the austenite finish temperature A_f, it is able to recover its predeformed shape. If a bias is applied to the material as it tries to recover its original shape, work can be extracted from the shape-memory alloy as it transforms. Therefore, shape-memory alloys are being considered for compact solid-state actuation devices to replace hydraulic, pneumatic, or motor-driven systems.

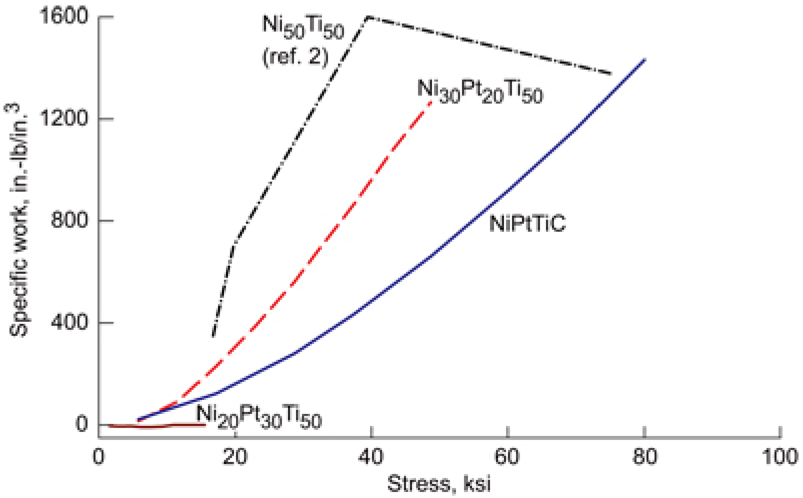
Currently available shape-memory alloys have a temperature limit of about 70 °C, and thus their use in turbine engines is quite restricted. The NASA Glenn Research Center has been investigating the properties of various ternary NiTi-X alloys to look for compositions that could be utilized as high-temperature shape-memory alloys for high-force actuator applications. Although many ternary NiTi-based alloys have high transformation temperatures, there are insufficient data to make a definitive determination of the suitability of these alloys as high-temperature actuator materials (ref. 1). We have determined that some alloys previously identified as promising candidates on the basis of their transformation temperature alone do not exhibit sufficient mechanical properties to be used in such applications (e.g., $Ni_{20}Pt_{30}Ti_{50}$). However, we have identified a baseline alloy, $Ni_{30}Pt_{20}Ti_{50}$ (at.%) and derivative compositions that look exceptionally promising.



Set of strain-temperature curves for $Ni_{20}Pt_{30}Ti_{50}$ *measured under various constant-stress conditions. The light and dark curves show the alloy response during heating and cooling, respectively.*

Long description of figure 1. Graph of strain in percent versus temperature in degrees Celsius for heating and cooling at 48 ksi (1266 in.-lb/in.^{3}), 37.3 ksi (862 in.-lb/in.^{3}), 28.7 ksi (562 in.-lb/in.^{3}), 17.2 ksi (232 in.-lb/in.^{3}), and 5.8 ksi (15 in.-lb/in.^{3}).

The baseline $Ni_{20}Pt_{30}Ti_{50}$ alloy has transformation temperatures of M_s, 270 °C; M_f, 245 °C; A_s, 260 °C; and A_f, 275 °C, permitting this alloy to be used at sustained temperatures of about 240 °C, over 3 times the temperature capability of commercial alloys. In simple extruded form, the material has a tensile ductility of about 5 percent at room temperature and is capable of 100-percent strain recovery (elastic + shape memory) when deformed up to its fracture limit. However, previous experience has shown that recovery under stress-free conditions is not an adequate assessment of the material's potential to perform work. Consequently, strain-temperature cycles were performed under varying constant applied stress levels. The work performed by the martensite-to-austenite transformation was determined by multiplying the transformation strain during heating by the applied stress level (see the preceding graph). The work capability of the material measured from these curves was over 1200 in.-lb/in.^{3} and appeared to be limited only by the tensile ductility of the alloy, which can be increased significantly through proper thermomechanical treatment.This work level is comparable to those of typical binary NiTi alloys (ref. 2).



Comparison of the amount of work performed by the martensitic transformation as a function of applied stress level for various NiTiPt alloys and binary NiTi. The 20 Pt-containing alloys can perform work similar to that of binary NiTi.

Long description of figure 2. Graph of specific work in inch-pounds per cubic inch versus stress in kilopounds per square inch for $Ni_{50}Ti_{50}$, $Ni_{30}Pt_{20}Ti_{50}$, NiPtTiC, and $Ni_{20}Pt_{30}Ti_{50}$.

Although the results are preliminary, it would appear that $Ni_{20}Pt_{30}Ti_{50}$ is an attractive material for use in high-temperature actuator applications. Continuum Dynamics, Inc., a leading designer of smart components for various propulsion systems, has reviewed these properties and has chosen this alloy for possible incorporation into the design of an adaptive supersonic inlet.

References

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2. Cross, W.B.; Kariotis, A.H.; and Stimlet, F.J.: Nitinol Characterization Study. NASA CR-1433, 1969.

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Headquarters program office: Aeronautics Research
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