Single Crystal High-Temperature Shape-Memory Alloys

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By careful control of alloy stoichiometry and heat treatment, we have produced a precipitation strengthened high-temperature shape-memory NiTiHf alloy with actuator capability to about 160 ºC[1]. This is nearly 80 ºC greater than current commercial alloys. It exhibits very high strength and exceptional work output combined with inherent dimensional stability far superior to conventional alloys – and is therefore attracting considerable interest from our aerospace partners. Recently, we had the opportunity to study a small single crystal of one of our alloy compositions, obtained from a collaborator at the University of Kentucky, who had it processed by a colleague in Russia. Samples from the single crystal exhibited record work output combined with excellent dimensional stability, all at high temperatures. In one orientation, the shape memory performance was extended to stresses as high as 1500 MPa, a 3X improvement in strength over polycrystalline forms. The crystals also exhibited astounding superelastic behavior, including strengths greater than 3000 MPa (which was the limit of the test fixture) and elastic, fully recoverable strains as high as 4%. These were not the result of a concentrated effort to optimize properties or microstructure, but simply the first attempt at processing a single crystal of our original alloy. However, the single crystal also contained large carbide impurities due to reaction with the crucible during single crystal growth. Regardless, these preliminary results demonstrate that through selection of crystal orientation, properties in a single crystal or a textured polycrystalline material could be engineered to exhibit higher strength or higher work output, without sacrificing dimensional stability. Thus the current proposal is to develop single crystal, high-temperature shape memory alloys using a "cleaner" single crystal Czochralski processing technique that significantly reduces or eliminates contamination associated with the growth process. These new materials are expected to have significantly greater strength, stability, and shape memory properties compared to polycrystalline forms at significantly higher temperature than current commercial alloys, but without carbide contamination. Several samples have been grown using NiTiPd and NiTiHf starting ingots. The transformation temperatures of the homogenized samples were approximately equivalent to those of the polycrystalline materials. Analysis in SEM and TEM did not show the presence of grain boundaries, indicating that the samples are indeed single crystal. Also, while there are carbides present in the samples, these are only due to carbon contamination in the original melt material, and are significantly smaller than those present in the Russian grown crystals. Carbon-free material is also being prepared as melt stock to generate carbide free single crystals. Mechanical testing is underway to determine the load-biased and pseudoelastic behavior of the samples in comparison to that of the Russian grown crystals.
