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Cold workability and shape memory properties of novel Ti–Ni–Hf–Nb high-temperature shape memory alloys

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The effect of Nb content on the cold workability, microstructure and shape memory properties of Ti–Ni–Hf–Nb alloys is investigated. The addition of Nb to Ti–Ni–Hf improves the cold workability due to the formation of a soft Nb-rich phase. The Ti–Ni–Hf–Nb alloys exhibit a high-temperature shape memory effect during heating and cooling cycles under various stress levels. As the Nb content increases, the shape memory properties of the Ti–Ni–Hf–Nb alloys become more stable although the shape recovery strain decreases.

Keywords: Shape memory alloys; Phase transformation; Cold working; Microstructure

Since the discovery of methods for achieving superelasticity and for stabilizing the shape memory effect in Ti–Ni alloys [1–3], these alloys have over the last couple of decades been increasingly used in various fields of industry including home appliances, medical devices and electronic devices owing to their unique properties of shape memory effect and superelasticity [4]. However, most practical applications of shape memory alloys are limited to temperatures below 373 K because of the low transformation temperatures of commercially available shape memory alloys such as Ti–Ni and Cu-base alloys. Recently shape memory alloys operating at high environmental temperatures (above 373 K) have attracted attention as solid-state actuators for use in aircraft engines, automobile engines and energy-generation systems due to their large stroke, high recovery force and high work output [5,6].

Up to now several types of shape memory alloys have been reported to exhibit a martensitic transformation start temperature above 373 K [5–12]. Among these, Ti–Ni–X alloys (where X = Pt, Pd, Hf or Zr) have received the most research attention [13–19]. The martensitic transformation temperatures increase with the replacement of Ni with Pd and Pt above a critical concentration [13–15]. Ti–Ni–(Pd, Pt) alloys exhibit a relatively stable shape memory effect at above 373 K with a small hysteresis. However, the high cost of precious metal alloying elements has the limited practical applications of Ti–Ni–(Pd, Pt) shape memory alloys. It has also been widely recognized that substitution of Zr or Hf for Ti increases the transformation temperature of Ti–Ni shape memory alloys [16–19]. The Ti–Ni–(Zr, Hf) alloys are regarded as more practical systems compared with the Ti–Ni–(Pd, Pt) alloys because of the relatively low price of the raw materials required; however, for several reasons no practical devices have yet been developed. One of the most serious problems with Ti–Ni–(Zr, Hf) alloys is their low workability: their hardness is increased and their cold workability and ductility are decreased significantly by the addition of Zr and Hf [6,20–22]. Improvement of the cold workability of Ti–Ni–(Zr, Hf) alloys is vital for manufacturing them into suitable sizes and shapes and for microstructure control. The introduction of a ductile phase is an effective way to improve the cold workability of brittle materials. It has been reported that the addition of certain alloying elements such as Nb, W and Ag to Ti–Ni binary alloys results in the formation of a ductile phase [23–26]. However, up to now there has been no

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