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Microstructure and Properties of Shape Memory Alloys

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Shape memory effects are very interesting functional properties of certain metallic alloys such as NiTi, CuZnAl or CuAlNi, to name the most popular ones. After considerable seemingly plastic deformation at low temperatures the elements restore their original shape just by raising the temperature by about 50-100°C, thereby seeming to remember their former shape. The reasons for this phenomenon are reversible martensitic transformations from one ordered structure to another ordered one with almost the same specific volume. This so called one-way shape memory effect has been thoroughly investigated and is well-understood nowadays and therefore many technical and some medical applications are in use or could be used. The so-called two-way shape memory effect changes the shape of an element not only during heating but also during cooling without external forces. Therefore this effect would be even more attractive for technical applications but it is not quite well understood from a scientific point of view, and this effect is smaller and less stable than the one-way effect.

This work addresses 3 topics: generation of two-way shape memory effects in NiTi, NiTiW and CuAlNi wire materials and investigation of the long-term stability of these effects; investigations on thin CuAlNi films produced by PVD; investigations on thin CuAlNi ribbons produced by melt-spinning.

NiTi based and CuAlNi shape memory alloys have been characterized regarding the influence of microstructural features on the magnitude and stability of an intrinsic two-way shape memory effect. Our results show that the fatigue behaviour can be controlled by microstructural optimization. However, since the features introduced into the microstructure to improve the stability, simultaneously cause a decrease of the obtainable effect size, a compromise is necessary with respect to specific applications. The largest two-way strain was achieved with annealed NiTi samples, which is a consequence of the easily occurring martensite reorientation processes. In NiTiW samples the effect is considerably lower; coarse grained CuAlNi samples show a larger effect than fine-grained ones. The degradation of the two-way shape memory effect due to cyclic application in NiTi based alloys is related to instabilities in the high-temperature and low-temperature modification. The stability of the effect can be strongly improved by the introduction of W dispersoids (Fig. 1). CuAlNi samples show also good dimensional stability and therefore good stability of the two-way effect during thermal cycling. These investigations have been performed with wire material of several millimeters in diameter. However, it would be very useful to produce shape memory elements in much smaller dimensions for possible applications as microsensors and microactuators. This leads to the second topic of this work.

CuAlNi thin films were successfully deposited on a glass substrate by a magnetron sputtering method and could be easily removed, so that free standing films were produced. The deposition rate increases with increasing sputtering power and decreases with increasing Ar pressure. The content of Al in the samples decreases gradually with increasing Ar pressure while the Cu content increases and Ni stays almost constant. The microstructure of the deposited thin films is columnar with a very small grain size (about 100-300 nm). No martensitic phases were found, therefore no shape memory effect occurred. After heat-treatment at 800°C and water-quenching the β_1'-martensite was found by XRD measurements and the shape memory effect was demonstrated. Though the PVD process was leading to good results, the handling of the thin films regarding the testing of mechanical and functional properties, training of two-way effects and thermal cycling for determining the stability of the effect, proved to be very difficult. Therefore another production route was tried, namely the melt-spinning process for producing thin but long ribbons of CuAlNi alloys, which leads to the third topic of this work.

In order to obtain thin semi-finished products for microactuator applications CuAlNi ribbons were produced via melt-spinning. Initially a serious of melt-spinning experiments had to be performed to study the correlations between processing parameters (wheel velocity, nozzle type and distance to the wheel, Ar-pressure etc.) and the dimensions and the microstructure of the ribbons. All ribbons exhibit a one-way shape memory effect immediately after melt-spinning. The microstructure of the alloy of optimal concentration (13 wt% Al, 4 wt.% Ni, balance Cu) is fully martensitic at room temperature. Because of the relatively large grain size (Fig. 2) the ductility of the ribbons is rather poor, therefore boron was added as a grain refining element. Thereby a smaller grain size was achieved and the ductility increased considerably. As the thickness of the melt-spun ribbons is rather inhomogeneous, additional rolling of the ribbons was carried out on a cold-rolling device. The thickness was reduced from initially 100-130 µm to 60 ± 5 µm in several steps. First successes with respect to the two-way shape memory effect have already been achieved.

The results of this work can contribute strongly to the overall knowledge in the field of shape memory alloys especially with respect to the stability of a trained two-way effect for specific technical and medical applications. Also it is possible to get good functional properties in very small samples for microsensor and microactuator applications.

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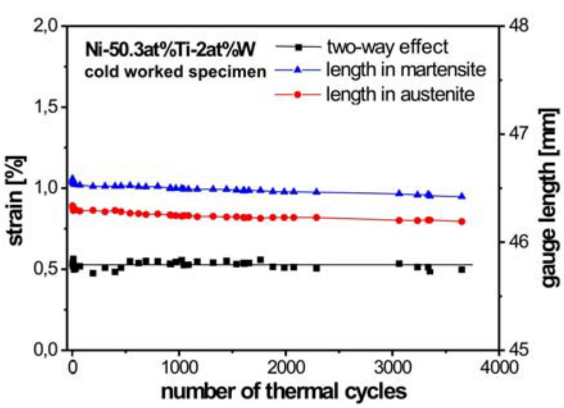

Fig. 1. Stability of the two-way shape memory effect during thermal cycling

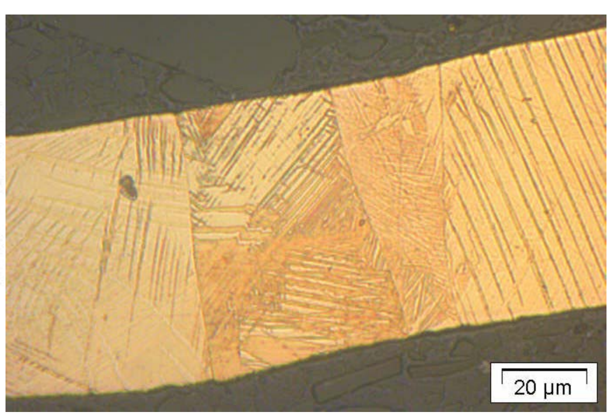

Fig. 2. Microstructure of a CuAl13Ni4 alloy after melt-spinning

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