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Martensitic Transformation in Fe-Pd Ferromagnetic Shape Memory Alloy Wires

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Abstract. Shape memory alloys are materials with the functionality controlled by a temperature change that leads to a reversible transformation from austenite into martensite. When magnetic field can also be used to influence the functionality, either by magnetic induced transformation or by magnetic induced reorientation. Each of mechanism is analyzed in the paper and their prevalence in the ferromagnetic shape memory alloy systems is discussed. FePd alloys manufactured by arc melting are characterized in the as cast, wire drawn and heat treatment state in view of their integration into functional applications with thermal and magnetic control of the actuation.
Structural and microstructural analysis is used to assess the particularities of this alloys in view of their integration into sensor and actuator-based applications.

1. Introduction

Shape memory alloys are materials that are known to show shape recovery following a plastic deformation by heating the alloy above a certain temperature that is specific to the chemical composition of that alloy.

Ferromagnetic shape memory Heusler alloys, are receiving increasing attentions due to their multifunctional properties: magnetocaloric effect (MCE), magnetic-field-induced strain (MFIS), magnetoresistance, etc. Ferromagnetic shape memory alloys when exposed to a magnetic field they show shape memory effects. The deformation induced by being exposed to a magnetic field is called magnetoelastic deformation. Examples of FSMA are: Ni-Mn-Ga, Fe-Pd, Fe-Pt, Co-Ni-Ga etc [1-5].

Ferromagnetic shape memory alloys are well-known to exhibit short response time and large reversible strains owing to high stability of ferromagnetic martensite, modulated structure, high magnetocrystalline anisotropy (MCA) and high saturation magnetization. For high temperature applications, high TC is also an important requirement [5-6].

The mode of deformation in ferromagnetic shape memory alloys (FSMAs) is the movement of twin boundaries under the influence of an applied magnetic field. Strain in shape memory ferromagnets takes place either through nucleation and growth of favorably oriented twin variants or by the growth of already present variant which are oriented favorably to the applied magnetic field [7].

Long range ordered intermetallics obtained based on Fe or Co and noble metals like Pt or Pd exhibit high uniaxial magnetocrystalline anisotropy with potential large energy products, good mechanical and corrosion properties. They are attractive for both thin film device applications (high density magnetic recording media) and permanent magnets [8-9].

The current work uses meltsuction method following arc melting for the fabrication of ferromagnetic shape memory alloy rods. The focus is on Fe-Pd shape memory alloys that could be used for actuators, valves, dumpers and biomedical applications.

2. Experimental details

Melt-suction was the method used to produce the Fe-Pd alloy, with this method the arc melted alloy is cast by suction into a mold channel due to chambers pressure differences, the alloy is then fast cooled when it gets in contact with the walls of the mold that are water-cooled (this leads to fast cooling of the alloy).

Fe-Pd shape memory alloys were manufactured by melt-suction, the alloy was melted in an arc melting equipment (Edmund Buhler GmbH), followed by melt-suction casting in a copper mold, resulting in a 3 mm diameter rod. The arc melting was performed in Ar atmosphere, after the chamber was high-vacuumed to $3x10^{-5}$ mbar. Several re-melting were made to ensure the homogeneity of the resulting alloys. The rod obtained by melt-suction was vacuum sealed at $3x10^{-5}$ in a quartz tube and was homogenized at 1000 °C for 10 hours, followed by furnace cooling. The homogenized samples were further annealed for 15 minutes at 1000 °C and quenched in room temperature water by breaking the quartz tube in water.

The composition and the microstructure of the samples used in the experiments was investigated in a TESCAN Vega 3LM electron microscope, equipped with a Bruker Quantax 200 Energy Dispersive X-ray Spectroscopy (EDX) system with Peltier-cooled XFlash 410M silicon drift detector.

The martensitic phase transformation of the manufactured rod was studied by the 4 wires electric resistivity method in a Picotest multimeter, on cooling, using liquid nitrogen as cooling agent. Further investigations of the martensitic transformation were performed in an Olympus optical microscope, equipped with a Peltier heating and cooling system (Figure 1).

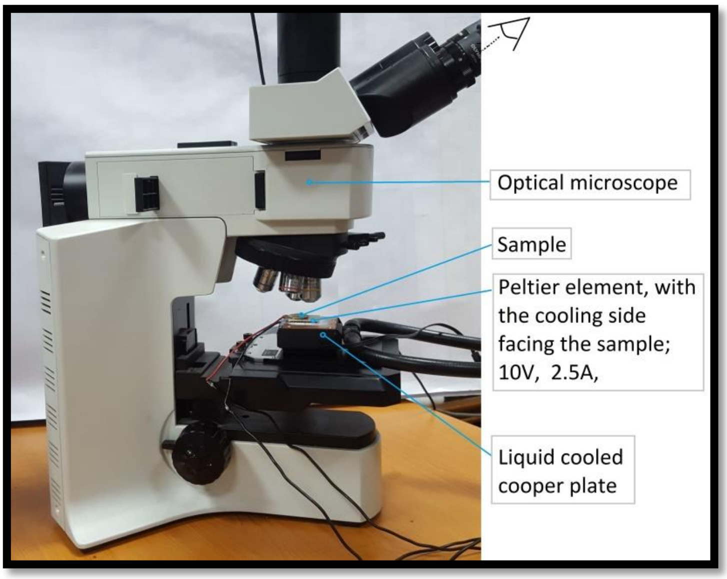

Figure 1. The martensitic transformation of the Fe-Pd alloy was observed using the optical microscope, the sample was placed on the cold side of a Peltier element, that was placed on a liquid cooled cooper plate.

3. Experimental results and dicussions

The EDX analysis of the alloy (in Figure 2a) indicated a composition of 68.26 at.% Fe and 31.74 at.% Pd, putting the alloy in the compositional range of the Fe-Pd where the shape memory properties have been reported and where the ordered FePd face centered tetragonal structure can be stabilized.

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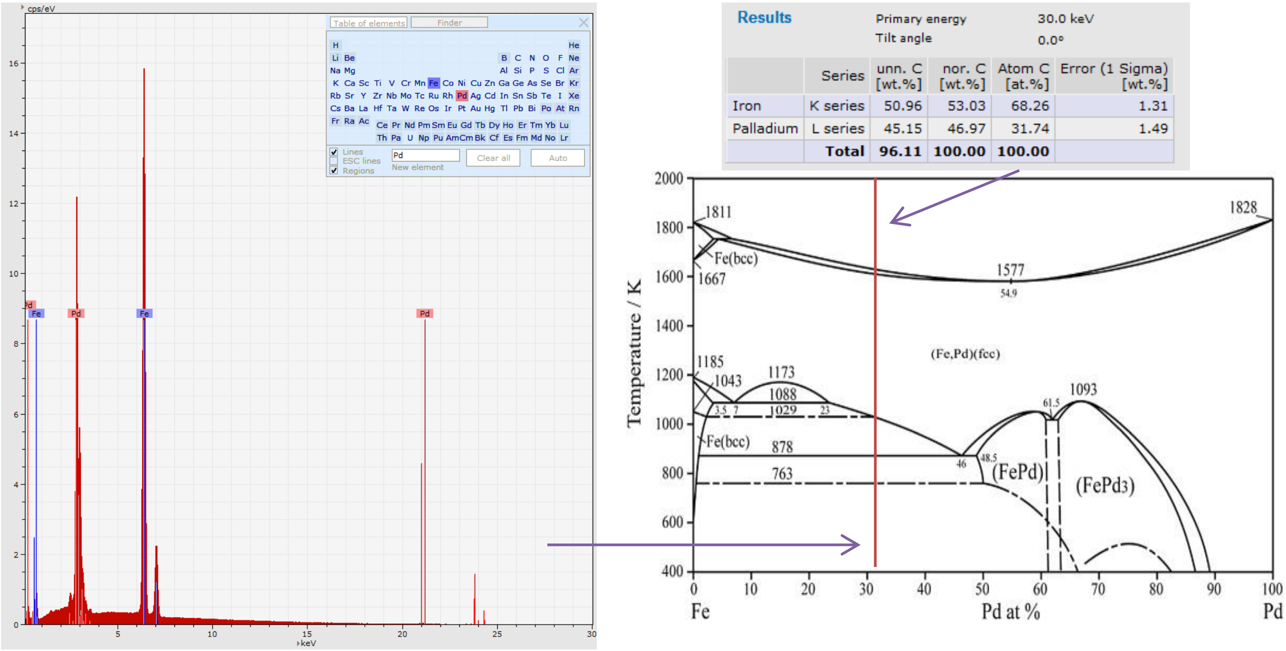

a) EDX compositional analysis of the Fe-Pd sample

b) EDX results (top) and Fe-Pd phase diagram [10] (bottom)

Figure 2. Analysis of the compositional range of the Fe-Pd shape memory alloy.

Further investigations by X-ray diffraction at room temperature allowed us to identify the corresponding peaks that set the structure into a predominantly austenite and a small fraction of martensite (Figure 3).

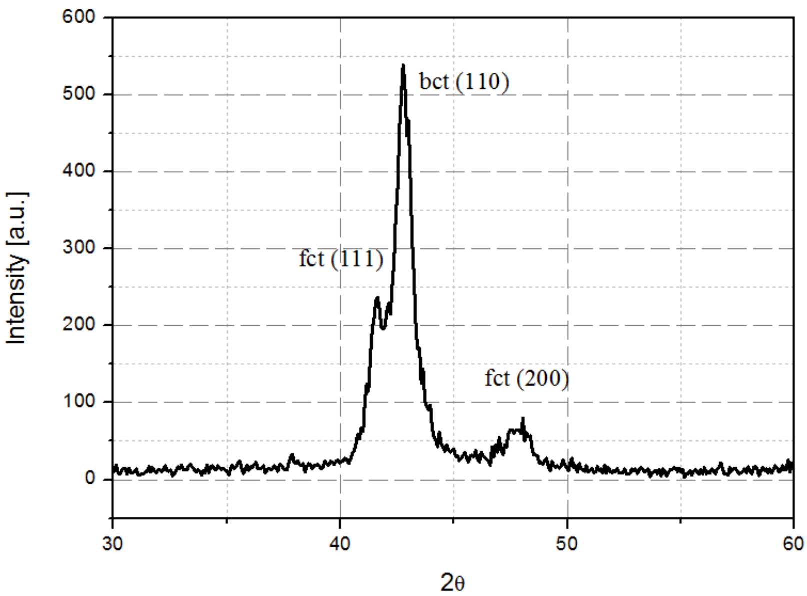

Figure 3. X ray diffraction data for the Fe-Pd alloy.

The X-ray diffraction observations were further confirmed by the temperature dependent optical microscopy, where the phase transformation was observed and recorded, with a typical martensitic structure observed at a temperature of -10°C vanishes on heating at +5 °C.

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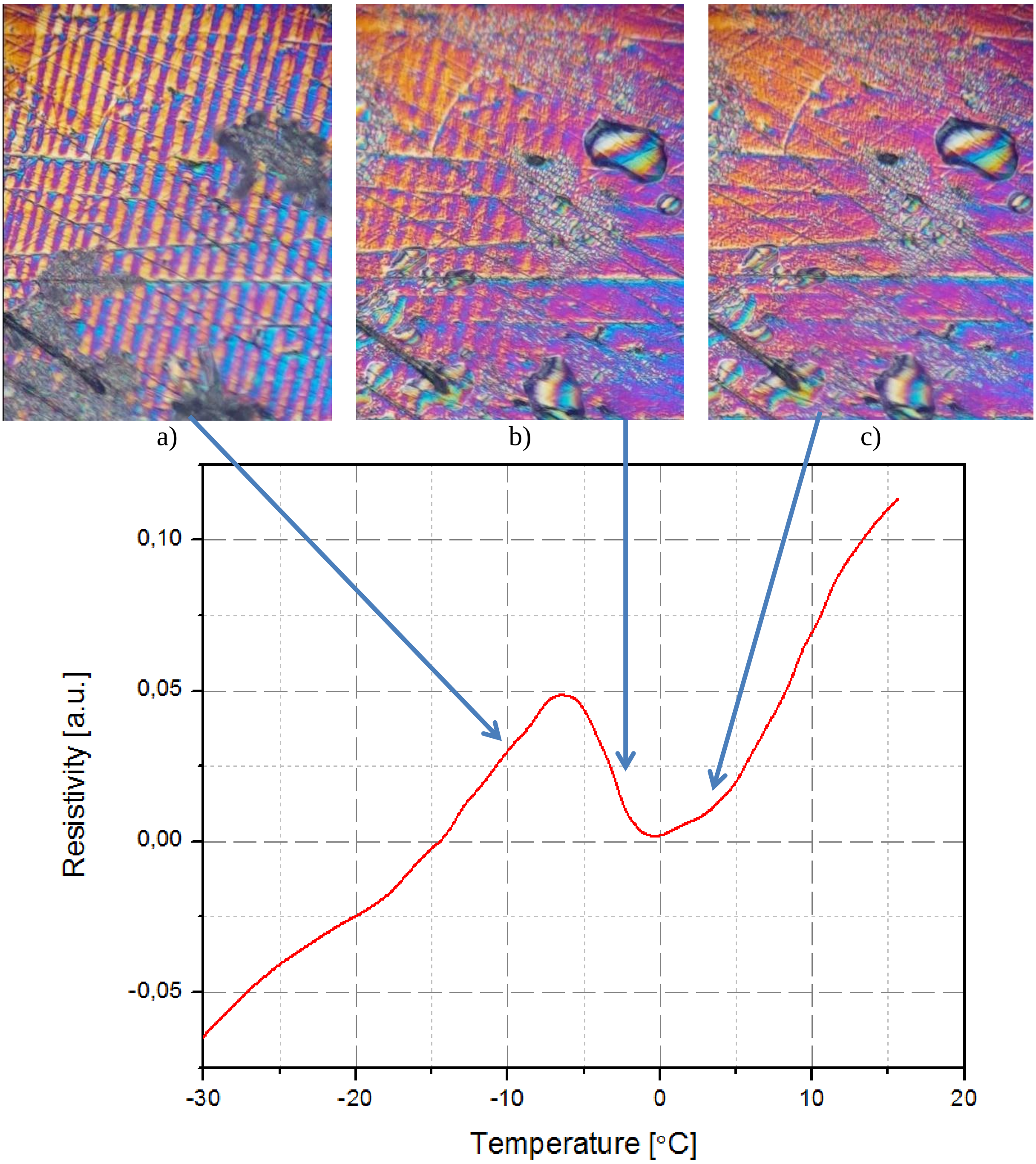

d)

Figure 4. Optical microscopy of the phase transformation (a - c) and electric resistivity measurement as a function of temperature for the Fe-Pd sample (d).

A further confirmation of the presence of the martensitic transformation was obtained from the electric resistivity measurements as shown in figure 4d, with the martensite and austenite slopes defining the transformation in the same range where the microstructural observations located it.

4. Conclusions

Fe-Pd alloys manufactured by melt suction as 3 mm diameter rods in the compositional range 68.26 at% Fe and 31.74 at. % Pd were austentic at room temperature and showed a martensitic phase transition upon cooling below 10°C.

The martensitic transformation on heating lead to the disappearance of the martensitic plates formed on cooling by heating above 5°C. The observations were also confirmed by electric resistance measurements.

5. References

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