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Strain rate sensitivity and deformation activation volume of coarse-grained and ultrafine-grained TiNi alloys

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Two TiNi alloys, $Ti_{49.4}Ni_{50.6}$ and $Ti_{50}Ni_{50}$, are subjected to equal-channel angular pressing (ECAP) resulting in the formation of a homogeneous ultra-fine grained microstructure. Tensile tests and strain rate jump tests are carried out in the temperature range of 25–400 °C to measure mechanical properties and strain rate sensitivity of both alloys before and after ECAP processing. Effect of grain size on mechanical behavior, strain rate sensitivity and mechanisms operating during plastic deformation of both alloys in the given temperature range is discussed.

Keywords: TiNi alloys; Severe plastic deformation; Ultra-fine grained material; Strain rate sensitivity; Activation volume

Titanium-nickel (TiNi) based alloys refer to the class of functional materials with the shape-memory effect (SME), stipulated by thermoelastic martensitic phase transformations [1,2]. These alloys are widely used as construction and functional materials in engineering and medicine [2,3]. It has been demonstrated over the last decade that grain refinement down to ultrafine- or nano-scale is a promising direction to enhance their mechanical and functional properties [4–11]. However, research on mechanical behavior and mechanisms operating during plastic deformation of the UFG TiNi alloys is limited [6,12].

Analysis of the mechanisms responsible for the material plastic flow at different temperatures is possible based on the data on strain rate sensitivity m and correspondingly calculated activation volume V [13]. Based on the analysis of activation volume, one may suggest a hypothesis about controlling deformation mechanisms in the UFG TiNi alloys. Moreover, manipulation with strain rate sensitivity in UFG materials is considered as one of the strategies to improve their ductility, since enhanced strain rate sensitivity can significantly improve their tensile ductility [14]. However, up to date, there are no available literature data on the effect of grain size on strain rate sensitivity and activation volume in the UFG TiNi alloys.

It is known that activation volume in materials with bcc- and hcp-lattices typically does not change with grain size, but in the case of fcc metals V decreases with decreasing grain size [13]. The intermetallic compound TiNi in the initial high-temperature austenite state has an atomic ordered structure B2 of CsCl type with parameters $a = 0.301$ nm, i.e. a bcc lattice. During cooling or under the applied stresses the B2-phase can transform into B19' phase with a monocline distorted orthorhombic elementary lattice with parameters $\alpha = 0.289$ nm, $\beta = 0.412$ nm, $\gamma = 0.462$ nm, $\beta = 97°$ [1,2]. Thus, below the temperatures of suppression of martensitic transformation (M_d), TiNi alloys are deformed in martensitic state (B19' phase); whereas at temperatures over M_d, TiNi alloys are deformed in austenitic state (B2 phase). The main objective of this work is to study the effect of grain size and temperature (i.e. phase) on strain rate sensitivity and activation volume of TiNi alloys.

Two TiNi alloys were chosen as the materials for this investigation – $Ti_{49.4}Ni_{50.6}$ and $Ti_{50}Ni_{50}$. The $Ti_{49.4}Ni_{50.6}$ alloy (manufactured by Intrinsic Devices, USA) is over-stoichiometric. The alloy belongs to the class of medical materials. At room temperature, it has the atomic-ordered B2 structure. The temperatures for martensite formation in the alloy are the following: $M_s = 11$ °C, $A_f = 42$ °C. After quenching and further heating, the $Ti_{49.4}Ni_{50.6}$ alloy may

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