Features of changing the temperatures of martensitic transformations, microstructure and properties in the Ti-50.8 at.% Ni alloy during multiple cycles

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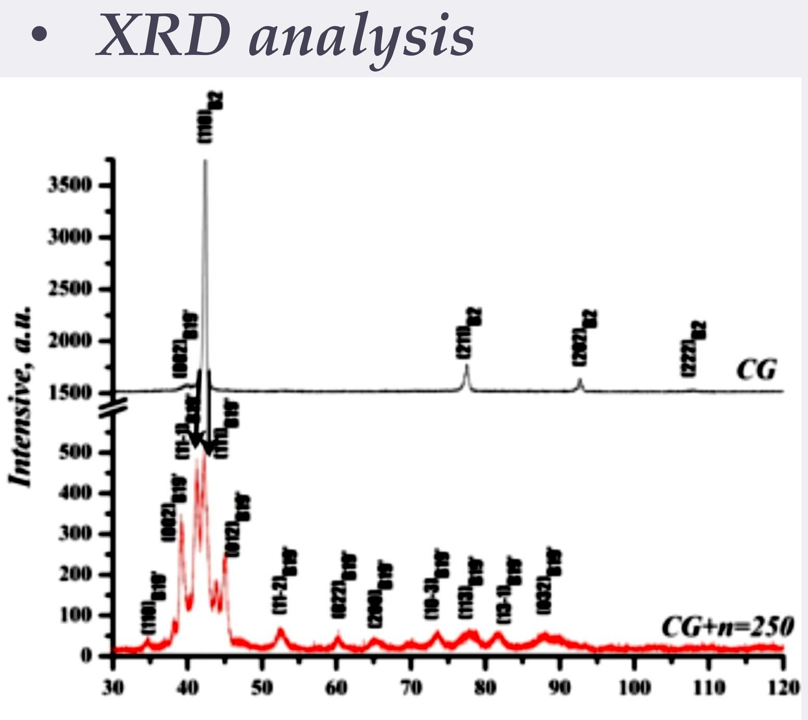
Introduction

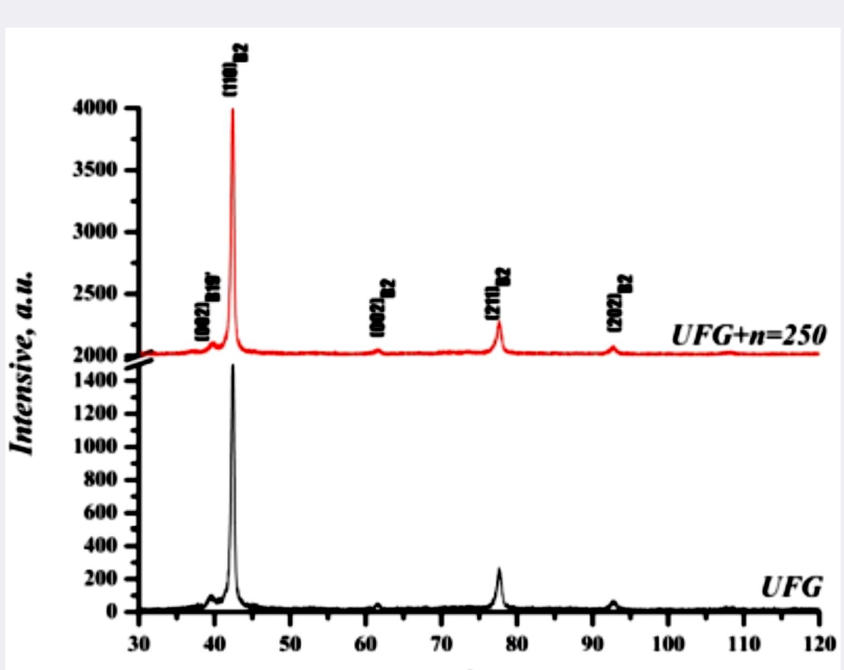
TiNi-based alloys belong to the class of functional materials with a shape memory effect (SME) caused by thermoelastic martensitic transformations. These alloys are widely used as structural functional materials in engineering and medicine. Thermal cycling (TC) is a technique used for additional enhancement of strength properties in some alloys. The term "thermoelastic transformation" in the strict sense excludes any noticeable irreversible changes. In the case of coarse-grained (CG) TiNi, some increase of the dislocation density takes place during multiple cycles of martensitic transformations, which is accompanied by a slight change of the martensitic transformation temperature and some enhancement of the yield stress during mechanical loading. But "phase hardening" resulting from thermal cycling of CG TiNi is not considerable. Processing of ultrafine-grained (UFG) and nanocrystalline (NC) states by severe plastic deformation techniques allows increasing service properties of different metals and alloys, including TiNi-based alloys. The two most popular SPD techniques are high-pressure torsion (HPT) and equal-channel angular pressing (ECAP). There are a limited number of researches reporting on the studies of the effect of thermal cycling on UFG TiNi alloys.

Material and Methods

The study was carried out on the $Ti_{49.2}Ni_{50.8}$(at.%) alloy subjected to homogenizing water quenching from 800 ºC. In order to form a UFG state, quenched cylinder samples (∅20mm, length 100 mm) treatment of samples were subjected to 8 passes of ECAP using a die-set with the angle of channels intersection of 120° at 450 ºC. Samples in different initial states were subjected to multiple martensitic transformations (thermal cycling). Thermal cycling treatment of samples in different initial states was carried out by cooling to the temperature of liquid nitrogen (-196 ºC) and heating to 150 ºC. The number of "heating – cooling" thermal cycles was from 0 to 250. The holding time at the heating and cooling temperatures was 3 minutes.
Calorymetric testing of the material was performed on a Mettler Toledo dsc 822e differential calorimeter. The fine structure of the material was studied with a JEOL JEM-2100 transmission electron microscope (TEM) at an accelerating voltage of 200 kV. Tensile mechanical tests were performed at room temperature with a test speed of 10^{-3} s^{-1} on a tensile machine designed at UUST.

• XRD analysis

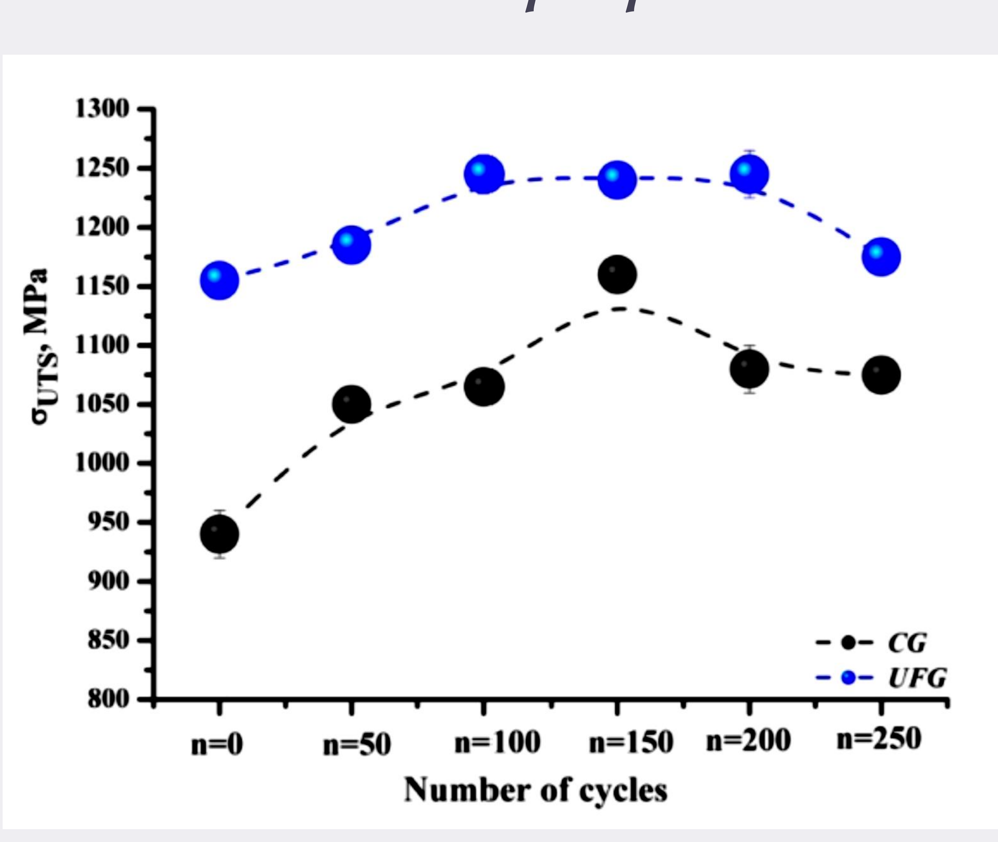


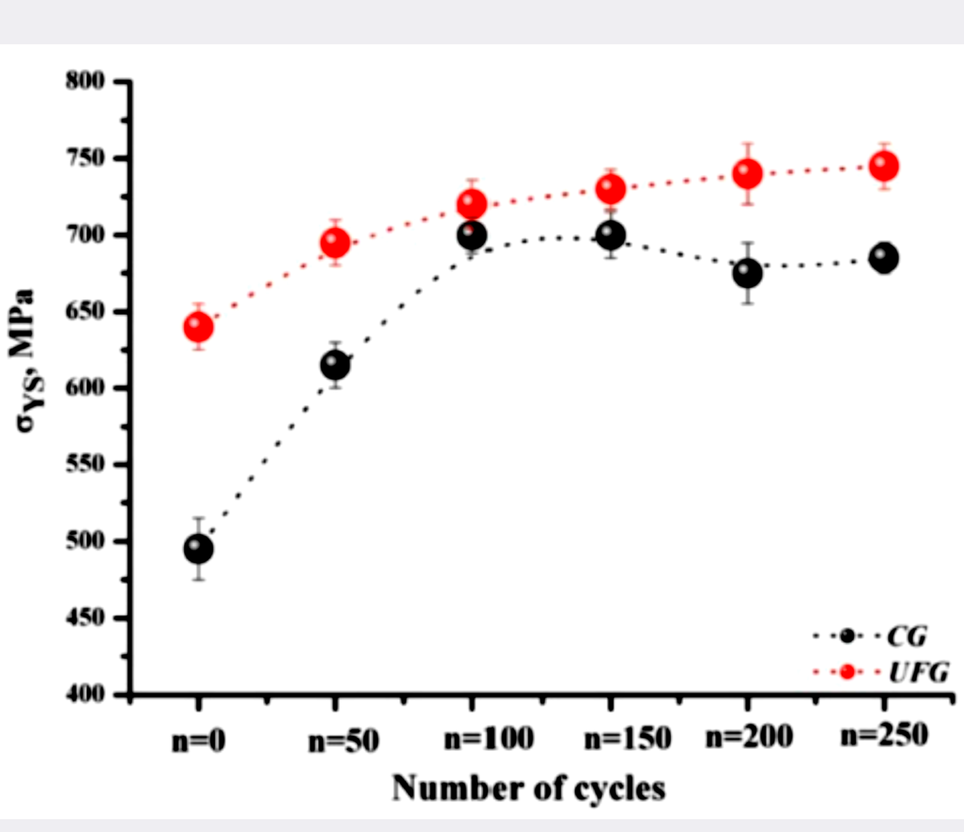


State	Parameters of Structure			
	Parameter Lattice a, Å	CSR, nm	$<\varepsilon^2>^{1/2} \times 10^{-4}$	$\rho \times 10^{15}$, m^{-2}
CG	3.013 ± 0.001	97 ± 2	0.8 ± 0.1	0.5 ± 0.1
CG + TC	2.895 ± 0.001 (monoclinic)	37 ± 2	2.2 ± 0.1	1.6 ± 0.1
Δ	0.118	60	1.4	1.1
UFG	3.011 ± 0.003	35 ± 3	2.7 ± 0.1	5.3 ± 0.15
UFG + TC	3.013 ± 0.001	19 ± 2	3.4 ± 0.1	7.1 ± 0.1
Δ	0.002	16	0.7	1.8

Δ = Parameter difference between the initial state of the alloy and the state after TC.

• Mechanical properties

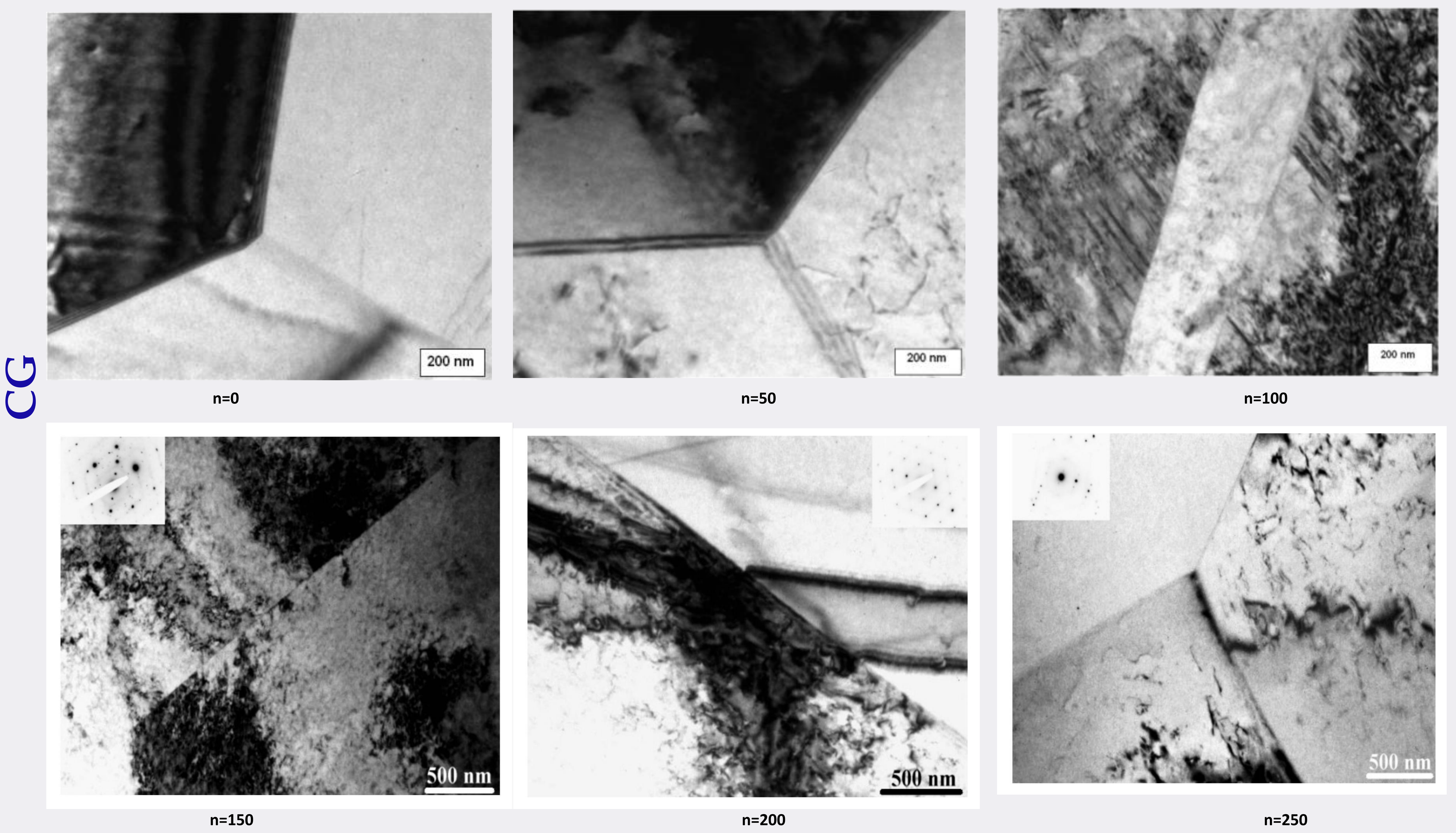




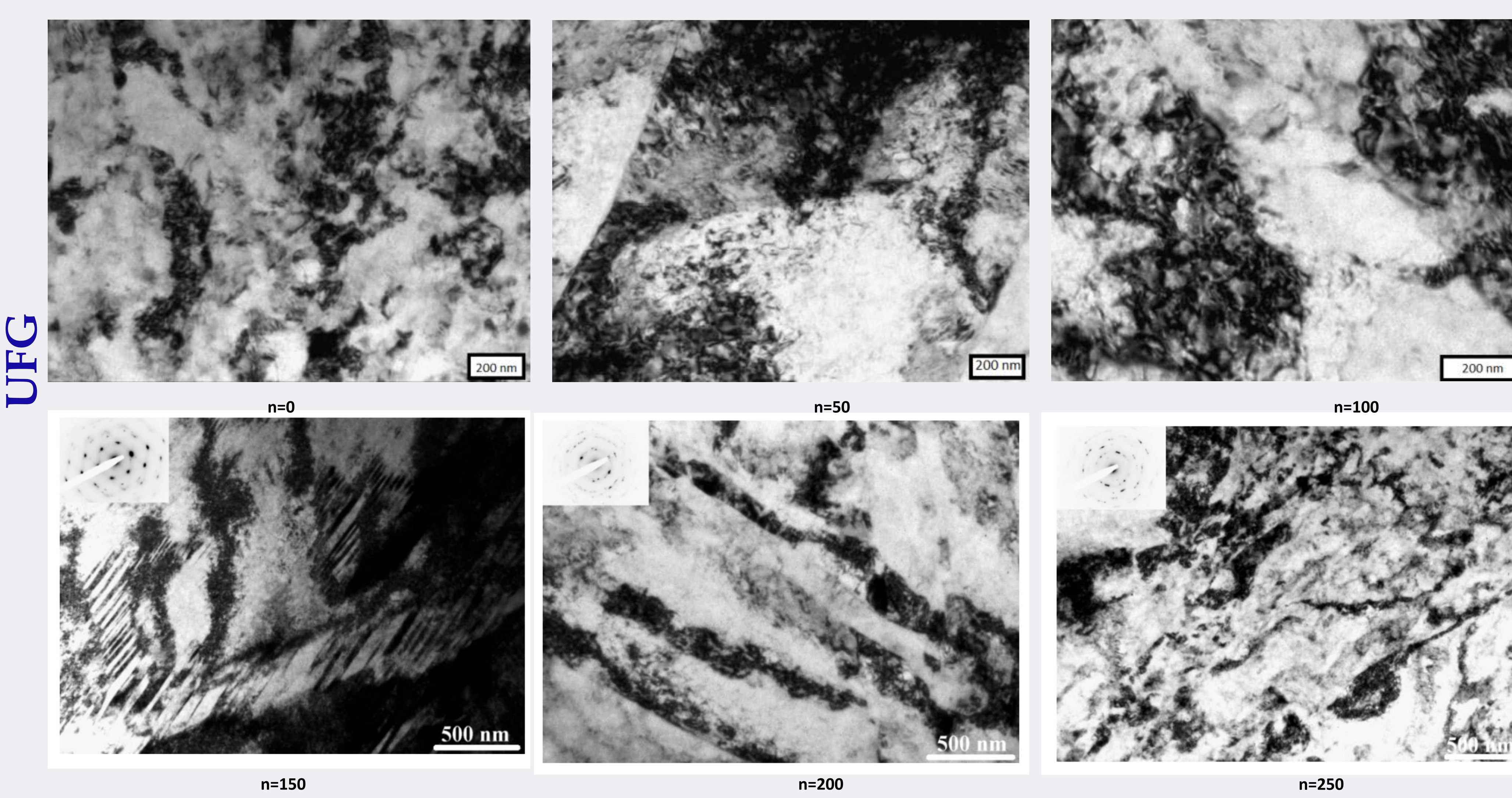
Results

• Microstructure (TEM)

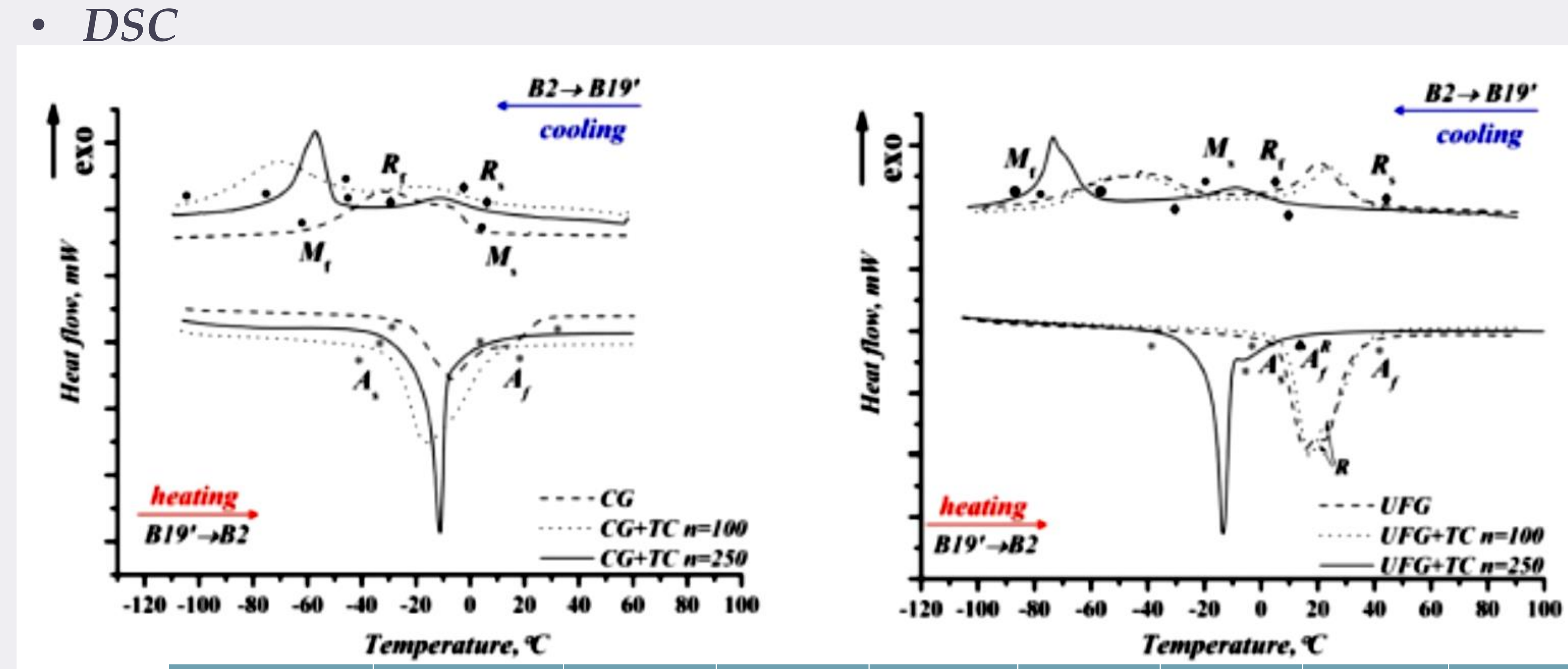
CG



UFG



• DSC



State	Number of cycles	M_s, °C	M_f, °C	Rs, °C	R_f, °C	A_s, °C	A_f, °C	A_f^R, °C
CG	n=0	3,1	-60,1	-	-	-25,1	26,8	-
	n=100	-38,6	-98,3	8,4	-	-29,5	8,4	-
	n=250	-49,6	-70,2	11,6	-29,	-18,3	-8,1	-
UFG	n=0	-13,5	-80,9	39,4	2,1	6,1	33,2	-
	n=100	-16,9	-74,2	38,6	2,2	7,8	36,6	-
	n=250	-59,7	-83,1	15,1	-32,1	-19,8	-9,8	7,9

*Churakova A.A., Gunderov D.V. Microstructural and mechanical stability of a Ti-50.8 at.% Ni shape memory alloy achieved by thermal cycling with a large number of cycles / Metals, 2020, 10, 2, 227

Conclusions

As a result of thermal cycling in the Ti49.2Ni50.8 alloy, the dislocation density increases, internal stresses increase in the coarse-grained and ultrafine-grained states, and the size of the structural components slightly decreases, which is associated with the formation of dislocation walls and subboundaries. An increase in the values of the ultimate strength and yield strength is observed with an increase in the number of thermal cycles in both coarse-grained and ultrafine-grained states. At the same time, in the case of a coarse-grained state, an increase is observed up to n=300 cycles, subsequently a slight decrease in values and their stabilization is observed. In the case of ultrafine-grained state up to 250 cycles, a further increase in the number of cycles shows a similar behavior to the coarse-grained state.
The Ti-50.8 at.% Ni alloy in the UFG state is more attractive for applications, since in this state a higher level of properties is obtained compared to the coarse-grained state. In addition, the UFG state shows greater stability during thermal cycling with a large number of cycles.
According to the data obtained in the coarse-grained state, during the direct martensitic transformation, one distinct exothermic peak appears on the DSC curves. During the reverse martensitic transformation, an endothermic peak is observed, associated with the appearance of a high-temperature austenitic phase B2 from a martensitic phase B19'. After thermal cycling with n = 100 cycles, a peak is observed from the intermediate phase R during direct martensitic transformation and a decrease in martensitic transformation temperatures (Ms, Af). After the maximum number of cycles, a multidirectional change in temperature was observed, including a slight decrease in the temperature of the beginning of the direct transformation (Ms) and the end of the reverse (Af), as well as an increase in the temperature of the end of the direct transformation (Mf) and the beginning of the reverse As.