**Ultralow-temperature superplasticity and its novel mechanism**

**in ultrafine-grained Al alloys**

# Materials and methods

The alloy with a composition of Al-2.04at%Zn-1.37at%Mg-0.04at%Zr (or well-known as Al-4.8wt%Zn-1.2wt%Mg-0.14wt%Zr) was processed by casting. The as-cast material was homogenized in air at 470°C for 8 h, and then hot extruded at 380°C. Then, disks with a diameter of 20 mm and a thickness of 1.4 mm were cut from the extruded rods for processing by high-pressure torsion (HPT). The HPT process is described in detail elsewhere [12]. Before HPT processing, the alloy was homogenized at 470 °C for 1 h and then water-quenched to room temperature (RT). The disks were subjected to 10 revolutions of HPT at RT under a pressure of 6 GPa and at a rotation speed of 1 rpm.

The microstructure of the HPT-processed sample was investigated by transmission electron microscopy (TEM). First, a thin foil was prepared by mechanical polishing and then it was thinned till perforation at -20 °C by twin-jet electropolishing using a chemical solution containing 33% HNO3 and 67% CH3OH. A Titan Themis G2 200 scanning transmission electron microscope (STEM) was used for TEM and energy-disperse X-ray spectroscopy (EDS) investigations. The microscope was equipped with a four-segment Super-X EDS detector. A corrector for the spherical aberration (Cs) was applied at the imaging part, while no probe-correction was present. The STEM images were taken by a Fishione high-angle annular dark-field (HAADF) detector. The elemental maps were recorded by EDS in spectrum-image mode.

Strain rate sensitivity of the investigated samples were determined by indentation creep carried out in the temperature range of 100$÷$170 oC using a Nanoindenter G200 machine working with maximum load of 50 mN and a three-sided, customized Berkovich pyramid. Elevated testing temperatures were realized using a commercial heating stage (MTS Nanoinstrument). The procedure for determination of strain rate sensitivity by using indentation creep can be found in [13].

Samples with a gauge length of 2.0 mm and a cross section of 1.0 × 0.8 mm were fabricated from the HPT-processed disk and deformed by tension at different strain rates and different temperatures lower than 0.5 × *T*m. Tensile tests were conducted at testing temperature of 120, 150, 170 °C and strain rate, $\dot{ε}$ of 5 × 10−4 s−1 by using the testing machine Instron 5982. Vickers microhardness was measured using a Zwick Roell ZHµ hardness tester with a load of 5 N for dwell time of 10 s.