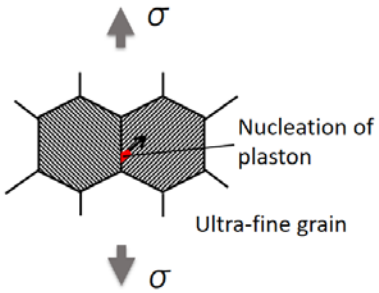
Development of structural materials with concurrent enhancement of strength and ductility: A challenge in ESISM

Isao TANAKA, Haruyuki INUI and Nobuhiro TSUJI : ESISM, Kyoto University

A tradeoff relationship between strength and ductility is well known in structural materials. Elements Strategy Initiative for Structural Materials (ESISM) has been working to achieve a breakthrough to overcome the trend not through the addition of alloying elements, but rather through microstructural control. Bulk nano-metals (BNM) are of our central interests. Whereas ordinary structural metallic materials are composed of 10 to 100 μm crystalline grains, BNM is composed of 1 μm or smaller grains. Generally speaking, BNM shows higher strength than an ordinary grain-size material. However, it often exhibits poor tensile strength, which can be ascribed to the initiation of the plastic instability in the early stage of the tensile deformation in BNM leading to necking of the sample. Such a behavior can be well explained by the conventional dislocation theory. Contrary to such a view, however, we found ductility of BNM can be clearly enhanced by selecting materials and controlling the nucleation of plastic deformation at grain boundary, i.e., “plaston” [1].



Materials	Plaston
pure Ti	non-basal dislocations
Cu alloys (low SFE)	deformation twins
metastable austenitic steels	martensites
high Mn steel	deformation twins

Figure: Mechanism of ductility enhancement in some BNMs by controlling nucleation of plaston at grain boundary.

We have employed advanced nano-analysis tools such as SEM, SEM/EBSD and TEM, together with beam-lines in J-PARC and SPring8. Neutron diffraction is particularly useful since *in-situ* analysis of mm-sized bulky samples can be made. Thermo-mechanical simulators are equipped both in J-PARC and Kyoto Univ. for the experiments.

Micro-pillar compression experiments have been extensively used in the group in order to analyze the defect mechanism/structure controlling the plastic deformation. Specimens ranging from nm to μm size are cut from polycrystalline samples by FIB, which are supplied for compression tests with minimal influence of preexisting defects prior to the tests. Thereby elementally process of plastic deformation can be experimentally analyzed [2].

In parallel to such experiments, theoretical calculations based on first principles methods have been systematically made. First principles phonon calculations [3] have been used to analyze the deformation twinning of HCP metals. Methods to analyze paramagnetic Fe by first principles calculations have also been established.

Bibliography

[1] Y. Z. Tian, et al; *Sci. Rep.*, 5, 16707 (2015) [2]J.Y. Zhang, K. Kishida and H. Inui; *Int. J. Plasticity* 92 45 (2017) [3] A. Togo, and I. Tanaka; *Scr. Mater.*, 108, 1 (2015)【Number of citations: 484】

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