**ORIENTATION-DEPENDENT PLASTIC DEFORMABILITY IN MICROPILLAR COMPRESSION OF OXIDE CERAMICS**

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Micromechanical testing, such as nanoindentation and micropillar compression, can be the promising tool for characterizing the plastic deformability of ceramics even at temperatures below macroscopic ductile-to-brittle transitions [1,2]. Such plasticity is possibly achieved by the fracture strength increase at small scales. The fracture strength, $\sigma_C$, is conventionally determined as a function of a crack dimension:

$$\sigma_C = \frac{AK_C}{\sqrt{\pi a}}, \quad (1)$$

where $A$ is a fracture-mode constant, $K_C$ is a fracture toughness, and $a$ is a principal crack radius. The principal crack dimension can be reduced with decrease in the sample volume, resultantly increasing the fracture strength beyond the plastic yield strength typically in orders of 1–10 GPa at micromechanical testing. Investigating such small-scale plasticity may contribute to the improvement of fracture toughness of ceramics in the future, which is possibly achieved by awakening the localized plasticity at the crack frontal zones.

In this study, orientation-dependent plasticity of several oxide ceramics, such as 10 mol% $Y_2O_3$-stabilized $ZrO_2$ (10YSZ) and non-doped $SrTiO_3$, was investigated through single-crystal micropillar compression experiments. Cylindrical micropillars with diameters of 0.9–1.1 μm and heights of 2.5–4.0 μm were fabricated using focused ion beam and compressed at room temperature with strain rates of $1 \times 10^{-3}$ $s^{-1}$ using a nanoindentation facility equipped with a flat-ended diamond tip. Surface slip trace analysis and cross-sectional dislocation characterization were performed by scanning electron microscopy (SEM) and transmission electron microscopy (TEM), respectively. The orientation dependence of such dislocation structure developments inside micropillars were numerically simulated using a crystal plasticity finite element method (CPFEM).

Nominal stress–strain curves of 10YSZ micropillars compressed at room temperature along different orientations are demonstrated in Fig. 1, indicating a significant orientation dependence in the plastic deformability. The [001] and [101] compressions exhibit plastic yielding but are associated with early fracture at strains below 10%. In contrast, extensive deformability is recognized in the [111] compression, where the pillar exhibited no fracture even after the nearly 40% strain. This enhanced plasticity could be associated with dislocation activities on multiple {001}<110> slip systems, as revealed by the slip trace analysis and dislocation characterization through SEM and TEM observation, respectively. Such plastic anisotropy was also observed from $SrTiO_3$ micropillars, where considerable deformability was observed along [001] compression, where multiple {101}<$\bar{1}01$> slip systems could be activated.

The CPFEM simulation also demonstrated the orientation dependence of dislocation structure development during micropillar compression. This suggests that the enhanced deformability at certain crystallographic orientations in oxide ceramics is attributed to the anisotropic slip activations and resultant dislocation structure development.

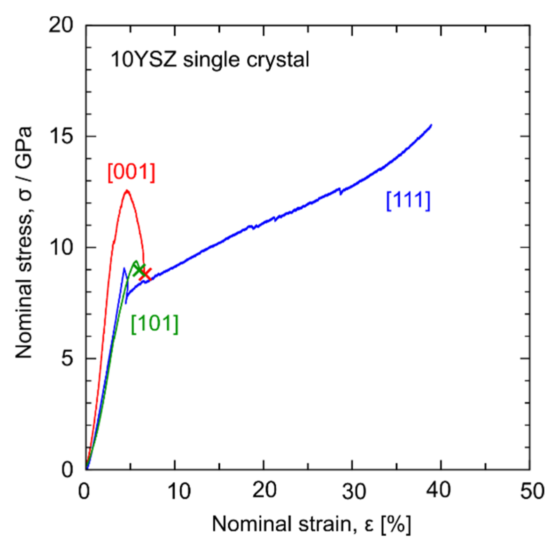


*Figure 1 – Nominal stress–strain curves of 10 YSZ micropillars at different crystallographic orientations.*

References
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[2] H. Masuda, K. Morita, M. Watanabe, T. Hara, H. Yoshida, T. Ohmura: Acta Mater. 203 (2021) 116471.