Evaluation of deformation behavior in harmonic microstructure through nanomechanical characterization

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（ナノ力学的評価による調和組織構造の変形挙動の評価）

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論文内容の要旨

An improved combination of strength and ductility is generally a trade-off relationship, and it remains a major research topic in the field of structural materials. A harmonic microstructure, consisting of a coarse-grained “core” region and a surrounding fine-grained “shell” region, exhibits a good balance between strength and ductility. Therefore, the strengthening mechanism that contributed to the excellent mechanical properties of the harmonic structure was investigated. Furthermore, the deformation and fracture behavior were also studied. The individual strengthening factor in the Hall-Petch model was investigated using nanoindentation technique to understand the strengthening mechanisms in the SUS304L stainless steel harmonic structure. Nanoindentation technique was applied locally, such as in the “grain interior” to evaluate the matrix strength (σ_0) and “on grain boundary” and “near grain boundary” to assess the grain boundary effect (k) for each region of the core and shell. The grain interior nanohardness was found to be higher in the core region than that in the shell, which is explained by the higher pre-existing dislocation density in the core region. The nanomechanical characterization of the “grain boundary” and the “near grain boundary” regions show a higher barrier effect due to the grain boundary in the shell than that in the core, which is presumably dominated by the higher internal strain at the shell grain boundary. Furthermore, a Hall–Petch plot was constructed using nanohardness, Vickers hardness, and grain size to estimate the k value. A higher k value in the shell was obtained than that for the core, which is consistent with the higher strengthening effect of the shell grain boundary that is evaluated independently in the local region. Subsequently, the local deformation and fracture behavior of SUS304L stainless steel harmonic structure were investigated by the nanoindentation technique. Specific nanoindentation comparison of various strains

on the deformed sample revealed that core region exhibited a tremendous increase in nanohardness with deformation, which reflects its capability for strain hardening. Moreover, this also enhances the uniform deformation by avoiding strain localization. Therefore, preventing early necking behavior. Furthermore, it was found that the nanohardness is the highest at the fractured end. The core and shell region can be observed moving towards the same nanohardness level, which indicates the degree of strain hardening with nominal strain in the core region is decreased. Since SUS304L stainless steel are prone to strain induced martensitic transformation ($\gamma \rightarrow \alpha'$) when subjected to plastic deformation, it is expected that the high amount α' martensite is present at the fractured end area especially at the core region. In addition, the deformation behavior of copper harmonic structure was investigated owing to its excellent ductility properties with improved mechanical properties compared to other materials. Particular attention was given to the shell–core boundary because it is the most distinct microstructure in the harmonic structure. Dislocation interactions at the shell–core boundary in the copper harmonic structure were directly measured using nanoindentation and microstructural observations via kernel average misorientation (KAM). KAM analysis showed that the dislocation density in the vicinity of the shell–core boundary within the core region gradually increases with increasing plastic strain. Subsequently, nanoindentation experiments were conducted in the “core grain interior”, “core–core boundary”, and “shell–core boundary”, which were determined by the KAM map. The nanohardness within the core grain interior near the shell–core boundary was found to increase with increasing KAM, indicating that the higher strength is primarily caused by the higher dislocation density. Furthermore, the critical load for nanoindentation-induced plasticity initiation was lower at the shell–core boundary than at the core–core boundary, indicating a higher potency of dislocation emission at the shell–core boundary. Because dislocation–dislocation interactions are one of the major causes of the increase in the flow stress leading to higher strain hardening rates during deformation, the excellent balance between strength and ductility is attributed to the higher potency of dislocation emission at the shell–core boundary.

〔作成要領〕

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