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Deformation mechanism of high performance harmonic structure designed materials

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ABSTRACT

Through many years, conventional material developments have emphasized on microstructural refinement and homogeneity. However, “Nano- and Homogeneous” microstructures do not, usually, satisfy the need to be both strong and ductile, due to the plastic instability in the early stage of the deformation. As opposed to such a “nano- and homo-” microstructure design, we have proposed “Harmonic Structure” design. It is a new material design paradigm allowing the enhancement of structural performance. The harmonic structure has a heterogeneous microstructure consisting of bimodal grain size together with a controlled and specific topological distribution of fine and coarse grains. In other words, the harmonic structure is heterogeneous on micro- but homogeneous on macro-scales. In the present work, the harmonic structure design has been applied to pure-Ti, Ni, Cu, Fe, Ti–6Al–4V alloy and SUS304L stainless steel via a powder metallurgy route consisting of controlled severe plastic deformation of the corresponding powder (pre-alloyed in the case of Ti–6Al–4V and SUS304L) via mechanical milling or high pressure gas milling, and subsequent consolidation using SPS. At a macro-scale, the harmonic structure materials exhibited significantly better combination of strength and ductility, under quasi-static loadings, as compared to their homogeneous microstructure counterparts. This behavior was essentially related to the ability of the harmonic structure to promote the uniform distribution of strain during plastic deformation, leading to improved mechanical properties by avoiding or delaying localized plastic instability.

KEYWORDS: harmonic structure, strength, ductility, metallic materials, deformation, ultra fine grain