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Harmonic-Structured Materials: Concept, Fabrication, and First Attempts of Elucidating Their Structure-Performance Relationship

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Abstract

The development of new materials and the tailoring of their performance for various applications is an ever-important matter having the history as long as the human being. They are key enablers in optimising existing and designing new technologies. When it comes to the structural performance of polycrystalline materials, it is well known that they typically have high ductility and low strength. Such characteristics can hardly meet new demands for modern applications. Extensive research over the past three decades demonstrated that the refinement of structural elements in such materials is a very efficient way to increase their strength, but is usually accompanied by a reduction in ductility, often to an unacceptable level. Such disparate trends are difficult-to-impossible to alter within traditional concept of materials with homogeneous structure.

One of the best solutions for mitigating this problem is the fabrication of multi-scale architectured structures. Of particular interest in such approach is the fabrication of 'harmonic' structure (HS) recently proposed by Ameyama and co-workers. It is characterised by bimodal grain size formation, which has a continuous three-dimensional ultrafine- (sub-micron scale-) grained skeleton encapsulating islands of coarse- (at least an order of magnitude larger-) grained islands. Such HS materials can be fabricated using a 'powder metallurgy' route allowing full control over the structure characteristics (various grain fractions and their topological distribution). The winning combinations of strength-ductility have been demonstrated in several HS materials, but the understanding of their structure-performance relationship is still in the embryonic stage.

In this talk, the concept of HS materials along with possible fabrication routes will be introduced. Furthermore, our attempts on elucidating the structure-performance relationship in harmonic structures *experimentally* using tensile and nano-indentation tests along with in-situ and post-mortem observations by optical and electron microscopies as well as Finite-Element *simulations* of these tests will be reported. This work reveals that HS materials demonstrate excellent combination of strength and elongation due to ultrafine-grained (strong) skeleton and coarse-grained (soft) areas absorbing lattice defects and re-distributing strain thus delaying its localisation and the plastic instability.

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