Editorial

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Perspectives on Titanium Science and Technology

Dipankar Banerjee

Department of Allergy and Immunology, University of Colorado School of Medicine, Aurora, Colorado

***Corresponding author:** Dipankar Banerjee, Department of Allergy and Immunology, University of Colorado School of Medicine, Aurora, Colorado
E-mail: dipankarbanerjee10@gmail.com

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Introduction

In the past 20 years, Ti alloys have become increasingly important structural materials for high-value, weight-sensitive products. The successes of applying Ti alloys have largely been the result of pragmatic engineering as opposed to bottom-up scientific discovery and application. Nevertheless, Ti alloys are being successfully used in aircraft, aircraft engines and rocket engines, among other products. As product realization cycles become shorter, the benefit of using modeling and simulation to reduce the time and cost of qualifying materials for a given application becomes increasingly important. High-fidelity models require sound physical understanding of the phenomena that govern materials behavior. To this end we have attempted to identify areas where additional research can enable better models.

Titanium alloys derive their properties from combinations of the two ductile phases based the hcp and bcc allotropic modifications of titanium. Several key features of these phases individually and in combination determine the plasticity and fracture behavior of these single-phase or two-phase mixtures. The alpha phase is both elastically and plastically anisotropic and stiffer and stronger when oriented with its c-axis parallel to the loading direction. Thus texture, both global and local, plays a key role in its plasticity. Its anisotropy extends to dislocation behavior through the non-planar core spread of screw “a” type dislocations that render this line direction relatively immobile. Composition, especially the Al and O content of alpha, sensitively affects its plasticity through its twinning response and slip character, whether planar or homogenous, through short-range order effects.

The fundamental role of alloying additions on plasticity at the atomistic level remains poorly understood. It is also possible that hydrogen at relatively low concentration levels plays larger role in determining ambient-temperature time-dependent properties than has been recognized thus far. Creep properties of the alpha phase are better than those of beta because of the intrinsically lower diffusivities in its close packed structure. Nevertheless the alpha phase can accumulate relatively large plastic strains at ambient temperatures under constant loading conditions below its yield stress. A strong interaction of dynamic strain ageing phenomena in the alpha phase with the creep process exists at intermediate temperatures but has not been well documented thus far.

The beta phase has a variable modulus and its elastic behavior including anisotropy can be controlled through alloying additions. It is also subject to a variety of thermal and stress-induced phonon and shear instabilities, a detailed understanding of which is only now beginning to emerge as the biomedical community exploits its low toxicity combined with a bone-matched modulus, in both conventional and shape-memory-related applications. In combination, the alpha and beta phases can be crystallographically oriented in a manner that strongly affects the plasticity of the two-phase mixture by enhancing anisotropy of slip through preferential alignment of some slip planes and directions in the two phases. Thermo mechanical processing is used to relatively reorient and obtain more isotropic morphologies of the two phases.

Quite recently, however, it has emerged that under many conventional processing conditions, especially in thick section products, micro textures reflecting this strong crystallographic alignment continue to persist and affect properties in unusual ways. Therefore, efforts to understand and model thermal and compositional effects on crystallographic variant distribution of the alpha phase as it precipitates from the parent beta, and the effects of variant selection on the pathways of subsequent micro structural evolution during processing, have only just begun to emerge.

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