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Crystallographic Orientation Relationships of Grain Boundary Alpha in Additively Manufactured Ti-6Al-4V

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Additive manufacturing (AM) of near net shape Ti-6Al-4V (Ti-6-4) parts is receiving increasing attention from the biomedical and aerospace communities looking to take advantage of AM's cost and time-to-production benefits for this important and widely used alloy. Ti-6-4 AM parts built using powder bed fusion techniques such as Electron Beam Melting (EBM) or Selective Laser Melting (SLM) are prone to porosity that may not be acceptable for aerospace applications subject to high stresses or cyclic loading, so are often consolidated by Hot Isostatic Pressing (HIP). Grain boundary alpha (GBα), which typically defines elongated prior beta grain boundaries aligned in the vertical direction with respect to the AM build process, is deleterious to fatigue properties and coarsens with sub-beta transus HIP cycling. An understanding of GBα's formation and crystallographic relationships to the surrounding microstructure may assist in interpreting its effect on mechanical properties and whether mitigating heat treatments are beneficial.

The present work examines the microstructure of EBM AM Ti-6-4 in the as-built and sub-beta transus (~900°C) HIP'd conditions. The analysis is focused on the crystallographic orientation relationships of GBα within these samples. Electron BackScatter Diffraction (EBSD) is the primary characterization tool applied here, since it allows quantitative mapping of various aspects of microstructure, including identification of individual grains and their size, shape, phase identity, crystallographic orientation and degree of internal lattice rotation. In EBSD data processing, GBα is easily discerned from surrounding material by grain morphology and its position between two colonies, which are themselves discerned by discrete sets of orientation colors among their constituent alpha lamellae. Once isolated, GBα may be analyzed individually or in comparison with neighboring colonies.

The as-built material has a classic as-cast microstructure, dominated by massive colonies of alpha platelets in a Widmanstätten pattern; HIP'd material is similar albeit with coarser grains. In both conditions the alpha platelets within a given colony are restricted in crystallographic orientation to a standard variant set, and beta grains positioned within the colony all conform to a single orientation that satisfies the Burgers orientation relationship [1] with them. Grain boundary alpha is apparent in both as-built and HIP'd conditions, but is coarser in the latter and more easily discerned. Both α platelets and GBα show a considerable degree of intra-grain lattice rotation, up to 15° among the analyzed regions of this sample, indicating residual deformation from cooling in the original build step. All GBα grains are oriented in a standard alpha variant orientation with respect to one of the two adjacent colonies, and so have a Burgers orientation relationship with the beta within that colony. Some GBα consists of two or more segments related by high angle (>15°) grain boundaries, and in one example, each segment is crystallographically oriented parallel to a different variant within the same neighboring colony. In both the as-built and HIPd materials, some GBαs are found with orientations that satisfy *both* neighboring colonies (e.g., Fig. 1). In these cases, the colonies have only that one variant orientation in common, and where beta is also analyzed, it shows inter-colony parallelism between one <110>$_{beta}$ direction and the <0001>$_{alpha}$ common to that variant. All of these orientation relationships are recognized in non-AM Ti-6-4 (e.g., [2]), so much of the well-established knowledge of GBα may be applied in AM Ti-6-4, including an understanding of its origin and its mitigation by post-HIP heat treatment. [3]

References:

[1] W. Burgers, Physica **1** (1934), p.561 – 586
[2] T. Furuhara *et al*, Metallurgical and Materials Transactions A **27** (1996), p.1635-1646
[3] This work was supported under The Aerospace Corporation's Internal Research and Development Program.

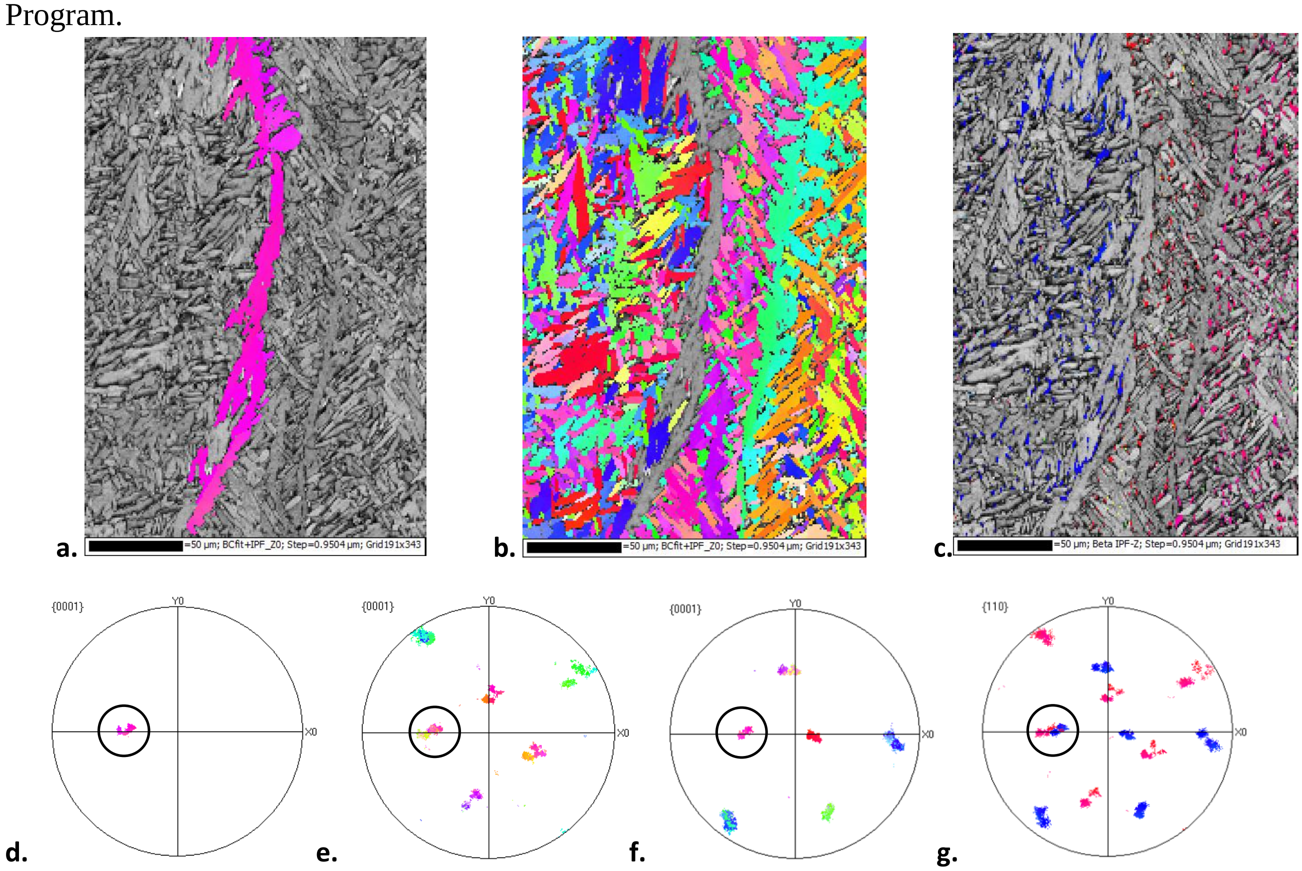

Figure 1. Grain boundary alpha in EBM-AM and HIPd Ti-6Al-4V, exhibiting a variant orientation with respect to both neighboring colonies. Build direction is approximately vertical. Inverse pole figure (IPF)-based orientation maps are given for the GBα (a), alpha in the neighboring colonies (b), and beta (c). Pole figures indicate that the {0001}$_{GB\alpha}$ is parallel to {0001} from one alpha variant from each adjacent colony (e, f), and that all betas accordingly have a nearly parallel {110} (g). Circle marks an identical position on all pole figures. Other pole figures (not shown) confirms that the GBα belongs to a variant common to both colonies.

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