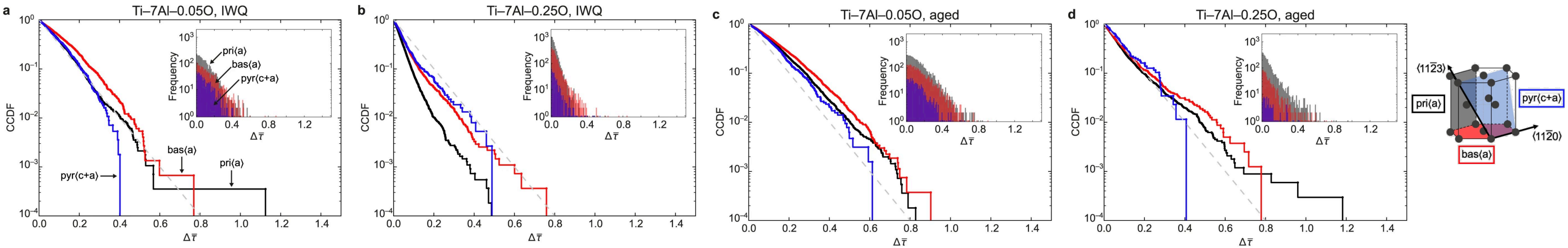
The influence of alloying on slip intermittency and the implications for dwell fatigue in titanium

Joel D. Brock, Cornell University, DMR-1829070

What is the discovery? | Titanium alloys exhibit a phenomenon known as dwell fatigue: when the alloys are held under persistent loads as low as 60% of yield stress, their fatigue lifetime is gradually reduced. The culprit for this degradation in performance is believed to be dislocation slip, which is an intermittent, scale bridging phenomenon, not unlike a nanoscale earthquake occurring in the alloy. Sudden dislocation slips can induce large stress bursts and initiate crack formation. In a new publication appearing in Nature Communications, a team lead by Felicity Worsnop (MIT) and David Dye (Imperial College London) has used high-energy diffraction microscopy at the FAST beamline at CHEXS to observe and quantify thousands of sudden “stress drop” events in thousands of different crystalline grains inside titanium alloys held under dwell fatigue conditions. The team was able to collect unprecedentedly precise statistics for the probability for different types of stress drop events to occur in different alloys. The figure below shows the probability for different stress drops associated with the possible 3 slip modes (illustrated at right), in 4 different alloys (a - disordered Ti-7AL, low oxygen content; b - higher oxygen content; c - low oxygen, after aging; d – high oxygen, after aging). They discover that interstitial oxygen promotes slip homogeneity, with a higher frequency of smaller stress drops being observed, whereas precipitation of regions with aluminum ordering results in fewer, larger events. Basal slip is observed to be the most common of the slip modes and gives rise to the largest slip events.



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Why is it important? | Dwell fatigue in titanium alloys has been implicated in several uncontained jet engine failures. Specifically, the problem of cold dwell fatigue crack initiation has the consequence that holds at relatively moderate stress can result in dramatic reductions in fatigue life in service in critical rotating parts in jet engines in certain situations. The high precision of HEDM measurements at FAST offers new insight into these microscopic processes and point towards new alloying strategies for mitigation of runaway slip band intensification.

Why did this research need CHEXS? | The FAST (Forming and Shaping Technology) beamline at CHEXS is dedicated to understanding engineering materials processing and performance. A key capability of FAST is the High Energy Diffraction Microscopy (HEDM) technique, which was used for this work. These measurements require the high flux of high energy x-rays which are available at FAST, as well as the suite of in-house detector and computational tools provided to users. Far-field-HEDM provides spatially resolved measurements of the grain-averaged crystallographic orientation, elastic strain tensor, centroid position, and relative volume of each individual grain for many hundreds to thousands of grains simultaneously. This research also made use of the advanced computational infrastructure (both hardware and software) available at FAST to tackle the "big data" challenges associated with building up comprehensive statistics from thousands of slip events, in samples containing thousands of crystalline grains.

How was the work funded?

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