Dynamic Ductility of Zirconium

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Abstract

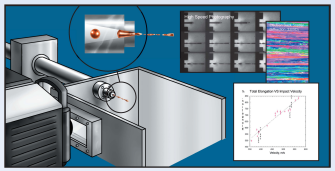
To create comprehensive models of mechanical deformation it is important to observe the effect of high strain on material. Dynamic extrusion is a mechanical test platform for examining this type of mechanical response. In this initial study the influence of extrusion velocity and texture on the dynamic tensile extrusion behavior of high purity, textured hexagonal closed packed (HCP) Zr will be examined. It is expected that twinning and slip will both be observed as deformation mechanisms that accommodate the grain elongations achieved during extrusion. The microstructural evolution of Zr as a function of extrusion velocity has been examined thereby allowing the observation of the effect of high strain on the microstructure and deformation of Zirconium.

Motivation

The effect of high strain and high strain rates, has been primarily studied in high symmetry cubic materials. It is less well known for low symmetry hexagonal metals; this study seeks to close the gap in this knowledge.

Introduction

Dynamic Extrusion – A process that accelerates specimens into a high strength steel die. Highly strained specimens are soft recovered for analysis



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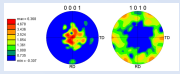
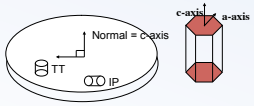
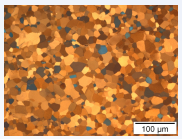


EBSD generated As Received clock rolled texture

Approach – Bullets were fabricated from a clock rolled plate of Zr with an average grain size of 35 µm and fired from a gas gun at varying velocities. Each shot was captured with high speed photography and samples were examined with optical and scanning electron microscopy

Initial microstructure and orientation have already been shown to influence the mechanical response of Zr at low strain rates (right). However less is known about the mechanical response at high strain rates





Microstructure of as annealed Zirconium. Average Grain size of 35 µm

* For this study bullets were extruded rather than spheres as depicted

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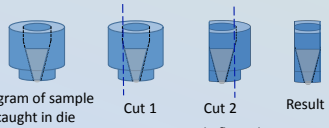
Experimental

Variables – Sample texture was kept constant. Velocity and orientation were varied which varies the strain and strain rate for each shot.

Post Mortem Analysis – Soft capture material was removed and each shot was weighed to assure all pieces had been collected.

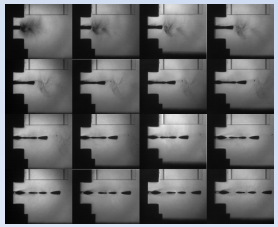
Fragments Caught in Extrusion Die – On many shots the metal was not fully extruded. In such cases the die was cut to facilitate removal without causing further deformation to the sample



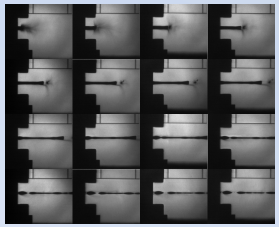
Both flat edges were slit as close to the sample as possible. This had to account for the conical shape of the sample

Results and Discussion

High Speed Photography – Photos reveal differences in the extrusion process and fragment breakup related to velocity



479.8 m/s

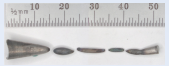


654.6 m/s

Characterization – Using a Stereo Microscope each shot was photographed and the pieces were measured.

479.8 m/s 

575.5 m/s 

517.6 m/s 

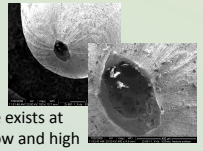
533.6 m/s 

654.6 m/s 

The plot to the right shows the total elongation of each test as a function of velocity.

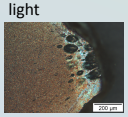
Fragments were observed in secondary electron mode in a Scanning Electron Microscope (SEM) to observe macroscopic deformation.

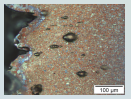
Shear is visible as a mode of deformation in low velocity shots



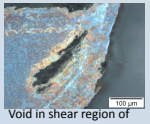
A fracture surface exists at the tips of both low and high velocity specimens, much like that seen in tensile low strain tests

Samples were mounted in epoxy and ground to a 1200 grit finish at their centerlines. They were etched with a mixture of 45 ml H_2O, 45 ml HNO_3, and 10 ml HF. Samples were observed optically using polarized light

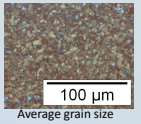




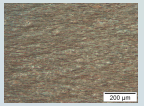
Void formation is visible in both observed shot velocities



Void in shear region of 517.6 m/s shot



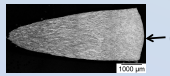
Average grain size has decreased



Grain elongation visible in fragment extracted from die

Comparison with previous work – Previous work has observed the extrusion of tantalum and copper using spheres rather than bullets. It is unclear whether differences are due to the initial shape or the material.

First piece extruded of tantalum



Convex

Piece left in die in copper

First piece extruded of Zr

Concave

Piece left in die in Zr

Summary and Future Plans

- Velocity strongly influences the large-strain-tensile ductility of Zr and thus percent elongation
- From these limited tests there appears to be a correlation between velocity and the number of fragments, further shots will have to be performed to verify this
- Until now most of the microstructural analysis of Zr has been observed in samples under 30% strain. This is only the initial portion of a study to analyze the mechanical response of Zr at strains far above 30%. In order to create accurate models it will be important to apply these tests to other orientations

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