ME - PhD Thesis Colloquium

Numerical and Experimental Investigation of Mixed-mode Fracture Behavior of Basal Textured Magnesium Alloys

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ABSTRACT

Magnesium (Mg) alloys are finding tremendous applications in automobile and aerospace industries owing to their low density, high specific strength, good machinability and damping characteristics. However, their structural application has been limited by low ductility, fracture toughness and poor corrosion resistance. Also, they are highly anisotropic and plastic deformation happens by slip and twinning. Numerous studies have been reported on the tensile and compressive deformation response of Mg alloys. However, their fracture behavior, especially under mixed-mode (combined modes I and II) loading is not well understood.

Crystal plasticity based finite element (CPFE) simulations employing Taylor homogenization for a basal-textured Mg alloy are first performed under plane strain, small scale yielding (SSY) conditions to study crack tip fields corresponding to different elastic mode mixities Me and for two notch orientations. It is observed that with decrease in Me, there is a dramatic enhancement in the normalized plastic zone size, along with a drop in the tensile hydrostatic stress (σH). However, the plastic strain levels near the notch tip elevate significantly. It is also found that for a given Me, the notch orientation can profoundly affect the distribution of individual slip/twin activities which contribute to the equivalent plastic strain and σH around the notch tip, as well as the notch tip opening and sliding displacements. Next, a method for evaluating the contributions from mode I and II components of loading to the energy release rate J in ductile asymmetric 4-PB specimens is proposed. The method is validated by conducting elastic-plastic finite element analysis of several such specimens exhibiting a range of Me as well as for specimens having different crack length to width (a/W) ratios and strain hardening exponents. Mode I and mixed-mode fracture experiments are performed on a rolled AZ31 Mg alloy using notched 4-PB specimens along with in-situ optical imaging. Applying the method described above, the evolution of J with load as well as notched fracture toughness, Jc, are ascertained for different levels of Me. It is found that Jc decreases monotonically by a factor of 2.2 as loading changes from mode I to II. Detailed microstructural characterizations are conducted and it is observed that fracture occurs by ductile micro-void growth and coalescence under mode I and by shear cracking for mode II. On the other hand, under mixed-mode loading, hybrid fracture involving micro-void coalescence and twin-induced quasi-brittle cracking takes place. The Jc versus Me trend is rationalized from the transition in operative fracture mechanism as well as contribution from background plastic dissipation. Also, in conjunction with appropriate fracture criteria, CPFE results predict the observed transitions in fracture mechanism and the strong drop in Jc with Me. Finally, the origin of anomalous tensile twins (TTs) observed during tensile loading along rolling direction (RD) of basal textured Mg alloys is investigated using 3D CPFE analysis by considering model textures and an actual texture. It is found from both sets of simulations that in grains where the c-axis is tilted away from ND (especially toward RD), strong basal slip is triggered, which through its effect on the local stress distribution plays a catalytic role in activating anomalous TTs.

ABOUT THE SPEAKER

Vaishakh K V is a PhD student in the Dept. of Mechanical Engineering, IISc Bangalore. He obtained a B. Tech degree in Mechanical Engineering from CET Kerala University, in 2009 and an M. Tech degree in Design Engineering from Applied Mechanics IIT Delhi, in 2014. After B. Tech, he worked for two years in Vedanta Aluminum Ltd. Also, before joining the Ph.D. program, he worked as a project associate in the Dept. of Aerospace Engineering IISc Bangalore for a year.