ME – PhD Thesis defence

Experimental and numerical study of mechanics and mechanisms of model fracture in a textured magnesium alloy

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ABSTRACT

Recently, magnesium alloys have gained increasing application in the automotive industry to achieve weight reduction in vehicle components which is crucial for enhancing fuel efficiency and meeting stringent emission requirements. Although magnesium alloys have attractive properties such as high strength-to-weight ratio, good machinability, castability, and damping characteristics, they have lower ductility and fracture toughness than aluminium alloys which hinder their utilization in structural components. Therefore, it is vital to understand the mechanics and mechanisms of fracture of these alloys. Thus, the specific objectives of this thesis are to study the three-dimensional nature of notch tip fields, mechanics of ductile fracture and effects of temperature and loading rate on mode I fracture behaviour of basal-textured magnesium alloys.Crystal plasticity-based finite element (CPFE) analyses are first performed to analyse the 3D nature of stationary mode I notch tip fields in a notched four-point bend specimen of a basal-textured magnesium alloy. Two notch orientations (TD-RD and ND-TD) are considered to bring out the effect of anisotropy exhibited by this alloy. The macroscopic simulation results agree well with a complimentary experimental study conducted pertaining to the TD-RD orientation. A pronounced thickness variation in stresses is perceived up to a radial distance of about 0.4 times the specimen thickness from the tip. The slip/twin activity near the notch tip is found to differ drastically for the two notch orientations. The strong anisotropy of this alloy also manifests in terms of differences in plastic zone shape and size, near-tip plastic strain/slip distributions and plane strain constraint ratio between the two orientations. Next, the mechanics of ductile fracture near a notch tip is investigated through CPFE simulations of an array of circular voids ahead of the notch tip, subjected to mode I plane strain, small scale yielding (SSY) conditions. The two notch orientations, as described above, are considered here as well. The equivalent plastic strain contours for the TD-RD orientation and isotropic case are similar irrespective of initial porosity level. Further, the void growth mechanism is found to depend on initial porosity level and notch orientation. The void growth in ND-TD is slower than the other two cases due to high hardening around the void, caused by tensile twinning and pyramidal <c+a> activity. Further, the tearing modulus and fracture toughness are highest for the ND-TD orientation.The effect of temperature and loading rate on the mode I fracture in a rolled AZ31 Mg alloy, having a near-basal texture, is investigated through carefully designed experiments. The high temperature experiments are conducted in the temperature range of 25 to 1000C using four-point bend specimens. On the other hand, experiments at four different loading rates ($\dot{J}$= 0.45 to 1.35 GN/ms) are conducted with three-point bend specimens using a Hopkinson pressure bar. Microstructural analysis reveals that the fracture mechanism changes from twin-induced quasi-brittle cracking to ductile void growth and coalescence as temperature is raised from 65 to 1000C or as the loading rate changes from static to dynamic. This corroborates with the decrease in tensile twinning near the tip with loading rate or temperature. By contrast, the density of twins near the far-edge of the ligament and associated texture change enhances strongly with temperature or loading rate. Simplified analyses are performed to show that the evolution rate of tensile twin volume fraction with J near the tip will diminish strongly, while micro-void growth rate will enhance between 25 and 1000C, thereby triggering the observed brittle-ductile transition. In the case of high loading rates this decrease in tensile twinning is attributed to the decrease in σ33 stress component near the tip due to decrease in triaxiality. The dramatic enhancement in fracture toughness above 650C or for loading rates higher than $\dot{J}$=0.45 GN/ms is rationalized from the transition in fracture mechanism and significant background plastic dissipation due to twinning.

ABOUT THE SPEAKER

Arjun Sreedhar S is a PhD student in the Dept. of Mechanical Engineering, IISc Bangalore. He obtained his B.Tech degree in mechanical engineering from Govt. Engineering College, Thrissur in 2012 and M.Tech degree in Mechanical Engineering (Machine Design) from NIT Calicut in 2017. After B.Tech, he worked as senior engineer in L&T Constructions for two years.