ME – PhD Thesis Defense

Fracture and indentation behavior of shape memory alloys

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December 12, 2025 at 10:00AM

Venue: Conference Room, ME@IISc

ABSTRACT

Shape memory alloys (SMAs) are metallic systems capable of recovering large strains, typically in the range of 7 to 10%. A clear understanding of the fracture behaviour of SMAs is crucial to prevent failures, especially in large components used for aeronautical and energy conversion/storage applications. Indentation, which is suitable for characterizing the mechanical properties of SMAs in small volumes, such as thin films, also needs to be analyzed from a mechanics perspective. The present thesis therefore aims to investigate the fracture and indentation behaviour of SMAs.

Three-dimensional finite element (FE) simulations of mixed-mode (I/II) loading of a notch in a NiTi SMA, initially in the austenite phase, are performed under small-scale transformation and yielding (SSTY) conditions. Two temperatures are considered, which are well below A_s and above A_f. The 3D structure of the notch tip fields, including stresses, equivalent plastic strain, and martensite volume fraction, is studied. Also, the effects of superelasticity (SE), plasticity, and temperature on the evolution of transforming and plastic zones, as well as the spatial distribution of above field quantities are systematically analysed. Further, mixed-mode (I/II) fracture experiments on a Ni-Ti SMA are conducted at temperatures below A_s (twinned martensite as initial phase) and above A_s (austenite as initial phase) using four-point bend specimens. In-situ optical imaging with DIC is performed to map out the strain and displacement fields on the specimen surface. The variations in fracture toughness with mode-mixity for the two temperatures are obtained. Post-facto fractography is carried out to clearly understand the fracture mechanism. The fracture toughness trend and origin of the operative fracture mechanism are rationalized from the above FE simulations. The growth and coalescence of a circular void near a notch tip in a SMA under 2D plane strain, mixed-mode, SSTY conditions is analyzed through FE simulations. The effects of mode-mixity, SE, and void location on the stress and inelastic strain distributions near the notch tip and void, as well as the critical energy release rate at coalescence of the notch and void, are examined.
FE analyses of spherical indentation of a SMA thin film bonded to a stiff elastic substrate, as well as, a bulk SMA specimen are performed to investigate the roles of SE, plasticity, substrate, and test temperature. The influence of these factors on the load-depth response, recovery characteristics, Oliver-Pharr modulus, and hardness is analyzed for the thin film sample and contrasted with the bulk SMA sample.

ABOUT THE SPEAKER

Tinku Kumar Mahato is a PhD student in the Dept. of Mechanical Engineering, IISc Bangalore. He obtained his B.Tech degree in Mechanical Engineering from BIT, Sindri, Jharkhand in 2014 and M.Tech degree in Mechanical Engineering (Manufacturing Science and Engineering) from IIT Kharagpur in 2017. After M.Tech, he worked as CAE analyst in SATVEN, Hyderabad. His research interests are broadly in mechanical behaviour of engineering materials.