ME – M.Tech (Res) Thesis Defense

Spherical Indentation Response of Bulk and Thin Film Shape Memory Alloys

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ABSTRACT

Shape memory alloys (SMAs) have the ability to recover large strains upon undergoing a thermomechanical cycle. In addition to being used as structural elements, they can be patterned as thin films which can be employed in MEMS devices where high activation force needs to be generated. SMAs typically exist in two phases, viz., a high-temperature austenite (A) and a low-temperature martensite (M) phase. This work is focused on the phenomenon of superelasticity, which occurs due to stress induced martensite phase transformation (SIMT) from the parent A-phase. While instrumented indentation is a useful tool to determine the mechanical behavior of small volumes of SMAs, it is a significant challenge to develop correlations between test data and material properties. The mechanics of indentation, which is complicated owing to an inhomogeneous stress field and ongoing SIMT underneath the indenter, is not well understood, especially in SMA thin films. Hence, in this work, analytical and numerical investigations of spherical indentation of SMA bulk and thin film specimens are performed. Since previous experiments have shown that SIMT can be pressure sensitive, a special constitutive model that can represent it is used. The studies are conducted at temperatures below the austenite start temperature, A_s, and above the austenite finish temperature, A_f, while varying the pressure sensitivity parameter γ_1 in the SMA model.

An expanding cavity model (ECM) is developed for analyzing indentation of pressure sensitive SMAs. To this end, an analytical solution is derived for the stresses, displacements and martensite volume fraction in an internally pressurized SMA hollow sphere, initially in the A-phase. The above analytical solution, which is validated against finite element (FE) analysis results, is then applied to develop the ECM. The evolution of transformation zone size and mean contact pressure, predicted by the ECM, are found to agree with complementary FE simulations over a range of indentation strain from 0.01 to 0.04. Also, the indentation stress-strain curve predicted by ECM taking into account pressure sensitivity of SIMT compares quite well with available experimental data for a Ni-Ti SMA. In order to understand the spherical indentation response of thin films of SMAs, FE simulations are conducted on a superelastic film of thickness t_f bonded to an elastic silicon substrate. The results obtained are compared with those pertaining to a bulk SMA specimen. At small indentation depths, the response of the thin film sample matches closely with the bulk specimen. However, as indentation depth increases, the transformation zone in the former is constrained by the interface to expand only in the radial direction. This results in a stiffer response of the coated sample at higher indentation depths, as reflected in load-displacement curves and Oliver-Pharr modulus. In contrast, the mean contact pressure for both specimens continues to agree well. The roles of pressure sensitivity, temperature, and normalized indenter radius R/t_f are also assessed. It is found that $R/t_f < 0.5$ should be used to minimize substrate influence and extract key properties of the SMA thin film.

ABOUT THE SPEAKER

Narayan Venkitachalam is a Master's student in the Department of Mechanical Engineering at IISc. He obtained his Bachelor's degree in Mechanical Engineering from SRM University, Kancheepuram, in 2013. Prior to joining IISc, he worked for five years in automotive product development at Mahindra and Mahindra Ltd., in the domain of modeling & simulation and its integration with IT-enabled design processes.