ME – PhD Thesis Colloquium

Understanding failure in heterogeneous materials

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ABSTRACT

The failure of heterogeneous materials is a practical problem that occurs in several diverse applications. Material heterogeneity can arise from porosity (e.g., due to some processing history), variation in continuum-scale properties (e.g., local Young's modulus and/or strength), or even local pre-existing stress fields (e.g., residual stress). As is to be expected, the presence of such heterogeneities can significantly complicate analyses of failure mechanisms and prediction of overall strength. In this work, we develop an experimental and numerical framework to better understand failure in the presence of heterogeneities. The work is divided into three parts:

In the first part, the design and development of an impact testing system is described in detail. This system uses a projectile accelerated by a gas gun to experimentally study impact and penetration problems. The design of the system is first outlined using a standard 1D compressible flow model, followed by a presentation of its calibration data. Two different types of impact tests are then outlined – Taylor-type impact tests wherein a deformable projectile strikes a relatively rigid target plate and plate-type impact wherein a rigid projectile strikes a deformable target plate.

The second part of the work is focused on the development of a 2D numerical framework for predicting dynamic fracture and failure in brittle materials. The method uses a network-based discretized description with flexible bond-type or beam-type interlinks. The former is shown to relate to linearized elastodynamics in the continuum limit, while the latter provides a description for rock-like materials that can undergo significant local material rotation. The advantage of this approach is that heterogeneities can be modeled with ease by varying the bond properties, and a simple bond breaking criterion simulates fracture. The model is benchmarked against those already present in the literature and shown to recover standard analytical results under suitable limits. The method is then applied to two common problems – failure in sheared 1D bi-material interfaces (analogous to frictional contacts) and multi-crack failure in brittle porous solids (e.g., consolidated brick samples). In both cases, failure is significantly modified (or even mediated) by local heterogeneities. The network-based model is shown to make predictions that are extremely challenging to obtain using usual continuum/finite element methods.

The final part of this work utilizes the experimental setup, and the numerical model developed in the first two parts, to study an industrially important problem – fracture and fragmentation of residually stressed glass. These glasses are manufactured using a heat treatment process (thermal tempering) or a chemical bath (ion exchange) that results in a non-homogeneous stress distribution through the bulk. This residual stress field is a fundamental driving force that determines the dynamics of crack growth and bifurcation. The study predicts the mechanism of fragment formation and its dependence on loading, residual stress distribution and intensity.

ABOUT THE SPEAKER

Vineet Dawara is a PhD student in Mechanical Engineering at the Indian Institute of Science (IISc), Bangalore, since 2019. He works under the guidance of Dr. Koushik Viswanathan at the Laboratory for Advanced Manufacturing and Finishing Processes (LAMFiP). His work primarily focuses on fracture mechanics, high-strain-rate impact phenomena, and the development of numerical models to investigate material behaviour under dynamic loading conditions.