Simulations of Dynamic Fracture and Fragmentation in Hard Rock Excavation

Project ID:

CHBU28

Principle Investigator:

Prof. Dr. Günther Meschke
Institute for Structural Mechanics
Department of Civil and Environmental Engineering, Ruhr University Bochum

Project Team:

Prof. Dr. Andreas Vogel
High Performance Computing in the Engineering Sciences
Department of Civil and Environmental Engineering, Ruhr University Bochum

M.Sc. Sahir Butt
Institute for Structural Mechanics
Department of Civil and Environmental Engineering, Ruhr University Bochum

HPC System:

JUWELS

Abstract:

This project investigated the dynamic fracture process in brittle materials using a peridynamic simulation model. Two main targets were addressed: Computational simulations of dynamic crack propagation resolved at the microscale were performed to investigate the influence of the crack speed on the evolution of the different portions of energy during fracture. The second goal was the simulation of the cutting process of rock material by means of cutting tools mounted at the cutting wheel of tunnel boring machines (TBM).

Dynamic Fracture:

Simulating dynamic fracture in brittle materials is a challenging task due to the complex interaction between the propagating crack and the surrounding material. However, the insights gained from such simulations are invaluable for understanding the fracture behavior of materials under extreme loading conditions. By accurately modeling the evolution of different portions of energy during fracture, as well as the influence of crack speed on the fracture process, researchers can gain a deeper understanding of the microstructural mechanisms of fracture. Such high-resolution simulations involve large system of equations. Solving such large system is only possible by using supercomputing cluster, such as JUWELS.

The computational model was able to reproduce the salient features of the dynamic fracture process, such as the onset of micro-branching instability, the crack surface topology obtained at different crack speeds, material toughening with increasing crack velocity, as well as the limit of crack velocity below the Rayleigh wave speed for mode-I cracks [2,3,5,6]. The results obtained from the simulations were found in good qualitative agreement with the experiments. The transition from a single crack to an ensemble of micro-branches leaves distinct features on the crack surfaces, and simulations were able to reproduce the mirror, mist, and hackle transition of the topology of the fracture surfaces observed in experiments (Figure 1).

These findings can be used to improve the design of materials and structures subjected to extreme loading conditions, such as aircraft structures and earthquake-resistant buildings. The mining and excavation industries can also benefit from insights gained from simulating rock cutting processes, allowing for more efficient and effective excavation processes. Overall, the insights gained from simulating dynamic fracture have wide-ranging applications and can contribute to advances in various fields of engineering and material science.

Hard Rock Excavation:

The simulation of rock excavation involves modeling the complex nature of rock behavior and the interaction between the cutting tool and the rock material. Accurate capturing of the material properties of the rock, the mechanical properties of the cutting tool, and the boundary conditions during excavation is required. However, insights into the mechanics of the rock excavation process, such as the effect of cutting tool design, the influence of the cutting parameters on the excavation efficiency, and the behavior of the rock under various excavation conditions, can be gained through simulation. These insights can be used to optimize the design of cutting tools, improve excavation techniques, and reduce costs and time in large-scale excavation projects. The findings from these simulations can benefit the mining and construction industries, as well as academic researchers, in improving the safety and efficiency of rock excavation processes.

The computational model was used to investigate the hard rock excavation process by simulating a full-scale LCM (Linear Cutting Machine) test, and the cutting forces obtained were compared with experiments [1,4,7]. Furthermore, the influence of straight and curved cutting paths in a homogeneous rock specimen using a scaled cutting disc and employing two cutting discs at various spacings was investigated using the model. Additionally, simulations were performed to investigate the excavation in mixed ground conditions, such as the case when a cutting disc moves from a soft to a hard rock domain and the case when the cutting disc moves from a soft/weathered rock domain into a hard rock domain. Furthermore, simulations were performed for a disc which has undergone significant localized wear to evaluate the residual excavation efficiency of damaged discs (Figure 2).

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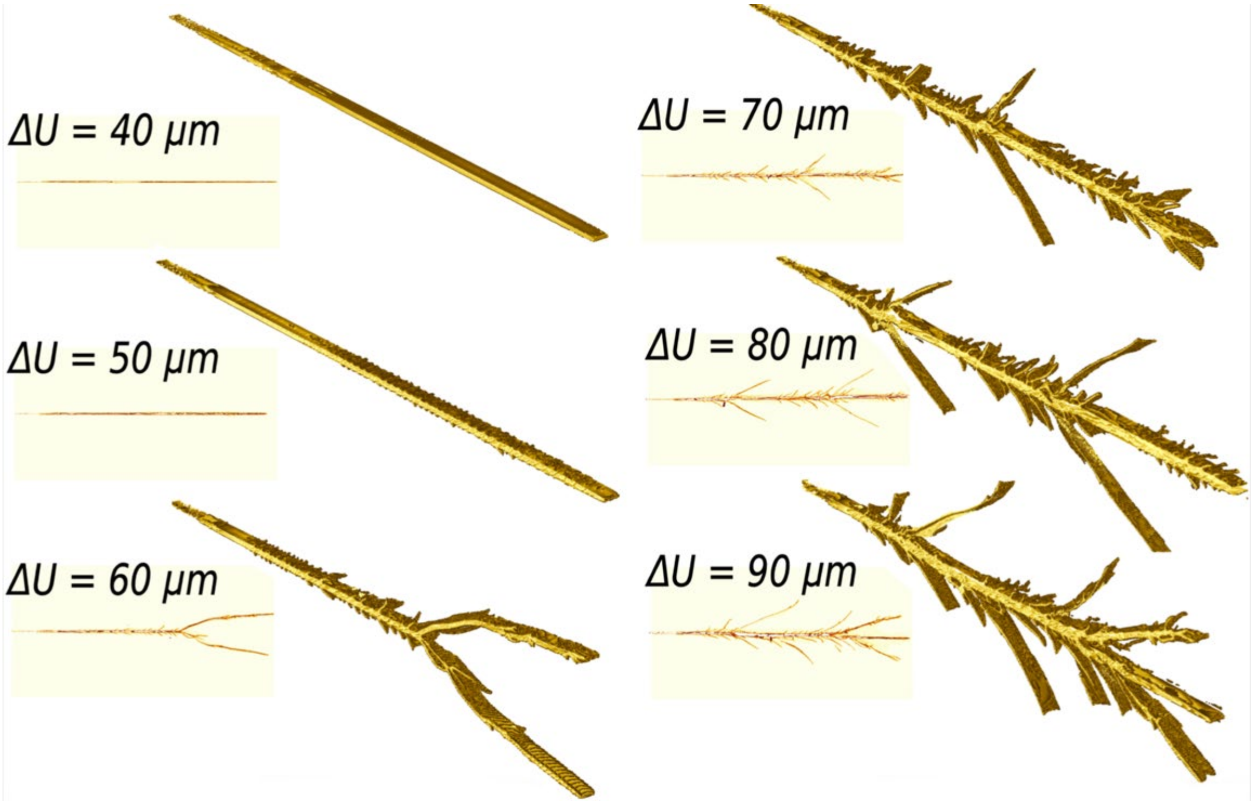

Figure 1: Simulations of crack propagation at different levels of stored elastic energy and the obtained three-dimensional fracture surfaces and branching patterns.

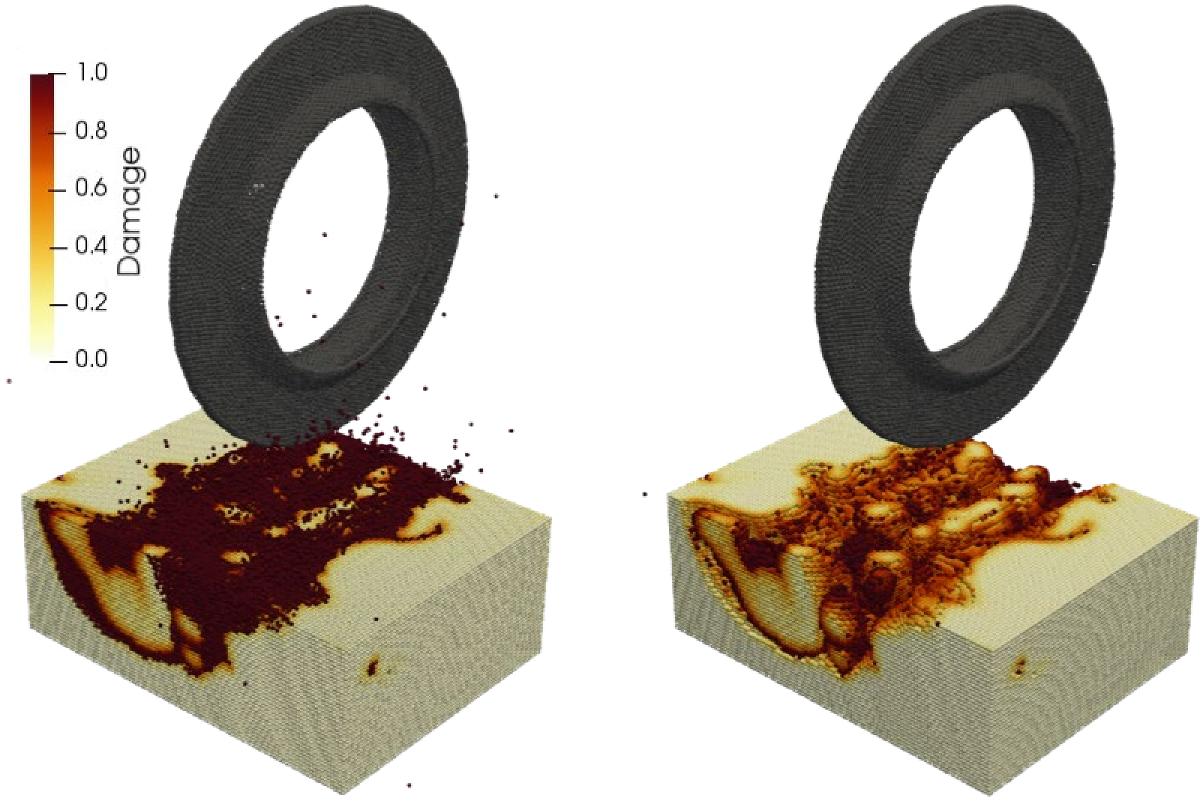

Figure 2: Simulation of a Linear Cutting test for a tool penetration and spacing of 6mm and 76 mm, respectively. Material points with a damage value greater than 0.95 are filtered out for visualization of the rock chip formation (right).