Unravelling Sharp Interfaces from Fracture to Biological Growth Through the Lens of Multifield Phase Field Modelling

The phase field method is a powerful computational framework for simulating complex systems with evolving interfaces, particularly where sharp boundaries and multifield interactions are involved. Unlike traditional interface-tracking techniques, it employs a continuous scalar field to represent different material states, enabling seamless handling of topological changes such as merging or splitting. This makes it especially well-suited for problems with intricate geometries and coupled physical phenomena like thermal, mechanical, and chemical processes.

In fracture mechanics, the phase field method has proven effective for modeling crack initiation and propagation without the need for explicit crack tracking. Cracks are represented as a smoothly varying field governed by energy minimization, allowing the method to naturally capture phenomena such as branching, coalescence, and complex crack paths. Its integration with elasticity and plasticity models enables accurate simulation of failure in brittle, ductile, and composite materials.

Recently, the method has found growing application in biomechanics, particularly in modeling growth-related phenomena such as tumor development and arterial atherosclerosis. These processes involve the coupling of mechanical deformation with biological growth and remodeling, which the phase field approach can represent through evolving geometries and material properties influenced by biological and mechanical stimuli. It provides a robust framework for studying disease progression where sharp interfaces between tissues or pathological zones are critical.

In this lecture, an introduction to the mathematical modeling of the phase field method is provided, along with discussion of its diverse applications, with a special emphasis on biomechanical systems. The focus is on numerical approaches, illustrating how computational methods offer deep insights into the interplay between mechanics and biological growth.

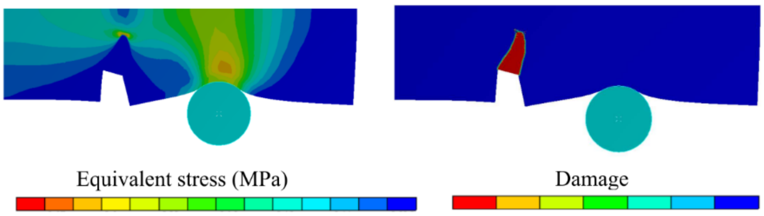

Figure 2 phase field modelling of wearing and tearing of rubber under contact with road [1]

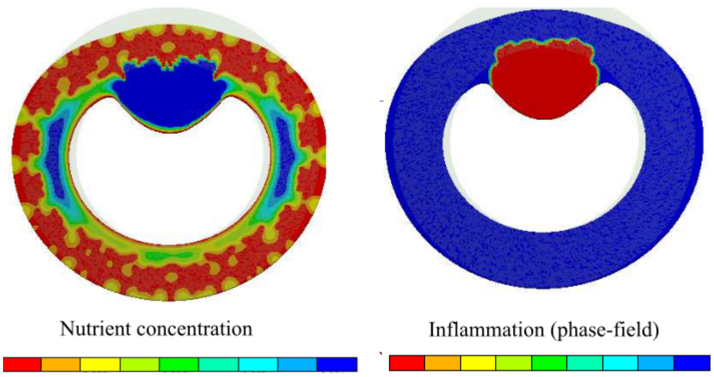

Figure 1 artery cross section: phase field modelling of inflammation-driven atherosclerosis [2]

References:

[1] Experimental investigation of the tire wear process using camera-assisted observation assessed by numerical modelling, J Licher, F Schmerwitz, M Soleimani, P Junker, Tribology International 189, 108918

[2] Numerical and experimental investigation of multi-species bacterial co-aggregation, M Soleimani, SP Szafranski, T Qu, R Mukherjee, M Stiesch, P Wriggers, Scientific Reports 13 (1), 11839

[3] Mathematical modeling and numerical simulation of atherosclerosis based on a novel surgeon's view, M Soleimani, A Haverich, P Wriggers, Archives of Computational Methods in Engineering 28 (6), 4263-4282.