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PREFACE

Special issue on computational methods for interface mechanical problems

Marco Paggi · Alberto Carpinteri · Peter Wriggers

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The examination of materials and structures shows that homogeneity is often a simplification of reality. Interfaces exist at different scales and they govern the material properties and the structural response. An ambitious task to be undertaken is the design of materials and structures with enhanced mechanical properties by tailoring the interfaces. However, this aim is very challenging and a combination of innovative experimental techniques, mathematical models and numerical methods has to be pursued. Research in this field is particularly active, as demonstrated by the rapidly increasing number of papers published every year in scientific journals on this topic (see Fig. 1). This graph, obtained by selecting in the Scopus database the articles having the words "interface" and "mechanics" in their title, abstract or keywords, shows the rapid evolution of the research in this area, with up to 1,400 papers published per year on interface mechanical problems.

At the micromechanical level, a great attention is paid to the characterization of the mechanical behaviour of heterogeneous materials starting from the properties of their constituents. At the macroscopic level, interface mechanical problems are crucial for all the structural components obtained by bonding or joining different parts together. Indeed, a great impulse to the research in this field has been given by numerical methods, which permit to consider realistic geometries of industrial interest and to take into account material and geometrical nonlinearities that are impossible to account for using analytical methods. Moreover, in the last decade, a great effort has been devoted to linking the micro- to the macro-scale through the development of multiscale numerical methods. However, the ambitious task of designing by simulation, building consistent links among different mechanisms and scales, still remains a critical issue and many challenges are involved.

Research on interface mechanical problems is also a very multidisciplinary field. Although it is impractical to list all the applications where interfaces play a crucial role, we try to mention the most notable ones. In physics and geophysics, fundamental research regards contact mechanics between rough surfaces. Applications range from the prediction of the tribological properties of electro-mechanical systems at the nanoscale to the study of the behaviour of natural faults at the planetary scale.

In civil engineering, quasi-brittle materials like concrete have highly heterogeneous and disordered microstructures. Material interfaces between aggregates and cement paste are responsible for strength and toughness. Moreover, they are also relevant for the chemical interaction with the environment and the related durability issues. Interfaces between steel reinforcement and concrete are also of paramount importance for structural design. In masonry structures, cracks often propagate along the interfaces between bricks and mortar and they are relevant for their static and dynamic behaviour. Strengthening of concrete and masonry structures by means of externally bonded reinforcement is also a technique that relies on material interfaces. To guarantee the overall structural safety of the strengthened member, a proper bonding has to be correctly designed, detailed and executed.

In mechanical and aeronautical engineering, joining between structural components leads to interfaces that can be the source of stress concentration or even intensification. At the

Marco Paggi—On leave from Politecnico di Torino, Torino, Italy.

M. Paggi (✉) · P. Wriggers
Institut für Kontinuumsmechanik, Leibniz Universität Hannover, Appelstraße 11, 30167 Hannover, Germany
e-mail: marco.paggi@polito.it

A. Carpinteri
Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, C.so Duca degli Abruzzi 24, 10129 Torino, Italy

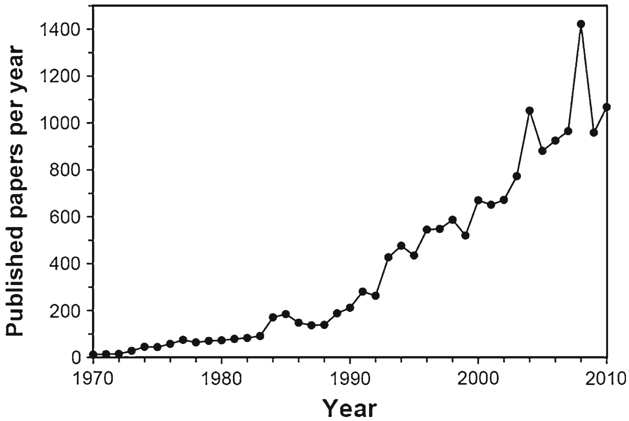

Fig. 1 Statistics of published papers per year with the words "interface" and "mechanics" in their title, abstract or keywords (source: Scopus)

microscopic level, materials have often a heterogeneous composition, as for instance metal matrix composites widely used for aerospace structures. In all of these cases, interface fracture, under monotonic and cyclic loading, is crucial for structural integrity.

In materials science, grain boundaries in polycrystalline materials govern their strength, hardness, toughness and conductivity. Engineering applications are also quite broad, ranging from metal forming to the design of innovative cutting tools. To complete this list, which is surely not exhaustive, the recent research on interfaces in biological materials has to be mentioned. For instance, hard tissues display a hierarchical microstructure with interfaces over a wide range of scales. Preliminary experimental observations suggest that they are responsible for the high toughness and great ability to tolerate defects of these biological materials, in spite of the relatively modest mechanical properties of their constituents. The design of bio-inspired materials mimicking these natural microstructures is envisaged to open new research frontiers.

To provide a forum for researchers to exchange their ideas and be informed by the state-of-the-art development, a symposium on Fracture and Contact Mechanics for Interface Problems was organized as part of the fourth European Conference on Computational Mechanics (ECCM 2010) held in Paris, France, May 16–21, 2010. The 4-day symposium featured more than 40 outstanding speakers with five keynotes and attracted a large audience. The presentations given reflected a wide spectrum of the interesting topics being pursued by different groups on fracture mechanics and contact mechanics of interfaces, with a wide range of applications. In light of the success of the symposium and responses, we organized a special issue on "Computational methods for interface mechanical problems" in the Journal of Computational Mechanics, with a selection of the best papers discussing advances in mathematical models and computational techniques for interface mechanical problems.

Based on the theme of this special issue, Spijker, Anciaux and Molinari proposed a molecular dynamics study of the frictional response of fractal rough surfaces including adhesion effects. This represents a substantial contribution towards the understanding of the physical origin of friction and may deserve important developments regarding the study of the evolution of wear of rough interfaces. Angelillo and Babilio proposed numerical solutions for the propagation of cracks based on the variational theory of fracture. This study, inspired by the seminal work by Griffith, suggests to treat linear elastic fracture mechanics problems as optimization problems. The stability of the solution algorithms for crack nucleation and propagation are also discussed. Kaliske, Dal, Fleischhauer, Jenkel and Netzker presented current and newly developed numerical strategies for the characterization of fracture processes according to nonlinear fracture mechanics. Two-scale simulations are also proposed in order to account for the scale differences of macroscopic mechanical structures reinforced with fibres. To deal with the natural statistical variability of fracture parameters, the authors pinpoint the importance of using stochastic methods in order to better characterize the mechanical response of heterogeneous materials. Vuik, Johnsthovel and van Gijzen proposed fast iterative methods for the structural analysis of large multiscale mechanical problems with interfaces. In the paper by Marfia, Sacco and Toti, a new coupled interface-body damage model for the study of the detachment process in concrete or masonry structures strengthened with FRP was proposed. In particular, to model interface fracture in a consistent way, damage, unilateral contact and friction are fully considered in the constitutive law of the interface. To model fracture in masonry structures, Giambanco, Fileccia Scimemi and Spada presented in their contribution an enhanced zero-thickness interface element taking into account the effect of the stresses in the layers adjacent to the interface. The implementation of this new constitutive law in the framework of zero-thickness interface elements is discussed in details and suitable integration schemes are adopted to avoid spurious oscillations of the stress field. Finally, Nackenhorst and Lutz proposed a bio-active interface constitutive model for the study of osseointegration and long-term remodelling. Relevant biomechanical applications concerning the biomechanical compatibility of hip-joint endoprosthesis are presented.

In conclusion, the collection of the seven papers in this special issue represents some of the most significant research directions that are being pursued by the researchers in the fields of numerical modelling of interface mechanical problems. Much more contributions in this field are however expected in the next years. With the significant advances in computational power and computing algorithms, more accurate interface constitutive laws coupling contact mechanics with fracture mechanics formulations should be pursued. We hope that the publication of this special issue will foster the diffusion of the mathematical models and the numerical methods for the study of interface mechanical problems across different disciplines and research fields.

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