COMPOSITE POLYMER FOAMS FOR HIGH ENERGY ABSORPTION CAPABILITY: FROM THEORY TO APPLICATIONS

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Research Background

In recent years, there has been a growing interest in polymer foams as materials for structural components in automotive and building industry [1] or more specifically for the development of implants, prostheses and biomaterials in tissue bioengineering to reconstruct injured cartilage [2]. These foams are distinguished in particular by their great lightness and versatility of their properties as a function of a) the chemical nature of the cell walls, b) the size dispersion of the cells and c) the volume distribution of the cells. Nevertheless, although these three-dimensional structures have been known and used for a while, many questions remain open in order to reliably link the structure of these materials to their mechanical properties, especially under large deformation. In particular, we lack a predictive model for temporal responses such as damping or creep. This point is crucial for the development of foams as absorbing shock structures or as biomaterials and for implant applications subject to static and dynamic loading and often subject to stress shielding. Also, in compressive loading conditions, the high energy absorption performance of polymeric foams is attributed to their different cellular-scale energy dissipation mechanisms, such as cell-wall bending, buckling, plastic yielding or brittle crushing. It is well established that the compressive response and energy absorption of polymeric foam are highly sensitive to the nominal density of the material. Such bending dominated behavior leading to a quite floppy character is a direct consequence of the natural foam morphology which closely follows Plateau's rules [3].

To take advantages of all the aforementioned properties, i.e large failure strains, and low overall weight, while retaining a good energy absorption performance combined to high strength, the concept of composite foam material has been proposed. The fundamental concept is to tailor a single foam structure from various components each having unique advantageous properties that can contribute to the enhancement of the energy absorption and strength of the structure as a whole, while keeping the structure as lightweight as possible.

The Goals of the Research (Thesis) :

- Based on the numerical foaming process simulation developed earlier [4], a model able to simulate the strong interactions between reinforcing particles and the melt polymer during foaming process on the one hand, and the mechanical behavior of composite structure under any load on the other hand, will be developed. Works have already been undertaken in the research unit in order to couple growing bubbles foam model with rigid boundaries. Extension towards reinforced particles or fibers seen with rigid-glued link first or as chemical components able to react with polymer in a second time will be envisaged. Especially tangential stress field that participate to macromolecular orientation at the bubble interface need to be implemented in the next simulation generation.

- For the understanding of mechanical properties of the composite PMMA foams, in-situ X-ray tomography experiments will be developed from which specific nonlinearities could be observed and compared to classical foams deformation mechanisms [5].
- The development of a finite element model including the reinforced particles effects will be the last part of the research work. This implementation will be done in the finite element code internal to the laboratory. It can be based on specific numerical foam structures as result of the first point of the present research program but also inspired from traditional foam structures responding to surface area minimization algorithm.

The overall goal is to be able to provide a predictive tool capable of simulating mechanical behavior of any composites foam structures subjected a static or dynamic load. This theory is not developped at present and thus the proposed research is totally novative.

Time Plan：

M1-M6: Bibliographic phase on composite foams: multi-physical foaming model, FEM modeling techniques

M3-M18: Development of the numerical foaming simulation based on PMMA experimental characterizations and in-situ X-ray PMMA foam analysis. Validation of the simulation process.

M6-M36: Finite elements modeling and study of mechanical properties

M24-M36: Simulation of specific cases, impact of high strain rate deformation on the mechanical properties and study of anisotropic aspects.

References.

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