Biological Materials: Control of Function through Interfaces

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Natural materials display an enormous richness in their properties despite the limited number of available constituents. This coverage of ”materials space” is achieved by a clever arrangement of the building blocks into hierarchical composites. By optimising the architecture at each hierarchical level it is possible to combine conflicting material properties such as stiffness and toughness from different component materials. Example of such effects are seen for example in bone and nacre. An important part of the design of Natural materials is controlled by the presence of multiple interfaces at different length scales. These interfaces, although making up a small volume fraction of the material, control a variety of properties such as toughness, deformability, transport, optics... In this presentation I will review and discuss several example from Nature where both the hierarchical design and interfacial design gives rise to new properties not possible in the bulk material.

Homogénéisation périodique d'un matériau élastoplastique compressible anisotrope : application aux structures sandwichs à coeur cellulaire.

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Par leurs bonnes propriétés mécaniques rapportées à leur masse, les matériaux cellulaires architecturés peuvent répondre à des problématiques essentielles du secteur aéronautique, notamment en termes de tenue structurale et de résistance à l'impact. Ils présentent en général trois échelles caractéristiques, l'échelle macroscopique de la structure, l'échelle mésoscopique associée à la cellule élémentaire et l'échelle microscopique liée au matériau constitutif. Leur modélisation complète a un coût prohibitif et leur modélisation multi-échelle est délicate. En effet, l'hypothèse de stricte séparation des échelles, indispensable pour toute approche d'homogénéisation périodique, n'est pas respectée dans nombre de structures sandwichs à coeur cellulaire en raison du faible nombre de cellules dans la hauteur du coeur.

L'étude du comportement multiaxial du matériau cellulaire à l'échelle de son Volume Elémentaire Représentatif (VER) [Ohno, 2010], nous permet par homogénéisation périodique d'expliciter le comportement macroscopique et d'identifier une Loi Homogène Equivalente (LHE) [Mortensen, 2010]. Un critère de plasticité non-quadratique, anisotrope, avec une sensibilité anisotrope à la pression hydrostatique, a été choisi [Bron, 2004]. La structure sandwich est ensuite modélisée en remplaçant le coeur cellulaire par un Milieu Homogène Equivalent (MHE). Pour des cas de chargements quasi-statiques, nous avons analysé l'influence des effets de bords sur le comportement macroscopique de la structure en fonction des différents types d'empilement des tubes, de la taille des structures sandwichs et du type de chargement. Afin de valider la demarche proposée, les empilements de tubes ont été considérés comme architecture cellulaire modèle (Figure 1), dans le but de permettre une comparaison entre expérience et modélisation. La méthode donne des résultats satisfaisants nous permettant donc d'envisager l'introduction d'un milieu continu généralisé, pour étendre la validité de l'approche à des chargements plus sévères [Kouznetsova, 2002], ainsi que l'extension à des chargements dynamiques.

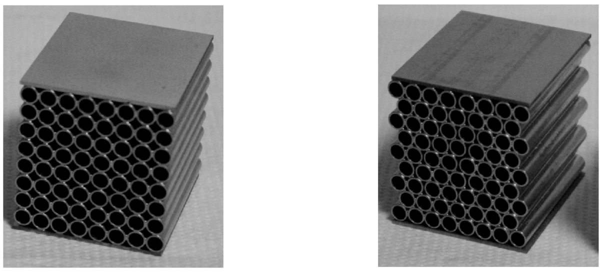

Figure 1 : Structures sandwichs étudiées (gauche: empilement carré, droite: empilement hexagonal)

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Effective Properties of Architectured Materials: Periodic Auxetics and Stochastic Networks of Infinite Fibres

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Architectured materials bring new possibilities in terms of functional properties, filling gaps and pushing the boundaries of Ashby's materials maps. The term "architectured materials" encompasses any microstructure designed in a thoughtful fashion, so that some of its materials properties have been improved. There are many examples: particulate and fibrous composites, foams, sandwich structures, woven materials, lattice structures, etc. The MANSART (ArchiTectured saNdwicheS MAterials) ANR project aims at exploring new tools and approaches to develop such materials for application in aeronautics. One engineering challenge is to predict the effective properties of such materials; numerical homogenization using FEA is used in this work. Two architectured microstructures are considered: periodic auxetics (negative Poisson's ratio materials) and stochastic networks of infinite fibres, also known as Poisson fibres.

Most materials naturally present a positive Poissons ratio, although auxetics have been engineered since the mid-1980s. Such materials have been expected to present enhanced mechanical properties such as shear modulus, fracture toughness, indentation resistance and acoustic damping. Design, modeling, simulation and characterization of auxetics have been conducted in this work. Anisotropy was investigated for both linear elastic and elasto-plastic behavior. The effect of auxeticity on plastic behavior was assessed. Macroscopic modelling was performed using a fully anisotropic Hill criterion within a compressible plasticity framework that is suitable for modelling metallic foams and cellular media.

For the case of Poisson fibres, a mathematical morphology framework for random microstructure generation was used. Poisson fibres are a tridimensional, infinite, unperiodizable medium, classical homogenization schemes cannot be used to predict effective properties. Effective mechanical properties can be bounded using kinetically uniform boundary condition (KUBC) and statically uniform boundary condition (SUBC). Using the representative volume element (RVE) size determination statistical method, due to the stationary character of this stochastic process, the size of the RVE is *a priori* unknown, i.e. the integral range, a correlation length that relates local variance to global variance, tends towards $+\infty$. One of the main goal for this work is to evaluate this size *a posteriori* based on numerical simulations. Scaling laws on the variance of mechanical properties can thus be obtained, which give us information about the statistical convergence of the mechanical properties with regard to the simulation size. Interesting results emerge from these simulations and new statistical scaling laws are presented.