PhD position in « materials sciences »
Starting in 2025 for three years

Buckling of coatings and thin films: an experimental and numerical study of the ageing of the adhesion properties

Financial support. MESR, 2200€ rough/m, 3 years contract

Supervisors:

COUPEAU Christophe (PR)	Institut PPrime, Université de Poitiers
DURINCK Julien (MdC)	Institut PPrime, Université de Poitiers
PARRY Guillaume (MdC-HdR)	Laboratoire SIMAP, Université de Grenoble-Alpes

Contact : christophe.coupeau@univ-poitiers.fr

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Required skills: Strong background in materials sciences and rupture mechanics. Technical skills in multiscale characterization of materials and/or in numerical simulations by finite elements.

Context. Thin films and coatings are used in a wide range of technological applications, such as microelectronics, packaging or optics. They often develop high residual stresses during the deposition process, sometimes about few GPa in compression. Such large compressive stresses may cause the nucleation and growth of buckling structures that generally result in the loss of functional properties that were initially conferred to such film/substrate composites. The aim of our studies is consequently to have a better understanding of the buckling phenomenon, by identifying the relevant parameters to prevent, to limit, or to control its occurrence.

In the past, our studies have focused on the effect of the elasticity and plasticity of substrates, the observation of specific blistering structures as a function of the mechanical properties of the thin films under consideration, the question of the external pressure exerted on the blistering structures, the limitations of the elastic theoretical framework for understanding buckling when plastic folds are observed, 2D materials such as graphene for which the blistering structures are debatable due to their ultimate thickness, etc.

We would now like to focus our attention on film/substrate adhesion properties, which control the propagation of interfacial cracking and, ultimately, the growth of blistering structures. Recent experimental observations have highlighted the growth of blisters at fixed mechanical stresses/loading, suggesting a significant variation in adhesion over time. As an example, Figure 1 shows a circular blister (Au 60 nm thick on a Si wafer) with numerous successive plastic folds, a signature of its growth kinetics.

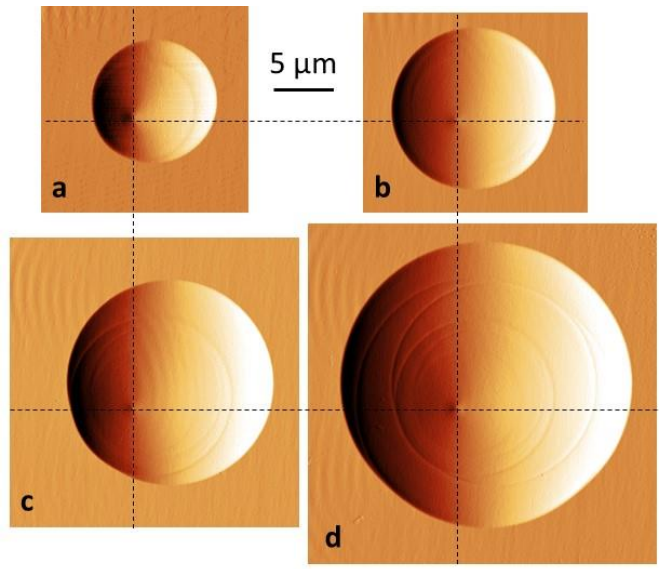

Figure 1 : Succesive growths of a circular buckle observed by AFM on a Au(60nm)/Si wafer (a) 3 days, (b) 7 days, (c) 14 days and (d) 21 days after the deposition.

In practical. The doctoral project will have both an experimental and a numerical component. The Institut Pprime will be in charge of the experimental part: in particular, it will be necessary to characterise the evolution of blistering structures under variable loading (mechanical and/or thermal), under a variable environment (controlled humidity level, chemically neutral atmosphere, etc.) and as a function of time. The numerical component will be led by Guillaume Parry at the University of Grenoble-Alpes. In particular, it will involve carrying out finite element numerical simulations (using the Abaqus code) to gain a better understanding of the mechanisms involved (with integration of a model of cohesive zones and time-varying adhesion).

Two types of materials will be studied: on the one hand, various thin metallic films (from a few dozen to hundreds of nm thick) showing spontaneous growths (such as the one above), the origin of which is unknown at this stage, and on the other hand, 2D materials (such as graphene) which show a phenomenon of easy sliding at the interface, favouring its reattachment to the substrate and the appearance of atypical structures that need to be understood.

Our recent publication in this research domain.

K. Meng, G. Parry, M.A. Hurier, C. Tromas, C. Coupeau
Influence of elasto-plastic behavior of thin films on circular buckling structures
International Journal of Solids and Structures 304 (2024) 113032

K. Meng, G. Parry, M. A. Hurier, N. Ben Dahmane, C. Coupeau
Elastic-plastic buckling of gold thin films into straight-sided blisters
Surface and Coatings Technology 482 (2024) 130642.

C. Coupeau, J. Durinck, G. Parry
Buckling structures, a relevant signature of the mechanical properties of film/substrate systems
Journal of Materials and Polymer Science, 4 (2024) 1
J mate poly sci, 4(1):1-4

A. Zuber, G. Parry, C. Coupeau, P.O. Reanult, V. Gauthier-Brunet, S. Dubois
Alumina scale buckling during high temperature oxidation of Cr_2AlC MAX Phase
Journal of European Ceramic Society 43 (2023) 7334.

C. Chil, J. Durinck, C. Coupeau
Buckling of graphene under compressive strain: DFT calculations and second generation REBO potential
Extreme Mechanics Letters 56 (2022) 101845

S.-J. Yu, G. Parry, C. Coupeau, L. Li
Pressure-induced transition from wavy circular to ring-shaped buckles
Int. J. of Solids and Struct. 225 (2021) 111053.

F.-Z. Abbes, C. Coupeau, J. Durinck, M. Talea, Y. Ni and G. Parry
Effect of substrate elasticity on thin films buckles morphologies: a phase diagram
Surface and Coatings Technology 408 (2021) 126817.

J. Durinck, G. Parry, S. Hamade, C. Coupeau, J. Colin
Influence of interface steps on the buckle delamination of thin films
JPMS 132 (2019) 103698

C. Coupeau, R. Boijoux, Y. Ni, G. Parry
Interacting straight-sided buckles: An enhanced attraction by substrate elasticity
Journal of the Mechanics and Physics of Solids 124 (2019) 526.

R. Boijoux, G. Parry, C. Coupeau
Buckle depression as a signature of young's modulus mismatch between a film and its substrate
Thin Solid Films 645, 041405 (2018)

R. Boijoux, G. Parry, J. Y. Faou, C. Coupeau
How soft substrates affect the buckling delamination of thin films through crack front sink-in
Applied Physics Letters 110, 141602 (2017)