PhD THESIS PROPOSAL

Improvement of miniaturized metallic components

Start: Fall 2024

Research Lab: GeM, UMR CNRS 6183 Institut de recherche en Génie civil Et Mécanique

Location: Saint-Nazaire

Keywords: Metallurgy, multicrystals, heat treatment, mechanical testing, plasticity

Topic:

CONTEXT

The necessary contribution of transport, energy or electronics industries to sustainable development leads them to lighten structures and/or reduce the dimensions of their parts, particularly in terms of sheet thickness, but also to use materials with a mechanical behavior remaining efficient, even when they are miniaturized. How-ever, a dramatic degradation of mechanical properties is observed during dimensional reduction [Hall 1951, Petch 1953, Thompson et al. 1973, Miyiazaki et al. 1979, Dubos et al. 2013]. The ambition of the MOCAMOR ANR project, within which this internship is proposed, is to remove these hindrances by an original approach and methodology combining experiments and modeling.

To do so, a Physical Vapor Deposition (PVD) method is proposed to coat a material on a substrate with the same chemical composition (deposit thickness in the order of one micron on a sheet with only few grains in its thickness) in order to restructure the sub-surface area of the substrate by a gradual evolution of this type of deposit [Dubos et al. 2022]. The challenge of MOCAMOR is to understand the physical mechanisms of the plastic deformation taking place in the newly generated subsurface zone. A particular attention will be paid to the film/substrate interfacial zone with the aim of restoring the mechanical performances of polycrystals to multicrystalline materials.

OBJECTIVES:

During this internship, two approaches will be implemented to get the muticrystals so as to decorrelate the process effects. On the first hand, 500 µm thick sheets will be used and subjected to different granular growth heat treatments (under secondary vacuum to avoid any oxidation) in order to obtain various thickness to grain size t/d ratios. On the second hand, sheets with different thicknesses set between 10 µm and 6 mm will also be heat treated to get identical grain size. For both strategies, the aim will be to monitor the formation of multicrystals in order to control granular growth during in situ annealing under a scanning electron microscope (SEM).

Secondly, their mechanical behavior will be monitored through in situ tensile tests in a SEM to obtain the necessary geometric dislocation evolution laws (GND) on the surface. In order to improve the mechanical properties, coatings will be deposited on the multicrystalline substrates. Two deposition methods (available in the Institut des Matériaux de Nantes cluster, collaborator of the

OPTIMUM regional project) will be used to perform the coatings: Direct Current Magnetron Sputtering (DCMS) and High-Power Impulse Magnetron Sputtering (HiPIMPS). Those have already demonstrated their high relevance for the development of a controlled microstructure deposition onto multicrystals. The characterization of the grain size, crystallographic texture and thickness of the deposits will allow to consider an optimization of the parameters in order to control and define the most suitable microstructure adapted to the role of barrier to the dislocations escape. The major challenge of this study is therefore to obtain a coating with a fine microstructure deposited on a substrate with a coarse microstructure (roughly hundred microns grain sizes), while maintaining excellent adhesion.

The step following the optimization of the deposition conditions will be to study by laboratory X-Ray Diffraction (XRD) the level of residual stresses generated by this additional layer. Once done, uniaxial tensile tests at different levels of deformation will enable to characterize macroscopically the contribution of the deposit as a barrier to the dislocation escape through free surfaces. An analytical study of the work hardening stages by a Kocks-Mecking type model will enable to evaluate the influence of the PVD layers on the surface effects, naturally occurring during the work hardening of multicrystals.

In order to understand the origin of the impediment to the dislocation motion by the microstructure of the deposits, an electron microscopy characterization of the structures (stacking length, cell size, wall density) will be carried out post mortem near the surface zones and in the core of pre-strained specimens, at different steps characteristic of work hardening stages. Moreover, these results will be compared to nanoindentation analyses, achieved through the specimen thickness in order to ensure their accuracy. Thanks to quantitative gradient analyses, the improvement of macroscopic mechanical properties, generated by PVD deposition onto multicrystalline structures, will be explained using these state-of-the-art microstructural analyses.

REFERENCES

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FINANCIAL CONTEXT

This internship is part of the MOCAMOR ANR project (2024-2028, N° ANR-23-CE08-0036-01) involving 1) the manufacturing of multicrystals and two-sided coatings manufactured with different strategies 2) the mechanical and microstructural characterization of coated multicrystals combined with an analytical work hardening modeling 3) the full field modeling of crystal plasticity considering the sheet microstructures. To fulfil this project, two Master students, two PhD students (starting fall 2024) will be recruited. The applicant will be able to take advantage of the new equipment acquired in 2023 as part of the CPER MAPE program and the concomitant numerical PhD work of a second thesis.

Required skills

- Highly motivated by scientific research, serious, curious
- Metallic material science, Strong experimental skills, Electron microscopy and diffraction, micro-mechanic testing

Application should be made by e-mail to the supervisors with the following enclosed documents:

Letter of application

CV

Diplomas and transcripts

Letter(s) of recommendation

Additional information

Duration of the internship: 36 months

Gross salary per month: 2250 €

PhD supervisor	**Co-supervisor**	
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