Experimental study and multi-scale modeling of material evolution induced by surface mechanical attrition treatment

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Introduction:

The LASMIS is one of the eight research teams of Charles Delaunay Institute (ICD) of the University of Technology of Troyes (UTT). ICD develops a transverse research activity in science and technology for risk control. The LASMIS team contributes to this transverse activity by developing knowledge and models in order to understand and predict the behavior of systems at the scale of mechanical component. One of the main research themes of the LASMIS focuses on the understanding of material physics and physics for product manufacturing simulation as well as the virtual product development approach.

The objective of this Ph.D. project is to model the nanocrystallization process of metallic materials due to Surface Mechanical Attrition Treatment (SMAT). SMAT is a technology originally developed by LASMIS and it is one of the areas of excellence of the team. This project will contribute to strengthening the research activities of LASMIS in particular in the field of elaboration and surface treatment of materials.

Project description:

SMAT is able to modify the coarse grained surface layer of a material into nanosized grains by severe plastic deformation (SPD). It is based on mechanical multi-directional impacts with high strain rates. A large number of defects such as dislocations and/or deformation twins can be progressively developed during the treatment, which finally leads to the formation of grains of nanometer size at the surface [1]. High compressive residual stresses coupled with nanosized grains induced by SMAT are expected to significantly improve the mechanical properties of materials [2,3].

Due to the promising application potential of SMAT, it is necessary to investigate the SMAT process both experimentally and numerically in order to obtain a better understanding and controlling of SMAT process. Experimental studies have shown that the properties of SMATed materials are highly influenced by their microstructure parameters, such as grain size, grain orientation and defect density. From the modeling viewpoint, it would be highly beneficial to establish numerical models of SMAT process in order to consider the influence of different parameters at different scales from micro-length to macro-length.

This subject aims on the one hand, to improve the modelling work at macroscopic scale previously realized by a Ph.D. student [4,5], and on the other hand to extend the work to mesoscopic scale for example based on single crystal plasticity theory. For this purpose, the scale transition technique will be used in this work to link the macroscopic behavior to the deformation mechanisms of the material at microscopic scale. In addition, dislocation evolution during SMAT will be studied using crystal plasticity finite element method (CPFEM). A dislocation based crystal plasticity model will be used in the form of user material subroutine of ABAQUS. Nanocrystallization process will be numerically investigated by simulating the evolution of dislocation density and stress strain states.

Experimental tests using dynamic nano-indenter and microscopy observations will be carried out in order to study mechanical properties and deformation mechanism under impact loadings. The experimental results will provide information for the material parameters of the model and validate the results of the numerical simulations.

Keywords:
SMAT, Nanocrystallization, Multi-scale modeling, Crystal plasticity, Finite Element Method,

References:

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[2] J. Zhou, Z. Sun, P. Kanouté, D. Retraint. *Effect of surface mechanical attrition treatment on low cycle fatigue properties of an austenitic stainless steel*. International Journal of Fatigue 103 (2017) 309-317.

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[4] Z. Chen, Z. Sun, B. Panicaud. *Constitutive modeling of TWIP/TRIP steels and numerical simulation of single impact during Surface Mechanical Attrition Treatment*. Mechanics of Materials 122 (2018) 69-75.

[5] Z. Chen, Z. Sun, B. Panicaud. *Investigation of ductile damage during surface mechanical attrition treatment for TWIP steels using a dislocation density based viscoplasticity and damage models*. Mechanics of Materials 129 (2019) 279-289.

Information about the supervisors:

Dr. Zhidan Sun

Dr. Zhidan Sun received his Engineer's degree in Mechanics from ENSMM in 2004. His Master's degree majoring in Materials Engineering was obtained from Ecole Polytechnique in 2005. Three years later he received his Ph.D. in Materials Engineering from INSA de Lyon. After spending two years (2008-2010) as post-doctoral researcher at CEMEF of MINES ParisTech, one year (2010-2011) as temporary lecture in ENSMA, and two years (2011-2013) as lecturer in University of Versailles, he is actually assistant professor in University of Technology of Troyes. Dr. Sun's research interests are focused on mechanical properties of materials in relation to microstructure and operating conditions. The work contains characterization of tensile and fatigue properties, analysis of damage and fracture mechanisms, as well as numerical modelling and simulation with finite element method. He has published more than 20 articles in rank A international journals.

Prof. Benoît Panicaud

Prof. Benoît Panicaud obtained a Master of engineering from Engineer School of La Rochelle and a Master of physics and mechanics of materials from University of Poitiers in 2001. He defended his PhD in University of La Rochelle in 2004, on the coupling between chemical and mechanical effects during high temperature oxidation of metals. After a postdoctoral position in University of Marseille on mechanical effects in semi-conductors, he became assistant professor in University of Technology of Troyes in 2006 and then professor in University of Technology of Troyes in 2013. His research interests include the micromechanics of damage, and the diffusion under stresses and its reverse coupling. He has published more than 50 articles in rank A international journals.