Coupled experimental and numerical investigations of microscale plastic deformation of friction-stirred high-strength aluminum alloys.

Florian Girault*[1,2], Louise Toualbi[2], Anna Ask[2], Alexandre Tanguy[1], and Eric Charkaluk[1]

[1]Laboratoire de mécanique des solides – Ecole Polytechnique, Centre National de la Recherche Scientifique, Institut Polytechnique de Paris – France

[2]ONERA-The French Aerospace Lab – ONERA – France

Abstract

7xxx-series aluminum alloys are widely used in the industry, particularly in the aerospace sector, notably due to their high strength-weight ratio. However, their use in additive manufacturing (AM) poses specific challenges owing to their inherent metallurgical characteristics. To mitigate these AM-specific defects, several solutions have been implemented, and innovative processes have been introduced, such as additive friction stir deposition. Enhancing these alternative methods necessitates an in-depth understanding of the deformation mechanisms within these alloys. Yet, their mechanical behavior is controlled by local plasticity at the microstructural level: cnsequently, achieving a detailed comprehension of the deformation of these alloys requires a micro-scale investigation of plasticity.

The methodology is the following. First, optical and scanning electronic microscopy are performed to analyze the structure of the deposited material. Then, in situ SEM tensile tests are performed, coupled with digital image correlation analysis based on lithography and speckle patterns to access the local strain fields. The impact of several microstructural features in plastic deformation localization is investigated and extensive post processing methods are presented. Coarsest intermetallic compounds are demonstrated to be fragile, triggering high strain concentration in their vicinity before early cracking. However, no particle-cluster effects are exhibited for this specific microstructure. In addition, multiple crystallographic parameters are correlated with grains' mean deformation, resulting in very low correlation coefficients, even for the Schmid factor. Finally, the impact of grain boundaries on strain localization is addressed, exploring several slip-blocking criteria proposed in the literature.

In parallel, simulations are performed at the scale of the grains aggregate. A Meric-Cailletaud law is used to model the behavior of digital twins of experimental specimens. Its calibration is based on results from tensile tests, nano-hardness tests, and data from the literature. By comparing the simulation and experiment results, the relevance of hypotheses regarding the localization of plastic deformation is addressed. This analysis is extended to more complex microstructure, including the interface between friction-stirred aluminum and the initial substrate. Finally, the limits of such micro mechanical experiments and simulations are discussed.

*Speaker