

Master thesis proposal

Towards the automation of dislocation density measurement in aluminum alloys using transmission electron microscopy and deep learning

Keywords : deep learning, transmission electron microscopy, aluminium alloys, dislocations

SCIENTIFIC DESCRIPTION :

Context:

Aluminum alloys are a class of materials widely used in industry due to their low density and excellent mechanical properties. Since the beginning of the 20th century, they have contributed significantly to the development of the aerospace industry. Structure-hardened aluminum alloys of the 2xxx family, of the Al-Cu-Mg type (or Duralumins), continue to be studied by physicists and metallurgists because subtle variations in their composition or the addition of small amounts of other elements (microalloying) [1,2] combined with new thermomechanical treatments [3,4] can result in improved macroscopic mechanical properties.

Everything depends on the nanostructure: on the one hand, in the fine precipitation sequences and, on the other hand, at the heart of the dislocations, nanometric linear defects and vectors of plastic deformation. In fact, in certain sheets that have undergone solution treatment and quenching, a significant increase in dislocations will influence hardening. For several years, our team has been studying materials from World War II aircraft wrecks in order to gain a better understanding of the aluminum alloys used by different nations and to understand the link between chemical composition, precipitation, forming processes, and resulting mechanical properties. The aim is to gain a better understanding of the links between elemental composition, thermomechanical treatments, and macroscopic mechanical properties in these complex alloys. This involves identifying nanoprecipitates and evaluating the quantity of dislocations introduced during manufacturing in thermomechanical processes. This last point is the subject of the proposed internship.

Techniques/methods in use :

Several experimental methods can be used to quantify dislocation density (dislocation length per unit volume), including X-ray diffraction (XRD) and transmission electron microscopy (TEM). While XRD provides an average value at the macroscopic scale, TEM observations allow for a more accurate local assessment at the grain scale. However, a statistically representative assessment by TEM ideally requires the acquisition and processing of a large number of images, acquired over a large field of view (several micron squares). Measuring density by image analysis is mainly a segmentation problem where dislocations must be delineated on an image, usually manually, which requires time and expertise in understanding dislocation contrasts. The idea of automating this work has recently emerged as a possibility through the use of deep learning methods [6], but has not yet been used in this context. The aim of the internship will be to establish a relevant and effective methodology for evaluating the density of dislocations in alloys using transmission electron microscopy. The alloys will be



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observed and studied in several states: remelted, quenched with or without pre-strain. In this internship, the student will first establish a protocol for acquiring TEM images and thickness measurements. Then, he/she will use a state-of-the-art neural network to segment the images. Finally, they will automatically calculate the dislocation densities. A critical analysis of the method's performance with respect to the images collected will enable its limits of application to be established. The results will be compared with macroscopic measurements obtained by XRD.

References:

1. C. Macchi, A. Tolley et al, Acta Mater, 98, (2015), 275–287
2. S.S. Liang et al, Materials Science and Engineering: A, 831 (2022)
3. Sun et al. Science 363 (2019), 972-975
4. J. Li et al., Materials Science and Engineering: A 767 (2019) 138429.
5. A. Duclos et al, Heritage, 7 (2024), 6772-6790.
6. R. Graham et al. Scientific Reports 9, no. 1 (2019): 12744

Applicant skills : The student must have a background in physics/materials science. Knowledge of transmission electron microscopy and skills in Python programming and image analysis would be highly appreciated.

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