
Elementary deformation mechanisms in single-crystal MAX phase Cr₂AlC: analysis of twin-dislocations interactions by micromechanical testing and Transmission Electron Microscopy

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Abstract

MAX phases are a family of materials characterized by their nano-lamellar structure, which grants them an advantageous combination of metallic and ceramic properties, making them attractive for various industrial applications. However, understanding their plastic deformation mechanisms remains a challenging and evolving field of study.

MAX phases exhibit a hexagonal crystallographic structure, and their plastic behaviour is predominantly governed by basal slip. However, this mechanism alone is insufficient to accommodate any given deformation. In other words, other mechanisms must intervene and indeed contribute to the plasticity of these materials. Recently, deformation twinning has been reported and characterized in Ti₂AlN and Cr₂AlC MAX phases. This was new since twinning had been ruled out in the early papers about MAX phases. This implies the necessity of a thorough re-examination and reevaluation of the mechanical properties and elementary deformation processes in MAX phases.

In this study, we aim to enhance our understanding of the elementary plastic deformation mechanisms in MAX phases, particularly about twinning. The objective is to examine the deformation structure of single-crystal Cr₂AlC MAX phase, induced by nanoindentation and micropillar compression tests on samples oriented in configurations where basal slip is the least favourable. To achieve this, the use of different experimental techniques is necessary, combining surface and volume characterization techniques such as atomic force microscopy (AFM), scanning electron microscopy (SEM), and transmission electron microscopy (TEM), with automated crystal orientation mapping such as (EBSD and ASTAR). TEM thin foils and micropillars are prepared using focused ion beam (FIB), ensuring the area of interest is precisely targeted. This will lead to a more comprehensive view of the structure under analysis and a better understanding of the overall deformation behaviour and mechanisms.

By combining the different techniques mentioned in the previous paragraph and exploring new TEM foil configurations, we were able to obtain original observations of deformation structures that clearly show dislocation-twin boundary interactions as well as dislocation

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cross-slip. These observations indicate the variety and complexity of the plastic response of these materials, which led us to conduct a more detailed analysis of these defects and deformation structures.

Ultimately, this detailed analysis will contribute to a better understanding of the diverse plasticity in MAX phases and highlights the significance of revisiting and expanding our knowledge of these materials under mechanical stress.