Thermomechanically coupled crystal plasticity modeling of plastic deformation evolution in fully lamellar TiAl microstructures

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ABSTRACT

Due to their outstanding thermomechanical properties, fully lamellar titanium aluminide (TiAl) alloys are very promising materials for high temperature applications in aircraft engines or automotive industry. The common operating temperature for TiAl alloys is around 700°C - 750°C, heading towards even higher temperatures with ongoing alloy development. The good thermomechanical properties of fully lamellar TiAl alloys, like e.g. their high creep strength, are closely related to their specific microstructure. This microstructure – grains that are subdivided into parallel lamellae which in turn contain grain-shaped platelets – has therefore been subject of intense research in the past.

In order to analyze, separate and understand the contributions of the various internal boundaries to the extraordinary strength of fully lamellar TiAl alloys, numerous groups conducted experiments with systematically altered microstructural lengths. This research is accompanied by experimental limitations, arising from the alloying process and experimental feasibility which might be overcome by modeling activities. The cycling thermomechanical load in operation and the strong – and anomalous – temperature dependence of the mechanical behavior of TiAl alloys are additional complicating factors that render both, experimental testing and constitutive modeling, challenging.

In order to support the understanding of the (thermo-)micromechanics and helping to find constitutive relations as well as micromechanical material parameters, we set up a thermomechanically coupled crystal plasticity model. In this model, the temperature dependence of material parameters is incorporated as well as the evolution of plastic defects with deformation and temperature. Special emphasis is placed on the strengthening provided by the various microstructural boundaries and the twin boundaries, formed during deformation. The twin dislocations of these twin boundaries show complex interactions with slip dislocations, causing the strong work hardening, observed in experiments, and are therefore also modeled explicitly.

The model is calibrated using selected literature experimental data and is able to reproduce the modeled mechanical effects, as intended, over a wide range of temperatures and microstructural parameters.

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